

# Tennessee Demonstration Project: AC Resurfacing of Four Locations in Tennessee Utilizing Intelligent Compaction Technology

Final Report  
March 2015

***HIGHWAYS FOR LIFE***  
*Accelerating Innovation for the American Driving Experience.*



U.S. Department of Transportation  
**Federal Highway Administration**

## FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. LIFE is an acronym for Longer-lasting highway infrastructure using Innovations to accomplish the Fast construction of Efficient 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](http://www.fhwa.dot.gov/hfl)

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<p>16. Abstract</p> <p>As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the Tennessee Department of Transportation was awarded a \$1,445,600 grant to demonstrate the use of proven, innovative technologies for intelligent compaction. This report documents the use of intelligent compaction technology to accelerate the resurfacing of four locations in Tennessee. Innovations in these projects increased safety, enhanced quality, and will provide increased longevity and lower maintenance costs for the people of Tennessee.</p> <p>Using the intelligent compaction technology increased the initial construction cost on all four projects by a total of 2.5 percent. As all equipment used on the projects was the same, with or without intelligent compaction technology, the increase is assumed to be entirely due to the rental of intelligent compaction hardware and software installed on the standard compaction equipment. There was no time savings on these specific projects, but it is assumed that the experience gained will allow more routine use of this technology in the future where time savings may be realized. This is especially true in the area of reduced testing.</p> <p>However, it is assumed that the overall quality of the projects was improved, especially with regard to the consistency of the compaction effort. This is expected to reduce the likelihood of early failures and increase the likelihood of reduced maintenance and longer project life. Even a 1-year increase in project life more than offsets the cost of the innovation in after accounting for the present value of future maintenance and early rehabilitation.</p> <p>To promote further interest and use of the innovations included in this project, TDOT, in conjunction with the FHWA, sponsored a 1-day showcase. The general consensus is that IC is a promising technology for the future of paving in Tennessee.</p>			
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**SI\* (MODERN METRIC) CONVERSION FACTORS**

**APPROXIMATE CONVERSIONS TO SI UNITS**

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
(none)	Mil	25.4	micrometers	µm
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
yd	Yards	0.914	meters	m
mi	Miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	square meters	m <sup>2</sup>
ac	Acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	Gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
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")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	Poundforce	4.45	Newtons	N
lbf/in <sup>2</sup> (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in <sup>2</sup> (ksi)	kips per square inch	6.89	megaPascals	MPa
<b>DENSITY</b>				
lb/ft <sup>3</sup> (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m <sup>3</sup>

**APPROXIMATE CONVERSIONS FROM SI UNITS**

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
µm	Micrometers	0.039	mil	(none)
mm	Millimeters	0.039	inches	in
m	Meters	3.28	feet	ft
m	Meters	1.09	yards	yd
km	Kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	Hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
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
<b>TEMPERATURE</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	Lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela per square meter	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	Newtons	0.225	poundforce	lbf
kPa	kiloPascals	0.145	poundforce per square inch	lbf/in <sup>2</sup> (psi)
MPa	megaPascals	0.145	kips per square inch	k/in <sup>2</sup> (ksi)

\*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

AADT	Annual Average Daily Traffic
AC	Asphalt Concrete
CMV	Compaction Meter Value
dB(A)	A-Weighted Decibel
FHWA	Federal Highway Administration
GPS	Global Positioning System
HfL	Highways for LIFE
IC	Intelligent Compaction
IRI	International Roughness Index
OBSI	Onboard Sound Intensity
OSHA	Occupational Safety and Health Administration
PDO	Property Damage Only
PQI	Pavement Quality Index
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SRTT	Standard Reference Test Tire
TDOT	Tennessee Department of Transportation

# INTRODUCTION

## HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

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

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—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 an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

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

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

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

### **Project Solicitation, Evaluation, and Selection**

FHWA issued open solicitations for HfL project applications in fiscal years 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 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 on 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 miles in a rural area or less than 1.5 miles in an urban area (in both cases at a travel speed 20 percent less than the posted speed).
- **Quality**
  - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches/mile.
  - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.
- **User Satisfaction**

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

## **REPORT SCOPE AND ORGANIZATION**

This report documents the Tennessee Department of Transportation (TDOT) HfL demonstration project, which involved accelerated construction on four resurfacing projects around the State. The report presents project details relevant to the HfL program, including innovative contracting, construction highlights, rapid construction, 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

In May 2013, TDOT awarded individual contracts to resurface pavement at four geographically distinct locations within the State of Tennessee. Individual contracts were let to maximize competition.

One of the major reasons TDOT decided to use IC technology was to complete these resurfacing projects with minimal inconvenience to the public through decreased construction time. In addition, the use of IC technology seeks to provide a continuous real-time examination of compaction effort that minimizes areas where substandard density could result in reduced service life.

The primary innovative feature employed in this project was the IC technology. The use of this technology is expected to result in a higher quality pavement along with greater consistency in quality, thus providing a longer lasting product with lower future maintenance costs.

All four of the projects let using IC technology were contracted using traditional contracting methods. IC requirements were bid as a lump sum item in the contract so that the actual cost of the equipment and methods could be tracked.

## DATA COLLECTION

On most HfL projects, data are collected before, during, and after construction, as appropriate, to demonstrate that the featured innovations can be deployed while simultaneously meeting the HfL performance goals for safety, construction congestion, quality, and user satisfaction:

- **Safety**
  - Work zone safety during construction—No motorist incidents were reported during construction. The TDOT exceeded the HfL requirements for work zone safety.
  - Worker safety during construction—No worker injuries occurred during construction, which exceeded the goal of less than a 4.0 rating on the OSHA 300 form.
  - Facility safety after construction—The use of IC technology is expected to minimize the need for spot maintenance activities throughout the life of the projects, limiting the exposure of both the public and the agency to future work zone activities.
- **Construction Congestion**
  - Faster construction—The IC technology did not significantly reduce the total construction time for these projects. While this did not meet the HfL goal of a 50 percent reduction, the overall quality of the project is expected to exceed that of a project constructed using traditional methods, reducing the need for future maintenance activities.

- Trip time during construction—The average travel time measured during construction was varied based on project location. Three of the locations showed little or no increase in travel time, due to very low traffic volumes. The other section did show some increase in travel time, but all work was conducted at night minimizing the impact to the public. The HfL goal of less than 10 percent increase in trip time compared to the average preconstruction speed was met.
- Queue length during construction—Given the low traffic volumes encountered on these projects, no queue length greater than the HfL performance goal of less than 0.5 miles was observed.
- **Quality**
  - Smoothness—The average post-construction IRI ranged from 46.5 inches/mile to 68 inches/mile on the four projects. While only one of the four met the HfL goal of less than 48 inches/mile, two others were very close, measuring between 49 and 52 inches/mile. The section with the highest IRI, SR 331 in Knox County, is an urban section with many entrances, hills, and curves that may have contributed to the higher numbers. All sections showed significant reductions from the pre-construction values, and TDOT considers all of them acceptable.
  - Noise—Post-construction noise values ranged from 101.6 dBA to 104.9 dBA, all above the HfL goal of 96 dBA. Only two of the projects showed a decrease in noise from pre-construction levels. Given the nature of the project locations, the agency considers the resultant levels to be acceptable.
- **User satisfaction**
  - User satisfaction—Due to the relatively short nature of the projects with respect to construction duration and the rural nature of the locations, no user satisfaction survey was conducted for these projects.

## **ECONOMIC ANALYSIS**

The cost of delivering these HfL projects was compared to the most likely traditional alternative technique, in this case the use of traditional compaction equipment testing methods. The traditional methods would have employed the same rolling equipment; therefore, the only innovation-related cost incurred by the agency was the direct cost of the IC components attached to the rollers. The bid item costs for the IC equipment ranged from \$27,000 to approximately \$112,000.

Thus, there was a slight additional upfront cost associated with the use of IC technology on these four projects. Individually, the increases ranged from 1.3 to 6.7 percent. The increase calculated for all projects combined added 2.5 percent to the total cost. While no immediate savings was realized in reduced testing or faster construction, the DOT believes that there could be savings in future projects when there is a higher comfort level with the technology on the part of both the agency and the contractor.

TDOT believes that some of the rental cost could be offset in the future by reduced testing, once the agency and the contractors become more familiar with the technology. However, as this was new technology, the actual amount of testing may have been slightly greater than normal, given the need to provide quality assurance for the new procedures.

## **LESSONS LEARNED**

There were minimal issues identified with the use of IC technology on these projects. However, there were issues identified that could help provide for more successful application of this technology in the future.

TDOT believes that it is important to construct a test strip prior to project construction to validate the process of IC data collection, data downloading, and review of the collected data. Some data were lost because it was not realized that the download procedures was not being done correctly.

Also, it is important to have a device available for inspectors, contractors, and others to easily translate the GPS coordinates created by the software to a point location along the project.

## **CONCLUSIONS**

While the initial cost of the IC technology is higher, TDOT believes that there is a definite advantage to IC technology for its ability to ensure that compaction is adequate and consistent along the length of paving projects. The long-term performance of the overlays produced using IC technology is expected to be greater than when using conventional methods. Less maintenance is expected than with conventional rolling techniques, because fewer areas are expected to escape the desired compaction levels.





## PROJECT DETAILS – GENERAL OVERVIEW

### BACKGROUND

The TDOT HfL demonstration project consisted of the resurfacing of four pavements at various locations using IC technology. The projects were located on SR 331 in Knox County, SR 58 in Hamilton County, US 64 in Lincoln County, and US 412 in Crockett County, as shown in figure 1.

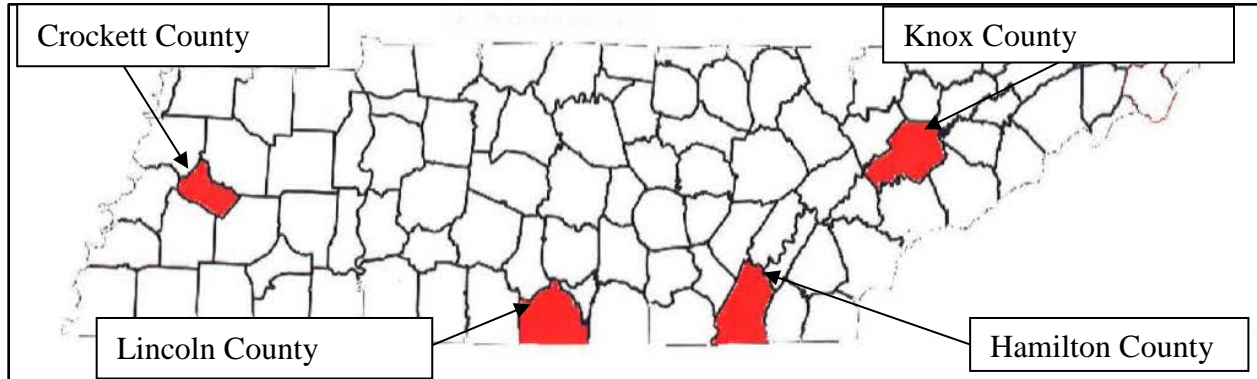


Figure 1. Map. General project locations.

Three of the four projects are four-lane divided facilities with relatively low traffic volumes. The fourth project (Knox County) is a two-lane undivided urban facility. The Lincoln and Hamilton County projects included milling of the surface prior to resurfacing, while the Knox and Crockett County projects involved only resurfacing of the existing pavement.

### INTELLIGENT COMPACTION TECHNOLOGY

The primary innovative feature employed in the Tennessee HfL project was the use of IC technology. IC refers to the use of modern vibratory rollers equipped with a series of state-of-the-art sensors, data collection/display features, and location equipment that provide real-time evaluation of compaction effort and a record of that data for future use.

Intelligent compaction (IC) technology generally consists of three main components:

- A response system (accelerometer) attached to a standard vibratory roller, measuring the vertical movement of the drum which is then related through software to a stiffness value (see figure 2).
- An onboard computer system for real-time monitoring, reporting, and storage of data (figure 3).
- A global positioning system (GPS) that relates the stiffness data to a physical location on the roadway (figure 4).

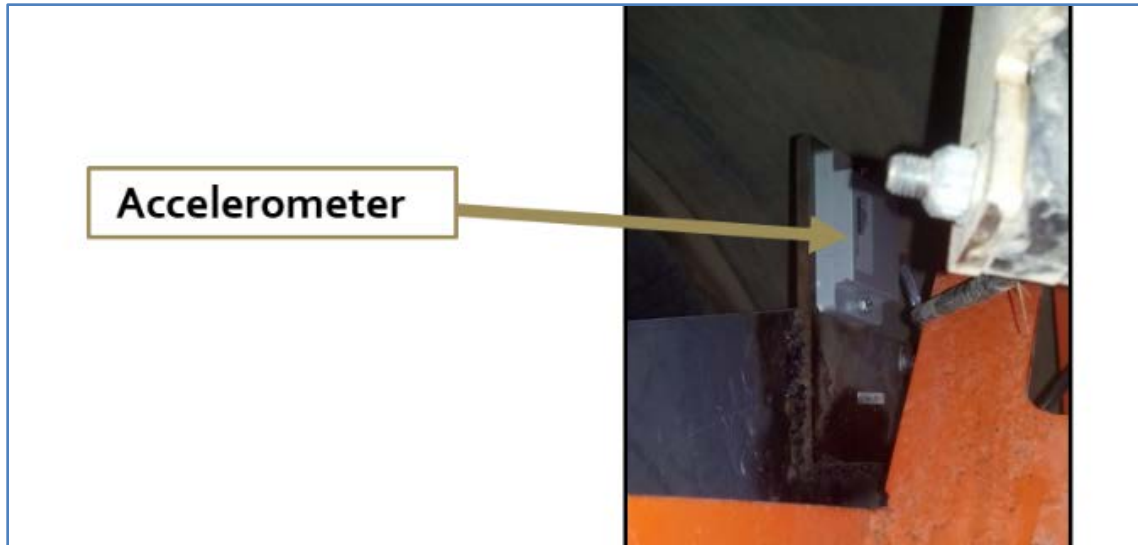


Figure 2. Photo. Accelerometer mounted to roller drum. (courtesy: University of Tennessee, Knoxville )



Figure 3. Photo. Roller-mounted computer screen used for real-time compaction information. (courtesy: University of Tennessee, Knoxville)



Figure 4. Photos. GPS location equipment. (courtesy: TDOT)

IC does not indicate directly the density or percent compaction of a soil or pavement. However, it can be used to estimate these values when calibrated to local conditions and using the actual rollers employed in the construction.

For the TDOT projects, the agency constructed a test strip used to calibrate the IC equipment before actual construction. Equipment was run over the test strip and the compaction meter value (CMV) collected for each pass of the roller along with mat temperature and location information.

CMV is calculated from the dynamic roller response (from the attached accelerators). It depends on characteristics of the roller such as diameter, weight, frequency, amplitude, and speed.

Conventional density testing was conducted, and TDOT examined the data to determine the number of passes that corresponded to the desired level of compaction. An example of the test results showing CMV plotted against the number of passes for a set material type and roller is shown in figure 5. In this case, the CMV levels off after the third pass of the roller.

