FHWA Research and Technology Evaluation

Roundabout Research

Final Report
June 2018

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U.S. Department of Transportation
Federal Highway Administration

Foreword

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

This report examines how FHWA's investment in roundabout research affected the availability and quality of such research, the adoption of roundabouts in the United States, and the impacts of those roundabouts on safety, operational, and environmental performance of the U.S. transportation system.

The findings of this report should be of interest to engineers, practitioners, researchers, and decision makers involved with the research, design, performance, and management of roundabouts and other alternative intersection designs.

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

Notice

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16. Abstract This evaluation assesses the effects of the Federal Highway Administration's (FHWA's) investment in roundabout research and related activities on the availability and quality of such research, the adoption of roundabouts in the United States, and the impacts of those roundabouts on safety, operational, and environmental performance of the U.S. transportation system. Although it is difficult measure the effect of specific FHWA activities, the evaluation found strong evidence of FHWA's influence on the acceptance, consideration, and adoption of roundabouts. The findings suggest that acceptance, consideration, and adoption are higher now than would have occurred without FHWA research and activities. FHWA laid the foundation for national adoption of roundabouts by providing empirical evidence of their safety and operational benefits, increasing awareness of and confidence in them among stakeholders, and contributing to the development of the design standards for implementation.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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List of Abbreviations and Acronyms

Abbreviation	Definition
AASHTO	American Association of State Highway Transportation Officials
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CMF	crash modification factor
FHWA	Federal Highway Administration
HCM	*Highway Capacity Manual*
HSA	Office of Safety
HSIP	Highway Safety Improvement Program
HSM	*Highway Safety Manual*
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act
MDSHA	Maryland State Highway Administration
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
PDO	property-damage-only
PoP	Publish or Perish
Resource Center	FHWA Resource Center
R&T	Research and Technology
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A legacy for Users
Safety R&D	Office of Safety Research and Development
SHDM	State Highway Design Manual
SHSP	Strategic Highway Safety Plan
TFHRC	Turner-Fairbank Highway Research Center
TRB	Transportation Research Board
VSL	value of statistical life
2000 Informational Guide	*FHWA's Roundabouts: An Informational Guide*, 2000
2010 Informational Guide	*FHWA's Roundabouts: An Informational Guide*, 2010

Executive Summary

Purpose of the Evaluation

The Federal Highway Administration (FHWA) has initiated an effort to evaluate the Research and Technology (R&T) development program. As part of being accountable to funders and policy makers, leaders of governmental transportation R&T programs must be able to effectively communicate the full range of benefits for their program. FHWA created the R&T evaluation program to help assess how effectively FHWA is meeting its goals and objectives and to provide useful data to inform future project selections. The Office of Safety Research and Development (Safety R&D) selected roundabout-research efforts for evaluation under this program.

The purpose of this evaluation is to assess the effects of FHWA's investment in roundabout research on the availability and quality of such research, the adoption of roundabouts in the United States, and the impacts of those roundabouts on safety, operational, and environmental performance of the U.S. transportation system.

Program Description

A roundabout is a circular intersection in which approaching traffic yields to circulating traffic. In the United States, roundabouts are often confused with traffic circles and rotaries, which have idiosynchratic rules regarding yielding traffic and do not adhere to modern intersection geometries. Interest in roundabouts as a safety countermeasure began internationally in the 1970s and 1980s for their ability to reduce speed and crash severity compared with traditional signalized intersections. Starting in the mid-1990s, FHWA initiated research and evaluation of roundabout safety and design, leading to several papers and the publication of *Roundabouts: An Informational Guide* in 2000 (herein the *2000 Informational Guide*).[2] Following publication of the guide, FHWA continued to collect higher-quality performance data, refine roundabout design state of the practice, and develop solutions to better accommodate cyclists and pedestrians—particularly pedestrians with vision impairments and disabilities. Later, FHWA activities across the FHWA Safety Discipline included development and sharing of educational resources, training, technical assistance, and a partnership with the National Cooperative Highway Research Program (NCHRP) for *Roundabouts: An Informational Guide, Second Edition.*[3] Mini-roundabouts field and safety evaluation, a successor to this earlier roundabout research, is showcased within the R&T Agenda.

This evaluation focuses on the FHWA contribution to roundabout research and technical guides, and the use of that information in changing stakeholders' awareness and attitudes, and eventual adoption of roundabouts as a safety countermeasure.

Methodology

Roundabouts remain the topic of ongoing research and educational activity domestically and internationally. At the time of evaluation planning, NCHRP had two active data-collection efforts underway related to roundabout cost and State roundabout policies and practices. To reduce potentially duplicative efforts, the evaluation team split the evaluation into two phases. This two-phased approach resulted in a more complete final evaluation that better traced the flow of FHWA research investments to present-day outcomes and impacts. This report covers the cumulative results of the two phases:

1. Phase I (November 2014–September 2015): Focused on metrics related to FHWA research products and short-term outcomes, longer-term outcomes of adoption, and safety and operational impacts.

2. Phase II (September 2015–December 2015): Supplemented the Phase I evaluation results with additional information on intermediate and longer-term outcomes related to States' changes in attitudes, policies, behavior, and adoption of roundabouts using inputs from two recently completed NCHRP projects:

   – *NCHRP Synthesis 488: Roundabout Practices*, which provided a comprehensive summary of State roundabout policies.(4)

   – *Estimating the Life-Cycle Cost of Intersection Designs*, an NCHRP Web-Only Document 220, which developed comparative lifecycle costs.(5)

The evaluation team created a logic model that identifies potential relationships between four evaluation areas to effectively investigate the outcomes and impacts of FHWA roundabout research. The team developed primary and secondary hypotheses with supporting performance measures under each evaluation area. These evaluation areas are the following:

- **Evaluation Area 1:** Availability and reliability of roundabout safety and performance data.
- **Evaluation Area 2:** Change in awareness and knowledge of and attitudes toward roundabouts.
- **Evaluation Area 3:** Adoption of roundabouts as a safety countermeasure.
- **Evaluation Area 4:** Safety, operational, environmental, and economic impacts of roundabouts.

To assess these hypotheses, the evaluation team collected documents, performed data analysis, and conducted semistructured interviews.

Data sources reviewed during the search for documents and related literature included FHWA program documents (internal and published), relevant research on roundabouts, Transportation Research Board (TRB) Annual Meeting programs, Roundabouts Listserv archives, and literature on technology diffusion. To assess the influence of FHWA research and outreach to State transportation departments, the evaluation team reviewed State-level materials including Strategic Highway Safety Plans (SHSPs), State Highway Design Manuals (SHDMs), and State transportation department websites. Where available, the evaluation team used quantitative analysis to better understand the funding, counts, and safety impacts of roundabouts.

Finally, the evaluation team conducted interviews with FHWA staff and the chair of the TRB Committee on Roundabouts to gather information to enhance understanding the scope and extent of FHWA activities, complementing the other analyses.

Findings

The findings for the evaluation of roundabout research highlight evidence from each evaluation area.

Evaluation Area 1: Availability and Reliability of Data

One of the goals articulated in FHWA's Office of Safety (herein the Office of Safety) strategic plan, *Safe Roads for a Safer Future: A Joint Safety Strategic Plan*, is for FHWA to improve safety data and expand capabilities for analysis and evaluation.[6] FHWA's early roundabout research (on which this evaluation focuses) predates this strategic plan, showing that providing high-quality, reliable safety has always been a FHWA and Safety R&D priority.

FHWA R&T's research activities from the 1990s and the *2000 Informational Guide* led to a significant increase in published material on roundabouts in the United States.[2,3] Initial FHWA contributions increased the availability of domestic roundabout information by synthesizing international and (limited) domestic safety and design research. In turn, these outputs clarified and focused the research questions for the domestic research community, with which FHWA actively partnered and supported. The number and breadth of FHWA citations in published domestic roundabout research confirms the extent and effects of FHWA's research activities. Moreover, roundabout research gave States the information and resources necessary to develop design manuals and guides of their own. FHWA developed materials for a variety of audiences including the research community, State transportation departments, local agencies, and the public. Interviews yielded information about the timing and effect of research and other activities on the research community, and showed that that FHWA played a key role in accelerating consideration of roundabouts as a research topic and the development of domestically focused safety and performance studies.

Evaluation Area 2: Change in Awareness, Knowledge, and Attitudes

FHWA research, culminating in the *2000 Informational Guide*, increased the availability of information on roundabouts in the United States.[2,3] These products provided interested States and stakeholders with more information on how to utilize roundabouts as a safety countermeasure, and an FHWA endorsement of the technology. Safety R&D worked closely with the Office of Safety and the FHWA Resource Center (herein the Resource Center) to conduct sustained outreach, including making policy changes and recommendations within FHWA. This outreach shaped State policies toward roundabouts and resulted in changes in transportation professionals' attitudes toward roundabouts as an intersection alternative.

Evaluation Area 3: Adoption of Roundabouts as a Safety Countermeasure

FHWA actively accelerated the early adoption of roundabouts by leading the promotion of roundabouts, developing safety and performance research, and specifically addressing the needs of the earliest adopters. FHWA activities and research increased the total number of roundabouts 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 roundabouts.

Funding provided under programs designed to increase safety and traffic-flow improvement and environmental benefits provided continued support to the earliest and most confident adopters, while providing reinforcement for late adopters. The Highway Safety Improvement Program (HSIP), and Congestion Mitigation and Air Quality Improvement (CMAQ) Program are two examples of such programs.

Despite the widespread increase and acceptance of roundabouts, the rate of adoption of roundabouts in the United States appears to have slowed. The United States is already behind many European and other countries in regard to adopting roundabouts, especially considering the proportion of roundabouts to traditional intersections. Negative public attitudes and high initial capital costs remain barriers to roundabout adoption.

Evaluation Area 4: Safety, Operational, Environmental, and Economic Impacts of Roundabouts

Evaluating the complete extent of the safety, environmental, operational, and lifecycle cost impacts of the roundabouts installed due to FHWA's influence exceeds the scope of this evaluation. The evaluation team's review of the literature confirms significant benefits from installing modern roundabouts in place of traditional intersection controls. Therefore, any roundabout adoption influenced by FHWA likely reduced emissions and improved operational flow, and continues to do so on an ongoing basis. Most importantly, FHWA-influenced roundabout adoption has reduced crashes of all kinds at U.S. intersections, including those with histories of serious injuries and fatalities. A simplified calculation of the safety effect of the approximately 2,400 roundabouts installed in the Unites States between 1990 and 2014 finds that roundabouts averted between 38,000 and 53,000 injury crashes, resulting in a total societal cost savings of over $9 billion during that period. While FHWA cannot claim exclusive credit for this benefit, its continued research and promotion of roundabouts has certainly been positive for roadway safety in the United States. This estimate is likely conservative when considering the total social impact of roundabouts, as this does not include environmental and operational benefits.

Conclusion

This evaluation found strong evidence of FHWA's influence on the consideration, acceptance, and adoption of roundabouts, beyond what might have occurred without FHWA research and activities. FHWA laid the foundation for nationwide adoption of roundabouts by providing empirical evidence of the safety and operational benefits of roundabouts, increasing awareness of and confidence in them among stakeholders, and aiding in developing national design standards for their implementation.

Furthermore, FHWA leadership continued beyond the foundational period. The agency took a strong national leadership role throughout the technology lifecycle, from research and standards development to funding and implementation of roundabout projects across the majority of States. Throughout the long history of roundabout activity, there has been strong internal coordination within FHWA, especially across Safety R&D, the Office of Safety (HSA), and the Resource Center. FHWA provided a consistent message about the benefits of roundabouts by including them in major initiatives and programs, including the 2008 and 2012 Proven Safety Countermeasures, HSIP, CMAQ eligibility, and Every Day Counts Round 2 (EDC-2).[7] FHWA further enhanced its influence and reach on roundabouts by actively participating and exchanging with the research and stakeholder communities, which included membership on NCHRP panels and the TRB Committee on Roundabouts, along with presentations, training, and technical assistance for transportation professionals.

Although growth in the number of roundabouts has been significant, there remains room for improvement in the United States. Domestic adoption of roundabouts (roughly 3,200 roundabouts) still lags behind leading adopter nations like France (estimated to have 30,000 roundabouts). To increase the number of roundabouts and promote other emerging safety countermeasures (e.g., alternative intersection designs), 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 to educating and supporting internal and external stakeholders, leaders, and other decisionmakers.

Recommendations

FHWA R&T roundabout research and related activities took place over two decades and spanned the range of the technology adoption lifecycle. The number of roundabouts significantly increased over this time period. However, as noted above, despite this significant growth, room for improvement remains as roundabout adoption in the United States lags behind leading adopter nations. 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: Begin investing in data collection on research diffusion and technology adoption during the early years of technology implementation.

A lack of data frequently limits attempts to evaluate the adoption, and especially the impact of, new transportation technologies. The early support for and existence of the Kittelson & Associates Roundabout Inventory–enabled analysis of roundabout adoption trends in near-real time by stakeholders.(3) The data also enables analyses such as the safety analysis conducted as part of this evaluation. In some cases, there is an individual or organizational initiative to collect this information. For example, the website divergingdiamond.com, presented by a private consultant, tracks the construction of diverging diamonds nationwide. Given the resource intensity required for such an effort, FHWA could strategically select a subset of technologies for which it would invest in systematic adoption data collection. Simultaneously, FHWA should track internal metrics related to research investment, the location and span of outreach, and technical assistance activities.

Recommendation: Research and promote information on roundabout costs and strategies for reducing roundabout costs.

As discussed under Evaluation Area 3, initial roundabout capital costs appear to be a barrier to roundabout adoption. *NCHRP Synthesis 488* notes that multiple State agencies expressed an interest in information and strategies related to reducing the cost to install roundabouts.(4) Additional research should be undertaken to identify the underlying cause for the high costs, in which the potential for cost savings may exist without compromising safety and performance benefits---both for individual components and the planning, design, and construction processes. FHWA investment in mini-roundabout research already represents a step in this direction, but there is additional progress to be made in identifying and disseminating helpful strategies to enable adoption.

Recommendation: Build cooperation across FHWA safety disciplines and the broader stakeholder community.

Throughout the long history of roundabout activity, FHWA's successful internal coordination, especially across the safety discipline (Safety R&D, Office of Safety, and the Resource Center), resulted in a highly visible and unified message to stakeholders. Documenting the coordination mechanisms, strategies, and activities that made this process successful and replicating them (as appropriate) across other programs and offices within FHWA could provide organization-wide benefits.

1. Introduction

1.1 Evaluation Purpose

The Federal Highway Administration (FHWA) initiated an effort to evaluate the Research and Technology (R&T) development program to help leaders of governmental transportation R&T programs effectively communicate the impacts of their programs. The R&T evaluation program helps FHWA assess how effectively it is meeting its goals and objectives, and to provide useful data to inform future project selections.

In its initial year, the R&T evaluation program worked with nine FHWA offices to identify projects for evaluation, and the FHWA Safety Program Area identified roundabout research efforts. This evaluation addresses FHWA's efforts related to conducting roundabout-related research and analysis, and supporting the adoption of the technology by State and local agencies.

