FHWA Research and Technology Evaluation

Innovative Intersection Design

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Foreword

The Federal Highway Administration's (FHWA) Research and Technology (R&T) Evaluation Program seeks to assess and communicate the benefits of FHWA's R&T efforts; ensure that the organization is expending public resources efficiently and effectively; and build evidence to shape and improve policymaking. FHWA partners with State transportation departments, local agencies, industries, and academia to conduct research on issues of national significance and accelerate adoption and deployment of promising research products.

This report examines how FHWA's investment in innovative intersection research through the Innovative Intersection Design program affected the availability and quality of such research; adoption of innovative intersection designs (IIDs) in the United States; and impacts of those IIDs on road-user safety, traffic mobility, and construction costs of intersections on the U.S. transportation system.[1] The findings of this report should be of interest to engineers, practitioners, researchers, and decisionmakers involved with the research, design, performance, and management of intersections and interchanges.

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Notice

Quality Assurance Statement

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16. Abstract
This report assesses the effects of the Federal Highway Administration's (FHWA's) investment in the Innovative Intersection Design research program and related activities on the availability and quality of such research; awareness and adoption of innovative intersection designs in the United States; and impact of deployed innovative intersection designs on road-user safety, traffic mobility, and construction costs of the U.S. transportation system.(1) The particular intersection and interchange designs researched by FHWA and included in this evaluation are diverging diamond interchanges, restricted-crossing U-turns, displaced left turns, median U-turns, and mini-roundabouts. Although it is difficult measure the effects of specific FHWA activities, the evaluation found strong evidence of FHWA's influence on the acceptance, consideration, and adoption of innovative intersection designs. The findings suggest awareness, adoption, and deployment are higher than they would have been without FHWA research and activities. FHWA laid the foundation for national adoption and deployment of innovative intersection designs by providing empirical evidence of the potential improvements to safety, mobility, and construction costs; increasing stakeholders' awareness of and confidence in them; and contributing to the development of design standards. FHWA's impact is conservatively estimated to have provided road-user safety, traffic mobility, and construction-cost benefits totaling more than $200 million (undiscounted) over the last decade.

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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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	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 (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for 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

Abbreviation	Definition
2010 AII Report	*Alternative Intersections/Interchanges: Informational Report*, 2010
AADT	annual average daily traffic
AID	Accelerating Innovation Deployment
BUILD	Better Utilizing Investments to Leverage Development
CAP-X	Capacity Analysis for Planning of Junctions
CFI	continuous-flow intersection
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CMF	crash modification factor
DDI	diverging diamond interchange
DLT	displaced left turn
DOT	department of transportation
EDC-2	Every Day Counts Round 2
FHWA	Federal Highway Administration
HfL	Highways for Life
HSA	Office of Safety
HSIP	Highway Safety Improvement Program
HQ	Headquarters
IID	innovative intersection design
ICE	Intersection Control Evaluation
ITRE	Institute for Transportation Research and Education
Mini-RA	mini-roundabout
MUT	median U-turn
NCHRP	National Cooperative Highway Research Program
NHI	National Highway Institute
Office of Safety	FHWA Office of Safety
Operations R&D	Office of Operations Research and Development
R&T	Research and Technology
RCUT	restricted crossing U-turn
Resource Center	FHWA Resource Center
ROI	return on investment
ROW	right-of-way
Safety R&D	Office of Safety Research and Development
SHDM	State Highway Design Manual
SHSP	Strategic Highway Safety Plan
SPICE	Safety Performance Intersection Control Evaluation
TIGER	Transportation Investment Generating Economic Recovery
TRB	Transportation Research Board

USDOT	United States Department of Transportation
VSL	value of statistical life

Executive Summary

Purpose of the Evaluation

The purpose of this evaluation is to assess the effects of FHWA's investment in innovative intersection design (IID) research on the availability and quality of such research, adoption of IIDs in the United States, and impacts of those intersections on safety and the operational performance of the U.S. transportation system.

Program Description

This report covers five types of intersections:

- A DDI, also referred to as a double crossover diamond interchange, reverses the directional traffic movements on the crossing arterial roadway.(3)
- An RCUT, also known as a superstreet (when signalized) and a J-turn (when unsignalized), prevents both left turn and through movements from the minor road. Vehicles must first turn right onto the major road, execute a U-turn downstream, and then return to the intersection to complete their journey.(3)
- A DLT, also referred to as a continuous-flow intersection or a crossover displaced left-turn intersection, displaces the left-turn traffic by having that traffic cross over the opposing through movement at a location that is several hundred feet upstream of the major intersection.(3)
- MUTs, also known as Michigan lefts or indirect lefts, have been used extensively in Michigan for decades, and are similar to RCUTs. At an MUT, vehicles cannot turn left at the major intersection but must instead continue through the intersection, make a U-turn several hundred feet downstream, and travel back to the intersection to make a right on the crossroad.(3)
- Mini-RAs are a smaller form of a roundabout where the central island is fully mountable.(4)

FHWA began conducting IID research in the early 2000s through the Office of Safety Research and Development (Safety R&D) team. Safety R&D staff explored the benefits of the various IIDs and published a few papers on the topic of IIDs, culminating in the publication of the *Alternative Intersections/Interchanges: Informational Report* (herein the *2010 AII Report*) in 2010.(3) Following the publication of the *2010 AII Report*, IID activities continued, and the program was chosen for inclusion in Every Day Counts Round 2 (EDC-2).(5) As part of EDC-2, four intersection guides, which were published in 2014, were developed for DDIs, RCUTs, DLTs, and MUTs.(6–9) FHWA has continued to develop higher-quality informational material and refine the state of the practice for IIDs. FHWA has also promoted IIDs through various activities and materials, including workshops and peer exchanges.

Methodology

The evaluation team created a logic model that identifies potential relationships between five evaluation areas to effectively investigate the outcomes and impacts of FHWA IID research. The team developed hypotheses under each evaluation area and defined testable performance measures for each evaluation. These evaluation areas are the following:

- Evaluation Area 1: FHWA decisionmaking processes regarding selection and promotion of research.
- Evaluation Area 2: Availability and reliability of IID road-user safety, traffic mobility, and construction-cost data.
- Evaluation Area 3: Change in awareness and knowledge of and attitudes toward IIDs.
- Evaluation Area 4: Deployment of IIDs.
- Evaluation Area 5: Safety, mobility, and construction-cost impacts of IIDs.

As described in the main body of this report, the evaluation team used a mix of qualitative and quantitative methods, including a literature review, data analysis, and semistructured interviews, to assess their hypotheses. The evaluation team conducted interviews with FHWA staff, intersection-design researchers, State departments of transportation (DOTs), and intersection-design consultants to gather information to enhance their understanding the scope and extent of FHWA activities, complementing the other analyses within the evaluation. The evaluation team reviewed a range of documents, including FHWA program documents (internal and published) and IID funding through Federal programs, intersection-design and -evaluation research published by FHWA and non-FHWA entities, State-level planning and informational materials, including State resources. The evaluation team computed a return-on-investment (ROI) analysis for FHWA IID research based on the extent of IID deployments and average safety, mobility, and construction-cost savings of IIDs as documented in safety and performance evaluations.

Findings

The findings for the evaluation of IID research highlighting evidence from each evaluation area are summarized as follows:

Evaluation Area 1: FHWA decisionmaking processes regarding selection and promotion of research.

- Finding 1a: The program leveraged available inputs for identifying IIDs for inclusion in the program as well as inputs for research efforts. FHWA promotional activities, specifically EDC, followed standards and procedures to identify the IID program for inclusion in the EDC-2 program.
- Finding 1b: FHWA R&T followed internal and informal procedures to identify intersection safety as a critical area of research and to develop the IID program portfolio to respond to that need.(1)

Evaluation Area 2: Availability and reliability of IIDs safety, mobility and construction-cost data.

- Finding 2a: Initial FHWA contributions increased the availability of domestic IID information by synthesizing the limited safety and design research that existed as well as partnering with outside researchers to create new research papers on IID-related topics. In turn, these outputs clarified and focused the research questions for the domestic research community, with which FHWA actively partnered and supported.

- Finding 2b: FHWA R&T's research activities from the early 2000s and the 2010 AII Report led to a significant increase in published material on IIDs in the United States.(3)

Evaluation Area 3: Change in awareness and knowledge of and attitudes toward IIDs.

- Finding 3a: FHWA research, culminating in the 2010 AII Report, increased the availability of information on IIDs in the United States.(3) These products increased awareness of IIDs by providing interested States and stakeholders with more information on how to utilize innovative designs and an FHWA endorsement of the designs.
- Finding 3b: Safety R&D worked closely with the FHWA Office of Safety (herein the Office of Safety) and the FHWA Resource Center (herein the Resource Center) to conduct sustained outreach, including making recommendations within FHWA, such as adding certain IIDs as Proven Safety Countermeasures.(10) FHWA's outreach also included trainings, workshops, and peer exchanges, all of which helped increase States' awareness of IIDs as viable intersection options.

Evaluation Area 4: Deployment of IIDs.

- Finding 4a: FHWA activities and research increased the total number of IIDs through continued agency funding and activity, producing further research materials, promotion, assistance, and funding. FHWA research aimed to increase the availability of design specifications, and standards augmented the resources available for States to use in creating their own design standards and implementing IIDs.
- Finding 4b: FHWA actively accelerated the early adoption of IIDs by leading the promotion of IIDs, developing safety and performance research, and specifically addressing the needs of the early adopters through workshops and technical assistance.
- Finding 4c: FHWA contributed to an increase in the amount of funding spent on IIDs relative to other traditional intersections.
- Finding 4d: FHWA's outreach efforts improved the selection and application of IIDs in the United States.

Evaluation Area 5: Safety, mobility, and construction-cost impacts of IIDs.

- Finding 5a: IIDs led to a reduction in construction costs compared to conventional intersection designs.
- Finding 5b: IIDs led to a reduction in the total number of crashes, the number of fatal and injury crashes, and the severity of injury crashes at intersections and to a reduction in the number of crashes downstream of IID intersections.
- Finding 5c: IIDs led to improved operational performance at intersections.
- Finding 5d: The impact of FHWA's IID program was estimated using an ROI analysis based on the extent of IID deployments, conservative assumptions about the role of FHWA in causing these deployments, and information about the average benefits for each IID. The average benefits of each IID were calculated using published evaluations of safety, mobility, and construction-cost savings of IIDs relative to conventional intersection designs.

Recommendations

FHWA IID research and related activities took place from 2000 to 2019 and spanned the range of the technology-adoption lifecycle. The number of IID deployments significantly increased over this period. However, despite this significant growth, room for improvement remains. To further increase the value of FHWA safety research to FHWA and its wider community of partners and stakeholders, the evaluation team offers the following recommendations for FHWA's consideration:

- Recommendation 1: FHWA should consider working with State or private partners to develop a more reliable, comprehensive national map of intersections that identifies the intersection design and other key features of the intersection that are relevant for researchers and practitioners.
- Recommendation 2: FHWA should promote consistency in nomenclature and definitions whenever possible and carefully consider the marketability of various terms.
- Recommendation 3: Building on the existing FHWA Focused Approach to Safety, which is a data-driven approach to selecting Intersection Focus States, FHWA should consider developing an additional level of strategic targeting that considers qualitative aspects of technology diffusion, such as information-sharing networks among States and technology champions.
- Recommendation 4: FHWA should consider standardizing the development and timing of intersection-design guidance for nonpassenger-vehicle road users or groups that may be impacted by IIDs, such as pedestrians, bicyclists, and nonstandard vehicles.

Conclusion

This evaluation found strong evidence that FHWA research and outreach activities aided in State and local agencies' acceptance, adoption, and deployment of IIDs, over and above what would have occurred in the counterfactual of no FHWA research or outreach activities. FHWA substantially increased the amount (and, in some cases, the quality) of IID research, demonstrating the safety, mobility, and construction-cost benefits of IIDs relative to conventional intersection- and interchange-design types. FHWA's outreach efforts in technical assistance and workshops increased awareness of IIDs and increased the adoption of IIDs as safety countermeasures across a number of States. FHWA's leadership in researching and promoting IID types through contributing to developing national design standards for their implementation and identifying IIDs as FHWA Safety Countermeasures increased confidence in IIDs among stakeholders.

FHWA successfully leveraged existing resources, such as research, and IID deployments to produce high-quality research products. FHWA R&T IID-research products were produced in coordination with stakeholders across FHWA and State DOTs, especially across Safety R&D, the Office of Safety, and the Resource Center. FHWA provided a consistent message about the benefits of IIDs by including them in major initiatives and programs, including EDC-2 and the 2017 round of Proven Safety Countermeasures.(5,10) FHWA further enhanced its influence and reach on IIDs by actively participating and exchanging with the research and stakeholder communities, which included Transportation Research Board papers and presentations along with training and technical assistance for transportation professionals. FHWA also provided materials, such as brochures and videos, to help State and local agencies convince the public and other stakeholders that IIDs were worth deploying. These efforts helped change awareness and acceptance of IIDs across the United States.

IIDs have seen considerable growth in the total number deployed in the past 20 years. However, areas of potential deployment growth remain for IIDs. The number of intersections and interchanges that are constructed or reconstructed each year are expected to grow as aging infrastructure needs to be replaced. IIDs like DDI and DLT can be used as a stopgap to provide safety and mobility benefits in the short term while funding for larger intersection and interchange reconstructions is unavailable. RCUTs, MUTs, and mini-RAs are low-cost solutions for intersections with safety issues and can be used in thousands or potentially hundreds of thousands of locations across the United States. To increase the number of IIDs and to ensure they are deployed only in contexts in which they are the best alternative, FHWA should continue cooperating and partnering with researchers across the safety discipline and the broader stakeholder community to ensure States are supported from early research through awareness and implementation.

The evaluation team's findings underscore how important FHWA national leadership on a specific topic, foundational and ongoing research, and the dissemination of resources are to educating and supporting internal and external stakeholders, leaders, and other decisionmakers.

1. Introduction

1.1 Evaluation Purpose

The Federal Highway Administration (FHWA) initiated the Research and Technology (R&T) Evaluation program to help FHWA leadership and program and project managers communicate the impacts of their research, ensure resources are being expended effectively, and build evidence to inform future projects and policymaking.

Since 2014, the R&T Evaluation program has worked with nine FHWA offices to identify and conduct evaluations. The FHWA Safety Program managers identified specific innovative intersection design (IID) research to include in the program, which included diverging diamond interchanges (DDIs), restricted-crossing U-turns (RCUTs), displaced left turns (DLTs), and median U-turns (MUTs). A related effort is FHWA's roundabout research, which was covered in an earlier report from the R&T Evaluation program.(11) Roundabouts will not be covered in this evaluation, but one of their successors, mini-roundabouts (mini-RAs), will be covered in this evaluation along with the other four IIDs.

The goal of the IID-research efforts was to reduce the number and severity of crashes at intersections as well as improve the performance of intersections in the United States. These efforts help FHWA advance the U.S. Department of Transportation's (USDOT's) goals and the FHWA Strategic Plan Objectives of safety, infrastructure, and innovation.(12)

The purpose of this evaluation is to bring together information on the adoption and impacts of IIDs with information on the timing, type, and levels of FHWA research results, data, and other resources. The evaluation design emphasizes understanding FHWA's contribution to the availability of IID-research results and data, its influence on changing internal and external stakeholders' awareness of IIDs, and its contribution to increasing adoption of IIDs in the United States. The evaluation ends with a return-on-investment (ROI) analysis of the IID program that compares the net benefits of incremental deployment of IIDs as a result of FHWA's interventions, in terms of safety and mobility benefits and construction-cost savings, against the total expenditures deployed by FHWA in the IID program. For the purposes of the ROI measure, nonmarket impacts, such as time savings and avoided injuries are converted to dollar terms using monetization factors found in USDOT guidance.

1.2 Program Background

This evaluation covers five types of intersections. As noted under Evaluation Purpose, roundabouts are not a part of this evaluation given that an evaluation report on the topic has already been published.(11) However, it is important to consider FHWA's work on intersection design in the context of roundabouts, which are arguably the lead alternative intersection design pioneered by FHWA. Their work on roundabouts began earlier than their work on the designs on which this evaluation focuses, and this earlier work on roundabouts may have laid the groundwork for easier acceptance of other alternative designs. While the specifics of the roundabout research program will not be discussed in this evaluation, except in the context of mini-RAs, the evaluation team acknowledges that the roundabouts program likely had spillover effects for the IID program.

The five intersection designs that are covered in this evaluation are DDIs, RCUTs, DLTs, MUTs, and mini-RAs. This section begins by describing the different IIDs before detailing the specifics of FHWA's IID program.

DDIs, also referred to as a double crossover diamond interchanges, reverse the directional traffic movements on the crossing arterial roadway. The first DDI in the United States opened in Springfield, MO, on June 22, 2009. Prior to this installation, the only known DDIs were in France.[3] Figure 1 shows a DDI in France.

Figure 1. Image. DDI in Perreux-sur-Marne, France.[3]

RCUTs, also known as superstreets (when signalized) or J-turns (when unsignalized), prevent both left turns and through movements from the minor-road. A traffic engineer named Richard Kramer published on the RCUT concept in the early 1980s; he is the first person known to have done so.[1] Vehicles from the minor road must first turn right onto the major road, execute a U-turn downstream, and then return to the intersection to complete their journey.[3] Figure 2 shows an RCUT.

Figure 2. Image. RCUT intersection in Loris, SC.

DLTs, also referred to as continuous-flow intersections (CFIs) or crossover displaced left-turn intersections, displace the left-turn traffic by having that traffic cross over the opposing through movement at a location that is several hundred feet upstream of the major intersection.(3) There were only a few DLTs constructed in the United States prior to FHWA's investment in IIDs. The first DLT intersection was constructed in Haddon Township, NJ, prior to 1995 (the exact year is unknown).(8) Figure 3 shows a DLT.

Figure 3. Image. Four-legged DLT intersection in West Valley City, UT.(8)

MUTs, also known as Michigan lefts or indirect lefts, have been used extensively in Michigan for decades; other early adopters include Florida, Maryland, New Jersey, and Louisiana.(3) At an MUT, vehicles cannot turn left at the major intersection and must instead continue through the intersection, make a U-turn several hundred feet downstream, and travel back to the intersection to make a right on the crossroad.(3) The key difference between an MUT and an RCUT is that an MUT allows the minor street through movement while the RCUT redirects the minor street through movement. Figure 4 shows an MUT in Michigan.

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Figure 4. Image. MUT in Southfield, MI.

Mini-RAs are a smaller form of a roundabout, where the central island is fully mountable.(4) Mini-RAs were invented by a U.K. engineer and researcher named Frank Blackmore in 1969, and the first known mini-RA was installed in Peterborough in the United Kingdom in 1969.(13) Mini-RAs became common in the United Kingdom and France before starting to appear in the United States in recent years.(14) Mini-RAs have all the same operating principles of modern roundabouts in a smaller format. Figure 5 shows a mini-RA.

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Figure 5. Image. Mini-RA in Maryland.(13)

FHWA began conducting IID research in the early 2000s through the Office of Safety Research and Development (Safety R&D) team. Safety R&D staff explored the benefits of the various IIDs and published a few papers on the topic of IIDs. In 2009, FHWA published TechBriefs on four of the IIDs of this evaluation, with DLTs receiving two TechBriefs—one for the interchange form and one for the intersection form.(15–19) The first major milestone in IID work, however, was the publication of the *Alternative Intersections/Interchanges: Information Report* (herein the *2010 AII Report*) in 2010.(3) The *2010 AII Report* mainly covered six alternative designs, although several other designs received smaller mentions.

Following the publication of the *2010 AII Report*, IID activities continued and the program was chosen for inclusion in Every Day Counts Round 2 (EDC-2).(5) As part of EDC-2, four intersection guides, which were published in 2014, were developed for DDIs, RCUTs, DLTs, and MUTs.(6–9) Work also continued on creating articles for *Public Roads* as well as papers for various research journals. FHWA has continued to develop higher-quality informational material and refine the state of the practice for IIDs. FHWA has also promoted IIDs through various activities and materials, including workshops and peer exchanges. Table 1 gives a timeline of IID activities, deployments, and FHWA outputs.

Table 1. Timeline of FHWA IID-related activities and outputs as well as major IID deployments.

Year	FHWA Activities and Outputs	Deployments and Milestones Outside FHWA
Pre-2000	FHWA R&D staff begin research on roundabouts and mini-RAs	RCUT: First deployment in Troy, MI (in 1990s, exact year unknown)[7] DLT: First deployment in Haddon Township, NJ (pre-1995, exact year unknown)[8] MUT: First deployments as early as the 1960s in Michigan[3] Mini-RA: First deployment in Columbia, MO (1995)[20]
2000	Mini-RA: *Roundabouts: An Informational Guide*[4] "Advantages of the Split Intersection" (*Public Roads*)[21]	–
2001	–	–
2002	FHWA R&D staff begin work on program for alternative intersection designs MUT: *Median U-Turn Design as an Alternative Treatment for Left Turns at Signalized Intersections*, coauthored by staff of FHWA's Office of Safety[22]	–
2003	DDI: *Diverging Diamond Interchange and Double Crossover Intersection – Vehicle and Pedestrian Performance*, coauthored by Bared[23]	DDI: Concept introduced in the United States by Gilbert Chlewicki; similar concepts have been deployed in France since the 1970s[24]
2004	DLT: *Design and Operational Performance of Crossover Displaced Left-Turn Intersections*, coauthored by Bared[25] All: *Signalized Intersections: Informational Guide* [26]	–
2005	DDI: *Design and Operational Performance of Double Crossover Intersection and Diverging Diamond Interchange*, coauthored by Bared[27] "Improving Signalized Intersections" (*Public Roads*)[28]	–
2006	–	–
2007	DDI: *Tech Brief: Drivers' Evaluation of the Diverging Diamond Interchange*[29] MUT: *Synthesis of the Median U-turn Intersection Treatment*[30]	–
2008	Roundabouts added as a Proven Safety Countermeasure[10]	–

Year	FHWA Activities and Outputs	Deployments and Milestones Outside FHWA
2009	DDI: *Tech Brief: Diverging Diamond Interchange*(15) RCUT: *Tech Brief: Restricted Crossing U-Turn*(16) DLT: *Tech Brief: Displaced Left-Turn*; and *Evaluation of Sign and Marking Alternatives for Displaced Left-Turn Intersections*(17,18,31) MUT: *Tech Brief: Median U-Turn*(19) "A New Left Turn" (*Public Roads*)(32)	DDI: First deployment in Springfield, MO(6)
2010	All: *Alternative Intersections/Interchanges: Informational Report*(3) Mini-RA: *Roundabouts: An Informational Guide, 2nd Edition*(33) Mini-RA: *Mini-Roundabouts Technical Summary*(14) "The Double Crossover Diamond" (*Public Roads*)(34) "Along the Road" (*Public Roads*)(35) "Doing More With Less" (*Public Roads*)(36)	—
2011	"Transportation Operations Laboratory: Article I – Modeling Transportation Systems: Past, Present, and Future" (*Public Roads*)(37) "Prizing Excellence" (*Public Roads*)(38)	—
2012	All: EDC-2 Promotion(5) RCUT: *Field Evaluation of a Restricted Crossing U-turn Intersection*(39) "They're Small But Powerful" (*Public Roads*)(40) "Along the Road" (*Public Roads*)(41)	—
2013	All: EDC-2 Promotion(5) All: *Signalized Intersections: Informational Guide, 2nd Edition*(42) "Why Drivers Do What They Do" (*Public Roads*)(43) "Design at the Crossroads" (*Public Roads*)(44) "Every Day Counts: The Second Phase" (*Public Roads*)(45) "North Carolina Steps Boldly Out of its Comfort Zone" (*Public Roads*)(46)	—
2014	All: FHWA IID promotional videos, including case studies(47) DDI: *Field Evaluation of Double Crossover Diamond Interchanges*(48) DDI, DLT, MUT, RCUT: Informational Guides(6–9) "The ABCs of Designing RCUTs" (*Public Roads*)(49) "Guest Editorial: Spotlight on Safety Solutions" (*Public Roads*)(50)	—

Year	FHWA Activities and Outputs	Deployments and Milestones Outside FHWA
2015	DDI: *Empirical Before-After Comparison of the Operational Performance of Diverging and Conventional Diamond Interchanges*, Analysis of data collected for FHWA project DTFH61-10-C-00029(51) "Internet Watch" (*Public Roads*)(52)	—
2016	"Targeting the Crosshairs" (*Public Roads*)(53) "Along the Road" (*Public Roads*)(54) "Building a Culture of Innovation" (*Public Roads*)(55) "Guest Editorial: Building Safety into the Infrastructure" (*Public Roads*)(56) "The Evolution of Geometric Design" (*Public Roads*)(57)	—
2017	MUT, RCUT: *Reduced Conflict Left-Turn Intersections (Proven Safety Countermeasure)*(10) RCUT: *Safety Evaluation of Signalized Restricted Crossing U-Turn Intersections*(58) "Doubling Down on Safety Innovations" (*Public Roads*)(59) "Roundabouts Coming Full Circle" (*Public Roads*)(60)	—

—Not applicable.