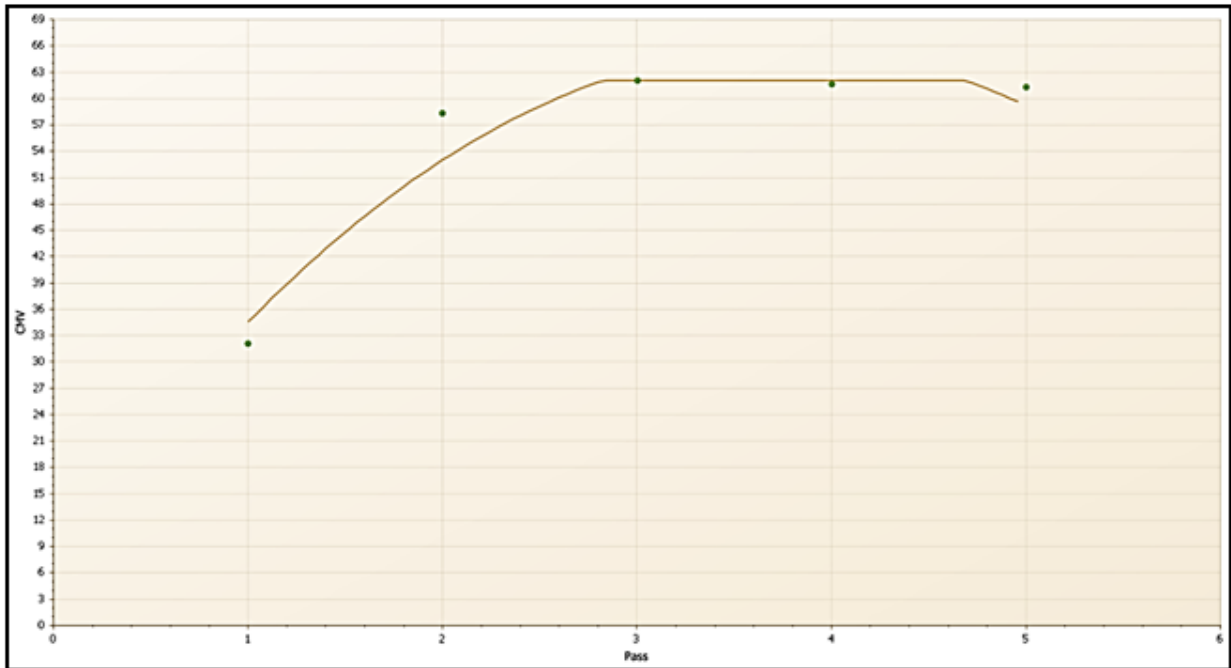


Figure 5. Graph. CMV vs. number of roller passes.

In the field, the operator was able to view the areas compacted through a color-coded display showing when the desired number of passes had been achieved. Figure 6 shows a photo of the screen taken during one of the Tennessee projects. The operator can see his location in the roadway, the number of passes for each portion of the lane, the mat temperature, and the target passes all in one location. These data were used to determine when the desired level of compaction was achieved.

Figure 7 shows an example of a report generated by the software. The data can be reported and stored in table form to show a variety of statistics associated with the compaction activities, including roller speed, frequency, temperature, and CMV for each roller equipped with the IC hardware and software.



Figure 6. Photo. Onboard computer screen showing color-coded display of roller passes.

All passes data																						
Breakdown Roller														Intermediate Roller								
Date	Roller Speed (kph)			Frequency (Hz)				Amplitude (mm)				Temperature (°C)			CMV		Roller Speed (kph)		Temperature (°C)			
	Mean	SD	CoV	Mean	SD	CoV	Mean	SD	CoV	Mean	SD	CoV	Mean	SD	CoV	Mean	SD	CoV	Mean	SD	CoV	
14-Oct	5.7	1.9	33	35	2	7	0.81	0.12	15	121	18.15	13	68.86	22.1	32	5.3	1.9	36	79	13.15	14	
15-Oct	6.5	2	31	37	2	4	0.79	0.09	11	117.8	20.25	15	61.69	18.8	30	6.2	1.8	30	78.2	13.76	14	
17-Oct	6.4	2	32	38	3	7	0.78	0.08	11	122.8	17.91	13	60.69	20.1	33	6.2	1.8	28	79.1	12.05	12	
18-Oct	6.5	1.9	30	38	2	5	0.79	0.09	11	124.1	17.23	12	55.49	18.2	33	6.1	1.7	28	79.6	11.14	11	
21-Oct	6.6	2	30	38	2	4	0.78	0.08	11	115.3	19.87	15	63.29	19.8	31	5.9	1.7	29	74.7	12.46	13	
22-Oct	6.1	1.9	31	38	2	5	0.78	0.09	12	111.4	22.77	18	73.27	25.9	35	4.9	1.9	38	66.2	10.03	12	
23-Oct	6.3	2	32	40	1	4	0.88	0.15	17	105.1	20.7	17	81.57	27.4	34	5.9	1.9	31	68.8	9.58	11	
24-Oct	6.5	1.9	30	38	1	4	0.87	0.15	17	114.2	19.63	15	69.95	19	27	6.3	1.8	28	72.9	12.1	13	
26-Oct	6.8	1.9	28	38	1	3	0.88	0.14	16	109.2	21.16	17	66.12	17.6	27	5.8	1.8	30	70.1	11.18	13	
28-Oct	6.3	2	32	38	1	3	0.84	0.13	15	109.9	22.16	17	63.79	18.7	29	5.9	1.7	30	77.1	12.76	13	
29-Oct	6.6	1.9	29	38	2	5	0.82	0.12	15	102.9	20.82	17	65.61	29.1	44	6.2	1.7	28	68.1	11.56	13	
30-Oct	6.7	1.9	29	38	2	5	0.83	0.11	13	92	24.53	22	69.02	26.4	38	6.3	1.8	29	68.3	12.37	14	
1-Nov	6.5	1.9	29	38	2	5	0.97	0.17	17	93.3	17.54	16	64.34	18.8	29							

Figure 7. Table screen shot. Statistics collected by software on example project.

## DATA COLLECTION

### Smoothness

Smoothness testing, required by HFL as a quality indicator, was performed on all four locations following the ASTM E 950 method for both the original and the newly overlaid pavement using a high-speed inertial profiler. Figure 8 shows the test vehicle with the profiler positioned in line with the right rear wheel.





Figure 8. Photo. High-speed inertial profiler mounted behind the test vehicle.

### Sound Intensity

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 five runs were made in the right wheel path of the mainline lanes. 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. Photos. OBSI dual-probe system and the SRTT.

## **Pavement Durability and Uniformity**

One of the main benefits of IC technology is the reduction in construction variability due to operator inconsistency. The knowledge of real-time compaction effort and mix temperature is expected to result in a far more uniform product with respect to compaction, known to be a major contributor to pavement quality and service life. A study reported in TRB publication “Effect of Compaction on Asphalt Concrete Performance” states that in general, a 1 percent increase in air voids (over the base air-void level of 7 percent) tends to produce about a 10 percent loss in pavement life. Also, elimination of “shoving” associated with rolling at higher than optimum temperature is expected to result in a smoother pavement for the traveling public.





## PROJECT DETAILS – SR 331, KNOX COUNTY

### BACKGROUND

As shown in figure 10, Knox County is located in eastern Tennessee. The HfL project in Knox County involved the resurfacing of SR 331, between McCamey Road in Knoxville and Pleasant Valley Lane near Corryton (see figure 11).

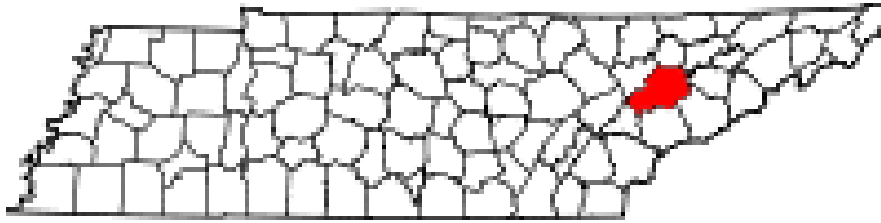


Figure 10. Map. Knox County, Tennessee.

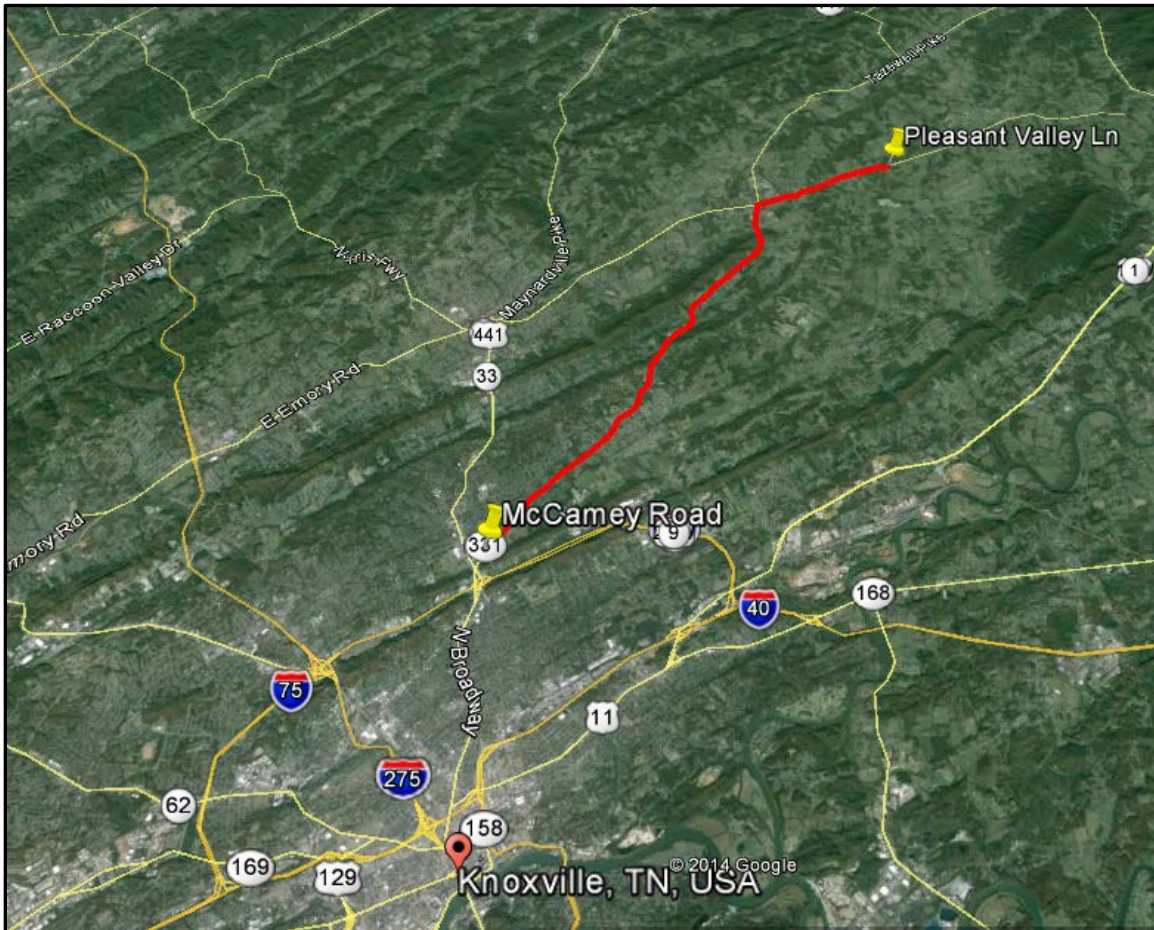


Figure 11. Map. SR 331 project location. (courtesy: Google Earth)

The project spans a distance of approximately 10.5 miles. Within these limits, SR 331 consists of a 2-lane urban roadway carrying between 5,000 and 16,000 vehicles per day. The existing pavement was an asphalt roadway with aggregate shoulders and a Pavement Quality Index (PQI) of approximately 3 on a 5-point scale.

### PROJECT DESCRIPTION

The improvement varied throughout the limits, based on the existing structure, but in general consisted of the application of an asphalt concrete (AC) leveling material followed by an AC surface mix. Figure 12 shows the typical section of the resulting overlay.

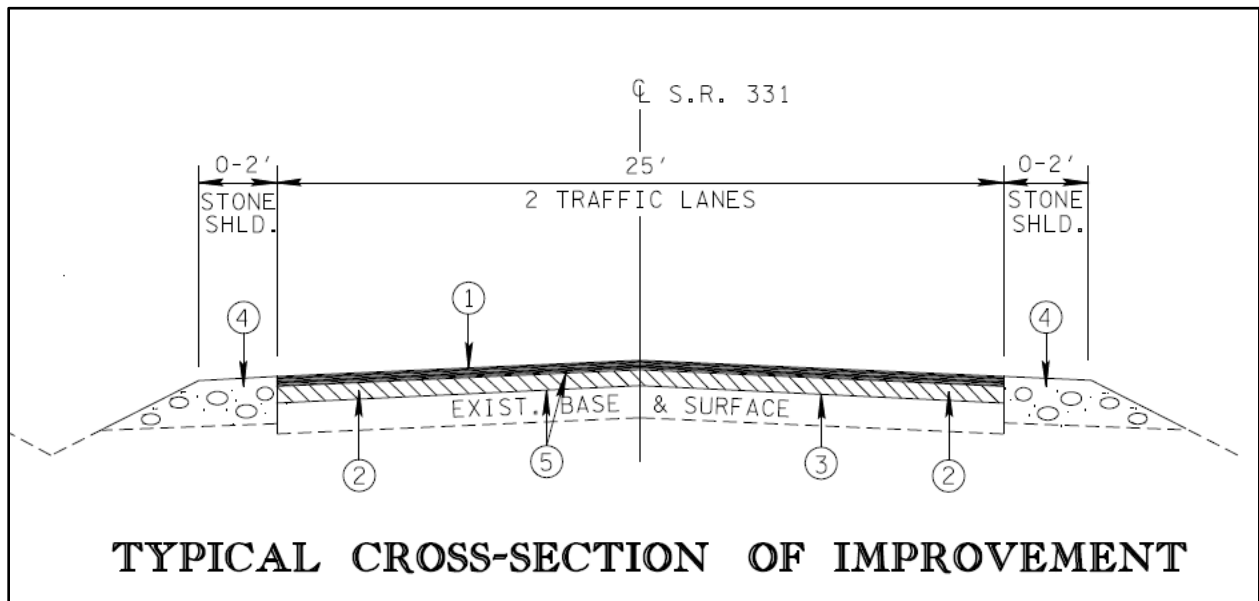


Figure 12. Diagram. Typical section of improvement on SR 331, Knox County.

### Bid Information

The project was awarded in July 2013 at a cost of \$1,527,094. The IC bid item for this project was \$31,580.

### Project Construction

Construction began on October 11, 2013, and was completed on November 20, 2013. The level course was composed of a PG 70-22 411TLD mix, with the final surface being a PG 70-22 411D mix. The mix design for the level course is shown in table 1, and the mix design for the surface course is shown in table 2.

Table 1. Mix design for Knox County SR 331, AC level course (411-TLD).

Asphalt Cement	PG 70-22	Marathon Petroleum Co. Knoxville			5.050
Percent AC in RAP 1:		Optimum AC Content: 5.7		Total	100.00
Percent AC in RAP 2:	6.5	Anti-Strip Supplier: Tri-State Sand LLC			
Anti-Strip Additive:	Ar-Maz			Dosage: 0.5%	
AC Contribution	Virgin AC	5.05	RAP AC	0.65	Percent Virgin AC: 88.6
Asphalt Specific Gravity:	1.032		Dust to Asphalt Ratio:	1.03	
% Fracture Face on CA:	n/a		% Glassy Particles on CA:	n/a	
Theo. Gravity of RAP 1:			Eff. Gravity of Agg.	2.797	
Theo. Gravity of RAP 2:					
Theo. Gravity of Mix:	2.549	TSR:	92.7	Lbs./Ft <sup>3</sup> :	159.0
L.O.I.:	17.5		Ignition Oven Corr. Factor:	0.45	
ADT	16,462		Warm Mix?	No	
Lab. Temperature			Plant Temperature		
Mixing Temperature ( $\pm 5^0$ F):	330		Mixing Temp. Range ( $^0$ F):	$290^0 \text{ F} \leq T \leq 330^0 \text{ F}$	
Lab. Compaction Temp. ( $\pm 5^0$ F):	290		Delivery Temperature ( $^0$ F):	$290^0 \text{ F} \leq T \leq 330^0 \text{ F}$	

Sieve Size	Percents Used						RAP Processed - 1/2	% Req. 100	Design Range
	# 8	#10	Natural Sand	Fine Slag					
	50.0	15.0	15.0	10.0			10.0		
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"									
1/2"	100	100	100	100			100	100	100
3/8"	89	100	100	100			98	94	90 - 100
No. 4	29	90	98	99			85	61	54 - 76
No. 8	6	60	90	90			67	41	35 - 57
No. 16									
No. 30	4	26	52	50			39	22	17 - 33
No. 50	3	19	24	25			24	13	10 - 18
No. 100	2.7	15.6	8.3	11.0			19.0	7.9	3 - 10
No. 200	2.3	13.1	5.0	5.0			15.0	5.9	4 - 7

Table 2. Mix design for Knox County SR 331, AC surface course (411-D).

