FHWA Research and Technology Evaluation

Geosynthetic Reinforced Soil–Integrated Bridge System Evaluation

Final Report
April 2018

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U.S. Department of Transportation
Federal Highway Administration

Foreword

The Federal Highway Administration (FHWA) has initiated an effort to evaluate the Research and Technology (R&T) development program and communicate the full range of benefits of their program. The R&T Evaluation Program helps FHWA assess how effectively it is meeting its goals and objectives and provides useful data to inform future project selections.

This report examines how FHWA's investment in geosynthetic reinforced soil–integrated bridge system development and outreach led to increased awareness of the technology and increased deployment. It contains important lessons about improving communication between our working groups and with our external stakeholders. The report also offers keen insights into two types of technology: traditional and disruptive.

Individuals working in any large organization developing and deploying new technologies will find this report of interest. State transportation department managers and engineers will find the lessons and recommendations particularly valuable.

Hari Kalla, P.E.
Associate Administrator, Office of Research,
Development, and Technology

Notice

Quality Assurance Statement

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16. Abstract The Federal Highway Administration's (FHWA's) Office of Corporate Research, Technology, and Innovation Management and the Office of Infrastructure Research and Development selected the Geosynthetic Reinforced Soil–Integrated Bridge System (GRS-IBS) program for evaluation. The evaluators were asked to focus on research topic selection, early research development, and deployers' decisions to adopt GRS-IBS. The study found that FHWA activities, including Every Day Counts, increased awareness of GRS-IBS among potential deployers. GRS-IBS research and deployment were challenged within FHWA by five internal barriers: poor communication, insufficient collaboration, gaps in evidence, dissemination issues, and resistance to change. GRS-IBS research and deployment were challenged outside FHWA by four external barriers: knowledge, financial, design, and political. GRS-IBS expresses some of the characteristics of a disruptive technology.			
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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List of Abbreviations and Acronyms

Acronym/ Abbreviation	Definition
AASHTO	American Association of State Highway Transportation Officials
ADT	average daily traffic
EDC	Every Day Counts
FHWA	Federal Highway Administration
GRS-IBS	geosynthetic reinforced soil–integrated bridge system
ID	identification
Infrastructure R&D	Office of Infrastructure Research and Development
MSE	mechanically stabilized earth
NBI	National Bridge Inventory
R&T	Research and Technology
RD&T	Research, Development, and Technology
Resource Center	FHWA Resource Center
RFP	request for proposal
TFHRC	Turner-Fairbank Highway Research Center
USDOT	U.S. Department of Transportation

Executive Summary

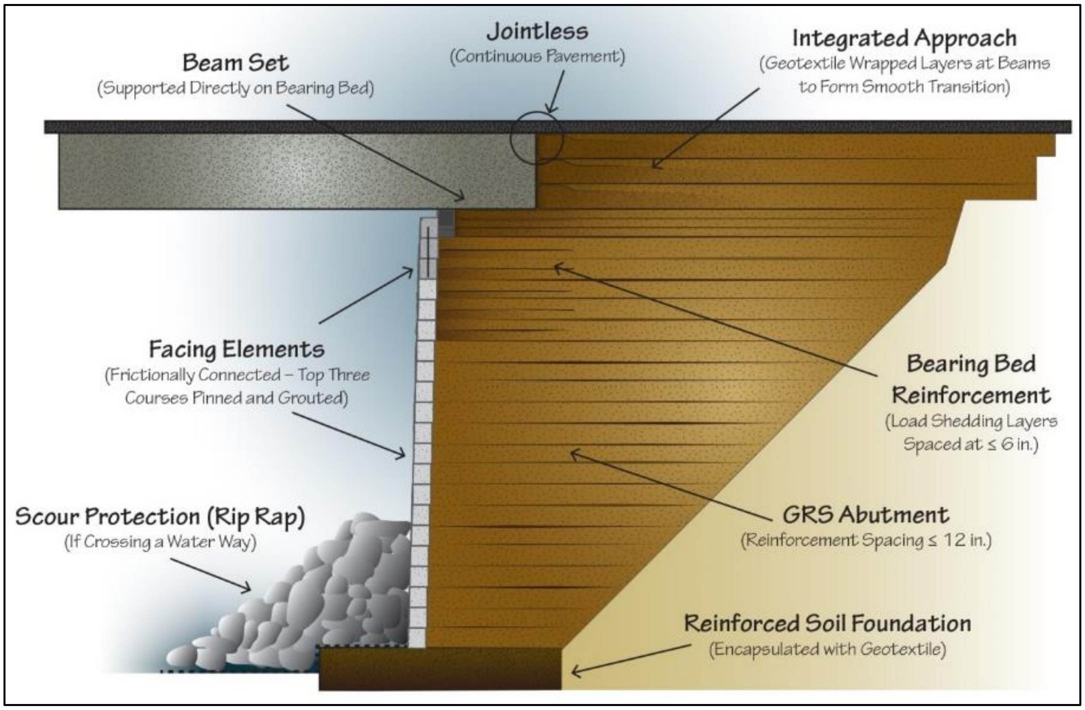
Purpose of the Evaluation

The Federal Highway Administration (FHWA) has initiated an effort to evaluate its Research and Technology (R&T) Program. For each evaluation, the FHWA's R&T Evaluation Program Evaluation Team (evaluation team) is made up of non-FHWA third-party evaluators not involved in the research programs and projects being evaluated. FHWA's Office of Corporate Research, Technology, and Innovation Management and the Office of Infrastructure Research and Development (Infrastructure R&D) selected the Geosynthetic Reinforced Soil–Integrated Bridge System (GRS-IBS) program for evaluation. The evaluation is intended to inform FHWA's research and development process for GRS-IBS and for other technologies. The stakeholders asked evaluators to focus on early research development and deployment decisions. Infrastructure R&D staff also asked the evaluation team to investigate barriers to GRS-IBS deployment and whether these barriers and the nature of the program suggest that GRS-IBS is a disruptive technology—and to discuss the ramifications of such a determination. The evaluation team identified many evaluation questions organized around four evaluation areas:

- FHWA's R&T Program model.
- GRS-IBS specific R&T model.
- Effectiveness of FHWA's outreach for GRS-IBS.
- Benefit of GRS-IBS to deployers.

Program Description

GRS technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. The technology was first applied in the United States by the Forest Service to build walls for roads in steep mountain terrain in the 1970s. Since then, FHWA has worked to evolve the technology into the GRS-IBS, which blends the roadway into the superstructure (see figure 1). Proponents of GRS-IBS argue that the approach is easy to design, can be constructed with generic, low-cost materials, can be built in variable weather conditions, and can easily be modified in the field. The American Association of State Highway Transportation Officials (AASHTO), a nonprofit association representing highway and transportation departments, has not adopted standards or guidelines for GRS-IBS. State and local agency specifications supersede AASHTO recommendations and may permit or restrict GRS-IBS deployment.



Source: FHWA.

Figure 1. Illustration. Major elements of GRS-IBS.

Infrastructure R&D staff began work on GRS-IBS for applications in bridge construction at FHWA's Turner-Fairbank Highway Research Center in the 1990s. They have produced and disseminated several technical documents to assist transportation agencies in implementing GRS-IBS including a *Synthesis Report* (2011), *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (2011), and *Sample Guide Specifications* (2012).(1–3) The first GRS-IBS was constructed in Defiance County, OH, in 2005. As of September 2015, the county had built 34 GRS-IBS bridges. GRS-IBS was selected for the first three rounds of FHWA's Every Day Counts (EDC) initiative, aimed at accelerating implementation of proven, market-ready technologies.

Methodology

The evaluation team aligned the four evaluation areas with major components of a logic model employed in many FHWA R&T evaluations. A logic model is a series of program lanes in a causal chain from left to right. Each lane contains multiple components that make explicit the anticipated relationships between an input (e.g., funding), an activity (e.g., research), an output (e.g., publications), an outcome (e.g., technology deployment), and an impact (e.g., cost savings). The team conducted 39 semi-structured interviews, targeting staff in 8 types of organizations:

1. FHWA headquarters.
2. FHWA Infrastructure R&D.
3. FHWA Resource Center (Resource Center).
4. State transportation departments.
5. Tribal, county, and local Governments.
6. Private sector, including Contractors.
7. AASHTO.
8. Academia.

Interview transcripts were coded using specialized qualitative data analysis software. Two structured datasets support the semi-structured interviews: an FHWA-maintained database of GRS-IBS bridges and the National Bridge Inventory, which includes known bridges in the United States. The databases are used to assess the impact of FHWA activities on the deployment of GRS-IBS bridges relative to non-GRS-IBS bridges during the period of FHWA activities (2005–2015). The evaluation team also reviewed many of the GRS-IBS documents FHWA produced since 2010 including materials for EDC.

Findings

- Infrastructure R&D management provides staff with a broad and flexible framework for selecting research topics, conducting research, and disseminating results. The organization does not have a single R&T model. The program teams enjoy discretion provided they show progress.

- FHWA pursued GRS-IBS research because its precursor, GRS, showed potential for saving time and money in the design and construction of single-span bridges.

- GRS-IBS was included in the FHWA program EDC-1 because FHWA staff who believed the technology was ready for deployment advocated successfully for its inclusion despite reservations from other FHWA staff who believed the technology needed further development and testing.[(4)]

- FHWA activities increased awareness of GRS-IBS among potential deployers.

- EDC activities increased awareness of GRS-IBS among potential deployers. GRS-IBS likely was included in the three EDC rounds to showcase FHWA's most recent research and evidence behind the technology and to continue to grow its user base.

- FHWA activities and outputs improved the attitude of potential deployers toward GRS-IBS. GRS-IBS bridges constitute a larger percentage of total bridges built between 2010 and 2015 than between 2005 and 2009, suggesting—along with interviewee observations—that FHWA activities and outputs have had a positive effect on deployment.

- GRS-IBS research and deployment were challenged within FHWA by five internal barriers: poor communication, insufficient collaboration, gaps in evidence, dissemination issues, and resistance to change.

- GRS-IBS research and deployment were challenged outside FHWA by four external barriers: knowledge, financial, design, and political.

- GRS-IBS expresses many of the characteristics of a disruptive technology including value proposition, match to customer requirements, and low complexity to user. Its growth potential is more traditional because potential customers are still constrained by site-specific geography, preexisting infrastructure, and financial resources.

Conclusion and Recommendations

The evaluation team offers FHWA managers and GRS-IBS team members the following recommendations.

Recommendation: Make market research part of engineering research.

Market research can help guide the selection of research topics by identifying the problems encountered by potential customers and—importantly—establishing a relationship with them.

Recommendation: Improve protocol concerning internal disagreements about FHWA technologies.

The presence of communities of practice does not guarantee that differences between individual staff members or engineering differences will be resolved. There has been and continues to be tension between geotechnical and hydraulic engineers concerning GRS-IBS. It is necessary to develop a protocol to work through differences between engineering disciplines and administrative units (i.e., headquarters, division offices, and the Resource Center).

Recommendation: Incorporate results of *Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS) Cost Study* into guidance materials.[(5)] FHWA should assess the results of the *GRS-IBS Cost Study* and incorporate findings and recommendations of that report as necessary into GRS-IBS guidance materials, and the guidance practices of Resource Center and U.S. Department of Transportation field offices. Create deployer-managed, web-based GRS-IBS inventory.

Tracking GRS-IBS deployments—especially small deployments—is difficult, expensive, and time consuming. Motivating deployers to contribute information to a public facing website will make the tracking process more manageable.

1. Introduction

The Federal Highway Administration (FHWA) has initiated an effort to evaluate the Research and Technology (R&T) development program. As part of being accountable to funders and policy makers, leaders of Government transportation R&T programs need to be able to communicate effectively the full range of benefits of their program. The FHWA R&T Evaluation Program is being created to help FHWA assess how effectively it is meeting its goals and objectives and to provide useful data to inform future project selections.

1.1 Evaluation Purpose

Identifying Key Outcomes and Evaluation Areas

FHWA's Office of Corporate Research, Technology, and Innovation Management and the Office of Infrastructure Research and Development (Infrastructure R&D) selected the Geosynthetic Reinforced Soil–Integrated Bridge System (GRS-IBS) program for evaluation. The evaluation is intended to inform FHWA's research and development process for GRS-IBS and other technologies. The stakeholders asked the evaluation team to focus on research topic selection, early research development, and deployers' decisions to adopt GRS-IBS. Geotechnical engineering researchers at the Turner-Fairbank Highway Research Center (TFHRC), being particularly interested in a better understanding of the barriers to deployment, requested the evaluation team compare GRS-IBS with the criteria for disruptive technologies to determine whether such a comparison explains its deployment trajectory to date. To a lesser extent, the evaluation team was asked to investigate whether and how GRS-IBS deployments benefitted infrastructure owners.

The evaluation team further refined these evaluation priorities through discussions with stakeholders at a kickoff meeting in late 2014 and a review of initial findings in late 2015. Table 1 shows the final reorganization of priorities into four evaluation areas with corresponding research questions.

Table 1. Summary of evaluation areas and questions.

Evaluation Area	Evaluation Questions
1. FHWA's R&T model	What are the typical protocols for research at FHWA, including the selection of research topics, collaboration between divisions, and dissemination of findings?
2. GRS-IBS specific R&T model	(a) How was GRS-IBS selected as a research topic? What problem or need does GRS-IBS potentially solve? (b) How did GRS-IBS come to be included in Every Day Counts (EDC), especially EDC-1?
3. Effectiveness of FHWA's outreach for GRS-IBS	(a) Did FHWA's activities increase awareness of GRS-IBS outside the organization? (b) Did EDC increase public awareness of GRS-IBS? Why was the technology included in multiple rounds of EDC? (c) Did FHWA activities and outputs improve the attitude of potential deployers toward GRS-IBS and result in greater deployment? (d) What internal barriers did GRS-IBS face? (e) What external barriers did GRS-IBS face?
4. Benefit of GRS-IBS to deployers	What are the benefits to deploying GRS-IBS?

1.2 Report Structure

Section 1 provides an overview of the purpose of the evaluation and a high-level description of the project's history.

Section 2 describes the evaluation methodology, including data sources, data collection methods, and data analysis methods.

Section 3 summarizes the evaluation's findings.

Section 4 describes general conclusions that the evaluation team drew from the evaluation. It discusses overarching lessons about the program and summarizes the evaluation team's recommendations for FHWA based on the findings of the evaluation.

1.3 Program Background

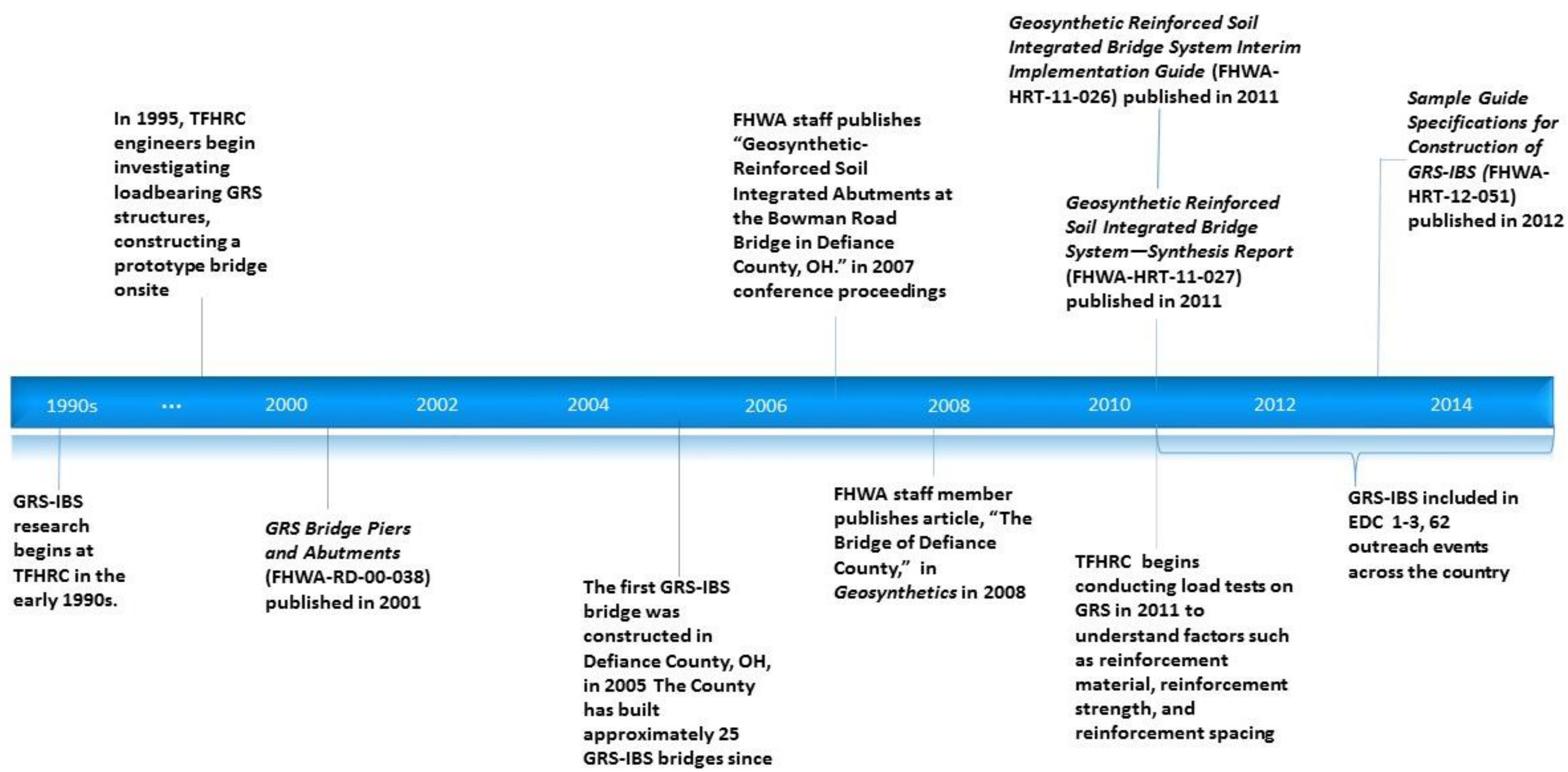
GRS technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. The technology was first applied in the United States by the Forest Service to build walls for roads in steep mountain terrain in the 1970s. Since then, FHWA has worked to evolve the technology into GRS-IBS, which blends the roadway into the superstructure shown in figure 1. Proponents of GRS-IBS argue that the approach is easy to design, can be constructed with low-cost materials, can be built in variable weather conditions, and can easily be modified in the field. However, the American Association of State Highway Transportation Officials (AASHTO) has not adopted guidelines for closely spaced GRS bridge abutments, and instead utilizes traditional design for mechanically stabilized earth (MSE). The GRS-IBS research program aligns with the FHWA R&T *Agenda*, Infrastructure Objective 5: "Improve highway condition and performance through increased use of design, materials, construction, and maintenance innovations."(6) The broad goal of the research and deployment effort is to aid transportation agencies in GRS-IBS deployment.