2. Evaluation Design

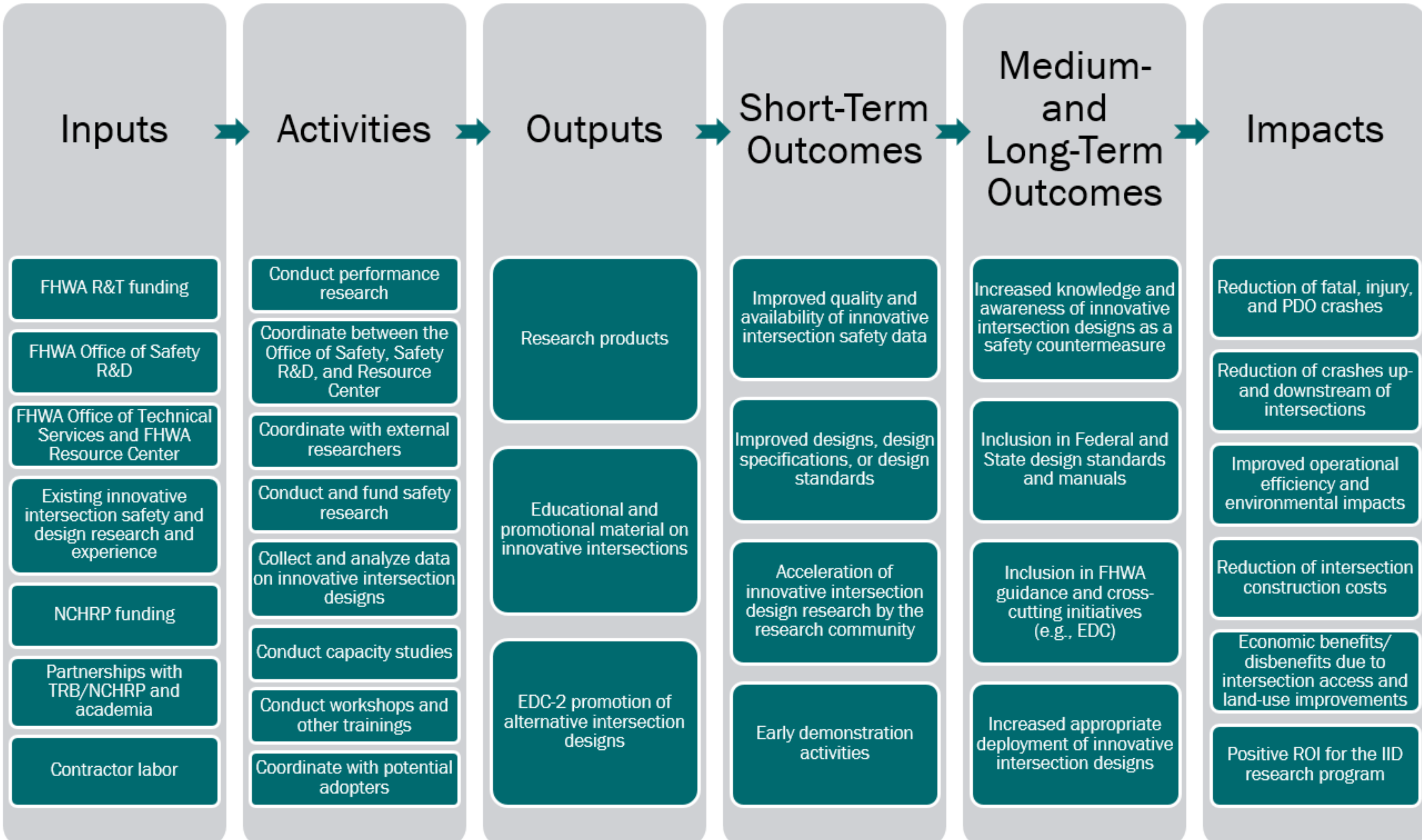
In 2018, the evaluation team met with key technical staff of FHWA's Office of Safety Technologies, Office of Safety R&D, the Intersections Research Program of the Safety R&D Roadway Team, and the Resource Center's Safety and Design team to define core evaluation hypotheses and the evaluation scope of IID research–program activities. In particular, the evaluation team sought to understand program goals, refine program activities and the timeframe assessed, gather available information, and identify which key stakeholders to include. After gathering and reviewing this information, the evaluation team selected evaluation methodologies most appropriate for the primary hypotheses.

2.1 Logic Model

A logic model is a logical series of statements that links program components (inputs, activities, outputs, outcomes, and impacts) in a chain of causality. It is not intended to be a comprehensive or linear description of all program processes and activities but rather to clearly show how program stakeholders expect program activities to affect change. The logic model helps explain the theories of change that drive the design of a program and provides hypotheses (i.e., if this is done, then that will happen) that can be tested in an evaluation. The evaluation team built this evaluation's logic model based on discussions with key FHWA program staff, a review of a previous and related evaluation (*FHWA Research and Technology Evaluation: Roundabout Research Final Report*), and a review of program documents.(11) Figure 6 is the IID-research logic model.

The logic model was used as a first step to designing this evaluation; the team identified a primary hypothesis, secondary hypotheses, and supporting performance measures within each evaluation area to assess how program inputs and activities achieved their intended outcomes and impacts. The discussion that follows in chapter 4 groups these associated secondary hypotheses around related findings.

Table 2, following the logic model, summarizes the primary and secondary hypotheses and some of the key performance measures. The evaluation-component column corresponds with the logic-model categories of short-term outcomes, medium- and long-term outcomes, and impacts.



Source: FHWA.

Figure 6. Graphic. FHWA R&T IID-research logic model.

Table 2. IID-evaluation hypotheses and performance measures.

Evaluation Area	Key Hypotheses	Key Performance Measures
1: FHWA decisionmaking processes regarding selection and promotion of research.	• FHWA has standards and procedures for selecting research areas and products for promotion that maximize ROI. They followed such procedures in selecting IIDs for promotion. • FHWA provided and leveraged inputs to IID research. • FHWA IID-research selection is based on State and local agency needs, targeting designs that have wide application or critical value.	• Description of the resources FHWA used as inputs to produce activities and outputs. • Description of FHWA standards and procedures for selecting research areas. • Description of FHWA's selection of IIDs for research. • Description of FHWA's selection of IIDs for promotion.
2: Availability and reliability of IIDs safety, mobility, and construction-cost data.	• FHWA improved the availability and quality of IID-related safety and performance data for researchers and State and local transportation agencies. • FHWA research advanced the development of design standards for IIDs. • FHWA accelerated research among research community on IIDs. • FHWA research was used by other researchers to advance availability and quality of data.	• Number of IID publications by FHWA staff or funded by FHWA. • Number of citations of FHWA IID publications. • Citations of FHWA IID publications in non-federally funded IID research. • Qualitative assessment from stakeholders. • Number of citations of FHWA IID publications in Federal and State design manuals. • Number of citations of FHWA IID publications that extend IID research (e.g., further design development).
3: Change in awareness and knowledge of and attitudes toward IIDs.	• FHWA IID-related research and outreach changed the level of awareness of IIDs as safety countermeasures in the United States. • FHWA IID-related research influenced the acceptance of IIDs as safety countermeasures by other FHWA programs. • FHWA IID-related research promoted acceptance of IIDs as safety countermeasures by transportation decisionmakers and practitioners. • FHWA IID-related outreach efforts influenced the acceptance of IIDs as safety countermeasures by transportation decisionmakers and practitioners.	• Number of FHWA IID-research publications. • Citations of FHWA IID-research publications. • Number of page visits or downloads of FHWA IID-related informational data and of FHWA IID related research. • Number of State and local agencies attending FHWA-supported IID-deployment demonstrations. • Number of State and local agencies attending EDC IID events. • Number of FHWA programs adopting IIDs in policies or guidance. • Change in FHWA IID-related policy or guidance. • Number of DOTs that FHWA IID-related outreach efforts helped to overcome barriers to IID acceptance. • Number of States with IID guidance in State Highway Design Manuals, State Highway Safety Plans, and similar materials. • Number of States adopting IID in policies or guidance. • Changes in State IID-related policies or guidance. • Number of States where FHWA IID-related outreach efforts helped transportation decisionmakers and practitioners to overcome barriers to IID acceptance.

Evaluation Area	Key Hypotheses	Key Performance Measures
4: Deployment of IIDs.	• FHWA accelerated early deployment of IIDs through outreach activities (number of IIDs deployed in early-adopter states that received early technical assistance). • FHWA contributed to an increase in number of IIDs deployed in the United States and an increase in the number of State and local agencies deploying IIDs. • FHWA contributed to an increase in the amount of funding spent on IIDs. • FHWA's outreach efforts have improved the selection and application of IIDs in the United States.	• Number of FHWA-supported deployments of IIDs. • Number of State and local agencies deploying IIDs each year. • Annual number of State and local agencies receiving and requesting IID resources and support. • Number of IIDs deployed each year. • Annual total of Federal grants awarded to IID projects. • Annual list of grant programs accepting IID-related project applications. • Qualitative assessment of IID deployment in the United States.
5: Safety, mobility, and construction-cost impacts of IIDs.	• IIDs led to a reduction in the total number of crashes, the number of fatal crashes, and the number and severity of injury crashes at intersections and to a reduction in the number of crashes downstream of IID intersections. • IIDs led to reduction in environmental impacts from intersections. • IIDs led to improved operational performance at intersections. • IIDs led to a reduction in construction costs compared to conventional intersection designs. • IID research has a net positive ROI.	• Safety effectiveness of IIDs and IID alternatives. • Number and severity of crashes at IID intersections. • Number and severity of crashes at intersections up- and downstream of IIDs. • Emissions and other environmental-impact (e.g., noise and water runoff) reductions of IIDs and IID alternatives. • Travel-time performance of IIDs and IID alternatives. • Construction costs of IIDs and IID alternatives. • Number of deployed IIDs. • Total cost of FHWA IID activities, outputs, and resources. • Average net benefits of IID deployment relative to IID alternatives.

3. Evaluation Methodology

The evaluation team used the following data-collection methodologies to inform this evaluation: literature and document review; quantitative data analysis; and semistructured interviews.

3.1 Literature and Document Review

A substantial portion of this evaluation was conducted through a review of literature, documents, and other sources regarding IIDs from the early 2000s to the present. The evaluation team used internet searches and citation mapping to identify all relevant FHWA-published literature and broader IID-related literature to help assess the influence of FHWA research and to understand the benefits of IID installations. The following section, Document Review, uses the terms "literature" to refer to scholarly publications and "document review" to refer to primary-source records, which are documents that FHWA produced for public consumption or for internal uses. The evaluation team collected archived information from the Transportation Research Board (TRB), documents and records from the Office of Safety, and general media articles related to IIDs for review and analysis. The evaluation team also conducted a State-by-State review of highway manuals, websites, and documentation.

Document Review

The evaluation team collected a variety of documents related to IIDs and used diverse methods to analyze and understand them.

FHWA Document Review

The evaluation team reviewed a wide variety of IID-related FHWA outputs, including FHWA-funded research, outreach documentation and materials, and program documents.

The evaluation team searched for FHWA-funded IID research through the evaluation team's library, consultation with FHWA's Office of Operations Research and Development (Operations R&D), and other publicly available sources, such as Transportation Research International Documentation and Google® Scholar™.(61) Collected data included title, year published, author(s), journal, publisher, the IID(s) on which the paper focused, and document type (e.g., report, journal article, and conference paper).

TRB Programs

To understand the growth of IIDs as a research topic among the transportation community, the evaluation team collected and reviewed the TRB Annual Meeting Final Programs from 1993 to 2019. The evaluation team searched for keywords relating to IIDs, including, but not limited to, "alternative intersections," "intersection design," "diverging diamond," "restricted crossing," "median U-turn," "displaced left turn," "continuous flow," "superstreet," and "mini-roundabout." Any session, poster, or paper that contained at least one of these keywords was then further reviewed to determine whether it was actually relevant to IIDs. The evaluation team tracked whether the presenter(s) were affiliated with FHWA. This method captured most of the presentations made by FHWA staff but may have overlooked some work funded by FHWA and presented by independent researchers.

State SHSPs, SHDMs, and State DOT Websites

To assess the influence of FHWA research and outreach on State departments of transportation (DOTs), the evaluation team reviewed State DOT websites, Strategic Highway Safety Plans (SHSPs), and State Highway Design Manuals (SHDMs) for all 50 States plus Washington, DC. SHSPs were gathered for all States and years available as of July 2019. The evaluation team studied the documents for references to FHWA IID publications.

All available SHDMs were collected for all States in July 2019. SHDMs were analyzed for content related to IIDs and references to FHWA IID materials.

State DOT websites were reviewed for IID materials and for references to FHWA IID materials in July 2019.

3.2 Literature Review

The following subsections detail the different methods used in the literature review.

IID Impacts Literature

To understand the range of impacts of adopting IIDs, the evaluation team relied primarily on existing literature. The evaluation team reviewed safety and performance evaluations of IIDs to analyze the benefits of IID deployment in the United States. The evaluation team did not directly correlate the role FHWA research has had on the numbers of IIDs to particular deployments in the United States. The goal of this review was to understand the overall impact IIDs have had on safety, mobility, and construction costs of intersections.

Citation Analysis

In addition to research collected for the FHWA document review, the evaluation team used qualitative analysis software to review the collected literature for citations to relevant FHWA publications. The analysis software allows users to upload documents, code documents by user-defined categories, and code spans of text in those documents using a user-defined coding scheme. The evaluation team coded literature where those literature cited or referenced FHWA IID publications, and produced analysis of the extent of citations of FHWA publications across the literature.

To assess the impact of all FHWA-primary and -sponsored work, the evaluation team examined how many IID-related research studies FHWA published and funded compared with the number of IID-research products focused on the United States. The *2010 AII Report* was FHWA's first major publication on the topic of IIDs, but a number of smaller works, which were also captured in this analysis, were published before then.

3.3 Data Analysis

When available, the evaluation team used quantitative analysis to better understand funding, counts, and impacts of IIDs. The evaluation team intended to use website analytics and download statistics to supplement this evaluation, but the relevant FHWA data, while partially available, were not formatted to allow ready analysis.

Federal Discretionary Grant-Funding Data

The evaluation team analyzed multiple FHWA funding programs under which IIDs are eligible, including the Highway Safety Improvement Program (HSIP) (Office of Safety), Congestion Mitigation and Air Quality Improvement Program (CMAQ) (Office of Planning, Environment, and Realty), Transportation Investment Generating Economic Recovery (TIGER), Discretionary Grants, and Better Utilizing Investments to Leverage Development (BUILD) Transportation Discretionary Grant program.(62–64)

The evaluation team reviewed the HSIP database for IID-related content published between 2009 and 2017. HSIP data provide information on the number of projects and the cost, year, and location (State) of projects. Information specific to the construction of IIDs is available only at the subcategory level; however, no deployments were authorized under this funding program with IIDs in the subcategory level.

The evaluation team reviewed CMAQ data produced between 1992 and 2019 (all available years) and considered three variables: State, funding amount, and year. Analyses examined the amount, growth, and State-by-State distribution of funds for IID deployments. Connections to other FHWA efforts are highlighted when appropriate and the number of IIDs funded through these programs (as a total of IIDs deployed in a year) is considered.

The evaluation team reviewed FHWA's discretionary funding programs for winning projects that included an IID as part of the project components. The grants reviewed included TIGER, BUILD, the Accelerating Innovation Deployment (AID) Demonstration Program, and FHWA Highways for Life (HfL).(64–66) Within descriptions and reports, the evaluation team used the following search terms: "mini," "roundabout," "diverging," "DDI," "RCUT," "MUT," "DLT," "CFI," "restricted crossing," "displaced," and "U-turn" to identify projects with IID components.

IID Inventory Data

To analyze the growth of IID deployment in the United States, the evaluation team used existing online databases of IID deployment for each of the five IIDs considered in this evaluation. These databases were supplemented by Google searches for IID-deployment announcements and other resources, such as FHWA documents and literature reviews. Mini-RA-deployment data were collected through the Kittelson & Associates Roundabouts Inventory Dataset because the data are collected on an ongoing basis and because the dataset provides the most accurate information available on mini-RA adoption.(20) DDI-deployment data were collected from two primary sources, which include Diverging Diamond Interchange's deployment database and IID-deployment data (available online) maintained by the Institute for Transportation Research and Education (ITRE).(67,68) Diverging Diamond Interchange's deployment data are actively maintained by their team and were last updated in June 2019. The ITRE Alternative Intersection and Interchanges database was last updated in 2016. In addition to DDI deployments, the ITRE Alternative Intersection and Interchanges database includes deployment data for RCUTs, MUTs, and DLTs (known as CFIs in the database) through 2016.

As there is no national register of IID deployment, IID-deployment data collection mostly relies on review of deployment announcements made through local news articles. Data collection, therefore, may not be completely representative of all deployment activities that have occurred in the United States, where such activities are not publicized widely. Thus, the deployment data in this evaluation are likely underestimated. Deployment data in this evaluation were verified, when possible, using Google Street View™, which captures pictures of roadways with time-stamp information. In many cases, deployment of an IID could not be identified in a particular year but could be identified in a given period. In those cases, the deployment was included in the analysis as occurring at the midpoint of the years as indicated by the Google Street View evidence.

A recent National Cooperative Highway Research Program (NCHRP) report, *Alternative Intersection Design and Selection*, was used to verify the evaluation-deployment scan, and the results of that report are used throughout the detailed report findings.(69) This NCHRP report surveyed States to identify the number of roundabouts, superstreets (RCUTs), MUTs, CFIs, DDIs, and other IIDs they had deployed; responses ranged from 0, 1–5, 6–10, 11–25, 26–50, and 51 or greater deployments. The deployment scan of this evaluation was consistent with NCHRP's reported number of IIDs deployed for 33 States, meaning the deployment scan identified numbers of deployments of each IID in each State that were consistent with the State-reported ranges of deployments. For the 17 States for which the deployment scan did not identify a deployment figure within the reported range, this report discusses the discrepancies and provides an estimate of the potential additional IIDs.

This analysis focuses on growth and timing of growth in the number of IIDs deployed per year, and the distribution of IIDs by individual State. When available, deployment-data variables used in the analysis included IID, design features, State, county, status (existing or removed), and year.

Safety, Mobility, and Construction-Cost Impact Analysis

The evaluation team reviewed publicly available safety evaluations of IIDs to collect safety-performance data. Safety-performance results from these evaluations were converted into crash modification factors (CMFs). The average CMF for each IID was applied to each IID deployment to estimate the total injury and fatal crashes averted and societal cost savings in the United States between 2000 and 2018. While simplified, this method of estimating crash reductions provides a sense of scale for the safety impact of IIDs.

A CMF is a multiplicative factor used to compute the number of crashes expected to occur at an intersection after the adoption of a countermeasure. Eight before-and-after studies, covering 192 IID deployments were used to develop an average CMF for each IID type for the purposes of this calculation. Separate CMFs were created for injury or fatal crashes and property-damage-only rates. The evaluation team calculated the total crashes prevented between 1990 and 2014 while assuming that all IIDs averaged the same CMF with identical before-and-after-installation crash rates. Most IIDs in the United States were converted from traditional stop-controlled or signalized intersections; thus, reported crash-reductions must be understood relative to traditional intersections.(20) Three separate distributions of crashes by severity were used to more accurately assess the safety impact of the crash reductions. These distributions were constructed from National Highway Traffic Safety Administration crash data from 2014 and from a 2007 study, *Pre-crash Scenario Typology for Crash Avoidance Research*.(70) USDOT inputs for value of statistical life (VSL) were used to estimate dollar figures of social costs.(71)

To establish mobility benefits, the evaluation team reviewed mobility evaluations of IIDs to calculate an average mobility benefit per IID. The results of the mobility evaluations that were used in this calculate were those that were quantified in units that could be monetized. Mobility is best captured in changes in travel time or changes in delay time as these values can be monetized using USDOT standard values of travel time. While travel time is the appropriate measure to use for monetizing mobility benefits, there are multiple ways to capture mobility benefits, and evaluations of mobility impacts of IIDs use a wide variety of these nonmonetizable performance measurements, including the number of stops per vehicle, change in average speed, or change in capacity of the intersection.

Because these alternative methods of measuring mobility performance are impossible or more difficult to monetize, results of the literature scan that provided mobility results in those measurements were not included. The analysis includes studies and evaluations of IID mobility only if the following criteria were met:

- The study results were provided in tabular, rather than graphical, form (e.g., results were provided in a table with specific numerical values rather than in a graph, where the specific values of the results are not given).
- The performance measure used in the study could be converted to seconds of travel time per vehicle.
- The analysis provided a comparison against conventional intersection mobility and was not an analysis of optimal signal phasing schemes.
- The performance measure captures the mobility impact for all users moving through the intersection rather than for particular routes (or turns) through the intersection.

Sixty-four studies provided mobility benefit–analysis results or, at least, discussed mobility-benefit claims. Of these studies, 17 provided results that met the criteria. Using the average travel-time savings for each IID, the evaluation team computed the total travel-time savings for each IID deployed using conservative assumptions about the IID's annual average daily traffic (AADT) and hours of peak travel. The value of travel time for personal-vehicle occupants was used to estimate dollar figures of social costs.(71)

Construction-cost impacts similarly were gathered through a literature review. The evaluation team compared the reported construction costs for IIDs against the construction costs of conventional or grade-separated alternatives.

3.4 Semistructured Interviews

The evaluation team relied substantially on interviews. While resources are available in documents and literature to evaluate the impacts of FHWA research activities, positive identification of FHWA impacts on awareness, adoption, and deployment of IIDs can be ascertained through interviews. In addition, interviews were required to understand the decisionmaking processes of FHWA staff. In all cases, the interviews provided both program staff and program stakeholders at the State-DOT level an opportunity to reflect on FHWA's IID program. The information obtained from these interviews has been incorporated into the evaluation findings as well as its recommendations.

The evaluation team conducted seven indepth, semistructured interviews with current and former FHWA staff active in IID research, outreach, and technical assistance as well as eight interviews with State DOT engineers, researchers, and design consultants. Interviewees came from Safety R&D, Operations R&D, the Office of Safety, and the Resource Center.

The evaluation team used the interviews to better understand the scope and extent of FHWA activities. The interviews also provided contextual details complementing other analysis methods to understand FHWA's role in contributing to the availability and reliability of IID safety and operational-performance data; engagement with the IID research and practitioner community; perception of stakeholders' awareness, knowledge, and attitudes toward IIDs; and the eventual adoption of IIDs as safety, mobility, and cost solutions.

4. Evaluation Findings

This chapter is divided into the five sections, one for each evaluation area the evaluation team examined. Each section contains an overview that assesses the evaluation area at a high level. In each section, there is also an indepth discussion of the findings. These specific findings address the evaluation team's key hypotheses. Findings are supported by evidence collected through the evaluation methods described in section 3.

The IID program had significant impact on the awareness, attitudes, and deployment of IIDs for the intersection safety community including Federal, State and local entities as well as for intersection design and safety researchers.

- Section 4.1 details how FHWA R&T followed internal and informal procedures to first identify intersection safety as a critical area of research, and how the program leveraged available inputs for identifying IIDs for inclusion in the program.

- Section 4.2 details how initial FHWA contributions increased the availability of domestic IID information which expanded the availability and quality of domestic IID research, and how FHWA publications specifically led to increases in published material on IIDs in the United States.

- Section 4.3 details how FWHA publications increased the availability of IID information in the United States, raising awareness of and competency in deploying IIDs, and how FHWA's publications changed attitudes about IIDs within other federal agencies, leading to increased promotion of IIDs through Federal partners.