Asphalt Cement	PG 70-22	Marathon Petroleum Co. Knoxville			5.066
Percent AC in RAP 1:		Optimum AC Content: 5.7		Total	100.00
Percent AC in RAP 2:	6.3		Anti-Strip Supplier: Westvaco Polychemical Dept.		
Anti-Strip Additive:	Evo-Therm			Dosage: 0.5%	
AC Contribution	Virgin AC	5.07	RAP AC	0.63	Percent Virgin AC: 88.9
Asphalt Specific Gravity:	1.025		Dust to Asphalt Ratio: 0.83		
% Fracture Face on CA:	n/a		% Glassy Particles on CA: n/a		
Theo. Gravity of RAP 1:			Eff. Gravity of Agg. 2.800		
Theo. Gravity of RAP 2:					
Theo. Gravity of Mix:	2.548	TSR:	89.9	Lbs./Ft <sup>3</sup> :	159.0
L.O.I.:	15.0		Ignition Oven Corr. Factor:		0.49
ADT	71,479		Warm Mix?		Yes
Lab. Temperature			Plant Temperature		
Mixing Temperature ( $\pm 5^0$ F):	270		Mixing Temp. Range ( $^0$ F): $250^0$ F $\leq$ T $\leq$ $290^0$ F		
Lab. Compaction Temp. ( $\pm 5^0$ F):	260		Delivery Temperature ( $^0$ F): $250^0$ F $\leq$ T $\leq$ $290^0$ F		

Sieve Size	Percents Used						RAP Processed - 1/2	% Req. 100	Design Range
	# 8	#10	Natural Sand	Fine Slag					
	40.0	10.0	15.0	25.0					
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"	100	100	100	100		100	100	100	
1/2"	95	95	100	100		100	98	95 - 100	
3/8"	66	80	100	100		97	84	80 - 93	
No. 4	19	46	90	98		76	58	54 - 76	
No. 8	7	28	60	88		58	42	35 - 57	
No. 16									
No. 30	3	12	28	50		35	23	17 - 29	
No. 50	2	7	20	20		23	12	10 - 18	
No. 100	2.0	5.0	15.0	7.0		17.0	7.0	3 - 10	
No. 200	1.0	3.0	13.0	3.5		12.0	4.7	0 - 6.5	

All paving at this location was done at night to minimize inconvenience to the public. Figure 13 shows the placement of the mat, while figure 14 shows the compaction equipment utilizing the IC technology.



Figure 13. Photo. AC mat placement (courtesy: TDOT)



Figure 14. Photo. IC roller in operation. (courtesy: TDOT)

## DATA ACQUISITION AND ANALYSIS

Safety, construction congestion and quality data were collected before, during and after construction for this project where appropriate. The primary purpose was to supply HfL with sufficient information to support the use of IC technology in future applications. This section details specific project data related to the HfL goals.

### Safety

No worker injuries were reported on this project.

Construction was completed using traditional traffic control for the paving operation. One lane was closed at a time and traditional flagging operations were employed.

There were no crashes reported during the construction, obviously meeting the HfL goal of a crash rate equal to or less than the pre-construction rate. Three-year crash data were provided for the period from January 1, 2009, through December 31, 2011. As can be seen in table 3, the 3-year crash rate for this location was slightly lower than the statewide average rate for a similar facility type.

Table 3. Crash rates Knox County SR 331 prior to construction.

Route	Termini	Length	Volume (3-year avg.)	Crashes (3-Year Totals 1/1/2009 – 12/31/2011)			3-Year Rate	3-Year Rate (Facility Type)
				Fatal	Injury	PDO		
SR 311	McCamey Road to Pleasant Valley Lane	10.47	16,462	2	121	282	2.146	2.335

PDO = property damage only

Some future safety benefit can be expected due to the general improvement in the condition of the pavement surface. A 3-year follow-up study will be conducted to determine the safety benefits of this improvement.

### Construction Congestion

The standard HfL goal for impact of construction on the public is a 50 percent reduction compared to conventional methods. The use of IC technology was expected to contribute to this goal, by identifying in real-time areas needing additional compaction and by reducing the time needed to do manual testing with a nuclear gauge behind the paving operation. However, the actual time for paving on this project was limited to only 10 days. It should also be noted that, on this project, all paving was done during nighttime hours when traffic was at a minimum, further reducing delay.

Due to the relatively short length and duration of the project, there was no noticeable change in construction time realized on this project. While this did not meet the HfL goal, the use of IC

technology is expected to reduce delay time in the future, by providing a longer lasting surface and fewer maintenance activities when compared to conventional compaction techniques.

### **Travel Time**

Travel time data were collected prior to construction on July 31, 2013. Times were recorded during the day for morning peak, morning non-peak, and afternoon peak periods. The non-peak morning travel time is assumed to be most comparable to the nighttime operating values. The average non-peak travel time from Emory Road to Jacksboro Pike was determined to be 10 minutes, 51 seconds, closely approximating free flow travel.

Travel times during construction were collected on October 28 and 29, 2013. The average travel time during construction (north and south directions) was calculated to be 14 minutes, 31 seconds, an increase of 3 minutes 42 seconds.

Given an annual average daily traffic (AADT) of 16,462 for this section and a duration of 10 days results in a total delay time of 10,151 vehicle-hours. However, in this case, the road was not closed 24 hours a day. All construction was done at night, between the hours of 8 PM and 6 AM. Review of an hourly traffic distribution for a count site located within the project limits indicates that only about 14 percent of the AADT could be expected during the closure hours. Applying this consideration, the total delay associated with this construction is estimated to be 1,421 vehicle-hours.

### **Queue Length**

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

### **Smoothness**

Smoothness testing, required by HfL as a quality indicator, was performed following the ASTM E 950 method for the original and the newly overlaid pavement using a high-speed inertial profiler.

The average IRI was initially measured at 116 inches/mile in the northbound direction and 103 inches/mile in the southbound direction. Post-construction IRI measured 67 inches/mile northbound and 69 inches/mile southbound, above the HfL goal of 48 inches/mile. Figures 15 and 16 illustrate the smoothness measurement results.

This project is located in an urban setting with relatively low operating speeds. The measured IRI should provide adequate smoothness for the traveling public, even though the HfL goal was not met.



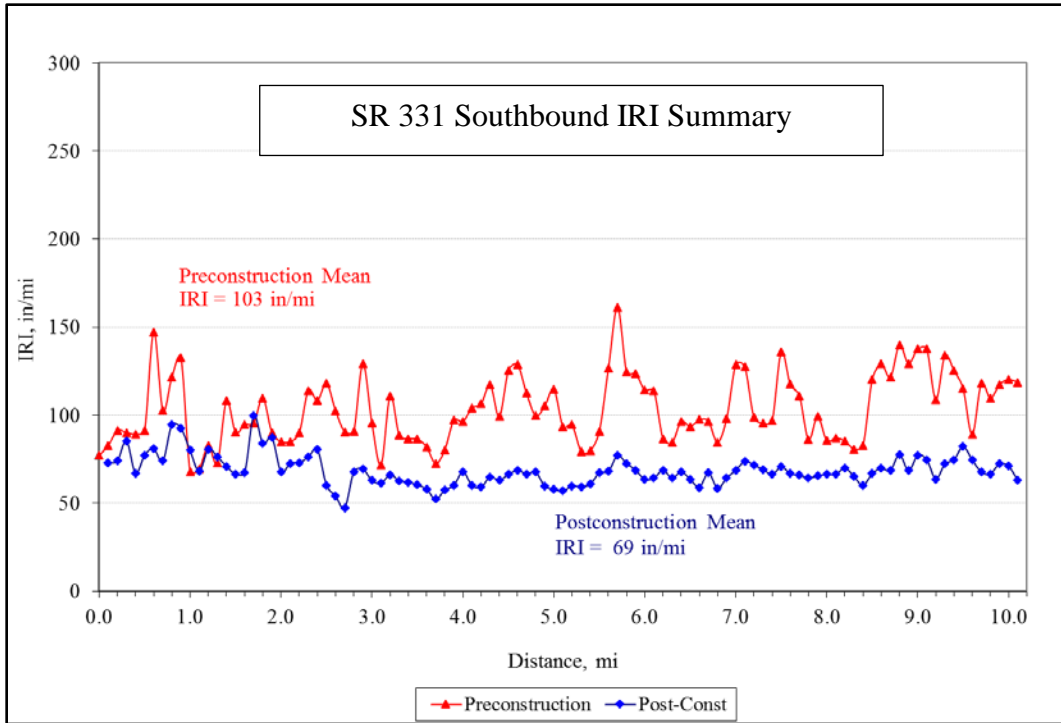


Figure 15. Graph. Summary of southbound IRI on SR 331.

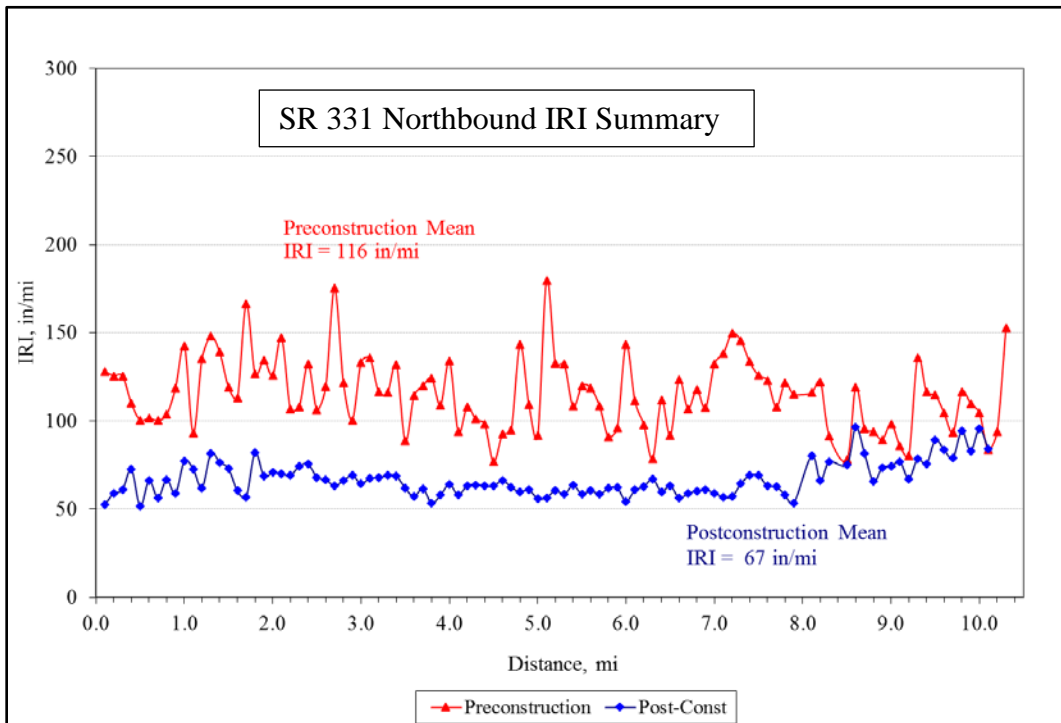


Figure 16. Graph. Summary of northbound IRI on SR 331.

## Sound Intensity

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 previously described.

The average of the front and rear sound intensity values was computed. 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 17.

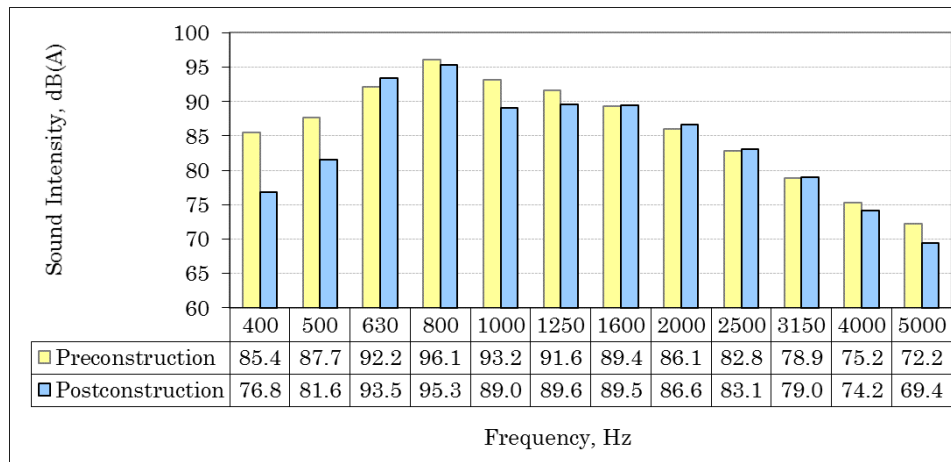


Figure 17. Graph. Mean A-weighted sound intensity frequency spectra.

Sound levels were calculated by using logarithmic addition of the one-third octave band frequencies between 315 and 4,000 Hz. The initial measurements of noise before construction averaged 100.1 dB(A) in both directions of travel. The post-construction measurement averaged 101.6 dB(A), an increase of 1.5 dB(A). While above HfL goal of 96 dB(A), TDOT considers the pavement noise component acceptable.

## USER SATISFACTION

Due to the rapid completion and the wide geographical separation of the four projects in this study, TDOT did not conduct a user satisfaction survey. It was also believed that the small difference in construction duration between the innovative methods used and traditional methods would not be noticeable to the public.

## ECONOMIC ANALYSIS

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

The only innovation employed on the Tennessee projects is the use of IC technology. The comparison made here looks at only this innovation versus a traditional overlay project constructed with traditional compaction and testing methods.

### Construction Time

The construction of the IC overlay project on SR 331 took 41 days to complete. TDOT estimated that the time to complete a project using traditional methods would have been approximately the same. While it was originally assumed that there would be some decrease in construction time, any potential reduction was eliminated by the “learning curve” associated with the equipment and software. Also, the relative short nature of the project did not lend itself to a significant reduction in construction time. While the total construction time for the project was 41 days, paving and compaction activities used only 10 of those days. The paving log for this location is shown in table 4.

Table 4. Paving schedule for the SR 331 project in Knox County.

Date (2013)	Activity	Start Coordinates		End Coordinates	
		North	East	North	East
10/24-10/25	Resurfacing	661374.9	2610205.3	654620.9	2602450.0
10/27-10/28	Resurfacing	654420.7	2602530.3	638589.6	2593997.3
10/29-10/30	Resurfacing	649041.3	2599592.0	627012.8	2585528.8
10/30-10/31	Resurfacing	657839.4	2602430.0	649005.9	2599707.0
11/03-11/04	Resurfacing	624066.8	2583668.5	622702.4	2582647.5

While the goal of a 50 percent reduction in construction time was not realized, it is assumed that providing a more consistent end product will result in a longer lasting surface and a reduction in routine maintenance in the future.

### Construction Capital Costs

The equipment required for the construction of these HfL projects is exactly the same as would be required for traditional construction practice, with the exception of the IC hardware and software, including the GPS, temperature sensors, accelerometers, computer collection and storage equipment, and evaluation software. The additional IC equipment and software was all bid as a separate item in the contract, so it can be assumed that all the additional capital cost is included in this single item.

For the Knox County project, the additional cost was \$31,580 out of a total contract cost of \$1,527,094, or about 2 percent of the project total cost.

All other factors being equal, the additional capital cost of IC technology on this project is assumed to be \$31,580.

### **User Cost**

Generally there are three categories of user costs used in an economic/life cycle analysis: detour/user costs, travel time costs, and safety-related costs.

