North Dakota Demonstration Project: Whitetopping on U.S. 2 West of Rugby

Final Report
September 2010

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 decisionmakers 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.

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As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the North Dakota Department of Transportation was awarded a $1 million grant to demonstrate the use of proven, innovative thin concrete overlay known as whitetopping and full lane closure for resurfacing U.S. Highway 2, west of the town of Rugby.

This report details the use of whitetopping to rehabilitate this major interregional highway. Using full lane closure during construction greatly reduced the duration of traffic interruption compared with traditional methods. Full lane closure on a major highway has been used on reconstruction projects in North Dakota but is typically not used for overlay projects. As a result, an estimated 19 days and $32,927 in road user costs were saved by implementing a full lane closure on this project. A life cycle cost analysis shows that the costs of whitetopping are within 1.8 percent of an asphalt alternative for both agency and road user costs during construction and future maintenance and rehabilitation.

The success of this project will encourage the use of whitetopping and full lane closure techniques as viable alternatives for future rehabilitation projects.</td></tr>
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ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.71	cubic feet	ft^3
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oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
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		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS					**FORCE and PRESSURE or STRESS**		
lb	pounds	4.45	Newtons	N	N	Newtons	0.225	pounds	lb
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k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa	MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)
		DENSITY					**DENSITY**		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3	kg/m^3	pounds per cubic foot	0.062	kilograms per cubic meter	lb/ft^3 (pcf)

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised September 1993)

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The project team would like to acknowledge the invaluable insights and guidance of Federal Highway Administration (FHWA) Highways for LIFE Team Leader Byron Lord and Program Coordinators Mary Huie and Kathleen Bergeron, 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 also is indebted to North Dakota Department of Transportation Engineers Robert Fode, Greg Semenko, Chris Holzer, andDarin Lindblom for their assistance and coordination during this project.

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ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ACPA	American Concrete Pavement Association
AADT	annual average daily traffic
dB(A)	A-weighted decibels
CDOT	Colorado Department of Transportation
DOT	department of transportation
FHWA	Federal Highway Administration
HfL	Highways for LIFE
HMA	hot-mix asphalt
Hz	hertz
IRI	International Roughness Index
M&R	maintenance and repair
MV	million vehicles
NDDOT	North Dakota Department of Transportation
NPV	net present value
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
PCC	portland cement concrete
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SI	sound intensity
SRTT	standard reference test tire

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 issued open solicitations for HfL project applications in fiscal years 2006, 2007, 2008, and 2009. 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 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 mile (mi) (0.8 kilometer (km)) in a rural area or less than 1.5 mi (2.4 km) 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 North Dakota Department of Transportation's (NDDOT) demonstration project, which involved rehabilitation of a major interregional highway, U.S. Highway 2, west of the town of Rugby. The report presents project details relevant to the HfL program, including innovative whitetopping construction and full lane closure, HfL performance metrics measurement, and economic analysis. Technology transfer activities that took place during the project and lessons learned are also discussed.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

U.S. 2 between Rugby and Berwick, ND, is a four-lane divided highway that serves as a vital interregional east-west route linking the northern portion of the State. In the westbound direction, the original hot-mix asphalt (HMA) pavement surface was in increasingly poor condition because traffic and harsh seasonal weather caused distresses to increase beyond the budget of normal maintenance efforts. Rutting, fatigue cracking, and severe transverse and longitudinal cracking made this section of U.S. 2 not only rough, but also unsafe for the traveling public.

Whitetopping offered NDDOT a cost-effective rehabilitation alternative to restore ride quality in the westbound lanes while leaving the existing deteriorated HMA pavement in place as a sublayer. Bonding between the original pavement and the new 7-inch (in) thick portland cement concrete (PCC) whitetopping optimizes the material properties and eliminates the need for dowel bars and tie bars that would be required in conventional concrete pavement. Not using steel reduces the initial project cost, increases construction speed, and simplifies any future repairs.

The U.S. 2 divided highway alignment presented a perfect opportunity to use full lane closure by shifting traffic onto the two open eastbound lanes, removing traffic from the work zone and enhancing worker and public safety during paving operations.

HFL PERFORMANCE GOALS

Safety, construction congestion, quality, and user satisfaction data were collected before, during, and after construction to demonstrate that whitetopping and total lane closure can be used to achieve the HfL performance goals in these areas.

- **Safety**
  - Work zone safety during construction—At the completion of construction, no motorist crashes were reported at the project location. The speed of construction and detouring traffic away from the construction zone played a key role in meeting the goal of keeping the crash rate well below historical levels for this segment of the highway. It is anticipated that 3-year average crash rates will meet the HfL criteria of 20 percent reduction because of the improved riding surface and new safety features, such as turn lanes and updated shoulder slopes.
  - 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. Worker safety was greatly increased by using full lane closure to eliminate live traffic from the work zone.

- **Construction Congestion**
  - Faster construction—Full closure of the U.S. 2 westbound lanes allowed the contractor to pave both lanes at the same time rather than in two passes. This helped reduce paving construction time by 36 percent. Under conventional construction, the impact on both road directions from construction-related

congestion was estimated at 53 days. Paving both westbound lanes in a single pass with whitetopping and the use of full lane closure reduced pavement construction to only 34 days. While not meeting the HfL goal of 50 percent reduction in the time highway users are impacted, the innovations made a substantial reduction toward this goal compared with traditional methods.

- Trip time—For safety, the speed limit was reduced by 10 miles per hour (mi/h) (16 kilometers per hour (km/h)) for head-to-head traffic on the original eastbound lanes, causing a 16 percent increase in trip time. Traditional phased construction would have reduced the speed limit even more (under traditional methods one westbound lane of traffic would have been maintained at 40 mph (64 km/h) and then 25mph (40 km/h) near the immediate work area), causing a greater increase in trip time.
- Queue length during construction—Even though the trip time was increased from one end of the project to the other, no noticeable backups occurred, keeping moving queue lengths well below the HfL criteria of 0.5 mi.

- **Quality**
  - Smoothness and noise— Quality was measured in terms of smoothness and noise both before and after construction. The field data document a 64 percent drop in post-construction IRI value, a considerable increase in smoothness. Pre-construction IRI was 199 inches per mile for the existing HMA pavement, while post-construction IRI was only 71 inches per mile, which fails to meet the HfL target value of 48 inches per mile but is still a vast improvement over the original pavement.
  - Noise—The sound intensity level went from 102.8 dB(A) to103.9 dB(A). Typically, newly constructed longitudinally tined concrete pavements have a noise intensity range from 102.0 to 105.0 dB(A), depending on the type of texture used in combination with the tining. Therefore, while the HfL goal of 96.0 dB(A) was not met, the noise level of the new pavement is reasonable.
  - User satisfaction—Post-construction survey results show that local communities were very accepting of the full lane closure concept, which kept traffic flowing freely and the public away from construction dust and debris. Public satisfaction is very high with the finished product and meets the HfL user satisfaction criteria.