- Section 4.4 details how FHWA activities and research increased the total number of IIDs in the United States, how FHWA activities accelerated the early adoption of IIDs by lead states, and how FHWA efforts increased the amount of funding available for IID deployment.

- Finally, section 4.5 details how FHWA's contributions to deployment led to safety, mobility, and construction cost benefits that likely exceeded the resources FHWA expended in the IID program, as demonstrated by an ROI analysis.

4.1 Evaluation Area One: FHWA Decisionmaking

The logic model developed for this evaluation suggests that FHWA research has standards and procedures for selecting research areas that maximize ROI. The evaluation team found strong evidence in support of most of the hypotheses within this evaluation area. The specific hypotheses for this evaluation area were the following:

- FHWA has standards and procedures for selecting research areas and products for promotion that maximize ROI. They followed such procedures in selecting IIDs for promotion.
- FHWA provided and leveraged inputs to IID research.
- FHWA IID-research selection is based on State and local agency needs, targeting designs that have wide application or critical value.

These hypotheses are laid out in Table 2 in section 2.1. These hypotheses are addressed collectively, not addressed individually, in this evaluation area because they were evaluated as a group. The findings laid out in this section collectively address these hypotheses.

In the next section, Overview of Findings, a summary of the findings for this overall evaluation area, followed by more detailed analysis, is presented.

Overview of Findings

FHWA R&T did follow procedures to select the IID program as a research area and the particular IIDs for the IID program portfolio, but the evaluation team was unable to establish whether FHWA uses specific formal standards for such selection, and therefore the program did not explicitly make these selections within a risk-and-reward-management framework. FHWA did follow decisionmaking procedures that relied on coordination between staff and leadership with input from stakeholders.

FHWA R&T targeted research designs that would have wide applicability and address particular needs of State and local agencies. Specifically, FHWA focused initial research efforts on IIDs that were likely to provide safety benefits. These designs had wide applicability across roadway contexts, such as urban and rural environments, and in terms of the number of States and metropolitan planning organizations that would benefit from use of the designs. While some designs are better suited to some contexts than others, FHWA selected an IID portfolio for the program that was likely to provide benefits for all States and most local agencies by including designs that were appropriate for different contexts.

The FHWA R&T team provided and leveraged existing resources as inputs to produce high quality IID research with the aim of maximizing the internal and external ROI. FHWA did not wholly create any of the IIDs within the program portfolio; rather, they leveraged the efforts of researchers in the United States and abroad. FHWA research was aimed at closing critical gaps in designs for these IIDs and in translating engineering designs into practical guidance for State and local practitioners.

FHWA followed standards and procedures for selecting the IID program as part of outreach efforts, particularly through the inclusion of the IID program in EDC-2.

Detailed Findings Summary

Finding 1a: FHWA IID research followed procedures for selecting research areas that maximized ROI, leveraged existing internal and external inputs, focused on needs of State and local agencies, and targeted designs that have wide application or critical value.

FHWA staff recognized the need for research that could address intersection safety, and around 2002 to 2003, Office of Operations Research and Development staff approached the Office Director of the Office of Safety HQ about a new research program that would address intersection safety. Noting the high rates of fatal and injury crashes at intersection, FHWA staff and directors discussed focusing on a number of design concepts that would address intersection crashes and form the basis for the IID program. In some cases, the choice to pursue a design was mandated by leadership.[1] FHWA researchers were given latitude within the program to begin new research inquiries, select research staff, and end research inquiries when further results would not be necessary. FHWA staff used engineering judgement to determine which designs were likely to

[1]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

provide safety benefits. Funding was provided every year as the R&T program demonstrated its continuing benefit. One FHWA researcher stated the following:

> *"The funding was limited, and we came up with the four intersections to do a more thorough, rigorous analysis. We determined from what was known, cost reasons and need of right-of-way, and so we determined based on these factors that these are likely to be more efficient."*[2]

FHWA often consulted and continues to consult with a variety of stakeholders. FHWA staff consult with State and local agencies about their needs and select design research that will directly support those needs. For IID research, FHWA staff consulted with State and local agencies directly and through FHWA division offices; direct contact between the office of R&T staff and with State and local agencies in the early years of the program mainly occurred through peer exchanges and workshops, with an increasing amount of interaction through design project reviews, requests for technical assistance, and other types of individualized assistance as the program continued through the present. FHWA staff also regularly engaged with other researchers through conferences and other research presentation settings both domestically and internationally.

FHWA identified intersection safety as a need in urban and rural contexts. Initially, FHWA researchers relied on data-driven approaches to identify intersections as a critical need given the rate of crashes at intersections relative to other parts of the roadway network. FHWA then relied on conceptual aspects of intersection design, primarily conflict-point analysis, to identify designs that would likely reduce crashes. The focus on safety as a critical identifier for IID selection for the program demonstrates that FHWA did not arbitrarily select either the research focus on IIDs or the particular IIDs. The internal procedures for selecting research areas and IIDs for this program involved an informal process that relied on engineering judgment about the characteristics of IIDs and their potential applicability, as well as program objectives defined through deliberation with key Turner-Fairbank Highway Research Center leadership, such as FHWA R&D's Focused Approach and FHWA R&D's four technical focus areas of intersections, roadway departure, pedestrian/bicycle, local and rural roads.[(72)] However, the evaluation team could not demonstrate that FHWA uses specific standards by which research areas are selected or IIDs were selected for inclusion in the intersections program. Standards for selecting research areas are a critical component for research program operations as they provide the ability to balance risk of various research areas. In the context of the IID program, formal standards of inclusion would have provided the ability to balance the risks and rewards of the portfolio as a whole. With this approach, the risk that FHWA would not generate an ROI from research funds spent any particular IID would be balanced by the potential that any one of the other IIDs would successfully generate net social return for the program as a whole.

In pursuing this research, FHWA actively leveraged existing IID research and resources, including existing deployments and design research. FHWA was careful to select designs that would have wide applicability and were likely to have considerable safety, mobility, and cost impacts. FHWA used novel research methods, such as simulation software, to test the mobility capability of designs.

FHWA discovered DDIs through conference presentations. FHWA also met directly with the original U.S. DDI researcher at a conference and leveraged their design work to further improve the simulation analysis and geometrics of the DDI design. FHWA's research expanded on the existing research by exploring a much wider range of scenarios with respect to volume and geometrics. Unlike the other designs, there were no existing DDIs in North America, though they had been used

[2]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

in France. An FHWA researcher noted that, after FHWA's research began, it did not take long for DDIs to start appearing in the United States, saying the following:

> *"We started the research in 2004, and the first one was built in 2009. So, it was a very high-speed implementation of the research."*[3]

After the first DDI was deployed in Missouri, FHWA began field evaluations of the design to support design research.

When the IID program began in the early 2000s, a number of RCUTs had already been deployed, and many MUTs had been deployed (primarily in Michigan). FHWA leveraged these deployments for their research efforts. MUTs were not formally researched in the program but were included in the various summary reports that FHWA developed as part of the program. The inclusion of MUTs in the IID research portfolio demonstrates the program's ability to identify critical research questions and designs that were appropriate for inclusion in FHWA's program materials and guidance documents. Another researcher speaking of the early research climate described how and when RCUTs were invented as follows:

> *"We did not have empirical evidence back then. The potential was really obvious. You can also tell it's a good idea when it is invented by different people in different places at different times... As far as I know, RCUT was invented separately four times: in Alabama, Maryland, Michigan, and finally the fourth time in North Carolina... That kind of indicates we might be on to something here."*[4]

The DLT design was selected for the IID-research program due to the fact that it could service roadways with higher volumes of traffic that were balanced in terms of directional flow and, principally, because it addressed the critical safety need of reducing left-turn crashes.[5] FHWA leveraged existing DLT deployments in Tijuana, Mexico, which were a four-approach version of the DLT. FHWA also relied on early U.S. deployments in places like New Jersey, Maryland, and Louisiana.

FHWA similarly did not invent MUTs, nor did they do specific field evaluations for this type of intersection design. The inclusion of MUTs in the IID program was largely through outreach and guidance efforts. Given the number of existing MUT deployments, there was little research effort required to develop MUTs for promotion. FHWA selected MUTs to be part of the IID program due to their success in early deployments and due to the fact they function well under conditions that other IIDs do not. However, FHWA has recently begun pursuing new field evaluations of MUTs to support existing research.[6]

FHWA similarly leveraged the existing mini-RA deployments and the wide range of modern roundabout research to continue to research the safety, mobility, and cost impacts of mini-RAs. Mini-RAs were widely used in the United Kingdom and Europe prior to their introduction in the United States. FHWA leveraged the Dimondale design, expanding on it to provide capability of the design to

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[3]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[4]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[5]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[6]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

be deployed in higher volume settings.[7] One FWHA employee described the genesis of FHWA's research efforts into mini-RAs as follows:

> *"What happened is I was collecting data in Michigan, [and] the county engineer told me he had a two-lane roundabout about 2 mi from mini-roundabouts, and that roundabout has a lot of safety problems. Then, I did some research after I came back, and I found this is not a unique problem, and many other states had similar problems… We decided to initiate that study because we know there are real problems in the field."*[8]

Finding 1b: FHWA followed EDC's standards and procedures for selecting research products for promotion to maximize ROI by focusing on State and local agency needs and designs with wide applicability.

FHWA maximized ROI by focusing on State and local agency needs throughout the process of selecting IIDs for promotion and outreach. The primary mechanism for FHWA to select research for promotion both with the Office of Safety and through the Resource Center was through the EDC program. IIDs were highlighted during FHWA's EDC-2 under the name "Intersection and Interchange Geometrics."(5) The program focused on DDIs, RCUTs, DLTs, MUTs, and modern roundabouts (although mini-RAs, a focus of this evaluation, were not specifically called out, they were appropriately grouped under the general roundabouts category). FHWA's success with R&T's *2010 All Report* created the demand that allowed IID outreach to begin.(3) One FHWA staffer said the following:

> *"…by the time we got to EDC-2 and by the time we were going through the exercise to choose what to include within the safety program, we had already been convinced of [IIDs'] value. From the FHWA brand standpoint, [the question was] 'is it worthy of inclusion in EDC?,' but from a program level, I think what R&D brought to the table is that [*2010 All Report*] was, I think, the single biggest step forward for our program. It documented the experience with these different intersection [designs], it gave us something to share with AASHTO and the practitioner community, and it gave us that springboard to a workshop to take this out into the field and have these face-to-face conversations with people and work through their acceptance of these ideas. It gave us the opportunity to identify state and local agencies that wanted to pursue it. I think the report in 2010 was a huge step and that was all R&D making that happen."*[9]

Although EDC is an FHWA program, it is still a State-based model that prioritizes the needs of States. For every round of EDC, FHWA solicits input from State agencies, local governments, private industry, and other stakeholders to determine the appropriate innovations for that round of EDC.(5) As one FHWA interviewee noted, "EDC is a partnership effort between FHWA and State DOTs."[10] The ultimate decision of what innovations to include is left to FHWA, but needs of State and local agencies play a large role in decisionmaking.

[7]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.
[8]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.
[9]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.
[10]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

For EDC-2, multiple States suggested various types of innovative intersections, including DDIs, roundabouts, and RCUTs, among others. Instead of focusing on a single intersection design, FHWA leadership decided to group the designs together into one larger initiative on intersection and interchange geometrics. FHWA chose designs based on consideration of State input and FHWA leadership objectives as demonstrated, for instance, by the inclusion of mini-RAs within EDC-2. One FHWA employee noted the following:

> *"When it came time to decide whether or not to include roundabouts in the EDC-2 toolbox, what we said was 'we had already been doing so much on roundabouts, did we really need to include them in EDC-2?' So, in that back and forth with leadership, what we decided we needed to promote were mini-roundabouts and roundabouts at interchanges, which were underutilized."*[11]

4.2 Evaluation Area Two: Availability and Reliability of Data

The logic model developed for this evaluation suggests that FHWA research advanced the availability and quality of safety and performance data for IIDs and accelerated consideration of IIDs by other researchers. The evaluation team found strong evidence in support of the hypotheses within this evaluation area. The specific hypotheses for this evaluation area were as follows:

- FHWA improved the availability and quality of IID-related safety and performance data for researchers and State and local transportation agencies.
- FHWA research advanced the development of design standards for IIDs.
- FHWA accelerated research among the research community on IIDs.
- FHWA research was used by other researchers to advance availability and quality of data.

These hypotheses are laid out in Table 2 in section 2.1. These hypotheses are addressed collectively, not addressed individually, in this evaluation area because they were evaluated as a group. The findings laid out in this section collectively address these hypotheses.

In the next section, Overview of Findings, a summary of findings for this overall evaluation area, followed by more detailed analysis, is presented.

Overview of Findings

FHWA R&T's research activities, from the early 2000s onward, significantly increased the amount of published material on IIDs in the United States. The results and outputs of FHWA's research were widely used in ongoing public and private IID research. The considerable impact of FHWA's research is evidenced by the number of and breadth of citations to FHWA research and research influenced by FHWA. IID research provided States with the information and resources necessary to develop their own design manuals and guides. Overall, FHWA developed materials for a variety of audiences, including the research community, State DOTs, local agencies, and the public. Interviews provided information about the timing of research and other activities and their effect on the research

[11] FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

community and showed that FHWA played an important role in accelerating consideration of IIDs as a research topic and in developing safety and performance studies focused on the United States.

Detailed Findings Summary

Finding 2a: Early and continued FHWA research increased the quality and availability of domestic IID-related safety and performance data. The increase in data quality and availability benefited researchers as well as State and local agencies.

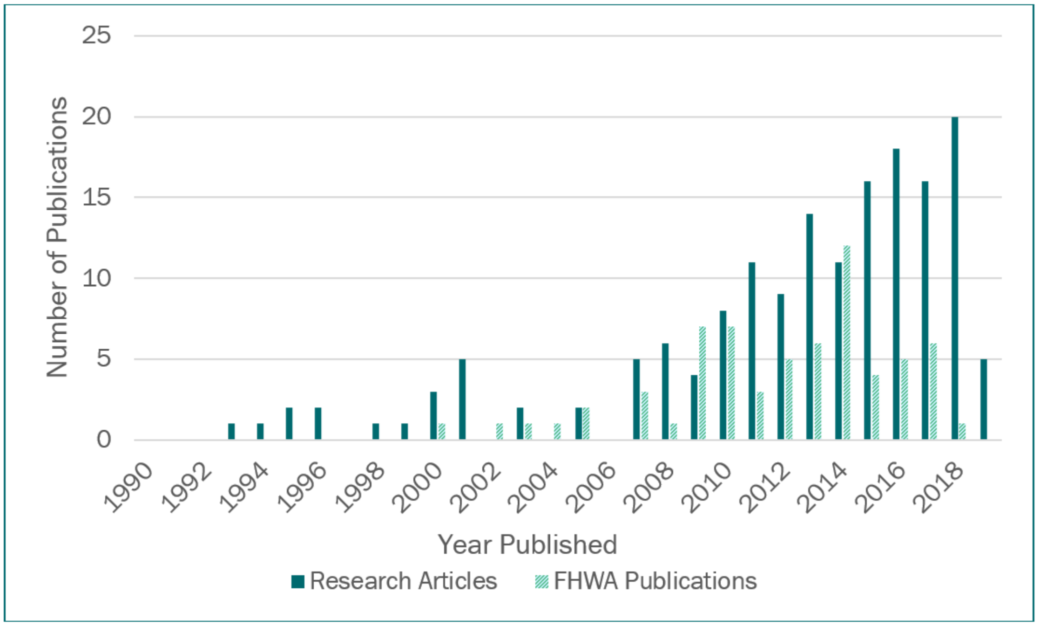
FHWA was a key player in the community of researchers working to increase the quality and availability of U.S. IID research and data. Prior to FHWA's involvement, information on IIDs outside the United States was limited, and the availability of such data differed by IID. Similarly, data on most IIDs were limited within the United States pre-2000. In the 1990s, research on IIDs in the United States was performed by just a handful of researchers, and IIDs were deployed in only a few States. Details on the timeline of FHWA activities are provided in section 1.2.

During the early days of the IID program, FHWA researchers became directly involved in the community of researchers; they published and provided expertise to both researchers and adopters. Staff from the Office of Operations Research and Development joined the IID-research community in the early 2000s and published multiple research articles with the assistance of various graduate students, and then, FHWA began publishing *Public Roads* articles and TechBriefs prior to the publication of the *2010 AII Report*.(3) The fact FHWA joined the IID community helped validate IIDs in a way that researchers alone could not. As one researcher said in an interview, "It wasn't just a little grad student that cared about it, it was FHWA that cared about it."[12]

This research conducted or funded by FHWA from the early 2000s through EDC-2 and even up to the time of this evaluation in 2019 has greatly increased the quality and availability of data and research. The *2010 AII Report* was important in demonstrating FHWA's commitment to IIDs and helped provide a valuable springboard for FHWA to start outreach efforts, as described in section 4.1.(3)

Figure 7 shows the number of IID-research publications per year by FHWA and non-FHWA sources; the included publications are specific to IIDs, rather than general intersection or safety research with IIDs included. The growth of IID-focused research increased dramatically in the late 2000s, which is when FHWA began publishing IID-related materials in earnest. The FHWA publications in figure 7 include reports and articles published directly by FHWA, as well as articles published by other sources that used FHWA funding or that have at least one FHWA author.

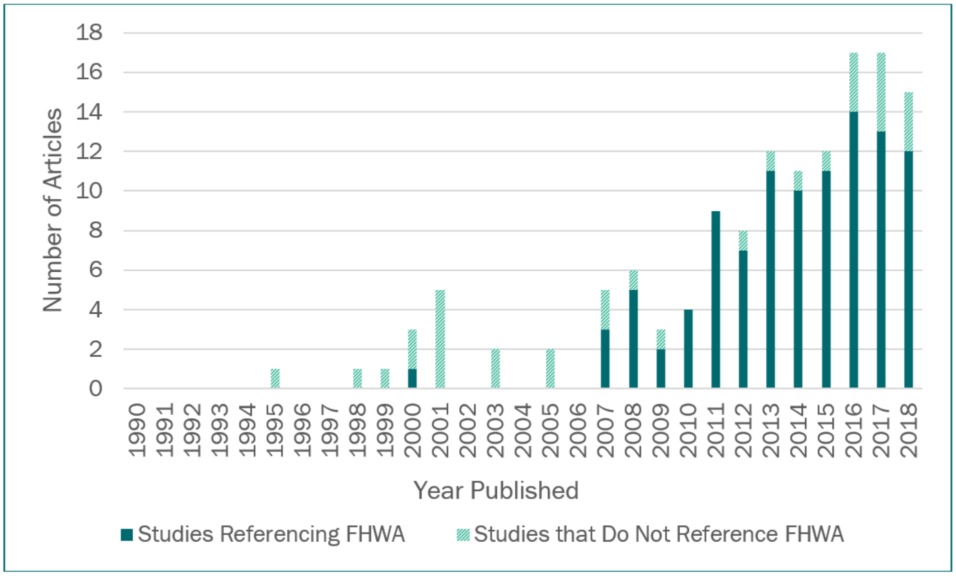
[12]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.



Source: FHWA.

Figure 7. Graph. Number of IID publications focused on the United States per year.

One measure of the impact of a research program is how often other researchers used program-related materials in its work. Figure 8 shows the number of IID publications focused on the United States per year by non-FHWA sources. The publications are broken down by those that did not reference an FHWA work and those that did. As the graph shows, the majority of studies (particularly from 2007 on, once there were more FHWA publications available to cite) referenced various FHWA publications related to IIDs. Some of the studies that did not reference FHWA IID works may still have referenced other FHWA materials, but only studies that reference an FHWA publication specifically on the topic of IIDs were counted as referencing FHWA. This figure includes fewer research articles than figure 7 as not every research article was able to be acquired and analyzed to determine whether FHWA was cited.



Source: FHWA.

Figure 8. Graph. Number of research publications that reference FHWA versus those that do not reference FHWA per year.

As figure 8 shows, FHWA is frequently cited in IID-research articles. It is not always cited, particularly in articles published before the late-2000s, which is when the FHWA IID program truly took off in terms of publications. In some years, however, every article analyzed by the evaluation team had cited FHWA in some way. In the most recent years, the share of articles that referenced FHWA has started to drop, which seems reasonable. As the field of literature on IIDs continues to grow, more articles available for researchers to cite, and the need to rely on the same publications decreases. FHWA works are valuable, but they are not the only resources available to researchers.

Another way of examining the citation data is to look at the popularity of specific FHWA publications. Although most researchers are citing FHWA publications, not every article cites the same FHWA publications. Additionally, not all FHWA publications could have been cited by every research article—the evaluation team is looking at FHWA's work on five IIDs, meaning research articles related to all five IIDs are included in the general analyses. However, an FHWA publication on RCUTs likely would not have been cited in a paper on DLTs. Table 3 presents several FHWA publications on IIDs and notes the number of research articles that the evaluation team found that cited each publication as well as the number of articles that could have cited the publication based on year of publication and general topic area.

It is important to note some caveats when interpreting table 3. First, this analysis does not distinguish between why or how an article might cite one FHWA report rather than another. Second, the analysis is not meant to indicate that FHWA publications are the gold-standard of research, with the implication that their publications should always be cited; rather, the analysis is meant to show only that FHWA works are frequently cited. If FHWA publications were never cited, the evaluation team could conclude that either FHWA did no outreach or that the publications were generally regarded as subpar research. As the table shows, each of the specific FHWA publications referenced was cited frequently, indicating that researchers were, at least, aware of FHWA's work. The citation analysis serves ultimately as a proxy for FHWA's influence, but it is an imperfect measure that should be considered in the broader context of other evaluation findings.

Table 3. Citations of specific FHWA publications.

FHWA Publication	Number of Research Articles Citing	Number That Could Have Cited	Percent Citing
2010 AII Report (FHWA-HRT-09-060)(3)	58	113	51
DDI Informational Guide (FHWA-SA-14-067)(6)	16	42	38
DLT Informational Guide (FHWA-SA-14-068)(8)	7	12	58
RCUT Informational Guide (FHWA-SA-14-068)(7)	9	20	45
MUT Informational Guide (FHWA-SA-14-069)(9)	6	11	55
TechBrief: Driver's Evaluation of the DDI (FHWA-HRT-07-048)(29)	17	68	25
TechBrief: MUT Synthesis (FHWA-HRT-07-033)(30)	10	20	50
TechBrief: DLT Intersection (FHWA-HRT-09-055)(18)	9	28	32
TechBrief: DCD Interchange (FHWA-HRT-09-054)(15)	16	66	24
TechBrief: Field Evaluation RCUT (FHWA-HRT-11-067)(39)	13	25	52

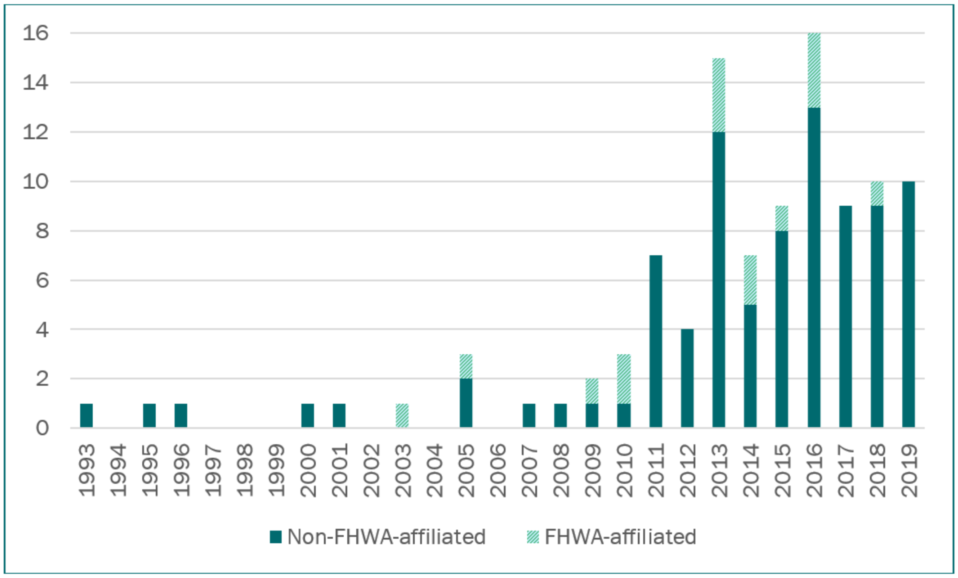
As can be seen in table 3, FHWA references are fairly popular among domestic IID literature. The *2010 AII Report* is cited by just over half of all IID-related articles examined by the evaluation team that have been published since the report came out.(3) Again, although this analysis is only a proxy for FHWA's influence, it does appear to show that FHWA has had a large impact on IID research.