#### *Detour/User Cost*

In the case of SR 311, there was no detour or reduced speed limit on the project. There were also no crashes during the construction period. Given the assumptions that there would be no difference in total time for construction, it is safe to assume that the only cost associated with the construction is the user delay caused by the paving itself.

#### *Travel Time Costs*

As previously discussed, the average delay encountered on this project was about 3 minutes, 42 seconds. The delay calculated (based on 14 percent usage during the hours of construction for a period of 10 days) results in a total delay of 1,421 hours.

However, TDOT estimates that, in this case, the project duration was not reduced by the use of IC technology, resulting in a cost differential of zero with respect to travel time.

#### *Safety Costs*

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

### **Cost Summary**

The data indicate that there was no direct savings as a result of the IC technology employed on this project. The fact that there was no change in project duration, travel time, or safety results in an increase in cost to the agency of \$31,580, the amount of the IC equipment rental.

Nonetheless, all indications are that the quality of the product has been improved through the use of IC technology. Discussions with agency personnel indicate that an increase in project life and a decrease in routine maintenance can be expected due to the more consistent application of compaction effort. The agency indicated that an overlay of this thickness could be expected to last approximately 6 years. If we assume that the same solution at the same cost would be employed in the future, and the life is extended by even 1 year, present value calculations indicate a savings of \$37,250, more than offsetting the initial cost incurred here.



## PROJECT DETAILS – US 412/SR 20, CROCKETT COUNTY

### BACKGROUND

Crockett County is located in western Tennessee, as shown in figure 18. This project involved the resurfacing of US 412/SR 20, between the Dyer County Line and Lyons/ Birmingham Road North of Alamo (see figure 19).

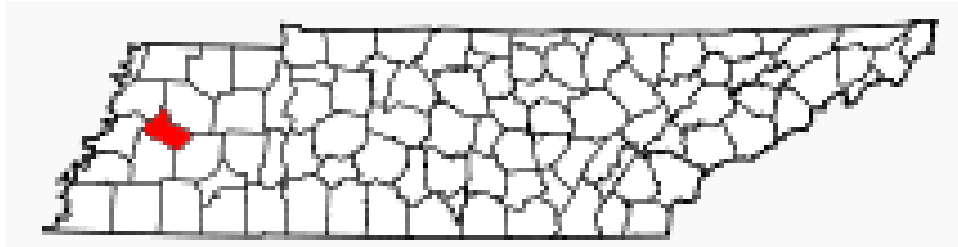


Figure 18. Map. Crockett County, Tennessee.

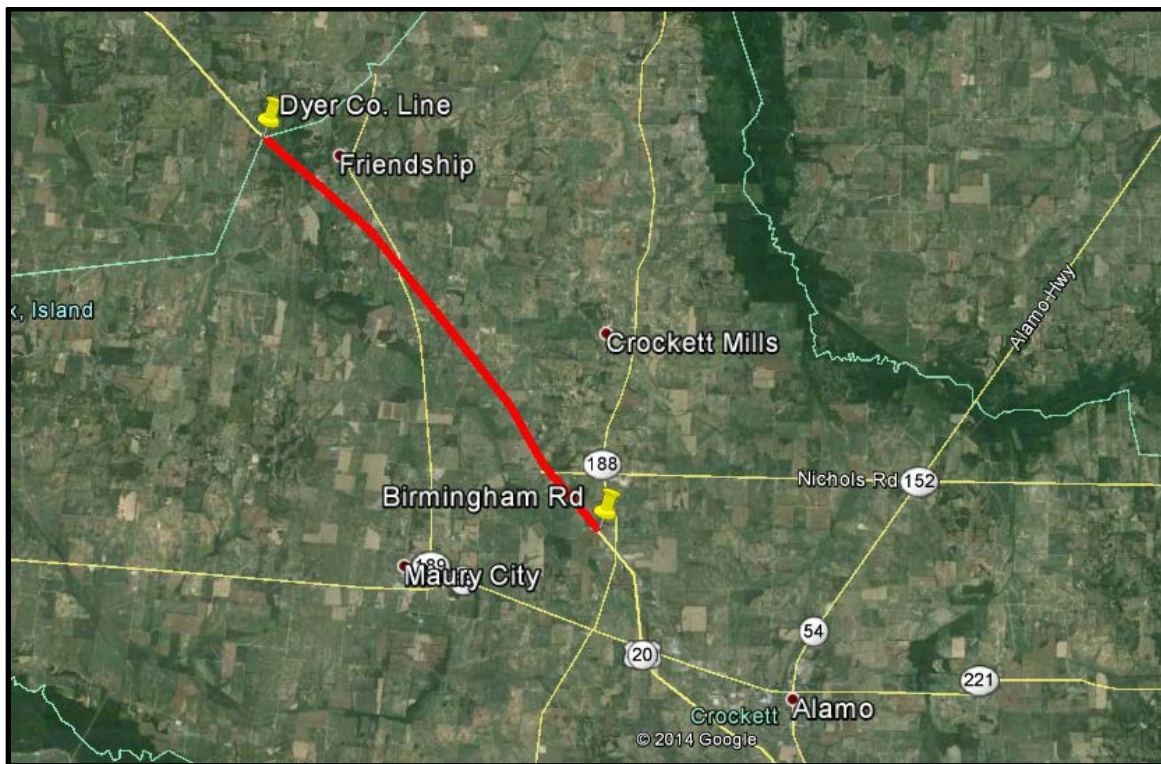


Figure 19. Map. US 412/SR 20 project location. (courtesy: Google Earth)

The project spans a distance of approximately 8.4 miles. Within these limits, SR 20 consists of a 4-lane rural roadway carrying between 9,000 and 10,000 vehicles per day. The existing pavement was an asphalt roadway with aggregate shoulders, and a PQI of approximately 3.2 on a 5-point scale. All four lanes were overlaid, for a total of 33.6 lane miles of paving.

## PROJECT DESCRIPTION

The improvement varied throughout the limits, based on the existing structure, but in general consisted of the application of an AC base leveling material approximately 0.4 inches thick followed by a 0.8-inch AC surface mix. The level course was composed of a PG 70-22 411TLD mix, with the final surface being a PG 70-22 411D mix. Figure 20 shows the typical section of the resulting overlay.

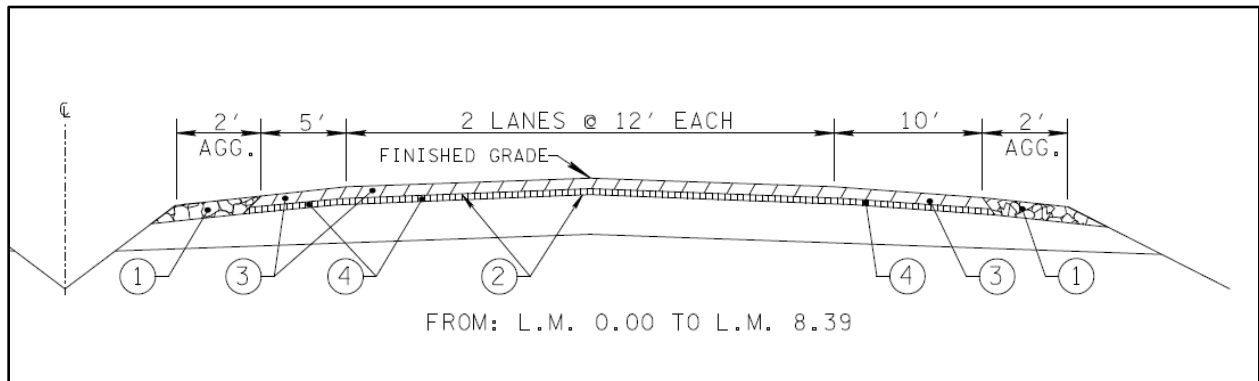


Figure 20. Diagram. Typical section of improvement.

## Bid Information

The project was awarded in July 2013 at a cost of \$4,229,508. The IC bid item for this project was \$55,000.

## Project Construction

Construction began on September 10, 2013, and was completed on December 23, 2013. Paving consisted of the application of an AC base leveling material approximately 0.4 inches thick followed by a 0.8-inch AC surface mix. The surface course was composed of a PG 70-22 411D mix. The mix design is shown in table 5.

Application of the overlay was completed using traditional paving methods. Figure 21 shows the paving laydown operation ahead of the IC equipment.

Table 5. Mix design for Crockett County US 412 surface course (411-D).

Asphalt Cement	PG 70-22	Ergon Asphalt & Emulsions, Memphis, TN			5.622
Percent AC in RAP 1:	5.8	Optimum AC Content:		6.2	Total 100.00
Percent AC in RAP 2:		Anti-Strip Supplier: Arr-Mazz Products.			
Anti-Strip Additive:	AD-here LA-2			Dosage: 0.5%	
AC Contribution	Virgin AC	5.62	RAP AC	0.58	Percent Virgin AC: 90.7
Asphalt Specific Gravity:	1.0416		Dust to Asphalt Ratio:	0.99	
% Fracture Face on CA:	91.7		% Glassy Particles on CA:	n/a	
Theo. Gravity of RAP 1:	2.428		Eff. Gravity of Agg.	2.531	
Theo. Gravity of RAP 2:					
Theo. Gravity of Mix:	2.325	TSR:	90.2	Lbs./Ft <sup>3</sup> :	145.1
L.O.I.:	9.1		Ignition Oven Corr. Factor:	0.23	
ADT	9,840		Warm Mix?	No	
Lab. Temperature			Plant Temperature		
Mixing Temperature ( $\pm 5^{\circ}$ F):	310		Mixing Temp. Range ( $^{\circ}$ F):	$290^{\circ}$ F $\leq$ T $\leq$ $330^{\circ}$ F	
Lab. Compaction Temp. ( $\pm 5^{\circ}$ F):	300		Delivery Temperature ( $^{\circ}$ F):	$290^{\circ}$ F $\leq$ T $\leq$ $330^{\circ}$ F	

Sieve Size	Percents Used						% Req. 100	Design Range
	D Rock	#10	Natural Sand			RAP Processed – 1/2		
	50.0	20.0	20.0			10.0		
2"								
1.5"								
1.25"								
1"								
3/4"								
5/8"	100	100	100	100		100	100	100
1/2"	93	100	100	100		100	97	95 - 100
3/8"	76	100	100	100		97	88	80 - 93
No. 4	47	94	90	100		79	70	54 – 76
No. 8	32	64	60	99		62	42	35 – 57
No. 16								
No. 30	12	12	33	65		36	29	17 – 29
No. 50	8	7	27	27		25	17	10 – 18
No. 100	6.0	5.0	21.0	4.0		14.0	9.4	3 – 10
No. 200	4.5	3.0	13.0	2.0		9.0	6.2	0 – 6.5

Figure 22 shows the compaction roller equipped with the IC technology following the laydown operation.





Figure 21. Photo. Typical AC placement.



Figure 22. Photo. IC-equipped compaction roller.

## DATA ACQUISITION AND ANALYSIS

Safety, construction congestion and quality data were collected before and after construction for this project where appropriate. The primary purpose was to supply HfL with sufficient information to support the use IC technology in future applications.

This section details specific project data related to the HfL project goals.

### Safety

No worker injuries were reported on this project. Construction of the project was completed using traditional traffic control for the paving operation. One lane was closed at a time using traditional flagging operations. There were no crashes reported during the construction, obviously meeting the HfL goal of a crash rate equal to or less than the pre-construction rate.

Three-year crash data were provided for the period from January 1, 2009, through December 31, 2011. The crash rates for this location before construction are shown in table 6. The overall rate is seen to be lower than the statewide average rate for a similar facility type.

Table 6. Crash rates prior to construction.

Route	Termini	Length	Volume (3-year avg.)	Crashes (3-Year Totals 1/1/2009 – 12/31/2011)			3-Year Rate	3-Year Rate (Facility Type)
				Fatal	Injury	PDO		
US 412	Dryer County Line to Lyons/Birmingham Rd	8.39	9,504	1	25	22	.549	.773

Some future safety benefit can be expected due to the general improvement in the surface condition of the pavement. A 3-year follow-up study will be conducted to determine the actual safety benefits of this improvement.

### Construction Congestion

The standard HfL goal for impact of construction on the public is a 50 percent reduction compared to conventional methods. The use of IC technology was expected to contribute to this goal by identifying in real time areas needing additional compaction and by reducing the time needed to do manual testing with a nuclear gauge behind the paving operation. However, the actual time for paving on this project was limited to only 13 days. Due to the relatively short length and duration of the project, there was no noticeable change in construction time realized on this project.

While this did not meet the HfL goal of a 50 percent reduction, the use of IC technology is expected to reduce delay time in the future, by providing a longer lasting surface and fewer maintenance activities when compared to conventional compaction techniques.

## Travel Time

At this location, US 412/SR 20 is a 4-lane divided facility carrying between 9,000 and 10,000 vehicles per day. Travel time data were collected prior to construction on August 4, 2013. Travel was free flow at the speed limit for the limits measured.

Travel times during construction were collected on October 28 and 29, 2013. The average travel time during construction (north and south directions) was calculated to be 7 minutes, 44 seconds in either direction, again indicating free flow travel at the posted 65 mph speed limit. Given these observations, there was no user delay and therefore no delay associated with this project.

## Queue Length

The capacity of the existing facility, even with one lane closed for paving, exceeded the requirements of traffic observed using the facility. No queue was observed during paving operations, thus meeting the HfL goal of no queue greater than one-half mile.

## Smoothness

Smoothness testing was performed following the ASTM E 950 method for the original and the newly overlaid pavement using a high-speed inertial profiler. The initial IRI for this project was measured at 89 inches/mile in the eastbound direction and 84 inches/mile in the westbound direction. Post-construction IRI measured 47 inches/mile eastbound and 46 inches/mile westbound, meeting the HfL goal of 48 inches/mile. Figures 23 and 24 summarize the smoothness testing results.

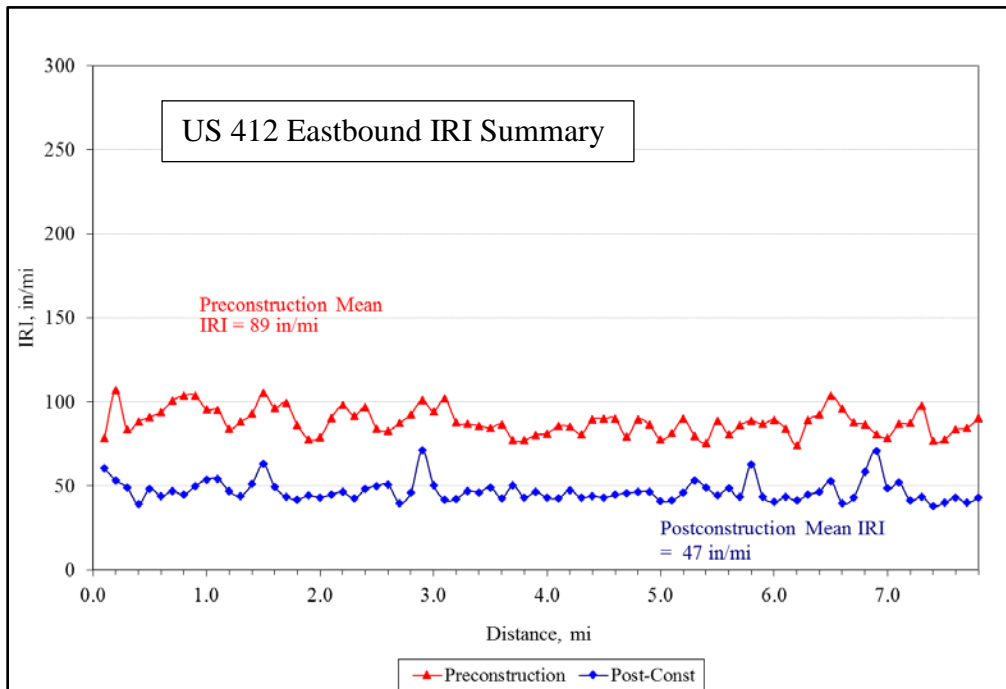


Figure 23. Graph. Pre- and post-construction smoothness data, US 412/SR 20, eastbound direction.