The goal of the roundabout research efforts was to reduce the number and severity of crashes at intersections in the United States. This goal supports Objective 2 of the Safety R&T Agenda "Accelerate the reduction in injury and fatal crashes at intersections."[8] While the roundabout research activities that are the focus of this evaluation predate the R&T Agenda, the current R&T Agenda formalizes what has long been the safety research program's focus: developing robust data analysis tools for transportation professionals to select, applying cost-effective countermeasures, and delivering safety improvements to the public. Mini-roundabout field and safety evaluation, a successor to earlier roundabout research, is featured as a showcase activity within the R&T Agenda.

The purpose of this evaluation is to bring together information on the adoption and impacts of roundabouts, 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 and reliability of roundabout research results and data, the use and perception of the quality of that information, its influence on changing internal and external stakeholders' awareness and knowledge, and eventual adoption of roundabouts as a safety countermeasure.

Identifying Key Outcomes and Evaluation Areas

The evaluation team identified key outcomes and impact areas to focus on in the roundabout evaluation through initial discussions with members of the R&T Evaluation Team and the Office of Safety Research and Development (herein Safety R&D) staff. Further discussions led to the development of a roundabout-research logic model that identifies potential relationships between four evaluation areas to effectively investigate the outcomes and impacts of FHWA roundabout research (see section 2.1). The logic model identifies the inputs, activities, and outputs from FHWA roundabout activities and the resulting short-term outcomes and long-term impacts, which represent a mix of short-term and long-term results. These areas were then categorized into four evaluation areas, as summarized in table 1.

Table 1. Summary of evaluation areas.

Results	Evaluation Area	Description
Short-term outcomes	Availability and reliability of data	FHWA's contribution to the availability and reliability of safety and performance data on roundabouts. This contribution includes safety evaluation data and evidence of benefits.
Medium-term outcomes	Change in awareness, knowledge, and attitudes	Intermediate outcomes of the changes in awareness and attitude about and confidence in roundabouts as a safety countermeasure within FHWA and among FHWA customers.
Long-term outcomes	Adoption as a safety countermeasure	The extent to which the number of roundabouts in the United States grew and the extent to which FHWA research contributed to that growth.
Impact	Safety, operational, environmental, and economic impacts	The extent to which the growth in the number of roundabouts in the United States contributed to improved safety, operational, environmental, and cost savings.

1.2 Report Structure

The following is a detailed list of the structure of this report:

- **Section 1:** This section provides an overview of the purpose of the evaluation and a high-level description of the project's history.
- **Section 2:** This section describes the evaluation methodology, including data sources, data-collection methods, and data-analysis methods.
- **Section 3**: This section summarizes the evaluation's findings.
- **Section 4**: This section describes general conclusions that the evaluation team drew from the evaluation. It discusses overarching lessons about the program and summarizes the evaluation team's recommendations for FHWA based on the findings of the evaluation.

1.3 Project and Program Background

Roundabouts are circular intersections where approaching traffic yields to circulating traffic. In the United States, roundabouts are often confused with traffic circles and rotaries, which have idiosynchratic rules regarding yielding traffic and do not adhere to modern intersection geometries. Those intersection designs were historically built in the northeastern United States and are often considered confusing to unfamiliar users. Further, they lack the safety benefits of the modern roundabout. Interest in roundabouts as a safety countermeasure began internationally in the 1970s and 1980s in an effort to reduce speed and crash severity from the levels experienced with traditional signalized intersections. In addition, interest grew domestically among consultants and transportation professionals in the 1990s. The first roundabout in the United States was constructed in Summerlin, Nevada, in 1990. Other early-adopter States included Maryland, Colorado, and Florida, which also began building modern roundabouts in the early 1990s.

FHWA began conducting roundabout research in 1994 through the Safety R&D. Safety R&D staff explored and promoted the benefits of roundabouts and published several papers on the topic of roundabouts. FHWA, independently and in partnership with the Maryland State Highway Administration (MDSHA) and transportation researchers, worked on multiple publications about roundabouts. Early research synthesized international understanding of roundabouts and evaluated the performance of early adopters in the United States. In 1997, FHWA initiated the development of *Roundabouts: An Informational Guide* in cooperation with domestic partners, including the Maryland, Ohio, and California transportation departments.[7] The publication of *Roundabouts: An Informational Guide* in 2000 (herein the *2000 Informational Guide*) synthesized information on and best practices for modern roundabouts in the United States, and it represented FHWA's formal endorsement of the roundabout as a safety countermeasure.[2]

Collectively, the *2000 Informational Guide* and other FHWA products evaluated safety performance, informed design standards, and developed higher quality, U.S.-focused safety performance data to better assure U.S. practitioners that roundabouts were an effective safety solution.

Following the publication of the *2000 Informational Guide*, roundabout-related activities continued, with focused activity across the Safety Discipline (the Safety R&D, Office of Safety, and Resource Center). FHWA continued to develop higher-quality informational material, refine roundabout design state of the practice, and develop solutions to better accommodate cyclists and pedestrians, particularly those with vision impairments and disabilities. FHWA also began promoting roundabouts, developing promotional materials, and distributing the *2000 Informational Guide*. FHWA promotion helped change the mindset and attitudes of State transportation department practitioners and road users from the assumption that circular intersections are dangerous or backward to a better understanding of their benefits. Table 2 shows a timeline of FHWA activities and outputs since 1990.

Table 2. Timeline of FHWA roundabout-related activities and outputs.[1]

Year	FHWA Research Activities or Influence	FHWA Acceptance of Roundabouts	FHWA Promotion of Roundabouts
1992	International Scanning Tour (see table 8)(9)	No activity	No activity
1993	No activity	No activity	No activity
1994	TRAF-NETSIM: a practical tool for traffic preemption and roundabout intersection–control modeling	No activity	No activity
1995	Report: *Roundabouts: A Direct Way To Safer Highways*(10)	No activity	No activity
1996	Funded Aimee Flannery safety and crash research	Supported States in developing design standards	No activity
1997	Funded Aimee Flannery safety and crash research Transportation Research Board (TRB) Report: *State-of-the-Art Design of Roundabouts*(11) TRB -TR News Report: *Roundabouts: Improving Road Safety and Increasing Capacity*(12)	Supported States in developing design standards	No activity
1998	Funded Aimee Flannery safety and crash research National Cooperative Highway Research Program (NCHRP) 264: *Modern Roundabout Practice in the United States* (see table 8)(13)	Supported States in developing design standards	No activity
1999	Funded Aimee Flannery safety and crash research	Supported States in developing design standards Precursor to the Full Day Workshop	Office of R&D provided technical assistance
2000	Report: *Roundabouts: An Informational Guide*(see table 8)(2) Institute of Transportation Engineers (ITE) Report: *Safety Impacts of Roundabouts*, The Traffic Safety Toolbox(14,15)	No activity	Office of R&D provided technical assistance Office of R&D and the Resource Center: Full Day Workshop

[1]Activites or publications that appear in table 9 in section 3.3 have been noted. As described in section 3.3, these are the more significant activities or publications in the history of roundabouts.

Year	FHWA Research Activities or Influence	FHWA Acceptance of Roundabouts	FHWA Promotion of Roundabouts
2001	Continued safety research	No activity	Office of R&D provided technical assistance Office of R&D and the Resource Center: Full Day Workshop Pamphlets and videos for various audiences including agencies and public
2002	Continued safety research	No activity	Office of R&D provided technical assistance Office of R&D and the Resource Center: Full Day Workshop Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support
2003	Continued safety research	*Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways* 2003 edition includes basic roundabout signing information[16]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support The Resource Center: Full Day Workshop
2004	Continued safety research	No acitivty	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support The Resource Center: Full Day Workshop
2005	Continued safety research	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (100% eligibility for roundabouts) (see table 8)[17,18]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support The Resource Center: Full Day Workshop
2006	Continued safety research	SAFETEA-LU (100% eligibility for roundabouts) (see table 8)[17,18]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support The Resource Center: Full Day Workshop

Year	FHWA Research Activities or Influence	FHWA Acceptance of Roundabouts	FHWA Promotion of Roundabouts
2007	Continued safety research FHWA sponsored the Traffic Control Devices Pooled Fund Study for MUTCD[19] Developed capacity equations for the *Highway Safety Manual* (HSM) and *Highway Capacity Manual* (HCM)[20,21] NCHRP 572: *Roundabouts in the United States* (see table 8)[22]	SAFETEA-LU (100% eligibility for roundabouts) (see table 8)[17,18] First roundabout in a national park (see table 8)	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support The Resource Center: Full Day Workshop
2008	Continued safety research Developed capacity equations for HSM and HCM Report: *Design Guide for Roundabout Lighting*, Illumination Engineering Society of North America (IESNA)[23] Report: *Enhancing Intersection Safety Through Roundabouts: An ITE Informational Report*[24]	SAFETEA-LU (100% eligibility for roundabouts) (see table 8) [17,18] 2008 Proven Safety Counter Measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support National Highway Institute (NHI) Workshop
2009	Continued safety research Developed capacity equations for HSM and HCM	SAFETEA-LU (100% eligibility for roundabouts) (see table 8)[17,18] 2008 Proven Safety Counter Measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop
2010	Continued safety research Developed capacity equations for HSM and HCM NCHRP 672: *Roundabouts An Informational Guide* (see table 8)[3]	2008 Proven Safety Counter Measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop Peer-to-Peer Program
2011	Continued safety research NCHRP 772: *Evaluating the Performance*[27] FHWA TOPR 34: *Accelerating Roundabout Implementation in the United States*[28]	2008 Proven Safety Counter Measures (see table 8)[25] MAP-21 (maintained 100% eligibility for roundabouts)[26]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop Peer-to-Peer Program

Year	FHWA Research Activities or Influence	FHWA Acceptance of Roundabouts	FHWA Promotion of Roundabouts
2012	Continued safety research NCHRP 772: *Evaluating the Performance*[27] FHWA TOPR 34: *Accelerating Roundabout Implementation in the United States*[28]	Moving Ahead for Progress in the 21st Century Act (MAP-21) (maintained 100% eligibility for roundabouts)[26] 2012 Proven Safety Counter measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop Peer-to-Peer Program
2013	Continued safety research NCHRP 772: *Evaluating the Performance*[27] FHWA TOPR 34: *Accelerating Roundabout Implementation in the United States*[28]	MAP-21 (maintained 100% eligibility for roundabouts)[26] EDC-2 under Intersection and Interchange Geometrics (see table 8)[7] 2012 Proven Safety Counter measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop Peer-to-Peer Program
2014	Continued safety research NCHRP 772: *Evaluating the Performance*[27]) FHWA TOPR 34: *Accelerating Roundabout Implementation in the United States*[28]	MAP-21 (maintained 100% eligibility for roundabouts)[26] EDC-2 under Intersection and Interchange Geometrics (see table 8)[7] 2012 Proven Safety Counter measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop Peer-to-Peer Program
2015	Continued safety research Funding NCHRP report on Crash Safety Models[2] FHWA TOPR 34: *Accelerating Roundabout Implementation in the United States*[28]	MAP-21 (maintained 100% eligibility for roundabouts)[26] 2012 Proven Safety Counter measures (see table 8)[25]	Pamphlets and videos for various audiences including agencies and public Office of Safety and Resource Center provided technical assistance and targeted support NHI Workshop Peer-to-Peer Program

[2]This report is currently in-progress and due to be published in 2018.

2. Evaluation Design

The evaluation team met with the R&T program manager, the Safety R&D technical director, and the Safety R&D roundabouts technical lead to define core evaluation hypotheses and gain a basic understanding of roundabout research activities. In particular, the evaluation team sought to understand program goals, refine program activities and the timeframe assessed, gather available information, and identify key stakeholders to include. After gathering and reviewing this information, the evaluation team selected evaluation methodologies most appropriate for the primary hypotheses.

Roundabouts remain a topic of ongoing research and educational activity in the United States and are supported by a number of agencies and champions. To leverage the data collection and findings from two active roundabouts studies being conducted by NCHRP, the evaluation team split the roundabouts evaluation into two phases. This two-phased approach reduced duplicative data collection efforts and resulted in a complete final evaluation product, which better traced the flow of FHWA research investment to present-day outcomes and impacts. This evaluation report incorporates the results of both phases of the evaluation. A description and timeline for each phase are provided:

1. **Phase I (November 2014–September 2015):** Focused on metrics related to FHWA research products and short-term outcomes, longer-term outcomes of adoption, and safety and operational impacts.

2. **Phase II (September 2015–December 2015):** Supplemented the Phase I evaluation results with additional information on intermediate and longer-term outcomes related to States' changes in attitudes, policies, behavior, and adoption of roundabouts using inputs from two recently completed NCHRP projects:

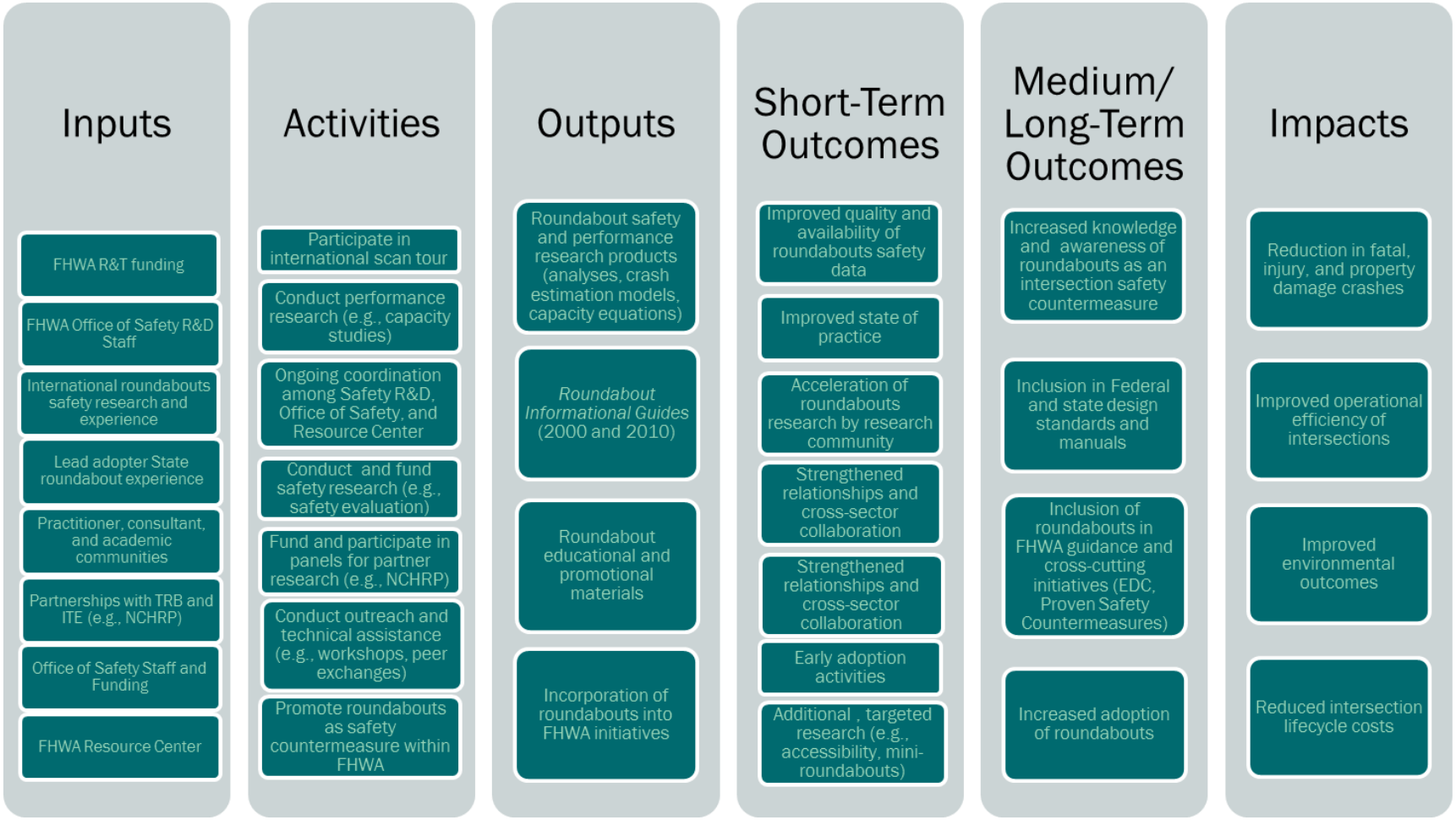
   – *NCHRP Synthesis 488: Roundabout Practices*, which provided a comprehensive summary of State roundabout policies.[4]