ECONOMIC ANALYSIS

The benefits and costs of this innovative project were compared with those of a similar resurfacing project with a more traditional delivery method. The result of a life cycle cost analysis indicates that NDDOT’s approach is similar in cost over the life of the pavement to conventional overlay methods. The actual savings were realized by minimizing the number of construction days, saving $32,927 in user delay costs during construction.

LESSONS LEARNED

With this project, NDDOT achieved a better understanding of the whitetopping method. Until now, whitetopping was not considered for major highway rehabilitation largely because of lack of local experience. This was the first major whitetopping project in North Dakota, and it was successful in demonstrating the constructability of whitetopping and enlightening designers and contractors alike on the viability of this innovative rehabilitation method.

The contractor on this project was able to use the milled HMA pavement as a stable haul road to supply fresh concrete to the paver. This is not always the case on whitetopping or any overlay project in which the original pavement is severely distressed and milling reduces the structural capacity of the pavement. NDDOT had originally specified that no traffic be permitted on the milled HMA pavement, but allowed the contractor access after no damage by haul trucks was observed.

During the first few days of paving, the contractor was extra diligent in timing sawcutting operations because of the possibility of shrinkage stress from large temperature swings during the late-season paving schedule. Some relief cuts were made to prevent uncontrolled cracking early in the paving schedule until curing rates were fully understood. After the first few days of paving, the contractor was more comfortable with the operation and was able to increase production. Also, the lack of steel reinforcing made production more efficient by eliminating the time required to set dowel baskets, as traditional concrete paving methods require.

CONCLUSIONS

The North Dakota whitetopping project on U.S. 2 exemplifies the Highways for LIFE principles. Paving construction time was cut by 36 percent compared with traditional paving operations, while a high level of safety was maintained for workers and the traveling public. Crashes are expected to be lower over the project’s service life because of design features and a durable pavement surface. The whitetopping and full lane closure innovations were major contributing factors in reducing the overall project cost. The postconstruction smoothness level, while not meeting the HfL goal, is a vast improvement over the smoothness level of the original pavement. The noise level after construction also does not meet the target value, but is within the range for similar textured pavements. Overall, the end users of the new roadway are very satisfied with the finished product.

PROJECT DETAILS

BACKGROUND

The purpose of this project was to improve the ride, improve the safety, and reduce the maintenance costs for 8.24 mi (13.26 km) of westbound U.S. 2 west of Rugby (figure 1). The original HMA road was a four-lane divided highway with limited access and no bridges within the project limits. Construction began in spring 2008, and the paving was completed and open to traffic in November 2008. The bid construction cost was $7,670,203 of which the Highways for LIFE grant was $1 million or about 13 percent of the project cost.

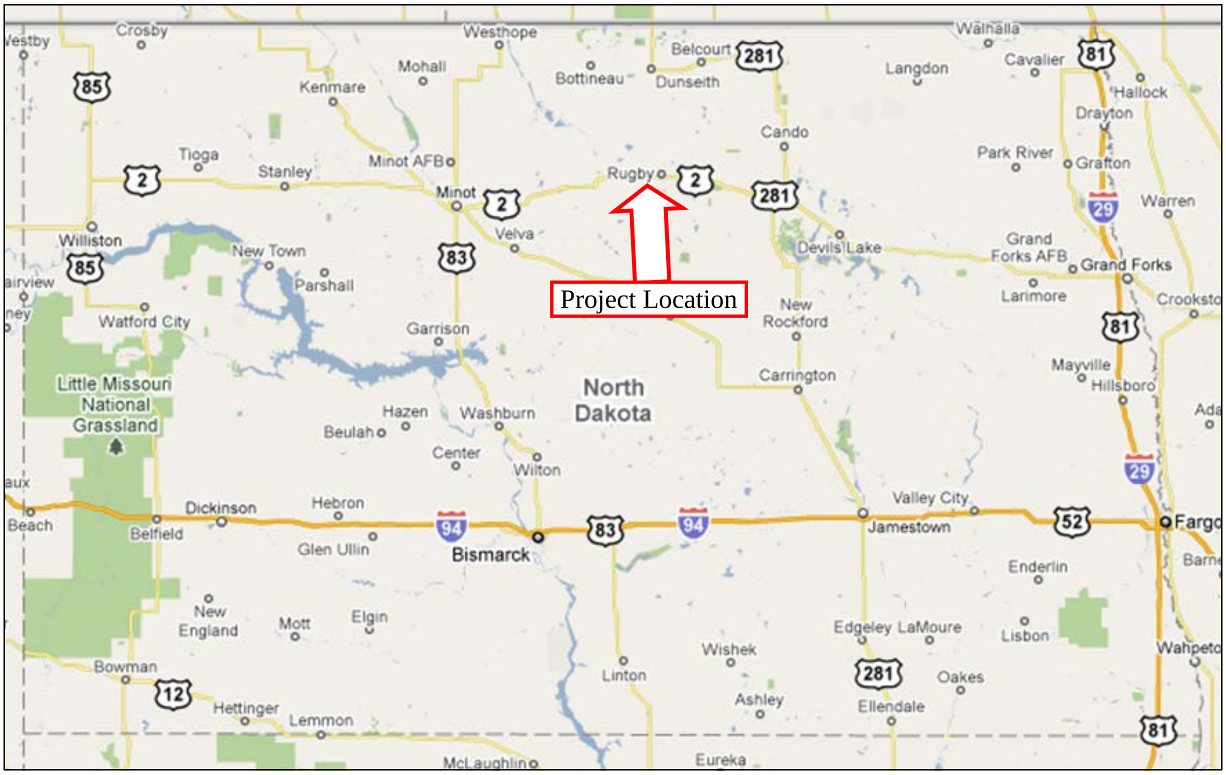


Figure 1. Project location. (Source: Google Maps)

PROJECT DESCRIPTION

Ride and distress ratings of this interregional highway were poor and the maintenance costs were dramatically increasing with time. Distresses such as rutting, alligator cracking, and severe transverse and longitudinal cracking were present over the length of the project. Figure 2 shows the original distressed pavement surface and a closeup of the surface texture.

Figure 2. Original roadway.