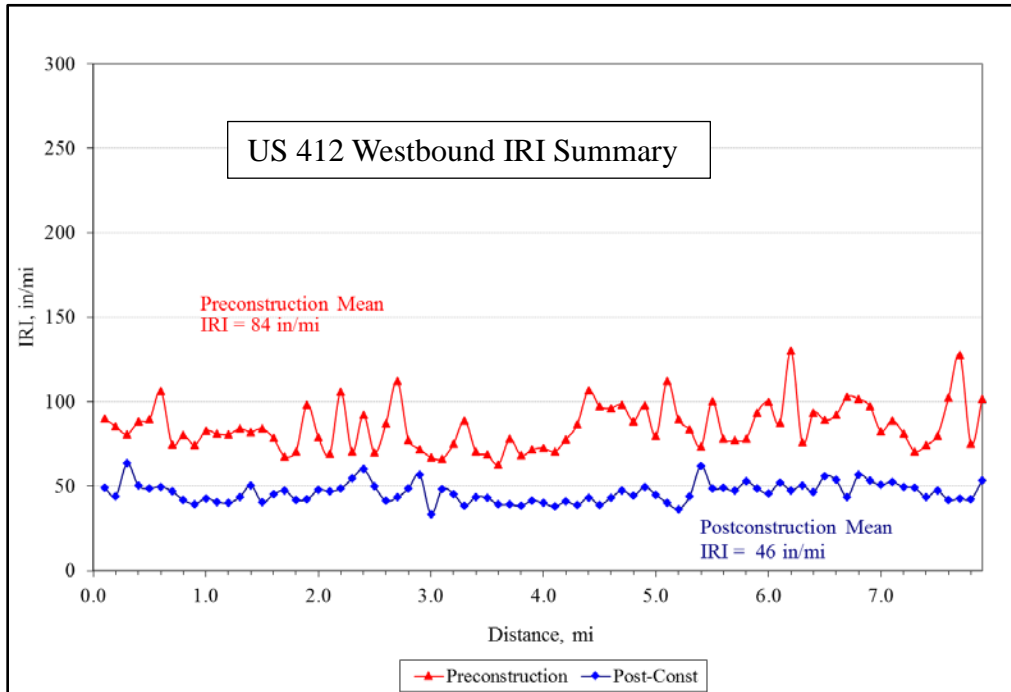


Figure 24. Graph. Pre- and post-construction smoothness data, US 412/SR 20, westbound direction.

## Sound Intensity

Sound intensity measurements were made using the AASHTO TP 76-08 test method. The sound measurements were recorded and analyzed using an onboard computer and data collection system. A minimum of five runs were made in the right wheel path of the mainline lanes. The two microphone probes simultaneously captured noise data from the leading and trailing tire-pavement contact areas.

The average of the front and rear sound intensity values was computed. 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 25.

Sound levels were calculated by using logarithmic addition of the one-third octave band frequencies between 315 and 4,000 Hz. The initial measurements of noise before construction averaged 105.4 dB(A) in both directions of travel. The post-construction measurement averaged 104.9 dB(A), a reduction of 0.5 dB(A) but still above the HfL goal of 96 dB(A). In a rural setting, TDOT considers the pavement noise component acceptable.

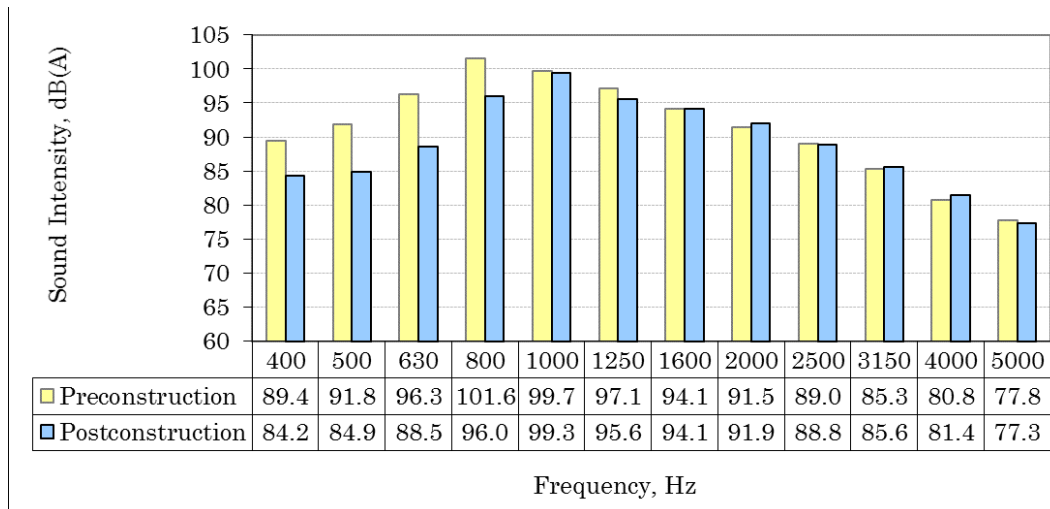


Figure 25. Graph. Mean A-weighted sound intensity frequency spectra.

## USER SATISFACTION

Due to the rapid completion and the wide geographical separation of the four projects in this study, TDOT did not conduct a user satisfaction survey. It was also believed that the small difference in construction duration between the innovative methods used and traditional methods would not be noticeable to the public.

## ECONOMIC ANALYSIS

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

The only innovation employed on the Tennessee projects is the use of IC technology. The comparison made here looks at only this innovation versus a traditional overlay project constructed with traditional compaction and testing methods.

## Construction Time

The construction of the IC overlay project on US 412/SR 20 in Crockett County took a total of 105 days to complete. However, while the total construction time for the project was 105 days, paving and compaction activities accounted for only 13 of those days.

TDOT estimated that the time to complete a project using traditional methods would have been approximately the same. While it was originally assumed that there would be some decrease in construction time, any reduction was eliminated by the “learning curve” associated with the equipment and software. Also, the relative short nature of the project did not lend itself to a significant reduction in construction time. The paving log for this location is shown in table 7.

Table 7. Paving schedule for the US 412/SR 20 project in Crockett County.

Date	Activity	Start		End		Direction
		North	East	North	East	
10/14/2013	Resurfacing	557204.7	1028819.3	558590.7	1027699.6	Westbound
10/15/2013	Resurfacing	558531.1	1027681.8	564027.6	1023488.6	Westbound
10/17/2013	Resurfacing	563924.6	1023536.1	571248.6	1019035.3	Westbound
10/18/2013	Resurfacing	571170.8	1019090.1	580399.2	1012110.4	Westbound
10/21/2013	Resurfacing	580842.3	1011730.8	569231.1	1020489.8	Eastbound
10/22/2013	Resurfacing	569296.1	1020441.1	557421.3	1028492.3	Eastbound
10/23/2013	Resurfacing	557164.1	1028802.1	566551.9	1022228.3	Westbound
10/24/2013	Resurfacing	566455.1	1022282.4	581099.3	1011618.4	Westbound
10/26/2013	Resurfacing	580778.3	1011750.8	569979.0	1019897.1	Eastbound
10/28/2013	Resurfacing	570049.8	1019861.3	559106.5	1027133.9	Eastbound
10/29/2013	Resurfacing	557196.8	1028771.3	568526.4	1021122.1	Westbound
10/30/2013	Resurfacing	568487.6	1021146.3	580892.0	1011757.8	Westbound
11/1/2013	Resurfacing	575736.2	1015547.2	575187.3	1015964.9	Eastbound

### Construction Capital Costs

In the case of all four IC projects awarded under this demonstration program, all IC hardware was leased and bid as a lump sum item in the contract. All IC equipment was installed on compaction equipment already owned by the contractor. It can therefore be assumed that the only cost associated with the IC technology is that cost itemized for that specific bid item in the contract.

The total cost to TDOT for construction of the Crockett County project was \$4,229,508. Of this, \$55,000—or about 1.3 percent of the total cost—was specific to lease of the IC equipment. All other factors being equal, the additional capital cost of IC technology on this project is assumed to be \$55,000.

### User Cost

Generally there are three categories of user costs used in an economic/life cycle analysis: detour/user costs, travel time costs and safety related costs.

#### *Detour/User Cost*

Standard traffic control methods were employed for construction of this project. One lane was closed at a time while conducting the paving operations, resulting in one-lane operation with flaggers. No detour cost was associated with this project. Therefore, the only user cost associated with the project would be in the area of delay.

#### *Travel Time Costs*

Travel time data were collected prior to and during construction. Preconstruction data were collected on July 31, 2013, and construction period data were collected on October 21, 2013. Data were collected on the entire corridor, with no intermediate values taken.



Because of the relatively low traffic volumes and high capacity on this corridor, there was no noticeable impact to mobility along the route. Discussions with TDOT indicated that there was no real “peak” traffic period on this route. This was confirmed by the preconstruction survey. Three runs were collected over the course of the day, morning peak, morning non-peak, and afternoon peak, with no more than 6 seconds difference in any of the travel times over the length of the project.

Travel times collected during construction showed a similar pattern. Eight runs were collected, four where the paving operation was present (one lane closed), and the other four in the opposing direction where no construction was present. There was no more than 10 seconds difference in any of the times, with the average travel time for all runs in both directions being exactly the same.

Given this observation, and the fact that there was no reduction in speed limit through the work zone, it is clear that under these traffic conditions, there was no impact in travel times for the public on this project and, thus, no cost differential for the use of IC technology in the construction.

### *Safety*

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

As was discussed previously, there were no incidents within the work zone for the duration of this project. Because the work duration would have been approximately the same for construction without the IC technology, it can be assumed that the safety costs for either would offset, resulting in a cost differential for the HfL innovation of zero.

### **Cost Summary**

The data indicate that there was no direct savings as a result of the IC technology employed on this project. The fact that there was no change in project duration, travel time, or safety results in an initial increase in cost to the agency of \$55,000, the amount of the IC equipment rental.

Nonetheless, all indications are that the quality of the product has been improved through the use of IC technology. Discussions with agency personnel indicate that an increase in project life and a decrease in routine maintenance can be expected due to the more consistent application of compaction effort. TDOT indicated that an overlay of this thickness could be expected to last approximately 6 years. If we assume that the same solution would be employed in the future, and the life is extended by 1 year, present value calculations (based on only the cost of paving items included in the bid) indicate a savings of \$79,259, more than offsetting the initial cost incurred here.

## PROJECT DETAILS – SR 58, HAMILTON COUNTY

### BACKGROUND

Hamilton County is located in southeastern Tennessee, as shown in figure 26. This project involved the resurfacing of SR 58, between Eller Road in Chattanooga and Lakewood Acres Drive near Harrison (see figure 27).

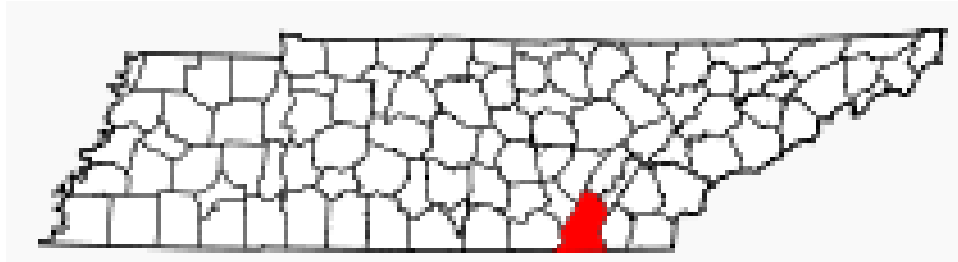


Figure 26. Map. Hamilton County, Tennessee.

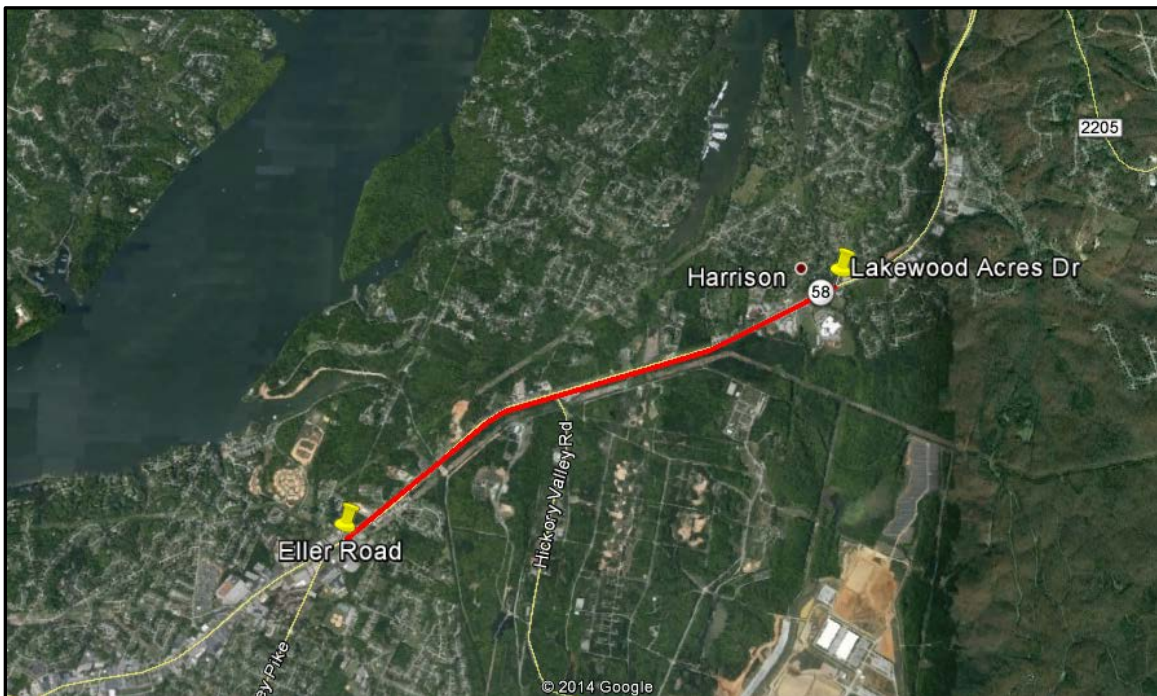


Figure 27. Map. SR 58 project location. (courtesy: Google Earth)

The project spans a distance of approximately 2.8 miles, with a total of 12.95 lane miles of paving. Within these limits, SR 58 has two typical sections. The first, from Eller Road to Clark Road, consists of a four-lane divided urban roadway. From Clark Road to Lakewood Acres Drive on the east end of the project is a four-lane facility with a continuous center turn lane. The AADT for the project is about 26,500 vehicles per day. The existing pavement was an asphalt roadway with paved shoulders and a PQI rating of approximately 3.3 on a 5-point scale.



**PROJECT DESCRIPTION**

The improvement varied throughout the limits, based on the existing structure, but in general consisted of cold planing the surface to a depth of 1.25 inches followed by the application of a 1.25-inch AC surface mix. Figure 28 shows the typical sections of the resulting overlays.

