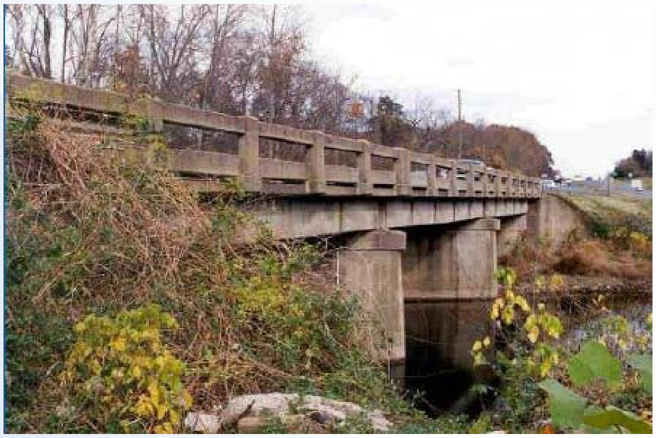
Virginia Demonstration Project: Rapid Removal and Replacement of U.S. 15/29 Bridge Over Broad Run Near Gainesville, VA

Final Report
August 2009

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.



U.S. Department of Transportation
Federal Highway Administration

FOREWORD

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

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. “Innovations” is an inclusive term used 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.

NOTICE

1. Report No.	2. Government Accession No	3. Recipient’s Catalog No

3. Title and Subtitle Virginia Demonstration Project: Rapid Removal and Replacement of U.S. 15/29 Over Broad Run Near Gainesville, VA	5. Report Date August 2009 6. Performing Organization Code
7. Authors Rex D. Gilley, P.E., Jagannath Mallela, Gary Hoffman, P.E., R.L.S., and Gerald L. Ullman	8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820	10. Work Unit No. (TRAIS) C6B 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590	12. Type of Report and Period Covered Final Report December 2007–March 2009 14. Sponsoring Agency Code

15. Supplementary Notes
Contracting Officers Technical Representatives: Byron Lord, Mary Huie

16. Abstract

As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the Virginia Department of Transportation (VDOT) was awarded a $600,000 grant to demonstrate the use of proven, innovative technologies for accelerated bridge removal and replacement. This report documents accelerated bridge construction (ABC) techniques used to remove, widen, and replace the superstructure of the U.S. 15/29 bridge over Broad Run over three weekends.

This report describes the existing bridge and the materials and methods used to widen the three-span bridge and replace the superstructure. Prefabricated superstructure segments, four per span, were used to simplify and expedite construction. Under conventional construction, the impact of this project on the traveling public was estimated at 100 days, but with the use of accelerated construction techniques, the impact was reduced to three weekend closures.

Using ABC techniques added approximately $260,000 to the initial construction cost of the project. However, a more comprehensive economic analysis including user cost savings shows that the project saved road users an estimated $2.16 million or about 65 percent over conventional construction practices. Because of the success of this project, VDOT plans to use ABC techniques on future projects.

17. Key Words accelerated bridge construction, construction manager general contracting, economic analysis, full lane closure, Highways for LIFE, innovative construction, prefabricated bridge elements and systems	18. Distribution Statement No restriction. This document is available to the public through http://www.fhwa.dot.gov/hfl/.

Security Classif.(of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages 37	21. Price

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
(none)	mil	25.4	micrometers	μm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (metric ton)	Mg (or "t")
	TEMPERATURE			
°F	[illegible]	[illegible]	[illegible]	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kilopascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megapascals	MPa
	DENSITY			
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
μm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celsius	1.8C+32	Fahrenheit	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megapascals	0.145	kips per square inch	k/in^2 (ksi)
	DENSITY			
kg/m^3	kilograms per cubic meter	0.0624	pounds per cubic foot	lb/ft^3 (pcf)

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

ACKNOWLEDGMENTS

The project team would like to acknowledge the invaluable insights and guidance of Federal Highway Administration (FHWA) Highways for LIFE Team Leader Byron Lord and Program Coordinators Mary Huie and Kathleen Bergeron, who served as the technical panel on this demonstration project. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document. The team also is indebted to Virginia Department of Transportation staff members Nick Roper, Khossrow Babaei, Charles M. Pruitt, Robert D. Legg, Alan Padgett, and Denise Almond and FHWA Virginia Division Bridge Engineers Claude Napier and Rodolfo (Rudy) Maruri for their tireless advice, assistance, and coordination during this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ABC	accelerated bridge construction
ADT	average daily traffic
CIP	cast-in-place
CMGC	construction manager general contracting
dB(A)	A-weighted decibel
DOT	department of transportation
FHWA	Federal Highway Administration
FY	fiscal year
HfL	Highways for LIFE
Hz	hertz
IRI	International Roughness Index
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SI	sound intensity
SR	State Route
SRTT	standard reference test tire
VDOT	Virginia Department of Transportation
VOC	vehicle operating costs

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 a HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

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

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

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

Project Solicitation, Evaluation, and Selection

FHWA issued open solicitations for HfL project applications in fiscal years 2006, 2007, 2008, and 2009. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, and contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

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

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

HfL Project Performance Goals

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

- **Safety**
    - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
    - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
    - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.

- **Construction Congestion**
  - Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
  - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
  - Queue length during construction—A moving queue length of less than 0.5 mile (mi) (0.8 kilometer (km)) in a rural area or less than 1.5 mi (2.4 km) in an urban area (in both cases at a travel speed 20 percent less than the posted speed).

- **Quality**
  - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.
  - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.
  - User satisfaction—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4-plus on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Virginia Department of Transportation’s (VDOT) HfL demonstration project, which involved accelerated removal and replacement of a bridge over a creek. The report presents project details relevant to the HfL program, including innovative contracting, superstructure and substructure design and construction highlights, rapid bridge removal and replacement, 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

The project lies within the limits of the Buckland Historic District in Prince William County, VA. The existing 53-year-old, two-lane structure carries the traffic of southbound U.S. 15/29, about 25,000 vehicles per day. The deteriorated superstructure, about 130 feet (ft) (39.6 meters (m)) long and comprised of three spans, is a reinforced concrete T-beam structure. The purpose of this project was to replace the deteriorated concrete T-beam superstructure and widen the bridge to increase shoulder width.

Traffic maintenance was a controlling factor in the replacement of the existing superstructure, since the adjacent historic properties preclude sufficient widening of the structure to allow two lanes of traffic on the bridge during construction or construction of an adjacent temporary bridge. The original scheme for the staged superstructure replacement was to have 12 individual night closures, one for each deck section. However, the greater risk of construction complications and the potential inability to reopen the highway to morning rush-hour traffic with the original scheme was paramount in the decision to use a three-weekend closure alternative. During construction, the phasing scheme was revised to detour traffic around the bridge and replace the superstructure sections over three weekends.

The project scope includes the following:

1. Replace and widen the existing substandard, functionally obsolete concrete T-beam superstructure (28 ft (8.5 m) curb to curb) with prefabricated segments using high-performance materials and rapid replacement methods.
2. Extend and modify piers using a corbel secured to the pier via grouted dowels and external post-tensioning.
3. Modify abutments by reconstructing seats and extending wingwalls.
4. Align roadway and perform approach work.
5. Maintain traffic during staged removal and replacement of bridge superstructure.

DATA COLLECTION

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

The safety goals for the project included both worker safety and motorist measures. The worker safety goal was an incident rate of 4.0 or less based on the OSHA 300 rate. The motorist goal during construction was a crash rate equal to or less than the preconstruction crash rate. No worker injuries occurred during construction. Six incidents involving motorists with flat tires occurred during construction because of a temporary patch on the abutment backwall, but no injuries or other vehicle damages occurred. Therefore, the project safety goals were met.

Under conventional construction, the impact on U.S. 15/29 from construction-related congestion was estimated at 100 days. With the use of ABC techniques, the impact was reduced to three weekend closures.

Quality was measured in terms of noise (OBSI) and smoothness (IRI) before construction. Preconstruction IRI was 215 inches per mile (in/mi) for the existing bridge deck. The HfL goal for IRI of 48 in/mi, while reasonably attainable on long, open stretches of pavement, was not met on the existing bridge. It is difficult to attain this level of average ride quality on a short bridge because the inevitable bumps at each end of the bridge influence the average. For this reason, postconstruction measurements were not taken.

ECONOMIC ANALYSIS

The economic analysis revealed that VDOT's approach generated a savings of about $2.16 million, or 65 percent, over the cost of conventional construction practices. A significant amount of the cost savings was from reduced delay costs.