   – *Estimating the Life-Cycle Cost of Intersection Designs*, an NCHRP Web-Only Document 220, which developed comparative lifecycle costs.[5]

2.1 Logic Model

To understand program theory and design, the evaluation team constructed an initial logic model of the roundabout research activities that identified potential relationships between four evaluation areas to effectively investigate the outcomes and impacts of FHWA roundabout research. A logic model is a series of statements that links program components (inputs, activities, outputs, outcomes, and impacts) in a causal chain. It describes the relationship between program resources, planned activities, and expected results. It is not a comprehensive or linear description of all program processes and activities, but rather makes explicit how program stakeholders expect program activities to affect change. The logic model helps to explain the theories of change that drive the design of a program and provides hypotheses (i.e., if one performs X, then Y will happen)

that can be tested. The evaluation team built the logic model based on discussions with key FHWA program staff and documents, as shown in figure 1.



Source: FHWA.

Figure 1. Image. FHWA R&T roundabout research logic model.

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 section 3 groups these associated secondary hypotheses around related findings. In addition to discussions with key FHWA program staff, the evaluation team reviewed Everett Rogers's *Diffusion of Innovations* to inform development of these evaluation areas and hypotheses.[29] In the book, Rogers describes a framework for understanding why individuals choose whether or not they will adopt new ideas, technologies, and behaviors. This framework addresses characteristics of the technology and adopters, the stages of decisionmaking, and the hypotheses and analysis methods incorporated into this framework, as appropriate. For example, in the hypothesis related to the diversity of materials, the evaluation team reviewed FHWA roundabout research outputs in light of both the intended target audience and the stage of decision making.

Table 3 summarizes the primary and secondary hypotheses and some of the key performance measures.

Table 3. Roundabout evaluation hypotheses and performance measures.

Evaluation Component (e.g., Near-Term Outcome, Long-Term Outcome, and Impact)	Key Hypotheses	Key Performance Measures
Evaluation Area 1: FHWA roundabouts R&T activities contributed to the state of the practice and data	FHWA research improved the availability of roundabout-related safety and performance data for researchers and practitioners FHWA research improved the quality of roundabout-related safety and performance data FHWA research advanced the state of the art for roundabouts FHWA research accelerated consideration of roundabouts by the transportation research community FHWA research was used by other researchers to advance the availability and quality of safety and performance data for roundabouts Initial R&T investment led to more targeted FHWA research	Number of citations and references to key FHWA outputs and activities work in non-Federally funded roundabout research Number of roundabout research studies published and funded by FHWA compared with number of U.S.-focused roundabout research products prior to the *2000 Informational Guide* Number and growth in citations and references of FHWA work in other roundabout research Use/contribution of research in Crash Modification Factors (CMF) Clearinghouse/HSM[30] Assessed diversity of research materials (multiple stakeholder audience types such as elected officials, traffic engineers, etc.) Incorporation of and reference to FHWA products in roundabouts design standards Adoption of FHWA work into the American Association of State Highway Transportation Officials (AASHTO) Green Book, HCM, HSM, and any other relevant products[31,21,32] Growth in roundabouts as a topic at TRB Annual Meetings since 1995

Evaluation Component (e.g., Near-Term Outcome, Long-Term Outcome, and Impact)	Key Hypotheses	Key Performance Measures
Evaluation Area 2: FHWA roundabouts activities contributed to changing awareness of, knowledge of, and attitudes toward, roundabouts	FHWA roundabout-related research changed the level of awareness of roundabouts as a safety countermeasure among the U.S. transportation community FHWA roundabout-related research influenced the attitude of other FHWA programs toward roundabouts as a safety countermeasure FHWA roundabout-related research influenced the attitude of transportation community toward roundabouts as a safety countermeasure	Number of times NHI roundabouts course was offered Number of States with roundabouts guidance in State Highway Design Manuals (SHDMs) and of those, the number referencing FHWA resources Number of States referencing roundabouts guidance in their SHDM Number of States referencing FHWA-funded resources in their SHDM Number of States with roundabouts included in their in their Strategic Highway Safety Plans (SHSPs) Change in FHWA roundabout-related policy or guidance practices Change in understanding of roundabouts as distinct from similar, negatively-perceived circular intersection designs (e.g., rotaries)
Evaluation Area 3: FHWA roundabouts R&T activities accelerated adoption of roundabouts	FHWA accelerated early adoption of roundabouts through outreach activities FHWA contributed to an increase in number of roundabouts built in the United States	Growth in the total number of roundabouts in the United States Growth in the number of States building roundabouts in the United States Number of roundabouts built in States that received early technical assistance compared with rate of roundabout adoption in non-early assistance States Growth in the number of States building roundabouts over evaluation period Perception of the impact of FHWA research on investment in roundabouts
Evaluation Area 4: FHWA roundabouts activities led to fewer fatal and serious injury crashes at intersections	Roundabouts have better safety performance compared to traditional intersections Roundabouts provide improved operational performance compared to traditional intersections Roundabouts have reduced environmental impacts compared to traditional intersections in the United States Roundabouts have reduced maintenance and lifecycle costs compared to traditional intersections in the United States	Existing research demonstrates a reduction in number of crashes at roundabouts versus traditional intersections Existing research demonstrates a reduction in number of and severity of crashes at roundabouts versus intersections Existing research demonstrates improved throughput performance at intersections Existing research demonstrates reduced emissions compared to traditional intersections

2.2 Evaluation Methodology

This evaluation was *summative,* meaning the evaluation focused on outcomes and impacts of FHWA's roundabouts activities on roundabouts development and deployment in the United States rather than evaluating the development and status of the efforts at a point in time during deployment (formative assessment). This evaluation was *retrospective*; therefore, the evaluation team relied primarily on documentary evidence, which was supplemented by data analysis (when available) and selected interviews.

Literature and Document Review

The bulk of this evaluation was conducted through the review of literature, documents, and other sources regarding roundabouts from the early 1990s to the present. The evaluation team worked with its librarians and those at the Turner-Fairbank Highway Research Center (TFHRC) to identify all relevant FHWA-published literature and broader roundabout-related literature to help assess the influence of FHWA research and to understand the benefits of roundabouts installations. The following section uses "literature" to mean scholarly publications, and "document review" refers to primary source records, which are documents that FHWA produced and other items. The evaluation team collected archived information from TRB, documents and records from the Office of Safety, and general media articles related to roundabouts 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 wide variety of documents related to roundabouts and used diverse methods to analyze and to understand them.

FHWA Document Review

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

The TFHRC library provided a list of FHWA-funded research as of June 2015. To supplement and complete that list, the evaluation team searched for FHWA-funded roundabout research through the evaluation team library, consulting FHWA's Office of Operations Research and Development (Operations R&D), and through other publically available sources, such as Transportation Research International Documentation and Google® Scholar™ through Publish or Perish (PoP).[33] Collected data included title, year published, author(s), journal, publisher, and document type (such as report, journal article, conference paper, etc.).

FHWA program documents were reviewed to achieve a better understanding of program activities and goals. To understand the diversity of materials FHWA produced, the evaluation team reviewed materials based on the stages in the *Diffusion of Innovations* decision innovation process and based on target audience. This *Diffusion of Innovations* framework describes five phases in the innovation adoption decisionmaking process: knowledge, persuasion, decision, implementation, and confirmation.[29] At each stage, different communication strategies may best encourage adoption. The 2013 evaluation of the Intersections Safety Program adapted and used this framework to develop recommended communication strategies under each phase.

For this evaluation, the evaluation team applied this adapted framework. To conduct this assessment, the evaluation team reviewed the list of FHWA products provided by the TFHRC library, as well as additional materials, to understand what phase of decisionmaking FHWA roundabouts products address. In addition to stage of adoption, the team also reviewed documents based on

intended audience. Target audiences included researchers, consultants, FHWA division offices, State transportation departments, local practitioners, and local leadership (i.e., elected officials).

TRB Programs

To understand the growth of roundabouts as a research topic among the transportation community, the evaluation team collected and reviewed the TRB Annual Meeting Final Programs from 1996 to 2013. The evaluation team broke down each program by categorized presentation and poster sessions. The index of sessions was searched for four keywords relating to roundabouts: intersection, geometry, unsignalized, and pedestrian. Any session that contained at least one of these keywords was then searched for presentation titles that mentioned roundabouts. The evaluation team tracked whether the presenter was listed with FHWA affiliation. 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 Transportation Department Websites

To assess the influence of FHWA research and outreach on State transportation departments, the evaluation team reviewed State transportation department websites, SHSPs, and SHDMs for all 50 States, plus Washington, D.C., SHSPs were gathered for all States and years available as of August 2015. The evaluation team studied the documents for references to roundabouts as a safety countermeasure.

SHDMs were collected for all States available in August 2015. Research by Arizona Transportation Department in 2003 was the baseline from which the evaluation team reviewed SHDMs for references to FHWA research over time.[34]

State transportation department websites were reviewed for links and references to FHWA roundabouts materials on their sites in August 2015.

Literature Review

Roundabout Impacts Literature

To understand the range of impacts of adopting roundabouts domestically, the evaluation team relied primarily on existing literature. The evaluation team limited analysis in the initial evaluation phase to a preliminary literature review, linking current understanding of roundabout benefits to the evaluation team's analysis of the effect that FHWA research has had on the numbers of roundabouts in the United States. The goal of this review was to understand the overall impact roundabouts have had on safety, operational, and environmental performance of intersections. In the second phase of this evaluation, the evaluation team reviewed the *NCHRP Web-Only Document 220: Estimating the Life-Cycle Cost of Intersection Designs* and incorporated its findings to expand the discussion of roundabout impacts to the full lifecycle cost of intersections, comparing a roundabout to other intersection designs.[5]

Citation Analysis

In addition to research collected for the FHWA document review, the evaluation team used two sources to count how often each document was cited. Harzing's PoP software allows users to search and organize the results of the Google® Scholar™ database and calculate a number of impact scores to assess the impact that a paper or researcher has had. The evaluation team conducted four separate searches using PoP: "modern roundabout" or "modern roundabouts;" "roundabout" or "roundabouts" not including "biology," "gene," "protein," "swings and roundabouts," "theorem," linguistics," "psychology," "magic," or "jealousy;" "roundabout" or "roundabouts" where ITE was the publisher; and the *2000 Informational Guide*.[2] All results returned fewer than PoP maximum of 1,000, so the results were exhaustive with respect to the search terms and conditions.

Data were cleaned to remove any internationally published or funded research and any non-transportation research. Non-U.S. published entries were removed by deleting columns with elements ".ca," ".uk," ".au," "korea," or conferences with international audiences. The evaluation team excluded results that lacked important data (year, publisher, source, or citation information), were published before 1980, or bore no relation to intersection management.

To assess the impact of all FHWA primary and sponsored work, the evaluation team examined how many roundabout research studies FHWA published and funded compared with the number of U.S.-focused roundabout research products. The *2000 Informational Guide* was used as the benchmark year, as it was the first major publication by FHWA (in cooperation with domestic partners, including Maryland, Ohio, and California transportation departments, and international experts from the United Kingdom, France, Australia, and Germany) and, as this evaluation area will demonstrate, was pivotal to roundabout research.

Listserv Analysis

In an effort to understand the research community of practice, the evaluation team analyzed content from the TRB Roundabout Committee-organized Listserv™ started in 2003.[35] The Listserv™ maintains data from August 2013 and provides a snapshot of activity in the roundabouts community and how well FHWA research and outreach is received. Its content is searchable through the Listserv™ web interface by keyword, date, and author's email address. The return content includes the Item #, Date, Time, Recs (the number of lines in the record), and Subject. The content of the post is then accessible by link. The evaluation team queried the Listserv™ for FHWA-related terms, including four NCHRP Synthesis Reports, which report on the state of the practice based on literature reviews and surveys of recent activities: "FHWA," (NCHRP) "264," (NCHRP) "572," (NCHRP) "672," (NCHRP) "772," Informational (Guide), "proven safety measures," "proven safety," "proven countermeasures," and "NCHRP."(See references 13, 22, 3, and 27.)

Roundabout Practice: A Synthesis of Highway Practice (NCHRP Synthesis 488)

During the evaluation planning process, the evaluation team learned about an ongoing NCHRP synthesis project with a scope and data-collection plan that partially overlapped the proposed evaluation team plan. In particular, the NCHRP project plan included a review of State roundabout policies, which included a questionnaire to all States on selection, design, and performance analysis of roundabouts. In coordination with the FHWA R&T program manager and the Safety R&D technical lead for this evaluation, the evaluation team made the decision to phase its evaluation to incorporate findings from the NCHRP synthesis upon its completion. For the second phase of the evaluation, the evaluation team incorporated the results of the *NCHRP Synthesis 488* into the findings of relevant evaluation areas.[4]

Data Analysis

When available, the evaluation team used quantitative analysis to better understand funding, counts, and impacts of roundabouts. 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.

HSIP/CMAQ Funding Data

The evaluation team analyzed two FHWA funding programs under which roundabouts are eligible for funding: the Highway Safety Improvement Program (HSIP) (Office of Safety) and the Congestion Mitigation and Air Quality Improvement Program (CMAQ) (Office of Planning, Environment, and Realty).

HSIP data provide information on the number of projects and the cost, year, and location (State) of projects. Information specific to the construction of roundabouts is available only at the subcategory

level. The HSIP database only provides this level of detail starting in 2013, and only 2 years of data were available for analysis (2013–2014).