Most of the existing pavement in this portion of U.S. 2 was 6 in of HMA over stabilized gravel base or plain aggregate base. Shoulders on the existing roadway were steeply sloped at 4:1. Figure 3 details the existing pavement sections. Several median crossovers are located within the project limits for crossroads and access to farms. The existing crossovers did not have turn lanes and offered only minimum queue storage area. The new design called for turn lanes and wider median crossovers, which will improve future traffic safety. The shoulders were reshaped from 4:1 to 6:1 to decrease the chance of vehicle rollover in the event of a roadway departure incident. Safety was improved not only by reshaping the embankment slopes and installing turn lanes, but also by eliminating hazardous rutting in the wheel paths with a new non-rutting concrete surface.

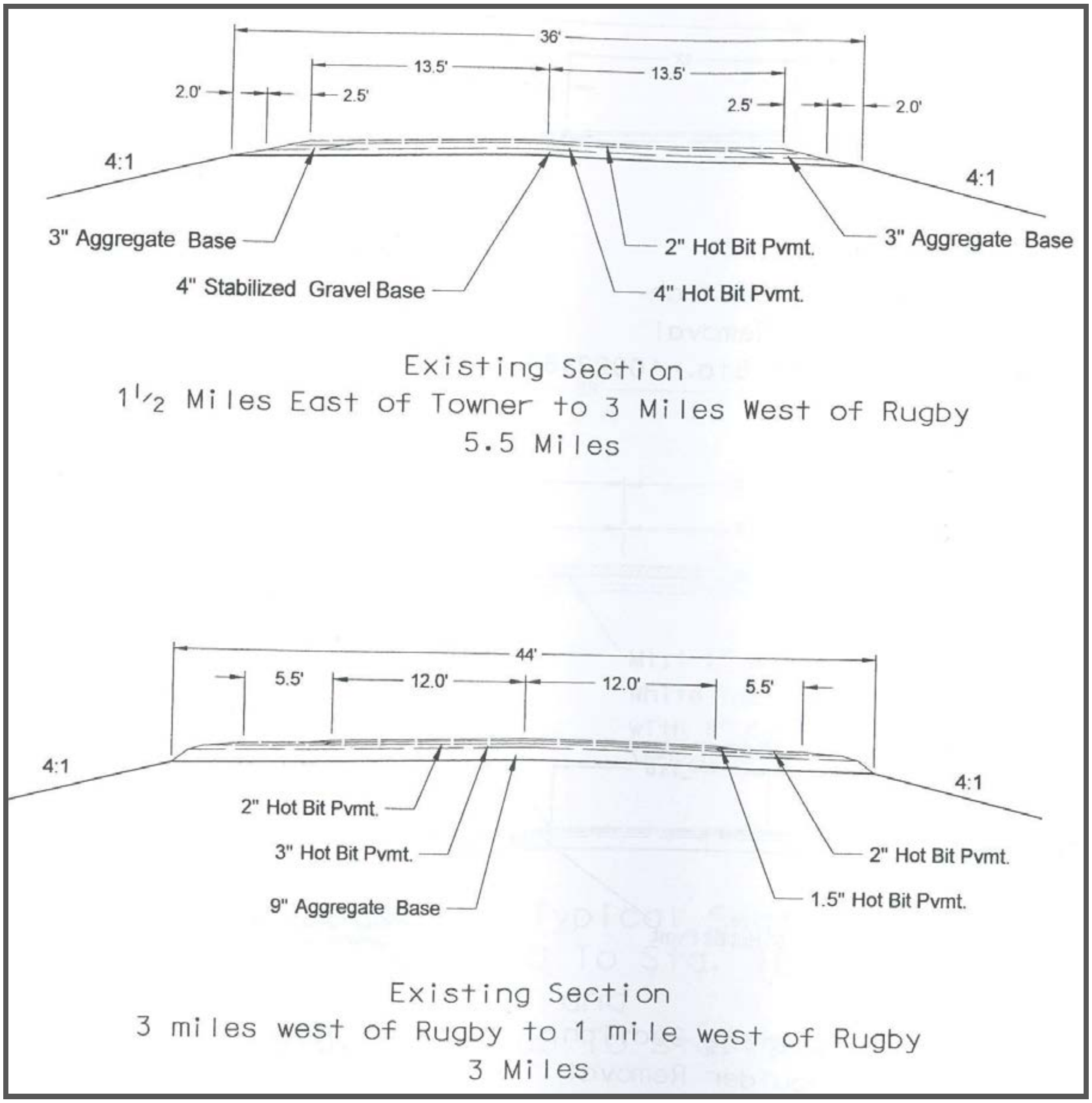


Figure 3. Existing pavement sections.

New construction consisted of milling about 1 in of existing asphalt surface from both westbound lanes and overlaying the milled surface with 7 in of PCC pavement. This whitetopping paving method was the main innovation on this project. Figure 4 shows the rough milled surface of U.S. 2 before the whitetopping was placed. The asphalt material left over from the milling operations was recycled as base material for the new shoulders.

Figure 4. Rough-milled surface of the original HMA pavement.

A key construction detail is using the pavement milling machine to create a rough surface on the existing HMA to facilitate bonding between the HMA and PCC layers. This bond is crucial because it allows the layers to flex together under traffic loading. The bonded pavement layers optimize the material properties by placing the upper layer of concrete in compression and the lower layer of asphalt in tension. The optimized pavement structure reduces the need for a thicker PCC, which would be required if the asphalt was removed.

The bond between the asphalt and concrete is relied on to hold the concrete panels together. As a result, it eliminates the need for dowel bars to provide load transfer across transverse joints and tie bars to keep the longitudinal joints closed. The lack of steel lowers the construction cost compared with conventional concrete pavements. The absence of steel also simplifies the construction process and will make future panel repairs easier and less expensive. Recycling the pavement at the end of its service life will also be simplified because the need to separate the steel from the concrete is eliminated.

Transverse joints were made with a single sawcut at 7-foot (ft) intervals, and longitudinal joints were sawcut at 7 ft for the driving lane and 6.5 ft for the passing lane. Joint sealant was not used because little movement is expected from the thermal expansion of the small-size panels. Figures 5 and 6 show details of the new pavement section and the joint detail. Paving was done late in the construction season, so large temperature swings raised concerns about early-age cracking. The contractor paid close attention to sawcut timing and made relief cuts during the first few days of paving to keep uncontrolled cracking in check.