Work on GRS-IBS for applications in bridge construction began at TFHRC in the 1990s. In 1995, Infrastructure R&D staff began investigating loadbearing GRS structures and constructed a prototype bridge onsite. In August 2011, Infrastructure R&D researchers began conducting load tests on GRS to better understand the impact of factors such as reinforcement material, reinforcement strength, and reinforcement spacing. Over the years, researchers at TFHRC have produced and disseminated several technical documents to assist transportation agencies in implementing GRS-IBS including a *Synthesis Report* (2011), *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (herein referred to as the *Interim Implementation Guide*) (2011), and *Sample Guide Specifications* (2012).(1–3)

Staff in Infrastructure R&D, the FHWA Resource Center (Resource Center), and FHWA Federal-Aid Division Offices have provided technical assistance to States interested in the technology. Researchers at TFHRC looked for jurisdictions to build a bridge. Local and county transportation agencies have taken the lead in adopting the GRS-IBS technology. The first GRS-IBS bridge was constructed in Defiance County, OH, in 2005. As of September 2015, the county had built 34 GRS-IBS bridges and reported that the design saved both construction time and costs when compared with other similar shallow-foundation bridge abutments. Other agencies have reported success at the local level using the GRS-IBS design.

GRS-IBS was selected for FHWA's Every Day Counts (EDC) initiative, aimed at accelerating implementation of proven, market-ready technologies. To further promote the technology to State transportation departments and local transportation agencies, FHWA conducted a total of 62 EDC outreach events across the country between February 2011 and July 2015, including 24 State transportation department workshops—some attended by representatives from multiple States, 15 showcases of GRS-IBS projects, and numerous presentations at conferences and on webinars. (For a complete list of FHWA EDC outreach events please refer to table 8 in the appendix.)

Work continues to further support and optimize the current GRS-IBS guidance and on the development of GRS-IBS wall design recommendations. Figure 2 provides a timeline of FHWA's efforts on GRS-IBS.



Source: FHWA.

Figure 2. Timeline. FHWA's GRS-IBS research and dissemination efforts.

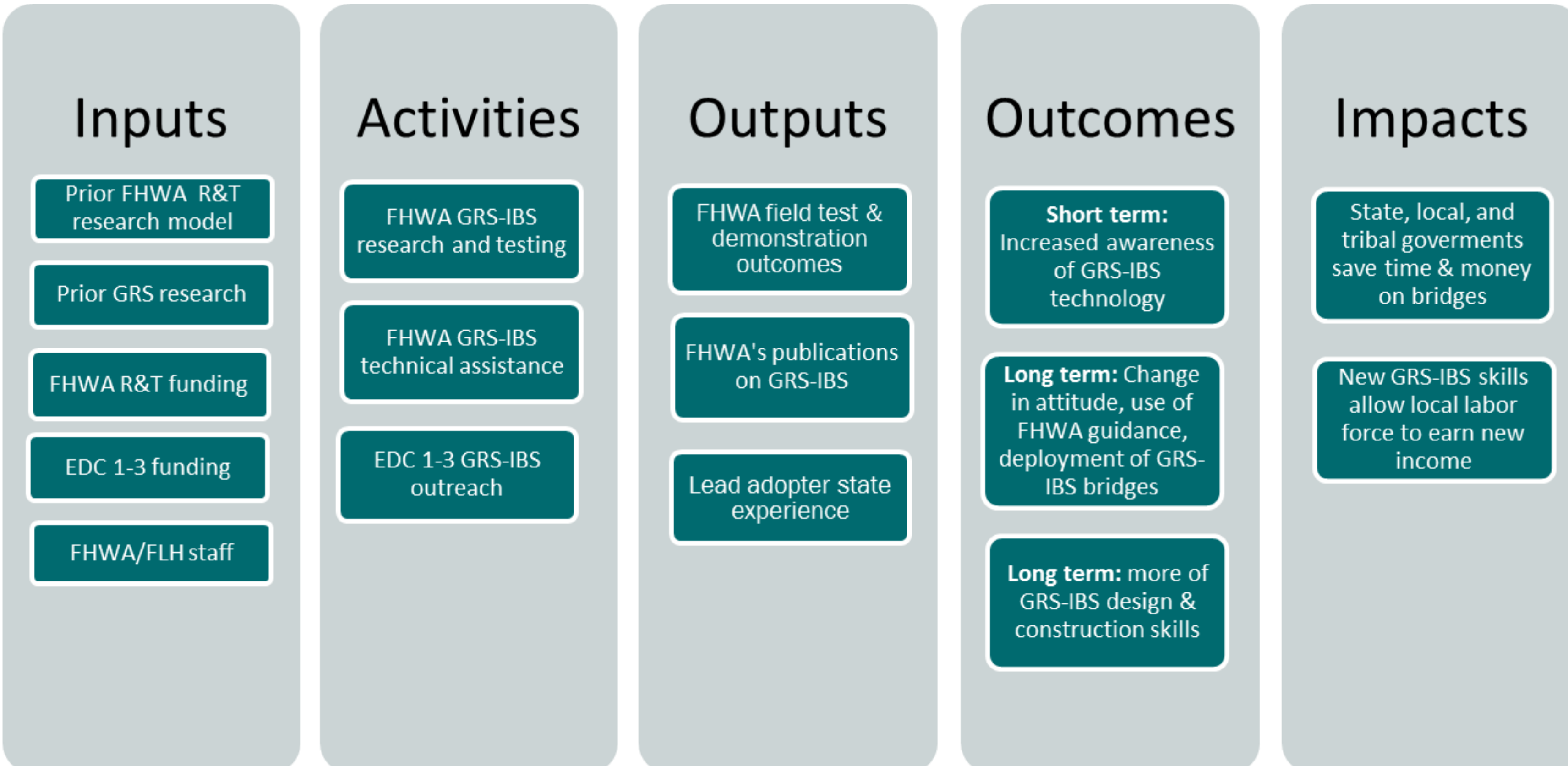
The next section of the report explains how these research and dissemination efforts will be evaluated and traced to program results.

2. Evaluation Design

The evaluation team met with the R&T Program Manager and the FHWA GRS-IBS program team in 2014 to discuss the program and purpose for the evaluation and to generate an initial set of research questions. After reviewing a draft evaluation report in late 2015, stakeholders requested that the evaluation team study the pre-EDC period in more depth and include an analysis of GRS-IBS informed by recent thinking on disruptive technologies.

2.1 Logic Models

The evaluation team aligned the four evaluation areas with major components of a logic model employed in many FHWA R&T evaluations and then refined the model further. A logic model is a series of program lanes in a causal chain from left to right. Each lane contains multiple components that make explicit the anticipated relationships between an input (e.g., funding), an activity (e.g., research), an output (e.g., publications), an outcome (e.g., technology deployment), and an impact (e.g., cost savings). A logic model is not a comprehensive or linear description of all parts of the program under investigation. It includes just enough detail to understand how stakeholders believe the program should work and to see which parts are functioning as expected and which parts are not functioning as expected. The logic model helps to explain the theories of change behind a program and provides hypotheses (i.e., if one performs X, then Y will happen) that can be tested. The evaluation team revised the logic model based on discussions with key FHWA staff (see figure 3).



FLH = Office of Federal Lands Highway.

Source: FHWA.

Figure 3. Illustration. Logic model.

Each lane of the logic model contains elements of a similar type. These elements flow from lane to lane from left (causes) to right (effects). *Inputs* includes all the resources FHWA assigned to GRS-IBS research and dissemination, including funding and staff. It also includes the explicit and implicit protocols that FHWA has in place to conduct R&T research and prior research on GRS (without IBS) conducted at TFHRC and around the world. GRS-IBS specific efforts make up the *Activities* lane. Modifications or deviations from standard FHWA R&T protocols go here. *Outputs* includes all FHWA R&T written material on GRS-IBS, both official products with a publication number and other products such as magazine articles. Prototype bridges and demonstrations are also outputs. *Outcomes* covers the effect outputs have on potential deployers. FHWA's GRS-IBS team members intend for their research to introduce the technology to potential deployers and lead to greater deployment. "Awareness" addresses whether potential deployers know that GRS-IBS exists. "Attitude" addresses whether potential deployers have a positive or negative view of the technology. GRS-IBS proponents claim that the technology has several advantages, such as faster construction and cost savings. These are some of the potential *Impacts*. *Barriers* (not shown) may exist that reduce or interrupt the cause and effect relationship between the elements so that some causes do not produce their intended effect.

2.2 Evaluation Methodology

This evaluation focuses on the initial selection of GRS-IBS as a research topic and its early development and deployment. It is *retrospective*, looking at past activities and current outcomes. The evaluation team relied primarily on semi-structured interviews with some support from quantitative data (counts of bridges) and review of documents. Table 2 shows the alignment of logic model lanes, evaluation areas, and data sources.

Table 2. Logic model lane, evaluation area, and data source.

Logic Model Lane	Evaluation Area	Data Source
Inputs	1. FHWA's R&T model	• Semi-structured interviews
Activities	2. GRS-IBS specific R&T model	• Semi-structured interviews
Outcomes	3. Effectiveness of FHWA's outreach for GRS-IBS	• Semi-structured interviews • FHWA documents • Documents provided by interviewees • FHWA GRS-IBS tracking spreadsheet • National Bridge Inventory
Impacts	4. Benefit of GRS-IBS to deployers	• Results of separate GRS-IBS BCA Study • Semi-structured Interviews

Semi-Structured Interviews

The evaluation team identified eight types of potential interviewees and designed a different interview protocol for each type. Then, the protocols were altered slightly before each interview based on the anticipated length of the conversation and current evaluation priorities. Questions deemed most pressing were asked first in case the interviewee needed to leave before answering all the questions in the protocol. The "semi-structured" aspect of these interviews refers to how the evaluators change questions and priorities based on information the interviewee provides. The evaluation team interviewed 39 individuals between April 13, 2015, and October 28, 2016, following a research design and protocol to comply with the Paperwork Reduction Act.(7) Table 3 provides a breakdown of interviewees by interview type and professional training.

Table 3. Interviewees by interview type and training.

Interview Type	Organization	Geotechnical Engineers	Hydraulic Engineers	Other Engineers	Non-Engineer	Total
1	FHWA Office of Infrastructure	2	1	2	1	6
2	Infrastructure R&D	4	1	1	1	7
3	Resource Center	1	2	0	0	3
4	State transportation departments	3	1	4	0	8
5	Tribal, county, and local Governments	0	0	2	1	3
6	Private sector, including contractors	3	0	4	0	7
7	AASHTO	2	0	1	0	3
8	Academia	0	0	2	0	2
–	Total	15	5	17	2	39

–Not applicable.

All interviews were conducted over the phone. Evaluators took notes on interviews prior to 2016. Evaluators recorded interviews conducted in 2016 with permission from interviewees, transcribing during the conversation and confirming from the recording as necessary. The transcripts were loaded into qualitative analysis software and coded inductively, grouping common responses and marking unusual responses. The coding schema for documents and quotes permits cross tabulating responses by interview type, interviewee training, interviewee experience, and other demographic or organizational variables. Crosstabs can be computed to reflect the number of times interviewees mentioned a particular concept (resulting in a count variable) or may be computed to reflect only whether interviewees mentioned a concept (resulting in a Boolean variable). The latter approach is used extensively in this report to communicate how many interviewees expressed a certain sentiment without biasing the result because one interviewee might have expressed the sentiment many times in his or her interview. As discussed with the interviewees, the recordings will not be shared and quotes from the transcript will not be attributed without permission.

Quantitative Data

Two structured datasets support the semi-structured interviews. FHWA maintains a database of known GRS-IBS bridges.[1] There are 57 columns of information including location, owning agency, construction date, bridge length, abutment type, project financial data, FHWA program support, and site details. FHWA collects the information in the GRS-IBS database by contacting owning agencies and parties involved in construction. Due to the collection process, the database includes many of the larger GRS-IBS bridges, but is likely missing most of the smaller GRS-IBS bridges. Although the quality of the database poses challenges, it represents the best available information on GRS-IBS bridges. There are 149 GRS-IBS bridges recorded as complete in the database. Between 2010 and 2015, there were 117 GRS-IBS bridges completed. Twelve bridges completed in 2016 and seven under construction are excluded from the analysis because the National Bridge Inventory (NBI) used for comparison, which includes non-GRS-IBS bridges (described in the following paragraph), also does not yet contain records from 2016.(8)

The NBI includes information about every public bridge in the United States.(8) State and Federal agencies that own public roadways are required to inspect bridges annually and to maintain databases of these inspections. These data are collected into a single database and are publicly available as the NBI. The inspections assess the physical and functional condition of the bridge superstructure and the condition of the substructure. Data on the type of abutment (substructure) are not included which was a limitation in the analysis. Other information is recorded about each bridge such as location data, agency information, and traffic data.

The databases are used to assess the impact of FHWA activities on the deployment of GRS-IBS bridges relative to non-GRS-IBS bridges during the period of FHWA activities (2005–2015). This analysis is a straight-forward comparison of the number of bridges built each year during the period in the NBI to those identified in the GRS-IBS database. This method is fully described in section 4.2. Some of the bridges in the GRS-IBS database can be linked to the NBI through the identification number in the NBI, but this linkage was not exploited because not all of the GRS-IBS bridges had been identified in the NBI.

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[1]This resource is an internal workbook maintained by Resource Center staff and was shared with the evaluation team for the purpose of this evaluation.

3. Evaluation Findings

This section details findings in each of the four evaluation areas. Each subsection includes a high-level overview through the lens of the logic model, a description of relevant data, and detailed findings including quotes from interviewees. The evaluation team anonymized interviewees by assigning a random numerical identification (ID) to each individual. In this report, quotes are cited in parentheses using the speaker's ID and the interview date. There will be a footnote for each quotation used in this document that shows the speaker ID, interviewer, month, and year the interview occurred. The ID does not permit readers to determine the identity of the interviewee, but does permit readers to determine whether quotes stem from the same individual or from multiple individuals. The date allows readers to know whether the interview occurred at the beginning or toward the end of the evaluation process.

3.1 Evaluation Area 1: FHWA's Approach to Research and Dissemination

This evaluation area does not have any subareas. The evaluation team sought to uncover the typical protocols for research at FHWA, including selection of research topics, collaboration between divisions, and dissemination of findings.

Overview

The logic model developed for this evaluation proposes that R&T efforts at FHWA inherit an "FHWA way" of conducting research and disseminating results. The evaluation team found no evidence for this. Instead, FHWA provides a broad and flexible framework for selecting research topics, conducting research, and disseminating results.

Relevant Data

This evaluation subarea was added toward the end of the investigation. Therefore, evaluation team members asked only a few interviewees questions about the existence of a standard or recommended FHWA research model. No interviewees knew of such a model or could recommend related documents. One interviewee explained how he, personally, once assessed potential research projects from a management position. The evaluation team consulted with colleagues within the FHWA R&T Evaluation Program evaluating other FHWA research programs to gain a broader understanding of FHWA's R&T process.

> Finding: Infrastructure R&D management provides staff with a broad and flexible framework for selecting research topics, conducting research, and disseminating results. The organization does not have a single R&T model. Program teams enjoy discretion so long as they show progress.

The evaluation team collected information about the research process at the TFHRC but was not able to collect information about the research process at other FHWA facilities. Infrastructure R&D managers grant program leads a lot of autonomy.

A review of other FHWA R&T efforts being evaluated by the FHWA R&T Evaluation Program suggests FHWA research teams define their own programs and work plans, resulting in diverse approaches to identifying needs, developing research, and disseminating findings (see table 4).

Table 4. Commonalities and differences between several FHWA R&T technologies and programs.