The evaluation team reviewed CMAQ data from 1991 to the present (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 roundabout deployment. Connections to other FHWA efforts are highlighted when appropriate and the number of roundabouts funded through these programs (as a total of roundabouts deployed in a year) is considered.

Roundabout Inventory Data

To analyze the growth of roundabouts deployment in the United States, the evaluation team used 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 roundabout adoption.[36] The variables used include: State, county, status (existing or removed), and year.

Data are generated through media reporting of roundabout deployment; therefore, it may be difficult to maintain consistency if the mainstreaming of roundabouts leads to reduced media reporting, and it is likely that the Kittelson & Associates database underestimates the number of roundabouts. Due to diminishing interest to locals and media outlets as the number of roundabouts increases, this underestimation of the number is especially true for jurisdictions with multiple roundabouts. For this reason, only data through 2012 were used. For instances in which the date was uncertain, the date was used rather than eliminating the data. The analysis focuses on growth and timing of growth in the number of roundabouts deployed per year, and the distribution of roundabouts by individual State.

Safety Impact Analysis

The evaluation team used CMFs ascribed to roundabouts to estimate total crashes averted and societal cost savings in the United States between 1990 and 2014. This simplified calculation provides a sense of scale for the safety impact of roundabouts. 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 roundabouts were used to develop an average CMF for the purposes of this calculation. Separate CMFs were created for injury/fatal crashes and for property-damage-only (PDO) rates. The evaluation team calculated the total crashes prevented between 1990 and 2014 while assuming that all roundabouts averaged the same CMF with identical before-and-after installation crash rates. Most roundabouts in the United States were converted from traditional stop-controlled or signalized intersections; thus, reported crash reduction impacts must be understood relative to traditional intersections.[36] 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 NHTSA crash data from 2014 and from a 2007 study, *Pre-crash Scenario Typology for Crash Avoidance Research*.[37] USDOT inputs for value of statistical life (VSL) and PDO costs were used to estimate dollar figures of social costs.[38,39]

Interviews

Given the breadth and depth of roundabout-related resources available, the evaluation team did not use interviews as a primary source of data collection, but rather relied on them to further understand FHWA activities from the 1990s to the present.

The evaluation team conducted six in-depth, semistructured interviews with FHWA staff currently or previously active in roundabout research, outreach, and technical assistance. Interviewees came from Safety R&D, Operations R&D, Office of Safety, and the Resource Center. Customized interview guides for each of these FHWA Offices are available in the Final Roundabouts Evaluation Plan.

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 roundabout safety and operational performance data, engagement with the roundabout research and practitioner community, perception of stakeholders' awareness, knowledge, and attitudes toward roundabouts, and the eventual adoption of roundabouts as a safety countermeasure.

The evaluation team also interviewed Gene Russell, chair of the TRB Roundabouts Committee from its founding to present. Interview questions addressed the history of roundabout research and activity in the United States, familiarity with FHWA resources, and awareness of and attitudes toward roundabouts among the practitioner community.

3. Evaluation Findings

This section is divided into the four evaluation areas that 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 in-depth discussion of the findings. These specific findings seek to address the evaluation team's key hypotheses. Findings are supported by evidence collected through the evaluation methods described in section 2.2.

3.1 Evaluation Area 1: Availability and Reliability of Data

Hypothesis: FHWA's contribution to the availability and reliability of safety and performance data on roundabout (including safety evaluation data and evidence of benefits).

The logic model developed for this evaluation proposes that FHWA research advanced the availability and quality of safety and performance data by improving the availability and quality of roundabout-related safety and performance data, advancing the roundabout state of the practice, and accelerating consideration of roundabouts by other researchers. The evaluation team found strong evidence in support of the hypotheses within this evaluation area.

One goal articulated in *Safe Roads for a Safer Future: A Joint Safety Strategic Plan* is for FHWA to improve safety data and expand capabilities for analysis and evaluation.(6) While the evaluation team focused on early FHWA roundabout research that predates the *Strategic Plan*, providing high-quality, reliable safety data has long been a goal of FHWA and Safety R&D. *Towards Zero Deaths: A National Strategy on Highway Safety* notes the following:

> *For countermeasures, it is necessary to understand how a particular feature or countermeasure works, the reliability of its performance, the range in road characteristics that factor into which strategies will be effective in a given location, and as mentioned above, identifying the extent of the existing system with those characteristics.(40)*

This understanding requires extensive research, something FHWA often provides, and from the broader transportation research community.

This evaluation area focuses on the extent to which FHWA contributed to the availability of roundabout-related data, research, and tools.

Overview of Findings

FHWA R&T's research activities through the 1990s to the *2000 Informational Guide* significantly increased the amount of published material on roundabouts in the United States. The results and outputs of FHWA's research were widely used and expanded all phases of roundabaout research. Initial FHWA contributions increased the availability of domestically relevant roundabouts information by synthesizing international research with the limited domestic safety and design research. These outputs clarified and focused the research questions for the U.S. research

community with whom FHWA partnered. The considerable impact of FHWA's research is evidenced by the number and breadth of citations of FHWA research and research influenced by FHWA. Roundabout 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 transportation departments, local agencies, and the public. Interviews provided information about the timing of research and other activities and their effect on the research community and showed that FHWA played an important role in accelerating consideration of roundabouts as a research topic and in developing U.S.-focused safety and performance studies.

Detailed Findings Summary

Finding: Early and continued FHWA research increased the quality and availability of domestic roundabout-related safety and performance data and accelerated the development of design standards for roundabouts.

Innovations often face strong opposition and significant barriers. In *Diffusion of Innovations*, Rogers proposes the idea of the "Champion," the person(s) committed to an innovation and willing to overcome indifference, opposition, and obstacles to implement a new technology.[29] Evidence demonstrates that FHWA R&T was an early champion of roundabouts, significantly increasing both the availability and quality of roundabout safety research in the United States through commitment to conducting domestic research and sharing the results of that research widely.

FHWA was a key player in what interviewees described as a broad community of researchers working to increase the quality and availability of U.S.-roundabout research and data. Prior to FHWA's involvement, there was extensive research and implementation of roundabouts outside the United States (particularly in the United Kingdom, France, Germany, and Australia). Early U.S. research relied heavily on these sources for information about design, safety, and performance data. FHWA's *2000 Informational Guide*, the culminating output of the 1990s FHWA-sponsored roundabout research, drew heavily from European research, and even included international researchers on the report panel.[2]

There were also many early non-FHWA U.S. champions of roundabout research, including individuals from the California Department of Transportation, MDSHA, and academia. These researchers urged examination and implementation despite opposition (from the public and from highway agencies). In addition, transportation research bodies like ITE, AASHTO, and TRB published or supported the publication of roundabout materials.

In interviews, FHWA staff honored the wide involvement of outside researchers. One FHWA interviewee emphasized that "…while FHWA has tried to do a lot and has succeeded; it hasn't been a one-man show. So many people [were involved], especially at State level… it's thanks to the States and champions that they get built." Another FHWA interviewee described it as a "team effort. FHWA, ITE, TRB… We all want roundabouts to be successful."

FHWA's involvement with roundabouts began in 1992 when Jerry Reagan, then chief of FHWA's Design Concepts Research Division at TFHRC, led an international scanning tour in France, the United Kingdom, Germany, Australia, and Japan to explore operational and safety features of roundabouts. That effectively generated internal interest to research roundabouts in a domestic context, and convinced Safety R&D team leaders that it would be good to develop a roundabouts guide. This increased interest led to funding of researchers outside FHWA through grants and support. In at least one case, graduate work (the student held an Eisenhower research fellowship) was funded in part in 1994–1995 through a grant established by the Safety R&D technical director

Justin True, Flannery wrote four articles from 1996 to 1999 studying the safety, capacity, and domestic crash experience of roundabouts.[41–44]

FHWA researchers were directly involved in the community of researchers; they published and provided expertise to both researchers and adopters. Joe Bared of FHWA published in *Public Roads*, *Transportation Research Record*, and *TR News*, and worked with early adopters such as MDSHA. Apart from direct work and funding of research, FHWA staff were panel members on collaborative research (notably the NCHRP 264 in 1997), gave presentations, spoke at conferences, and conducted workshops for division offices and agencies.[13] Other FHWA staff made similar contributions to outside work, including Mark Doctor, who served on the Technical Advisory Committee of the Florida Roundabouts Guide published in 1996.[45]

This early research conducted or funded by FHWA from 1994 through 2000 directly increased the quality and availability of data and research. After 2000 and throughout the later stages of roundabout safety research, FHWA showed an ongoing commitment to safety research. Three later-stage research projects were positively evaluated by the CMF Clearinghouse, a database of safety countermeasures maintained by FHWA.[22,46,47] CMFs are reviewed by practitioners looking for solutions to highway safety problems. Studies reviewed under the CMF rubric are given a rating of 1 to 5 stars, based on the quality of the research. A single paper may have multiple countermeasure areas under which it can be evaluated, such as "Convert high-speed rural intersection to roundabout, Crash Type: all, Crash Severity: All." Table 4 shows the star ratings for FHWA and non-FHWA CMF studies, counting each countermeasure area separately.

Table 4. Number of roundabout CMF studies by origin and rating.

CMF Rating (Number of Stars)	Non-FHWA	FHWA (Funded or Conducted)
1	5	--
2	16	1
3	30	15
4	43	19
5	--	4
Total	94	39

--Information not applicable.

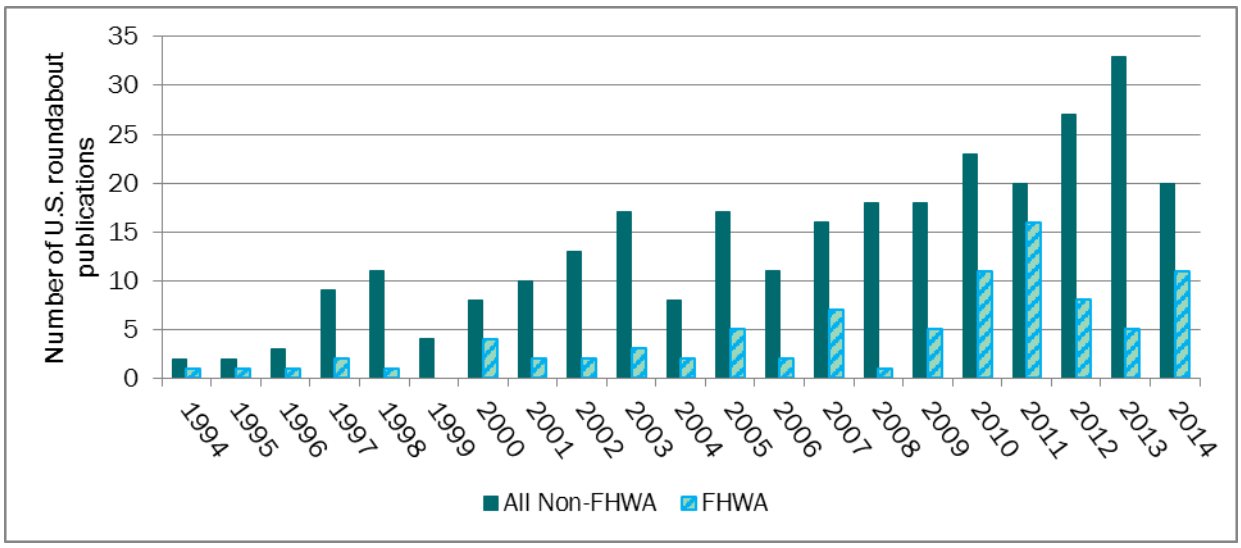
The results show that FHWA conducted quality research on the safety of roundabouts and showed roundabouts to be better than alternatives (e.g., signalized intersections). Further, such safety outcomes reveal roundabouts to be compatible with the goals of local and State traffic agencies, including improving highway safety.

The *2000 Informational Guide* was important in demonstrating FHWA's commitment to roundabouts. FHWA gathered, synthesized, and made accessible the international research for a much wider domestic audience than what academic literature had reached at that point.

Prior to the *2000 Informational Guide*, there were several attempts to organize existing roundabouts literature, including the NCHRP 264 report and *Evolution of Roundabout Technology: A History-Based Literature Review* by Edmund Waddell of the Michigan Department of Transportation.[13,48] Waddell described the evolution and state of roundabout research in the United States through 1997, reporting on only a handful of U.S. papers that dealt with the geometric design and operations of roundabouts, including research by FHWA in *State of the Art Design of Roundabouts*.[11] NCHRP

264 and Waddell offer strong evidence of the relative paucity of research before 1997 and reveal the gap that the *2000 Informational Guide* filled.[13,48] The *2000 Informational Guide* also provided a snapshot of the scope of roundabout research in the United States at that time. The report includes over 100 references of which a small portion was research conducted in the United States for a domestic audience.[2]

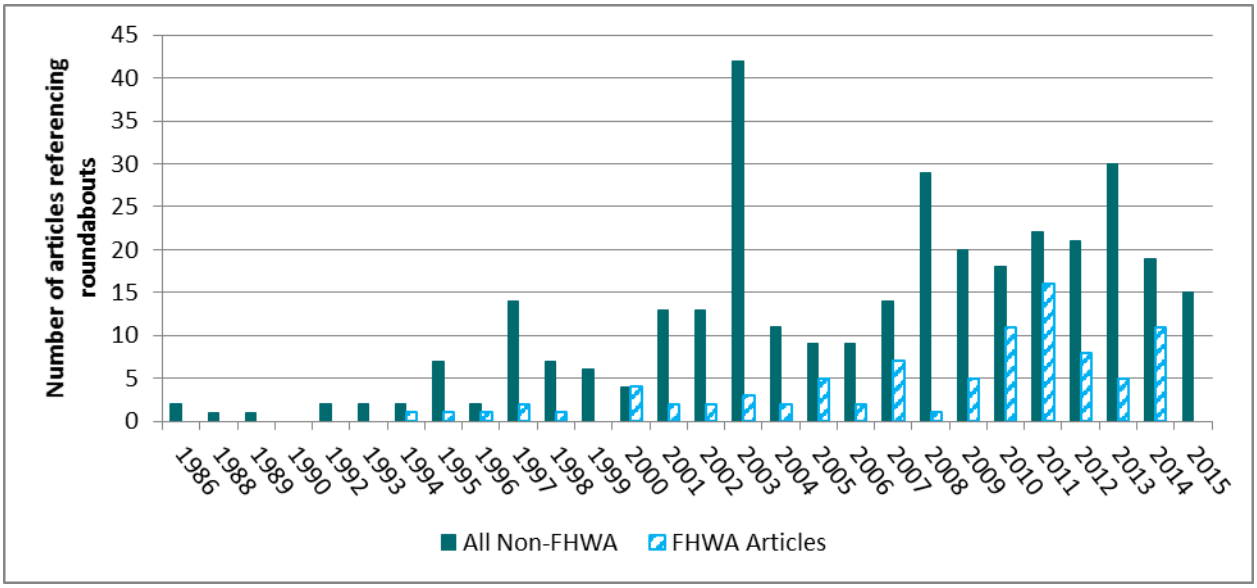
Figure 2 shows the number of roundabout research publications per year by FHWA and non-FHWA sources, where the publications are specific to roundabouts, rather than general intersection or safety research with roundabouts included. The growth of both roundabout-focused research and research citing roundabouts increased through 2013, with a marked growth in publications mentioning roundabouts after 2000. FHWA remains involved in producing materials.