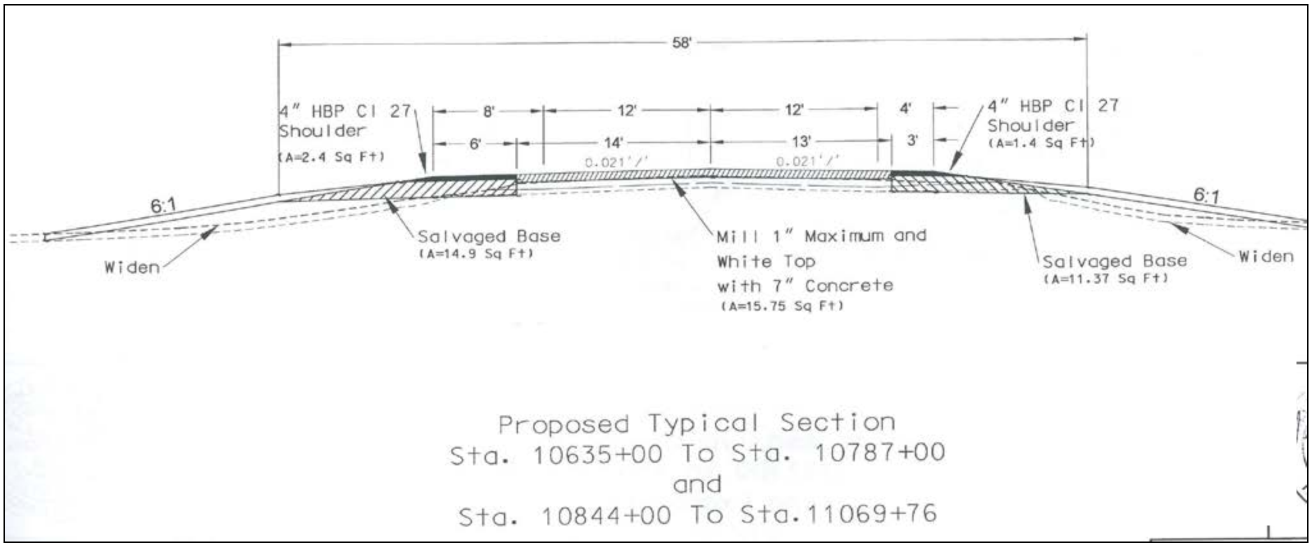


Figure 5. New pavement section.

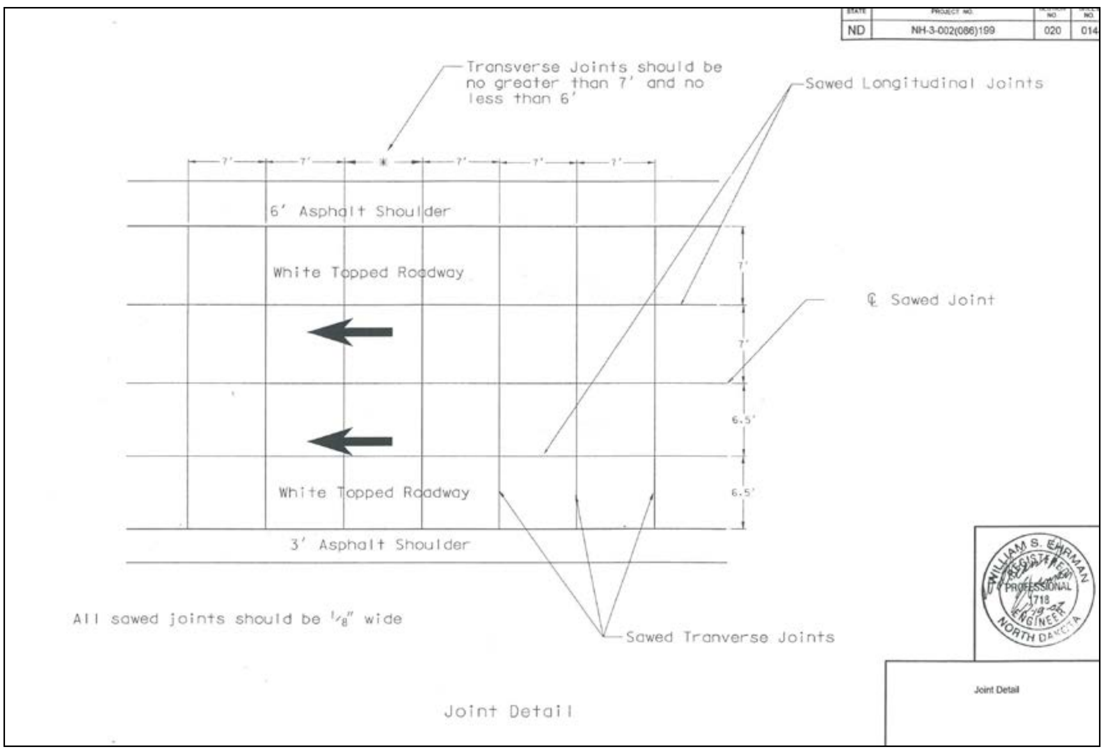


Figure 6. Joint detail.

Whitetopping exists on one short test section in North Dakota, but a full whitetopping project had never before been constructed in the State. This project served as a full-scale trial to introduce the whitetopping innovation to practitioners and builders in North Dakota. Figures 7 and 8 show the finished pavement. Figure 8 provides a close look at the longitudinally tined surface texture and the sawcut joints.

Figure 7. Completed whitetopped pavement.

Figure 8. Closeup of the completed whitetopping showing the longitudinally tined surface texture and sawcut joints.

Whitetopping, rather than a conventional asphalt overlay, was chosen for this project for several practical reasons, which are outlined in the American Concrete Pavement Association (ACPA) Engineering Bulletin *Whitetopping—State of the Practice* (EB210P,1998) and presented in table 1.

Table 1. Comparison of whitetopping and conventional asphalt overlay.

Whitetopping	**Asphalt Overlay**
1. Whitetopping improves the structural capacity of a roadway for longer time periods.	1. After the first overlay, the lives of successive overlays become progressively shorter.
2. Maintenance requirements are low.	2. Frequent maintenance is required.
3. Whitetopping can uniformly fill asphalt ruts and correct the road's surface profile.	3. Once rutting occurs, placing an asphalt overlay will not prevent its recurrence. Rutting reappears because of asphalt's inability to get proper compaction in the wheel ruts and to stand up to today's high tire pressures and traffic loads.
4. Because concrete stiffness is much greater than that of asphalt, reflective cracking does not occur.	4. Reflective cracking occurs.
5. Fuel consumption is slightly less because there is not much pavement deflection.	5. Fuel consumption is slightly more because the deflecting pavement absorbs some of the energy that otherwise would be used to propel the vehicle.

NDDOT developed new specifications for this whitetopping project, using whitetopping specifications from Colorado, Illinois, Iowa, and Michigan as a basis.

A large portion of the project success stems from the use of full lane closure to route westbound and eastbound traffic head to head on the eastbound lanes, similar to interstate median crossover work zones. By closing both lanes at once, the contractor was able to complete paving in one pass rather than the two used in staged construction, reducing paving time. Moreover, separating live traffic from the paving operations greatly enhanced safety for workers and the traveling public. The safety and construction congestion benefits of the full lane closure are quantified in the next section of this report.