Technology and Programs	Need Identified via State DOT or User Feedback	Need Identified via Local Champion or Advocate	Need Identified via Other Method	Research Developed in Phases	Research Developed via User Feedback or a U.S. Scan	Research Developed via Other Method	Findings Shared via Publications, Trainings, or Websites	Findings Shared via EDC	Findings Shared via a Major Standards Guide	Findings Shared via AASHTO
Adaptive signal Control	N/A	Yes	International use	Yes	N/A	N/A	Yes	Yes	N/A	N/A
Gusset plate	N/A	N/A	Emergency use	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Geosynthetically Reinforced Integrated Soil–Integrated Bridge System	Yes	Yes	N/A	N/A	N/A	Working closely with early adopters	Yes	Yes	Yes	N/A
High Friction Surface Treatments	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Managing Risk on Renewal projects	Yes	N/A	N/A	N/A	N/A	Work via contractor	N/A	N/A	N/A	N/A
National Household Travel Survey	Yes	Yes	N/A	N/A	Yes	Expert task force	Yes	N/A	N/A	N/A
Roadside Revegetation	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A
Roundabouts	N/A	Yes	International use	N/A	N/A	N/A	Yes	Yes	Yes	N/A
Warm Mix Asphalt	Yes	N/A	N/A	Yes	N/A	Expert task force	N/A	N/A	(Planned)	(Planned)

N/A = not applicable; DOT = department of transportation.

One interviewee who once had the authority to approve or deny research spending at FHWA explained the following:

> *"I didn't meddle in how it [a research topic] was developed as long as the team leader could defend the value and the viability. I wasn't going to meddle with how money was spent. I left the team leader to defend the whole program. From the FHWA level and nationally."*[1]

USDOT Program researchers were given a large amount of autonomy to solve the nation's transportation issues, especially at TFHRC.

Among the sample of FHWA R&T projects portrayed in table 4, the research topic emerged most often because the U.S. Department of Transportation (USDOT) or users of USDOT programs and materials identified a research need. No single approach to developing research proved more common than any other. Dissemination of findings most often involved publications, trainings, or websites. Several programs relied on multiple elements from the table. For example, FHWA initiated roundabouts research—in part—due to prior international interest in the topic and the presence of a local champion. Dissemination involved publications, standards setting, and EDC. Note that the Warm Mix Asphalt program plans to release a standards document and to seek AASHTO approval in the future. This report continues to elaborate on the table entry for GRS-IBS, explaining how FHWA identified the research need, shared research findings, and supported implementation efforts.

3.2 Evaluation Area 2: GRS-IBS Specific Approach to Research and Dissemination

This evaluation area focuses on the initial selection of GRS-IBS as a research topic and the selection of GRS-IBS for EDC. Each subarea has its own evaluation questions, overview, data, and findings.

Subarea 2(a): Selection As a Research Topic

Evaluation subarea 2(a) pertains to GRS-IBS's selection as a research topic. The evaluation team sought to answer the following two questions:

1. How was GRS-IBS selected as a research topic?
2. What problem or need does GRS-IBS potentially solve?

The following section details the findings of the evaluation team.

Overview

The logic model proposes that FHWA researchers follow an organization-wide method for selecting a research topic. As reported for evaluation area 1, researchers at TFHRC enjoy autonomy in selecting research topics although they have to defend their decisions to management. R&T programs are a form of applied research (as opposed to fundamental research) and therefore seek solutions to specific problems.

[1]Interviewee #28, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), August 2016.

Relevant Data

More than a decade has passed since serious work on GRS-IBS began within FHWA. No interviewees could recall the exact events leading to selection of the research topic or provide related documents. Six interviewees provided background information.

> Finding: FHWA pursued GRS-IBS research because its precursor, GRS, showed potential to save adopters time and money and to make them less reliant on specialized contractors and equipment. Adopters saw a niche for the approach with low traffic bridges.

The GRS-IBS team's January 2011 implementation plan positions the technology as a convenient replacement for aging bridges, especially those under 90 ft.(2) Many team members felt that the technology offered a do-it-yourself alternative to dependence on large contractors and specialized materials and equipment. One member of the GRS-IBS team explains that the technology was attractive because of the following:

> *"its generic nature—as opposed to a different practice, MSE [which is] vendor driven in design. GRS-IBS encourages leading states and consultants to design the whole project, [offering] internal and external stability. It's faster to build, opening up [opportunities] to other contractors, not necessarily specialized in bridge design."*[2]

Traditional bridge building methods involving poured concrete and steel require heavy machinery that might be inaccessible or cost prohibitive to small counties and rural areas. GRS-IBS abutments can be built by hand using granular backfill materials, geosynthetics, and a facing element (e.g., concrete modular blocks). Many adopters saw an immediate niche for GRS-IBS for bridges with low average daily traffic (ADT) and without heavy flooding. One GRS-IBS user explained that

> *"We're not comfortable yet putting this [near a] …heavy flood event until we can see how [it] performs in those conditions. We'll use [GRS-IBS] …on our smaller bridges [with] low ADT—not on interstates."*[3]

Thirteen interviewees identified reasons GRS-IBS was initially pursued. Eight of these interviewees are current or former FHWA employees. Ten of the interviewees report that stakeholders needed a technique that was cost effective, fast, and did not require heavy equipment.

Three interviewees state that GRS-IBS was well suited to a particular part of the market but differed as to which part of the market the technology fit best. Some thought GRS-IBS initially looked ideal for small bridges, which are very common in the United States. In 2000, when Infrastructure R&D staff were starting work on GRS-IBS, the median length for bridges according to the NBI was 77 ft. Other interviewees noted that the technology could easily accommodate much larger bridges. The GRS-IBS program team and early adopters saw additional benefits after the technology had been promoted through EDC. For example, some users noted that learning to deploy GRS-IBS builds the confidence and self-reliance of local Government construction crews. The problems that GRS-IBS might help to solve and the benefits users might receive are possibly more numerous than program team members originally planned.

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[2]Interviewee #35, phone interview conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), May 2015.

[3]Interviewee #16, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

Keeping with the previous finding that FHWA (within Infrastructure R&D) does not have a centralized, formal process for identifying research topics, after GRS-IBS team members identified the need for the technology, they shared this with management, provided a persuasive argument—and received funding.

Subarea 2(b): Selection for EDC

Evaluation subarea 2(b) was about GRS-IBS's selection for EDC. The evaluation team sought to discover how GRS-IBS came to be included in EDC, especially EDC-1.

Overview

FHWA implemented the EDC initiative to highlight innovative technology. EDC is "a State-based model to identify and rapidly deploy proven but underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce congestion and improve environmental sustainability."[(9)] GRS-IBS was part of EDC-1 (2011–2012), EDC-2 (2013–2014), and EDC-3 (2015–2016). It is not part of EDC-4 (2017–18). The logic model proposes that EDC funding and outreach activities should lead to improved GRS-IBS deployment outcomes and impacts. Stakeholders asked the evaluation team to investigate how and why GRS-IBS was included in EDC, especially EDC-1.

Relevant Data

Ten interviewees who currently work for or previously worked for FHWA and have some knowledge about the EDC selection process explained why GRS-IBS was likely chosen for EDC-1, but their explanations do not form a single narrative. Information gathered from the interviews and from the GRS-IBS team's 2011 implementation plan can also be compared against the Technology Readiness scale developed for FHWA's Exploratory Advanced Research (EAR) Program (OSTR-2015-01).[(2,10)]

> Finding: GRS-IBS was included in EDC-1 because FHWA staff who believed the technology was ready for deployment advocated successfully for its inclusion despite reservations by other FHWA staff who believed the technology needed further development and testing.

Of the 10 interviewees with knowledge about EDC-1, 7 believe that GRS-IBS was at the right stage for inclusion in EDC-1 and exactly the sort of technology that EDC was implemented to promote. For example, one FHWA employee familiar with the EDC selection process explained the following:

> *"Mike Adams [at TFHRC] had done his work and they were circulating the draft [GRS-IBS] manual within FHWA for approval. He had already been out to Defiance County [Ohio] and deployed it in the field on several projects."*[4]

Three interviewees believed that GRS-IBS was chosen too early and still lacked the necessary research to be showcased in EDC-1. For example, another FHWA employee involved with EDC explained the following:

> *"I would not have picked GRS-IBS in the first round. I would have let the team do more research before we picked this technology. Many times we pick this technology that has been*

[4]Interviewee #28, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), October 2016.

> *used by some States `to leverage those States as examples, but we didn't have that with GRS-IBS. [It was] a little premature to pick in the first round, probably should have waited."*[5]

This division between people who felt the technology was ready for widespread deployment and people who felt the technology was not ready for widespread deployment reoccurs throughout this report.

The concept of "technology readiness level" (TRL) within FHWA arose from the need to compare the readiness of various alternative modal approaches.(11) It is also useful in investigating GRS-IBS's ripeness for deployment through EDC-1. FHWA's TRL scale has nine levels that advance through four categories (basic research, applied research, development, and implementation). By the start of EDC-1, the GRS-IBS team had achieved significant gains in all four categories, with 45 GRS bridges constructed across 9 States, 28 of them using the full GRS-IBS technology.(11) From this point of view, GRS-IBS had achieved the highest level (nine) by the start of EDC-1 and was, therefore, fit for acceptance into the initiative. As with any technology, potential adopters continued to raise questions and detractors continued to point out shortcomings, which led the GRS-IBS team to pursue new investigations concerning scour and load testing. The readiness scale assumes a linear progression that ends with implementation. However, technologies are often implemented repeatedly for which sufficient evidence suggests they will work even while research continues into other contexts. From this point of view, a proponent could focus on a successful context for deployment and rate GRS-IBS at TRL nine, while a detractor could focus on a context unfit for deployment or where evidence is still lacking and rate GRS-IBS at TRL four—the start of applied research.

3.3 Evaluation Area 3: Awareness, Attitude, and Decision to Deploy—Changes and Barriers to Change

This evaluation area focuses on the short term and long-term outcomes of FHWA's GRS-IBS activities and outputs. Short-term outcomes are changes in awareness of GRS-IBS outside FHWA with specific attention to the effect of EDC on GRS-IBS awareness. Long-term outcomes involve changes in attitude toward GRS-IBS, use of FHWA guidance, and deployment of GRS-IBS. The evaluation team also examined barriers to change, identifying internal barriers (within FHWA) and external barriers (encountered by potential deployers and other stakeholders).

Subarea 3(a): Effect of FHWA Activities on Awareness

Evaluation subarea 3(a) is about the effect of FHWA activities on potential deployers' awareness of GRS-IBS. The evaluation team sought to uncover if FHWA's activities increased awareness of GRS-IBS outside the organization.

Overview

The logic model proposes that FHWA activities may increase awareness of GRS-IBS among potential deployers.

[5]Interviewee #32, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

Relevant Data

Twenty-two non-FHWA interviewees familiar with GRS-IBS reported how they first heard about the technology. FHWA supplied the evaluation team with a list of local, county, and State contacts who had shown an interest in GRS-IBS or actually deployed the technology. The list is biased toward deployers over non-deployers, but it is unclear whether it is also biased toward contacts who first learned about GRS-IBS from FHWA over other sources.

Finding: FHWA activities increased awareness of GRS-IBS among potential deployers.

Out of 22 non-FHWA interviewees, 9 reported first learning about GRS-IBS through FHWA outside of EDC. For example, representatives of a tribal nation hired a private contractor to reconstruct an aging bridge and then learned of funding opportunities for GRS-IBS projects. The contractor pursued GRS-IBS training at an FHWA demonstration project and eventually redesigned and constructed the bridge using the technology.[6] A State transportation department engineer described a non-EDC training with 30 attendees that included FHWA material on GRS-IBS.[7] Four interviewees first learned about GRS-IBS through EDC specifically. EDC activities and FHWA material will be addressed in more detail in the following section, "Relevant Data." The remaining 10 interviewees first learned about the technology through their own studies or experiences. Geotechnical engineers represented half of the interviewees who learned about GRS-IBS outside of FHWA entirely. One such engineer explained that GRS-IBS seemed like a natural extension of approaches he was already familiar with the following:

> *"During meetings, discussions about this method [GRS-IBS] came up. The idea of using module block facings with lots of closely spaced, geosynthetic layers has always been understood to be a good idea."*[8]

Subarea 3(b): Effect of EDC Activities on Awareness

Evaluation subarea 3(b) is about the effect of EDC activities on potential deployers' awareness of GRS-IBS. The evaluation team sought to uncover the answers to the following two questions:

1. Did EDC increase public awareness of GRS-IBS?
2. Why was the technology included in multiple rounds of EDC?

The evaluation team's findings are summarized in the following section.

Overview

FHWA promoted GRS-IBS for the first three rounds of EDC, six years of information distribution. Regardless of opinion about GRS-IBS as a bridge building technology, interviewees generally felt that EDC has had a positive effect on public awareness and adoption.

Relevant Data

Eleven interviewees reported on the impact EDC on GRS-IBS awareness. Four of 11 interviewees worked for FHWA.

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[6]Interviewee #11 and Interviewee #19, phone interviews conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), September 2016.

[7]Interviewee #29, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[8]Interviewee #6, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

Finding: EDC activities increased awareness of GRS-IBS among potential deployers. GRS-IBS was included in three EDC rounds because the FHWA team continued to produce new evidence and to address concerns.

All 11 interviewees who commented on this topic agreed that EDC increased awareness of GRS-IBS among potential deployers. Interviewees who believed the technology was ready for deployment applauded the outreach efforts while those who believed the technology needed more development and testing expressed concerns.

The evaluation provides examples of both points of view. Viewing enhanced awareness positively, one private consultant asserted the following:

> *"Every Day Counts has really promoted this [GRS-IBS] [Redacted, Resource Center employee] has done a fabulous job, has been invaluable to get the word out and have States use it."*[9]

Some engineers already familiar with GRS abutments first learned about GRS-IBS at EDC. An interviewee associated with both AASHTO and FHWA summarized the effect of EDC on the technology in this manner:

> *"If not for the EDC push, GRS would still be languishing in a laboratory."*[10]

However, this interviewee feared some adopters might select GRS-IBS because of this intense EDC push and not because it was the best solution for their particular engineering problem. A State transportation department engineer felt, similarly, that FHWA encouraged people to adopt EDC technologies as a way of showing support for EDC itself:

> *"The EDC initiative felt forced. Felt like the objective was to accomplish EDC initiatives—not to do the best [engineering] job. So that people could check a box and say they'd met an objective."*[11]

GRS-IBS is the only technology to have been included in more than two EDC initiatives. One interviewee proposed an explanation for this distinction. In his opinion, the GRS-IBS program team continued to produce new research and support for the technology that warranted dissemination through EDC. He acknowledged that some staff members felt that before EDC-1 research on GRS-IBS was insufficiently rigorous; however, he explains, the team was conducting valid analytical modeling:

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[9]GRS consultant, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), May 2015.

[10]Interviewee #36, phone interview conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), May 2015.

[11]Interviewee #8, phone interview conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), May 2015.

> *"Since it [GRS-IBS] was moving forward with additional research on scour, longer spans, and higher skews…[FHWA] now [was] available to do some analytical modeling and provide criteria for appropriate soil compaction to make this work…not just rule of thumb type of stuff. I don't know why it got into [EDC] 2 and 3 but this probably had a lot to do with it."*[12]

Subarea 3(c): Effect of FHWA Activities on Attitude and Deployment

Evaluation subarea 3(c) examines the effect of FHWA activities on attitudes affecting the deployment of GRS-IBS. The evaluation team sought to ascertain if FHWA activities and outputs improved the attitudes of potential deployers' toward GRS-IBS that resulted in greater deployment.

Overview

The logic model proposes FHWA activities and outputs result in two related, long-term outcomes: more positive attitudes toward GRS-IBS and more GRS-IBS deployments.

Relevant Data

The evaluation team drew upon both qualitative and quantitative data to answer the evaluation questions in this subarea.

Qualitative

Nineteen interviewees reported a shift in the attitude of potential deployers toward GRS-IBS. Some interviewees also identified a reason for that shift. The evaluation team conducted only one interview with a potential deployer who had a generally positive attitude toward GRS-IBS due, in part, to FHWA activities, but decided *not* to deploy the technology. Therefore, separating attitude shift from decision to deploy as originally proposed in the logic model is not possible in this report and long-term outcomes (attitude and deployment) are reported jointly. While common sense suggests a positive shift in attitude toward GRS-IBS leads to greater deployments, the evaluation team recommends research focused on non-deployers familiar with the technology to understand whether geographic context, funding, or other reasons prevent them from building a GRS-IBS bridge.

Quantitative

The analysis includes measures calculated from two bridge databases. FHWA maintains a database of GRS-IBS bridges, which likely includes most of the large bridges and lacks most of the small bridges. The NBI is a database of all bridges in the U.S., and while the NBI includes both GRS-IBS and non-GRS-IBS bridges, it does not specify this detail.(8) The analysis considers those bridges that were built or rebuilt from 2005–2015, and separately those built from 2010–2015. There are two primary reasons for this. First, the major effort of FHWA in promoting the technology outside the organization were through EDC-1, EDC-2, and EDC-3. EDC-1 ran from 2011 to 2012, thus it was reasoned that absent communication about the technology (no major publications, advertisements, efforts of the Resource Center, FHWA Division Offices, and others), there were not enough resources for an agency to deploy the technology apart from direct active involvement from FHWA. Second, the interim guidelines were not produced until January 2011.(2) Agencies would have been hesitant or unable to deploy GRS-IBS technology without the direct guidance of FHWA researchers and GRS-IBS practitioners.

Given some of these data limitations the comparisons drawn are only able to cut at most basic design barriers. That is, there is not enough information to determine whether there are financial or political reasons for which the GRS-IBS technology was not deployed. To the extent that this analysis

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[12]Interviewee #28, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), August 2016.

does not fully consider external barriers, such as design barriers (e.g., hydrology) or political barriers (e.g., State restrictions on shallow foundation), it cannot provide a full and accurate account of GRS-IBS market penetration.