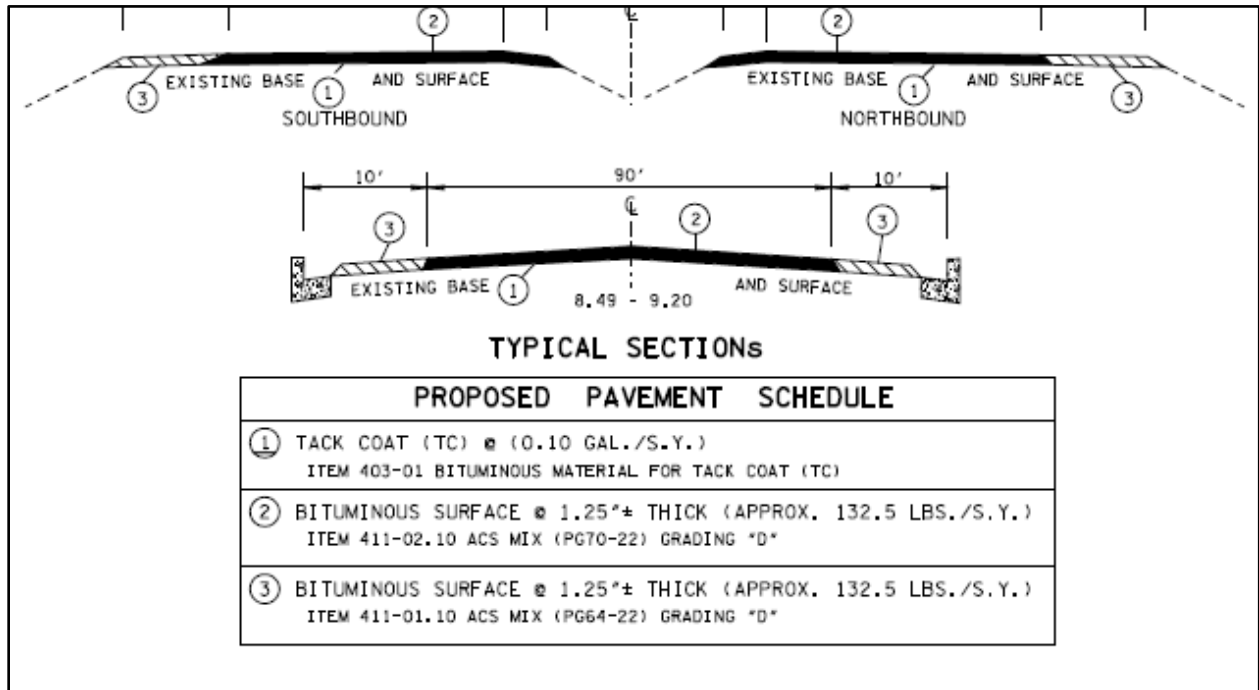


Figure 28. Diagram. Typical sections of improvements.

**Bid Information**

The project was awarded in July 2013 at a cost of \$1,673,709. The IC bid item for this project was \$27,086.

**Project Construction**

Construction began on October 4, 2013, and was completed on November 15, 2013.

The surface of the roadway was cold planed approximately 1.25 inches prior to paving. Paving consisted of placement of a surface course, 1.25 inches thick (132.5 #/sq. yard) using PG 70-22 Graded D asphalt. The surface course was composed of a PG 70-22 Grade D. The mix design for the AC surface course is shown in table 8.

Figure 29 shows the placement of the mat, while figure 30 shows the compaction equipment utilizing the IC technology.

Table 8. Mix design for Hamilton County SR 58 surface course (411-D).

Asphalt Cement	PG 70-22	Phillips 66, Knoxville			5.249
Percent AC in RAP 1:		Optimum AC Content: 6.1		Total	100.00
Percent AC in RAP 2:	5.7	Anti-Strip Supplier: Tri-State Sand LLC			
Anti-Strip Additive:		TS 23	Dosage: 0.5%		
AC Contribution	Virgin AC	5.25	RAP AC	0.85	Percent Virgin AC: 86.0
Asphalt Specific Gravity:	1.031		Dust to Asphalt Ratio:		0.60
% Fracture Face on CA: n/a		% Glassy Particles on CA: n/a			
Theo. Gravity of RAP: 2.45		Eff. Gravity of Agg. 2.646			
Theo. Gravity of Mix: 2.415		TSR:	89.3	Lbs./Ft <sup>3</sup> :	150.7
L.O.I.: 6.8		Ignition Oven Corr. Factor:		0.23	
ADT 26,500		Warm Mix?		No	
Lab. Temperature		Plant Temperature			
Mixing Temperature ( $\pm 5^0$ F): 315		Mixing Temp. Range ( $^0$ F): $290^0 \text{ F} \leq T \leq 330^0 \text{ F}$			
Lab. Compaction Temp. ( $\pm 5^0$ F): 305		Delivery Temperature ( $^0$ F): $290^0 \text{ F} \leq T \leq 330^0 \text{ F}$			

Sieve Size	Percents Used						% Req. 100	Design Range
	#7	#8	#9	#10	Natural Sand	RAP Processed - 1/2		
2"	8.0	42.0	5.0	5.0	25.0	15.0		
1.5"								
1.25"								
1"								
3/4"								
5/8"	100	100	100	100	100	100	100	100
1/2"	86	100	100	100	100	100	99	95 - 100
3/8"	48	95	100	100	100	90	92	80 - 93
No. 4	9	34	81	87	95	69	57	54 - 76
No. 8	3	7	23	57	84	53	36	35 - 57
No. 16								
No. 30	2	4	6	26	64	31	24	17 - 29
No. 50	2	3	4	19	28	20	12	10 - 18
No. 100	1.5	2.0	2.0	14.8	4.0	14.0	4.9	3 - 10
No. 200	1.0	2.0	2.0	11.5	2.0	10.3	3.6	0 - 6.5



Figure 29. Photo. AC mat placement. (courtesy: TDOT)



Figure 30. Photo. IC roller in operation. (courtesy: TDOT)

## DATA ACQUISITION AND ANALYSIS

Safety, construction congestion, and quality data were collected before and after construction for this project where appropriate. The primary purpose was to supply HfL with sufficient information to support the use IC technology in future applications. This section details specific project data related to the HfL goals.

### Safety

No worker injuries were reported on this project.

Construction of the project was completed using traditional traffic control for the paving operation. One lane was closed at a time, and traditional flagging operations were employed.

There were no crashes reported during the construction, obviously meeting the HfL goal of a crash rate equal to or less than the pre-construction rate.

Statewide crash rates were available by facility type. The section from Eller Road to Clark Road would be considered an urban 4-lane divided section with a statewide rate for that type given as 1.777 crashes per 1 million vehicle miles traveled. The section from Clark Road to Lakewood Acres Drive would be classified as a 4-lane section with continuous turning lane. The statewide rate for this facility type was given as 2.467 crashes per 1 million vehicle miles traveled.

The most current data available were for the complete years from 2009 through 2011. Crash data was provided for the entire project length, regardless of facility type, with the results shown in table 9. The 3-year rate shown for the facility type is a weighted average (based on length) of provided statewide data. The 3-year crash rate for this location was slightly below the statewide rate.

Table 9. Crash rates prior to construction.

Route	Termini	Length	Volume (3-year avg.)	Crashes (3-Year Totals 1/1/2009 – 12/31/2011)			3-Year Rate	3-Year Rate (Facility Type)*
				Fatal	Injury	PDO		
SR 58	Eller Road to Lakewood Acres Drive	2.77	26,270	0	37	131	1.644	1.937

\*Weighted by length based on facility type

Some future safety benefit can be expected due to the general improvement in the condition of the pavement surface. A 3-year follow-up study will be conducted to determine the safety benefits of this improvement.

## **Construction Congestion**

The standard HfL goal for impact of construction on the public is a 50 percent reduction compared to conventional methods. The use of IC technology was expected to contribute to this goal by identifying in real time areas needing additional compaction and by reducing the time needed to do manual testing with a nuclear gauge behind the paving operation. However, the actual time for paving on this project was limited to only 8 days.

Due to the relatively short length and duration of the project, there was no noticeable change in construction time realized on this project. While this did not meet the HfL goal of a 50 percent reduction, the use of IC technology is expected to reduce delay time in the future by providing a longer lasting surface and fewer maintenance activities when compared to conventional compaction techniques.

## **Travel Time**

Travel time data were collected prior to construction on August 1, 2013. Times were recorded during the day for morning peak, morning non-peak, and afternoon peak periods. Limits for the data collection were expanded slightly to include any influence to travel outside of the active project. The average travel time from the Route 153 ramp to Ooltewah Road was determined to be 7 minutes, 54 seconds.

Travel times during the construction were collected on October 30 and 31, 2013. The average travel time during construction (east and west directions) was calculated to be 8 minutes, 25 seconds, an increase of 31 seconds.

## **Queue Length**

Considering the overall capacity of the facility compared to the traffic volume, there was no queue associated with the paving operations, thus meeting the HfL goal of no queue greater than one-half mile.

## **Smoothness**

Smoothness testing was performed following the ASTM E 950 method for the original and the newly overlaid pavement using a high-speed inertial profiler.

The initial IRI for this project was measured at 88 inches/mile in the northbound direction and 84 inches/mile in the southbound direction. Post-construction IRI measured 52 inches/mile in both directions. While not meeting the HfL goal of 48 inches/mile, there was a considerable improvement from the pre-construction values, and TDOT considers these IRI levels acceptable.

Figures 31 and 32 summarize the smoothness testing results.

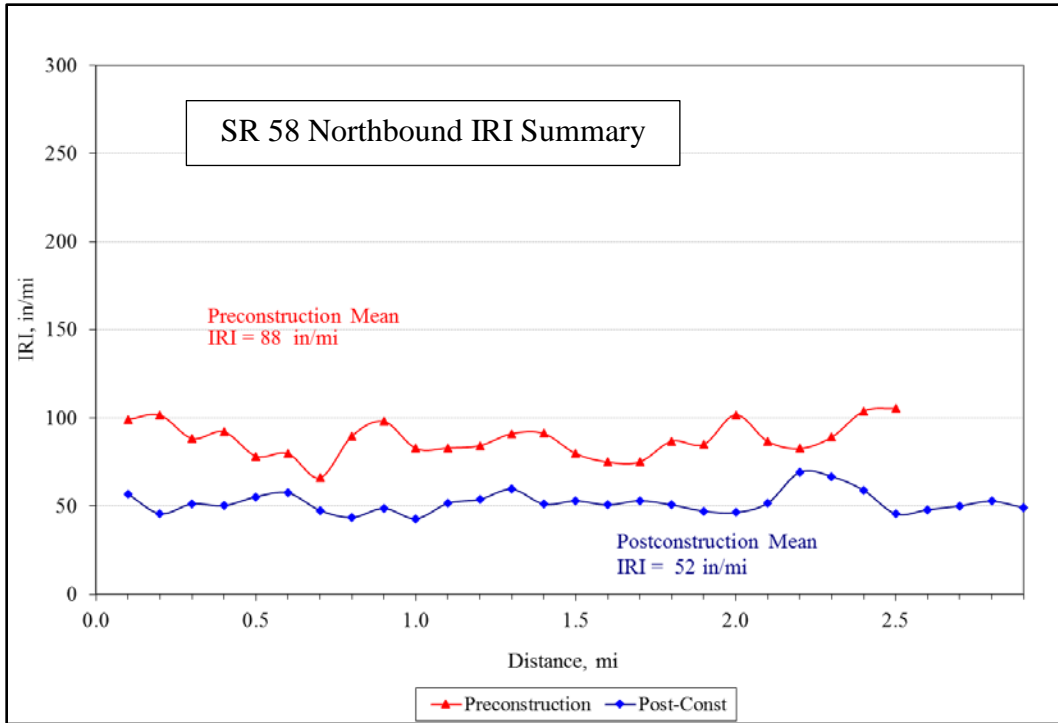


Figure 31. Graph. Pre- and post-construction smoothness data, SR 58, northbound direction.

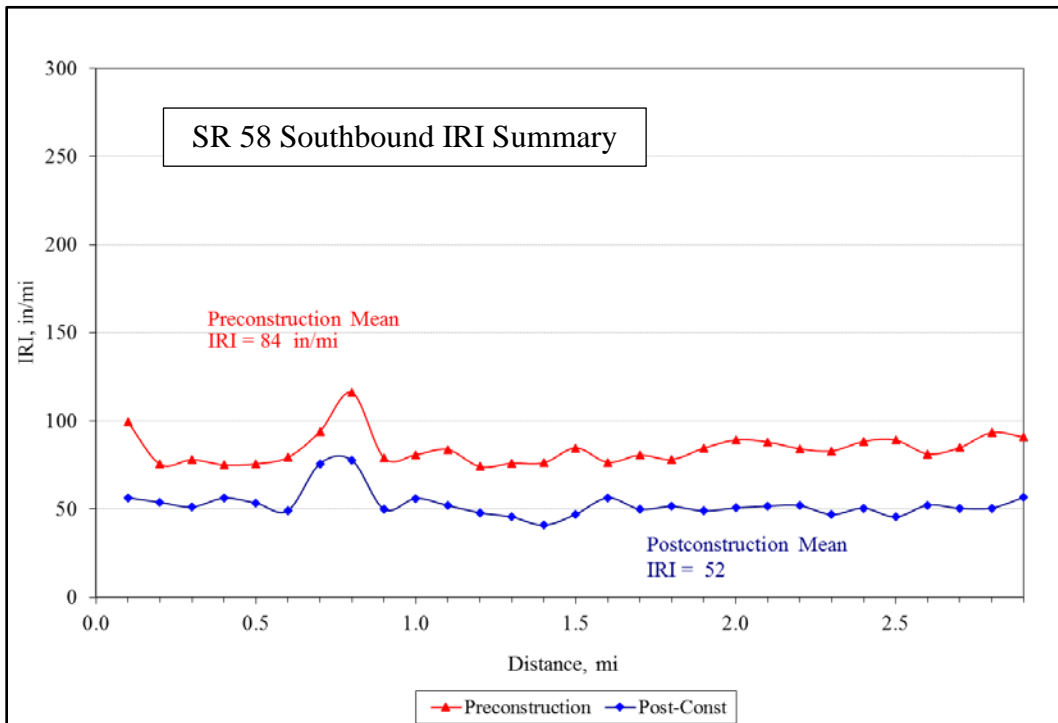


Figure 32. Graph. Pre- and post-construction smoothness data, SR 58, southbound direction.

## Sound Intensity

Sound intensity measurements were made using the AASHTO TP 76-08 test method. The sound measurements were recorded and analyzed using an onboard computer and data collection system. A minimum of five runs were made at highway speed in the right wheel path of the mainline lanes. The two microphone probes simultaneously captured noise data from the leading and trailing tire-pavement contact areas.

The average of the front and rear sound intensity values was computed. 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 33.

Sound levels were calculated by using logarithmic addition of the one-third octave band frequencies between 315 and 4,000 Hz. The initial measurements of noise before construction averaged 105.3 dB(A) in both directions of travel. The post-construction measurement averaged 102.8 dB(A), a reduction of 2.5 dB(A) but still above the HfL goal of 96 dB(A). In a rural setting, TDOT considers the pavement noise component acceptable.

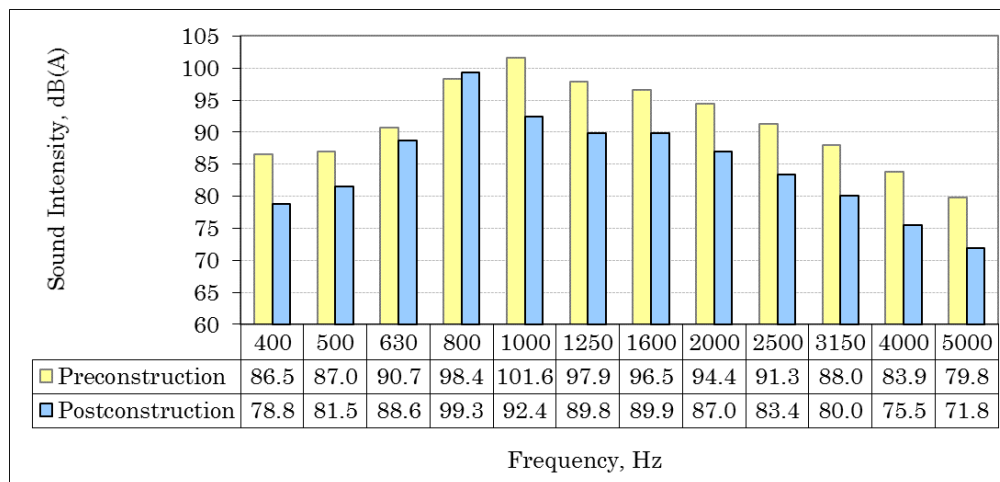


Figure 33. Graph. Mean A-weighted sound intensity frequency spectra.