LESSONS LEARNED

While the project was behind schedule initially, cooperation and collaboration by the State and the contractor resulted in three weekend closures that allowed the project to get back on schedule and the bridge to open to traffic in late September 2008 as originally planned. Also a factor in the decision to go to three weekend closures was consideration of the allowable tolerances of the replacement segments and their fit-up when placed in the field. Lessons learned on this project include the following:

- Providing a more detailed as-built survey better ensures proper fit and coordination with the proposed replacement scheme.
- Investigating the availability of materials such as rolled beams ensures they can be obtained.

Contracting Process

The contract included special language to ensure the minimum impact to U.S. 15/29 traffic. Disincentive charges were assessed for failure to restore all traffic lanes by 5 a.m. An A + B bidding procedure was used in which the A component represents the total unit bid price and the B component represents the total number of working nights to complete the superstructure replacement. A nightly road user and maintenance of traffic cost of "$C" was established for the project. The low bidder was determined by the lowest combination of A + B according to the following formula:

$$A + [(B) \times (C)] = \text{TOTAL BID}$$

A disincentive/incentive of "$C" per night was included for completion in more than or less than the number of working nights identified in the B component of the bid. The incentives under the A + B bidding were limited to 5 to 10 percent of the contract amount maximum.

Design and Construction

The design and construction process was successful because of the following:

- Stakeholders were involved throughout the process.
- The owner and designer worked together to devise a construction scheme to minimize impacts on users.
- The owner and contractor worked together to refine the construction scheme to minimize user impacts and keep the project on schedule.

Public Involvement

During the design phase of the Route15/29 bridge, VDOT worked closely with the Buckland Preservation Society to integrate its concerns into the design and construction process. While VDOT did not conduct surveys, all indications are that the public views this superstructure replacement as a success as indicated by the many positive comments from citizens and public officials at the ribbon cutting ceremony.

CONCLUSIONS

The project to replace and widen the superstructure of the U.S. 15/29 bridge over Broad Run was fully successful in meeting the project goals for safety, construction congestion, and user satisfaction. No worker injuries or crashes occurred during the construction, and crash and injury rates on the widened deck with updated railings are expected to be lower. The impact of construction on traffic from the three weekends of full closure was significantly less than it would have been for conventional construction techniques over an estimated 100-day schedule (total delays of 9,461 vehicle-hours versus an estimated 720,000 vehicle-hours). The durability of the replacement superstructure is expected to be superior to conventional construction because of the use of high-performance materials and prefabricated superstructure elements, which lead to lower life-cycle costs for the bridge. In addition, while the initial construction cost of the bridge was higher for the scheme used, the overall cost to VDOT and the motoring public was much lower than it would have been using traditional methods.

PROJECT DETAILS

BACKGROUND

The VDOT HfL demonstration project consists of a bridge superstructure replacement and widening with prefabricated segments using high-performance materials and rapid placement methods. The project is located on U.S. 15/29 over Broad Run near Gainesville, VA, 0.55 miles (mi) (0.88 kilometers (km)) north of State Route 215 (Vint Hill Road), as shown in figure 1 below. U.S. 15/29 is a four-lane divided highway at the project site. Because of the traffic volume on this route, detailed construction schemes were developed to minimize the length of the required lane closures and restrict them to offpeak nighttime hours. While HfL program concepts do apply to large, complex bridge projects, the same concepts also need to apply to smaller bridges because the majority of the bridges on the national inventory are short-span rural bridges similar to this urban bridge.


Bridge Site

Figure 1. Location map for U.S. 15/29 bridge over Broad Run.

PROJECT DESCRIPTION

The U.S. 15/29 bridge over Broad Run (VDOT Project No. 0015-076-115, M600) carries southbound Lee Highway over Broad Run in the Buckland Historic District in Prince William County, VA. The district initiated a project review to fulfill the provisions of Section 106 of the National Historic Preservation Act. The Section 106 consulting parties included the Buckland Preservation Society, consisting primarily of directly affected local residents. The society's interests were considered and incorporated into this project.

The existing 56-year-old, two-lane structure carries about 25,000 vehicles per day (figure 2). The deteriorated superstructure is about 130 ft (39.6 m) long and comprised of three equal spans of reinforced concrete T-beams on concrete piers. Total width of the existing bridge is 33 ft (10 m). In addition to the deteriorated superstructure, the bridge has substandard shoulder widths, resulting in the need to widen the bridge. The new total superstructure width is 38.5 ft (11.7 m), consisting of a 4-ft (1.2-m) median shoulder, two 12-ft (3.6-m) lanes, and an 8-ft (2.4-m) outside shoulder. Because the bridge is next to the Buckland Historic District, widening to the median side was required. Similarly, a temporary structure could not be used, which led to the development of a detailed construction sequence dovetailed with a detailed traffic maintenance scheme.

The project was advertised in September 2007 and awarded to Flippo Construction Company, Inc. in December 2007. The prime contractor selected Coastal Precast Systems, LLC to prefabricate the superstructure elements.

Figure 2. Existing southbound U.S. 15/29 bridge over Broad Run, looking north.

Superstructure Construction

The replacement scheme used four prefabricated segments per span, for a total of 12 segments, consisting of two rolled steel beams made composite with the 7.5-inch (in) (190.5-millimeter (mm)) high-performance lightweight concrete deck (figures 3, 4, and 5). A waterproofing membrane and a 3-in (76.2-mm) hot-mix asphalt overlay were placed over the concrete deck for the finished riding surface. The original as-designed scheme for replacing these segments consisted of 12 night closures, one per segment. During these night closures (9 p.m. to 5 a.m.), one lane would remain open for traffic to cross the bridge. Two lanes of traffic would be open during the day.

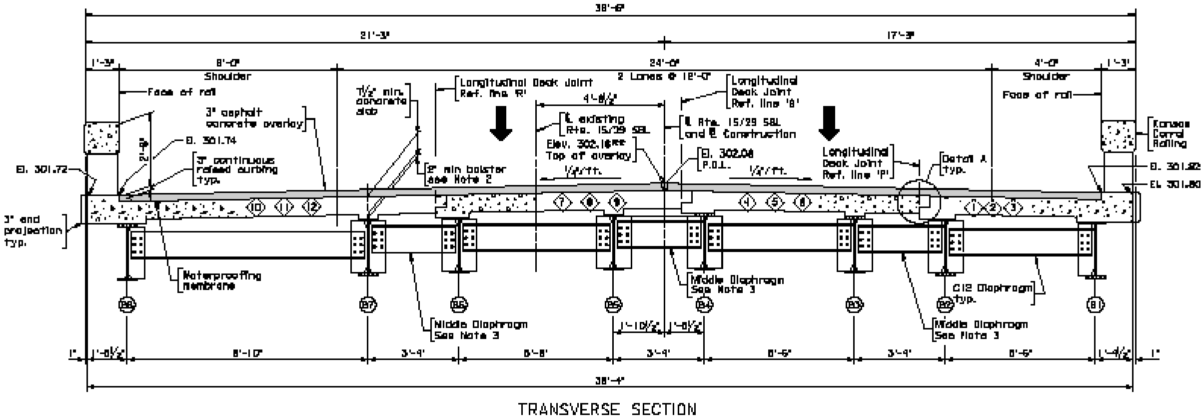


Figure 3. U.S. 15/29 bridge over Broad Run section.

Figure 4. Steel beams for U.S. 15/29 bridge at Coastal Precast Systems precasting yard.

Figure 5. Steel beams for U.S. 15/29 bridge at Coastal Precast Systems precasting yard.

During construction, however, concerns about the schedule as well as how the segments would fit together led the contractor to propose a revised scheme. The revised scheme resulted in a defined detour route (see figure 6). The segments were replaced during three weekend full closures of the southbound lanes. As a result, rather than 12 separate single-lane closures on 12 nights, complete road closures on three weekends were used to replace the 12 superstructure segments, one span per weekend. VDOT's Public Affairs Office notified the public about the project and the traffic pattern during construction through news releases to the local media. Variable message system (VMS) boards were placed along the highway before construction to inform road users about the closure. The three full closures resulted in reduced risk because all four prefabricated segments were fitted together one span at a time. This change in the construction scheme also allowed the project to get back on schedule and be completed by the original completion date. A detailed discussion of the full closure traffic impacts is presented later in this report. Figure 7 shows the removal of one of the superstructure sections. Figure 8 shows the bridge superstructure partially replaced.