Source: FHWA.

Figure 2. Graph. Number of U.S.-focused roundabouts publications per year.

Figure 3 shows the number of non-FHWA research materials that mention roundabouts compared to the number of FHWA roundabouts papers. These references occur in research specifically related to roundabouts, (i.e., has "roundabout" in the title rather than general intersection-design research). The later peak for FHWA-funded roundabout research includes publications focused on topics such as mini roundabouts. Both figure 2 and figure 3 show an early peak around 2000 for non-FHWA publications, likely reflecting U.S. interest after publications like the *2000 Informational Guide*.

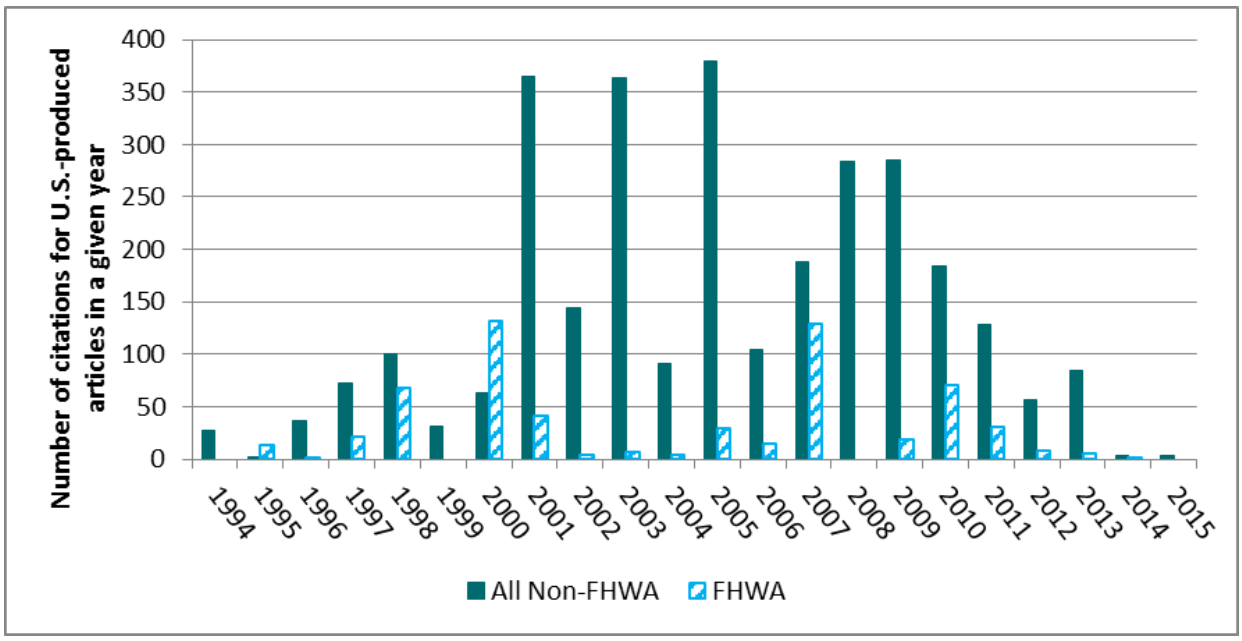


Source: FHWA.

Figure 3. Graph. Number of publications referencing roundabouts per year compared to FHWA publications.

Interviews with roundabout researchers revealed the paucity of U.S. research in the early 1990s. As put by one FHWA interviewee (who today works for FHWA but was involved in roundabout research before FHWA employment), "…when we were going through 672 (the 2010 revision of the *Roundabouts Informational Guide* (herein the *2010 Informational Guide*)), in focus groups, people said that if this is just an NCHRP paper, it doesn't hold the weight that FHWA work does. FHWA's name is on the cover, which is unusual. That was huge."(3)

One measure of the impact of a research program is how often other researchers used the materials in its work. The evaluation team used Google® Scholar™ citation data to analyze how FHWA research was used by other researchers and found significant impact. Characteristics of research can reasonably be inferred from the breadth of citation, such as perceived expertise or leadership and quality. Figure 4 shows how many articles that cited roundabout-focused papers were published by year, broken down by FHWA and non-FHWA. Included are papers that are not roundabout-focused, but from which it can be seen how the research community in general (accessibility, planning, general intersection, safety, operations, etc.) responded to the availability and quality of the roundabouts data. There is a clear increase in the number of citations for roundabout research after 2000, marking a moment of mainstreaming of roundabouts; for example, there were over 350 citations published in 2001.



Source: FHWA.

Figure 4. Graph. Number of citations for articles produced in the United States in a given year.

The *2000 Informational Guide*'s impact was examined more closely to quantify its reach into roundabouts publications since that time. Of the 130 papers that cited the *2000 Informational Guide*, 80 had a strong citation reach themselves. Combined, these 80 papers had more than 1,100 of the roughly 2,700 non-FHWA citations (approximately 40 percent) from 2001 forward. The direct and secondary effects of the *2000 Informational Guide* have, at the very least, a great nominal impact. The evaluation team stresses that this analysis is not one of causality or necessity; it is possible that these publications would have been published without FHWA's influence. Rather, it strongly suggests that FHWA played a role in the acceleration of roundabout research availability and consideration.

Finding: FHWA produced materials for a range of audiences across the technology adoption lifecycle.

In *Diffusion of Innovations*, Rogers describes five phases in the innovation adoption decisionmaking process: knowledge, persuasion, decision, implementation, and confirmation (p. 169).[29] At each stage, different communication strategies may work best to encourage the adoption of innovations. This framework was adapted and used for an Evaluation of the Office of Safety Intersections Safety Program; it includes recommended communication strategies appropriate to each phase. For example, at the knowledge phase, briefing materials, fact sheets, and videos are useful to educate the public and elected officials about potential benefits of intersection safety solutions, while in the persuasion phase, interpersonal communication among peers is typically highly effective. The Office of Safety Intersections Evaluation summarized these strategies:[49]

> *At the knowledge stage, individuals may be most influenced through mass media that provides general information describing the innovation, the problem it is intended to solve, and the advantages of adopting the innovation. At the persuasion stage, interpersonal communication may be most effective. At the implementation phase, individuals may require specific information about how to implement a particular innovation. Finally, at the confirmation phase, individuals consider evaluative information from their personal experiences implementing the innovation.*[1]

The research products, outreach, technical assistance, and other activities FHWA engaged in over its 20-year involvement in roundabouts reflect a range of communication strategies that are effective at each phase of innovation adoption decisionmaking. Table 5 provides examples of recommended communication strategies at each phase. Some resources may fit into multiple categories; the examples are intended as illustrations. Some of these products, especially those in the earlier years of roundabouts activity (1995–2000) directly result from FHWA R&T–funded research through Safety R&D. Others, especially those that follow the *2000 Informational Guide*, are products and services provided by the Resource Center and HSA to disseminate the results and encourage adoption based on benefits demonstrated in the foundational research.

Table 5. Examples of FHWA roundabout activity by adoption decisionmaking phase.

Phase	Recommended Communication Strategies	Examples of FHWA Roundabouts Products and Activities
Knowledge	Brief, basic information about the benefits, costs, and applications of safety innovations.	*Public Roads* article: "Roundabouts: A Direct Way to Safer Highways"(1995)[10] Video: *The Case for Roundabouts* (2001)[50] Roundabouts Fact Sheet (2006)[51] *Public Roads* article: "They're Small But Powerful" (2012)[52]
Persuasion	Interpersonal communication providing subjective evaluative information based on experiences applying innovation.	Peer-to-Peer Program exchanges and peer assistance (2010–2014) Workshops for States, counties, and cities in cooperation with FHWA division offices (mid-1990s–present) Direct project-level technical assistance provided by Safety R&D staff
Adoption decision	Passively marketed, detailed information about applications, benefits, and costs of the innovation	NCHRP Synthesis 572 (2007)[22] Alternative Intersections/Interchanges Informational Report (2009)[53] *Roundabouts Informational Guides* (2000, 2010)[2,3] CMFs
Implementation	Detailed information about how to best apply and/or adapt innovation under different conditions.	*Roundabouts Informational Guides* (2000, 2010)[2,3] Technical assistance (ongoing) NHI Roundabouts Course (2011–present) HCM, HSM, and *Manual on Uniform Traffic Control Devices*[54,32,55]

[1]This information is from an interal FHWA evaluation report that was not published.

Phase	Recommended Communication Strategies	Examples of FHWA Roundabouts Products and Activities
Confirmation	Supportive, reinforcing messages about benefits of and peer use of innovation, newsletters highlighting best practices, and evaluative research.	Roundabouts Fact Sheet (2006)(51) *TR News* article: "Implementing Modern Roundabouts in the United States" (2014)(46) *Best practices for Roundabouts on State Highways* (2013)(56) Roundabouts Listserv[2] (ongoing)(35)

In addition to engaging in multiple approaches during the adoption decisionmaking phases, FHWA demonstrated a commitment to make its research results accessible across different stakeholder groups by adapting its resources for presentation to disparate audiences. FHWA developed and funded roundabouts products and activities aimed at a variety of intended audiences, reflecting the range of stakeholders engaged in the process of transportation decisionmaking.

Audiences for FHWA resources vary and include a broad array of stakeholders. Earlier audiences for the roundabout research products included internal FHWA partners, researchers, academics, private consultants, and professional associations, plus staff and leadership at early-adopter States and local public agencies. As roundabout research results demonstrated conclusive and significant safety benefits, Safety R&D's partners at FHWA headquarters offices and the Resource Center engaged primary audiences on the subject, including staff and leadership at State transportation departments and local public agencies and Division Office safety specialists.

The following are six categories of the roundabout products developed for each audience:

- **Researchers:** roundabout safety evaluation data, roundabout safety and operational research.
- **Consultants:** roundabout safety and operational research, roundabout informational guides and other on-the-job guides/tools, case studies.
- **FHWA Division Offices:** summary presentations, case studies, technical assistance, *Roundabouts Informational Guides*, *Public Roads* articles.
- **State transportation departments management and staff:** peer exchanges, trainings, case studies, technical assistance, CMFs.
- **Local practitioners:** case studies, peer exchanges, technical manuals.
- **Elected officials and leadership:** videos, brochures/one-pagers, fact sheets.

Overall, evidence shows that FHWA's research and communication strategies were diverse and targeted to give stakeholders the basic tools to understand and raise awareness of the benefits of roundabouts, emphasizing peer learning and support for practitioners. The timing and use of lead adopters as resources for the HSA Roundabouts Peer-to-Peer Program is an example of the recognition that different States or jurisdictions within a State vary in adoption phase and the awareness of the effectiveness of peer-to-peer communication. The Office of Safety Staff and

[2]While the Roundabouts Listserv is not a FHWA-sponsored or affiliated activity, FHWA staff do contribute, and it is a forum on which roundabouts information, including FHWA products and activities, is shared.

Funding Roundabouts Peer-to-Peer Program matched peers from lead-adopter States with requests for technical assistance from States and local agencies.

Finding: FHWA research accelerated the development of design standards for roundabouts.

FHWA had a significant impact in providing the research and background used in the development of design standards for roundabouts. Roundabouts are in several national design-level publications, and FHWA's work is in four of these.

TRB's HCM is a publication that provides methodologies to estimate capacities of various highway designs.(21) A TRB committee oversees this publication that focuses on the latest techniques and research. The 2000 edition featured roundabout design work referencing six sources; four were international. Of the domestic studies, one was a FHWA-sponsored study by Aimee Flannery. The 2010 edition incorporated capacity equations from the NCHRP 572 document funded by FHWA.(21)

Beyond the 2000 and 2010 *Roundabout Informational Guide*s, additional FHWA research and funding also supported design. Task Order Project Request 34 addressed issues such as including rectangular rapid flash beacon treatment at multilane crosswalks, updating the HCM capacity model, and examining fatal and severe injury crashes. FHWA supported the Illumination Engineering Society of North America's *Design Guide for Roundabout Lighting* published in 2008 and the ITE *Enhancing Intersection Safety through Roundabouts* in 2008.(23,15)

The *Green Book*, or *2001 A Policy on Geometric Design of Highways and Streets*, was developed by AASHTO committees and then approved by FHWA via official rulemaking as the Federal policy on Highway design standards.(57) Circular intersections have been featured in the *Green Boo*k for a number of years. The 2011 edition (Federal policy as of this publication) references two sources specifically focused on roundabouts, the NCHRP 264 and the *2000 Informational Guide*, and references the HCM.(13)

In 2010, AASHTO published the first HSM.(20) This document, which was overseen by an AASHTO committee, includes methods to quantitatively measure crash frequency and severity at different locations. It includes background on human factors and fundamentals of safety, provides a management process for highway safety, includes predictive measures to model crash frequency and severity, and includes CMFs. As summarized by one FHWA interviewee, "The *2010 Highway Safety Manual* helped move toward data-driven [evaluation techniques]. There are tools now." FHWA's funding of NCHRP 572 provided crash models for the 2010 publication.(22)

FHWA's *Manual on Uniform Traffic Control Devices* (MUTCD) in 2003 mentioned roundabouts, but it made no specific recommendations.(16) The 2009 edition had significantly more guidance for marking roundabouts, which reflects the expanded need for recommendations from 2003 to 2009.(55) Safety R&D sponsored research through the Traffic Control Device Transportation Pooled Funds in 2004 and 2007, which provided content for the 2009 edition.

FHWA's *2000 Informational Guide* and FHWA-funded research around crash models and capacity equations guided traffic engineers, consultants, and other practitioners into implementing roundabouts within national design standards.

Finding: FHWA research accelerated consideration of roundabouts by the transportation research community and led to more targeted FHWA investment.