Finding: FHWA activities and outputs improved the attitude of potential deployers toward GRS-IBS. GRS-IBS bridges constitute a larger percentage of total bridges built between 2010 and 2015 than between 2005 and 2009, suggesting—along with interviewee observations—that FHWA activities and outputs have had a positive effect on deployment.

Of nineteen interviewees reporting a shift in the attitude of potential deployers toward GRS-IBS, all reported the shift being in the positive direction. Fifteen of them attributed the shift directly to FHWA activities. Seven of those 15 were themselves FHWA employees and therefore likely to view the organization's activities favorably. The other eight interviewees were potential deployers or associated with AASHTO. For example, a State transportation department engineer reported the following:

> *"without FHWA and EDC, it would have taken much longer to implement this technology. The presentations that were given in Every Day Counts workshops gave leadership the confidence to move forward with implementation."*[13]

Shifts in attitude also occurred outside FHWA's direct activities and outputs but may have been catalyzed by them. Out of eight interviewees reporting such a shift, one was an FHWA employee while seven others were potential deployers. For example, a county engineer built a GRS-IBS bridge in 2010 with another engineer who was less familiar with the technology. The latter has since gone on to build two such bridges a year. The former predicts a rapid rise in the number of local deployments because of the following:

> *"Other county engineers have said, 'When you build your next [GRS-IBS] bridge, let me know because I want to watch.'"*[14]

Collaboration and information sharing at the county level—in this case, in Ohio—is increasing local awareness of GRS-IBS, introducing potential deployers to FHWA research and resulting in deployments.

Seventeen out of 23 interviewees not directly working for FHWA reported that FHWA played a role in their deployment of GRS-IBS through direct support in design issues, design guidance documents, or in the decision to deploy. Five out of seven private contractors reported that FHWA provided meaningful support during the deployment phase or toward the decision to take on a GRS-IBS project. One interviewee from a tribal nation related the process of convincing a contractor who had never heard of GRS-IBS to scrap the traditional bridge he had designed and to adopt FHWA's technology:

[13]Interviewee #2, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[14]Interviewee #15, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

> *"[the contractor] originally designed the traditional bridge we were going to build. [We] then discussed the EDC initiatives to save costs…he scratched his head and said, 'well I think we can try it.' Then when FHWA was hosting the site visits, I took him with me. Before… [we] approached the council I made sure he wanted, thought he could do it. I put him in contact with FHWA's EDC folks. [It was] a collaborative effort overall. The council said go for it and they started writing grant applications."*[15]

One interviewee reported building three GRS bridges without FHWA's expertise and materials. He worked as a geotechnical engineer for a different U.S. Government agency before the development of GRS-IBS.[16]

The two available databases permit examining the deployment of GRS-IBS bridges of various lengths over time. GRS-IBS technology began to be deployed in 2005 as a means of demonstrating the method developed by Infrastructure R&D researchers. From 2005 to 2009, there were seven deployments of the technology: six in Defiance County, OH, and one in St. Lawrence County, NY. Some of these deployments were demonstrations. Deployments between 2010 and 2015 reflect the impact of FHWA activities including EDC. During this period, agencies and States were presumably deploying the GRS-IBS technology with support from FHWA but assuming the risk and costs themselves.

The first analysis of these databases estimates the deployment of GRS-IBS bridges as a percentage of all bridges constructed (or reconstructed) in the United States regardless of bridge size or characteristics. Figure 4 shows the results during the period from 2005 to 2009. Figure 5 shows the results during the period from 2010 to 2015. The vertical axis displays the percentage of bridges constructed using GRS-IBS. The horizontal axis displays the length of the bridge in feet. The total number of bridges are marked at the top of each column. Comparing the percentage of bridges of roughly the same size built using GRS-IBS between the two time periods provides one way of tracking technology adoption. There is a modest increase in GRS-IBS deployments in terms of percentage in the later period, primarily for bridges between 50 and 110 ft long. For example, between 2005 and 2009, no GRS-IBS bridges were built in the 90- to 100-ft range—although one GRS-IBS bridge was built in the 130- to 140-ft range. Between 2010 and 2015, 6 GRS-IBS bridges were built in the 90- to 100-ft range—nearly 30 percent of the 22 total bridges that length.

The second analysis of these databases estimates the deployment of GRS-IBS bridges as a percentage of all bridges constructed (or reconstructed) in the United States that match the criteria in the 2011 *GRS-IBS Interim Implementation Guide*.(2) The evaluation team applied the following two filters to the universe of bridges:

- Span length less than 140 ft (less than 20 ft is not considered a bridge by NBI standards).
- Single span.

More criteria can be drawn from the *Interim Implementation Guide*, but the evaluation team was unable to apply them.(2) The NBI does not track information about bridge abutments and does not contain sufficient scour information to eliminate bridges that should be removed for hydrological or geologic reasons. Several non-FHWA and FHWA interviewees also suggested that—depending on various factors—a deep foundation bridge could be replaced by a (shallow foundation) GRS-IBS,

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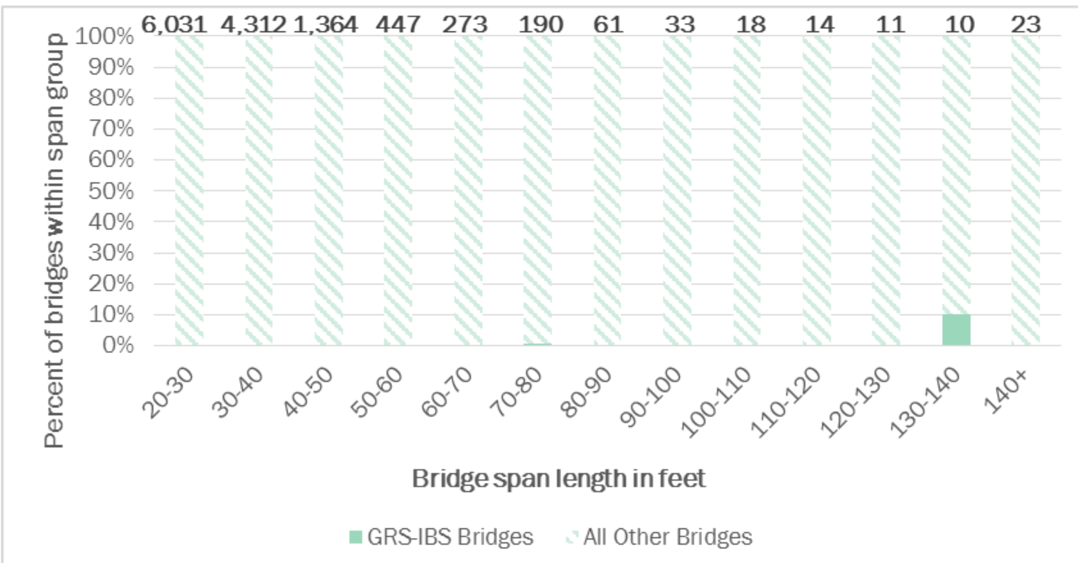
[15]Interviewee #11, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), September 2016.

[16]Interviewee #36, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

which makes filtering out truly incompatible bridges far more difficult. Figure 6 shows the results during the period from 2005 to 2009. Figure 7 shows the results during the period from 2010 to 2015. There is a considerable increase in GRS-IBS deployments in percentage terms in the later period, primarily for bridges between 50- and 110-ft long. For example, between 2005 and 2009, no GRS-IBS bridges were built in the 90- to 100-ft range. Between 2010 and 2015, 6 out of 6 (100 percent) of the bridges built in the 90- to 100-ft range were GRS-IBS.

The results suggest that GRS-IBS has had increased market penetration for bridges of greater span length. An FHWA decisionmaker said that the GRS-IBS research goal back in 2000 was to provide a low-cost solution for bridges at the U.S.-median bridge length.[17] He recalled the median length to be 60 ft. Although NBI data shows the median bridge length in 2000 was under 30 ft, market penetration for bridges around 60 ft is substantial and increasing. GRS-IBS likely has more penetration in the market for smaller bridges than this analysis reveals. FHWA staff find it easier to identify large GRS-IBS deployments and difficult (to impossible) to identify small GRS-IBS deployments.

Figure 4 shows the percentage of bridges built from 2005 to 2009 using GRS-IBS and separated by span length.

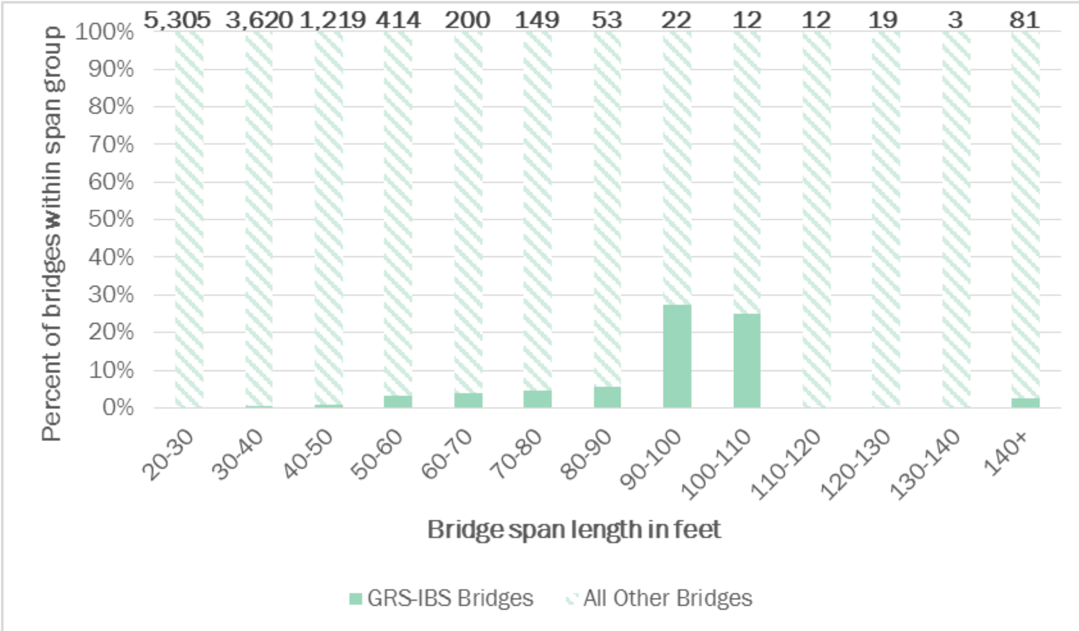


Source: FHWA.

Figure 4. Graph. Percentage of bridges built from 2005 to 2009 using GRS-IBS by span length (ft).

Figure 5 shows the percentage of bridges built from 2010 to 2015 using GRS-IBS and are categorized by span length.

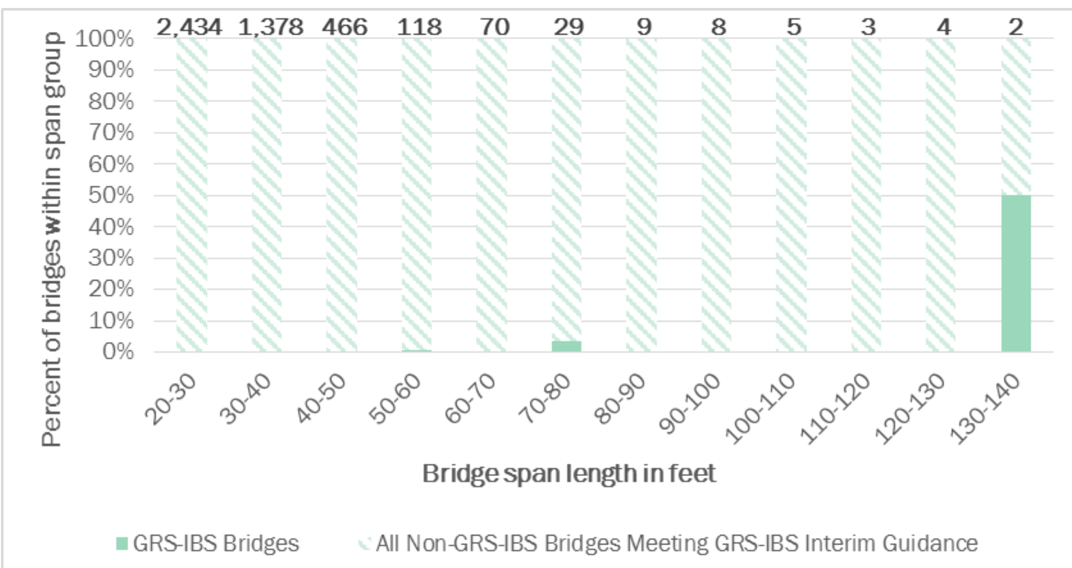
[17] Interviewee #28, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), August 2016.



Source: FHWA.

Figure 5. Graph. Percentage of bridges built from 2010 to 2015 using GRS-IBS by span length (ft).

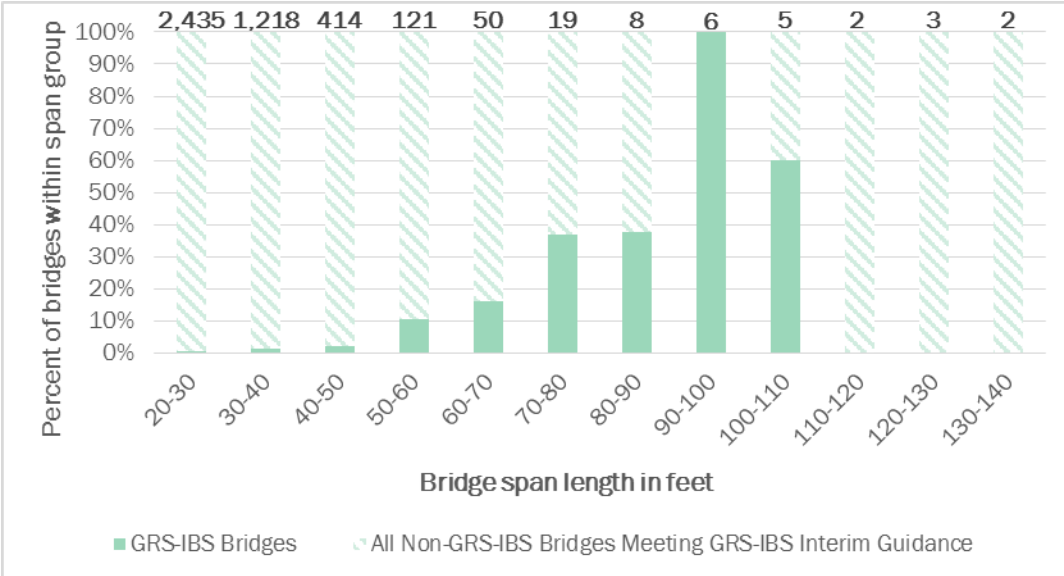
Figure 6 shows the percentage of bridges built from 2005 to 2009 fitting GRS-IBS interim criteria and GRS-IBS bridges categorized by span length.



Source: FHWA.

Figure 6. Graph. Percentage of interim criteria bridges built from 2005 to 2009 using GRS-IBS by span length (ft).

Figure 7 shows the percentage of bridges built from 2010 to 2015 fitting GRS-IBS interim criteria and GRS-IBS bridges separated by span length.



Source: FHWA.

Figure 7. Graph. Percentage of interim criteria bridges built from 2010 to 2015 using GRS-IBS by span length (ft).

While the collected evidence suggests that FHWA activities and outputs have had a positive impact on awareness of, attitude toward, and deployment of GRS-IBS, the evaluation team identified several *barriers*, both internal to FHWA and external to FHWA that reduce or block some of the cause-and-effect relationships proposed in the logic model. These barriers are explored in subarea 3(d) and subarea 3(e).

Subarea 3(d): Internal Barriers to Deployment

Evaluation subarea 3(d) is about internal barriers to the deployment of GRS-IBS. The evaluation team sought to uncover the answers to the following two questions:

1. What internal barriers did GRS-IBS face?
2. What triggered these barriers?

The following section further examines these questions.

Overview

The logic model proposes an ordered progression of elements from inputs through impacts. Interviews revealed several internal barriers that slow or block the production, dissemination, and use of GRS-IBS research within FHWA.

Relevant Data

Twenty-two interviewees described events or processes that generate resistance within FHWA to achieving stated organizational goals concerning GRS-IBS.

Finding: GRS-IBS research and deployment were challenged within FHWA by five internal barriers: poor communication, insufficient collaboration, gaps in evidence, dissemination issues, and resistance to change.

Analyzing interview transcripts, the evaluation team identified five types of internal barriers. These are conceptualized as occurring primarily between certain lanes of the logic model, for example in the transition between inputs (e.g., funding and staff) and activities (e.g., research and testing). Table 5 describes the barriers, locates them on the logic model, and shows how many interviewees described associated phenomena. Some interviewees mentioned more than one internal barrier.

Table 5. Internal barriers to GRS-IBS deployment within FHWA.

Internal Barrier	Logic Model Transition	Description	Number of Interviewees
Poor communication	Inputs to activities	Non-technical misunderstandings or friction between FHWA staff members prevents activities from being fully effective	8
Insufficient collaboration	Inputs to activities	Real or perceived scarcity of discussions between geotechnical engineers and members of other engineering disciplines prevents activities from being fully effective	10
Gaps in evidence	Activities to outputs	Real or perceived problems with GRS-IBS research prevents outputs from being fully effective	9
Dissemination issues	Activities to outputs	Real or perceived problems with the technical information released about GRS-IBS prevents outputs from being fully effective	10
Resistance to change	Inputs through outputs	Real or perceived unwillingness of some FHWA staff members to accept new engineering ideas prevents an unbiased examination of GRS-IBS strengths and weaknesses	8

Each of these barriers is discussed in more detail in the following five sections.