Finding 2b: FHWA research and activities were associated with accelerated research among the research community on IIDs and advanced the development of design standards for IIDs.

Every year, the TRB hosts its Annual Meeting in Washington, DC. Starting in 1921, the TRB Annual Meetings now boast nearly 5,000 presentations on 750 transportation topics and are attended by over 12,000 transportation professionals from around the world. As one method of measuring the growth of IID research in the United States, the evaluation team reviewed and analyzed the number of IID presentations at annual TRB meetings.

Figure 9 shows the number of IID presentations at the TRB Annual Meeting. The number of IID presentations clearly increases over time. The first IID presentation in this study period appears in the 1993 Annual Meeting, and the focus was on MUTs. The number of IID presentations steadily increases to a peak of 16 in 2016. In total, the evaluation team identified 103 IID presentations.[13] The data show that FHWA was among the first organizations to present IID-research findings at TRB and made efforts to increase their presence at TRB around the time of EDC-2.

[13]These numbers may not be complete as the search specifications will not return presentations under different session titles.



Source: FHWA.

Figure 9. Graph. TRB Annual Meeting IID activities (1993–2019).

Figure 9 shows that, while the trend in IID activities at TRB from year-to-year has not been consistent, the overall trend is upward, with increases in FHWA presence around 2009 and 2010, when FHWA was publishing multiple smaller TechBriefs and preparing for the publication of the *2010 AII Report*.(3) There were also several FHWA-affiliated presentations at TRB on IIDs in 2013 and 2014, during the time of EDC-2. Additionally, FHWA teamed up with TRB to host the Alternative Intersections and Interchanges Symposium in Salt Lake City, UT, in 2014.(73)

FHWA has clearly had a strong presence at TRB on the topic of IIDs, but the majority of IID presentations at TRB have not been affiliated with FHWA. This fact indicates significant interest among the broader research community on the topic of IIDs, and the figure also shows that the increasing interest corresponds, at least to a certain extent, with FHWA IID activities. In 2011, the year after the *2010 AII Report* was published, there is a large jump in the number of IID activities at TRB. Although there is not enough information here to necessarily imply causation, there is evidence that the number of IID publications at TRB is correlated with increases in FHWA IID activities.

Beyond just TRB, interviewees indicated that FHWA had a large role in accelerating research. One interview stated the following:

> *"Fortunately, [staff] at FHWA thought [the DDI] was interesting and did some further research on it. I thought his research was instrumental, not only because he confirmed my result… but being able to validate my result plus show that … it had even more widespread capabilities than I thought initially."*[14]

The same interviewee went on to say that FHWA work gave the DDI, as well as other IIDs, more validity in the research community. Other interviewees concurred with this idea, stating that FHWA had helped push these designs forward and stir further interest in the research community.

[14]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

The results from the interviews along with the TRB and other research findings indicate that FHWA work was, at least, strongly associated with accelerated research and the development of standards. Although it is highly likely that FHWA's work caused at least some of the elevated interest in IIDs, it is difficult for the evaluation team to prove causation in this instance. At least one FHWA interviewee stated their belief that FHWA caused the increased research as follows:

> *"Many people now are doing more research on refining signalization for the DLT, refining signalization for the DDI, and you have conferences specific to different types of intersection… [FHWA] was a major catalyst to have people give it more attention and more research from faculty, students, institutes like ITE, AASHTO, TRB… Prior to having this program area and conducted in house research and developed the [*2010 AII Report*], not much was going on."*[15](3)

4.3 Evaluation Area Three: Change in Awareness, Knowledge, and Attitudes

The logic model developed for this evaluation suggests that FHWA's research increased awareness of IIDs and changed attitudes toward IIDs, increasing confidence in alternative designs as viable options for intersection design. The evaluation team found strong evidence in support of the hypotheses within this evaluation area. The hypotheses for this evaluation area were as follows:

- FHWA IID-related research and outreach efforts changed the level of awareness of IIDs as a safety countermeasure in the United States.
- FHWA IID-related research and outreach efforts influenced the acceptance of IIDs by other FHWA programs as a safety countermeasure.
- FHWA IID-related research promoted acceptance of IIDs as a safety countermeasure by transportation decisionmakers and practitioners.
- FHWA IID-related outreach efforts influenced the acceptance of IIDs as a safety countermeasure by transportation decisionmakers and practitioners.

These hypotheses are laid out in Table 2 in section 2.1. These hypotheses are addressed collectively, not addressed individually, in this evaluation area because they were evaluated as a group. The findings laid out in this section collectively address these hypotheses.

According to Toward Zero Deaths, transportation agencies should incorporate newer concepts and methods with their existing processes, guidelines, and tools.(74) As positive results from research give agencies the data and analytical tools (and, thus, the confidence) to deploy IIDs. Affirmative results also encourage FHWA to prioritize IIDs for study and promotion. FHWA activities, such as oversight, research, development, deployment, evaluation, technical assistance, outreach, and training, provide partners and stakeholders the skills and resources to understand and implement safety improvements.

Section 4.2, focuses on changes within the research community. This evaluation area investigates to what extent FHWA research products, resources, and activities were known about and used by States and were effective in overcoming uncertainties that limit safety investment by articulating the benefits of those investments. Section 4.3 investigates hypotheses that assess whether FHWA IID

[15]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

products and activities contributed to changes in awareness, knowledge, and attitudes among transportation practitioners.

In the next section, Overview of Findings, a summary of findings for this overall evaluation area, followed by more detailed analysis, is presented.

Overview of Findings

FHWA research and outreach increased awareness of IIDs in the United States. FHWA products provided interested States and stakeholders with more information on how to utilize IIDs and gave FHWA's stamp to the technology. Safety R&D worked closely with the Office of Safety and Resource Center to conduct sustained outreach on IIDs, including creating training courses. In turn, this sustained outreach has shaped State policies toward IIDs and influenced transportation professionals' attitudes toward IIDs as an alternative to conventional intersections. FHWA's research and outreach efforts are ongoing and will likely continue to have positive impacts on awareness and acceptance.

Detailed Findings Summary

Finding 3a: FHWA IID-related research and outreach efforts increased awareness and changed attitudes toward IIDs as viable options for intersection designs in the United States.

In the early 2000s, there were very few IIDs in the United States, and the ones that did exist were concentrated in a select number of States, like the MUTs in Michigan. As FHWA research moved forward, including the publication of the *2010 AII Report* and the beginnings of EDC-2, awareness of IIDs increased across the United States.(3,5) To understand the change in awareness and attitudes that FHWA activities generated, the evaluation team examined the type of outreach activities in which FHWA was engaged and then looked to State policies and publications for references to FHWA materials to identify citations and references to those research and outreach materials.

Training, Outreach, and Technical Assistance

The National Highway Institute (NHI) is the training and education arm of FHWA. NHI has hundreds of trainings in more than 18 transportation industry–related program areas. Courses are developed in collaboration with FHWA staffers as well as State and local agencies and industry partners. These courses are a key way for FHWA to reach out to transportation professionals and showcase new, innovative technologies and ideas.

Beginning in 2011, the Innovative Intersections and Interchanges Course (FHWA-NHI-380109) was introduced into the NHI catalogue.(75) The course is typically a 1-d session that provides an overview of innovative designs' principal features, advantages and disadvantages, and general applicability.

From 2010 to 2019, the IID course (FHWA-NHI-380109) had been taken by 789 participants, the vast majority of whom have been from State agencies. There have also been a fair number of private industry participants as well as participants from other Federal agencies and from within FHWA itself. Table 4 shows the total number of attendees by year and type for this NHI course. The year with the highest attendance rates was 2013, which was during EDC-2. NHI has conducted this course 37 times.

Table 4. Attendance, by year and attendee type, for Innovative Intersections and Interchanges Course (FHWA-NHI-380109).

Fiscal Year	FHWA	Federal	State	MPO	LTAP	Private	Academia	Other	Total
2011	5	0	114	0	0	0	0	0	119
2012	4	0	73	0	0	0	0	0	77
2013	5	26	103	4	26	18	0	1	183
2014	4	0	54	0	0	0	0	0	58
2015	1	0	64	0	7	12	0	0	84
2016	0	0	23	0	12	32	0	1	68
2017	2	32	25	0	0	0	0	0	59
2018	0	0	27	0	0	0	0	0	27
2019	7	0	75	0	12	19	0	1	114
Total Attendance	28	58	558	4	57	81	0	3	789

MPO = metropolitan planning organization; LTAP = local technical-assistance program.

Information on mini-RAs is provided in the NHI course on roundabouts.(76) Since 2011, this course has had 691 participants. Similar to the IID course, this course is mainly attended by participants from State agencies, although there have also been a fair number of private industry participants. NHI has conducted this course 30 times since 2011.

Table 5. Attendance, by year and attendee type, for Modern Roundabouts Course (FHWA-NHI-380096).

Fiscal Year	FHWA	Federal	State	MPO	LTAP	Private	Academia	Other	Total
2011	0	4	48	1	24	0	1	0	78
2012	0	0	0	0	0	0	0	0	0
2013	4	0	109	2	62	36	1	1	215
2014	1	0	47	0	0	8	0	0	56
2017	3	0	92	0	14	54	0	2	165
2018	1	0	39	1	11	19	0	1	72
2019	30	0	67	0	8	0	0	0	105
Total Attendance	39	4	402	4	119	117	2	4	691

MPO = metropolitan planning organization; LTAP = local technical-assistance program.

In addition to the NHI courses, FHWA staff have conducted other courses and workshops on the topics of IIDs. There were two courses conducted during the years of EDC-2, and FHWA has conducted many other workshops that were not affiliated with either EDC-2 or NHI. The number of these courses by year can be seen in table 6. As the table shows, FHWA conducted numerous workshops during and right after EDC-2, even if the workshops were not formally affiliated with EDC-2. Across just 2014 and 2015, FHWA conducted 58 workshops on IIDs.

Table 6. FHWA's other intersection-design workshops.

Year	EDC-2	Non-NHI, Non-EDC	Total
2013	1	2	3
2014	1	27	28
2015	0	32	32
2016	0	19	19
2017	0	1	1
Total	2	81	83

General findings from the interviews have indicated the importance of all these workshops for increasing awareness of IIDs. One FHWA staffer said the following:

> *"If I was a State DOT designer and I wasn't plugged in to the TRB committee and I wasn't in a State that had one of the leading research groups on traffic engineering, how am I going to know it's out there? ... I think when we were doing the workshops for the [2010 AII Report] that was a big part of what we were doing; we were introducing people to research and work that's out there."*[16(3)]

Interviews with State agencies indicated that FHWA trainings and outreach had a role in helping certain States become aware of IIDs. Multiple interviewees recalled attending at least one FHWA-affiliated event or indicated that they spoke more informally with FHWA. One State employee explicitly stated that they first learned about DDIs "through conversations with FHWA."[17] Another practitioner said that "the workshops were a huge success."[18]

Apart from formal courses, FHWA also helped set up peer exchanges. Unfortunately, the number of peer exchanges and attendees were not tracked by FHWA, limiting the ability of the evaluation team to assess their effect. However, qualitative findings from the interviews did indicate that multiple interviewees could remember attending a peer exchange that had some degree of FHWA involvement.

Some interviews indicated that States had been aware of certain designs, particularly the MUT, before FHWA's involvement as that design has been deployed in Michigan for decades. However, even when a State is aware of a design, they might not always be open to trying something new. FHWA played a critical role in, not just increasing awareness, but also changing attitudes among industry professionals and helping increase acceptance. One practitioner stated the following:

> *"FHWA helps very much in [overcoming resistance by our fellow professionals]. FHWA ... [carries] a weight and an authority that cities and States don't necessarily have. So FHWA coming out publicly, loudly, in favor of this general concept of alternative designs and these particular designs helped a great deal with fellow professionals for sure."*[19]

[16]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[17]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley, Joshua Fowler, and Kendall Mahavier in July 2019.

[18]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[19]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

Outreach efforts exist beyond just convincing State DOTs. The workshops helped increase awareness of IIDs among engineers, contractors, and State employees, but the general public and politicians also need to be convinced of the benefits of a new intersection design. FHWA's outreach was largely targeted toward the States themselves, however, FHWA also provided resources and guidance for States that were looking to explain to the public and other stakeholders why these new designs would be right for their community.

Multiple interviewees indicated some degree of public pushback against the designs. Sometimes, interviewees named specific groups, such as businesses or farmers, and other times, interviewees indicated more general public pushback. One State employee said the following:

> *"I think it's been a fear of the unknown number one … and, secondly, with all these alternative designs, they are all doing something in common. They are usually [lengthening] certain movements for the benefit of the entire intersection. … We often don't hear from the general intersection users who are benefiting, we are hearing from the lower number who do travel further out of the way."*[20]

There is a natural fear of the unknown and a fear of change associated with trying a new intersection design. FHWA created numerous resources, including brochures and videos, to help agencies showcase the benefits of the designs to convince reluctant stakeholders that the designs would be improvements. However, FHWA provided materials that States were able to use to build more confidence within their agencies and for the broader public. State websites were reviewed for links to FHWA IID materials. This evaluation revealed that 36 States included at least some FHWA IID-related materials. Of State websites, 25 included FHWA DDI materials, 25 included FHWA RCUT materials, 18 included FHWA DLT materials, 21 included FHWA MUT materials, and 21 included FHWA mini-RA materials. A practitioner stated, "FHWA has also done a great service in providing materials to reach the public. The website is terrific, the brochures, the videos… Those have been helpful when we go out to the public."[21] Although FHWA was not the only resource used by agencies, FHWA training and outreach had a marked effect on increasing awareness and improving attitudes toward IIDs.

State Policies and Publications

A shift in attitudes is demonstrated by the influence of FHWA products on State policies and publications. To measure the influence of FHWA in State highway policy on IIDs, the evaluation team sought references to FHWA materials in SHDMs and State SHSPs as well as on State websites.

The evaluation team examined State DOT websites to determine whether there was IID information on the website. All 50 States as well as Washington, DC, were included in this analysis.

Across all 51 agency websites, at least half had guidance on their websites for either DDIs, DLTs, MUTs, or RCUTs, but States that had guidance for one of these IIDs did not necessarily have guidance for all the others. The most commonly featured design was DDIs, which were included on 44 State DOT websites. Although most States had guidance for larger roundabouts, only 20 had specific guidance on mini-RAs. Details on how many States offered guidance on their websites and how many States referenced FHWA can be seen in figure 10.

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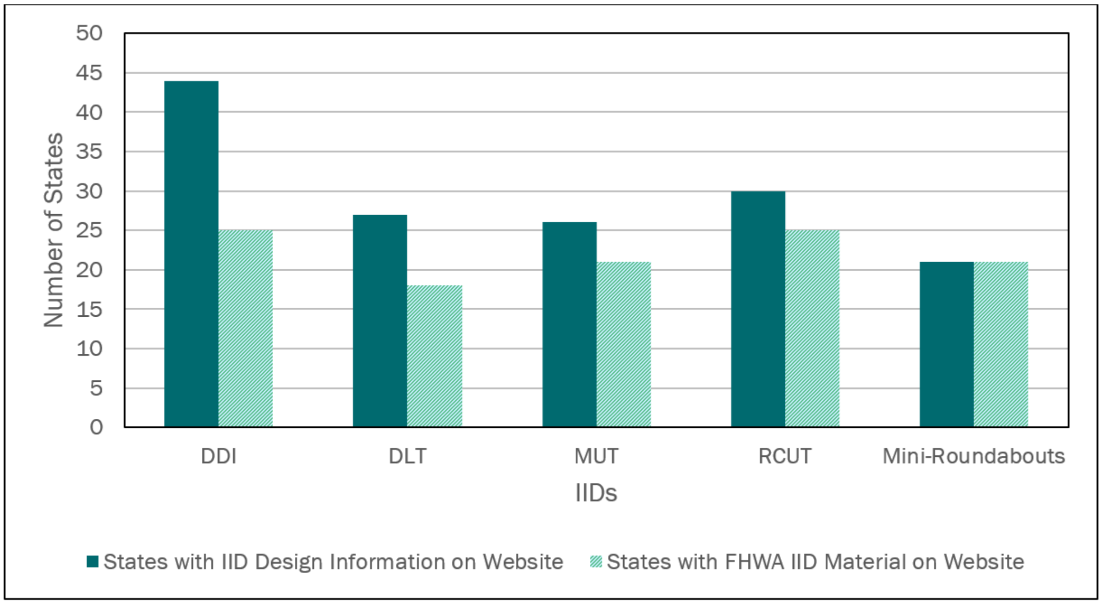
[20] State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley, Joshua Fowler, and Kendall Mahavier in July 2019.

[21] Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.



Source: FHWA.

Figure 10. Graph. State IID website information and FHWA references.

As figure 10 shows, many States referenced FHWA in their guidance. For mini-RAs, every State that included design information on their website also referenced FHWA, with one State (Utah) linking to FHWA information on roundabouts without specifically providing any of their own information on mini-RAs. One interviewee indicated that their State had "relied heavily on FHWA" during the process of creating a design guide.[22] An FHWA staffer noted that FHWA assisted States, such as California and Florida, with design guides and helped numerous other States more generally with specific IID projects. The interviewee said the following:

> *"For example, Alabama, we've helped them review their first DDI plan. For California, we helped develop their State design bulletin. We've helped Connecticut with a plan review of a proposed DDI. We helped Delaware. We've helped Florida with their guidance and considerations for DDI. We've helped Georgia with their review of projects. We've provided training to Idaho, Illinois, Indiana, Kentucky… It'd be a shorter list of States that we haven't worked with [than ones that we have worked with]."*[23]

Finding 3b: FHWA IID research influenced the attitude of other FHWA programs toward IIDs as safety countermeasures.

FHWA adopted certain IIDs as Proven Safety Countermeasures to encourage State construction of IIDs. This decision demonstrates FHWA's broader support for IIDs and shows that support extends beyond just FHWA's research division.

Roundabouts have been included as a Proven Safety Countermeasure since 2008, when such countermeasures were first designated.(10) A July 10, 2008, memorandum from the FHWA Associate Administrator of Safety designated nine highway safety–improvement techniques as "Proven Safety

[22] State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[23] FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

Countermeasures" and included modern roundabouts as one of the nine.[10] Proven Safety Countermeasures are underutilized techniques, and the memorandum directed FHWA Division Offices and Federal Lands offices to meet with their States and tribal governments to promote the use of the designated countermeasures.[10] Although mini-RAs are not specifically mentioned as a countermeasure, the general inclusion of roundabouts speaks to the support more generally for this intersection design.

In 2012 and 2017, the list of Proven Safety Countermeasures was updated. In 2017, "reduced left-turn conflict intersections" were added to the list of countermeasures.[10] These intersections are noted specifically as referring to RCUTs and MUTs.

Proven Safety Countermeasures are chosen as a result of collaboration between a variety of experts from the three FHWA safety disciplines. Staff considered potential as a countermeasure as well as current levels of adoption. Inclusion on the list does not guarantee State adoption but does show the commitment that FHWA has to IIDs and strongly encourages States to, at least, consider the literature on their safety benefits.

The coordination involved in choosing these IIDs as safety countermeasures reflects the close cooperation between Safety R&D, the Office of Safety, and the Resource Center. These offices have collaborated closely for several years to help interested States, publish a wide variety of materials on IIDs, and establish IIDs as a priority at FHWA. The approach has diminished skepticism of the efficacy and usefulness of IIDs among States and other stakeholders.

4.4 Evaluation Area Four: Contribution to Adoption and Deployment

The logic model developed for this evaluation suggests that FHWA activities helped accelerate the adoption of existing IIDs and contributed to the adoption of new IIDs in the United States. The evaluation team found strong evidence supporting some of the hypotheses within this evaluation area; however, demonstrating an empirical, causal link for IID deployments not funded directly by FHWA programs was not possible. The specific hypotheses for this evaluation area were as follows:

- FHWA accelerated early deployment of IIDs through outreach activities (number of IIDs deployed in early states that received early technical assistance).
- FHWA contributed to an increase in number of IIDs deployed in the United States and in the number of State and local agencies deploying IIDs.
- FHWA contributed to an increase in the amount of funding spent on IIDs.
- FHWA's outreach efforts improve the selection and application of IIDs in the United States.

These hypotheses are laid out in Table 2 in section 2.1. These hypotheses are addressed collectively, not addressed individually, in this evaluation area because they were evaluated as a group. The findings laid out in this section collectively address these hypotheses.

In addition to contributing to the awareness, availability, and quality of IID research, FHWA activities influenced the adoption and deployment of IIDs. To understand how FHWA contributed to the increase in adoption and deployment of IIDs, the evaluation team developed a list of IID deployments using existing databases of IIDs supplemented with internet searches for DDIs, RCUTs, DLTs, and MUTs and a comprehensive database of roundabouts that includes mini-RA deployments. The comprehensive database developed by the evaluation team was analyzed against FHWA activities in early-adoption States compared to those who sought FHWA assistance later. Using information about Federal funding, FHWA publications, and the comprehensive IID database, the evaluation team analyzed the impact of FHWA activities across States.

This evaluation area explores the effect that FHWA research and other activities had on adoption of IIDs by considering the timing and type of intervention in each State. Further building on the analyses in sections 4.2 and 4.3, this evaluation also demonstrates how FHWA leadership in research and promotion of IIDs as safety, mobility, and cost-saving solutions led to the consideration of IIDs, accelerated their adoption, and contributed to growing the number of IIDs deployed in the United States.

For the purposes of this evaluation, adoption occurs when an agency decides to accept or be willing to deploy an IID, whereas deployment is when an agency actually constructs an IID. Agencies may adopt an IID as an acceptable design and would consider using it where applicable but may not actually select the IID for deployment due to a number of factors.

In the next section, Overview of Findings, a summary of findings for the overall evaluation area, followed by a more detailed analysis of each related hypothesis, is presented. It is difficult to determine empirically when State adoption of IIDs occurred apart from deployments, but in some cases, such determination was possible and is noted where appropriate.

Overview of Findings

FHWA's research and promotion of IIDs led to an increase in the number of IIDs deployed in the United States. FHWA accelerated early deployment of IIDs through outreach activities and early technical assistance. In particular, early DDI deployments were supported through FHWA outreach and early technical-assistance activities.

FHWA contributed to an increase in deployments and State and local agency deployers of IIDs. FHWA contributed significantly to the early deployment of DDIs and their subsequent deployments, and FHWA activities continue to generate DDI deployments. There are more than 110 DDIs currently deployed in the United States and nearly the same number planned. FHWA contributed significantly to the deployment of RCUTs, which are being deployed increasingly frequently and in more States. FHWA has had a limited impact on the deployment of DLTs, and these are not deployed as frequently as DDIs. FHWA promotional activities contributed to the deployment of MUTs. However, MUT deployment has not been as robust as deployments of other IIDs even though States continue to consider these designs and to deploy them.

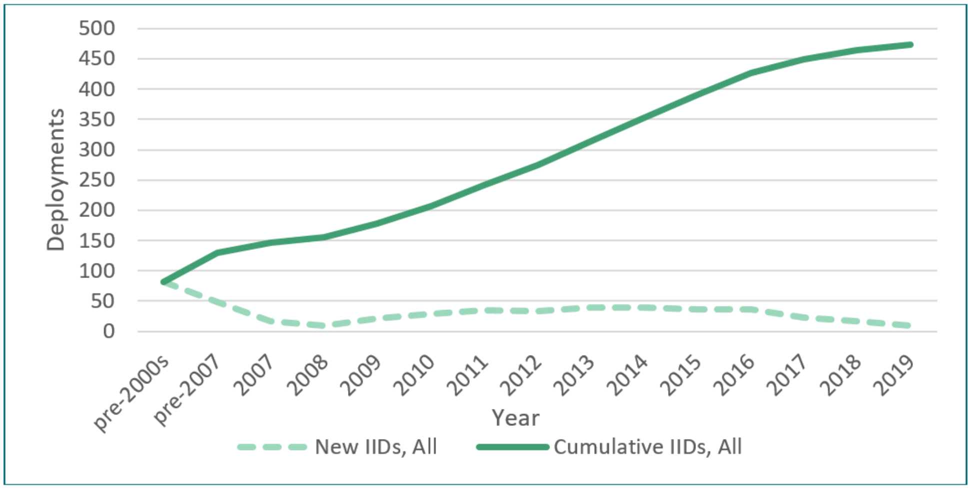
FHWA contributed to the number of IIDs deployed in the United States through directly funding IID deployments. More than $71.7 million have been granted for projects with an IID-deployment component since 2009 across four separate discretionary grants. This funding total is in addition to any nondiscretionary Federal funding that was leveraged by States for IID deployments.