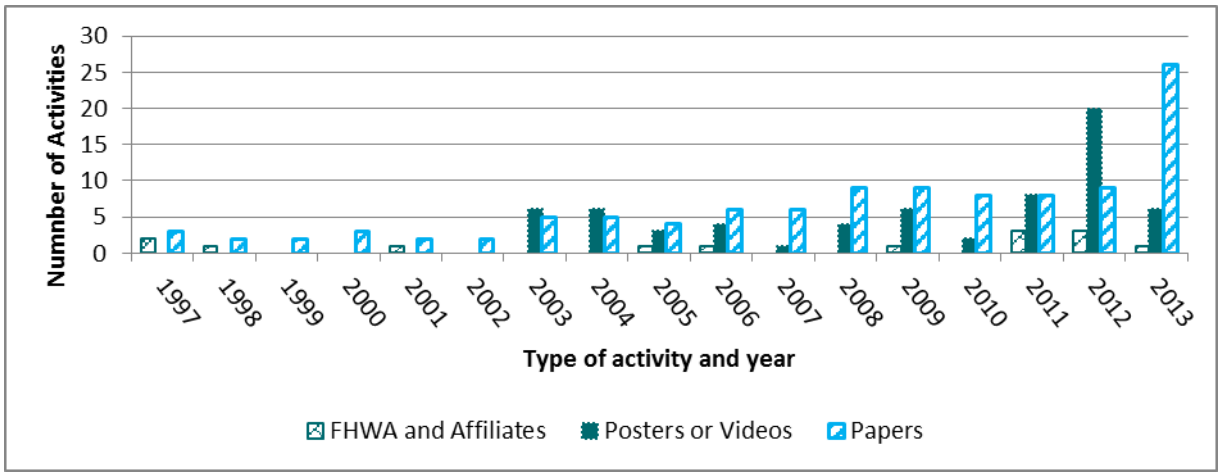
Every year, the TRB hosts its Annual Meeting in Washington, D.C. Starting in 1921, the TRB Annual Meetings now boast nearly 5,000 presentations on 750 transportation topics, and is attended by over 12,000 transportation professionals from around the world. As one method of measuring the growth of roundabout research in the United States, the evaluation team reviewed and analyzed the trend in Final Programs for select TRB Annual Meetings, which lists every presentation for each meeting.

Eugene Russell (Kansas State University) led an organizational meeting in 2003 to gather various roundabout researchers and practitioners at TRB in a subcommittee. The Roundabout Listserv was launched after that meeting.(35) The TRB Task Force on Roundabouts was formed out of that subcommittee in 2006. FHWA staff members were engaged in this committee from the beginning and were members of and contributors to the task force, subcommittee, and now the standing committee. The success of the Task Force in research, conferences, and other activities spurred by the growing popularity of roundabouts in the United States led to the approval of the Task Force as a permanent standing committee in April 2012. The Committee on Roundabouts looks to build on the groundwork laid by the Task Force to continue to promote modern roundabouts as an effective intersection treatments on the roadways of the United States and other countries:

> *The TRB Committee on Roundabouts is concerned with all factors encompassing modern roundabouts. The Committee provides focus within TRB on current issues and future research needs pertaining to modern roundabouts. It serves as a forum for discussions about roundabout research, projects, and policy for all interested stakeholders; identifies research needs and develops research problem statements to meet the needs; and facilitates the exchange of knowledge by various media, meetings, and conferences.(54)*

Figure 5 shows the number of roundabout presentations at the TRB Annual Meeting. There is a clear increase in the number of roundabout presentations. The first roundabout presentation in this study period appears in the 1997 Annual Meeting. The number of roundabout presentations steadily increases to a peak of 32 in 2013. In total, the evaluation team identified 188 roundabout presentations. The most common organizations that presented were FHWA with 13, North Carolina State University with 12, and Kittelson & Associates, Inc. with 10.[3] Presentations by Aimee Flannery were counted as affiliated given the relationship to FHWA. The data show that FHWA was among the first to present roundabout research findings at TRB and has made a recent push in presentation since the *2010 Informational Guide*.

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



Source: FHWA.

Figure 5. Graph. TRB Annual Meeting roundabout activities (1996–2013).

To assess the impact of FHWA research on the community of practitioners' understanding of the appropriate use of roundabouts, the evaluation team investigated a unique community of transportation practitioners focused on sharing information about roundabouts: TRB's Roundabouts Listserv.

In 2003, TRB Committee members created the Listserv to engage and organize information sharing in the roundabout community.[4] Members can access archived content from August 2013 through the website and any new material by email. The Listserv has strong support from the FHWA committee and is active in sharing information and discussing developments in roundabout research, adoptions, and developments. The listserv archived activity provides information about collaboration and information sharing in the roundabout community, and also about the extent to which FHWA supported that community through research. Presently, the Listserv has over 400 users.

The evaluation team analyzed available records for mentions of FHWA reports and work. The Listerv analysis showed that over one third of threads cited FHWA materials (224 out of 631). This was limited in that the evaluation team only had access to 2 years' worth of records, both quite late in the period of analysis. Still, this shows FHWA's impact on the research community as researchers informally discuss FHWA products, and often encouraged one another to use those sources.

One FHWA interviewee noted that the document review showed evidence that FHWA and its stakeholders are committed to updating key resources as information evolves. The *2010 Informational Guide* provides a significant update and expansion over the first edition. It incorporates more domestic empirical evidence and examples than the *2000 Informational Guide*, which relied nearly exclusively on international practice. The *2010 Informational Guide* also aligns with the 2010 HCM (first edition), and the 2009 MUTCD. Without FHWA's strong initial and sustained investment, roundabout adoption would "not be where it is today." FHWA's ongoing commitment across Safety R&D, the Office of Safety, and the Resource Center to researching and promoting roundabouts likely played a key role in the success of this technology. Without the continued support after the *2000 Informational Guide*, interest in and adoption of roundabouts may have lost momentum.

[4]Section 3.1 gives the history of how the TRB Roundabouts committee was started, and some of its other outputs.

As roundabouts are more accepted and mainstream, the research has been increasingly applied. There has been a transition from research and analysis to evaluating safety benefits, or from persuasion information to education, implementation, outreach, and targeted technical assistance.

Safety R&D research has focused on accessibility for disabled and vision-impaired pedestrians and general pedestrian research, as shown in the NCHRP Report 674, *Crossing Solutions and Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities.*[58] FHWA also led research to study and promote mini-roundabouts, which are roundabouts with smaller inscribed diameters and traversable centers. FHWA conducted safety and crash analyses using before and after crash histories, conflict analysis, microsimulation, and field testing. Mini-roundabouts can fit into existing intersection boundaries, expanding the applications where roundabouts can be deployed.

The success of roundabouts and FHWA's support of the technology encouraged researchers to focus on other alternative intersection designs, such as the diverging diamond intersection (DDI). Support for alternative intersection designs can be seen in the inclusion of modern roundabouts with four other intersection and interchange geometric designs as part of EDC-2.[7] Early-adopter States (such as Florida) have already begun adopting the technology and investigating its effects.

3.2 Evaluation Area 2: Change in Awareness, Knowledge, and Attitudes

Hypothesis: FHWA's contribution to the availability and reliability of safety and performance data on roundabouts. This includes safety evaluation data, and evidence of benefits.

The logic model developed for this evaluation proposes that FHWA's research increased awareness and, critically changed attitudes and increased confidence in modern roundabouts as a safety countermeasure, both within FHWA and among its stakeholders. The evaluation team found strong evidence in support of the hypotheses within this evaluation area.

According to *Towards Zero Deaths*, transportation agencies should incorporate newer concepts and methods with their existing processes, guidelines, and tools.[40] As positive results from research give agencies the data and analytical tools (and thus the confidence) to deploy them. Affirmative results also encourage FHWA to prioritize roundabouts for study and promotion. Activities such as oversight, research, development, deployment, evaluation, technical assistance, outreach, and training complement this by providing partners and stakeholders the skills and resources to understand and implement safety improvements.

While section 3.1 focuses on the change in availability of tools and data, this evaluation area asks 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. The evaluation team will seek to demonstrate this through hypotheses that assess whether FHWA roundabout products and activities contributed to changes in awareness, knowledge, and attitudes among transportation practitioners.

A summary of findings for this evaluation area overall is below, followed by more detailed analysis of the findings.

Overview of Findings

FHWA research, culminating in the *2000 Informational Guide*, increased available information on roundabouts in the United States. These products provided interested States and stakeholders with more information on how to utilize roundabouts as a safety countermeasure, and also gave FHWA's stamp to the technology. Safety R&D worked closely with the Office of Safety and the Resource Center to conduct sustained outreach on roundabouts, including making policy changes and recommendations within FHWA. In turn, this sustained outreach has shaped State policies toward roundabouts and influenced transportation professionals' attitudes toward roundabouts as an intersection alternative.

Detailed Findings Summary

Finding: FHWA roundabout research increased awareness and changed attitudes in the transportation community toward the roundabout as a safety countermeasure.

FHWA R&T's research activities from the 1990s to the *2000 Informational Guide* significantly increased published material on roundabouts in the United States, as discussed in section 3.1. The publication of the *2000 Informational Guide* began a partnership between Safety R&D, the Office of Safety and the Resource Center to market and promote roundabouts as a viable safety countermeasure. These activities increased visibility and awareness of roundabouts and their safety benefits; in addition, it has informed attitudes toward roundabouts as a safety countermeasure.

Throughout the 2000s, FHWA's increasing commitment to promoting and marketing roundabouts made clear that roundabouts were not a European oddity, but a safety technology with FHWA's "stamp of approval." The value of the FHWA brand as a mark of credibility and authority was cited by Hillary Isebrands as a reason why the 2010 NCHRP 672 revision of the *2010 Informational Guide* was co-branded with FHWA.[3]

To understand the change in awareness and attitudes FHWA activities generated, the evaluation team first cataloged the sort of outreach activities in which FHWA was engaged, 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

Unfortunately, detailed historical records of technical assistance and other means of outreach are difficult to find before 2010. Interviews with FHWA staff provided history of the involvement of Safety R&D, Office of Safety, and the Resource Center in roundabout promotion and assistance, while modern records provide a sense of the types of activities FHWA engages in and their reach.

Before publishing the *2000 Informational Guide*, most work related to roundabouts occurred within Safety R&D. Joe Bared, Wei Zhang, and other staff consulted and gave technical assistance to over 30 States and local officials seeking to install roundabouts on an ad hoc basis. Following publication of the guide, Safety R&D continued its assistance, but this work gradually moved to the Office of Safety and Resource Center team in the natural progression of the research cycle. They produced videos and other outreach materials (as detailed in section 3.1) and began providing a full-day workshop in cooperation with Safety R&D. They also provided structured assistance in the form of a roundabout peer-to-peer technical assistance program. The Resource Center and Safety R&D staff assist with planning, design, and general roundabout information. The Office of Safety offers workshops and other types of general outreach to States and municipalities.

Beginning in 2007, the Roundabouts Course was introduced into the NHI catalogue. Based on ad hoc presentations by Office of Safety, the course has been offered 14 times to 349 participants. One

version is a 1-day session presenting an overview of roundabouts, their safety benefits, and their general applications. A recent addition is a 2-day version, which focuses on in-depth technical issues and design considerations.

As part of its roundabout Peer-to-Peer Program the Office of Safety has led exchanges to encourage States with significant experience to share techniques and lessons with other interested States, an approach that helps States overcome the legacy perceptions many have with circular intersection designs. In 2010, the Northeast Roundabouts Intersections Peer Exchange was held to target States with a legacy of traffic circles and rotaries that may have delayed implementation of modern roundabouts; eight northeastern States participated.

FHWA also, when appropriate, engages in public outreach. One of the biggest challenges for new roundabouts has been public acceptance. When FHWA staff have served as technical experts in popular media, they changed perceptions of roundabouts as complicated or dangerous. A recent *New York Times* article, for instance, featured Jeff Shaw, the Intersections Safety Program Manager for FHWA, discussing the growth in popularity of roundabouts in the United States.(59)

These outreach activities introduced the transportation community (beyond researchers) to roundabouts and their benefits. However, beyond simply familiarizing States with the topic, outreach activities have helped break down initial hesitance toward circular intersections. Several interviewees commented on the general conservatism of State transportation department traffic engineers. Their work necessitates a "do-no-harm" approach that requires novel countermeasures (such as roundabouts) to meet a high standard of proof to be adopted. Particularly given the safety concerns for rotaries and other traditional circular intersections, many States were slow to consider and adopt roundabouts. FHWA's clear commitment and its research leadership into guidance, design standards and assistance, and evidence of clear benefits helped transform attitudes of transportation practitioners on roundabouts.

State Policies and Publications

This shift in attitudes is clearly demonstrated by the influence of FHWA products on State policies and publications. To measure the influence of FHWA in State highway policy toward roundabouts, the evaluation team sought references to FHWA materials in SHDMs, State roundabout guides, and State SHSPs. Increases in both the inclusion of roundabouts and references to FHWA research is evidence of FHWA research's influential role in increasing awareness and influencing attitudes toward roundabouts among its stakeholders.

In 1997, a NCHRP survey requested the source of guidelines that municipalities used to design their roundabouts. Most cities used the Maryland Department of Transportation (26 percent), Australian (30 percent), or Ourston and Doctors (22 percent) guidelines.(41) A 2003 report by the Arizona Department of Transporation, *Roundabouts: An Arizona Case Study and Design Guidelines*, detailed the state of practice for State roundabout guidelines and policy documents and explicitly references the use of the FHWA document *Roundabouts: An Informational Guide* in these early State roundabout documents.(34) Table 6 summarizes these findings.

Table 6. FHWA influence on early State departments of transportation roundabouts guidance.[60]

State	Document	Year Developed	FHWA Document	Influence
Maryland	*Roundabout Guide*[61,62]	1995, 2003	*Roundabouts: An Informational Guide*	By 2003, Maryland had replaced liberal reference to *Austroads' Traffic Engineering Practice Part 6: Roundabouts with the FHWA Informational Guide*.[63]
Florida	*The Florida Roundabout Guide*[64]	1996	--	Mark Doctor of FHWA was on the panel for this document.
New York (draft)	*Highway Design Manual Chapter 26: Roundabouts*[65]	2000	*Roundabouts: An Informational Guide*	"...largely based on the FHWA guide," with "many of the figures and tables coming directly from the guide." Used FHWA roundabout categories.
Pennsylvania	*Guide to Roundabouts*[66]	2001	*Roundabouts: An Informational Guide*	"It is designed as a supplement to aid to determining whether a roundabout is a feasible alternative for a specific location." Directs readers to the *2000 Informational guide* for information about roundabouts.[2] Used FHWA roundabout categories.
Washington	*Design Manual*[67]	2001	*Roundabouts: An Informational Guide*	"...primarily based on the principle from the informational guide." Used FHWA's roundabout categories.
Missouri	*Project Development Manual*[68]	2002	*Roundabouts: An Informational Guide*	"In most cases, the principles and dimensions are based on the FHWA guide," with some modifications specific to Missouri standards.
Kansas (then under development)	as of then, untitled[69]	under development circa 2003	*Roundabouts: An Informational Guide*	"The document should be a supplement to the FHWA guide and not attempt to reproduce all the information in that guide."

--Information not applicable.

Since 2003, there has been substantial growth in the inclusion of roundabouts in SHDMs. The evaluation team reviewed available SHDMs as of August 2015 for references to roundabouts and to FHWA roundabout design specifications. Out of 50 States, 2 manuals were irretrievable and 16 made no reference to roundabouts. Of the 32 that did make reference to roundabouts, 25 directly cited FHWA materials. State design manuals that referenced FHWA primarily cited *Roundabouts: an Informational Guide*, NCHRP 672 (co-branded FHWA and NCHRP), and the *Manual on Traffic Control Devices*.[16] Some States referenced FHWA exclusively and explicitly, while others used multiple sources in addition to FHWA resources such as AASHTO's Roundabouts Design Manual (eight States) or Kittelson & Associates (two States).