Poor Communication

The TFHRC conducts GRS-IBS research and initially worked with early adopters in Defiance County. The Resource Center introduced the technology more broadly and promoted it to the public. There have been disagreements between these two work units concerning division of duties and the strength of evidence behind GRS-IBS. Such disagreements are an important part of developing a new technology. However, some stakeholders felt that communication was not always as cordial and professional as it could have been. One of the GRS-IBS leads at TFHRC explained that when GRS-IBS was handed over to the Resource Center, staff there asked how to move FHWA guidance out of "interim" status. The reply from TFHRC researchers was that Resource Center employees should not work on such matters:

> *"That had an impact on implementation. At the beginning, there was a lot of animosity [and] hurt feelings. They had their own vision on how it should be deployed but others [at Turner-Fairbank] had a different idea."*[18]

[18]Interviewee #34, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), April 2015.

Insufficient Collaboration

Ten interviewees, all geotechnical and hydraulics engineers, felt that hydraulics engineers did not become involved in GRS-IBS until late in the research process. FHWA maintains communities of practice for collaboration across disciplines and these comments could refer back to a time before FHWA's communities of practice were active. The timing and extent of collaboration on GRS-IBS within FHWA remains unclear. One hydraulics engineer reports that members of his discipline were consulted as an afterthought:

> *"Hydraulics [were] not engaged at all until the [GRS-IBS] program launched. Then [the GRS-IBS team] had second thoughts and thought there might be issues with scour and should ask hydraulics engineers what they thought. [But] the horse had already left the barn. It came as second thought to involve hydraulics, [they] were so anxious to get it out on the street."*[19]

Another hydraulics engineer reports that members of his discipline avoided engaging directly on GRS-IBS research:

> *"Hydraulics folks didn't coordinate early enough or speak up enough. They thought if they ignored it [GRS-IBS], it would go away—but that's not the case. [We are now] playing a lot of catch-up and asking a lot of questions about why things weren't addressed earlier on. Why weren't these changes addressed earlier than EDC-3?"*[20]

Collaboration participants holding different views or interpretations about the same meetings might also explain varying reports. Some individuals might have been relatively silent, while others were ready to speak up. Some individuals might have felt more welcome to speak than others.

Gaps in Evidence

Interviewee comments in this category involve poor communication and insufficient collaboration, but merit their own category because they also suggest differences in how the disciplines assess findings, calculate risks, and determine that a technology is ready for deployment. For example, a hydraulics engineer suggested the following:

> *"[FHWA] needs to make the panel include a devil's advocate to say, 'where can this [GRS-IBS] possibly have issues so we are making informed decisions on the EDC areas?' Sometimes people are wrong. Hydraulics is overly conservative but has touched all of the bases to get consensus going forward before selection, it should not be after selection when there is already momentum [to deploy the technology]."*[21]

The evaluation reveals a possible lack of consensus about when a technology is ready for deployment. Some engineers outside of the core GRS-IBS team felt that the approach was "still a research project" and not ready for public deployment. GRS-IBS continues to be a research topic at TFHRC focusing on expanding its use and applications. The disagreement might concern whether the gaps in evidence are sufficient to warrant keeping the technology from public application.

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[19]Interviewee #26, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), May 2015.

[20]Interviewee #17, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), April 2015.

[21]Interviewee #17, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), April 2015.

Communities of practice may provide a venue for experts in different engineering fields to express concerns—but may not provide a structured method for resolving concerns.

Dissemination Issues

According to several interviewees, potential GRS-IBS adopters are still unaware of what the technology offers and do not understand how it might be able to address their specific engineering needs. For example, one geotechnical engineer employee outside of FHWA with a lot of knowledge of and confidence in GRS-IBS said the organization needed to do the following:

> *"More about getting the word out through publications, passing on reference information, [and] helping get the word out that this is a viable technology with savings and benefits. [It is] up to management whether they are willing to take a stake with risk, or remain conservative."*[22]

An FHWA hydraulics engineer who works with potential adopters noted the following:

> *"Shallow foundation bridges had been built but were discouraged via word of mouth from headquarters. They have more inherent risk than deep ones do. I got involved to help promote correct design. [The information] should have been out there at EDC-1."*[23]

GRS-IBS, as a shallow foundation bridge, faces the long-held belief by many in the bridge building industry that this type of foundation carries risks. The evaluation team could not determine whether comments such as this suggest that GRS-IBS proponents could better convey in their publications when the technology should and should not be used—or, suggest that engineers from other disciplines have doubts about the safety of GRS-IBS, which they share with potential deployers. The result, however, is that non-geotechnical engineers were unsure whether to promote the technology, even after it had been accepted into EDC-1. If they promoted the technology, they sometimes added to the recommended design in ways that reduced its advantages. An interviewee familiar with GRS-IBS and EDC explained the following:

> *"On EDC-1, I heard they [users] were getting conflicting info from headquarters on whether or not they should or should not be deploying it. By EDC-2, the geotechnical engineers were on board…but then we faced issues with hydraulics and structural engineers…All the additional counter measures they wanted to add to the design made it not cost effective anymore."*[24]

Other interviewees noted the manual describing how to implement GRS-IBS was non-committal by its very nature of being referred to as "interim."

Resistance to Change

Proponents for GRS-IBS claim that some detractors have legitimate engineering concerns that must be investigated while other detractors oppose the technology because it is new and different—and

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[22] Interviewee #36, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[23] Interviewee #17, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), April 2015.

[24] Interviewee #12, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), October 2016.

perhaps even challenges vested interests in traditional bridge building techniques. The evaluation team did not independently investigate the basis of claims for or against GRS-IBS. The comments in this category reflect the opinions of GRS-IBS proponents and individuals who possess knowledge of multiple FHWA projects. For example, an interviewee familiar with many EDC programs acknowledges there is often pushback against new research initiatives, but also noted the following:

> *"The thing with GRS-IBS was that this [pushback] continued after the interim guidance was signed. It never died down. Everything else was eventually embraced."*[25]

EDC promoted novel technologies and experienced professionals inside FHWA were sometimes resistant to their novelty. However, as time passed, the other technologies were accepted into the fold while GRS-IBS remained—and possibly remains to this day—a technology that some employees refuse to support.

Subarea 3(e): External Barriers to Deployment

Evaluation subarea 3(e) is about external barriers to GRS-IBS deployment. There were two questions the evaluation team sought to answer within this area and they were:

1. What external barriers did GRS-IBS face?
2. What triggered these barriers?

The following section summarizes findings to these questions.

Overview

The logic model proposes an ordered progression of elements from inputs through impacts. Interviews revealed several external barriers that slow or block deployment of GRS-IBS.

Relevant Data

The evaluation team interviewed 16 Federal stakeholders and 23 non-Federal stakeholders about their experience with potential deployers or as a potential deployer.

> Finding: GRS-IBS research and deployment were challenged outside FHWA by four external barriers: knowledge, financial, design, and political.

Three State transportation department interviewees were asked about what, if any, regulatory, decision-process limitations influence their decision to deploy GRS-IBS. Site conditions vary by State, as do institutional structures. Moreover, several agencies have deployed multiple bridges and faced different barriers on each project. All 39 aforementioned stakeholders provided insights into external barriers that the evaluation team organized, inductively, into four major types (knowledge, financial, design, and political) and multiple subtypes.

Table 6 summarizes the external barrier types.

[25] Interviewee #12, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), October 2016.

Table 6. External barriers by type, subtype, and stakeholders.[26]

Barrier Type	Barrier Subtype	Description	Non-FHWA Individuals (23 Total)	FHWA Individuals (16 Total)
Knowledge	Level of awareness and knowledge	Whether stakeholders were aware or knowledgeable enough about the technology	12	10
Knowledge	Confused for MSE	Stakeholders did not understand the difference between GRS-IBS and MSE	4	4
Finance	Bid issues	Stakeholders had difficulty correctly bidding or failed to pursue project because of bidding issues	2	1
Design	Considered "still a research project"	Stakeholders or those supporting stakeholders considered the product still a research project and not deployment-ready	7	7
Design	Relative benefits	Other methods considered as efficient	9	3
Design and political	Perceived as risky	Stakeholders at various levels (engineer or non-engineer decisionmakers) saw the technology as too risky, particularly with respect to scour	16	10
Political	Reluctance to change	Decisionmakers are reluctant to change from current methods	18	9
Political	AASHTO or industry acceptance	Conflicting standards and the degree of acceptance from industry groups was a barrier to acceptance by some agencies	14	9

Each of these external barriers is explored in more detail in the following five sections.

Knowledge Barriers

Ten of 16 FHWA interviewees and 12 of 23 non-FHWA interviewees discussed problems with awareness of or knowledge about GRS-IBS and specific confusion between GRS-IBS and MSE. Four of 23 non-FHWA and 4 of 16 FHWA interviewees said that stakeholders were confused about design differences between GRS-IBS and MSE. One FHWA geotechnical engineer interviewee explained the following:

[26]Interviewees in table 6 can be represented across multiple barriers and barrier subtypes. Total unique interviewees is 39.

> *"AASHTO guidelines for MSE walls don't apply [to GRS-IBS] but an engineer will say the calculations for GRS have to meet AASHTO [guidelines for MSE walls]."*[27]

Another FHWA geotechnical engineer explained that the challenge is to convince deployers to stick to a pure GRS-IBS implementation:

> *"[We] have to convince the designers that it's ok for a bridge to settle more than one eighth of an inch. [We are] convincing designers to accommodate settlement in the design. Convincing designers that the bridge isn't going to wash out."*[28]

Financial Barriers

Financial barriers create hard limits on bridge funding and in-house labor. The agency may simply not have enough money or people available to plan and build a bridge. Most interviewees said that GRS-IBS was financially beneficial and did not cite expense as a barrier. However, two interviewees noted that because GRS-IBS design does not require heavy equipment or proprietary technology, some contractors that relied on heavy equipment or proprietary technology would be hesitant to support GRS-IBS. Two additional interviewees noted that firms and agencies did not understanding how to bid or how to request bids for GRS-IBS projects. This clearly reflects a knowledge barrier, but warrants special attention since it deals with financial matters that could greatly hamper deployment. Another theme was a disconnect between the needs of the local or county agency and those of the State. For the local or county agency, cost savings matter, but at the State level there was less understanding about the need to reduce cost. An FHWA employee familiar with GRS-IBS noted the following:

> *"FHWA gets it, local governments get it, States rarely do. For every dollar saved on a bridge, we know what that means. The cost savings are real and justify any risk."*[29]

Design Barriers

Interviewees raised three design issues. First, some stakeholders considered the technology to be "a research project" and not ready for deployment. Second, other bridge construction methods were considered sufficient. Third, site geography may not be well suited to GRS-IBS deployment. For example, the initial GRS-IBS implementation guidance recommends using a single span less than 140 ft long.

A natural overlap between design issues and political issues is that some practitioners perceive GRS-IBS to be risky. Sixteen of 23 non-FHWA interviewees and 10 of 16 FHWA interviewees discussed the perception that GRS-IBS presents risks that other bridge types do not. These concerns often came not from the interviewee directly, but from colleagues or Government officials who may not have understood the design specifications. One FHWA geotechnical engineer shared the following:

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[27]Interviewee #32, phone interview conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[28]Interviewee #2, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[29]Interviewee #15, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

> *"I've run into that in numerous places with my districts—people propose to put these small bridges on GRS abutments and someone, like the drainage engineer, will jump up and say, 'no we can't do that because we have all this water flow and water up to the site and it's just going to wash away all the material.'"[30]*

Concern about a proposed bridge's proximity to water proved to be a frequent issue.

Political Barriers

Political barriers are limitations on how an agency can use its funding and local labor resources. Such limitation either outright prevents the selection of GRS-IBS or makes GRS-IBS less competitive against approaches that are more traditional. Political barriers include disagreements with and a lack of support from key decisionmakers. For example, 18 of 23 interviewees reported encountering an unwillingness to change, from engineers to political decisionmakers. One FHWA employee familiar with GRS-IBS explained that sometimes GRS-IBS proponents face the following:

> *"[an] old school mentality—contractors and more senior design staff… [who are] used to traditional steel and concrete. Breaking tradition is the hardest thing [in opposition] right now. [There is] reluctance to try a new technology. Senior crew leader refers to them [GRS-IBS bridges] as Lego® bridges."[31]*

Nine of 16 FHWA interviewees and 14 of 23 non-FHWA stakeholders discussed the level of adoption of GRS-IBS by AASHTO and other industry bodies as a barrier to greater deployment. Interviewees reported conflicting recommendations from FHWA, AASHTO, and several State transportation departments regarding engineering specifications and design requirements for GRS-IBS. FHWA and AASHTO had both previously been pushing deep foundations and discouraging shallow foundations. The shallow foundations in GRS-IBS, to some interviewees, therefore represented a departure for FHWA. Some engineers interpret ASHTO language as favoring deep foundations for bridges over water, although other engineers argue that the ASHTO section on scour contains no such preference. Two GRS-IBS team members explained that FHWA actually permits either type of foundation for water crossings as long as it is properly designed.[32] Still, some engineers felt strongly that updated design guidance needed to come from AASHTO and, because the current GRS-IBS design procedures to them appeared to be inconsistent with AASHTO, they would not use the guidance materials.

Two engineers who had built GRS-IBS bridges argued that the lack of AASHTO support was an excuse for other, unstated, concerns. Challenging the view that an engineer needed a specific AASHTO recommendation regarding GRS-IBS, one asked the following rhetorically:

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[30]Interviewee #2, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[31]Interviewee #33, phone interview conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[32]Interviewee #35 and Interviewee #22, phone interviews conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), May 2015.

> *"What does it mean to be adopted by AASHTO? [The Association] never aspired to be an [industry standard] stamp on anything. But some states use them that way. Goes to [show] the conservativism in engineering and [of] bridge designers."*[33]

Another engineer claimed FHWA could have positioned GRS-IBS better within the specifications AASHTO already provides:

> *"[The] biggest challenge is that they [FHWA] have basically turned against what is already available to use and are trying to redefine this technology to their flavor. There is one flavor and it's reinforced soil, but they are trying to define [it] differently which is a big problem. If they would just have promoted using [existing] AASHTO specs."*[34]

State statutes may impose political barriers as well. A State may not permit shallow foundation bridges on certain soil types or bar in-house labor on contracts over a certain threshold. Some States require agencies to report alternative designs that were not selected for the project, but reporting requirements are not uniform across jurisdictions even within a single State. For example, Ohio imposes some restrictions for State and Federal funds. Bridge engineers, in particular, emphasized that their State-approved design guidelines typically require a design life of 50 to 100 years. Two GRS-IBS team members assert that, when used appropriately, structural GRS-IBS elements last at least 75 years with the geotextile lasting possibly over 100 years.[35] A deployer argued that even if GRS-IBS lasted only 30 to 50 years, the technique was still cost effective.[36] However, if local or State engineers opt to underestimate the design life of GRS-IBS, the technique might require a special exemption. Due to budget and time constraints, the evaluation team did not identify agencies that considered deploying GRS-IBS but chose not to deploy, which might have revealed more information about political (and other) barriers.

Figure 8 shows the major types of barriers and their intersections. A Venn-diagram approach to identifying external barriers reminds practitioners and evaluators to consider all the deployment barriers that might be present for a State, county, local, or tribal Government.

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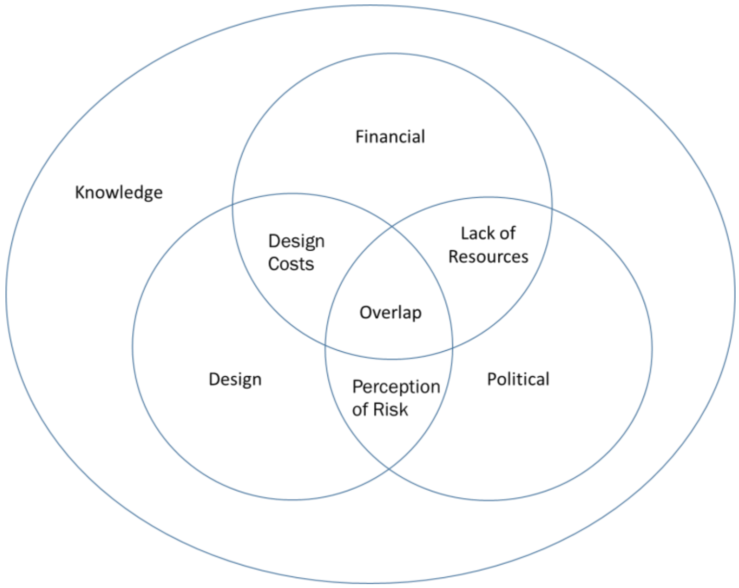
[33] Interviewee #20, phone interview conducted by Heather Hannon (evaluation team) and Andrew Reovan (evaluation team), May 2015.

[34] Interviewee #4, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), May 2015.

[35] Email exchange with FHWA staff.

[36] Interviewee #16, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.



Source: FHWA.

Figure 8. Diagram. Venn diagram of external barriers.

3.4 Evaluation Area 4: Impact of GRS-IBS Deployment

The FHWA team pursued GRS-IBS research to enable communities to save time and money over traditional construction by deploying the technology. This evaluation area focuses on these impacts. One of the areas the evaluation team sought to uncover was GRS-IBS's impact on cost and schedule. For example, does GRS-IBS save agencies money over traditional construction?

Overview

The logic model proposes that deploying GRS-IBS enables State, county, local, and tribal agencies to save time and money on bridges. It also proposes that learning GRS-IBS design and construction benefits the local labor force.