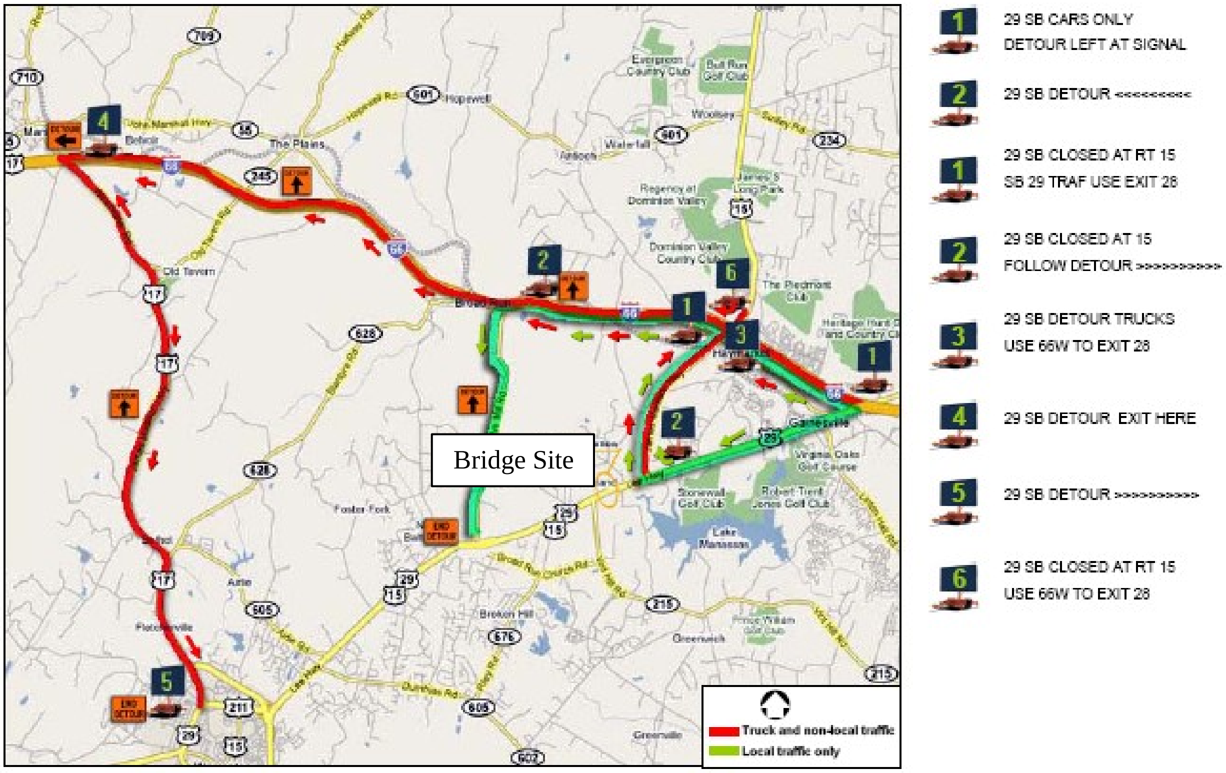


Figure 6. Authorized detour route map.

Figure 7. Removal of part of the existing superstructure of the U.S. 15/29 bridge.

Figure 8. Portion of superstructure replaced on the U.S. 15/29 bridge.

Substructure Construction

The existing foundations were found to have adequate capacity to carry the additional superstructure dead and live loads, which simplified the construction of the substructure piers and abutments. The abutments and pier stems as well as the wingwalls were reworked and widened to accommodate the increased width. See figure 9 for reconstruction of one wingwall. The pier stem extension is shown in figure 10. The corbel bracket shown in figure 10 was accomplished using grouted dowels and external post-tensioning that extended from one end of the pier cap to the other. Ducts were placed outside the existing concrete along with the necessary reinforcing steel and steel anchor plates. New concrete was formed and poured for the larger pier cap. Once the concrete strength reached the required strength, the strands were placed and stressed to complete the cap.

Other features of the bridge replacement and widening include corrosion-resistant reinforcing steel in the reinforced concrete members, high-performance grout in the transverse post-tensioning tendons for the pier widening, self-consolidating concrete in the beam seats, and a deck extension at the abutments to eliminate the expansion joints at the abutments.

As shown in figure 11, some road work widening was required to provide the necessary shoulder widths on the roadway approaches to the bridge. The complete structure and roadway are shown in figure 12.

Prefabricated Bridge Components and Materials

Traditional construction for a bridge of this type would have been done with composite rolled steel beams with a cast-in-place concrete deck. Construction would have required several stages and many lane closures with significant traffic maintenance effort. Because of the traffic volume on this bridge, modular prefabricated elements were chosen for the superstructure replacement. Each of the 12 segments consists of two rolled steel beams made composite with a concrete deck slab (figures 3, 4, and 5). These segments were fabricated by Coastal Precast Systems, LLC in Chesapeake, VA, and were shipped by truck to the bridge site.

DURABILITY

For this bridge superstructure replacement, VDOT selected prefabricated bridge elements and high-performance materials for their superior quality and durability over traditional construction materials and elements. The prefabricated high-performance, lightweight concrete deck and rolled structural steel beam system, waterproofing membrane, and hot-mix asphalt overlay resulted in a bridge that will last longer and perform better than the previous bridge.

Figure 9. Wingwall modifications on the U.S. 15/29 bridge.

Figure 10. Pier widening on the U.S. 15/29 bridge.

Figure 11. U.S. 15/29 bridge approach pavement preparation,
looking south toward the bridge.

Figure 12. Completed U.S. 15/29 bridge over Broad Run, looking south.

DATA ACQUISITION AND ANALYSIS

Data collection on the VDOT HfL project consisted of acquiring and comparing data on safety, construction congestion, quality, and user satisfaction before, during, and after construction. The primary objective of acquiring these types of data was to provide HfL with sufficient performance information to support the feasibility of the proposed innovations and to demonstrate that ABC technologies can be used to do the following:

- Achieve a safer work zone environment for the traveling public and workers.
- Reduce construction time and minimize traffic interruptions.
- Produce greater user satisfaction.

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

SAFETY

If traditional construction methods had been used, the project would have impacted highway users for an estimated 100 days and nights. The revised construction scheme used to build the project reduced this impact significantly, reducing crash potential and improving safety during construction. Constructing prefabricated modular segments offsite also enhanced worker safety because they were not working adjacent to traffic.

The safety goals for the project included both worker safety and motorist measures. The worker safety goal was an incident rate of 4.0 or less as measured by the OSHA 300. The motorist goal during construction was a crash rate equal to or less than the preconstruction crash rate. No worker injuries occurred during the project. Six incidents involving motorists with flat tires occurred during construction because of a temporary patch on the abutment backwall, but no injuries or other vehicle damages occurred. Therefore, the safety goals were met on the project.

The replaced superstructure improves the safety of the existing bridge by adding 8 ft (2.4 m) to the face-to-face curb dimensions to increase the width of the substandard shoulders. The exterior shoulder was widened from 2 ft (0.6 m) to 8 ft (2.4 m) and the median shoulder from 2 ft (0.6 m) to 4 ft (1.2 m). The substandard railings on the bridge were replaced with crash-tested Kansas Corral railings attached to the prefabricated modular segments.

CONSTRUCTION CONGESTION

Introduction

The project’s primary congestion goal was to reduce construction impact on motorists by 50 percent compared to conventional construction methods. Using conventional cast-in-place construction would have impacted motorists for an estimated 100 days and caused diurnal nonrecoverable queuing problems of about 1.5 to 2 mi (2.4 to 3.2 km) during rush-hour peaks. VDOT employed innovative A + (B x C) bidding to incentivize and accelerate the construction. The use of prefabricated superstructure elements reduced the construction impact to only three weekends.

The three weekends of full road closures of the southbound lanes were conducted on U.S. 15/29 at Buckland in fall 2008. During each weekend closure, officials diverted traffic onto two primary defined detours. Local traffic southbound was directed to leave the highway at the U.S. 29–U.S. 15 intersection, travel north on U.S. 15 to SR 55 (John Marshall Highway), turn westbound onto SR 55 to Beverly’s Mill Road, turn south on Beverly’s Mill Road, and rejoin U.S. 15/29. The northbound local detour was the opposite. Nonlocal traffic (including trucks) traveled the southbound detour by following Interstate 66 westbound to U.S. 17 and turning south on U.S. 17 to rejoin U.S. 15/29 (the northbound nonlocal detour was the opposite of this). Figure 12 illustrates the defined detours.

The implications of this traffic management approach on travel times needed to be quantified, particularly to compare conventional construction techniques to the three-weekend closure scheme. Therefore, travel time studies were performed in August and September 2008. One set of studies was conducted on a weekend when the highway was closed and all traffic was diverted to the detour. Another set was conducted on weekend days when the highway was open to traffic. The results of these studies showed increases in travel times of up to 14 minutes and 7 minutes for local and through traffic, respectively, traveling in the southbound direction. This produced a calculated total delay for the three weekend closures of 9,461 vehicle-hours. This compares favorably to the estimated total delay of 720,000 vehicle-hours that would have resulted from conventional construction over a 100-day (daytime and nighttime) construction period.