NCHRP Synthesis 488 – Roundabout Practices provides further insight into the use of FHWA design materials and performance analysis by State transportation departments.(4) The report examined State transportation department design guidance and online materials for the explicit use of FHWA design guidance. The report notes that Maryland has made explicit use of FHWA design guidance, as described in table 6. Further, the survey conducted for the report asked State DOTs to describe their level of use of FHWA roundabout design guidance. Of the 37 State transportation departments that responded, three said they do not use or rarely use the NCHRP Report 672.(3) Twenty-three States used the NCHRP Report 672 to supplement materials they have developed or to supplement materials from other sources. The remaining 11 States use NCHRP Report 672 as the exclusive source of design guidance. In addition, the synthesis found that 54 percent of State transportation departments used NCHRP Report 672's illumination guidance. For performance analysis, the results of the questionnaire to States show that 36 of the reporting States (72 percent) use at least one form of the 2010 HCM model.

Iowa's Department of Transportation design manual referenced Wisconsin's Department of Transportation (WisDOT) design manual, which demonstrates diffusion of roundabout research not only by FHWA, but also among States. The acceptance that early adopters had toward roundabouts and FHWA design specification progressed to late adopters. Florida, Maryland, and Kansas all benefited from roundabout champions early in their adoption domestically: Kenneth Todd (Maryland) and Eugene Russell (Kansas). Florida had one of the first roundabout guides. These States also took the lead in incorporating roundabouts into their State design manuals, frequently using FHWA resources to do so. Table 6 summarizes examples of this relationship.

In addition to SHDMs, the evaluation team collected and reviewed available SHSPs from the 50 States as of June 2015, identified whether a State uses or plans on using roundabouts as a safety countermeasure, and recorded the emphasis areas under which roundabouts occurred. Mandated in 2005 as a component of the HSIP, an SHSP is a statewide blueprint for reducing highway fatalities and serious injuries on public roads. States identify key safety needs and guide investment decisions toward strategies and countermeasures with the potential to save the most lives and integrate the four E's of highway safety: engineering, education, enforcement, and emergency medical services.

There were 110 State SHSPs (including Washington, D.C.) spanning 2005 to 2015. Some States published updates more regularly than others, and Ohio's SHSP was unavailable. Thirty-two of the most recent SHSPs mention roundabouts. Twelve States have never mentioned roundabouts and six cite roundabouts in 2005–2007, but not in their most recent version. Table 7 lists the States that currently mention roundabout usage in their SHSPs. For a full list of which years each State references roundabout usage in their SHSPs please refer to table 16 in appendix C.

Table 7. Roundabouts in recent SHSPs.[5]

Strategic Highway Safety Plan	States
Does not mention roundabouts	AZ, CT, FL, GA, HI, IN, IA, KY, LA, MD, MA, MI, MT, NM, OK, WA, WV, WY
Does mention roundabouts	AL, AK AR, CA, CO, DE, ID, IL, KS, ME, MN, MS,MO, NE, NV, NH, NJ, NY, NC, ND, OR, PA, RI, SC, SD, TN, TX, UT, VT, VA, WI
No data	OH

[5]Data for table 5 is from 110 SHSPs respresenting all States (including Washington, D.C., and excluding Ohio) from 2005 to 2015.

While not emphasized in any SHSP, roundabouts were included as intersection safety countermeasures. Roundabouts were cited under General Intersection Safety (28 States), Proven Safety Countermeasure (7 States), Pedestrian/Bike Safety (6 States), Speed Reduction (6 States), and Older Driver Safety (4 States).

Although some States provided more specific reasons and goals of roundabout installation, most States listed roundabouts as a one of multiple safety countermeasures. Of seven States that mentioned roundabouts as a proven safety countermeasure, five referenced the NCHRP 500 report *Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, which cites the FHWA *2000 Informational Guide*.[6](70)

In addition, 13 States noted that they plan on providing more education for the public on roundabouts. This education includes brochures, fliers, emails, website pages, and community classes.

In addition to the SHDMs and SHSPs, the evaluation team examined State transportation department websites as an indicator of roundabout acceptance and to understand how important it is to each State to communicate roundabout information to users of the site, including resources for local traffic agencies and for drivers. Among the 51 State transportation department websites (including Washington, D.C.) 32 feature information or have a standalone informational site on roundabouts. Of these, 21 have links to or use FHWA resources. These include the *2000 Informational Guide,* the *2010 Informational Guide*, NCHRP 572, NCHRP 672, FHWA's roundabouts webpage, FHWA's roundabout brochures, FHWA Technical Summary, and FHWA videos. (See references 2, 3, 22, 10, 71, 55, and 72.)

In recent years, many States have adopted policies that encourage consideration of roundabouts for new intersections. NCHRP Synthesis 488 reported on and updated the results of a 2010 review of State roundabout policies and found that out of 50 States and Washington, D.C., 42 had some type of roundabout policies.(4) Of those, 11 formally require analysis of roundabout alternatives, and another 19 States encourage this analysis, with 5 requiring justification for using a non-roundabout intersection control method. Some States use Intersection Control Evaluation policies, which increased the number of roundabouts evaluated.

The 2016 NCHRP Synthesis 488, *Roundabouts Practices*, included a review of publicly available roundabout information on State transportation department websites, and categorized State roundabout policies into five types based on the degree of roundabout consideration required by agencies within the State.(4) Of the 50 States and Washington, D.C., 7 States had no policy or mention of roundabouts, a decrease from 2010. These seven states were Alabama, Idaho, Mississippi, North Dakota, Oklahoma, West Virginia, and Wyoming. Thirteen States explicitly allowed roundabouts, while 18, the plurality, explicitly encouraged roundabouts where applicable. The 18 states that encourage roundabouts include states such as Indiana, Massachusetts, Michigan, Nevada, Ohio, and Oregon. There are also eight states categorized as evaluating roundabouts, and five states that prefer using roundabouts. The five states that prefer the use of roundabouts are Alaska, New York, Rhode Island, Vermont, and Virginia.

Finding: FHWA roundabout research influenced the attitude of other FHWA programs toward roundabouts as a safety countermeasure.

[6]A number of FHWA staff are thanked in the acknowledgements of this document as well.

Two changes regarding the funding and consideration of roundabouts were adopted by FHWA and the U.S. Department of Transportation (USDOT) to encourage State construction of modern roundabouts. The first was the addition of roundabouts to the list of safety projects eligible for 100-percent reimbursement from FHWA. The second was the adoption of Roundabouts as a Proven Safety Countermeasure by FHWA. Both demonstrate FHWA's support of roundabouts.

Up to 10 percent of a State's Federal aid grant may be spent on safety projects eligible for 100-percent Federal reimbursement. Typically, an interstate highway project is reimbursed at 90 percent of cost; other projects are reimbursed at 80 percent. These safety projects are known as eligible for the "G" matching ratio and are listed explicitly in the authorizing highway legislation under 23 USC 120(c).(73) Projects include a wide range of improvements (e.g., highway rest areas) and have been included since the Intermodal Surface Transportation Efficiency Act in 1991.(74) Importantly, these projects are eligible for higher reimbursements, which is not guaranteed. Project reimbursement is decided by Division offices in coordination with State transportation departments.

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) reauthorization of 2005 added the following to the list of the 100-percent eligible safety projects: "traffic circles" (also known as roundabouts).(17) With this inclusion, all Federal-aid or HSIP roundabouts projects became eligible for 100-percent Federal reimbursement.

The evaluation team was not able to determine the specific motivation for the inclusion of roundabouts into SAFETEA-LU. Interviewees at FHWA were not able to identify nor recall the origin of this language, and neither were interviewees who were members of the roundabout research community. Searches of the Congressional Record and SAFETEA-LU Conference Committee report did not yield the rationale for the language's inclusion. No evidence points to a specific member of Congress for including the language in SAFETEA-LU; it is unclear if FHWA advocated for this inclusion.(17)

The timing of this inclusion, in 2005, follows significant investment by FHWA in roundabout research, including the *2000 Informational Guide*, which had publicized roundabouts as a safety intervention by the time SAFETEA-LU language was adopted.(17) Regardless of its origin, one FHWA interviewee noted that this policy was useful in demonstrating both Federal commitment to roundabouts as a safety improvement and in encouraging States to pursue roundabouts as a safety alternative.

A July 10, 2008, memorandum from the FHWA Associate Administrator of Safety designated eight highway safety improvement techniques as "Proven Safety Countermeasures" and included modern roundabouts as one of the eight.(23) 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 discuss possible roundabout implementation. Roundabouts were one of two 2008 countermeasures chosen for the second round of Proven Safety Countermeasures in 2012.

Proven Safety Countermeasures were 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 for roundabouts, and strongly encourages States to at least consider the literature on their safety benefits.

The coordination involved in choosing roundabouts as a safety countermeasure reflects of the close cooperation between Safety R&D, the Office of Safety and the Resource Center. These offices have collaborated for 20 years to help interested States, to publish a wide variety of materials on roundabouts, and to firmly establish roundabouts as an FHWA priority. The result of this approach is

diminished skepticism of the efficacy and usefulness of roundabouts among States and other stakeholders.

3.3 Evaluation Area 3: Adoption of Roundabouts as a Safety Countermeasure

Hypothesis: FHWA's contribution to the availability and reliability of safety and performance data on roundabouts, including safety evaluation data and evidence of benefits.

The logic model developed proposed that FHWA activities helped accelerate early adoption of roundabouts, thus influencing the upsurge in the number of roundabouts 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 roundabouts not funded directly by FHWA programs was not possible.

Beyond affecting the awareness, availability, and reliability of roundabout research for the broader transportation community, FHWA activities influenced the adoption of roundabouts. To understand the role FHWA played in roundabout deployments, the evaluation team used the most comprehensive inventory of roundabouts built in the United States available, and connected roundabout construction with FHWA activities in early-adoption States against those States who sought FHWA assistance later. Using information about Federal funding, FHWA publications, and the comprehensive roundabout 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 roundabouts by considering the timing and type of intervention in each State, drawing from relevant theories in the diffusion literature. Further building on the analyses in sections 3.1 and 3.2, this evaluation also demonstrates how FHWA leadership in research and promotion of roundabouts as a safety countermeasure led to the consideration of roundabouts, accelerated their adoption, and contributed to growing the number of roundabouts.

A summary of findings for the overall evaluation area is presented next, followed by a more detailed analysis of each related hypothesis. Where it made sense, the evaluation team grouped related hypotheses for the discussion.

Overview of Findings

FHWA actively accelerated the early adoption of roundabouts by leading the promotion of roundabouts, developing safety and performance research, and specifically addressing the needs of the earliest adopters. FHWA activities and research increased the total number of roundabouts through continued agency funding and activity, producing further research materials, promotion, assistance, and funding. FHWA research aimed at increasing the availability of design specifications and standards augmented the resources available for States to use in creating their own design standards and implementing roundabouts.

Funding provided under programs designed to increase safety and traffic-flow improvement and environmental benefits provided continued support to the earliest and most confident adopters, while providing reinforcement for late adopters. The HSIP and Congestion Mitigation and Air Quality Improvement (CMAQ) Program are two examples of such programs.

Despite the widespread increase and acceptance of roundabouts, the rate of adoption of roundabouts in the United States appears to have slowed. This is despite the United States already being behind many European and other countries in the proportion of roundabouts to traditional intersections. Still, negative public attitudes and high initial capital costs remain barriers to adoption.

Detailed Findings Summary

Finding: FHWA accelerated early adoption and contributed to an increase in the number of roundabouts built in the United States.

FHWA accelerated and supported the growth in roundabout deployment with activities that helped agencies overcome barriers. The success of the growth in roundabouts may be attributed to the confluence of multiple factors: the coordinated efforts of multiple leaders (as described in section 3.2), the characteristics of roundabouts, and the operational and safety performances of roundabouts. In section 3.4, the evaluation team explores the effectiveness of roundabouts as a safety countermeasure, relative operational performance, and relative reduction of environmental impacts compared with traditional signalized intersections, and finds that roundabouts are more effective.

FHWA's products and outreach address obstacles States face in adopting roundabouts. As FHWA and the broader roundabouts community have promoted their work, roundabouts have seen an explosion of adoption in the United States. In some cases, FHWA funding sources have been used directly to further the pace of this adoption.

States and municipalities faced many obstacles to adopting roundabouts. Initially, States were reluctant to adopt a novel technology without sound backing from authoritative sources. In general, roundabouts suffer from public skepticism and opposition, and local drivers require time to become accustomed to them. On a broader scale, many States with historic traffic circles face larger hurdles in convincing traffic engineers and the public that modern roundabouts are a credible alternative.

The earliest adoptions were driven by champions within local and State agencies and by contractors (e.g., Nevada, Colorado, and Maryland). By 1995, 12 States had adopted a roundabout. As described by Rogers, these early adopters can be characterized as innovators, adopters who have an ability to deal with the high degree of uncertainty, both financial and operationally, associated with the construction of roundabouts. These innovators required minimal support and partnership, and relied on international sources and internal expertise.

Through activities such as the international scanning tour and technical advisory contributions to State roundabouts designs (Florida's *1996 Roundabouts Guide*), FHWA provided expertise and experience with the technology that contributed to roundabouts use.[64] Fourteen additional States adopted their first roundabout between 1996 and 1999. The work published by Joe Bared, the studies funded by FHWA, and the partnership with early adopters (Maryland and Florida) reinforced the benefits of roundabouts to early adopters.

In 1997, NCHRP surveyed all U.S. States regarding the use of roundabouts.[43] Forty-four States responded, and 9 reported that roundabouts were in operation, under construction, or in design, with 38 operating roundabouts. Major incentives were increased safety, shorter delays, lower costs, and enhanced aesthetics. Sixty-six percent of all respondents reported at least one of these. Overall the impacts of these roundabouts were positive; 73 percent of respondents indicated that vehicle delay, capacity, and safety had improved. All respondents reported that they were satisfied, and 79 percent said they were planning more roundabouts.

Although the general consensus toward roundabouts was positive in the 1997 survey, only 38 roundabouts were operational in the entire United States. Many States with no roundabouts provided numerous reasons why. Major concerns included uncertainties of efficiency, safety, and liability, and fear that drivers would not adapt. Other worries were difficulty of adequate signage, resistance of politicians and public, uncertainty about appropriate applications, and construction logistics. Some of these concerns might have been resolved had more research and information on roundabouts been available. Indeed, several respondents indicated that they would like more performance results of existing roundabouts, or that they were awaiting more guidelines from FHWA. This open reliance on FHWA and other authoritative transportation bodies (such as AASHTO) reflects the characteristics of the majority, who rely on outside influence and take longer to adopt.

FHWA activities that followed are detailed in sections 3.1 and 3.2, and very likely provided the FHWA stamp of authority that States needed. FHWA activities and outputs increased from 1997 onward, culminating in the *2000 Informational Guide*. FHWA research and engagement grew, and activity by the broader community of researchers and practitioners did as well. Table 8 presents the history of roundabouts deployment with the cumulative number of roundabouts built to date and the major research or activity that occurred. Looking in the years following the publication of major FHWA milestones, particularly the 2000 Informational Guide, the number of roundabouts built per year grew dramatically. A poster from the 4th International Conference on Roundabouts depicted maps of the adoptions by State in 2000 and 2013.[75] FHWA's activities helped provide the impetus to break through State barriers to adoption.