Relevant Data

The evaluation team interviewed 23 individuals about the impact of deploying GRS-IBS: 7 State transportation department engineers, 7 private contractors, 4 local and tribal decisionmakers, 3 members of AASHTO, and 2 members of academia.

Finding: The three benefits interviewees described most often were cost savings, ease of construction, and time savings.

Less common benefits (mentioned by three or fewer interviewees) were lower maintenance, the ability to construct bridges independent of weather, elimination of the "bump,"[37] a shortened span, and accommodation of different soil conditions and settlements.

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[37]The "bump" is the feeling a driver gets when they pass the threshold of where the bridge span connects to the rest of the road. This "bump" is a side effect of traditional abutment construction methods.

The most common benefits are interrelated. For example, there are likely to be cost savings from simpler construction (holding materials constant) because the bridge may take less time to build, reducing variable costs (like labor). Seventeen of 23 interviewees mentioned cost savings as a benefit. For example, one engineer the evaluation team spoke with exclaimed the following:

> *"If it were up to me, I'd be putting every bridge on the system on GRS-IBS. We could save so much money on these smaller bridge replacements. There are more application environments throughout KS, and the bridges don't worry about scour because there's limited water. The incremental savings would add up significantly, even if there were a few failed deployments."*[38]

Some interviewees estimated the percentage of GRS-IBS saved over a traditionally constructed bridge. The estimates ranged from 15 percent (one interviewee) to 50 percent (three interviewees) and even 66 percent (two interviewees). One interviewee estimated the absolute savings above $100,000. The reasons given for costs savings were that GRS-IBS requires less skilled labor, agencies could build behind an existing abutment, the materials were less expensive, and the bridge deck could be shorter. This point of view was not universal however. One interviewee claimed GRS-IBS was neither more nor less expensive than traditional construction.

Fifteen interviewees mentioned time savings as a GRS-IBS benefit. Relative to other abutment designs, those for GRS-IBS require fewer days to complete. One interviewee, with the assistance of their local crew, constructed an abutment in a single day. Two interviewees mentioned completing a bridge in around three weeks. Three other interviewees separately suggested that the technology took less time to deploy than traditional methods but that construction still took well over a month. Their exact estimates were "43 days," "6 to 8 weeks," and "3 months." The different lengths of time leave some room for interpretation. Another engineer familiar with GRS-IBS compared the different ways to build abutments:

> *"[GRS-IBS takes] less than typical abutments time, six to eight days per abutment versus cast in place concrete—six to seven days just to cure concrete between pours, probably overall double time or more like triple [that of GRS-IBS]."*[39]

State, county, local, and tribal Governments usually do not design and build a GRS-IBS bridge entirely alone. Three interviewees mentioned that the more familiarity a contractor had with the technology the more quickly it could be deployed.

Ten interviewees suggested that GRS-IBS is simpler than other approaches to deploy because it relies on fewer components and the designs are easier to follow. Five interviewees mentioned that GRS-IBS does not require heavy construction equipment, such as for driving piles into the bridge foundation. Two interviewees described how GRS-IBS technology allowed for flexibility in design and even during construction.

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[38] Interviewee #21, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), May 2015.

[39] Interviewee #30, phone interview conducted by Andy Berthaume (evaluation team) and Heather Hannon (evaluation team), April 2015.

Several interviewees communicated that the opportunity to use local labor in bridge construction was itself a great benefit. An FHWA employee once closely associated with EDC explained the following:

> *"smaller agencies and Tribes truly understand that they can go out and…with their own staff, build their own bridges, take care of deficient infrastructure much quicker than before using this technology."*[40]

A contractor who works closely with tribal Governments described the following, in his opinion:

> *"The whole [advantage of] Every Day Counts…was to be able to employ the people of the pueblo and to help teach them the skills…We had two workforce investment laborers who now work on a construction crew out in Phoenix. They learned the skills that helped them stay employed on another project."*[41]

According to a Pew Research study, one in four Native Americans and Alaska Natives are living in poverty and FHWA wanted to promote technologies to aid less populated counties into being more self-sufficient.(12) GRS-IBS may have an impact on equity in these communities and others in which low-skill jobs are difficult to find. Instead of hiring expensive, highly trained contractors, agencies can employ local workers. GRS-IBS might turn the considerable need for replacement bridges across the United States into needed employment and training opportunities.

An unpublished FHWA report, *GRS-IBS Cost Study,* investigated the factors leading to divergence between expected cost and final cost of GRS-IBS abutments.(5) That report's study team contracted an independent bridge construction contractor with experience in both bridge construction and GRS-IBS deployment to estimate project costs. This contractor had not previously bid, reviewed, or constructed any of the projects under investigation. Coordinating with FHWA and the contractor, the report team selected 13 projects for further review from an initial set of 23 projects. The selected projects were all contracted to an entity outside of the owner-agency and expressed the largest divergence in cost from the agency engineer estimates. The contractor rebid estimates of the GRS-IBS design provided by the agency engineer and additionally constructed a cost estimate of an alternative design. While the focus of the *GRS-IBS Cost Study* was to better understand the cost drivers of GRS-IBS and reasons for cost divergence, the study revealed the following six issues that might reduce the benefits imparted by GRS-IBS.(5) The remaining quotes in this section all come from this cost study.

1. *Wall-height ratio*: Walls 17 ft high and over cost considerably more than smaller walls. The contractor reasoned that the larger the total area of the GRS-IBS deployment, the more difficult it would be to deploy the technology.

> *As the labor percentage of project cost increases contractors add a large O&P [overhead and profits] percentage to a project bid or choose not to bid the job. Seven of the 13 projects had three or less bidders.*

[40]Interviewee #12, phone interview conducted by Andy Berthaume (evaluation team) and Andrew Reovan (evaluation team), April 2015.

[41]Interviewee #19, phone interview conducted by David Epstein (evaluation team), Jonathan Badgley (evaluation team), and Chris Calley (evaluation team), October 2016.

2. *Hydrological issues*: The presence of water in several different contexts adds considerably to bridge costs. These contexts include the following:

> *Control of water through the work site during construction…Scour protection in front of the RSF and GRS-IBS wall…Water table proximate to the required excavation depth.*

3. *Material and transportation availability*: Block of appropriate quality and other necessary materials might be limited in certain regions of the United States or the cost of transport to the worksite might reduce GRS-IBS cost savings.
4. *Contractor familiarity with GRS-IBS*: Contractors responding to a request for proposal (RFP) may not possess the skill with the technique or acquisition of materials. This may cause some contractors to not submit bids, not be able to bid under budget, or for there to be no bids at all.
5. *Competitive bidding*: When insufficient contractors familiar with GRS-IBS bid on the contract, the cost–benefit of GRS-IBS is reduced:

> *The number of bidders is the best direct indicator found during this study of how risky contractors view a pure GRS-IBS project—they refuse to bid.*

> *Less than five bidders almost guarantees higher pricing.*

6. *Mechanics of RFPs*: The way agencies write RFPs can affect whether the potential cost–benefits of GRS-IBS are realized. Estimators need to itemize bid items rather than request a lump sum. Relatedly, the design engineers may lack of historical data on materials needed for GRS-IBS and their prices.

4. Models of Technology Diffusion

FHWA GRS-IBS team members requested that the evaluation team consider whether the concept of disruptive technologies helps to explain the opportunities and challenges GRS-IBS has encountered.

4.1 Introduction to Diffusion and Disruption

This section introduces the work of two technology theorists, Everett Roger and Clayton M. Christensen. Then, it compares the market penetration of GRS-IBS over time against the predictions of these two theorists to determine which better explains GRS-IBS diffusion.

Rogers's *Diffusion of Innovations* is the seminal work in the field of technology adoption and provides a general framework for understanding the diffusion of technologies.(13) Not all technologies are well received and are widely adopted, but there is a general path of diffusion for those that are. This path is characterized by an S-shaped curve of adoption for circumstances in which initial adoption is slow but occurs at an increasing rate until it reaches an inflection point after which the majority of users have adopted the technology. The adoption of the technology then expands at a decreasing rate until it reaches full adoption. Roger's characterizes adopters along this path by their motivations and characteristics, such as openness to change and connectedness to information sharing networks. Earlier adopters are innovators who are open to new technologies and well connected. Later adopters are more resistant to change, more deliberative in making decisions, or less connected to information sharing networks.

Importantly, among those first adopters are a few users who are considered champions of the technology. These users are well connected to other users and are considered reliable sources of information. They spend effort and energy promoting the technology. Through interviews and the GRS-IBS database it was identified that GRS-IBS does have early adopters and champions, both within and outside of FHWA. They use their information network and expertise to raise awareness about and improve public attitudes toward the technology.

Christensen's *Disruptive Innovation* offers a specific type of technology diffusion, one that could be captured by Roger's framework but that has a stricter application and pays more attention to the attributes of the specific market in which a new technology develops.(14) Christensen describes disruptive technology as "a process by which a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up market, eventually displacing" incumbents.(15)

Technologies are not disruptive if they present a completely new product and, therefore, create a completely new market. For example, the personal computer created a new market. It did not compete with incumbent products in an existing market. Disruption can occur only when an existing market fails to provide the ideal product for a niche set of users. Research in incumbent firms focuses on sustaining the relationship between the firm and its existing customers and not on acquiring new customers. Incumbents are improving along a trajectory of innovation and eventually overshoot their own customers' needs. Disruptors are improving in a more radical way that initially would appear only to benefit niche or lower-end customers. Eventually, the appeal of disruptive technology becomes universal. Determining whether a technology is disruptive can be difficult to determine in practice. The concept has been developed primarily through case studies. Despite this, a set of four criteria for disruptive innovation can be drawn from Christensen's works.

- *Value proposition*: This describes the technology's cost relative to its attributes. The incumbent technology is seen as the only option and at a higher price point.

> *Disruptive technologies bring to a market a very different value proposition than had been available previously. Generally, disruptive technologies underperform established products in mainstream markets. But they have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use.*[16]

- *Match to requirements*: Naturally, whether a technology is disruptive depends on not just facts about the technology itself but also on the state of the market at the time of the introduction of the technology. The match of requirements criteria establishes that the incumbent market technology does not accurately match the needs of the users, but that the disruptive technology more closely does.

> *Many of the disruptive technologies we studied never surpassed the capability of the old technology. It is the trajectory of the disruptive technology compared with that of the market that is significant.*[16]

> *First, disruptive products are simpler and cheaper; they generally promise lower margins, not greater profits. Second, disruptive technologies typically are first commercialized in emerging or insignificant markets. And third, leading firms' most profitable customers generally don't want, and indeed initially can't use, products based on disruptive technologies.*[16]

- *Complexity to user*: This describes the ease with which a technology can be used. Incumbents engaged in sustaining innovation continue to produce technologies that match the initial demand of their customer base but do not explore the potential for users who need less, are less sophisticated, or need the technology more cheaply.

> *As companies tend to innovate faster than their customers' needs evolve, most organizations eventually end up producing products or services that are actually too sophisticated, too expensive, and too complicated for many customers in their market.*[14]

- *Growth potential*: This is the extent to which the new technology can capture market share or capture new users.

> *They [disruptive technologies] all created massive growth; to flip Joseph Schumpeter's famous phrase, creative destruction, on its head, this is creative creation. After taking root in a simple, undemanding application, disruptive innovations inexorably get better until they change the game, relegating previously dominant firms to the sidelines in often stunning fashion.*[17]

To better compare GRS-IBS empirically against these two theories of innovation diffusion, the evaluation team estimated the technology's growth potential.

4.2 GRS-IBS Growth Potential

The evaluators considered growth potential based on demand for bridge replacement and growth potential based on State deployment patterns.

Demand for Replacement Bridges

The evaluation team considered the retrospective market potential of GRS-IBS bridges by identifying bridges for which GRS-IBS technology could potentially be deployed using basic design restrictions. Because of data, budget, and time constraints, there was no way to identify edge case bridges that were delayed in being repaired or built. Similarly, there was no way to identify why a bridge was built in the year that it was in the NBI. There may have been bridges that were fast-tracked, bridges built or rebuilt because the financial potential of GRS-IBS made it more feasible for one agency than for another, or bridges that GRS-IBS made more feasible to construct now than at some future date. This has relevance because the analysis only considered the construction activities in a subset of years. There are bridges that may need to be rebuilt, but the financial situation of the agency does not permit them to be rebuilt.

The evaluation team defined the future deployment potential of GRS-IBS as the bridges in the NBI that could be replaced by GRS-IBS technology using the recommendations of the 2011 *Interim Implementation Guide.*[(2)] Bridges are assumed to have 50 to 75 years of useful life, and many standing today are thought to be approaching the end of useful life.[(18)]

Figure 9 and figure 10 show the level of bridges built or rebuilt in a given year and the 50- and 75-year horizons of useful life for the bridges that currently exist. These analyses assume that the bridges are rebuilt in their final year of useful life.[1] The graphs are scaled to the same vertical axis values to give a sense of the difference in scale between the criteria. As researchers and practitioners develop more techniques and increase applications of GRS-IBS technology (developing methods for dealing with site specific issues), GRS-IBS is applicable if not feasible for a larger share of the bridges built or rebuilt. Figure 9 shows the number of current bridges that reach end of an assumed 75 years of useful life from 2017 to 2060, and the number of bridges that reach an assumed end of life of 50 years from 2017 to 2060. These two categories are bridges that may be replaceable by GRS-IBS if there no restrictions to GRS-IBS's use. Figure 10 displays the same values but uses the *Interim Implementation Guide* criteria to restrict which bridges in the future would potentially be replaceable by GRS-IBS.[(2)] Only those single-span bridges between 20 and 140 ft in span length and are not movable type bridges are shown.

Figure 9 shows a graph of bridges reaching the end of their 50th year of life and bridges reaching the end of their 75th year of life with no excluding criteria.

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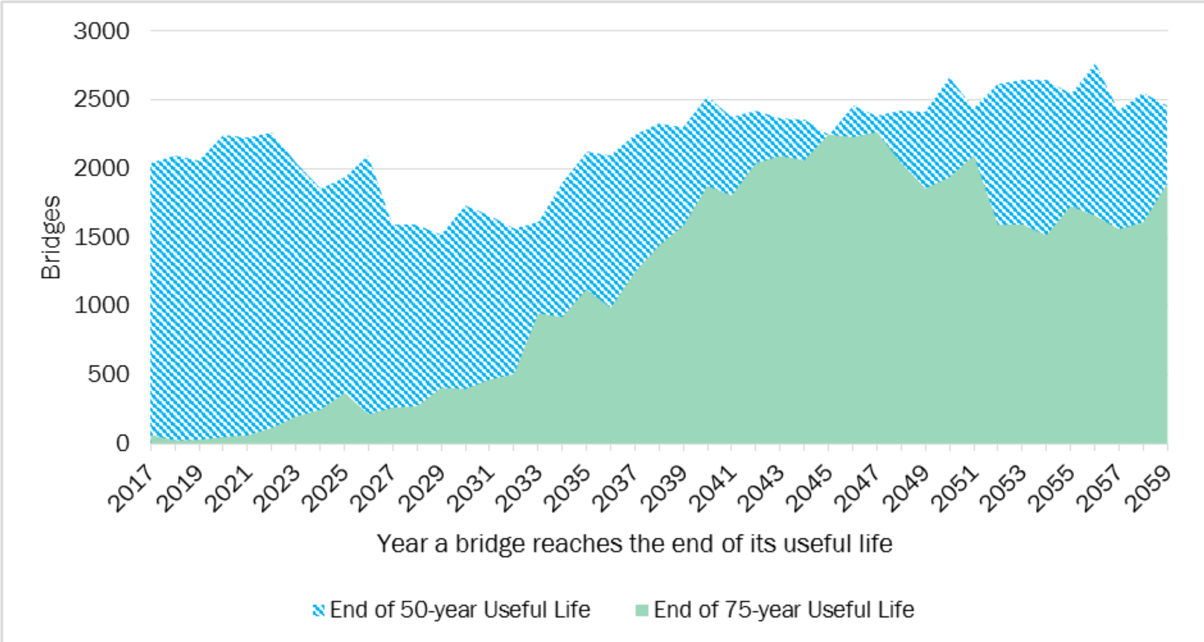
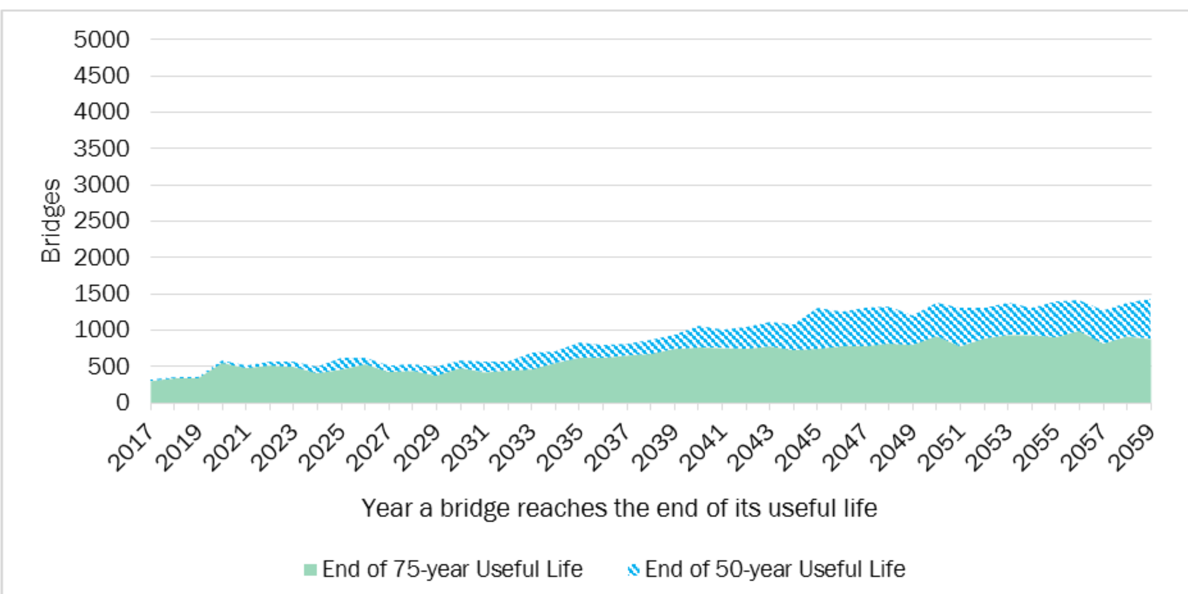
[1]These are upper-bound estimates of replaceable bridges as there may be other design limitations that are not accounted for in this analysis.