DATA ACQUISITION AND ANALYSIS

Data on safety, traffic flow, quality, and user satisfaction before, during, and after construction were collected to determine if this project met the HfL performance goals. The primary objective of acquiring these types of data was to quantify the project performance and provide an objective basis from which 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 NDDOT project met the specific HfL performance goals in these areas.

SAFETY

The crash data from the original pavement (see below) shows that one injury crash and no fatal crashes occurred within the project limits during the 3-year study period. This is not a significant numbers of crashes. However, to help keep injury and fatal crashes to minimum, NDDOT, as previously mentioned, upgraded the roadway to enhance safety by flattening shoulder slopes, installing turn lanes, and eliminating dangerous wheelpath rutting.

Existing Crash Data

Study period = Nov. 1, 2003, to Oct. 31, 2006 = 3 years
Reported crashes = 24 total crashes, 0 fatal, 1 injury, 23 property damage only
Westbound U.S. 2 annual average daily traffic (AADT) = 2,905
Crash rate (with deer) = 0.95 per million vehicles (MV)
Crash rate (no deer) = 0.24/MV

Nature of Crash

Crashes involving animals = 18
Roadway departure = 2
Overturn/rollover = 4 (3 occurred on icy road, 1 occurred on wet road)

At the completion of construction, no incidents involving motorists or construction workers were reported. Worker safety was greatly increased by eliminating live traffic from the work zone with full lane closure. Also, the detour speed limit was lowered to minimize the possibility and severity of crashes.

CONSTRUCTION CONGESTION

The full lane closure allowed the contractor to relocate the westbound traffic to an eastbound lane, completely separating the paving operations from live traffic. By doing so, eliminated the need to slow traffic to 40 mph (64 km/h) through the work zone and then drastically reducing the speed limit to 25 mph (40 km/h) around the immediate work area as would be required for traditional construction.

During construction the speed limit was reduced from 70 mi/h (112.7 km/h) to 60 mi/hr (96.6 km/h) for the eastbound head-to-head traffic lanes. Reducing the speed limit caused trip time to increase from 6.9 minutes to 8.0 minutes. Even though the trip time was increased, traffic flowed freely and no noticeable backups were reported. As a result, queue lengths for vehicles approaching and traveling through the detour were nonexistent.

QUALITY

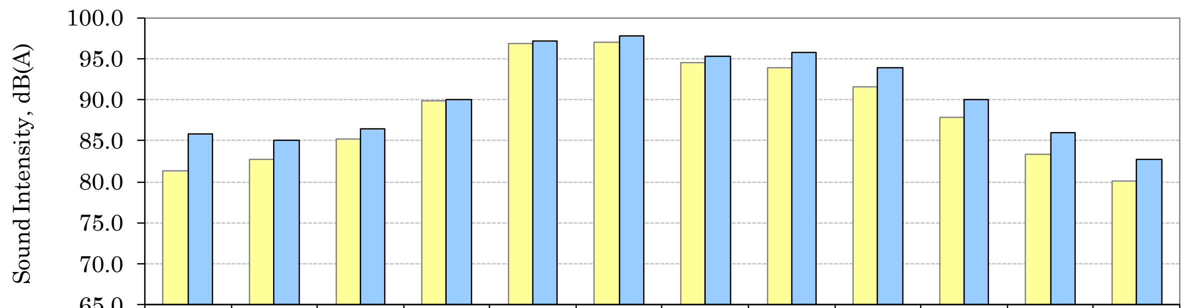
Sound Intensity Testing

NDDOT had not used the onboard sound intensity (OBSI) test method on any past projects. However, this method was used to collect tire-pavement sound intensity (SI) on the existing and newly rehabilitated pavement on the U.S. 2 project. OBSI measurements were obtained at highway speed.

Sound intensity measurements were made using the current OBSI technique AASHTO TP 76-08, which uses dual vertical sound intensity probes and an ASTM-recommended standard reference test tire (SRTT). The sound measurements were recorded and analyzed using an onboard computer and data collection system. A minimum of three runs were made in the right wheelpath of the project. The two microphone probes simultaneously captured noise data from the leading and trailing tire-pavement contact areas. Figure 9 shows the dual probe instrumentation and the tread pattern of the SRTT.

Figure 9. OBSI dual probe system and the SRTT.

The average of the front and rear SI values was computed to produce SI values. Raw noise data were normalized for the ambient air temperature and barometric pressure at the time of testing. The resulting mean sound intensity levels were A-weighted to produce the noise-frequency spectra in one-third octave bands, shown in figure 10.



Frequency, Hz	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
Pre-Rehab	81.4	82.8	85.2	89.9	96.9	97.0	94.6	93.9	91.5	87.8	83.4	80.1
Post-Rehab	85.8	85.0	86.5	90.1	97.1	97.7	95.2	95.7	93.9	89.9	85.9	82.6

Figure 10. Mean A-weighted sound intensity frequency spectra.

Sound levels were calculated by using logarithmic addition of the one-third octave band frequencies between 315 and 4,000 hertz (Hz). The sound level was 102.8 for the original distressed HMA pavement and 103.9 for the newly completed whitetopping pavement. Newly constructed longitudinally tined concrete pavements typically have an SI ranging from 102.0 to 105.0 dB(A), depending on the type of pretexture used in combination with the tining.[1] Although the HfL goal of 96.0 dB(A) was not met, the sound level of the new pavement is reasonable.

Smoothness Measurement

The project did not include the HfL goal for IRI of less than 48 inches per mile. However, like most States, NDDOT has other specifications for testing the surface tolerance and ride quality of concrete pavements. Section 550.04.P of NDDOT's *Standard Specifications for Road and Bridge Construction* (2002) is summarized below:

- The finished surface tolerance is tested with a 10-ft straightedge. High spots greater than 0.125 in are ground smooth with diamond grinding equipment. If grinding more than 0.5 in, cores shall be taken to insure minimum the pavement thickness is still intact.
- This project was paved with a slipform paver and is subject to edge settlement restrictions in fresh concrete of not more than 0.375 in. Persistent edge settlements of more than 0.25 in require suspension of work while operational corrections are made.
- Surface smoothness is determined with a California profilograph to insure a surface with a profile of 0.5 in or less per 0.1 mi. Grinding and corrective action are taken as necessary to produce a smooth surface.

[1] Hall, J.W., Smith, K.L., Littleton, P., *Texturing of Concrete Pavements* (NCHRP Report 634), National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2009.

The contractor did not have any unexpected issues achieving the NDDOT contract smoothness specifications outlined above. Smoothness testing required by the HfL goal and following the ASTM E 950 method was done in conjunction with noise testing using a high-speed inertial profiler built in to the noise test vehicle. Figure 11 shows the test vehicle with the profiler positioned in line with the right rear wheel.