Data Collection

Researchers used the floating vehicle methodology to collect travel times, attempting to mimic the typical driving speed of other vehicles along the various roadway segments. Data were collected only during daytime hours, since at night traffic demands would be lower and any effects of the total roadway closure would be smaller. Researchers collected data during a scheduled full roadway closure on August 23 and 24, 2008 (Saturday and Sunday). Researchers returned to the site on two subsequent weekends (September 13 and September 21) to obtain Saturday and Sunday travel times when U.S. 15/29 was not closed. A continuous 90-mi (144.8-km) loop on U.S. 15/29 and detour routes was designed, and data collection personnel traveled it repeatedly on each day of data collection. Four circuits were completed on each day of data collection for the normal (nonclosure) weekend for a total of eight circuits. Three circuits were completed for each day of data collection during the total roadway closure weekend for a total of six circuits. After discussions with the data collection crew and review of project diary information, it was determined that the data collected on August 23 occurred while U.S. 15/29 remained open. Therefore, only the data collected on August 24 was used to estimate the effects of the full roadway closure.

The data collection circuit was identified by a series of 21 different nodes where interim travel time readings were taken. Table 1 identifies each node followed in sequence during each data collection circuit, as well as the approximate travel distance to that node from the previous node. The use of multiple data collection nodes allowed researchers to directly compare individual roadway segments (with and without a full roadway closure in place) and to combine those segments in various ways to quantify the impacts on the entire length of the two detour routes.

Table 1. Node definitions for travel time data collection circuit.

Node	Description	Distance From Previous Node in Miles (Kilometers)
1	U.S. 29 SB @ I-66 WB Entrance Ramp	---
2	U.S. 29 SB @ U.S. 15	4.0 (6.4)
3	U.S. 15 NB @ SR 55	2.7 (4.3)
4	SR 55 WB @ Beverly's Mill Road	3.7 (5.9)
5	Beverly's Mill Road @ U.S. 15/29	4.0 (6.4)
6	U.S. 15/29 SB @ Exit Ramp Gore to U.S. 211/29 BR	4.3 (6.9)
7	U.S. 211/29 BR @ U.S. 17	1.3 (2.0)
8	U.S. 17 NB @ I-66 EB Entrance Ramp	10.0 (16.0)
9	I-66 EB @ U.S. 15 Overpass	11.6 (18.6)
10	I-66 EB Exit Gore @ U.S. 29 NB	2.7 (4.3)
11	U.S. 29 NB @ I-66 Entrance WB	1.0 (1.6)
12	I-66 EB @ U.S. 15 Overpass	2.5 (4.0)
13	I-66 EB Exit @ U.S. 17	11.6 (18.6)
14	U.S. 17 @ U.S. 211/29 BR	10.0 (16.0)
15	Entrance Ramp Gore Onto U.S. 15/29 NB	1.4 (2.2)
16	U.S. 15/29 NB @ Beverly's Mill Road	4.2 (6.7)
17	Beverly's Mill Road NB @ SR 55	4.0 (6.4)
18	SR 55 EB @ U.S. 15	3.7 (5.9)
19	U.S. 15 SB @ U.S. 29	2.7 (4.3)
20	U.S. 29 NB @ I-66 WB Entrance Ramp	4.0 (6.4)
SUBTOTAL		89.0 (143.2)
Additional Nodes for Normal (Nonroadway Closure) Travel Times		
21	U.S. 29 SB @ U.S. 15	4.0 (6.4)
22	U.S. 29 SB @ Beverly's Mill Road (turnaround)	3.0 (4.8)
23	U.S. 29 NB @ U.S. 15	3.0 (4.8)
24	U.S .29 NB @ I-66 WB Entrance Ramp	4.0 (6.4)
SUBTOTAL		14.0 (22.5)
OVERALL TOTAL		103.0 (165.7)

The travel time data were entered on a spreadsheet for reduction and analysis. Data from each travel time circuit were combined in an overall average for each study period and compared. Tables 2 and 3 summarize these data. A slight increase (7 percent) in the total travel times on the second day of the non-full roadway closure travel time study was noted. Data collection personnel indicated there was a strong police presence on the corridor and alternative routes during the second day of the full roadway closure, which may have reduced speeds and caused this slight increase. Consequently, an average travel time across both days was used as a conservative estimate of the effect of the closure.

Table 2. Travel time data in before (no full roadway closure) condition.

Data Collection Node	Elapsed Travel Time from Previous Node, Seconds													
	Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8	Run #9	Run #10	Run #11	Run #12	Avg.	Std. Dev.
U.S. 29 SB @ I-66 WB Entrance Ramp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U.S. 29 SB @ U.S. 15	332	327	332	273	358	424	360	340	472	427	332	417	366	57
U.S. 15 NB @ SR 55	220	196	223	194	248	217	230	193	233	181	206	205	212	20
SR 55 WB @ Beverly’s Mill Road	242	273	274	275	259	232	260	254	265	242	248	247	256	14
Beverly’s Mill Road @ U.S. 15/29	300	344	332	306	307	317	350	291	311	294	321	313	316	19
U.S. 15/29 SB @ Exit Ramp Gore to U.S. 211/29 BR	348	316	337	285	344	320	390	328	326	326	348	286	330	28
U.S. 211/29 BR @ U.S. 17	243	172	117	94	154	128	130	181	177	117	105	128	146	42
U.S. 17 NB @ I-66 EB Entrance Ramp	578	592	594	616	616	595	610	574	578	556	600	592	592	18
I-66 EB @ U.S. 15 Overpass	565	560	567	487	574	592	590	596	593	579	576	572	571	29
I-66 EB Exit Gore @ U.S. 29 NB	167	166	185	116	170	172	146	155	164	150	190	160	162	19
U.S. 29 NB @ I-66 WB Entrance Ramp	38	72	33	134	72	71	54	35	78	98	74	75	70	28
I-66 EB @ U.S. 15 Overpass	150	110	131	151	127	116	172	158	115	76	113	111	128	26
I-66 EB Exit @ U.S. 17	618	656	654	610	632	614	623	620	608	610	670	640	630	21
U.S. 17 @ U.S. 211/29 BR	613	734	728	706	731	688	668	628	617	656	695	636	675	45
Entrance Ramp Gore Onto U.S. 15/29 NB	198	172	197	155	183	180	109	170	152	158	169	168	168	24
U.S. 15/29 NB @ Beverly’s Mill Road	384	300	369	344	351	329	365	343	398	358	378	323	354	28
Beverly’s Mill Road NB @ SR 55	311	301	293	311	290	328	330	291	303	292	311	305	306	14
SR 55 EB @ U.S. 15	226	232	258	228	235	262	254	319	271	330	309	268	257	32
U.S. 15 SB @ U.S. 29	176	348	252	188	331	321	266	219	273	360	210	348	274	66
U.S. 29 NB @ I-66 WB Entrance Ramp	394	548	376	290	401	356	309	321	313	338	583	543	398	103
TOTAL	6103	6419	6252	5763	6383	6262	6216	6016	6247	6038	6438	6337	6206	197
Travel Times on U.S. 15/29 (Lee Highway) Across Bridge														
U.S. 29 NB @ I-66 WB Entrance Ramp	0	0	0	0	0	0							0	0
U.S. 29 SB @ U.S. 15	351	364	356	447	532	431							414	71
U.S. 29 SB @ Beverly’s Mill Road	263	237	178	249	270	209							234	35
U.S. 29 NB @ U.S. 15	183	195	191	235	315	257							229	51
U.S. 29 NB @ I-66 WB Entrance Ramp	307	529	456	330	347	373							390	85
TOTAL	1104	1325	1181	1261	1464	1270							1268	123

Table 3. Travel time data during full roadway closure conditions.