Source: FHWA.

Figure 9. Graph. Series of year of 75th year of bridge life and 50th year of bridge life with no excluding criteria.

Figure 10 shows a graph of bridges reaching the end of their 50th year of life and bridges reaching the end of their 75th year of life based on the interim guidance.



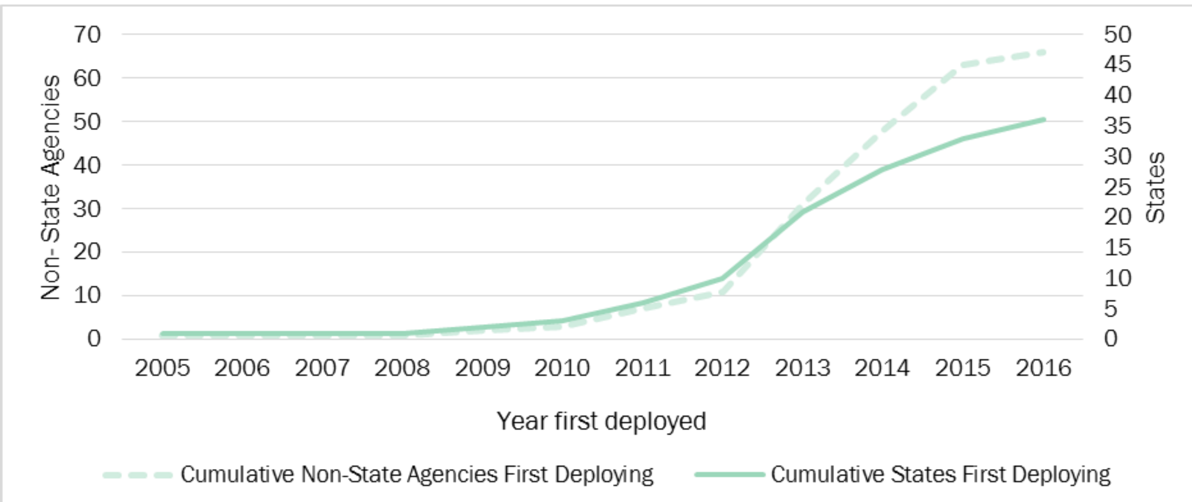
Source: FHWA.

Figure 10. Graph. Series of year of 75th year of bridge life and 50th year of bridge life based on the interim guidance.

Deployment Across States and Agencies

The evaluation team studied the behavior of States and agencies to identify patterns in the deployment of GRS-IBS. There is a strong negative correlation between the first year of deployment and the number of bridges deployed for a given State (–0.76). A negative correlation between first adoption and number of deployments is natural, because States (or agencies) need time to process whether deployment was successful. In addition, deployment itself takes time, from decision to completion of construction; States may not have had an opportunity to deploy additional GRS-IBS bridges. The earliest adopting States (Ohio and New York) have an order of magnitude more deployments than the average number of deployments by States from 2012–2016.

Figure 11 shows the most up-to-date information available about the deployment of bridges in the United States as of December 2016. There is a shift in the rate of deployment from 2012–2013 compared to previous years. This coincides with the conclusion of the EDC-1 efforts during which many potential deployers first heard about the technology.



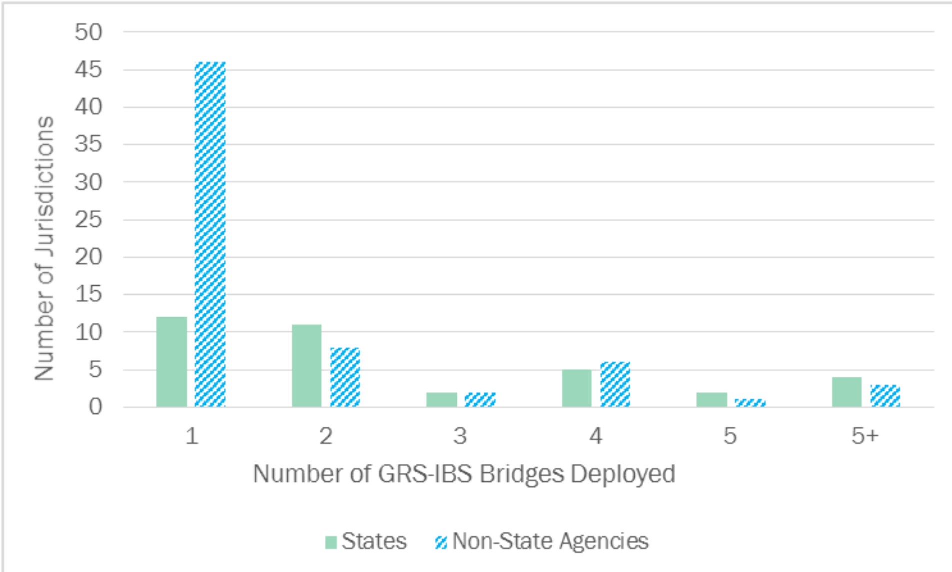
Source: FHWA.

Figure 11. Graph. Cumulative first-time owner-agencies and States with completed GRS-IBS by year.

Figure 12 shows the number of agencies by the number of GRS-IBS bridges deployed. The majority of States and non-State agencies that have deployed have only one or two deployments. Given the rate of deployment growth for both States and non-State agencies this shows that even where adoption and deployment of the GRS-IBS technology has occurred there has not yet been many additional deployments. There are a number of reasons why this could have occurred, which are detailed as follows:

- The agency or State has only recently deployed the technology and is planning or is in the middle of further deployments.
- The agency or State is still processing the experience of deployment and deliberating internally about the experience and whether they would consider a second deployment.
- The agencies have decided not to deploy again.
- The agencies have not had the opportunity to deploy again.

Interview evidence suggests that GRS-IBS technology has tended to be polarizing: those open to the technology are more likely to want to use it as often as design or other limitations allow, where agencies who did not view it positively would not deploy it. The evaluation team expects there will be future deployments of the technology by those agencies that have already deployed the technology.



Source: FHWA.

Figure 12. Graph. Number of completed GRS-IBS bridges per unique owner-agency from 2005–2016.

This analysis has several limitations. First, the NBI database does not contain abutment information and so the most accurate criteria cannot be applied to define a true GRS-IBS potential population. Second, the GRS-IBS database does not contain NBI ID numbers for all bridges and so true population limitations cannot be gathered from the NBI database. For example, supposing no GRS-IBS bridges of superstructure type "X" have been deployed, although while design limitations do not preclude the use of GRS-IBS bridges with superstructure type "X," the lack of deployment represents some norm within the GRS-IBS-willing population of agencies to not deploy in circumstances requiring superstructure type "X." Such a limitation may not always hold, as the assumptions about bridge span length and number of spans have been relaxed, but they are relevant for assessing the correct market potential in which FHWA set guidance stating otherwise. There are certainly more GRS-IBS bridges constructed than are in the GRS-IBS database. The more often a technology is deployed the harder it is to track deployment through indirect means, such as newspaper announcements. Also, since GRS-IBS is no longer part of EDC, the reporting and collection mechanisms for GRS-IBS may be diminished.

4.3 Situating GRS-IBS Between a Traditional and Disruptive Technology

The evaluation team matched the GRS-IBS approach to bridge design and construction against the descriptions of traditional (incumbent) and disruptive technologies across the four key attributes identified previously. For each attribute, the team determined whether the GRS-IBS appeared to better fit the incumbent or disruptive technology description. Table 7 shows the results of the analysis.

Table 7. Disruptive innovation criteria and the fit of GRS-IBS technology.

Criteria	Traditional Type of Technology (Incumbent)	Disruptive Type of Technology	GRS-IBS Description	GRS-IBS Fit
Value proposition	Offers an incrementally better option at higher cost to the same customers	Offers a fundamentally different option at lower cost to customers not yet satisfied	Similar materials. Lower cost and effort	Disruptive
Match to requirements	Exceeds the requirements of most potential users	Meets the minimum requirements of at least a subset of potential users.	Fills need of many users for basic, single-span bridges	Disruptive
Complexity to user	Overly sophisticated	Simplified	Can be designed and built by a small team without a contractor	Disruptive
Growth potential	Incremental	Massive	Demand heavily constrained by geography, local priorities, and existing infrastructure	Traditional

The *value proposition* of GRS-IBS fits the description of a disruptive technology. Interviewees were asked about the benefits of GRS-IBS technology and 17 of 23 interviewees referenced cost savings as a major component of the benefits of the technology. This was especially true for agencies who were deploying in areas where heavy machinery is difficult to use or for users with limited resources to construct a bridge.

As shown previously, GRS-IBS has made strong gains in bridges over 50 ft in length. While interviewees have suggested that the technology has a strong value proposition for smaller bridges, the data from 2010–2015 (albeit imperfect) suggests the niche use is for bridges of a longer span length. GRS-IBS also fits the description of a disruptive technology in the *match to requirements* criteria as agencies across the spectrum of resources or constraints (funds, time, experience managing construction) have successfully deployed the technology, even for bridges over a 100 ft long. GRS-IBS appears to reduce complexity for the user compared with other methods of deployment, holding site conditions and contractor experience constant.

FHWA demonstrations and subsequent deployment by agencies without the direct oversight of FHWA engineers, shows that the technology can be adopted by users with limited experience managing projects in-house. Agencies deploying this technology may have used in-house labor and management for the first time instead of relying exclusively on a contractor. Ten of 23 interviewees found the technology to be less complex than other methods. This further suggests GRS-IBS is disruptive with respect to reduced complexity. According to data from the NBI database, assumptions about bridge site, bridge design attributes, and the fact that many bridges are approaching the end of their useful lives, GRS bridges should meet the interim guidance design limitations for replacement of a single-span bridge within the range of 20 to 120 ft.

The growth potential for GRS-IBS may be even greater considering some interviewees theorized that multi-span deployments and longer lengths were possible. However, the bridge inventory analysis only provides the upper bound of applicability and it is not yet clear how many bridges could possibly be rebuilt using GRS-IBS. Some of the external barriers, certainly the political barriers, may be symptoms of GRS-IBS's disruptive properties. However, geology, geography, and the pre-existing road system place real limits on the technology's growth potential. For this reason, the evaluation team currently considers GRS-IBS to have the growth potential of a traditional technology rather than a disruptive technology.

There are relevant dissimilarities between the examples given by Christensen and GRS-IBS. First, no one firm controls the GRS-IBS deployment; use of its design and implementation cannot be restricted legally except where implementers are self-restricted (agencies may be restricted in deploying the technology because of the source of the money or by design limitations, for instance). In fact, the space of bridge designs is not restricted like in a consumer market where firms compete for the same consumers with legally protected but similar products. There is competition among the firms that bid on various portions of the project, whether design or construction, but that competition is based on the skills and expertise of the firms to provide a good design or quality cost-effective construction, not on whether the firm has a legally protected GRS-IBS design or GRS-IBS construction technique. Second, the demand side of the market for bridges is more heterogeneous than the markets for the archetypal disruptive technology market. Christensen uses an example of the computer hard drive market in the 1980s.(15) The suppliers in that market were providing a single kind of hard drive that was replaced by a single other kind. In the bridge market however, the needs or preferences of an agency for a given site depend on many factors and can vary widely. As discussed previously, site conditions may not be suitable for GRS-IBS because of the potential for scour or because of specific soil conditions. Different agencies have different risk tolerances. As with any technology, the full adoption picture is only clear in hindsight. It remains to be seen whether GRS-IBS continues to capture market share in the longer span lengths and what market share it can capture in the smaller bridge lengths (40 ft and below).

5. Conclusions and Recommendations

The purpose of this evaluation is to inform FHWA's research and development process for GRS-IBS and for similar new technologies. Members of FHWA's GRS-IBS team at TFHRC were particularly interested in better understanding barriers to deployment and requested the evaluation team compare GRS-IBS with the criteria for disruptive technologies to determine whether such a comparison explains its deployment trajectory thus far. The evaluation team aligned the four evaluation areas with four major components of a corresponding logic model: FHWA's R&T model (inputs); GRS-IBS-specific R&T model (activities); effectiveness of FHWA's outreach for GRS-IBS (outcomes); and benefits of GRS-IBS to deployers (impacts). Evaluators conducted 39 interviews and analyzed 2 bridge databases, arriving at the following findings:

- Infrastructure R&D management provides staff with a broad and flexible framework for selecting research topics, conducting research, and disseminating results. The organization does not have a single R&T model. Program teams enjoy discretion so long as they show progress.
- FHWA pursued GRS-IBS research because its precursor, GRS, showed potential for saving time and money in the design and construction of low-traffic bridges.
- GRS-IBS was included in EDC-1 because FHWA staff who believed the technology was ready for deployment advocated successfully for its inclusion despite reservations by other FHWA staff who believed the technology needed further development and testing.
- FHWA activities increased awareness of GRS-IBS among potential deployers.
- EDC activities increased awareness of GRS-IBS among potential deployers. GRS-IBS was included in three EDC rounds because the FHWA team continued to produce new evidence and to address concerns.
- FHWA activities and outputs improved the attitude of potential deployers toward GRS-IBS. GRS-IBS bridges constitute a larger percentage of total bridges built between 2010 and 2015 than between 2005 and 2009, suggesting—along with interviewee observations—that FHWA activities and outputs have had a positive effect on deployment.
- GRS-IBS research and deployment were challenged within FHWA by five internal barriers: poor communication, insufficient collaboration, gaps in evidence, dissemination issues, and resistance to change.
- GRS-IBS research and deployment were challenged outside FHWA by four external barriers: knowledge, financial, design, and political.

These findings and the analyses that revealed them point toward a small set of recommendations.

5.1 Recommendations

The evaluation team recommends FHWA managers and GRS-IBS team members consider the following four recommendations.

Recommendation: Market research part of engineering research.

Market research can help guide the selection of research topics by identifying the problems encountered by potential customers and—importantly—establishing a relationship with them. This relationship permits FHWA researchers to "test sell" potential customers on upcoming technologies and adjust both the technology and their promotion of the technology accordingly. This process would work similarly to a movie trailer for next year's blockbuster, building anticipation for the technology and making potential customers more aware of expected benefits—even before research is completed. Market research also involves planning for threats and opportunities by learning from similarly positioned technologies in other markets, as well as learning from stakeholder feedback. Market research for engineering research could also involve setting and routinely revisiting goals for public awareness of, attitude toward, and deployment of the technology.

Recommendation: Improve protocol concerning internal disagreements about FHWA technologies.

The presence of communities of practice does not guarantee that differences between individual staff members or engineering differences are resolved. There has been and continues to be tension between geotechnical and hydraulic engineers concerning GRS-IBS. It is necessary to develop a protocol to work through differences between engineering disciplines and administrative units (i.e., headquarters, division offices, and the Resource Center). One possibility is to employ an outside mediator or conflict resolution specialist to participate in scientific discussions that are not making progress. Such an effort may also include internal webinars to allow staff in different locations to discuss controversial technologies and research. Critics should help design research that would, if successful, convince them of a technology's merit. FHWA management may want to determine when and how employees can communicate contrary views about formally approved FHWA programs and technologies—especially programs with which employees have no formal connection. Those views are likely better expressed in writing and deliberated within FHWA.

Recommendation: Incorporate results of *GRS-IBS Cost Study* into guidance materials.[(5)]

FHWA should assess the results of the *GRS-IBS Cost Study* and incorporate findings and recommendations of that report as necessary into GRS-IBS guidance materials as well asthe guidance practices of Resource Center and USDOT field offices.[(5)]

Recommendation: Create deployer-managed, web-based GRS-IBS inventory.

Tracking GRS-IBS deployments, especially the many small deployments, is exceedingly difficult and time consuming. Motivating deployers to contribute information to a public facing website may make the tracking process more manageable and require a far lower funding commitment. Deployers would enter information about potential and actual GRS-IBS deployments along with associated documents and photos. In return, FHWA would randomly select one entry a year to feature in a newsletter, sending copies to local newspapers where the bridge is located. Local staff planning a particularly novel bridge might receive additional training from FHWA experts interested in documenting the implementation and its outcome.

Appendix. Evaluation Interviewees and FHWA Research Outputs

Interviewees

The following subsections present interview questions based on four possible interview groupings drawn from the subsection on semi-structured interviews. While the evaluation team separated interview responses into eight separate categories based on interviewee, the team used only four sets of questions. The email text was sent to each interviewee with the relevant questionnaire to guide the interview discussion. Interviews were scheduled throughout April 2015.