FHWA contributed to the appropriate deployment of IIDs, meaning that IIDs are being deployed in locations and under conditions in which they are best suited to provide benefits. FHWA contributed to expanded deployment through outreach, such as IID workshops and technical assistance, and by providing decision-support tools. In some cases, IIDs have been removed, which usually occurs because underlying traffic volumes have exceeded the thresholds that make the designs appropriate. These removals should not be viewed as failures of the design. Instead they show the designs are effective under limiting circumstances.

Detailed Findings Summary

Finding 4a: FHWA contributed to an increase in deployments and number of State and local agencies deploying IIDs in the United States.

The total number of IIDs deployed in the United States has increased substantially since FHWA began publishing research on and promoting IIDs. Figure 11 shows the number of existing IIDs deployed and the cumulative number of IIDs identified in the deployment scan by year.[24] This figure reflects the deployments identified and verified in the deployment scan conducted by the evaluation team but may not reflect all existing deployments.

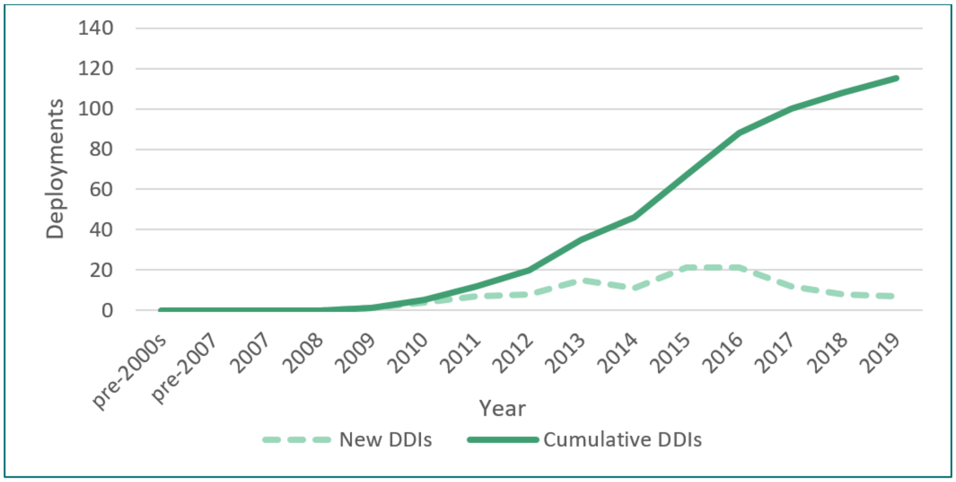


Source: FHWA.

Figure 11. Graph. New and cumulative IIDs by year.

Figure 12 shows the number of existing DDIs and the cumulative number of DDIs identified in the deployment scan by year. The graph shows that DDI deployments began in 2009 with increasing annual deployments through to 2016, when the annual deployment peaks at around 20 DDIs per year and then gradually declines to around 10 per year in 2019. There are more than 110 existing DDI deployments in the United States today. DDIs continue to be selected for deployment across the country. The deployment scan found that approximately 20 DDIs were currently under construction, and over 120 have been proposed or planned for deployment.

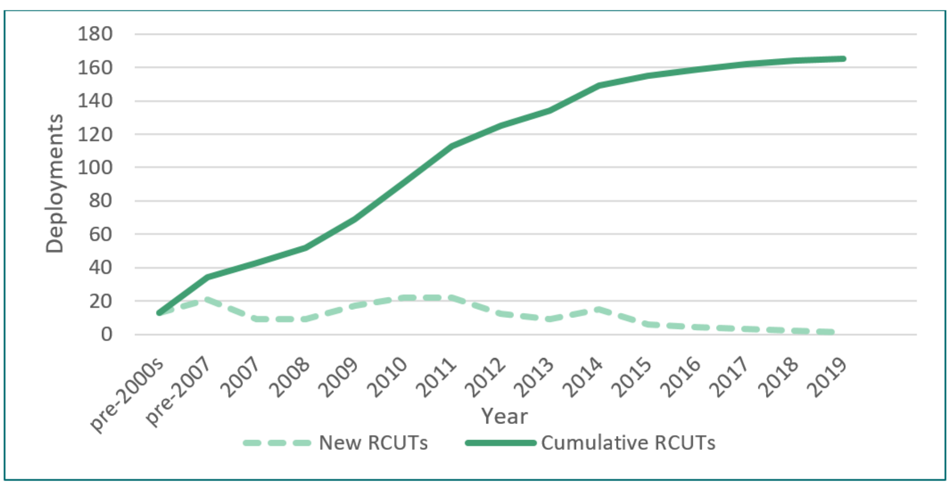
[24]The deployment numbers in figure 11 through figure 16 do not include deployments that have since been removed. IID deployments that have been removed are discussed later in this evaluation area. These numbers are not adjusted for the *Alternative Intersection Design and Selection* State-reported ranges of deployed IIDs because those figures do not detail the year in which the deployments occurred. The additional deployments suggested in *Alternative Intersection Design and Selection* that were not identified in the deployment scan are discussed for each IID as appropriate.



Source: FHWA.

Figure 12. Graph. New and cumulative DDIs by year.

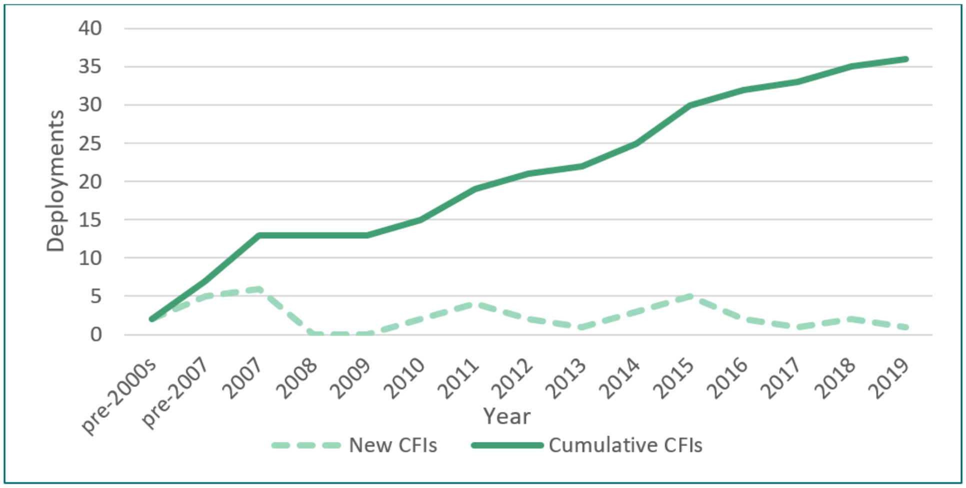
Figure 13 shows the number of existing RCUTs and the cumulative number of RCUTs identified in the deployment scan by year. The reduction in deployment levels in recent years is likely more a demonstration of declining reporting or difficultly in determining the number of RCUTs deployed. The deployment scan likely underestimated the number of existing RCUTs in the United States. Table 17 shows the range of additional RCUT deployments reported in *Alternative Intersection Design and Selection* compared to those identified in the deployment scan.(69) In total, there are at least 96 and potentially more than 220 additional RCUTs that have been deployed that are not captured in Figure 13, suggesting that the number of RCUTs deployed across the country has increased dramatically in the past few years.



Source: FHWA.

Figure 13. Graph. New and cumulative RCUTs by year.

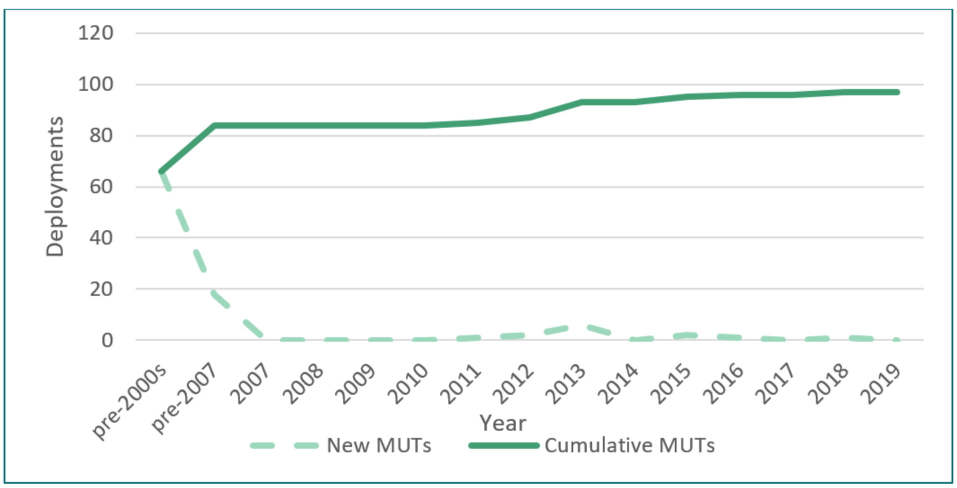
Figure 14 shows the number of existing DLTs and the cumulative number of DLTs identified in the deployment scan by year. DLTs have experienced modest growth, and DLTs are concentrated in a small number of States that have appreciated their value and have locations that are appropriate for their deployment.



Source: FHWA.

Figure 14. Graph. New and cumulative DLTs by year.

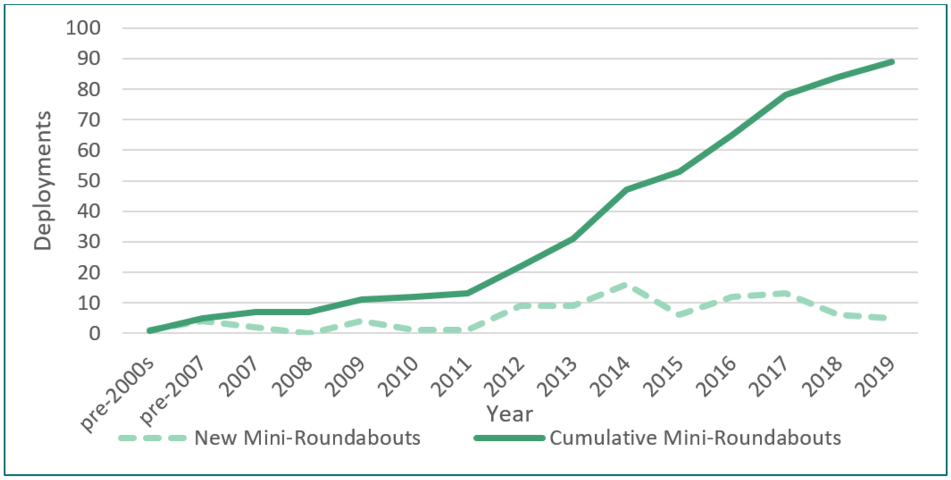
While MUTs are well known and appreciated for their safety benefits, they are not widely deployed or being adopted at rates comparable to the other designs. Figure 15 shows the number of existing MUTs identified in the deployment scan and the cumulative number of MUTs deployed each year. MUTs have not seen significant deployment since Michigan's early deployments, many of which occurred in the 1960s.(77) MUTs are used heavily in some States and have been for a number of years. In *Alternative Intersection Design and Selection*, California, Minnesota, Florida, and New York each reported having deployed as many as five MUTs that were not identified in the deployment scan.(69) Therefore, the total number of MUTs may be as high as 120 or greater.



Source: FHWA.

Figure 15. Graph. New and cumulative MUTs by year.

Figure 16 shows the number of existing mini-RAs identified in the deployment scan and the cumulative number of mini-RAs deployed by year. The figure shows that new mini-RAs were steadily around 10 deployments per year from 2012 through 2017 with some slowing in 2018 and 2019. This slowing in the last few years is likely due to the difficulty of tracking mini-RA deployments, which are, by design, smaller investments with smaller impacts on local communities in terms of right-of-way (ROW). Mini-RAs are not typically deployed on State-owned roads as they are more appropriate for intersections with low AADT. These intersections are usually owned by local agencies, and local agency activity is less transparent than State activity.



Source: FHWA.

Figure 16. Graph. New and cumulative mini-RAs by year.

Several States identified FHWA resources and outreach as integral to their level of deployment; interviewees believed there would be fewer IID deployments today if FHWA had not started their research program. As discussed in section 4.3, interviewees said that FHWA helped State DOTs overcome barriers; FHWA's authority and leadership position helped convince professionals that IIDs were worth considering, and the materials FHWA produced helped States reach out to the public and convince stakeholders that the designs are safe. By helping to overcome these barriers, FHWA clearly contributed to increased levels of IID deployment across the United States.

Interviews also covered FHWA's influence more generally, beyond just overcoming barriers to deployment. One State interviewee stated that they "have looked at RCUTs now because of FHWA,"[25] while a different interviewee stated the following:

> *"I want to reinforce the value that FHWA, the Resource Center, some of the research material produced by FHWA… some of the one-on-one help, whether that's the Resource Center or the local division office. Perhaps we could have gotten to where we are, but it would have taken several years longer, and I'm not sure that we would have gotten to where we are."*[26]

[25]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley, Joshua Fowler, and Kendall Mahavier in July 2019.

[26]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley, Joshua Fowler, and Kendall Mahavier in July 2019.

FHWA employees made similar statements, arguing that FHWA has been a leader in intersection design for years. One interviewee stated the following:

> *"I think what's exciting in the intersection area is that... FHWA has been a leader. It's been a leader since the 1990s, I would say, and of course, I've been involved in roundabouts for a long time before coming to FHWA.... I really think that ... even though I wasn't involved on the FHWA side, I have already said that roundabouts wouldn't be where they are today without FHWA, and I think it is no different with a lot of these other innovative intersections, with DDI, and with CFI, and with all the other [designs] included in that [*2010 AII Report*]."*[27(3)]

Two State employees appreciated the fact that FHWA respects the autonomy of States and does not push for involvement where it is unwanted. It was noted that one of the ways FHWA has helped States to deploy IIDs was simply by not stopping States from trying these new designs. One State employee said the following:

> *"They have done a fantastic job of staying out of our way... FHWA has helped us to innovate by being a good partner and by not stopping us.... We showed [a particular IID deployment plan] to FHWA, and they asked useful questions... they never stood in our way in terms of saying 'no, you can't do this because we've never seen it before.'"*[28]

As described in the interviews, FHWA's efforts were an important component to increased deployment of IIDs among State and local agencies. Figure 17 shows the yearly, cumulative number of States that have deployed IIDs by IID type. At least 43 States have deployed an IID, and States are continuing to explore deploying different IIDs as they gain confidence in the idea of deploying IIDs compared to conventional designs. In addition to the increase in State deployments, the number of local agencies that are deploying IIDs is increasing. The deployment identified more than 420 different local jurisdictions where IIDs have been deployed.

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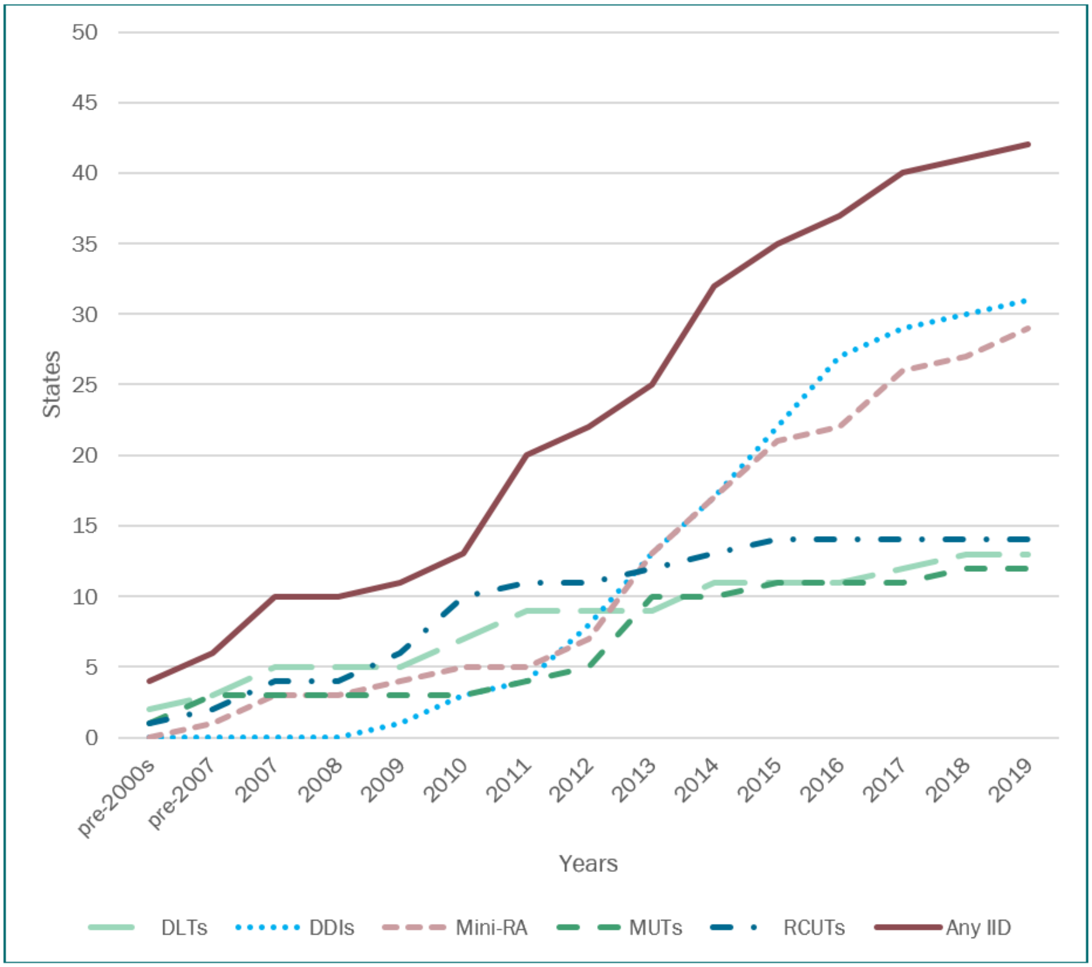
[27]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[28]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.



Source: FHWA.

Figure 17. Graph. Cumulative number of States deploying at least one IID, by IID.

When evaluating the success of IIDs, considering the baseline level of intersections and interchanges as well as the baseline rate of deployment are important. In terms of the number of intersections and interchanges of any design that exists, interviewees were able to provide some information about the total number that could exist, which puts the extent of current IID deployment and future deployments in perspective. With respect to intersections generally, one State employee said the following:

> *"We have 24,000 intersections on our system… In any given year, we do not reconstruct that many intersections. Of course, we treat intersections in one way or another, we touch every one of them, but in terms of going in and changing them, not that many. Probably, in a year, we might do 15 or perhaps 20 in a big year… so not that many."*[29]

[29]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley, Joshua Fowler, and Kendall Mahavier in July 2019.

With respect to interchanges, where growth is more limited than intersections due to the smaller number of interchanges relative to intersections, another State employee said the following:

> *"I think we have around 500 or so interchanges on our interchange system… Again, we're not going to touch most of those for decades, so how many actually projects are we doing out there? We've got the capability in the next 10 years to put in 14 more [DDIs] and we will go modestly with those."*[30]

States are continuing to consider IIDs to meet their safety, mobility, and cost-reduction needs, and the expectation that IIDs will continue to be deployed at an increasing rate in the future is widespread. With respect to DDIs, one consulted engineer said that they believed DDIs could see what they considered "exponential" growth in deployments each year, increasing to 25 to 50 per year nationally.[31] For RCUTs, the expectation is that deployments could increase substantially even beyond that of DDIs. One State reported having a substantial number of locations where RCUTs might be applicable, 20,000 to 30,000 intersections where a major road meets a minor road.[32] Of all the IIDs examined in this evaluation, mini-RAs likely have the greatest applicability due to their size. It was noted that the design has "explosive growth potential" due to the fact that they are much cheaper and fit under some funding thresholds.[33]

For other designs, there is less optimism about an increasing rate of deployment without more refinement to overcome barriers. One interviewee said the following of potential DLT deployment:

> *"[DLTs] are hard to implement… getting 10 a year on the ground would be an accomplishment in the near term… that would be a pretty big goal initially. If we could start solving the access problems… we could get to 25 to 50 a year."*[34]

Another interviewee speaking of the potential for MUT and DLT deployments said the following:

> *"… MUT and DLT I think they will probably be even less than DDI. To me they are very specific, very spot type of alternatives… major meets major, and we just don't have, this State or anybody else, have that many of those… If we have 10 of each of those I think we'll be doing well."*[35]

These results demonstrate that there is broad opportunity for IIDs and that there is optimism that IIDs will be deployed at greater rates than conventional designs. The deployment of IIDs in recent years has been an obvious success considering the relatively slow rate of intersection and interchange construction and reconstruction.

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[30]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[31]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[32]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[33]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[34]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[35]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

Finding 4b: FHWA accelerated early deployment of IIDs through outreach activities, including workshops and technical assistance.

FHWA provided early targeted technical assistance to States through division offices, the Resource Center, and the Office of Safety. FHWA supported a number of early deployments and evaluations of early deployments that gave confidence to early adopters to deploy these designs. The confidence of early State deployers who received FHWA technical assistance and training was propagated to other States who reached out to the initial deployers for technical assistance.

FHWA provided training and resources to States directly through their outreach activities, giving States the confidence, knowledge, and resources necessary to make informed deployments. Table 7 shows the total number of IIDs deployed by State and the number of FHWA-funded trainings conducted by State and year, including the NHI Roundabouts course, the NHI IID course, and the non-NHI FHWA trainings offered by R&T staff.[36] While there is no direct correlation between the number of workshops hosted in a State and the number of IIDs deployed by a given State, the table does demonstrate that FHWA has provided training and guidance to a wide range of States who have had some success in deploying IIDs. For these trainings and technical assistance, FHWA leveraged resources effectively to meet the growing demand of State and local agencies who wanted information and guidance on IID adoption and deployment, including recruiting consultants knowledgeable about IIDs. One interviewee said the following about FHWA's training and resources:

> *"I was the lead on the consultant side. I personally went to almost 25 of them. I had two other consultants with me who helped out sometimes…. One of the most successful EDC programs FHWA has had thus far."*[37]

[36]FHWA provided this data to the evaluation team. In some cases, whether an event should be counted as a single event or multiple events was unclear. The evaluation team decided, when trainings occurred at the same location over multiple days, the training would be counted as one event, and when trainings occurred over multiple days in multiple cities, they would be counted as separate events.

[37]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

Table 7. FHWA-funded trainings by year and State, and total IIDs deployed.