## USER SATISFACTION

Due to the rapid completion and the wide geographical separation of the four projects in this study, TDOT did not conduct a user satisfaction survey. It was also believed that the small difference in construction duration between the innovative methods used and traditional methods would not be noticeable to the public.

## ECONOMIC ANALYSIS

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

The only innovation employed on the Tennessee projects is the use of IC technology. The comparison made here looks at only this innovation versus a traditional overlay project constructed with traditional compaction and testing methods.

### Construction Time

The construction of the IC overlay project on SR 58 in Hamilton County took a total of 43 days to complete. TDOT estimated that the time to complete a project using traditional methods would have been approximately the same. While it was originally assumed that there would be some decrease in construction time, any reduction was eliminated by the “learning curve” associated with the equipment and software. Also, the relative short nature of the project did not lend itself to a significant reduction in construction time. While the total construction time for the project was 43 days, paving and compaction activities used only 8 of those days. The paving log for this location is shown in table 10.

Table 10. Paving schedule for SR 58 in Hamilton County.

Date	Activity	Start		End		Direction
		North	East	North	East	
10/22/2013	Resurfacing	283328.8	2224513.5	284837.5	2227503.8	Both
10/23/2013	Resurfacing	283357.7	2224530.5	284854.7	2227463.5	Both
10/24/2013	Resurfacing	283377.0	2224541.8	284853.2	2227478.0	Both
10/28/2013	Resurfacing	283083.3	2223835.0	280689.7	2217472.0	Westbound
10/29/2013	Resurfacing	281921.6	2219926.5	278092.4	2214509.0	Both
10/30/2013	Resurfacing	278041.1	2214483.8	283029.0	2223845.0	Both
10/31/2013	Resurfacing	278028.0	2214439.0	283057.5	2223809.8	Both
11/1/2013	Resurfacing	278082.5	2214467.5	281928.0	2219933.0	Both

While the goal of a 50 percent reduction in construction time was not realized, it is assumed that providing a more consistent end product will result in a longer lasting surface and a reduction in routine maintenance in the future.

### Construction Capital Costs

The equipment required for the construction of these HfL projects is exactly the same as would be required for traditional construction practice, with the exception of the IC hardware and software. The additional IC equipment and software was all bid as a separate item in the contract, so it can be assumed that all the additional capital cost is included in this single item.

For the Hamilton County project, the additional cost was \$27,086 out of a total contract cost of \$1,673,709, or about 1.6 percent of the project total cost. All other factors being equal, the additional capital cost of IC technology on this project is assumed to be \$27,086.



## **User Cost**

Generally there are three categories of user costs used in an economic/life cycle analysis: detour/user costs, travel time costs and safety related costs.

### *Detour/User Cost*

In the case of SR 58, there was no detour or reduced speed limit on the project. There were also no crashes during the construction period. Given the assumptions that there would be no difference in total time for construction, it is safe to assume that the only cost associated with the construction is the user delay caused by the paving itself.

### *Travel Time Costs*

As previously discussed, there was a slight increase in travel time associated with the construction of this HfL project. The average delay of 31 seconds applied to a volume of approximately 26,500 equates to a little more than 18,000 vehicle-hours of delay over the 8-day paving period. However, the agency estimates that the duration would have been the same for traditional compaction methods, resulting in a cost differential of zero for the innovation.

### *Safety*

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

## **Cost Summary**

The data indicate that there was no direct savings as a result of the IC technology employed on this project. The fact that there was no change in project duration, travel time, or safety results in an initial increase in cost to the agency of \$27,086, the amount of the IC equipment rental.

Nonetheless, all indications are that the quality of the product has been improved through the use of IC technology. Discussions with agency personnel indicate that an increase in project life and a decrease in routine maintenance can be expected due to the more consistent application of compaction effort. The agency indicated that an overlay of this thickness could be expected to last approximately 6 years. If we assume that the same solution would be employed in the future, and the life is extended by 1 year, present value indicate a savings of \$40,826, more than offsetting the initial cost incurred here.

## PROJECT DETAILS – US 64, LINCOLN COUNTY

### BACKGROUND

As shown in figure 34, Lincoln County is located in southern Tennessee. The HfL project in Lincoln County involved the resurfacing of US 64, between the Giles County Line (located east of US 64) and I-65 east of Pulaski and SR 244 (see figure 35).

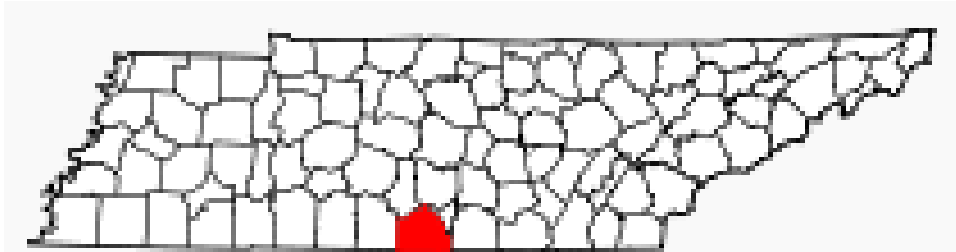


Figure 34. Map. Lincoln County, Tennessee.

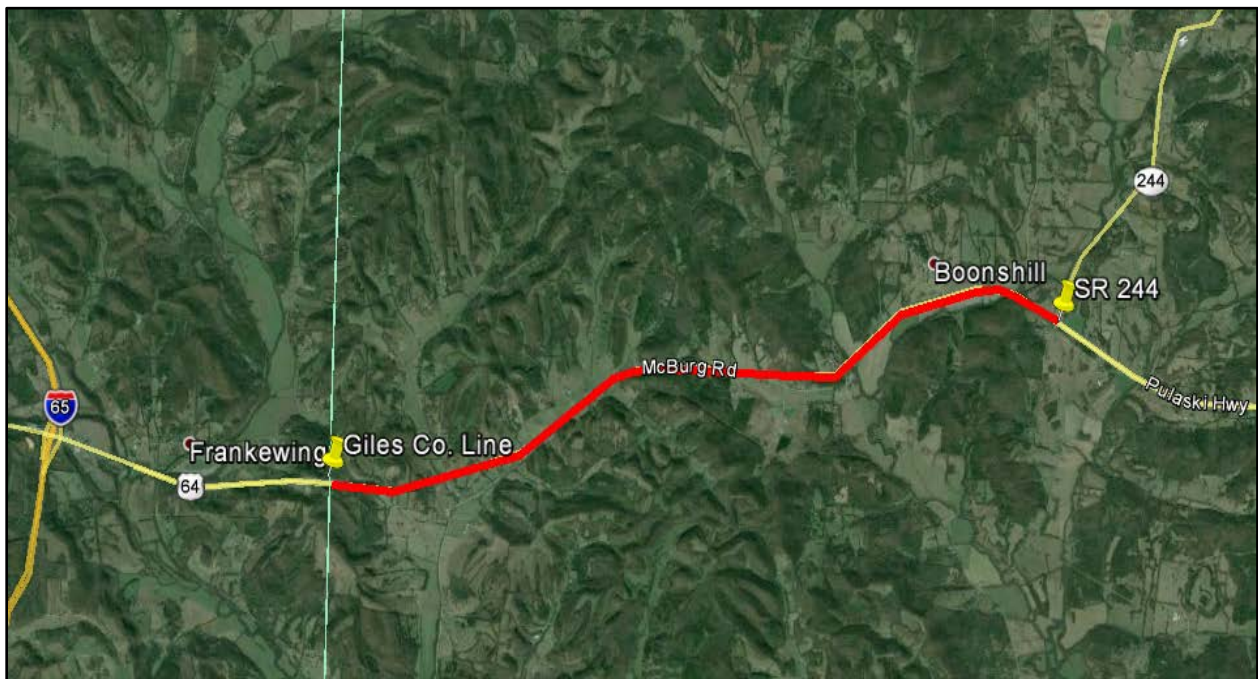


Figure 35. Map. US 64 project location. (courtesy: Google Earth)

The project spans a distance of approximately 6.6 miles. Within these limits, US 64 consists of a 4-lane rural roadway carrying about 5,480 vehicles per day. The existing pavement was an asphalt roadway with paved shoulders and a PQI of approximately 3.5 on a 5-point scale. All four lanes were overlaid, for a total of 25.5 lane miles of paving.

## PROJECT DESCRIPTION

The improvement consisted of cold milling the existing pavement followed by the application of an AC surface mix 1.25 inches thick. A tack coat was applied to areas that were milled, and a fog seal was applied to the existing shoulder surfaces. Figure 36 shows the typical section of the resulting overlay.

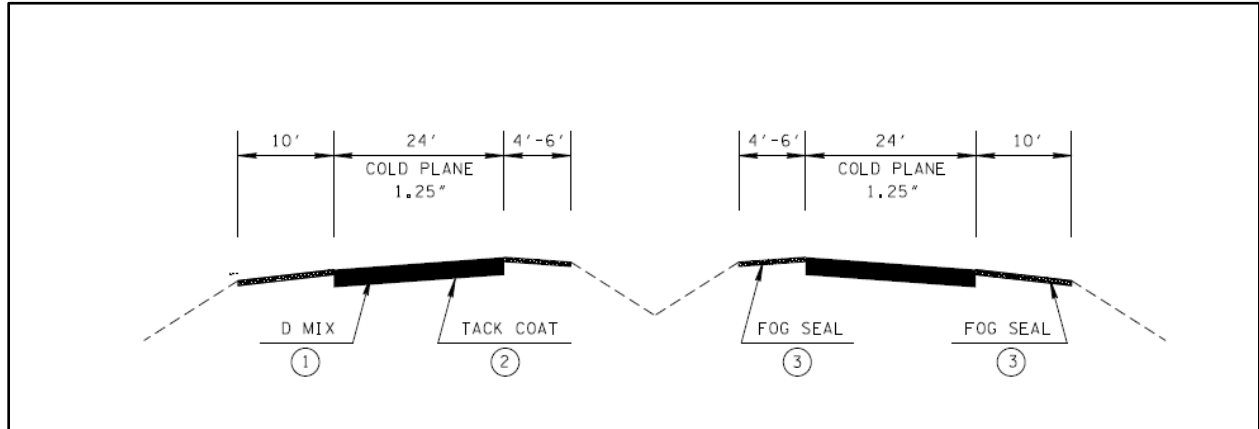


Figure 36. Diagram. Typical section of improvement.

## Bid Information

The project was awarded in July 2013 at a cost of \$1,689,999. The IC bid item for this project was \$112,620.

## Project Construction

Construction began on October 3, 2013, and was completed on November 3, 2013.

Due to the relatively low traffic volumes and excess capacity of the facility, all paving at this location was done during normal daytime working hours.

The improvement consisted of cold milling the existing pavement followed by the application of an AC surface mix 1.25 inches thick. The surface course was composed of a PG 64-22 Grade D mix. A fog seal was applied to the existing shoulder surface. The mix design is shown in table 11.

Figure 37 shows the placement of the mat, while figure 38 shows the compaction equipment utilizing the IC technology.

Table 11. Mix design for Lincoln County, US 64 AC surface course (411-D).

Asphalt Cement	PG 64-22	Ergon Asphalt & Emulsions, Nashville Terminal			5.331
Percent AC in RAP 1:		Optimum AC Content:	5.9	Total	100.00
Percent AC in RAP 2:	5.7	Anti-Strip Supplier: Arr-Mazz Products.			
Anti-Strip Additive:	Pavegrip 300			Dosage: 0.3%	
AC Contribution	Virgin AC	5.33	RAP AC	0.57	Percent Virgin AC: 90.4
Asphalt Specific Gravity:	1.029		Dust to Asphalt Ratio:	0.92	
% Fracture Face on CA:	n/a		% Glassy Particles on CA:	n/a	
Theo. Gravity of RAP 1:	2.519		Eff. Gravity of Agg.	2.644	
Theo. Gravity of RAP 2:					
Theo. Gravity of Mix:	2.420	TSR:	86.5	Lbs./Ft <sup>3</sup> :	151.0
L.O.I.:	19.0		Ignition Oven Corr. Factor:	1.35	
ADT	5,480		Warm Mix?	No	
Lab. Temperature			Plant Temperature		
Mixing Temperature ( $\pm 5^0$ F):	300		Mixing Temp. Range ( $^0$ F):	$270^0 \text{ F} \leq T \leq 310^0 \text{ F}$	
Lab. Compaction Temp. ( $\pm 5^0$ F):	285		Delivery Temperature ( $^0$ F):	$270^0 \text{ F} \leq T \leq 310^0 \text{ F}$	

Sieve Size	Percents Used						% Req. 100	Design Range
	D Rock	#10 Hard Limestone	#10 Soft Limestone	Natural Sand		RAP Process ed - 1/2		
	40.0	10.0	20.0	20.0		10.0		
2"								
1.5"								
1.25"								
1"								
3/4"								
5/8"	100	100	100	100		100	100	100
1/2"	96	100	100	100		100	98	95 - 100
3/8"	72	100	100	100		95	88	80 - 93
No. 4	24	94	95	96		76	65	54 - 76
No. 8	11	63	56	81		57	44	35 - 57
No. 16								
No. 30	3	26	37	51		30	25	17 - 29
No. 50	3	18	27	15		20	13	10 - 18
No. 100	2.2	14.0	19.3	1.7		11.7	7.7	3 - 10
No. 200	1.8	11.9	13.6	0.3		7.5	5.4	0 - 6.5



Figure 37. Photo. AC mat placement.



Figure 38. Photo. IC roller in operation.

## DATA ACQUISITION AND ANALYSIS

Safety, construction congestion, and quality data were collected before and after construction for this project where appropriate. The primary purpose was to supply HfL with sufficient information to support the use IC technology in future applications.

This section details specific project data related to the HfL goals.

### Safety

No worker injuries were reported on this project.

Construction of the project was completed using traditional traffic control for the paving operation. One lane was closed at a time using traditional flagging operations. There were no crashes reported during the construction, obviously meeting the HfL goal of a crash rate equal to or less than the pre-construction rate.

Crash data were provided for the entire project length. The most recent data available were for the complete years between 2009 and 2011.

For the purpose of this report, the crash rates were calculated using the supplied crash data and AADT for the same data years. The crash rates for this location before construction are shown in table 12. As shown in the table, the 3-year crash rate for this location was lower than the statewide average of the 3-year rate for a similar facility.

Table 12. Crash rates prior to construction.

Route	Termini	Length	Volume (3-year avg.)	Crashes (3-Year Totals 1/1/2009 – 12/31/2011)			3-Year Rate	3-Year Rate (Facility Type)*
				Fatal	Injury	PDO		
US 64	Giles County Line to SR 244	6.4	4,388	0	4	14	.585	.733

Some future safety benefit can be expected due to the general improvement in the surface condition of the pavement. A 3-year follow-up study will be conducted to determine the actual safety benefits of this improvement.

### Construction Congestion

The standard HfL goal for impact of construction on the public is a 50 percent reduction compared to conventional methods. The use of IC technology was expected to contribute to this goal by identifying in real time areas needing additional compaction and by reducing the time needed to do manual testing with a nuclear gauge behind the paving operation. However, the relatively short length of the improvement along with the ability to rapidly deploy thin overlay construction made it impossible to quantify the time savings on this project.



While this did not meet the HfL goal of a 50 percent reduction, the use of IC technology did reduce the work associated with traditional testing and should provide a more consistent high-quality surface.

### **Travel Time**

Travel time data were collected prior to and during construction. Preconstruction data were collected on August 2, 2013, and construction period data were collected on October 21, 2013.

Data were collected for the entire corridor, with no intermediate values taken. The relatively low volumes and high capacity resulted in minimal impact to mobility along the route. Discussions with TDOT personnel indicated that there was no real “peak” traffic period on this route. This was confirmed by the preconstruction survey. Three runs were collected over the course of the day, morning peak, morning non-peak, and afternoon peak, with no more than 3 seconds difference in any of the average travel times over the length of the project. Travel times collected during construction showed a similar pattern.