Data Collection Node	Elapsed Travel Time from Previous Node, Seconds			
	Run #1	Run #2	Average	Std. Dev.
U.S. 29 SB @ I-66 WB Entrance Ramp	0	0	0	0
U.S. 29 SB @ U.S. 15	375	330	353	32
U.S. 15 NB @ SR 55	305	570	438	187
SR 55 WB @ Beverly's Mill Road	290	294	292	3
Beverly's Mill Road @ U.S. 15/29	335	369	352	24
U.S. 15/29 SB @ Exit Ramp Gore to U.S. 211/29	381	312	347	49
U.S. 211/29 BR @ U.S. 17	90	150	120	42
U.S. 17 NB @ I-66 EB Entrance Ramp	584	595	590	8
I-66 EB @ U.S. 15 Overpass	580	595	588	11
I-66 EB Exit Gore @ U.S. 29 NB	170	155	163	11
U.S. 29 NB @ I-66 WB Entrance Ramp	70	75	73	4
I-66 EB @ U.S. 15 Overpass	126	125	126	1
I-66 EB Exit @ U.S. 17	825	673	749	107
U.S. 17 @ U.S. 211/29 BR	749	707	728	30
Entrance Ramp Gore Onto U.S. 15/29 NB	157	170	164	9
U.S. 15/29 NB @ Beverly's Mill Road	277	309	293	23
Beverly's Mill Road NB @ SR 55	336	300	318	25
SR 55 EB @ U.S. 15	300	331	316	22
U.S. 15 SB @ U.S. 29	364	295	330	49
U.S. 29 NB @ I-66 WB Entrance Ramp	300	368	334	48
TOTAL	6,614	6,723	6,669	77

Travel Time Comparison Results

Differences in Operating Conditions on Detour Route Segments

Table 4 summarizes a segment-by-segment comparison of the average travel times when the full roadway closure was in place on U.S. 15/29 (i.e., during) to when the full closure was not in place (i.e., before). Simple t-tests were performed to determine statistical significance of any differences. As table 2 indicates, the full roadway closure had significant effects on several detour route segments for southbound U.S. 15/29 traffic in the corridor:

- U.S. 15 northbound from U.S. 29 to SR 55—a 225-second travel time increase (107 percent)
- SR 55 westbound from U.S. 15 to Beverly's Mill Road—a 36-second increase (14 percent)
- Beverly's Mill Road southbound from SR 55 to U.S. 15/29—a 36-second increase (11 percent)
- I-66 westbound from the U.S. 15 overpass to the U.S. 17 interchange—a 119-second increase (19 percent)
- U.S. 17 southbound from I-66 to U.S. 211/29—a 53 second increase (8 percent)

Table 4. Comparison of segment travel times, before versus during roadway closure.

Data Collection Node	Average Travel Time From Previous Node, Seconds			T-stat
	Before	During	Diff.	
U.S 29 SB @ I-66 WB Entrance Ramp	0	0	0	NA
U.S. 29 SB @U.S. 15	366	353	-14	-0.53
U.S. 15 NB @ SR 55	**212**	**438**	**225**	**2.68****
SR 55 WB @ Beverly's Mill Road	**256**	**292**	**36**	**6.57****
Beverly's Mill Road @ U.S. 15/29	**316**	**352**	**36**	**2.84****
U.S. 15/29 SB @ Exit Ramp Gore to U.S. 211/29 BR	330	347	17	0.70
U.S. 211/29 BR @ U.S. 17	146	120	-26	-1.03
U.S. 17 NB @ I-66 EB Entrance Ramp	592	590	-2	-0.29
I-66 EB @ U.S. 15 Overpass	571	588	17	1.39
I-66 EB Exit Gore @ U.S. 29 NB	162	163	1	0.09
U.S. 29 NB @ I-66 Entrance WB	70	73	3	0.28
I-66 WB @ U.S. 15 Overpass	128	126	-2	-0.20
I-66 WB Exit @ U.S. 17	**630**	**749**	**119**	**2.45****
U.S. 17 @ U.S. 211/29 BR	**675**	**728**	**53**	**2.45****
Entrance Ramp Gore Onto U.S. 15/29 NB	168	164	-4	-0.42
U.S. 15/29 NB @ Beverly's Mill Road	**354**	**293**	**-61**	**-4.15****
Beverly's Mill Road NB @ SR 55	306	318	12	1.00
SR 55 EB @ U.S. 15	**257**	**316**	**59**	**3.78****
U.S. 15 SB @ U.S. 29	274	330	55	1.66
U.S. 29 NB @ I-66 WB Entrance Ramp	398	334	-64	-1.43

*Significantly Different ($\alpha = 0.05$).

Although there were some travel time increases on detour routes serving the northbound U.S. 15/29 traffic, these were not substantial enough in most cases to be detected as statistically significant. There was one exception: SR 55 eastbound from Beverly's Mill Rd to U.S. 15—a 59-second increase (23 percent).

Meanwhile, one segment on U.S. 15/29 northbound between U.S. 17 and Beverly's Mill Road actually experienced a 61-second (21 percent) decrease.

Effect of Full Roadway Closure on Route Travel Times

Table 5 summarizes the increase in total travel times caused by the total roadway closure of U.S. 15/29. VDOT defined two types of detour routes, one for local traffic attempting to travel on the U.S. 15/29 segment affected by the closure and another for through traffic (including trucks) using the highway. For both routes, total travel times that would have been possible by using U.S. 15/29 were compared to the defined alternative route.

The local detour route, because of its length compared to the U.S. 15/29 segment, increased travel times by 848 seconds (14 minutes) per diverted trip southbound and by 734 seconds (12 minutes) northbound. For through traffic, the effect of the detour was much less pronounced. Through traffic in the southbound direction that followed the detour along I-66 and U.S. 17 rather than using U.S. 15/29 experienced travel time increases of 398 seconds (nearly 7 minutes). In the northbound direction, the through traffic detour travel time was 186 seconds (slightly more than 3 minutes) longer than if the U.S. 15/29 highway had been available for use. All of the increases shown in table 5 were highly significant.

Table 5. Comparison of normal (before) travel times to detour travel times during full roadway closure.

Route	Average Travel Time Along Route, Seconds			T-stat
	Via U.S 15/29	Via Detour	Diff.	
Local Detour Southbound (Intersection of U.S. 15 and U.S. 29 to the U.S. 15/29 Intersection at Beverly's Mill Road)	234	1,082	848	14.63*
Local Detour Northbound (U.S. 15/29 Intersection at Beverly's Mill Road to the Intersection of U.S. 15 and U.S. 29)	229	963	734	29.63*
Through Detour Southbound (U.S. 29 at I-66 to U.S. 15/29 at U.S. 17)	1,124	1,603	398	10.36*
Through Detour Northbound (U.S. 15/29 at U.S. 17 to U.S. 29 at I-66)	1,147	1,340	186	8.19*

*Significantly Different ($\alpha = 0.05$)

Quantification of Total Delays Generated by the Full Roadway Closure

As expected, the travel time studies indicated that traffic diverted from U.S. 15/29 experienced significant increases in travel time. In addition, this diverted traffic caused additional congestion on certain segments of the detour routes and increased travel times for those drivers normally using those segments. Full quantification of the total delays caused by the full roadway closure requires estimating the amount of diverted traffic from U.S. 15/29 that used either the local diversion route or the through diversion route.

Researchers were able to obtain traffic count data from several VDOT sensors in the study corridor:

- U.S. 15/29 between Beverly's Mill Road and Vint Hill Road
- U.S. 17 just south of I-66
- I-66 just east of U.S. 17

Together, these three sensor locations allowed for a detailed analysis of diversion behaviors in the corridor. The U.S. 15/29 sensor location was located in the defined local detour segment. As such, it provided an indication of the amount of local traffic not diverting at all (i.e., those with local destinations not affected by the total road closure). Meanwhile, the I-66 and U.S. 17 sensor locations allowed for an assessment of traffic choosing to use the through or truck detour defined above.

The total roadway closures were performed on three nonconsecutive weekends:

- 9 p.m. on Friday, August 15, through 10 p.m. on Saturday, August 16
- 7 p.m. on Saturday, August 23, through 12:05 p.m. on Sunday, August 24
- 7 p.m. on Saturday, September 6, through 2:45 p.m. on Sunday, September 7

Table 6 summarizes the comparison of hourly traffic counts occurring on the other nonholiday weekends in August and September to the hourly counts during these total roadway closure hours. Northbound counts (and I-66 eastbound counts) were generally unaffected by the total roadway closure on U.S. 15/29. It appears that most drivers did not divert at the Beverly's Mill Road detour, but continued on U.S. 15/29 to a destination within the segment before the bridge closure or onto Vint Hill Road (SR 215, which serves subdivisions in the area).

Table 6. Traffic count comparison during total roadway closure.