State	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total Trainings	Total IIDs Deployed
AK	—	—	—	1	—	2	—	—	—	1	4	3
AL	—	—	—	—	2	—	—	—	—	—	2	7
AR	—	—	—	—	—	—	1	—	—	—	1	—
AZ	—	—	—	—	—	1	—	—	—	—	1	2
CA	—	—	—	—	1	1	1	—	—	1	4	1
CO	—	—	—	—	—	—	—	—	—	—	—	11
CT	—	—	—	—	—	—	—	—	1	—	1	—
DE	—	—	—	—	—	—	—	—	—	—	—	3
FL	—	—	1	—	6	1	2	1	—	—	11	6
GA	—	2	—	—	2	—	—	—	—	—	4	8
IA	—	—	—	—	1	—	—	—	—	—	1	3
ID	—	—	—	—	—	—	—	—	—	—	2	2
IL	—	—	1	—	2	—	—	—	—	2	5	3
IN	—	1	—	—	1	—	—	—	—	—	2	7
KS	—	—	—	1	—	1	—	—	—	—	2	7
KY	—	1	—	—	—	4	—	—	—	—	5	2
LA	—	—	3	—	—	4	—	3	—	—	1	13
MA	—	—	—	—	1	—	1	—	—	2	4	1
MD	—	—	—	—	—	—	—	—	—	—	—	34
ME	—	—	—	—	—	—	1	—	—	—	1	—
MI	—	—	—	—	—	—	—	—	—	—	—	86
MN	—	—	—	—	1	5	1	—	1	1	9	22
MO	—	—	—	—	1	1	—	—	—	—	2	32
MS	—	—	—	—	—	—	—	—	—	—	—	3
MT	—	—	—	—	1	—	—	—	—	—	1	1
NC	—	—	—	1	—	—	1	—	—	—	2	113
NE	—	—	—	—	—	—	1	—	—	—	1	2
NH	—	—	—	—	—	1	—	—	—	—	1	—
NJ	—	—	—	—	—	—	1	—	—	—	1	7

State	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total Trainings	Total IIDs Deployed
NM	—	—	—	—	—	—	—	—	—	—	—	1
NV	—	—	1	—	—	—	—	—	—	—	1	3
NY	—	—	—	—	—	5	—	—	—	—	5	4
OH	—	—	—	11	3	—	8	3	2	5	32	9
OK	—	—	—	—	1	2	2	—	—	—	5	—
OR	—	—	—	—	—	—	—	—	—	—	—	2
PA	—	—	—	1	2	—	2	—	—	—	5	1
PR	—	—	—	—	1	—	—	—	—	—	1	—
RI	—	—	—	—	—	—	—	—	—	1	1	1
SC	1	—	1	1	1	—	—	1	—	1	6	2
SD	—	—	—	—	—	—	1	—	—	—	1	—
TN	—	—	—	—	—	4	—	—	—	—	4	3
TX	—	—	—	1	—	—	1	—	—	—	2	16
UT	—	—	—	—	—	—	—	—	—	—	—	26
VA	—	—	—	—	4	—	—	1	—	1	6	7
VT	—	—	—	—	—	1	—	—	—	—	1	1
WA	—	—	—	—	2	—	—	—	—	—	2	15
WI	—	—	—	—	—	—	—	—	—	—	—	3
WY	—	—	—	—	—	—	—	—	—	—	—	1
Grand Total	1	6	7	17	33	33	24	9	4	15	149	474

—Not applicable.

Finding 4c: FHWA contributed to an increase in the amount of funding spent on IIDs relative to other traditional intersections.

Federal grants, which totaled more than $71.7 million since 2009, were made available to States for IID deployments.

BUILD and TIGER Grants

The FHWA BUILD grant and its predecessor, the TIGER grant, are discretionary grants available for projects on nonfederally funded surface-transportation assets that "promise to achieve national objectives" and meet further selection criteria, such as demonstrated net benefits, safety, state of good repair, economic competitiveness, environmental sustainability, quality of life, and innovation.(64) A total of $38.8 million in BUILD grant funding has been awarded to projects deploying IIDs. In particular, in 2018, awards were granted to two projects that were deploying new IIDs. It should be noted that one 2018 BUILD grant award was granted for a project that called for removing an existing RCUT and turning the larger intersecting road into a freeway, limiting access to the crossing roads. Table 8 shows these BUILD grant awards for IID projects.

Table 8. BUILD grant awards for IID-related projects.

Year	Project Name	Location	IID	Award ($)	Project Total ($)	Description
2018	State Trunk Highway 29 - County Highway VV Multimodal Interchange Project	Brown County, WI	RCUT	19,758,000	27,828,000	Remove RCUTs and turns roadway into freeway restricting access for crossing roads.
2018	I-70 and Turner Diagonal Interchange Improvements	Kansas City, KS	DDI	13,844,000	30,344,000	Replace the existing interchange with a DDI.
2018	I-65 Interchange at Buckner Road	Williamson County, TN	DDI	25,000,000	48,279,000	Install a new DDI as well as construct an extension road to connect to the new interchange.

AID Demonstration Grants

FHWA AID demonstration grants provide funding for transportation investment projects that primarily "include an innovation proven in real-world application, though not routinely used by the applicant."(65) The grant carries a maximum funding amount of $1 million per project. The AID demonstration grant has awarded a total of $5.7 million of funding for seven projects since 2015. Projects include two mini-RAs, four DDIs, and one RCUT. Table 9 describes each of these AID grants.

Table 9. AID demonstration grants awarded to IID-related projects.

Award Recipient	Award Year	Innovation	Award Amount ($)
Virginia and the Town of Vienna	2014	Mini-RA	211,200
Delaware	2015	DDI	1,000,000
Michigan	2015	DDI	1,000,000
Minnesota and the City of St. James	2015	Mini-RA	864,000
Maine	2017	DDI	600,000
Oklahoma	2017	DDI	1,000,000
Minnesota	2017	RCUT	1,000,000

HfL Grant

The FHWA HfL program was established "to advance longer-lasting highway infrastructure using Innovations to accomplish the fast construction of efficient and safe highways and bridges."(66) The grant requirements include that the project must involve "constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway" and that it "must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction."(66) The program awarded funding to the following two projects with IID components:

- The HfL program awarded funding to Johnson County, KS, to support evaluation of smart work-zone technology during the construction of the I-35–Homestead Lane interchange. This project supported evaluation of the smart technology during deployment of the DDI design.(78) This research may lead to further reductions in cost of DDI construction and may have contributed to the deployment of DDI in this case.

- The HfL program awarded funding to New York State DOT for a demonstration project that involved the construction of a DDI at I-590 and Winton Road in Brighton, NY.(79) This DDI was the first in New York, and the funding was used to demonstrate several innovation strategies, including speed construction, congestion reduction, and work zone–safety improvements.(79) The project considered alternative designs, such as roundabouts, single-point urban interchanges, and triple left-turn bays, before selecting DDIs as other designs would have required significant ROW acquisitions and would have required bridge replacements.

Specific funding amounts for each project were not discussed in the HfL project reports.

CMAQ Grant

CMAQ was established in Intermodal Surface Transportation Efficiency Act of 1991 and has been reauthorized under each of the following Transportation Bills.(63) The discretionary grant program provides funding for surface transportation projects that improve air quality and relieve congestion. CMAQ evaluated a number of IIDs as capable of providing air-quality improvement and congestion mitigation.[38] As shown in Table 10, $27.2 million of CMAQ awards were granted to 13 different IID-related projects from 2009 to 2017. The majority (11) of the CMAQ awards were granted to DDI and DLT deployments. Two CMAQ grants were granted to projects with mini-RA aspects. In one case, the

[38] Congestion mitigation benefits of IIDs are discussed in more detail in section 4.5.

project was committed to, at least, considering a “compact” roundabout, which is likely a mini-RA.[39] Table 10 shows the CMAQ grants.

Table 10. CMAQ grants awarded to IID-related projects.

State	CMAQ Project ID	Year	CMAQ Funding ($)	Total Project Cost ($)*	Description
OH	OH20090067	2009	1,250,000	40,528,000	Install DLT
OH	OH20100013	2010	275,000	3,440,000	Install DLT
UT	UT20100007	2010	559,000	600,000	Install DLT
OH	OH20100013	2015	2,651,000	4,436,000	Install DLT
OH	OH20100013	2017	737,000	921,000	Install DLT
KS	KS20120004	2012	413,000	459,000	Install DDI
MO	MO20130037	2013	7,000,000	10,254,000	Install DDI
MI	MI20140020	2014	163,000	200,000	Install DDI
UT	UT20140006	2014	3,009,000	3,228,000	Install DDI and other improvements
UT	UT20140006	2015	3,108,000	3,334,000	Install DDI
GA	GA20160016	2016	7,679,000	9,599,000	Install DDI
AK	AK20160007	2016	227,000	250,000	Consider "compact" roundabout for intersection
VA	VA20170021	2017	101,000	390,000	Install mini-RA

*Total cost values may not be representative of the IID deployment itself as other project elements may be included in the overall total.

Finding 4d: FHWA's outreach efforts improved the selection and application of IIDs in the United States.

FHWA’s outreach efforts improved the selection and deployment of IIDs in the United States at locations that are most appropriate for the designs subject to the budgetary and other constraints of the deploying agencies. Proper intersection- and interchange-design selection is critical because intersection and interchange assets have long lives, are disruptive and costly to change, and have a potentially large impact on safety and mobility. Therefore, it is important for intersection deployments to use the best designs available to maximize impact and reduce cost.

FHWA decision-support tools and resources were also critical in giving State and local agencies the confidence and knowledge to deploy IIDs at sites for which they were most appropriate. *Alternative Intersection Design and Selection* surveyed States on how frequently they used various resources to evaluate and select intersection designs for a given site.(69) In addition to widespread use of FHWA resources, such as the *Highway Capacity Manual*, the *Highway Safety Manual*, and the *Manual of Uniform Traffic Control Devices*, use of FHWA alternative intersection guides were widespread. (See references 3, 6–9, and 80–82.) Forty States reported using the guides at least “Sometimes,” and 18 used it “Always” or “Almost Always.”(69)

[39]The naming convention of “mini-roundabouts” has not been uniformly accepted throughout the transportation community.

FHWA tools, such as the Safety Performance Intersection Control Evaluation (SPICE) tool and the Capacity Analysis for Planning of Junctions (CAP-X), were critical resources for a number of States.[83,84] Sixteen States reported using CAP-X "at least "Sometimes," while six reported using CAP-X "Always" or "Almost Always." One stakeholder said of the CAP-X tool:

> *"I would say really practical easy-to-use tools like CAP-X are really helpful, and that's a tool that, if you've got the turning volumes at your intersection, that's all you need to input. That's 10 min of work to input the numbers, and it can give you a quick look at what intersections or interchanges are feasible and which aren't from a capacity standpoint."*[40]

Other FHWA efforts that also contributed to appropriate design selection and enhanced the overall impact of the IID program occurred in parallel to the IID program. As part of EDC-2, FHWA promoted a design-selection methodology called Intersection Control Evaluation (ICE), which "is a data-driven, performance-based framework and approach used to objectively screen alternatives and identify an optimal geometric and control solution for an intersection."[83] While FHWA did not develop ICE, it has contributed to State awareness of the methodology. A limited number of States have adopted ICE formally, but many more use informal ICE-style evaluation methods for selecting intersection designs.[41] Importantly, SPICE was developed from FHWA's ICE efforts, which highlights the interaction between FHWA's IID program and the ICE program.

While FHWA contributed to appropriate design selection through their efforts with ICE, States did have some mixed results in the appropriateness of the innovative designs that were selected for deployment. One potential signal of inappropriate deployments is the extent to which IIDs are removed after deployment. If FHWA promotional activities were too strong, they may have induced States to deploy IIDs in areas where they are not best suited. One State interviewee was thankful that FHWA was not prescriptive and did not pressure them to adopt designs, while another State interviewee was concerned that some designs were too heavily promoted, particularly the DDI.[42]

An appropriate target for FHWA, in terms of measuring the impact of their promotional efforts, is that, in some small number of cases, agencies find that the IIDs do not perform better than conventional designs because this would mean that IIDs were being deployed up to the point where the marginal benefit of deployment is zero. Alternatively, if IIDs were being removed regularly then it would potentially signal that agencies are being pressured to deploy or are misinformed about whether the design was, in fact, the best alternative.

While some IIDs have been removed since their deployment, removal of IIDs is not a frequent occurrence. Based on the deployment scan and literature review of this evaluation, at least seven IIDs, of which five were RCUTs and two were MUTs, have been removed. In some cases, the decision to remove the IID was based on separate changes to the roadway that made the particular design ineffective or inappropriate, such as the removal of RCUTs where one of the intersecting roadways was being converted to a restricted-access roadway (as was the case in the aforementioned BUILD grant).

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[40]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[41]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[42]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019; State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

Another signal of whether IIDs are being appropriately deployed is whether deployers are satisfied with the performance of their IIDs. *Alternative Intersection Design and Selection* surveyed all 50 States about how they would rate the performance of their IIDs on scale of 1 to 10, with 1 meaning outstanding and 10 meaning poor.(69) The results show that IID deployments are rarely regretted. DDIs were the most frequently rated of the designs and the most consistently highly rated, with the lowest score being a 5 and the average score being 8.4. Nineteen States rated their DDI performance at 9 or 10. RCUTs were rated by 18 deployers and similarly favored with an average score of 8.2 out of 10. MUTs were rated by 14 agencies with an average score of 7.4. DLTs were rated by 12 States and had the lowest average score of all IIDs, 6.3. Two States rated their DLT performance lower than 5, which could suggest a bimodal experience. DLTs are not as favored as the other designs but are still positively rated on average.

4.5 Evaluation Area Five: Safety, Mobility, and Construction-Cost Impacts

The logic model developed for this evaluation suggests that FHWA research and outreach led to a positive ROI on FHWA's research investment in IIDs. This return is the result of increased and appropriate IID deployments that generated safety, mobility, and construction-cost benefits relative to conventional intersection and interchange designs. The specific hypotheses for this evaluation area were:

- IIDs led to a reduction in number of crashes at intersections, reduction in the number of fatal crashes at intersections, reduction in the number and severity of injury crashes at intersections, and a reduction in the number of crashes downstream of IID intersections.
- IIDs led to reduction in environmental impacts from intersections.
- IIDs led to improved operational performance at intersections.
- IIDs led to a reduction in construction costs compared to conventional intersection designs.
- IID research has a net positive ROI.

These hypotheses are laid out in Table 2 in section 2.1. These hypotheses are addressed collectively, not addressed individually, in this evaluation area because they were evaluated as a group. The findings laid out in this section collectively address these hypotheses.

In the next section, Overview of Findings, a summary of findings for this overall evaluation area, followed by more detailed analysis, is presented. Finally, the evaluation team conducted an ROI analysis using conservative assumptions about the benefit of each IID and the role that FHWA played in the deployment of IIDs in the United States. This particular finding is inferential and provisional, and it should not be interpreted as a fact about the specific value of the IID program.

Overview of Findings

FHWA's research and promotion of IIDs led to a positive ROI from IID deployment through increasing IID deployments that had better outcomes relative to the design alternatives in safety, mobility, and construction cost.

Safety impacts are the largest share of these benefits. Relative to conventional intersections, IIDs significantly reduce crashes (particularly fatal crashes), resulting in substantial life and cost savings. Mobility benefits are the most important factor States consider when making intersection investment decisions, and IIDs provide substantial mobility benefits in terms of reductions in the average seconds of delay (or travel time) for vehicles passing through the intersection. Finally, agencies consider construction costs, but it is not the most important factor in deciding whether to deploy an IID. However, depending on the IID and whether the construction is new or a retrofit of existing infrastructure, IIDs can provide substantial construction-cost savings relative to conventional intersections. Construction-cost benefits can be on the order of millions of dollars of savings compared to conventional alternatives. The evaluation reviewed the literature for environmental impacts, but information regarding emissions reductions or lifecycle environmental impacts was limited and is not included in this report.

The ROI on FHWA's research and outreach investment was calculated using a back-of-the-envelope calculation that assumes an average safety, mobility, and cost-savings benefit for each IID deployment identified in the deployment scan (as discussed in section 4.4). Using modest assumptions for the number of IID deployments to which FHWA research or outreach contributed, the results of the analysis show that FHWA research and outreach induced significant ROI, on the order of millions of dollars of benefits.

Detailed Findings Summary

Finding 5a: IIDs led to a reduction in construction costs compared to conventional intersection designs.

In many contexts, IIDs are capable of providing substantial construction-cost savings compared to conventional intersection and interchange designs. IIDs are neither appropriate in all contexts, nor do they always improve safety, mobility, and construction-cost savings. Selecting the appropriate design for a site requires making trade-offs between relative gains in safety, mobility, and construction costs compared among the various alternative designs considered. Table 11 shows the results of the evaluation scan of IID construction costs compared to conventional intersections. The reported lowest, average, and highest cost savings are calculated as the construction cost of the conventional intersection minus the construction cost of the IID.

Table 11. IID construction costs compared to conventional intersection and interchange alternatives.

IID	Construction Type/ Comparison Design	Number of Cost Estimates	Lowest Cost Savings ($)*	Average Cost Savings ($)*	Highest Cost Savings ($)*
DDI	All	17	−12,000,000	4,502,647	42,000,000
DDI	New	9	−12,000,000	−2,045,000	11,410,000
DDI	Retrofit	8	1,750,000	11,868,750	42,000,000
RCUT	All	6	−3,350,000	4,116,000	22,764,000
RCUT	Conventional	4	−3,350,000	−1,067,000	1,032,000
RCUT	Grade separated	2	6,200,000	14,482,000	22,764,000
DLT	Grade separated	5	−5,955,000	17,209,000	33,000,000
MUT	All	6	−1,190,000	9,840,000	28,300,000
MUT	Conventional	3	−1,190,000	313,000	2,539,000
MUT	Grade separated	3	4,900,000	19,367,000	28,300,000
Mini-RA	Conventional	2	600,000	700,000	800,000

*Positive values represent construction-cost net benefits for IIDs relative to comparison design. Negative values are possible when the construction costs of IIDs are greater than their conventional alternatives.

As Table 11 demonstrates, the cost benefits of DDIs depend on site specifics. While DDI cost effectiveness depends on project circumstances, retrofit DDIs provide substantial cost effectiveness in most contexts. Expanding, raising, and rebuilding interchanges can become extremely costly, and for contexts in which vehicle-volume growth is expected to exceed or change to exceed the DDI's mobility-efficiency bounds, they can be more expensive in the long-run than other alternatives. One interviewee noted the following:

> *"In some cases, you can use existing bridges without widening them and increase capacity by 30 percent, but then you have to improve channelization on the ramp terminals. So a project that would have cost you maybe $20 or $30 million can be done with $2 or $3 million. The one in Springfield, MO, cost maybe $3 million. Imagine they had to build one that had eight lanes instead of five lanes, it would have cost $20 million. Plus, the discomfort and delays during construction, it would take maybe 1 or 2 years to finish. Instead, the DDI was done in 6 mo. So, you can save $10 million easily per site. Even if you have to build a new one, it will be much narrower."*[43]

The construction-cost benefits of RCUTs particularly depend upon traffic volume at the deployment. RCUTs are cost competitive with conventional intersections when traffic levels do not require grade separation. Unsignalized RCUTs are more cost competitive with conventional designs, but signalized RCUTs are roughly comparable to conventional intersection designs. However, RCUTs have demonstrated significant cost savings when compared to grade-separated interchanges. The tradeoff between safety benefits and construction-cost savings is especially pertinent when comparing RCUTs to grade separation as RCUTs dramatically, though not completely, reduce certain types of crashes, while grade separation eliminates those same crashes but at significantly higher

[43]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

costs. Interviewees were in agreement that the RCUT has strong construction-cost savings compared to grade separation. One interviewee noted the following:

> *"The cost difference between an RCUT and an interchange, kind of just the general cost, is about $1 million or maybe a little less for the RCUT, and maybe around $10 million for the interchange, and the difference is more pronounced in an urban corridor, around $30 million, with the right-of-way. It's a big motivator for the agency. It's really helped the agency here."*[44]

One interviewee, speaking of the decisionmaking process of a local agency, described the value of RCUTs as follows:

> *"Their desire was to do an interchange: 'It is dangerous enough and we have enough serious injury or fatal crashes.' They wanted to convert the intersection into a grade-separated diamond interchange, and at that time, one interchange even in rural areas, would cost about $18 to $20 million. With that same amount of money, let's say it's $20 million, it's only enough to do one interchange, but if we use the same amount of money to do an RCUT, we can do probably 30 to 40 intersections, we've basically solved the safety problem at 30 to 40 intersections instead of 1."*[45]

The cost benefits of DLT similarly depend on whether the alternative design is grade separated or conventional. When compared to conventional intersections, DLTs may be more expensive due to the extensive street layout, traffic-control devices, and larger footprints requiring ROW acquisition. In some locations, higher costs were incurred due to ROW required for channelized right turns. Interviewees were consistent about the source of costs for DLTs but also their construction-cost benefits compared to grade separation. One interviewee noted the following:

> *"[Land acquisition] was an important factor, and of course, it takes a long time to purchase the land. And it's a very long, extensive process, so this is one of the reasons. And the other reason is to look at the capacity improvement. Some of them gave higher capacity improvements, others didn't as much... [DLTs are] applicable mainly when you have balanced flows on the opposing arterial, if you have 50–50 or 40–60 [share of directional traffic flow] or closer to that on the opposing arterial and when it has heavy left turns.*[46]

Another interviewee described the benefits of DLT as follows:

> *"You can't avoid $35 million on grade separation. Cost of [DLT] varies, and utility complex matters, etc. You are going to have those nuances, but end of the day, it has been a cost savings. Imagine a fly-over ramp in Durango as you approach downtown, not cost effective, doesn't fit with the community."*[47]

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[44]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[45]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[46]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[47]Practitioner; phone interview conducted by evaluation team members Jonathan Badgley and Joshua Fowler in July 2019.

Another interview described their strategy of using DLTs as a medium-term solution to grade separation as follows:

> *"We put in a ton of [DLTs] to get another 10 years and then built interchanges. The original [DLT] was around $7 million, and subsequent ones were cheaper than that, $5–6 million."*[48]

The literature review of MUT construction costs provided a number of cost estimates. Compared to conventional intersection designs, the costs of MUTs were modest, averaging approximately $300,000, but compared to grade-separated designs, MUTs were significantly more cost effective. The cost benefits of MUTs were not cited by the interviewees, reflective of the limited number of recent deployments of MUTs.

The mini-RA is generally understood to be less costly than the modern roundabout because it requires less ROW-acquisition and pavement costs due to its smaller footprint. Construction-cost data for mini-RAs, particularly cost data relative to conventional intersections, are limited due to the scarcity of cost estimates. Earliest cost estimates for mini-RAs showed that they could cost less than $50,000 (2001 U.S. dollars).(85) Mini-RAs in alternative contexts, such as part of a larger interchange system like the relaxed bowtie system, were estimated to cost anywhere from $15,000 to $30,000.(86) FHWA estimates that mini-RAs can cost anywhere from $25,000 to $400,000 per intersection depending largely on the capacity.(87) One interviewee corroborated the construction-cost figures and explained what made mini-RAs less expensive than a modern roundabout as follows:

> *"They needed to buy less than 0.1 acres of land. It required a very small right-of-way acquisition. And they didn't need to relocate the storm drains. I think cost was $400,000 per intersection, so $800,000 for two intersections."*[49]

Cost is a limiting factor for State and local agencies in determining which designs can be deployed as, without the proper funding, some design alternatives are not feasible. The safest alternative, with respect to right-angle crashes, is grade separation, where flows of traffic are separated from one another so that collisions are not possible, but this design is also the most expensive alternative because it requires substantial construction. Despite the obvious trade-off between safety and mobility with construction costs, State respondents to the *Alternative Intersection Design and Selection* survey reported that construction costs are not a significant factor in the decision to deploy an intersection or interchange design.(69) Construction cost was the only factor with a significant response rate (20 percent) of "rarely." Consistent with this result, one interviewee noted that the public is typically not as aware of how cost is a factor and that, in cases where an RCUT would provide the same safety benefits at lower cost, their public preferred the more expensive grade separation.[50]

[48]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

[49]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019.

[50]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

Finding 5b: IIDs led to a reduction in the total number of crashes, the number of fatal and injury crashes, and the severity of injury crashes at intersections and to a reduction in the number of crashes downstream of IID intersections.

FHWA began to pursue IIDs because they recognized that intersections were among the most dangerous locations on U.S. roads. The evaluation of IIDs since this time has demonstrated the crash-reduction potential of IIDs compared to conventional alternatives. Table 12 shows the summary statistics of the literature review of CMFs by IID and crash type. A CMF is "a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site."(88) A CMF less than 1 represents a decrease in crashes (of one minus CMF), a value of 1 represents no impact, and a value greater than 1 represents an increase in crashes (of "CMF minus one").