Figure 11. High-speed inertial profiler mounted behind the test vehicle.

Figure 12 graphically shows the test results taken on a 1-mi section of the original distressed HMA pavement on the west end of the project. Construction activities restricted testing to the west end of the project, but the section is nonetheless representative of the entire project. Testing was conducted on nearly the full length of the newly constructed whitetopped pavement. The graph shows a spike in the new pavement's IRI values near the east end of the project because of a small dip in the road. Otherwise, the IRI values are relatively consistent along the project. The original pavement values are much more variable, largely because of the cumulative effects of patches, rutting, and transverse cracking.

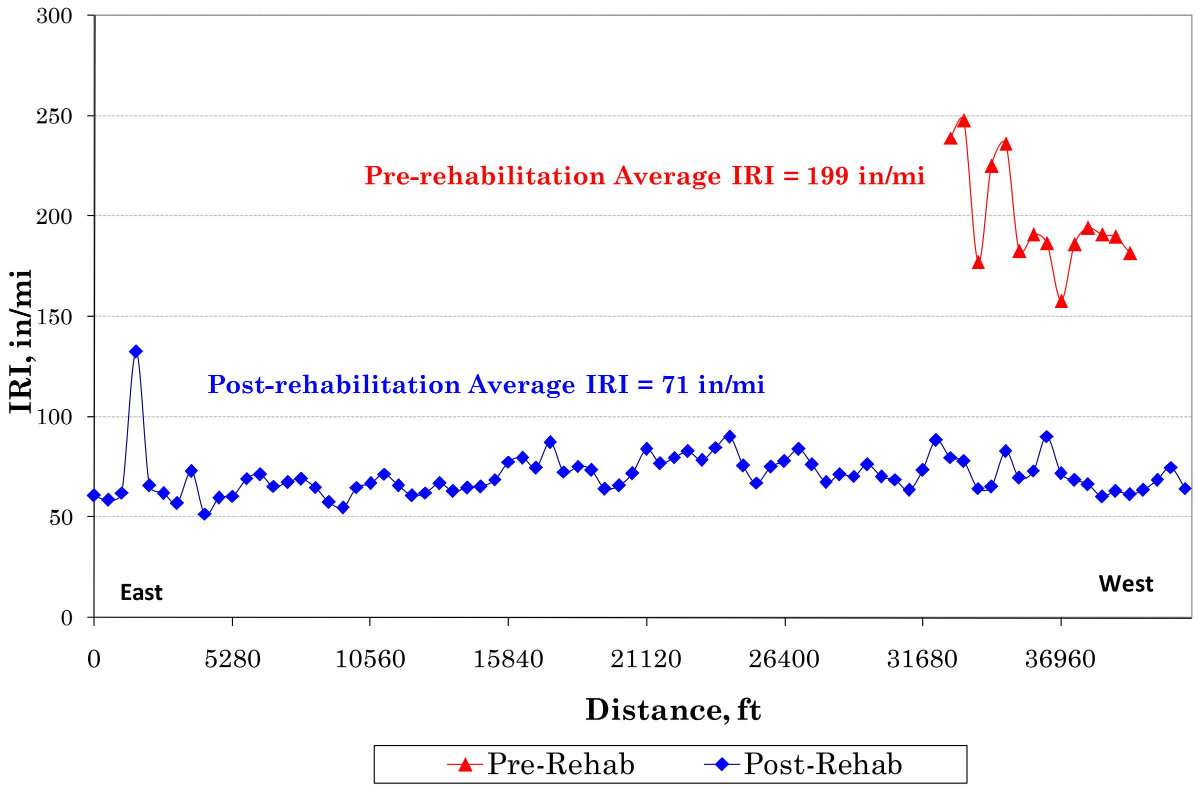


Figure 12. Mean IRI values for the old and new pavements.

Smoothness testing shows a 64 percent drop in postconstruction IRI value. Preconstruction IRI was 199 inches per mile for the existing HMA pavement, while postconstruction IRI was only 71 inches per mile. The new pavement does not meet the HfL target value of 48 inches per mile, but is still a substantial improvement over the original pavement.

USER SATISFACTION

The HfL requirement for user satisfaction is a performance goal of 4-plus on a Likert scale of 1 to 7 for the following two questions:

- How satisfied are you with the results of the new pavement compared to the condition of the previous pavement?
- How satisfied are you with the approach NDDOT used (full lane closure) to construct the new pavement in terms of minimizing disruption?

A stakeholder survey was conducted by NDDOT in which survey forms were distributed to nearby residents and businesses within a mile of the project during and after construction. The survey used a 5-point instead of a 7-point scale. A 4-plus (57 percent) favorable response or better on a 7-point scale is equivalent to a 2.9 plus response on a 5-point scale. The mean response value for both questions was above 4, which indicates that the level of satisfaction for this project exceeded the HfL goal. The tallied survey results are in Appendix A.

TECHNOLOGY TRANSFER

FHWA, in conjunction with the ACPA regional office, sponsored a 1-day open house to showcase whitetopping as a viable innovation for pavement rehabilitation. The open house was held Sept. 23, 2008, in Rugby, ND. The event featured presentations by NDDOT and FHWA engineers, as well as the contractor and whitetopping experts. More than 40 transportation professionals from NDDOT, FHWA, local agencies, concrete producers, and pavement designers attended the showcase (figure 13). The agenda is in Appendix B.

Figure 13. Speakers and participants at the showcase.

During the showcase, FHWA representatives provided an overview of the HfL program and an in-depth presentation on whitetopping, especially the Colorado Department of Transportation's (CDOT) extensive research on and implementation of concrete overlay projects. ACPA Regional Executive Director David Sethre detailed the benefits of whitetopping as proven from a historical viewpoint. Clayton Schumaker of NDDOT discussed project details from project development through the process of including whitetopping as an innovation to achieve HfL objectives. The contractor provided an insider's perspective on placing whitetopping. The presentations were followed by a visit to the project site, where participants examined the paver and several miles of completed whitetopping and sawcutting operations. The showcase concluded with a panel question-and-answer session. Figure 14 shows the site visit.

Figure 14. During the showcase, participants gathered by the paver to discuss the project and sawcutting operations.

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 (as-built) adopted on an HfL project with those from a more traditional delivery approach (baseline) on a project of similar size and scope.