	Traffic Occurring During Total Roadway Closure Hours	Traffic Normally Occurring During Those Hours	Change	% Change
U.S. 29 NB	40,712	43,075	-2,363	-5.5
I-66 EB	34,783	34,830	-47	-0.1
U.S. 17 NB	20,258	20,604	-346	-1.7
U.S. 29 SB	4,860	42,176	-37,316	-88.5
I-66 WB	43,365	37,767	+5,598	+14.8
U.S. 17 SB	28,485	20,117	+8,368	+41.6

The situation was markedly different in the southbound direction on U.S. 15/29 (and westbound on I-66). Only a small portion of traffic normally using the route in the southbound direction in the vicinity of the sensors actually did so during the hours of the total closure. These vehicles presumably came from Vint Hill Road or from businesses on U.S. 15/29 south of the total bridge closure point. Some of the vehicles (between 5,598 and 8,368) that did not travel down U.S. 15/29 showed up in higher I-66 and U.S. 17 counts. The remainder of the diverted traffic presumably used the local detour route. Applying the increased travel time estimates shown in tables 4 and 5 to these traffic counts yields an overall estimate of the delays generated by the closures.

Through traffic southbound (delays from table 5):

(5,598 + 8,368)/2 * (398/3,600) = 6,983* 0.111 = 772 vehicle-hours

Local traffic southbound (delays from table 5):

(37,316 – 6983)*(848/3,600) = 30,333*0.236 = 7,145 vehicle-hours

Additional delays incurred by other westbound I-66 drivers (delays from table 4):

37,767*(119/3,600) = 1,248 vehicle-hours

Additional delays incurred by other southbound U.S. 17 traffic (delays from table 4):

20,117* (53/3,600) = 296 vehicle-hours

TOTAL = 772 + 7,145 + 1,248 + 296 = 9,461 vehicle-hours

Comparison to Original Phasing Scheme

Since the construction phasing scheme was changed after the project started from twelve weeknight closures to full closures over three weekends, it is prudent to compare the traffic delay impact between these two schemes.

Using VDOT traffic count data from U.S. 29, it is estimated that (0.89*6572=) 5,489 vehicles southbound and (0.055*4748=) 261 vehicles northbound would be impacted during each weeknight of full roadway closure. Assuming the same estimates of increased travel time to this U.S. 29 traffic because of northbound and southbound detours, it is anticipated that the use of weeknight full roadway closures would have yielded 1,346.1 vehicle-hours of delay each night. Compared to the three weekend full roadway closures that were ultimately used which generated a total of 9,461 vehicle-hours of delay, it would have taken only about seven of the scheduled twelve weeknights of closures to reach the same amount of total delay that occurred over the three weekend full closures. Perhaps more important, if the nighttime full roadway closure had not been removed each morning by 5 a.m. (because of construction problems), there was a potential for gridlock to develop because peak period (5 to 9 a.m.) traffic volumes on U.S. 29 exceed 9,000 vehicles northbound and 3,500 vehicles southbound. These volumes alone exceed those occurring over the entire nighttime work period. Although not specifically estimated in this analysis, the queuing that likely would have developed on the detour routes would have escalated exponentially, generating more delay in one peak period alone than occurred during the entire series of weekend closures used in this project. Therefore, the modified construction work scheme not only reduced the estimated traffic impact by almost one-half, it also greatly reduced the risk of traffic impact during critical peak-flow periods.

QUALITY

The project goals for quality were to improve the ride quality, reduce the noise, and provide a new and durable bridge. The existing deteriorated bridge deck required continuous maintenance and patching of potholes, creating frequent traffic congestion. The rough deck surface created a safety hazard and wear and tear on vehicles. The new superstructure provides a durable, maintenance-free bridge deck by using lightweight, high-performance concrete materials and corrosion-resistant reinforcing steel, all prefabricated in a controlled manufacturing environment. The durability is further improved by the application of a waterproofing membrane and hot-mix asphalt overlay. The asphalt overlay and membrane on the bridge is extended over the multiple pier joints with a special detail to deter reflective cracking. This also reduces the noise intensity compared to riding on a bridge deck with multiple expansion joints. A slab extension over the backwalls at the abutments eliminates the joints at the abutments, further minimizing noise, improving ride quality, and reducing water infiltration at the backwall.

Sound Intensity Testing

Preconstruction noise testing was done on July 10, 2007. Noise data was not collected after construction because of the short length of the bridge. Onboard sound intensity (OBSI) measurements were obtained from the bridges at the posted highway speed of 45 miles per hour (mi/h) (72.4 kilometers per hour (km/h)).

Sound intensity (SI) measurements were made using the current accepted onboard sound intensity (OBSI) technique AASHTO TP 76-08, which includes dual vertical sound intensity probes and an ASTM standard reference test tire (SRTT). The sound measurements were recorded using the Bruel and Kjaer PULSE software and data collection system. Three runs were made in the right wheelpath of the outer lane of each bridge. The two microphone probes simultaneously captured noise data from the leading and trailing tire-pavement contact areas. Figure 13 shows the dual probe instrumentation and the tread pattern of the SRTT.

Figure 13. OBSI dual probe system and the SRTT.

The average of the front and rear SI values was computed with the Bruel & Kjaer PULSE software to analyze the raw data signals over the full length of the bridge decks to produce sound intensity values. Raw noise data were normalized for the ambient air temperature and barometric pressure at the time of testing. The resulting mean sound intensity levels are A-weighted to produce the noise-frequency spectra in one-third octave bands, as shown in figures 14 and 15.

Global noise levels were calculated by using logarithmic addition of the third octave band frequencies between 315 and 4,000 hertz (Hz). The global noise levels were 100.6 and 98.6 dB(A) for the northbound and southbound prerehabilitated bridges, respectively. The original portland cement concrete bridge deck surfaces were distressed and weathered and likely to be noisier than the newly constructed surfaces. Noise values from the two bridges are relatively similar in frequencies and overall decibel levels. For reference, a 3.0-decibel difference in noise is considered noticeable. Postconstruction noise levels were not measured for this project.

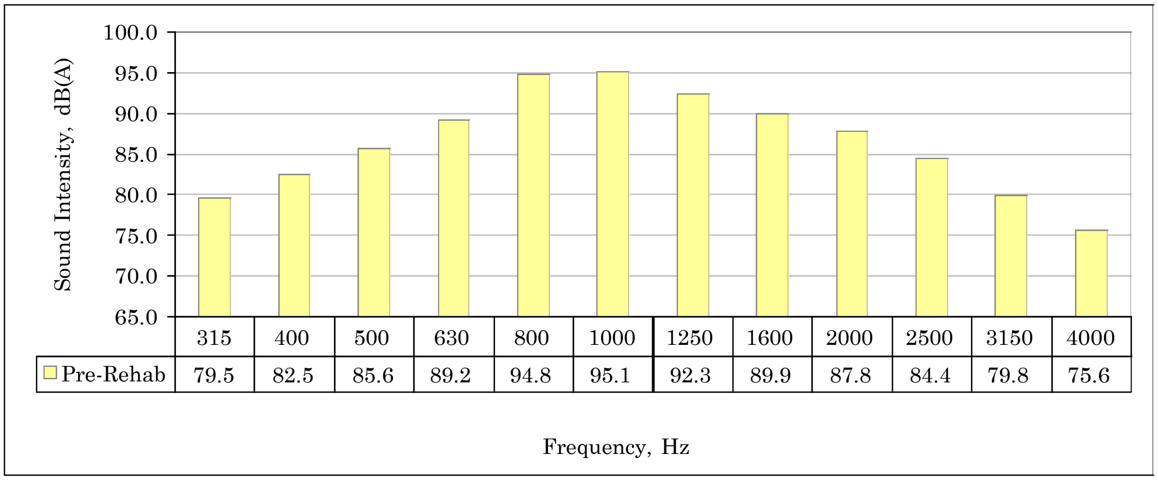


Figure 14. Northbound bridge mean A-weighted sound intensity frequency spectra.

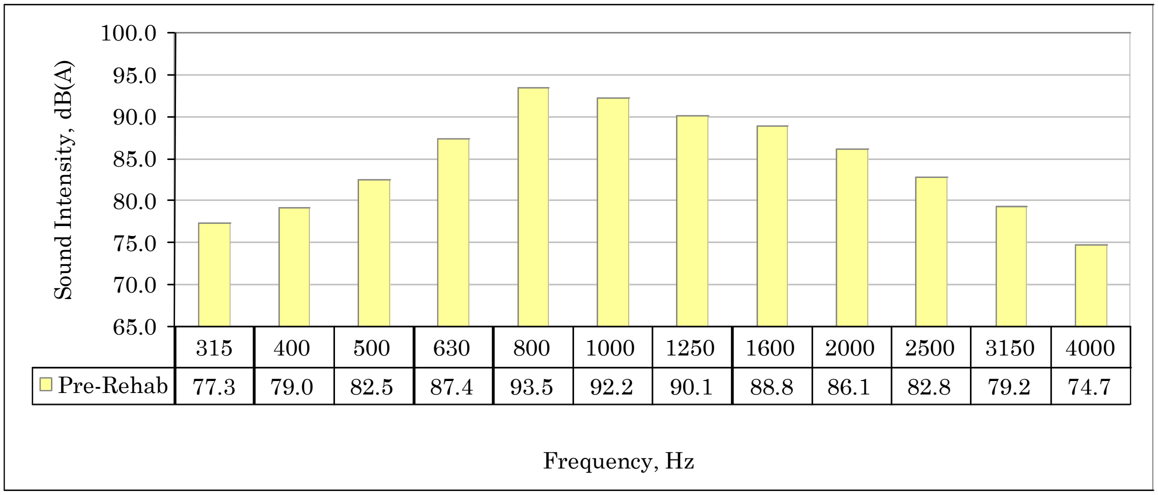


Figure 15. Southbound bridge mean A-weighted sound intensity frequency spectra.