Table 12. CMFs by IID and crash types

IID	Crash Type	Count of CMFs Computed or Reported	Average CMF	Standard Deviation of CMFs	Minimum CMF	Maximum CMF
DDI	Fatal and injury	37	0.49	0.26	0.19	1.38
DDI	Injury	1	0.59	—	0.59	0.59
DDI	PDO	27	0.62	0.21	0.28	1.20
DDI	All	39	0.80	0.40	0.17	2.02
RCUT	Fatal	7	0.00	0.00	0.00	0.00
RCUT	Fatal and injury	12	0.64	0.38	—	1.53
RCUT	Injury	20	0.76	0.54	0.07	2.00
RCUT	PDO	1	1.31	—	1.31	1.31
RCUT	All	39	0.83	0.63	0.18	4.05
DLT	Fatal	1	0.00	—	0.00	0.00
DLT	Injury	1	0.83	—	0.83	0.83
DLT	PDO	1	0.73	—	0.73	0.73
DLT	All	17	1.10	0.30	0.76	1.85
MUT	Injury	9	0.68	0.19	0.30	0.97
MUT	All	9	0.69	0.16	0.41	0.96
Mini-RA	Injury	1	0.67	—	0.67	0.67
Mini-RA	All	2	0.25	0.25	—	0.50

—Not applicable.
PDO = property damage only.

IIDs, on average, provide substantial crash reductions primarily due to the reduction in the number and angle of contact points.

DDIs, on average, reduce injury and fatal crashes by nearly 50 percent, though variability is wide, with the minimum CMF being 0.19 and maximum being 1.38 for studies reporting combined fatal and injury crashes. One interviewee described the safety benefits of DDI as follows:

> *"The ones where we've installed them, we've seen the crashes go down, I think because, where we put them in, we had a lot of congestion due to the left running traffic. It also makes it less severe and makes it easier for our first responders to get to them if there aren't parked cars anywhere."*[51]

RCUTs have strong safety benefits for both fatal and injury crashes. Seven study results show complete reduction in fatal crashes after RCUT deployment. The CMFs for the study results that combined fatal and injury and those that focused on injury-only crashes were more modest at 0.64 and 0.76, respectively. One interviewee spoke of the benefits of RCUTs in reducing the targeted crash type as follows:

> *"I think we saw an 88-percent reduction in right-angle crashes, which are our more severe crash types, mostly due to the fact that we're eliminating that left-out maneuver that has the most potential for a severe crash occurring. So that, in and of itself, has been one of the key contributing factors to the safety benefits we've had. Since the first deployment in 2007 and all the other deployments, I think we've just had one fatality tied to a J-turn, and that was a unique circumstance."*[52]

The safety benefits of DLTs seem to vary significantly by their deployment and generally fall near a CMF of 1, with the average for all crashes being 1.10. The DLT is designed specifically to reduce left-turn crashes but may impact (may even increase) other crash types. MUTs enjoy modest crash safety benefits compared to conventional intersections that allow left turns by crossing traffic with CMFs slightly below 0.70. One interviewee spoke very highly of the safety potential of MUTs, saying the following:

> *"The boulevard section with the MUT is the safest road cross section that we can build in [our State] after the freeway. Freeway is number one, and then, MUT is second in safety."*[53]

While crash data on mini-RAs are limited, the mini-RA is shown to have strong safety benefits with an average CMF of 0.25. Because mini-RAs are deployed at low-volume roads with lower speeds, the baseline crash injury severity is anticipated to be low, meaning that, although the mini-RAs have demonstrated strong crash reductions, the total crash benefits are likely limited.

The impact of IIDs on upstream crashes, crashes that occur on adjacent intersections, was extremely limited. One study focused on RCUTs found that there was possible crash mitigation for an intersection adjacent to an RCUT deployment, but this mitigation was not statistically significant.(89) Further research into the network impacts on safety of IIDs may be a valuable research area.

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[51]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in June 2019.

[52]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in June 2019.

[53]State transportation agency employee; phone interview conducted by evaluation team members Jonathan Badgley and Kendall Mahavier in May 2019.

Finding 5c: IIDs led to improved operational performance at intersections.

IIDs can provide mobility benefits for users by allowing more efficient movement through the intersection for a majority or all users through changing how cross-traffic left turns are made. Table 13 shows the summary results of the literature review for mobility impacts. The table shows the number of studies and the summary statistics for the average vehicle delay reduction or average vehicle total travel time reduction for all vehicles moving through the intersection. These results encompass all vehicle paths, including through traffic as well as turning lanes.

Table 13. IID mobility improvements by reductions in average delay or travel time relative to conventional intersections.

IID	Count of Study Results	Average of Reductions in Delay or Travel Time (s/Vehicle)	Standard Deviation of Reductions in Delay or Travel Time (s/Vehicle)	Minimum of Reductions in Delay or Travel Time (s/Vehicle)	Maximum of Reductions in Delay or Travel Time (s/Vehicle)
DDI	55	(25.2)	52.3	(199.0)	135.6
RCUT	8	(103.3)	149.6	(492.0)	(15.2)
DLT	58	(36.1)	37.7	(195.3)	2.2
MUT	19	(47.1)	21.1	(74.1)	0.1
Mini-RA	3	(7.4)	2.4	(10.8)	(5.3)

Note: Values in parentheses are negative.

Capacity is the primary concern of agencies when considering new designs. State respondents to the survey in *Alternative Intersection Design and Selection* reported that capacity was the most important consideration when making design decisions, with 78 percent of States reporting that this factor is “Always” or “Almost Always” taken into account.[54](69)

Finding 5d: FHWA IID research and outreach efforts has a net positive ROI.

FHWA IID research has had a net positive ROI through increased deployments of IIDs that are likely to have provided significant safety, mobility, and cost-reduction benefits. The ROI analysis relates an average safety, mobility and construction-cost benefit for each deployment in the deployment scan. Because of the inherent uncertainty of the benefits, the analysis uses conservative assumptions about the scale of those benefits. In particular, the analysis assumes the following:

- Travel-time benefits (peak hour average annual volume) are conservatively based on AADT data in the Highway Performance Monitoring System for roadways that would accommodate the IID type. Travel-time savings assume that all travel is personal-vehicle travel, that conservatively vehicle occupancy is 1 rather than the 1.68 passenger vehicle occupancy value in USDOT guidance, and that travel time is valued at the DOT recommended rate for personal travel of $14.80/h.(71)
- Safety benefits are estimated for fatal crashes only, rather than for all injury crashes, to be conservative. Fatal crashes are assumed to occur at the national rate for fatal crashes from FHWA’s 2017 Highway Statistics.(90) For each IID, the CMF used is the most conservative

[54]This is the highest rate of State respondents reporting that the factor is always or almost always reported.

average CMF among the fatal, injury-and-fatal, or injury crashes. In many cases, the injury-and-fatal and injury CMFs imply less crash reduction than the CMF for fatal crashes (particularly for RCUTs and DDIs), and thus, using these CMFs will be conservative. The value of fatal crashes reduced uses the USDOT VSL of $9,600,000.(71)

- Construction-cost benefits assume the average construction-cost difference between the IID and the closest relevant alternatives. These figures come from published evaluations as discussed above and shown in table 11.

The following calculations were made to scale and monetize safety and mobility impacts:

- Travel-time reduction (s/vehicle) are the average travel time savings reported in table 13.
- Annual travel-time reduced is calculated as the product of travel-time reduction (s/vehicle), assumed peak-hour volume, 4 h of peak travel, 260 weekdays per year, and vehicle-occupancy of 1 all divided by 3,600 s (to convert the result into hours).
- Annual-crashes reduced per year assumes the fatal-crash rate reported in FHWA's 2017 Highway Statistics per 100 million vehicle miles traveled multiplied by the number of rush-hour vehicles.(90)

Table 14 shows these calculations and the inputs for each IID. The benefits of each IID deployed can be calculated using the average safety, mobility, and construction costs for each IID type. For instance, based on the results of Table 14, the annual undiscounted benefit of a DDI is $323,232 in travel-time savings, $299,520 in fatal-crash savings, and a one-time construction-cost benefit of $4,502,647. In total, a DDI can be expected to provide $5,125,399 in benefits relative to a conventional interchange in the first year and an undiscounted $622,752 in safety and mobility benefits annually thereafter.

Table 14. Assumed annual average benefits per IID deployed.

IID	Travel-Time Reduction (s/Vehicle)	Assumed Peak Hour Annual Average Vehicle Volume	Annual Travel Time Reduced (h)	Annual Travel-Time Savings Per IID ($)	CMF (Fatal)	Assumed Fatal Crash Rate (per 100 million VMT)	Annual Fatal Crashes Reduced	Annual Fatal-Crash Savings per Year ($)	Average Construction Costs Relative to Baseline per IID Deployed ($)
DDI	25.2	3,000	21,840	323,232	0.8	0.48, urban interstate	0.031	299,520	4,502,647
RCUT	103.3	1,000	29,842	441,665	0.83	1.34, urban principal arterial	0.010	99,840	1,067,000
DLT	36.1	2,000	20,858	308,695	1.1	1.04, urban minor arterial	0.021	199,680	17,208,933
MUT	47.1	2,000	27,213	402,757	0.69	1.34, urban principal arterial	0.021	199,680	9,839,911
Mini-RA	7.4	200	428	6,328	0.25	0.74, urban local	0.002	19,968	700,000

VMT = vehicle miles traveled.

A share of the benefits of IIDs are assumed to be due to FHWA's influence in acceptance, adoption, and ultimately deployment. This share reflects the impact of FHWA's efforts, which can be thought of as how many of these designs would not have been deployed or not have been deployed as soon as they were without FHWA's contributions. The analysis assumes a conservative 10 percent as the share of the contribution FHWA made that ultimately impacted State and local agencies to deploy IIDs. Table 15 shows the cumulative IIDs deployed in the United States since 2009 that are assumed to be due to FHWA's contributions, assuming 10 percent of all deployments would not have occurred but for FHWA's influence. The evaluation team chose 2009 as the starting year of the analysis because that is the year the *2010 AII Report was* released.(3)

Table 15. Cumulative IIDs deployed in the United States since 2009 assumed due to FHWA's influence (10 percent of IIDs), by IID Type.

Year	DDIs	RCUTs	DLTs	MUTs	Mini-RAs	IIDs, All
2009	0.1	1.7	—	—	0.4	2.2
2010	0.5	3.9	0.2	—	0.5	5.1
2011	1.2	6.1	0.6	0.1	0.6	8.6
2012	2.0	7.3	0.8	0.3	1.5	11.9
2013	3.5	8.2	0.9	0.9	2.4	15.9
2014	4.6	9.7	1.2	0.9	4.0	20.4
2015	6.7	10.3	1.7	1.1	4.6	24.4
2016	8.8	10.7	1.9	1.2	5.8	28.4
2017	10.0	11.0	2.0	1.2	7.2	31.4
2018	10.8	11.2	2.2	1.3	7.8	33.3
2019	11.5	11.3	2.3	1.3	8.3	34.7

—Not applicable.

Table 16 shows the annual cumulative benefits from safety, mobility and construction costs that can be attributed to FHWA's research and outreach efforts under conservative assumptions about the benefits for each IID and FHWA's contribution. The total benefit is approximately $200 million with roughly half of these benefits coming from DDI and RCUT deployments. Even assuming 5 percent of the IIDs were influenced by FHWA's efforts instead of 10 percent (as shown in table 16), the total benefits (approximately $100 million) would far exceed FHWA's spending.

Table 16. Cumulative annual benefits of IIDs attributable to FHWA (10 percent) under conservative assumptions, by IID type.

Year	DDIs ($)	RCUTs ($)	DLTs ($)	MUTs ($)	Mini- RAs ($)	IIDs, All ($)
2009	512,540	893,342	—	—	290,518	90,283
2010	2,624,975	1,128,873	3,543,462	—	373,666	5,413,230
2011	6,524,130	173,093	10,732,060	1,044,235	459,444	18,586,776
2012	11,371,752	2,499,493	14,580,547	3,192,948	1,128,887	32,773,627
2013	20,305,354	5,979,533	16,758,977	9,639,088	1,821,997	54,504,950
2014	28,122,925	9,631,630	22,531,708	10,181,282	3,047,181	73,514,726
2015	41,750,922	14,568,931	32,000,412	12,811,945	3,588,142	104,720,351
2016	56,686,698	19,936,233	36,408,111	14,518,861	4,580,657	132,130,561
2017	68,317,395	25,572,687	39,145,755	15,241,786	5,749,987	154,027,609
2018	78,645,234	31,424,142	43,705,966	17,008,946	6,375,095	177,159,382
2019	88,958,735	37,436,447	46,596,122	17,792,114	6,943,350	197,726,768

—Not applicable.

Under these conservative assumptions about the impact of IIDs and the role that FHWA played in IID deployment, it is highly likely that FHWA IID research has had a positive and significant ROI. While the figure of FHWA's total spending on research and outreach was not available, FHWA was able to provide cost estimates for some of the IID project outputs. For FHWA R&D research products, FHWA estimated spending $0.25 million on the *2010 AII Report*, and an average of $0.05 million on each of the five TechBriefs.[3,15–19] The recent FHWA original research project on mini-RAs was estimated to cost around $0.35 million, and the costs of ongoing research projects from 2014 to the present were estimated to total around $1 million. For outreach efforts, particularly EDC-2, FHWA estimated spending of roughly $1.25 million to develop the information guides, brochures, videos, case studies, workshop materials, and so on. Particular estimates of the early research products or the outreach efforts of FHWA's Resource Center were not available. However, a rough but reasonable estimate of the total cost of the IID program since early 2000s is $4.0 million. Therefore, under the conservative assumptions about FHWA's role in IID deployment, the agency's IID program yielded societal benefits (in avoided crashes and delays and other cost savings) of up to $50 per $1 invested ($200 million/$4 million). Readers should exercise caution with these results as they are not official in that the deployment-benefit and program-cost values have not been discounted and, therefore, do not reflect the time value of money. The program costs mostly predated the realization of benefits so that the benefits are strictly higher than the program costs in undiscounted value.

5. Recommendations

FHWA IID research and related activities took place over a decade and half and spanned the range of the technology-adoption lifecycle. The number of IID deployments has significantly increased over this period. However, despite this significant growth, room for improvement remains. To further increase the value of FHWA safety research to FHWA and its wider community of partners and stakeholders, the evaluation team offers the following recommendations for FHWA's consideration.

Recommendation 1: FHWA should consider working with State or private partners to develop a more reliable, comprehensive national map of intersections that identifies the intersection design and other key features of the intersection that are relevant for both researchers and practitioners.

FHWA has generally been reliant on unofficial or third-party websites to track deployments of innovative technologies. The deployment tracking of this evaluation relied on three separate sources that were of limited reliability and required substantial effort to validate and complete. A lack of robust national intersection data frequently limits attempts to evaluate the adoption and deployment of new technologies, not just intersection designs, and especially limits the ability to make informed choices about where to deploy Federal resources. Creating a database of intersections would enable analyses of intersection designs by both researchers and practitioners. Researchers could use the intersection database to connect intersection designs to safety data from the Fatality Analysis Reporting System or other sources, while practitioners could use the database to identify intersections across the nation that are similar to their intersections and devise best practices based on the geometrics and issues faced at a particular intersection.

The intersection map would not have to be created completely in-house; FHWA could coordinate and consult with various third-party vendors to help create the foundation of the database. The creation of the database would likely require substantial time and effort to develop initially. To reduce the potential burden of this effort, the database could start with interchanges as there are fewer of those than intersections, and then, as new data are available, the database could be expanded to include intersections. Ultimately, such an effort would require resources to develop, and FHWA should explore the value of this resource with stakeholders to determine whether it would be cost beneficial. Further, FHWA should explore cost-effective methods of maintaining this database. Such methods could include reliance on State reporting or other third-party transportation technology firms that regularly generate similar data. For many potential users, the benefit of access to a national database would exceed the minimal cost of contributing information about new deployments.

This recommendation builds on a recommendation from the *Roundabouts R&T Evaluation Report* as well as a recommendation from *Alternative Intersection Design and Selection*.(11,69) Although the specific recommendation differs across these reports, the general theme of increasing data availability on intersection designs is consistent.

Recommendation 2: FHWA should promote consistency in nomenclature and definitions whenever possible and carefully consider the marketability of various terms.

The evaluation team noticed that the intersection designs often have alternative names and, preferred terminology and the exact definitions of the terms are inconsistent across the country. One State may call it an RCUT, another may call it a superstreet or J-turn, and a third may use all terms interchangeably. During this evaluation's interviews, the evaluation team would sometimes have to offer a few alternative names to ensure that the interviewee correctly understood which design to discuss.

Differences in terminology are often a common aspect in early exploration of new areas, however, now that these designs are beginning to experience more widespread deployment, it is important to ensure researchers and practitioners are using the same terminology. Use of different names can be a barrier to information sharing. If one researcher calls it a “continuous-flow intersection” and the other calls it a “displaced left turn,” the researchers may remain unaware that the other’s research is relevant for the same design. In particular, this can be problematic for a practitioner who is trying to learn more about a design for the first time—if their first introduction to a design is that it is called a “Michigan left,” they might not know to search for “median U-turns” as well. Additionally, Different terms can create the erroneous impression that there is some (subtle) difference between the designs when there is not. Where there are subtle differences between the designs, FHWA can contribute to shaping the terminology to ensure consistency.

Using terms and nomenclature in accordance with existing industry standards or establishing new standards will enhance the research work being done on IIDs. As an industry leader, FHWA could play an important role in trying to ensure that researchers and practitioners across the country use a more standardized naming convention for intersection designs. Relatedly, FHWA should consider the branding issues that may arise from their choice of naming conventions. The IID program began as the “Alternative Intersection Design” program, and as one interviewee noted, FHWA “branded that wrong.”[1] The word “innovative” is likely more appealing to State agencies, the general public, and other stakeholders than the word “alternative.” As FHWA invests in new areas and technologies, the evaluation team encourages FHWA to use standardized terminology that carefully considers what terms will be the best for marketing and branding.

Recommendation 3: Building on the existing FHWA Focused Approach to Safety, which is a data-driven approach to selecting Intersection Focus States, FHWA should consider developing an additional level of strategic targeting and marketing that considers qualitative aspects of technology diffusion, such as information-sharing networks among States and technology champions.

FHWA has long used data-driven approaches to identify States for targeted intervention, such as through the Focused Approach to Safety. FHWA should build on this data-driven approach to include another strategic layer that considers qualitative aspects of a State that would make it an ideal target for Federal intervention. A data-driven approach would include considering States’ receptivity to new technologies and the level of influence that States have on other States. When developing marketing and outreach for new research products, FHWA should consider mapping States’ information sharing networks so that they can leverage States that are considered influential or knowledgeable and who other States look to for guidance. For instance, a number of States had champions of particular IIDs that were influential in increasing IID awareness, adoption, and deployment. Missouri was an early leader in deployment of both roundabouts and DDIs, Utah is a leader with DLT deployments, North Carolina is a leader with RCUT deployments, and Michigan is a leader of MUT deployments. This evaluation was not able to uncover which States are generally the most influential in the realm of intersection design, but further interviews with State DOTs could likely provide this information. If FHWA mapped the network of information sharing that occurs between States, then it would be easier to target the States that are most likely to be able to inspire other States to try a new design or technology. For example, many States use California DOT’s

[1]FHWA employee; phone interview conducted by evaluation team members Jonathan Badgley, Kendall Mahavier, and Sean Peirce in April 2019

benefit–cost analysis tool, Cal-BC, for benefit–cost analyses, and while the tool can be used to analyze many highway-infrastructure investments, it does not currently include intersection improvements, like IIDs, among the potential investments.(91) FHWA could encourage the inclusion of FHWA research products in widely used State-developed tools and resources, such as Cal-BC, thus leveraging States' influence among other States.

This approach could be part of a larger strategy of managing FHWA resources more effectively. Given limited funds, FHWA can define the optimal level of deployment of new research designs relative to its deployment goals and available resources. Data-driven objectives such as defining the target number of deployments, the target number of deploying State, the target number of influencers who have adopted the technology, or the funding threshold would help guide FHWA in its research and outreach efforts.

Once the deployment target is met or the allocated resources are expended, FHWA can suspend or reduce efforts in promoting those research products and redirect resources to other projects. This approach could help reduce the possibility of designs being over deployed in areas where they are not the best option and under deployed in areas that could benefit from the design. FHWA does not currently appear to have any formal process by which they can evaluate the ROI of continued outreach on existing research versus investing in research on new concepts. Developing such a process could help ensure that resources are spent efficiently and that FHWA is having the largest impact possible.

Recommendation 4: A series of additional guidance is typically needed for new intersection designs. FHWA should continue to develop guidance for all users who may interact with a new technology and, to the extent possible, plan for development of that guidance as early in the design and testing phases of the research as practicable.

With intersection designs, it is not enough to provide guidance solely on the specific design elements. Rather, multiple other types of guidance are important for maximizing safety, promoting outreach, and maximizing deployment. Although the majority of users of a new intersection design may be passenger cars, several other types of users should also be considered, including pedestrians, bicyclists, trucks, tractors, and other unique vehicles. Guidance for all these users will aid State agencies in convincing the public that these designs are worth adopting, and this type of guidance was something that FHWA was lacking in the early days of IID deployment. While these users often represent only a small share of total users, if not addressed, their concerns can delay or stop a deployment.

Another area to be considered is nontransportation impact, such as guidance on how a new design may impact property access and local traffic patterns. While the ultimate analysis of property-access and traffic-pattern impacts must be determined and valued by the agency, these areas of concern are often barriers to deployment and may be overcome through additional FHWA guidance.

6. Conclusion

This evaluation found strong evidence that FHWA research and outreach activities aided in State and local agencies' acceptance, adoption, and deployment of IIDs over and above what would have occurred in the counterfactual of no FHWA research or outreach activities. FHWA substantially increased the amount (and, in some cases, the quality) of IID research, demonstrating the safety, mobility, and construction-cost benefits of IIDs relative to conventional intersection and interchange designs. FHWA's outreach efforts in technical assistance and workshops increased awareness of IIDs and increased the adoption of IIDs as countermeasures across a wide number of States. FHWA's leadership in researching and promoting IIDs through contributing to developing national design standards for their implementation and identifying IIDs as FHWA Safety Countermeasures increased confidence in IIDs among stakeholders.

FHWA successfully leveraged existing resources, such as research and existing IID deployments to produce high-quality research products. FHWA R&T IID-research products were produced in coordination with stakeholders across FHWA and State DOTs, especially across Safety R&D, the Office of Safety, and the Resource Center. FHWA provided a consistent message about the benefits of IIDs by including them in major initiatives and programs, including EDC-2 and the 2017 round of Proven Safety Countermeasures.[5,10] FHWA further enhanced its influence and reach on IIDs by actively participating and exchanging with the research and stakeholder communities. Such participation included TRB papers and presentations, along with other presentations, training, and technical assistance for transportation professionals. FHWA also provided materials, such as brochures and videos, to help State and local agencies convince the public and other stakeholders that IIDs were worth deploying. These efforts helped change awareness and acceptance of IIDs across the United States.

IIDs have seen considerable growth in the total number deployed in the past 20 years. However, areas for potential deployment growth for IIDs remain. The number of intersections and interchanges that are constructed or reconstructed each year are expected to grow as aging infrastructure needs to be replaced. IIDs, like DDIs and DLTs, can be used as a stopgap to provide safety and mobility benefits in the short term, when funding for larger intersection and interchange reconstructions is unavailable. RCUTs, MUTs, and mini-RAs are low-cost solutions for intersections with safety issues and can be used in thousands or potentially hundreds of thousands of locations across the United States. To increase the number of IIDs and to ensure they are deployed only in contexts in which they are the best alternative, FHWA should continue cooperating and partnering across the safety discipline and with the broader stakeholder community to ensure that States are supported from early research through awareness and implementation.

The evaluation team's findings underscore how important FHWA national leadership on a specific topic, foundational and ongoing research, and the dissemination of resources are for educating and supporting internal and external stakeholders, leaders, and other decisionmakers.