CONSTRUCTION TIME

For the as-built scenario the actual construction time needed to mill, pave, and install turn lanes was only 34 days. For the baseline scenario, the construction time is based on a NDDOT time estimate for conventional pavement rehabilitation using North Dakota's mine and blend bituminous base-hot bituminous paving method or mine-and-blend method. An equivalent mine-and-blend design of the type constructed on US 2 (5.5 in of HMA on 18 in of granular base, assuming 5 in of the original base could be reused and 13 in of new base placed on top) would have resulted in 53 days. Using this information the total number of days saved during paving operations is 53 – 34 = 19 days. Table 2 details the mine-and-blend calculation.

Table 2. Time estimate for an equivalent Mine-and-Blend rehabilitation.

Work Item	Quantity	Unit	Production per Day	Start Day	Item Duration	End Day
Grade 6 Turn Lanes	1	Each	1	0	6	6
CI-3 Aggregate Base for Blending	176,748	Ton	5,000	4	36	40
Mine-and-Blend	8.24	Mile	0.5	24	17	41
Hot Bituminous Pavement	59,083	Ton	3,500	36	17	53

Notes:
Aggregate: 13 in depth, 8.24 mi length, 54 ft width, and 1.875 ton per cubic yard.
HMA: 5.5 in depth, 8.24 mi length, 40 ft width, and 2 ton per cubic yard.

CONSTRUCTION COSTS

A conventional mine-and-blend overlay NDDOT project (AC-HPP-NH-3-281(091)112 PCN#16385) had a similar scope (paving, earthwork, widening, etc.) and was constructed during the same year on U.S. 281 between Carrington and New Rockford. The conventional project serves as a suitable cost comparison, and the following information is a subjective analysis of the likely cost differential rather than a rigorous computation of the cost differential. The conventional project covered 13.07 mi (20.94 km) of two-lane highway and had a $6,764,162 contract value. Prorating the contract value to an 8.24-mi project length equates to $4,686,077, of which $3,213,381 was for items related to paving and traffic control. In comparison, $4,691,765 of the $7,670,203 as-built project was for paving and traffic control. The pavement construction cost for the whitetopping was $1,478,384 higher than the conventional overlay. Table 3 presents a breakdown of the baseline and as-built contract costs.

Table 3. Capital cost calculation table.

Cost Category	Baseline Case[1]	As-Built Case[2]
Pavement Construction		
Paving (driving lanes, turn lanes, and shoulders)	$ 3,068,639	$ 4,606,665
Traffic Control	$ 573,992	$ 85,100
Pavement Construction Total	**$ 3,213,381**	**$ 4,691,765**
Other Construction Costs		
Engineering	$ 421,602[3]	$ 863,907
Earthwork	$ 573,992	$ 1,009,368
Other (striping, seeding, signage, etc.)	$ 428,646	$ 1,092,463
Special Items		
Borrow Material	$ --	$ 1,700
Haul Road Repair and Restoration	$ --	$ 5,000
Utility Adjustments	$ --	$ 6,000
Fuel and Material Cost Adjustments	$ 48,456	$ --
Total Project	**$ 4,686,077**	**$ 7,670,203**

[1] Baseline values are supplied by NDDOT estimate details and are prorated for the 8.24-mi project length.
[2] As-built values are supplied by NDDOT contract detail estimate.
[3] Engineering costs are typically 10 percent of construction cost, according to NDDOT.

User Costs

Generally, three categories of user costs are considered in an economic or life cycle cost analysis: vehicle operating costs, delay costs, and crash and safety-related costs. The user cost for this analysis focused on the delay cost to identify the differences between the as-built and baseline alternative. During construction the speed limit was reduced from 70 mi/h (112.6 km/h) to 60 mi/h (96.6 km/h) for the head-to-head detour on the eastbound lanes. NDDOT provided the delay time and cost information in table 4, which shows that the added time to travel the detour increased travel time by 1.1 minutes and the total user cost per day was $1,733. The benefit to the traveling public was $32,927. The benefit was essentially the cost saved per day for each day of construction reduced by the innovative approach.

Table 4. U.S. 2 user delay cost per day.

Detour	Detour time, (min)	Normal time, (min)	Delay time, (min)	2006 AADT (both directions)		Cost/hour	User delay cost/day
EB/WB traffic	8.0	6.9	1.1	Trucks	810	$ 26.16	$ 388
				Autos	5,000	$ 14.67	$ 1,345
				Total user cost/day =			**$ 1,733**
				Total user savings = ($1,733*19 days)			**$ 32,927**

Initial Cost Summary

From an initial construction cost standpoint, the innovative approach was $1,478,384 more than traditional paving. In terms of user delay cost during initial construction, $32,927 was saved by reducing the construction period. The net increase over traditional construction was $ 1,445,457 in terms of initial costs.

LIFE CYCLE COST ANALYSIS

A life cycle cost analysis (LCCA) based on a 4 percent discount rate and present worth method was performed to provide a detailed context to further compare the as-built and baseline projects. A deterministic approach was used to examine construction and future maintenance costs over the 20-year service life criteria chosen by NDDOT in the original design process. Both the agency costs and user costs are examined in this LCCA.

LCCA Agency Costs

Agency costs considered are those costs NDDOT is directly responsible for and include the cost of materials, labor, equipment, and traffic control necessary to construct and maintain the pavement over the service life.

The type, scheduling, and cost of maintenance and repair (M&R) of the baseline HMA pavement is based on NDDOT's experience with similar highways in its geographic region. After initial construction, NDDOT expects to seal cracks in 2 to 3 years and every other year thereafter, followed by a slurry seal in 3 years and again in 7 to 8 years. In 15 to 20 years NDDOT anticipates the need for a thin (3-in) HMA overlay. NDDOT's maintenance cost estimates for these activities are table 5.

Table 5. NDDOT HMA maintenance costs.

Activity	Cost/mi (2009 dollars)
Crack seal	$7,500/mi
Slurry seal	$32,000/mi
HMA overlay	$135,000/mi
Note: Costs include material, labor, equipment, and traffic control.	

In North Dakota, engineers have ample experience with maintaining HMA pavements, but only limited experience with maintaining whitetopping pavements over long time periods. Other agencies, such as CDOT, have a well-established and -documented history with highway whitetopping projects,[2] which indicates that at year 20 rehabilitation may include diamond grinding to restore smoothness and repair of 1 percent of the pavement panels. This would place rehabilitation beyond the service period for this analysis. A growing consensus of DOTs[3] suggests that whitetopping M&R recommendations are similar to conventional concrete

[2] G. Lowery, "Life Cycle Cost Analysis of Thin Whitetopping," *Proceedings of the International Conference on Best Practices for Ultrathin and Thin Whitetoppings*, Denver, CO, 2005.

[3] R. Rasmussen and D. Rozycki, *Thin and Ultrathin Whitetopping*, National Cooperative Highway Research Program, Synthesis 338, Washington DC, 2004.

pavements. NDDOT anticipates only minimal distresses and no additional maintenance costs to the district's budget.