During construction, 10 runs were collected, 5 where the paving operation was present with 1 lane closed, and the other 5 in the opposing direction where no construction was present. There was no more than 6 seconds difference in any of the times, with the average travel time for all runs in both directions being within 2 seconds of each other.

Given this observation, and the fact that there was no reduction in speed limit through the work zone, it is clear that under these traffic condition, there was no impact in travel times for the public on this HfL project and, thus, no cost differential for the use of IC technology in the construction.

### **Queue Length**

The capacity of the existing facility was such that there was no traffic slowdown or queue associated with any construction on this project, thus meeting the HfL goal of no queue greater than one-half mile.

### **Smoothness**

Smoothness testing was performed following the ASTM E 950 method for the original and the newly overlaid pavement using a high-speed inertial profiler.

The initial IRI for this project was measured at 89 inches/mile in the eastbound direction and 93 inches/mile in the westbound direction. Post-construction IRI measured 53 inches/mile eastbound and 46 inches/mile westbound. While the average of 49.5 inches/mile did not meet the HfL goal of 48 inches/mile, TDOT considers this value acceptable, and it shows a considerable improvement from the pre-construction values. Figures 39 and 40 show the results of the smoothness testing.

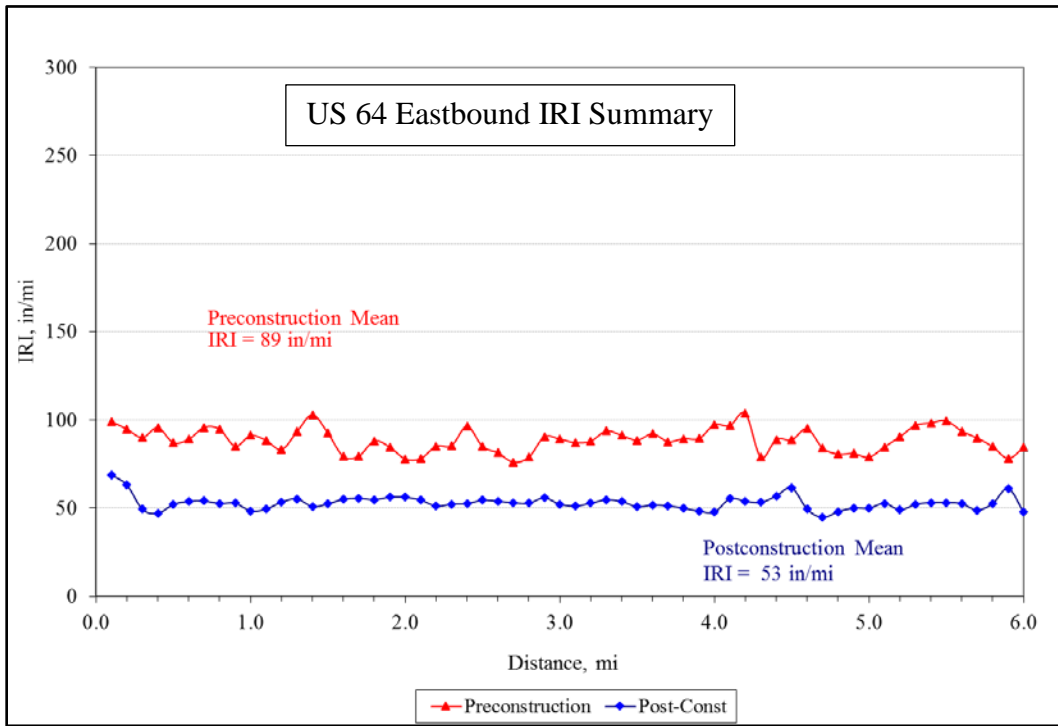


Figure 39. Graph. Pre- and post-construction smoothness data, US 64, eastbound direction.

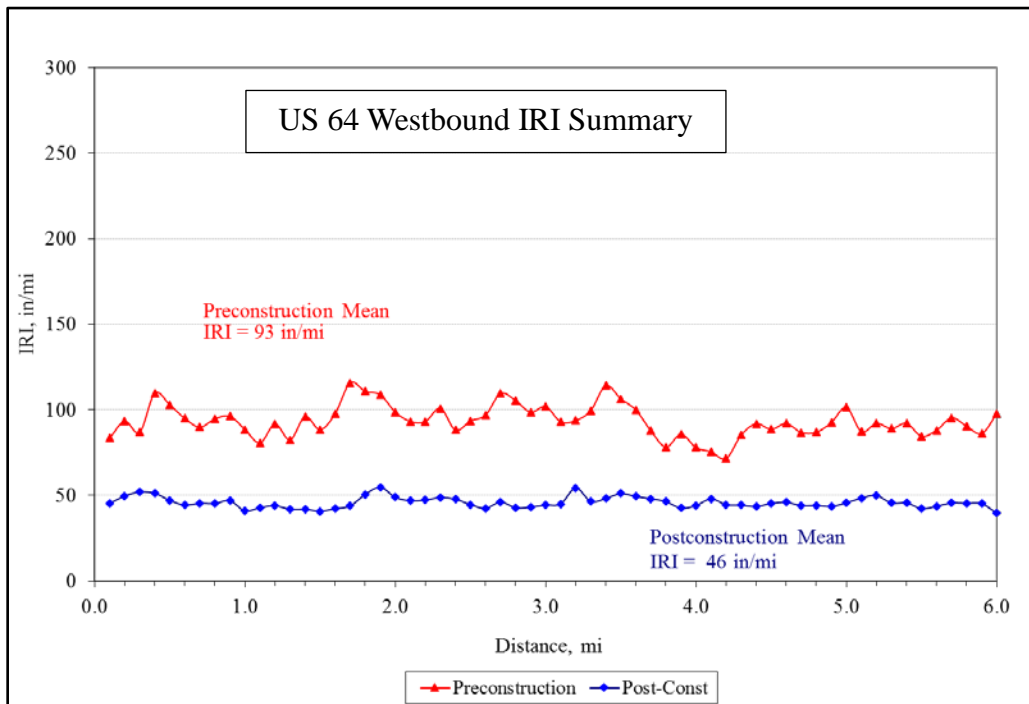


Figure 40. Graph. Pre- and post-construction smoothness data, US 64, westbound direction.



## Sound Intensity

Sound intensity measurements were made using the AASHTO TP 76-08 test method. The sound measurements were recorded and analyzed using an onboard computer and data collection system. A minimum of five runs were made in the right wheel path of the mainline lanes. The two microphone probes simultaneously captured noise data from the leading and trailing tire-pavement contact areas.

The average of the front and rear sound intensity values was computed. 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 41.

Sound levels were calculated by using logarithmic addition of the one-third octave band frequencies between 315 and 4,000 Hz. The initial measurements of noise before construction averaged 103.6 dB(A) in both directions of travel. The post-construction measurement averaged 104.9 dB(A), an increase of 1.3 dB(A). While above HfL goal of 96 dB(A) in this rural setting, TDOT considers the pavement noise component acceptable.

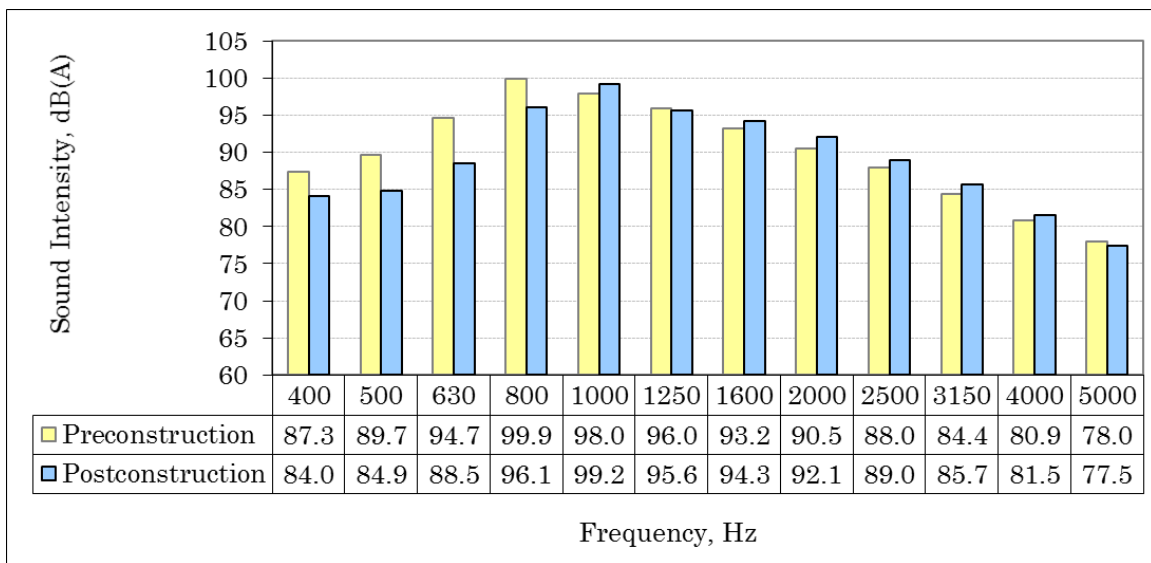


Figure 41. Graph. Mean A-weighted sound intensity frequency spectra.

## USER SATISFACTION

Due to the rapid completion and the wide geographical separation of the four projects in this study, TDOT did not conduct a user satisfaction survey. It was also not believed that the small difference in construction duration between the innovative methods used and traditional methods would be noticeable to the public.

## ECONOMIC ANALYSIS

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

The only innovation employed on the Tennessee projects is the use of IC technology. The comparison made here looks at only this innovation versus a traditional overlay project constructed with traditional compaction and testing methods.

### Construction Time

The construction of the IC overlay project on US 64 in Lincoln County took a total of 59 days to complete. TDOT estimated that the time to complete a project using traditional methods would have been approximately the same. While it was originally assumed that there would be some decrease in construction time, any reduction was eliminated by the “learning curve” associated with the equipment and software. Also, the relative short nature of the project did not lend itself to a significant reduction in construction time. While the total construction time for the project was 59 days, paving and compaction activities used only 8 of those days. The paving log for this location is shown in table 13.

Table 13. Paving schedule for US 64 project in Lincoln County.

Date	Activity	Start		End		Direction
		North	East	North	East	
10/21/2013	Resurfacing	312166.0	1720444.4	316808.1	1734960.3	Eastbound
10/22/2013	Resurfacing					
10/23/2013	Resurfacing	312165.9	1720450.9	316360.4	1739111.1	Eastbound
10/24/2013	Resurfacing	316386.7	1739008.8	318289.0	1752357.9	Eastbound
10/30/2013	Resurfacing	318339.7	1752403.3	316441.2	1739380.9	Westbound
11/1/2013	Resurfacing	316434.3	1739451.5	312235.9	1720477.1	Westbound
11/4/2013	Resurfacing	318365.3	1752403.4	316931.4	1735499.8	Westbound
11/5/2013	Resurfacing	316937.5	1735544.6	312255.1	1720477.4	Westbound

While the goal of a 50 percent reduction in construction time was not realized, it is assumed that providing a more consistent end product will result in a longer lasting surface and a reduction in routine maintenance in the future.

### Construction Capital Costs

The equipment required for the construction of these HfL projects is exactly the same as would be required for traditional construction practice, with the exception of the IC hardware and software. For this project, the additional IC equipment and software was all bid as a separate item in the contract, so it can be assumed that all the additional capital cost is included in this single item. The additional cost was \$112,620 out of a total contract cost of \$1,689,999, or about 7 percent of the project total cost. All other factors being equal, the additional capital cost of IC technology on this project is assumed to be \$112,620.

## **User Cost**

Generally there are three categories of user costs used in an economic/life cycle analysis: detour/user costs, travel time costs and safety related costs.

### *Travel Time Costs*

There was no detour or reduced speed limit on the US 64 project. Given the assumptions that there would be no difference in total time for construction, it is safe to assume that there was no user delay and thus no travel time cost incurred as a result of the paving operation.

### *Safety*

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

## **Cost Summary**

The data indicate that there was no direct savings as a result of the IC technology employed on this project. The fact that there was no change in project duration, travel time, or safety results in an increase in cost to the agency of \$112,620, the amount of the IC equipment rental. Nonetheless, all indications are that the quality of the product has been improved through the use of IC technology.

## **HIGHWAY FOR LIFE PROJECT COST SUMMARY – ALL LOCATIONS**

Overall, there was no direct cost savings associated with the innovation employed on these four projects. The construction time was considered to be the same for all four projects as would have been the case using traditional compaction techniques. All compaction equipment employed on these projects was the same as could be expected for projects not employing IC, except the rental of the IC equipment itself.

There were no travel time costs associated with these projects. The relatively low traffic volumes and high capacity of the facilities, coupled with the requirement to work at night at some locations, and the fact there was no detour or work zone speed reduction, contributed to this finding. By the same logic, there were considered to be no safety costs, as there was no change in construction time and there were no crashes during the project work.

Given these assumptions, the additional cost for the use of IC technology on these projects is assumed to be the bid cost for the lump sum item “Intelligent Compaction Equipment” included in each contract. The innovation cost of all four projects totaled \$226,286 out of a total cost of \$9,120,310, an increase of about 2.5 percent.

However, as was discussed in the individual project reports, it is assumed that the overall quality of the projects was improved, especially with regard to the consistency of the compaction effort. This is expected to reduce the likelihood of early failures and increase the likelihood of reduced maintenance and longer project life. As was demonstrated earlier, even a 1-year increase in project life more than offsets the cost of the innovation.



## TECHNOLOGY TRANSFER

To promote further interest and use of the innovations included in this project, TDOT, in conjunction with the FHWA, sponsored a 1-day showcase. The showcase was held October 23, 2013, at the Four Points Sheraton in Nashville. The event featured presentations by the FHWA, TDOT, and the project contractor. The presentations were followed by a field trip to the project on US 64 in Lincoln County to observe paving with IC technology (see figures 41 and 42).

Approximately 50 people attended the showcase from TDOT, FHWA, local agencies, the construction and consulting industries, and academia. The program included the following presentations:

- Opening comments provided by Paul Degges, Deputy Commissioner and Chief Engineer for TDOT and Pamela Kordenbrock, Division Administrator for FHWA, Tennessee Division.
- An overview of the Highway for LIFE program in video format.
- A national perspective on pavement innovations provided by Antonio Nieves Torres, Construction Engineer, FHWA Office for Infrastructure.
- Project design overview by Mark Woods, State Asphalt Materials Engineer, TDOT.
- Project construction overview by Brian Egan, Director of Construction, TDOT.
- Project construction overview (contractor's perspective) by Mike Hunter, Asphalt Division Technical Director, Tennessee Road Builders Association.
- Observations on using intelligent compaction/lessons learned by Jay Bledsoe, Principal Engineer, Applied Research Associates.
- IC equipment overview by Brandon Bates, Technology Support Specialist, SiTech.
- Field trip to US 64 HfL project.

Overall, the comments concerning the IC technology were favorable. Both the agency and the contractors indicated that they believe this will become a common technology in the future and that it provides a high-quality product for the public. It was assumed that increased use will result in a higher "comfort level" for all involved, which could result in faster construction and decreased cost in the future. This is especially true in the area of testing. The ability to collect data on 100 percent of the surface compacted, as opposed to the current practice of sampling with a nuclear gauge once in every 1,500 linear feet, is seen as a great benefit in both time and quality.

Another benefit noted by the contractor's representative was the ability to use IC technology as a training tool for new roller operators. The ability to "see" exactly where you have been on the surface is beneficial to new or relatively inexperienced operators.

The general consensus is that IC is a promising technology for the future of paving in Tennessee.



Figure 41. Photo. Showcase participants at the job site.



Figure 42. Photo. Observation of IC roller on AC surface course.

## **ACKNOWLEDGMENTS**

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

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