Appendix. Deployment-Scan Discrepancies

The deployment scan of this evaluation and *Alternative Intersection Design and Selection* established the number of IIDs deployed by States in different ways so that the consistency of the IID counts could only be partially substantiated.(69) The survey in *Alternative Intersection Design and Selection* asked State respondents to identify the number of IID deployments in each State by ranges of 0, 1–5, 6–10, 11–25, 26–50, and 51 or greater, whereas this evaluation tried to identify and verify specific deployments by location. The evaluation team compared the *Alternative Intersection Design and Selection* reported ranges of IID deployments by State with the deployment scan and identified any inconsistencies, which are cases in which the State says the number of deployments (e.g., 6 to 10 deployments) disagrees with the deployment scan (e.g., only 3 of IID deployments in that State were identified). The following is a list of the discrepancies between the deployment scan and the survey in the *Alternative Intersection Design and Selection*:

- Idaho deployed an MUT in 2018, but they do not claim so in *Alternative Intersection Design and Selection*.
- Alabama deployed a DDI since the survey was administered.
- In *Alternative Intersection Design and Selection*, New Jersey claimed to not have deployed any IIDs, but this evaluation identified and verified, through Google Maps™, seven IID deployments.
- South Carolina appears to have misreported the number of DDIs deployed in the survey in *Alternative Intersection Design and Selection* as their first deployment of a DDI is expected in fall 2019.(92)
- Oklahoma appears to have misreported the number of DDIs deployed in the survey in *Alternative Intersection Design and Selection* as their first deployment of a DDI is expected in fall 2019.(93)
- Washington appears to have misrepresented the number of DDIs deployed in the survey in *Alternative Intersection Design and Selection* as their first deployment of a DDI is expected in 2021.(94)

The deployment scan and *Alternative Intersection Design and Selection* reported deployments significantly disagreed on the number of RCUT deployments as described in table 17.

Table 17. Difference between the deployment scan and deployments reported in *Alternative Intersection Design and Selection*.

State	RCUT Deployments
DE	5–9
FL	1–5
GA	25–50
IL	1–5
KY	1–5
MI	22–46
MN	13–37
MO	5–19
NY	1–5
SC	10–25
WA	6–10
WI	6–10

IID deployments were removed for various reasons and not all due to performance issues inherent to the design. For example, the RCUT removed as part of the BUILD grant funding discussed in section 4.4 was removed because traffic volumes required grade separation. Six other removals were discovered by the evaluation team in the course of the deployment scan. Two were MUTs and four were RCUTs, and four of these removals were in Texas. Table 18 notes the removals that were identified with the earliest year in which the IID does not appear in Google Maps, the type of IID, and the city and State where the IID was located.

Table 18. IID removals identified in deployment scan.

Year	IID Type	City	State
2007	MUT	Houston	TX
2011	RCUT	Austin	TX
2011	RCUT	San Antonio	TX
2014	MUT	Plano	TX
2014	RCUT	West Valley City	UT
2016	RCUT	Frederick	MD

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References

1. Federal Highway Administration. (n.d.). "Alternative Intersection Design - Safety." (website) FHWA, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/alter_design/, last accessed October 23, 2020.

2. Formulanone. 2020."Camp Creek at I-285 Aerial" (website). Available online: Camp Creek at I-285 Aerial | This is called a Diverging Diam... | Flickr, last accessed June 2, 2021.

3. Hughes, W., Jagannathan, R., Sengupta, D., and Hummer, J. (2010). *Alternative Intersections/Interchanges: Informational Report (AIIR)*, Report No. FHWA-HRT-09-060, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/09060/09060.pdf, last accessed September 11, 2019.

4. Robinson, B., Rodegerdts, L., Scarborough, W., Kittelson, W., Troutbeck, R., Brilon, W., Bondzio, L., et al. (2000). *ROUNDABOUTS: An Informational Guide*, Report No. FHWA-RD-00-067, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/00067/00067.pdf, last accessed September 11, 2019.

5. Federal Highway Administration. (n.d.). "EDC-2 Innovations." (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/innovation/everydaycounts/edc-2.cfm, last accessed September 23, 2019.

6. Schroeder, B., Cunningham, C., Ray, B., Daleiden, A., Jenior, P., and Knudsen, J. (2014). *Diverging Diamond Interchange Informational Guide*, Report No. FHWA-SA-14-067, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14067_ddi_infoguide.pdf, last accessed September 11, 2019.

7. Hummer, J., Ray, B., Daleiden, A., Jenior, P., and Knudsen, J. (2014). Restricted Crossing U-*turn Informational Guide*, Report No. FHWA-SA-14-070, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/rltci/fhwasa14070.pdf, last accessed September 11, 2019.

8. Steyn, H., Bugg, Z., Ray, B., Daleiden, A., Jenior, P., and Knudsen, J. (2014). *Displaced Left Turn Informational Guide*, Report No. FHWA-SA-14-068, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14068_dlt_infoguide.pdf, last accessed September 11, 2019.

9. Reid, J., Sutherland, L., Ray, B., Daleiden, A., Jenior, P., and Knudsen, J. (2014). *Median U-Turn Informational Guide*, Report No. FHWA-SA-14-069, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14069_mut_infoguide.pdf, last accessed September 11, 2019.

10. Federal Highway Administration. (n.d.). "Proven Safety Countermeasures." (website) FHWA, Washington, DC. Available online: https://safety.fhwa.dot.gov/provencountermeasures/, last accessed September 23, 2019.

11. Badgley, J., Condon, J., Rainville, L., and Li, D. (2018). *FHWA Research and Technology Evaluation: Roundabouts Research Final Report*, Report No. FHWA-HRT-17-040, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/randt/evaluations/17040/17040.pdf, last accessed September 11, 2019.

12. Federal Highway Administration. (n.d.). "FHWA FY 2019-2022 Strategic Plan." (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/policy/fhwaplan.cfm, last accessed November 11, 2019.

13. The National Academies of Sciences, Engineering, and Medicine. (2017). *TRB Webinar Program: Mini-Roundabouts: Is the US Ready to Take Advantage of Their Benefits?* Presented at the Transportation Research Board, Washington, DC. Available online: http://onlinepubs.trb.org/onlinepubs/webinars/170321.pdf, last accessed November 11, 2019.

14. Federal Highway Administration. (2010). *Mini-Roundabouts*, Report No. FHWA-SA-10-007, FHWA, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/innovative/roundabouts/fhwasa10007/fhwasa10007.pdf, last accessed September 11, 2019.

15. Federal Highway Administration. (2009). *TechBrief: Double Crossover Diamond Interchange*, Report No. FHWA-HRT-09-054, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/09054/09054.pdf, last accessed September 11, 2019.

16. Federal Highway Administration. (2009). *TechBrief: Restricted Crossing U-Turn Intersection*, Report No. FHWA-HRT-09-059, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/09059/09059.pdf, last accessed September 11, 2019.

17. Federal Highway Administration. (2009). *TechBrief: Displaced Left-Turn Interchange*, Report No. FHWA-HRT-09-056, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/09056/09056.pdf, last accessed September 11, 2019.

18. Federal Highway Administration. (2009). *TechBrief: Displaced Left-Turn Intersection*, Report No. FHWA-HRT-09-055, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/09055/09055.pdf, last accessed September 11, 2019.

19. Federal Highway Administration. (2009). *TechBrief: Median U-Turn Intersection*, Report No. FHWA-HRT-09-057, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/09057/09057.pdf, last accessed September 11, 2019.

20. Kittelson & Associates. (2019) *Roundabouts/Traffic Circle Inventory Database.* Kittelson & Associates Inc., Seattle, WA. Available online: http://roundabout.kittelson.com, last accessed September 11, 2019.

21. Bared, J.G. and Kaisar, E. I. (2000). “Advantages of the Split Intersection.” *Public Roads*, *63*(6), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/00mayjun/advantages.cfm, last accessed September 16, 2019.

22. Bared, J.G. and Kaisar, E.I. (2002). “Median U-Turn Design as an Alternative Treatment for Left Turns at Signalized Intersections.” *ITE Journal*, Institute of Transportation Engineers, Washington, DC. Available online: https://www.researchgate.net/publication/285630661_Median_U-turn_design_as_an_alternative_treatment_for_left_turns_at_signalized_intersections, last accessed September 16, 2019.

23. Edara, P.K., Bared, J.G., and Jagannathan, R. (2003). “Diverging Diamond Interchange and Double Crossover Intersection — Vehicle and Pedestrian Performance.” *Transportation Research Record*, *1912*, pp. 31–38, Transportation Research Board, Washington, DC.

24. ATS/American. (n.d.). “Diverging Diamond Interchange: History.” (website) ATS/American, Wesley Chapel, FL. Available online: https://divergingdiamond.com/history/, last accessed September 23, 2019.

25. Jagannathan, R. and Bared, J. G. (2004). “Design and Operational Performance of Crossover Displaced Left-Turn Intersections.” *Transportation Research Record*, *1881*, Transportation Research Board, Washington, DC.

26. Rodegerdts, L.A., Nevers, B., Robinson, B., Ringert, J., Koonce, P., Bansen, J., Nguyen, T., et al. (2004). *Signalized Intersections: Informational Guide*, Report No. FHWA-HRT-04-091, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/04091/04091.pdf, last accessed September 16, 2019.

27. Bared, J.G., Edara, P.K., and Jagannathan, R. (2005). “Design and Operational Performance of Double Crossover Intersection and Diverging Diamond Interchange.” *Transportation Research Record*, *1912*, pp. 31–38, Transportation Research Board, Washington, DC.

28. Bared, J.G. (2005). “Improving Signalized Intersections.” *Public Roads*, *68*(4), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/05jan/03.cfm, last accessed September 17, 2019.

29. Federal Highway Administration. (2007). *TechBrief: Drivers’ Evaluation of the Diverging Diamond Interchange*, Report No. FHWA-HRT-07-48, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/07048/07048.pdf, last accessed September 11, 2019.

30. Federal Highway Administration. (2007). *TechBrief: Synthesis of the Median U-Turn Intersection Treatment, Safety, and Operational Benefits*, Report No. FHWA-HRT-07-033, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/07033/07033.pdf, last accessed September 11, 2019.

31. Bared, J. (2009). *Evaluation of Sign and Marking Alternatives for Displaced Left-Turn Intersections*, Report No. FHWA-HRT-08-071, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/08071/08071.pdf, last accessed September 25, 2019.

32. Jagannathan, R., Hughes, W., and Bared, J. G. (2009). "A New Left Turn." *Public Roads*, *73*(1), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/09julaug/04.cfm, last accessed September 17, 2019.

33. Rodegerdts, L., Bansen, J., Tiesler, C., Knudsen, J., Myers, E., Johnson, M., Moule, M., et al. (2010). *Roundabouts: An Informational Guide: Second Edition*. National Academy of Sciences, Washington, DC. Available online: https://doi.org/10.17226/22914, last accessed September 23, 2019.

34. Bared, J. and Saiko, D. (2010). "The Double Crossover Diamond." *Public Roads, 74*(3), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/10novdec/01.cfm, last accessed September 13, 2019.

35. Federal Highway Administration. (2010). "Along the Road." *Public Roads, 73*(5), FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/10mar/alongroad.cfm, last accessed September 17, 2019.

36. Hasson, P. and Moler, S. (2010). "Doing More With Less." *Public Roads, 74*(2), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/10septoct/05.cfm, last accessed September 17, 2019.

37. Bared, J., Yang, C.Y.D., Huang, P., and Vangorder, R.S. (2011). "Transportation Operations Laboratory: Article I – Modeling Transportation Systems: Past, Present, and Future." *Public Roads*, *75*(2), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/11septoct/02.cfm, last accessed September 13, 2019.

38. Struve, B. and Breen, T. (2011). "Prizing Excellence." *Public Roads, 74*(5), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/11marapr/05.cfm, last accessed September 17, 2019.

39. Inman, V.W. and Haas, R.P. (2012). *Field Evaluation of a Restricted Crossing U-Turn Intersection*, Report No. FHWA-HRT-11-067, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/hsis/11067/001.cfm, last accessed September 17, 2019.

40. Zhang, W., Bared, J., and Jagannathan, R. (2012). "They're Small But Powerful." *Public Roads*, *76(3),* Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/12novdec/03.cfm, last accessed September 13, 2019.

41. Federal Highway Administration. (2012). “Along the Road.” *Public Roads, 76*(2), FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/12septoct/alongroad.cfm, last accessed September 17, 2019.

42. Chandler, B.E., Myers, M.C., Atkinson, J.E., Bryer, T.E., Retting R., Smithline, J., Trim, J., et al. (2013). *Signalized Intersections Informational Guide, Second Edition*, Report No. FHWA-SA-13-027, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/conventional/signalized/fhwasa13027/fhwasa13027.pdf, last accessed December 9, 2019.

43. Yang, C.Y.D., Shurbutt, J., and Philips, B. (2013). “Why Drivers Do What They Do.” *Public Roads*, *76*(4), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/13janfeb/03.cfm, last accessed September 13, 2019.

44. McCarthy, J., Bared, J., Zhang, W., and Doctor, M. (2013). “Design at the Crossroads.” *Public Roads*, *77*(1), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/13julaug/01.cfm, last accessed September 17, 2019.

45. Bergeron, K. (2013). “Every Day Counts: The Second Phase.” *Public Roads, 76*(5), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/13marapr/01.cfm, last accessed September 17, 2019.

46. Thompson, J. (2013). “North Carolina Steps Boldly Out of Its Comfort Zone.” *Public Roads, 77*(1), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/13julaug/04.cfm, last accessed September 17, 2019.

47. Federal Highway Administration. (2020). “Alternative Intersections.” (YouTube Playlist) FHWA, Washington, DC. Available online: https://www.youtube.com/user/USDOTFHWA/playlists?view=50&sort=dd&shelf_id=10, last accessed October 15, 2019.

48. Zhang, W. (2014). *TechBrief: Field Evaluation of Diverging Diamond Interchanges*, Report No. FHWA DTFH61-10-R-00030, Federal Highway Administration, Washington, DC. Available online: https://itre.ncsu.edu/research/wp-content/uploads/sites/2/2017/11/DDI-Safety-TechBrief_YR4.pdf, last accessed October 15, 2019.

49. Zhang, W. and Kronprasert, N. (2014). “The ABCs of Designing RCUTs.” *Public Roads, 78*(2), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/14sepoct02.cfm, last accessed September 13, 2019.

50. Evans, M.R. (2014). “Guest Editorial: Spotlight on Safety Solutions.” *Public Roads, 78*(2), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/14sepoct/editorsnotes.cfm, last accessed September 17, 2019.

51. Yeom, C., Hummer, J.E., Schroeder, B.J., Cunningham, C., Vaughan, C., and Rouphail, N.M. (2015). "Empirical Before-After Comparison of the Operational Performance of Diverging and Conventional Diamond Interchanges." *Journal of Transportation of the Institute of Transportation Engineers, 7*(1), pp. 35–56, Institute of Transportation Engineers, Washington, DC. Available online: https://www.ite.org/pub/?id=63e82d48%2De3af%2De353%2Dc443%2D5adf7b86b0b3, last accessed September 23, 2019.

52. Boris, C. (2015). "Internet Watch." *Public Roads, 78*(5), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot/gov/publications/publicorads/15marapr/iwatch.cfm, last accessed September 17, 2019.

53. Albee, M., Peach, K., Shaw, J., and Soika, J. (2016). "Targeting the Crosshairs." *Public Roads, 80*(3), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/16novdec/01.cfm, last accessed September 13, 2019.

54. Federal Highway Administration. (2016). "Along the Road." *Public Roads, 79*(4), FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/16janfeb/alongroad.cfm, last accessed September 17, 2019.

55. Nadeau, G.G. (2016). "Building a Culture of Innovation." *Public Roads, 80*(2), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/16sepoct/01.cfm, last accessed September 17, 2019.

56. Trentacoste, M.F. (2016). "Guest Editorial: Building Safety into the Infrastructure." *Public Roads*, *80*(3), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/16novdec/editorsnotes.cfm, last accessed September 17, 2019.

57. Struve, B., Doctor, M., Maifield, D., and Chen, C. (2016). "The Evolution of Geometric Design." *Public Roads*, *79*(5), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/16marapr/05.cfm, last accessed September 13, 2019.

58. Hummer, J. and Rao, S. (2017). *Safety Evaluation of Signalized Restricted Crossing U-Turn Intersections*, Report No. FHWA-HRT-17-082, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/research/safety/17082/17082.pdf, last accessed September 11, 2019.

59. Griffith, M.S., Cheung, J., Satterfield, C., and Shaw, J. (2017). "Doubling Down on Safety Innovations." *Public Roads*, *80*(5), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/17marapr/03.cfm, last accessed September 17, 2019.

60. Isebrands, H. and Shaw, J. (2017). "Roundabouts Coming Full Circle." *Public Roads*, *81*(3), Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/publications/publicroads/18autumn/01.cfm, last accessed September 17, 2019.

61. Transportation Research Board. (2020). "TRID." (website) National Academies of Sciences, Engineering, and Medicine, Washington, DC. Available online: https://trid.trb.org/, last accessed October 15, 2019.

62. Federal Highway Administration. (2017). "Highway Safety Improvement Program." (website) FHWA, Washington, DC. Available online: https://safety.fhwa.dot.gov/hsip/, last accessed October 15, 2019.

63. Federal Highway Administration. (2017). "Congestion Mitigation and Air Quality Improvement (CMAQ) Program." (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/environment/air_quality/cmaq/, last accessed October 15, 2019.

64. United States Department of Transportation. (2019). "About BUILD Grants." (website) USDOT, Washington, DC. Available online: https://www.transportation.gov/BUILDgrants/about, last accessed October 15, 2019.

65. Federal Highway Administration. (2017). *AID Demo: Accelerated Innovation Deployment*, FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/innovation/grants/edc4_aiddemo_factsheet.pdf, last accessed October 15, 2019.

66. Federal Highway Administration. (2017). "Highways for LIFE." (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/hfl/, last accessed October 15, 2019.

67. ATS/American. (2017). "DDI Openings by Date." (website) ATS/American, Wesley Chapel, FL. Available online: https://divergingdiamond.com/ddi-openings-by-date/, last accessed October 15, 2019.

68. Institute for Transportation Research and Education. (2020). "Alternative Intersections and Interchanges." (website) North Carolina State University, Raleigh, NC. Available online: http://go.ncsu.edu/aii, last accessed October 15, 2019.

69. Brown, H., Edara, P., Hartman, G., and Chlewicki, G. (2019). *Alternative Intersection Design and Selection*, NCHRP Project 20-5, Topic 50-11, National Cooperative Highway Research Program, Washington, DC.

70. Najm, W.G., Smith, J. D., and Yanagisawa, M. (2007). *Pre-crash Scenario Typology for Crash Avoidance Research*, Report No. DOT-HS-810-767, National Highway Traffic Safety Administration, Washington, DC. Available online: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/pre-crash_scenario_typology-final_pdf_version_5-2-07.pdf, last accessed October 15, 2019.

71. Office of the Secretary. (2018). *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*, United States Department of Transportation, Washington, DC. Available online: https://www.transportation.gov/sites/dot.gov/files/docs/mission/office-policy/transportation-policy/14091/benefit-cost-analysis-guidance-2018.pdf, last accessed October 15, 2019.

72. Federal Highway Administration. (n.d.). "Safety R&D Overview." (website) FHWA, Washington, DC. Available online: https://highways.dot.gov/research/research-programs/safety/safety-rd-overview, last accessed October 23, 2020.

73. Federal Highway Administration. (2014). "Conference Agenda." (website) Teach America, Quincy, FL. Available online: http://teachamerica.com/ai14/, last accessed December 9, 2019.

74. Federal Highway Administration. (2014). *Toward Zero Deaths*, United States Department of Transportation, Washington, DC. Available online: http://www.towardzerodeaths.org/wp-content/uploads/TZD_Strategy_12_1_2014.pdf, last accessed October 9, 2019.

75. National Highway Institute. (n.d.). "Course Description: Innovative Intersections and Interchanges." (website) United States Department of Transportation, Washington, DC. Available online: https://www.nhi.fhwa.dot.gov/course-search?course_no=380109, last accessed October 15, 2019.

76. National Highway Institute. (n.d.). "Course Description: Modern Roundabouts: Intersections Designed for Safety." (website) United States Department of Transportation, Washington, DC. Available online: https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=380096&res=1&sf=0&course_no=380096, last accessed October 15, 2019.

77. Michigan Department of Transportation. (2019). "Michigan Lefts," (website) MDOT, Lansing, MI. Available online: https://www.michigan.gov/mdot/0,4616,7-151-9615-161777--,00.html, last accessed September 19, 2019.

78. Federal Highway Administration. (2014). *Kansas Demonstration Project: The Use of Smart Work Zone Technology During Construction of the I-35/Homestead Lane Interchange in Johnson County Kansas*, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/hfl/projects/ks_swz_i35_johnsoncounty.pdf, last accessed August 19, 2019.

79. Federal Highway Administration. (2013). *New York Demonstration Project: Improvements to the Winton Road/I-590 Interchange in Rochester*, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/hfl/projects/ny_ddi_wintonroad_i590.pdf, last accessed August 19, 2019.

80. Federal Highway Administration. (2012). *Manual on Uniform Traffic Control Devices for Streets and Highways*, Federal Highway Administration, Washington, DC. Available online: https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf, last accessed September 3, 2020.

81. Transportation Research Board. (2016). *Highway Capacity Manual*, National Academies of Sciences, Engineering, and Medicine, Washington, DC.

82. American Association of State Highway and Transportation Officials. (2010). *Highway Safety Manual*, American Association of State Highway and Transportation Officials, Washington, DC.

83. Federal Highway Administration. (2019). "Intersection Control Evaluation (ICE)." (website) FHWA, Washington, DC. Available online: https://safety.fhwa.dot.gov/intersection/ice/, last accessed October 15, 2019.

84. Federal Highway Administration. (2017). "Capacity Analysis for Planning of Junctions (Cap-X) Tool." (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/software/research/operations/cap-x/, last accessed October 15, 2019.

85. Waddell, E. and Alberston, J. (2005). “The Dimondale Mini: America’s First Mini-Roundabout.” Transportation Research Board, Subcommittee on Roundabouts International Conference on Roundabouts, Washington, DC. Available online: http://onlinepubs.trb.org/Onlinepubs/circulars/ec083/28_Waddellpaper.pdf, last accessed September 23, 2019.

86. Zhang, W. and Kronprasert, N. (2014). “Unlock DDI’s Capacity by Re-Routing Left-Turns at Nearby Intersections.” *Access Management Theories and Practices - Proceedings of the 2nd International Conference on Access Management*, Shanghai, China.

87. Zhang, W. (2017). “Mini-Roundabout, Is the US Ready to Take Advantage of their Benefits?” (webinar) Transporation Research Board, Washington, DC. Available online: http://onlinepubs.trb.org/onlinepubs/webinars/170321.pdf, last accessed September 23, 2019.

88. Federal Highway Administration. (2019). “Crash Modification Clearinghouse.” (website) FHWA, Washington, DC. Available online: http://www.cmfclearinghouse.org/faqs.cfm#q1, last accessed September 30, 2019.

89. Hummer, J.E., Haley, R.L., Ott S.E., Foyle, R.S., and Cunningham, C.M. (2010). *Superstreet Benefits and Capacities*, Final Report: Project 2009-06, North Carolina Department of Transportation, Raleigh, NC. Available online: https://rosap.ntl.bts.gov/view/dot/20271/dot_20271_DS1.pdf, last accessed October 24, 2019.

90. Federal Highway Administration. (2019). “Highway Statistics 2017.” (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/policyinformation/statistics/2017/, last accessed October 25, 2019.

91. California Department of Transportation. (2019). “Transportation Economics.” (website) Caltrans, Sacramento, CA. Available online: https://dot.ca.gov/programs/transportation-planning/economics-data-management/transportation-economics, last accessed December 9, 2019.

92. Marks, J. (2019). “That York Co. I77 and Gold Hill Road interchange? Here’s when construction may start.” *The Herald*, The Herald, Rock Hill, SC. Available online: https://www.heraldonline.com/news/local/article230605244.html, last accessed August 20, 2019.

93. Oklahoma Department of Transportation. (2019). “Elk City's Diverging Diamond Interchange at I-40 & SH-6 Coming soon: Oklahoma's first DDI.” (website) ODOT, Oklahoma City, OK. Available online: https://www.ok.gov/odot/What's_New/I-40_and_SH-6_Diverging_Diamond_Interchange.html?fbclid=IwAR0jvphVvr9bNJZ0AiTe33qxDM2Le1U-5ABxA_EqfJuHFFK-gboD8v0d9sg, last accessed August 20, 2019.

94. Washington State Department of Transportation. (2019). “I-5 - SR 510 Interchange - Reconstruct Interchange.” (website) WSDOT, Olympia, WA. Available online: https://www.wsdot.wa.gov/Projects/I5/sr510interchange/default.htm, last accessed August 20, 2019.

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