LCCA User Costs

User costs during construction were considered in this LCCA and were a function of the vehicle operating cost from table 4 and the additional time needed to travel though the work zones associated with M&R activities. Free-flowing traffic conditions were assumed to be present through work zones, given that no observed backups occurred on the head-to-head detour during the as-built construction. Similar free-flowing conditions would likely exist while crews executed M&R activities and constructed the alternate baseline pavement when traffic would be maintained on the adjacent lane. During these periods, a work zone speed limit of 45 mi/h (72.4 km/h) was used in the analysis.

The slurry seal application was expected to take no longer than a day. Overlay operations would take longer because of the amount of HMA to be placed. To overlay the mainline lanes, the project would require about 19,317 tons of HMA, calculated as follows:

amount of HMA = project length X lane width X overlay thickness X unit weight of HMA

where:

project length	= 8.24 mi x 5,280 ft/mi = 43,507 ft
lane width	= 24 ft (both lanes)
overlay thickness	= 0.25 ft
unit weight of HMA	= 148 lbs/ft^3

Assuming a typical paving crew can place 1,700 tons/day, the overlay operation would last 12 days (19,317 tons/1,700 tons/day).

LCCA Summary

The agency and user costs and the timing of these costs were combined to formulate a projected expenditure stream for the as-built and baseline pavement designs. The FHWA RealCost software was used to calculate the anticipated net present value (NPV) of future costs of the expenditure stream through the use of the discount rate, allowing for a direct dollar-for-dollar comparison. The salvage value of each alternative is included in the analysis and represents the value of the remaining useful service life of the initial construction and the remaining usefulness of the last M&R activity. Life cycle cost NPV was calculated as follows:

$$NPV = Initial\,Cost + \sum Future\,Cost * \left[\frac{1}{(1+i)^n} \right]$$

where:

NPV	= net present value, $
i	= discount rate, percent
n	= time of future cost, years

The LCCA shows the whitetopping pavement to be within $83,067 or 1.8 percent of the baseline option in combined agency costs and user costs during construction.

Table 6. LCCA summary table.

Cost Category	Age (yrs)	Baseline (Mine-and-Blend) Pavement	As-Built (Whitetopping) Pavement
Pavement Construction, Earthwork, Traffic Control, Preliminary Design and Engineering, Construction Engineering Delay-Related User Costs	0	$ 3,213,381 $ 62,011	$ 4,691,765 $ 7,521
Preventive Maintenance, Crack Seal Agency cost = 8.24 mile @ $7,500 per mile	2	$ 61,800	$ 0
Preventive Maintenance, Slurry Seal Agency cost = 8.24 mile @ $7,500 per mile Delay-related user cost	3	$ 263,680 $ 456	$ 0 $ 0
Preventive Maintenance, Crack Seal Agency cost = 8.24 mile @ $7,500 per mile	5	$ 61,800	$ 0
Preventive Maintenance, Crack Seal 8.24 mile @ $7,500 per mile	7	$ 61,800	$ 0
Preventive Maintenance, Crack Seal 8.24 mile @ $7,500 per mile	9	$ 61,800	$ 0
Preventive Maintenance, Slurry Seal 8.24 mile @ $32,000 per lane-mile Delay Related User Cost	10	$ 263,680 $ 600	$ 0 $ 0
Preventive Maintenance, Crack Seal 8.24 mile @ $7,500 per mile	12	$ 61,800	$ 0
Preventive Maintenance, Crack Seal 8.24 mile @ $7,500 per mile	14	$ 61,800	$ 0
Thin HMA Overlay (Preliminary Design and Engineering, Construction, Construction Engineering, Traffic Control) Delay-Related User Costs	16	$ 1,112,400 $ 57,019	$ 0 $ 0
Preventive Maintenance, Crack Seal 8.24 mile @ $7,500 per mile	18	$ 61,800	$ 0
Salvage Value	20	$ 0	$ 0
Total Actual Costs		**$ 5,405,827**	**$ 4,699,286**
Net Present Value of All Costs		**$ 4,616,219**	**$ 4,699,286**

Cost Summary

The initial summary of construction costs and user delay costs indicates that whitetopping costs more than traditional construction. However, a closer look at the agency costs and user costs during initial construction and M&R activities suggests these costs differ by 1.8 percent. The narrow LCCA differential is considered insignificant given the extent of variables in the analysis. The actual cost saving realized by the whitetopping resides in the user cost savings during initial construction of $32,927 by delivering the project in less time than traditional construction.

APPENDIX A: USER SATISFACTION SURVEY

On a scale of 1–5, please rate your satisfaction level with the following. (1 meaning strongly disagree and 5 meaning strongly agree)**.**

	1	2	3	4	5	Average	Response Count
Approach used to construct the new road in terms of minimizing disruption (surveyed during construction)	0.0% (0)	0.0% (0)	0.0% (0)	54.5% (6)	45.5% (5)	4.45	11
The condition of the new roadway compared to its previous condition (surveyed after construction)	0.0% (0)	0.0% (0)	0.0% (0)	40.0% (4)	60.0% (6)	4.60	10
					Average Response	4.53	

APPENDIX B: WORKSHOP AGENDA

US 2 - Concrete Overlay
Open House

Pizza Inn
Highway 2 East, Rugby, North Dakota
Tuesday, September 23, 2008
Moderator: David Sethre, ND-ACPA

9:30 am	**Registration**
10:00 am	**Welcome and Introductions** *Francis Ziegler, NDDOT Director for Engineering*
10:15 am	**Highways for LIFE Overview** *Wendall Meyer, FHWA ND Division Administrator*
10:30 am	**National Perspective on Concrete Overlay** *Ahmad Ardani*, Applied Research Associates, Inc.
11:00 am	**BREAK**
11:15 am	**North Dakota Perspective on Concrete Overlay** *David Sethre, ND-ACPA Executive Director*
11:45 am	**Project Overview** *Clayton Schumaker, NDDOT* Geotechnical/Research Engineer
12:15 pm	**Contractor's Perspective on Concrete Overlay** *Steve Gerster/Don Shonyo, Progressive Contractors, Inc.*
12:30 pm	**LUNCH**
1:30 pm	**Project Tour** *Steve Gerster/Don Shonyo, Progressive Contractors, Inc.*
3:00 pm	**Questions and Answer Wrap-up** *Panelists:* *Ahmad Ardani*, Applied Research Associates, Inc. *David Sethre, ND-ACPA Executive Director* *Clayton Schumaker, NDDOT* Geotechnical/Research Engineer *Steve Gerster/Don Shonyo, Progressive Contractors, Inc.*
3:30 pm	**Adjourn**

Showcase Speaker List

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