Group A: Agencies who use GRS-IBS technology

Dear Mr. /Ms. <State or local official>,

The USDOT Volpe Center is supporting the Federal Highway Administration (FHWA) by conducting a retrospective evaluation of Geosynthetic Reinforced Soil Integrated Bridge System (GRS) technology.[(19)] You have been identified as someone whose agency has used GRS-IBS technology. I would like to schedule a one-hour phone interview with you to learn more about your experience with GRS-IBS. Your participation will help us develop a qualitative assessment of the effectiveness of GRS-IBS outreach activities and implementation and help FHWA better deliver new technologies…

Effectiveness of Outreach for Building Awareness of GRS-IBS Technology

Usability of GRS-IBS Guidance

Adoption of GRS-IBS Technology

Organizational Barriers and Opportunities

Please let me know if you are interested in talking with us. If you are, please let me know your availability in the coming weeks and I can schedule a time that is convenient for you.

Thank you for your assistance,

<Volpe Name>

Interview Questions:

General Information and Awareness

1. What is your job and level of involvement with bridge design and construction?
2. How long have you been with your organization/doing bridgework?
3. When and how did you become aware of the GRS-IBS technology?
4. Did you or any member of your team participate in any GRS-IBS outreach events, such as Every Day Counts?

   a. If yes, which ones?
   b. How have outreach and demonstration events from FHWA increased your awareness of GRS-IBS technology?

5. How much experience do you have with GRS-IBS?

   a. Has your organization built any GRS Integrated Bridge Systems?
   b. What is your role in the design and construction of GRS Integrated Bridge Systems?

6. What do you feel is the greatest benefit of using the GRS-IBS technology?
7. What do you feel is the greatest challenge of implementing the GRS-IBS technology?

Implementation Guide and Materials

8. Are you aware of the GRS-IBS Implementation Guide and Sample Guide Specifications for Construction from FHWA?

   a. If yes: how did you hear about those materials? How/where did you access them?
   b. If no: would an implementation guide prove useful to your organization? Or would another tool prove more useful and why?

9. To what extent have you adopted the practices described in the design guidance?
   [If none, skip to question 14]
10. Did GRS-IBS Implementation Guide help you to deploy GRS-IBS technology?
   [If no, skip to question 13]

   a. If yes, how?
   b. If no, why?

11. Have the GRS-IBS Implementation Guide, Sample Guide Specifications for Construction, or other materials from FHWA assisted in streamlining your <u>construction efforts</u>?

   a. If yes, please explain how.
   b. If no, please explain why not.

12. Are there differences in quality between GRS-IBS installations before and after using FHWA's guidance?

   a. Do you have supporting data?

13. Did you contact FHWA technical staff for assistance?

GRS-IBS Implementation and Design

14. Has adoption of GRS-IBS technology on one or more projects reduced construction costs?

   a. Do you have supporting data?

15. Is there any instance where it increased costs?

   a. Do you have supporting data?

16. Has adoption of GRS-IBS technology on one or more projects reduced construction delay?

   a. Do you have supporting data?

17. For any projects you support, have you chosen not to use GRS-IBS technology in favor of other technology (e.g. MSE walls specifications)?
    a. If yes, did you use any related guidance?
    b. Why or why not?

Organizational Culture and Support

18. How have and leadership support, at FHWA and within your own organization, influenced GRS-IBS implementation?
19. Which aspects of organization culture—in FHWA and stakeholder organizations—have helped or hindered GRS-IBS adoption?
20. What additional opportunities do you see to adopt GRS-IBS?
21. What organizational barriers do you face in GRS-IBS adoption?

Group B: Agencies who have not used GRS-IBS technology

Dear Mr. /Ms. <State or local official>,

The USDOT Volpe Center is supporting the Federal Highway Administration (FHWA) by conducting conduct a retrospective evaluation of Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) technology. You have been identified as someone whose agency has not used GRS-IBS technology. I would like to schedule a one-hour phone interview with you to learn more about your awareness of and experiences with GRS-IBS technology. Your participation will help us develop a qualitative assessment of the effectiveness of GRS-IBS outreach activities and implementation across the nation.

Attached is a list of interview questions. The evaluation team will be evaluating the following four areas:

Effectiveness of Outreach for Building Awareness of GRS-IBS Technology

Usability of GRS-IBS Guidance

Adoption of GRS-IBS Technology

Organizational Barriers and Opportunities

Please let me know if you are interested in talking with us. If you are, please let me know your availability in the coming weeks and I can schedule a time that is convenient for you.

Thank you for your assistance,

<Volpe Name>

Interview Questions:

General Information and Awareness

1. What is your job and level of involvement with bridge design and construction?
2. How long have you been with your organization/doing bridge work?
3. When and how did you become aware of the GRS-IBS technology?

4. Did you or any member of your team participate in any GRS-IBS outreach events, such as Every Day Counts?
    a. If yes, which ones?
    b. How have outreach and demonstration events from FHWA increased your awareness of GRS-IBS technology?
5. How much experience do you have with GRS-IBS?
    a. Has your organization built any GRS Integrated Bridge Systems?
    b. What is your role in the design and construction of GRS Integrated Bridge Systems?
6. What do you feel is the greatest benefit of using the GRS-IBS technology?
7. What do you feel is the greatest challenge of implementing the GRS-IBS technology?
8. Are you aware of the GRS-IBS Implementation Guide, Sample Guide Specifications for Construction, and related materials from FHWA?
    a. If yes: how did you hear about those materials? How/where did you access them?
    b. If no: would an implementation guide prove useful to your organization? Or would another tool prove more useful and why?
9. Have you used GRS-IBS technology in another agency?
    a. If yes, what was your role?
    b. If no, why not?

GRS-IBS Implementation and Organizational Support

10. Have you evaluated or used the practices described in FHWA's GRS-IBS Implementation Guide or Sample Guide Specifications for Construction?
11. Have you chosen not to use the GRS-IBS guidance in favor of other guidance (e.g. MSE walls specifications)?
    a. If yes, what was the guidance?
    b. Why?
12. How has leadership and vertical support within your organization(s) helped or hindered GRS-IBS adoption?
13. How have support and leadership from FHWA or other outside organizations influenced GRS-IBS implementation?
14. Which aspects of organization culture—in FHWA and stakeholder organizations—have helped or hindered GRS-IBS adoption?
15. What additional opportunities do you see to adopt GRS-IBS?
16. What organizational barriers do you face in GRS-IBS adoption?

Group C: FHWA Division Office and Resource Center Staff

Dear Mr. /Ms. <other>,

The USDOT Volpe Center is supporting FHWA's Office of Research, Development and Technology (RD&T) by conducting a retrospective evaluation of Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) technology. I would like to schedule a one-hour phone interview with you to learn more about your awareness of and experience with GRS-IBS. Your participation will help us develop a qualitative assessment of the effectiveness of GRS-IBS outreach activities and implementation across the Nation.

Attached is a list of interview questions. The evaluation team will be evaluating the following four areas:

Effectiveness of Outreach for Building Awareness of GRS-IBS Technology

Usability of GRS-IBS Guidance

Adoption of GRS-IBS Technology

Organizational Barriers and Opportunities

Please let me know if you are interested in talking with us. If you are, please let me know your availability in the coming weeks and I can schedule a time that is convenient for you.

Thank you for your assistance,

<Volpe Name>

Interview Questions:

General Information and Awareness

1. What is your job and level of involvement with bridge design and construction?
2. How long have you been with your organization/doing bridge work?
3. Did you or any member of your team participate in any GRS-IBS outreach events, such as Every Day Counts?
    a. If yes, which ones?
    b. How have outreach and demonstration events from FHWA increased your awareness of GRS-IBS technology?
4. What was your involvement in the development of GRS-IBS guidance materials?
5. What do you feel is the greatest benefit of using Geosynthetic Reinforced Soils on bridge projects?
6. What do you feel is the greatest challenge of implementing the GRS-IBS technology?

Implementation Guide and Materials

7. Have you evaluated or used the practices described in FHWA's GRS-IBS Implementation Guide or Sample Guide Specifications for Construction?
8. Have you chosen not to use the GRS-IBS guidance in favor of other guidance (e.g. MSE walls specifications)?
    a. If yes, what was the guidance?
    b. Why?
9. What additional opportunities do you see to adopt GRS-IBS?

Organizational Culture and Support

10. How have organizational culture and leadership support, both at FHWA and at stakeholder organizations, influenced GRS-IBS implementation?
11. How has leadership and vertical support within your division helped or hindered GRS-IBS adoption?
12. Which aspects of organization culture—in FHWA and stakeholder organizations—have helped or hindered GRS-IBS adoption?
13. What additional opportunities do you see to adopt GRS-IBS?
14. What organizational barriers do you face in GRS-IBS adoption?

Group D: Other (consultants, researchers)

Dear Mr. /Ms. <other>,

The USDOT Volpe Center is supporting the Federal Highway Administration (FHWA) by conducting a retrospective evaluation of Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) technology. I would like to schedule a one-hour phone interview with you to learn more about your awareness of and experiences with GRS-IBS. Your participation will help us develop a qualitative assessment of the effectiveness of GRS-IBS outreach activities and implementation across the Nation.

Attached is a list of interview questions. The evaluation team will be evaluating the following four areas:

Effectiveness of Outreach for Building Awareness of GRS-IBS Technology

Usability of GRS-IBS Guidance

Adoption of GRS-IBS Technology

Organizational Barriers and Opportunities

Please let me know if you are interested in talking with us. If you are, please let me know your availability in the coming weeks and I can schedule a time that is convenient for you.

Thank you for your assistance,

<Volpe Name>

Interview Questions (Group D1 – Industry Experts):

General Information and Awareness

1. What is your job and level of involvement with bridge design and construction?
2. How long have you been with your organization/doing bridge work?
3. When and how did you become aware of the GRS-IBS technology?
4. Did you or any member of your team participate in any GRS-IBS outreach events, such as Every Day Counts?
    a. If yes, which ones?
    b. How have outreach and demonstration events from FHWA increased your awareness of GRS-IBS technology?

5. How much experience do you have with the GRS-IBS technology?
6. What do you feel is the greatest benefit of using the GRS-IBS technology?
7. What do you feel is the greatest challenge of implementing the GRS-IBS technology?

Implementation Guide and Materials

8. Are you aware of the GRS-IBS Implementation Guide and Sample Guide Specifications for Construction from FHWA?
    a. If yes: how did you hear about those materials? How/where did you access them?
    b. If no: would an implementation guide prove useful to your organization? Or would another tool prove more useful and why?
9. To what extent have you adopted the practices described in the design guidance? [If none, skip to question 14]
10. Did GRS-IBS Implementation Guide help you to support deployment of GRS-IBS technology? [If no, skip to question 13]
    a. If yes, how?
    b. If no, why?
11. Are there differences in quality between GRS-IBS installations before and after using FHWA's guidance?
    a. Do you have supporting data?
12. Did you contact FHWA technical staff for assistance?

Organizational Culture and Support

13. How have organizational culture and leadership support, both at FHWA and at stakeholder organizations, influenced GRS-IBS implementation?
14. How has leadership and vertical support within your organizations helped or hindered GRS-IBS adoption?
15. Which aspects of organization culture—in FHWA and stakeholder organizations—have helped or hindered GRS-IBS adoption?
16. What additional opportunities do you see to adopt GRS-IBS?
17. What organizational barriers do you face in GRS-IBS adoption?

Interview Questions (Group D2 – Consultants and Engineers):

General Information and Awareness

1. What is your job and level of involvement with bridge design and construction?
2. How long have you been with your organization/doing bridge work?
3. When and how did you become aware of the GRS-IBS technology?
4. Did you or any member of your team participate in any GRS-IBS outreach events, such as Every Day Counts?
    a. If yes, which ones?
    b. How have outreach and demonstration events from FHWA increased your awareness of GRS-IBS technology?

5. How much experience do you have with GRS-IBS?
    a. Has your organization built any GRS Integrated Bridge Systems?
    b. What is your role in the design and construction of GRS Integrated Bridge Systems?
6. What do you feel is the greatest benefit of using the GRS-IBS technology?
7. What do you feel is the greatest challenge of implementing the GRS-IBS technology?

Implementation Guide and Materials

8. Are you aware of the GRS-IBS Implementation Guide and Sample Guide Specifications for Construction from FHWA?
    a. If yes: how did you hear about those materials? How/where did you access them?
    b. If no: would an implementation guide prove useful to your organization? Or would another tool prove more useful and why?
9. To what extent have you adopted the practices described in the design guidance? [If none, skip to question 14]
10. Did GRS-IBS Implementation Guide help you to deploy GRS-IBS technology? [If no, skip to question 13]
    a. If yes, how?
    b. If no, why?
11. Have the GRS-IBS Implementation Guide, Sample Guide Specifications for Construction, or other materials from FHWA assisted in streamlining your <u>construction efforts</u>?
    a. If yes, please explain how.
    b. If no, please explain why not.
12. Are there differences in quality between GRS-IBS installations before and after using FHWA's guidance?
    a. Do you have supporting data?
13. Did you contact FHWA technical staff for assistance?

GRS-IBS Implementation and Design

14. Has adoption of GRS-IBS technology on one or more projects reduced construction costs?
    a. Do you have supporting data?
15. Is there any instance where it increased costs?
    a. Do you have supporting data?
16. Has adoption of GRS-IBS technology on one or more projects reduced construction delay?
    a. Do you have supporting data?
17. For any projects you support, have you chosen not to use GRS-IBS technology in favor of other technology (e.g. MSE walls specifications)?

  a. If yes, did you use any related guidance?
  b. Why or why not?

Organizational Culture and Support

18. How have organizational culture and leadership support, at FHWA and within your own organization, influenced GRS-IBS implementation?
19. Which aspects of organization culture—in FHWA and stakeholder organizations—have helped or hindered GRS-IBS adoption?
20. What additional opportunities do you see to adopt GRS-IBS?

What organizational barriers do you face in GRS-IBS adoption?

List of GRS-IBS Events Held During EDC-1, -2, and -3

The evaluation team was tasked with a quantitative assessment of the impacts of EDC on the dissemination of GRS-IBS technology. A list of EDC outreach events (including webinars) provided by the FHWA research team is provided in table 8.

Table 8. List of GRS-IBS events held during EDC-1, -2, and -3.

Date	Location	Type of Event
February 7–9, 2011	Puerto Rico	Workshop
February 2011	Illinois	T.H.E. Conference
May 3, 2011	Hawaii	Workshop
August 17, 2011	North Dakota	NW Geotechnical Conference
August 21, 2011	Maine	NE Geotechnical Conference
August 28, 2011	Pennsylvania	Workshop
October 26, 2011	North Dakota	LTAP Regional Conference
November 8, 2011	Virginia	Workshop
December 8, 2011	On line	Webinar—GRS Part 1
January 5, 2012	Online	Webinar—GRS Part 2
January 18, 2012	Indiana	Workshop
February 2, 2012	Online	Webinar—GRS Part 3
February 16, 2012	Online	Webinar EDC exchange
March 15, 2012	Pennsylvania	Workshop
April 20, 2012	West Virginia	Workshop
May 7, 2012	Pennsylvania	PSATS workshop
May 10, 2012	Wisconsin	Showcase
May 30, 2012	Rhode Island	Workshop
June 1, 2012	New Hampshire	Workshop
June 12, 2012	Pennsylvania	Workshop at IBC
July 31, 2012	Iowa	Workshop
September 26, 2012	Ohio	MW Geotechnical Conference
October 24, 2012	Virginia	SE Geotechnical Conference

Date	Location	Type of Event
November 15, 2012	Phoenix	Tribal summit
February 7, 2013	Wyoming	ASCE local conference
February 26, 2013	New Jersey	Workshop
March 27, 2013	Delaware	Showcase
April 8 2013	Online	FIU Webinar
April 23–24, 2013	North Carolina	Workshop
April 29, 2013	Nebraska	Workshop
May 13, 2013	Vancouver	Workshop
May 15, 2013	Pennsylvania	Workshop
June 6, 2013	Minnesota	Showcase
June 18, 2013	New York	Showcase
July 18, 2013	Pennsylvania	Showcase
August 17, 2013	Utah	Showcase
September 18, 2013	Montana	Showcase
November 13, 2013	Maryland	MSPE Conference
January 30, 2014	Connecticut	Workshop
February 19, 2014	Louisiana	Pre-bid meeting
March 5, 2014	Virginia	Pre-bid meeting
April 22, 2014	Oklahoma	Showcase
April 30, 2014	Puerto Rico	Showcase
May 5, 2014	Ohio	Workshop
May 15, 2014	Florida	Showcase
June 19, 2014	Massachusetts	Showcase
July 16, 2014	Maryland	Showcase
August 19, 2014	Michigan	Showcase
August 28, 2014	Missouri	Showcase
September 10, 2014	Arizona	Workshop
September 30, 2014	Nebraska	Showcase
November 13, 2014	Kansas	Presentation at KU Conference
December 3, 2014	Florida	Workshop at ABC Conference
December 17, 2014	Connecticut	Workshop
January 20, 2015	Arizona	Meeting with DOT/division
April 16, 2015	Idaho	Pre-bid meeting
April 20, 2015	Indiana	Pre-bid meeting
April 30, 2015	Mississippi	Workshop
June 11, 2015	Pennsylvania	Workshop at IBC
June 30, 2015	Online	FIU Webinar on NE IBRD project
July 2015	Pennsylvania	GRS activity and specification meeting

Date	Location	Type of Event
September 15, 2015	Online	Webinar—EDC exchange hosted by LTAP
September 21, 2015	Indiana	Showcase
September 23, 2015	Louisiana	Showcase
September 25, 2015	Nebraska	Workshop
October 13, 2015	Colorado	Showcase
October 21, 2015	South Dakota	Presentation at LTAP Local Roads Conference

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