Smoothness Measurement

Smoothness testing was done in conjunction with noise testing using a laser profiler manufactured by International Cybernetics Corporation built in to the noise test vehicle. Figure 16 shows the test vehicle with the laser positioned in line with the right rear wheel.

Three test runs in each wheelpath in each direction were conducted. The left and right wheelpath test runs were averaged to produce a singe International Roughness Index (IRI) value with units of inches per mile (in/mi). Resulting IRI values are plotted in figure 17 at 10-ft (3-m) intervals.

Figure 16. Laser profiler mounted behind the test vehicle.

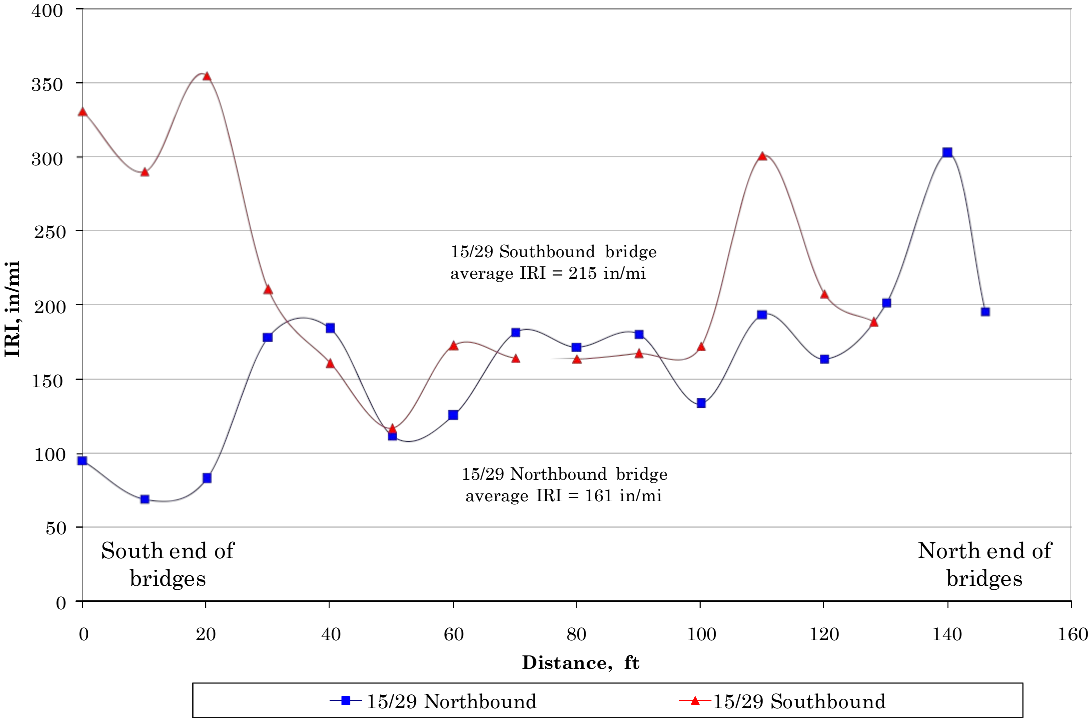


Figure 17. Mean IRI values.

The overall IRI values are 161 and 215 in/mi for the prerehabilitated northbound and southbound bridges, respectively. Postconstruction IRI is anticipated to be lower because a new hot-mix asphalt concrete overlay will be applied. However, postconstruction ride quality was not measured. Figure 17 shows large peak values at the ends of each bridge corresponding to pavement distress near the expansion joints. Figure 18 shows the existing southbound bridge deck.

Figure 18. Prerehabilitated southbound bridge deck.

USER SATISFACTION

The Buckland Preservation Society's interests were considered and incorporated into the project. A memorandum of agreement signed between the Section 106 consulting parties and VDOT specifically required the use of the accelerated nighttime construction method for the superstructure replacement, as discussed previously in this report. In addition, VDOT sought to provide the best long-term solution for this bridge crossing.

VDOT did not send survey letters as part of this process. As stated previously, significant work was done with the residents of the Buckland Historic District during the design phase. The following quote was sent to VDOT from a representative of that group:

"On behalf of the Buckland Preservation Society and neighbors at Buckland . . . Congratulations . . . Excellent Work! . . . .Very Special Thanks to Nick Roper for all his initial efforts!"

Public officials at the ribbon cutting ceremony (see agenda in Appendix B) held on October 14, 2008 highlighted the positive benefits that the rehabilitated bridge would have on their community and also VDOT's outreach efforts to the public during the bridge construction phase to keep them informed of the projects progress. The citizens at the ceremony expressed their approval of the new bridge and how it was constructed to minimize impact on the users. The project's Partnering Charter had two public relations objectives. The first objective was to cultivate and open and honest relationship with the public to effectively communicate with the public about the purpose of the project and project progress. The second objective was to respectfully respond to the public's inquires, comments, and concerns.

TECHNOLOGY TRANSFER

To promote the innovations of prefabricated bridge elements, traffic maintenance schemes, and accelerated construction, VDOT, the Maryland State Highway Administration, the South Carolina Department of Transportation, and FHWA sponsored a 1-day workshop for transportation professionals. The July 22, 2008, workshop was held in Frederick, MD. The workshop featured presentations by State highway agency staff members, construction contractors, and FHWA consultants on construction projects in the three States. A construction site visit was scheduled for workshop participants, but the timing of the placement of the elements to be viewed did not work out with the workshop date. Attending the workshop were individuals from each State agency, FHWA, the construction industry, and local agencies Figure 19 and 20 are images from the workshop. The workshop agenda and list of presenters is in Appendix A.

Figure 19. Workshop presenters and participants.

Figure 20. Workshop presenters, Robert (Bob) Price (left), Khossrow Babaei (right), both from VDOT, and John Morgan (center) from the Flippo Construction Company.

ECONOMIC ANALYSIS

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

For this economic analysis, VDOT supplied most of the cost figures for the as-built project. The assumptions for the baseline case costs were made based on discussions with VDOT staff and national literature.

CONSTRUCTION TIME

VDOT believes that, through the use of the full lane closures over three weekends and ABC techniques, it was able to dramatically reduce the impact of this project's construction on roadway users. The user impact was reduced from 100 total days of navigating through a work zone to 6 weekend days of traveling on designated detours.

DETOUR

As noted earlier, the designated local and nonlocal (including truck) detours added about 11 mi (17.7 km) to the trip length. As indicated in the "Travel Time Comparison Results" section, the total trip time increase because of the detours was 9,641 vehicle-hours. The following is a calculation of the total additional vehicle-miles traveled based on a VDOT estimated two-way annual average daily traffic (AADT) of 24,000:

24,000 (vehicles per day) x 6 (weekend days with full lane closures) x 11 miles (detour length)
= 1,584,000 vehicle-miles

CONSTRUCTION COSTS

Table 7 presents the differences in construction costs between the baseline and the as-built alternatives. All of the as-built cost estimates were provided by the VDOT project engineer assigned to this job. The baseline cost was determined by adjusting the cost of the prefabricated superstructure elements using historical unit costs for the steel beams, concrete deck, and deck reinforcing steel had they been constructed in the traditional fashion. Traffic control costs were estimated based on the 100 days of closure required for the baseline case. Traffic control for either the baseline or as-built case was substantial because of the approach roadway work. The baseline cost estimate is inexact, and the information presented is a subjective analysis of the likely cost differential rather than a rigorous computation of a cost differential. Several other assumptions were made in selecting significant cost factors and determining some unit costs, as noted in table 7.

Table 7. U.S. 15/29 bridge capital cost calculation table.

Cost Category	Baseline Case	As Built (ABC)
Preliminary Design and Engineering[1]	$ 242,900	$ 254,000
Bridge and Roadway Construction		
Bridge Superstructure[2]	$1,263,700	$1,508,200
Bridge Substructure	$ 420,700	$ 420,700
Roadway	$ 638,400	$ 638,400
Construction Engineering[3]	$ 404,800	$ 436,200
Mobilization[4]	$ 222,800	$ 263,900
Traffic Control[5]	$ 153,000	$ 87,000
Total Cost	$3,346,300	$3,608,400

Notes:

[1] For the baseline case, design was assumed as 9 percent of the construction cost. VDOT provided the cost for the actual design fee for the as-built scheme.

[2] For the baseline case, an estimate was made for the cost of the steel beams and concrete deck had they been done in a conventional fashion. For the as-built case, the costs shown were compiled from VDOT as-built costs.

[3] Includes quality assurance program costs, which are assumed as 15 percent of the construction cost.

[4] Assumed as 9 percent for the baseline case. Includes mobilization, surveying, and contractor field office for the as-built case.

[5] Assumed traffic control costs for the baseline case over 100 days. Includes costs for Jersey barrier, flaggers, signs, trucks, and police patrol ($10,000), etc. Because of the amount of approach roadway work required, the increase in traffic control required for the baseline case for the bridge does not significantly impact the total cost.

USER COSTS

Generally, three categories of user costs are used in an economic or life-cycle cost analysis: vehicle operating costs (VOC), delay costs, and crash- and safety-related costs. Because the anticipated period of user impact during the bridge replacement was relatively short (100 days for the baseline case versus 6 days for the as-built case) and the site under consideration is in an area with relatively low crashes (VDOT estimates one crash per 5.5 million vehicle-miles traveled), it was decided not to compare safety-related costs for the baseline and as-built cases. However, VOC and delay costs were compared and are discussed in the following subsections.

VOC

Baseline Case

For the baseline case, VDOT expects that a majority of the traffic would have passed through the work zone, considering that the designated detour routes would have generated an 11-mi (17.7-km) additional trip length in each direction.

As-Built Case

Since full-lane closures were enforced for the as-built case for three weekends, 100 percent of the traffic was forced to use detour routes. It was assumed that all traffic used the designated detours for this analysis. As reported earlier, the total additional vehicle-miles traveled because of traffic detouring was about 1,584,000. Assuming average unit costs of \$0.23 per mile for passenger cars and \$0.62 per mile for trucks for the variable operating costs[1] (including costs for fuel, maintenance, tires, repair, and depreciation) and assuming that roughly 10 percent of the total vehicles are commercial trucks, the following VOCs are computed:

Passenger vehicles:

VOC_{car} = 24,000 (vehicles) *0.9 (fraction of passenger vehicles)* 11 (miles of detour) * \$0.23 (per mile) * 6 (days)
= \$327,888

Commercial vehicles:

VOC_{truck} = 24,000 (vehicles) *0.02 (fraction of trucks)* 11 (miles of detour) * \$0.62 (per mile) * 6 (days)
= \$19,642

The total VOC because of the detour is \$347,530.

Delay Costs

The cost differential in delay costs was included in this analysis to identify the differences in costs between the baseline and as-built alternatives.

Baseline Case

For the baseline case, VDOT expects that a queue length of 1.5 mi (2.4 km) would have been generated on a conservative basis. Based on the volume data collected for this report, queuing was likely to occur only during peak periods (5 to 9 a.m. and 3 to 7 p.m.) in peak directions. This is a total of 8 hours per day, or 33 percent of the time. Assuming a 5 mi/h (8 km/h) speed limit, the time in queue can be calculated as follows:

Time in queue = 1.5 (mi) * 5 (mi/h) = 0.3 hours

Assuming a composite unit cost of \$15 per hour for passenger cars and commercial vehicles, the delay cost for the baseline case can be computed as follows:

$Delay_{baseline}$ = 24,000 (AADT) * 0.3 (hours in queue) * 100 (days) * \$15 (per hour cost) * 0.27
(fraction of traffic traveling in peak periods in peak directions)
= \$2,916,000

---

[1] Based on *The Per-Mile Costs of Operating Automobiles and Trucks*, G. Barnes, 2003, adjusted for fuel price increase and inflation in 2008. Variable costs include fuel, maintenance, tires, repair, and depreciation.

As-Built Case

As noted earlier, the detours caused a total delay of 9,461 vehicle-hours for the three weekend closures. Keeping the composite unit cost for delay the same as for the baseline case, the delay cost for the as-built case is computed as follows:

$\text{Delay}_{\text{as-built}}$ = 9,461 (hours of delay) * \$15 (per hour cost)
= \$141,915

COST SUMMARY

From a construction cost standpoint, traditional construction methods would have cost VDOT about \$262,100 less than accelerated construction (see table 7). Employing full lane closures over three weekends resulted in an additional cost of \$347,530 in VOC. However, the ABC techniques saved an estimated \$2,774,085 (\$2,916,000 - \$141,915) on delay costs. Therefore, the net savings on this project totaled \$2,164,455 [(\$2,774,085 – \$347,530) – \$262,100]. The HfL accelerated construction project delivery approach realized an overall cost savings that far exceeded the incremental increase in cost from the use of prefabricated bridge elements. Moreover, a downward trend in costs can be expected because of gained efficiencies and reduced perceived risks as VDOT continues to implement this and other innovative bridge technologies.

APPENDIX A: WORKSHOP AGENDA

July 22, 2008

MD/VA/SC HfL Showcase
Prefabricated Bridge Elements
AGENDA

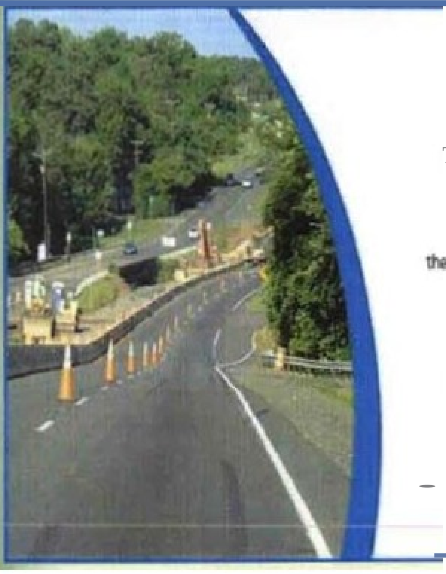
8:30am - 9:00am	Registration	Room A
9:00am-9:10am	Welcome and Introductions Doug Rose, Deputy Administrator - MDSHA	
9:10am-9:30am	Highways for LIFE Overview Nelson Castellanos, Delmar Division Administrator - HfL	
9:30am-10:00am	National Perspective on Prefabricated Bridge Elements & Systems Vasant Mistry - FHWA	
10:00am -10:40am	MDSHA/Contractors Jeff Robert, Project Engineer - MDSHA John Narer, Project Engineer - MDSHA Contractor Representative (TBA)	
10:40am -11:00am	Break	
11:00am • 11:40am	VDOT/Contractors Khossrow Babaei, Assistant District Bridge Engineer VDOT Robert Price, Resident Administrator VDOT	
11:40am ·1:00pm	Lunch (Provided)	Room S
1:00pm -1:40pm	SCOOT/Contractors Randy Cannon, Bridge Project Engineer - TRC Bener Amado, Bridge Program Manager - SCOOT	Room A
1:40pm · 2:30pm	Video Presentations Jerry Burgess, Field Project Engineer- MDSHA	
2:30 · 3:30pm	Open Panel Discussion All Speakers	
3:30pm-3:45pm	Evaluations and Adjourn	

HIGHWAYS FOR LIFE

Accelerating Innovation for the American Driving Experience.

APPENDIX B: AGENDA FOR RIBBON CUTTING CEREMONY

Route 15/29 Bridge Strengthening and Widening Ribbon Cutting



DOT

Tht V•9N Ilepwnent o1 TrM\SpOIWICn
JOU ıı) .rt81d
· Ctlttttih(for

the Route 29 bridge over Broad Run at Buckland

111he Gilnesv‗ ‗ Presbyltnin Chutth
16127lte Hlgtr.v'f, Ga!nmille

lueldoy, Oaol.r 14, 2008 at 11:00 a.m.

Jtmlll ''''' . 1(9.lJl.lfS(I 01
/l''''tt *9''''9'11

October 14, 2008

Agenda

Bob Price, opening/emcee, Resident Administrator for Prince William/Loudoun Counties

Delegate Robert G. Marshall, 13th District

Supervisor, Wally Covington, Prince William County, Brentsville District

Claude Napier, FHWA Representative

r. David Blake, President of Buckland Preservation Society

Nick Roper, VDOT Northern VA District Structure and Bridge Engineer

Bob Price, Closing Comments