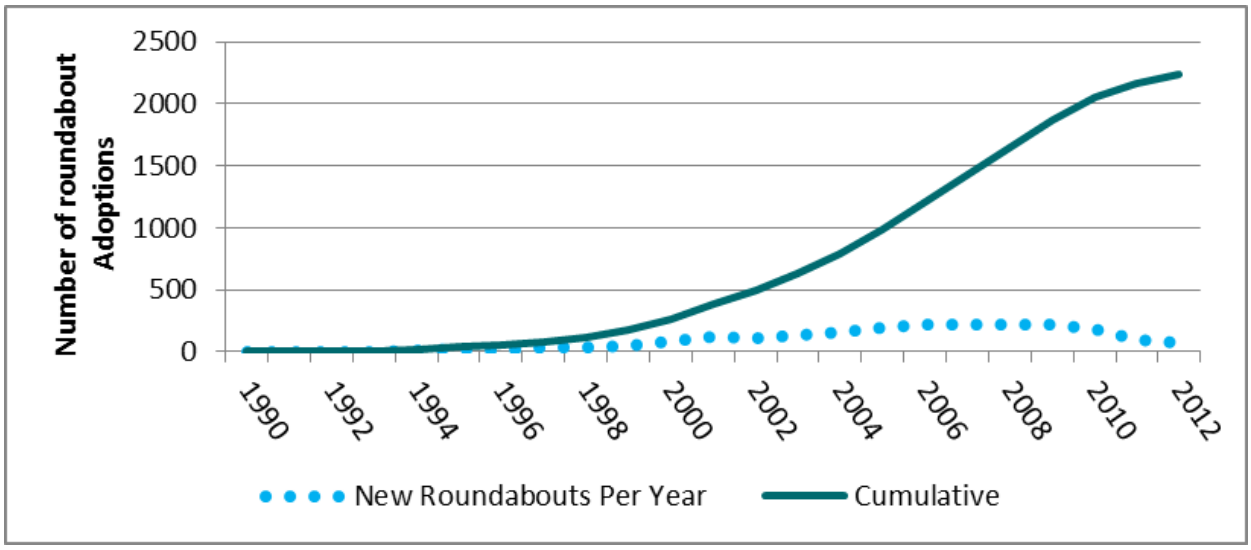
Table 8. Roundabouts built in the United States and major publications or events.[8]

Year	Roundabouts in the United States	External Milestone	FHWA Major Publications or Events
1990	2	First roundabout constructed (Summerlin, NV)	--
1991	4	--	--
1992	9	--	FHWA International Scanning Tour[9]
1993	12	--	--
1994	20	--	--
1995	40	Vail Colorado and MDSHA roundabouts constructed	--
1996	51	FL *Roundabouts Guide*[64]	--
1997	82	NCHRP 264[13]	--
1998	119	--	NCHRP Synthesis of Highway Practice 264: *Modern Roundabout Practice in the United States, State-of-the-Art Design of Roundabouts*[13]
1999	173	--	--
2000	262	--	FHWA's *Roundabouts: An Informational Guide*[2]
2001	382	--	--
2002	495	--	--
2003	627	Ongoing publication of studies on safety of roundabout installations; TRB Task Force founded	--

Year	Roundabouts in the United States	External Milestone	FHWA Major Publications or Events
2004	790	Publication of WisDOTdesign guidance	--
2005	992	--	SAFETEA-LU signed into law (100-percent eligibility for roundabouts)[17] HSIP
2006	1,210	TRB Task Force becomes subcommittee	--
2007	1,433	--	NCHRP Report 572: *Roundabouts in the United States, Federal Lands Highway Program installs first roundabout for a National Park Service at Golden Gate National Park* [22]
2008	1,653	--	FHWA declares the modern roundabout a proven safety countermeasure
2009	1,871	--	--
2010	2,055	--	NCHRP Report 672: *Roundabouts: An Informational Guide, Second Edition*[3]
2011	2,159	--	--
2012	2,235	--	2012 Proven Safety Countermeasures, TRB Roundabouts Subcommittee becomes standing committee, Roundabouts included in EDC-2 under Intersection and Interchange Geometrics[25]
2016	3,200	--	--

--Information not applicable.

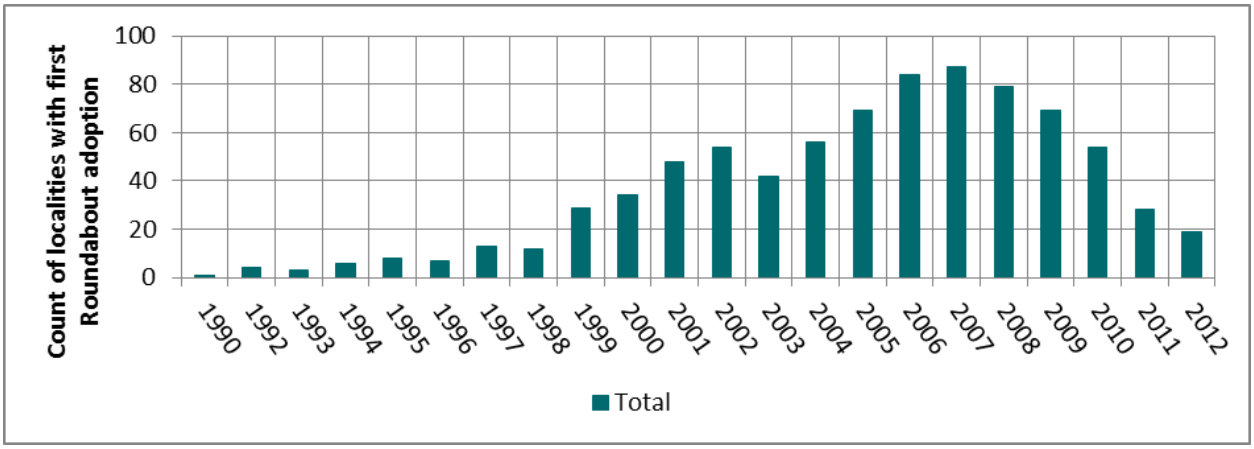
Table 8 and figure 6 show the cumulative and yearly growth of roundabouts, highlighting the boom of installations in the 2000s. Interviews with staff at Kittelson & Associates and at FHWA attribute the drop in growth seen in the last 2 years as reflecting limitations in the latest data, not a true downturn.



Source: FHWA.

Figure 6. Graph. Cumulative and annual growth of roundabouts.[8]

The first round of adoptions required indications of a promising technology, the next round required FHWA's authoritative stamp, and many required more consistent messaging and outreach by FHWA staff. Figure 7 shows the number of localities deploying their first roundabout by year. This provides a closer look at the consideration and acceptance of roundabouts than a State level would. By 2006–2007, there is a peak in the first deployment, and so growth in the cumulative deployment of roundabouts thereafter is driven by agencies with roundabouts. At this time, FHWA changed outreach strategies and focused its attention on States that may still be opposed to or uninformed about roundabouts through peer-to-peer exchanges and technical assistance, the EDC-2 Program, and NHI trainings.



Source: FHWA.

Figure 7. Graph. Count of localities with first roundabout adoption.[9]

[8]Additionally, there are more than 450 roundabouts without any year data.

[9]Table 12 in appendix A shows the year of first adoption and the total present number of roundabouts for each state.

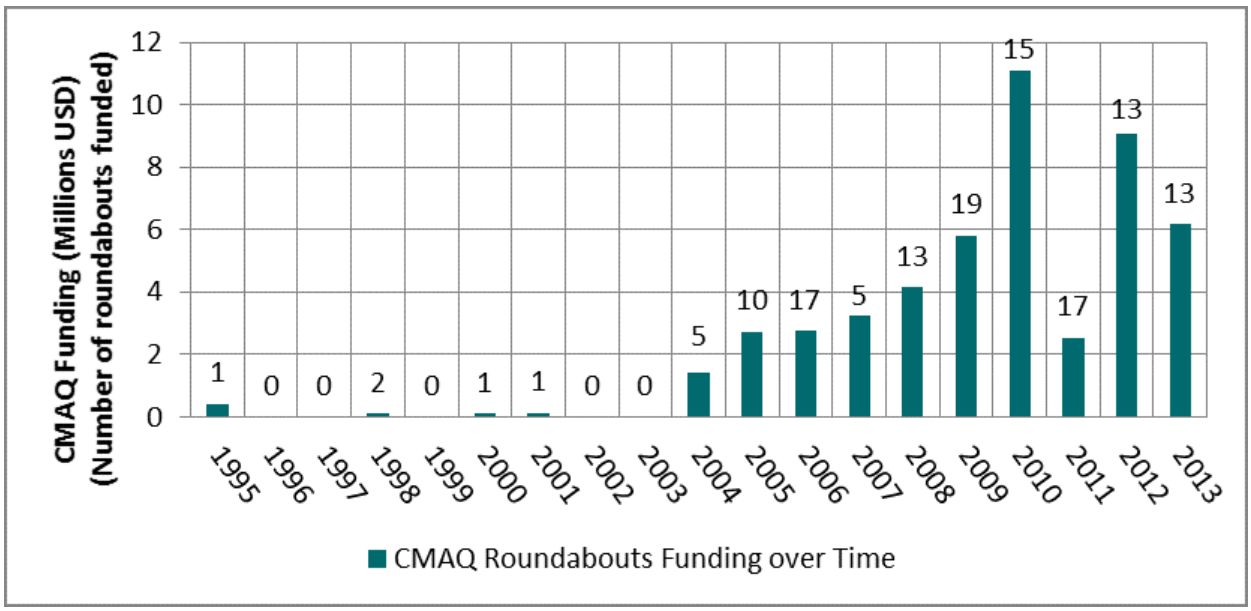
For later adopters, FHWA outputs and activities were consistently offered, allowing agencies to explore roundabouts at their comfort level. In New England States and New Jersey, which had historically negative experiences with rotaries, the Resource Center focused on overcoming those barriers by providing trainings and involving States in peer-to-peer interactions. FHWA staff encountered confusion about circular intersections and worked to eliminate false perceptions and clarify the differences between a roundabout and a traffic circle. In some cases this was particularly difficult because of the high cost and publicity of removing perceptions about the latter.

FHWA's efforts may have contributed to roundabout adoption by the late majority. Expanded funding eligibility of roundabouts under SAFETEA-LU plus their inclusion in CMAQ-eligible projects contributed to roundabout growth as well. These funding sources helped States already using roundabouts to keep deploying them, and contributed to consideration by States that were less confident by making deployment more cost effective.

The Congestion Mitigation and Air Quality Improvement (CMAQ) Program is an FHWA-administered program established in 1991 as part of the Intermodal Surface Transportation Efficiency Act and later reauthorized under two other bills through the present.[10](76) The program aims to support surface transportation projects that improve air quality and relieve congestion. The CMAQ *Policy and Guidance* explicitly names roundabouts for traffic-flow improvement.(77) Using roundabouts to improve air quality indicates FHWA's effectiveness in intra-agency communication about roundabouts benefits. The evaluation team finds further evidence of FHWA's support for deployment in the number of roundabouts receiving funding through CMAQ.

Between 1995 and 2013, 132 projects including roundabout renovation or construction received nearly $50 million in funding from CMAQ. These projects ranged from simple renovations that costed $10,000 to projects that included the construction of multiple roundabouts planned at over $3,000,000. Figure 8 shows the total CMAQ roundabouts funding per year in million U.S. dollars and the total number of roundabouts that CMAQ funded in that year. CMAQ roundabout funding starts to rise in 2003 and reaches a peak of over $11 million in 2010. The increased later spending could also have been a function of the 2009 American Recovery and Reinvestment Act (which provided $27 billion for road construction and repair).(78) Overall, CMAQ funding for roundabouts for environmental improvement has increased significantly since 2003.

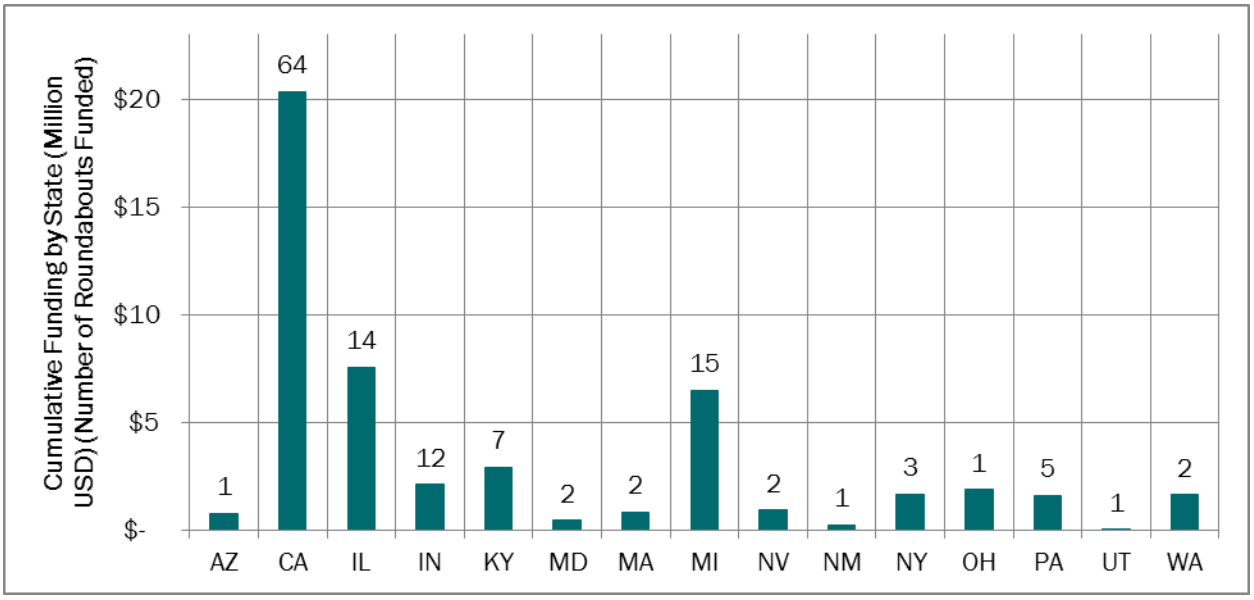
[10]Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240) established the CMAQ program. In August 2005, CMAQ was reauthorized and expanded under SAFETEA-LU such that 100 percent of funding was grantedto roundabout projects under Section 1947. Most recently, the CMAQ program was reauthorized in 2012 by MAP-21, which maintains the full funding expansion of SAFETEA-LU.



Source: FHWA.

Figure 8. Graph. Total CMAQ roundabout funding and number of roundabouts built.

Figure 9 shows cumulative CMAQ roundabouts funding by State between 1995 and 2013. In total, 15 States have received some funding for roundabout projects. California has received the most, with over $20 million. Ohio, Illinois, and New York adopted their first roundabout after 2000. Funding availability likely increased demand for roundabouts given their limited exposure and usage of roundabouts prior to 2004.



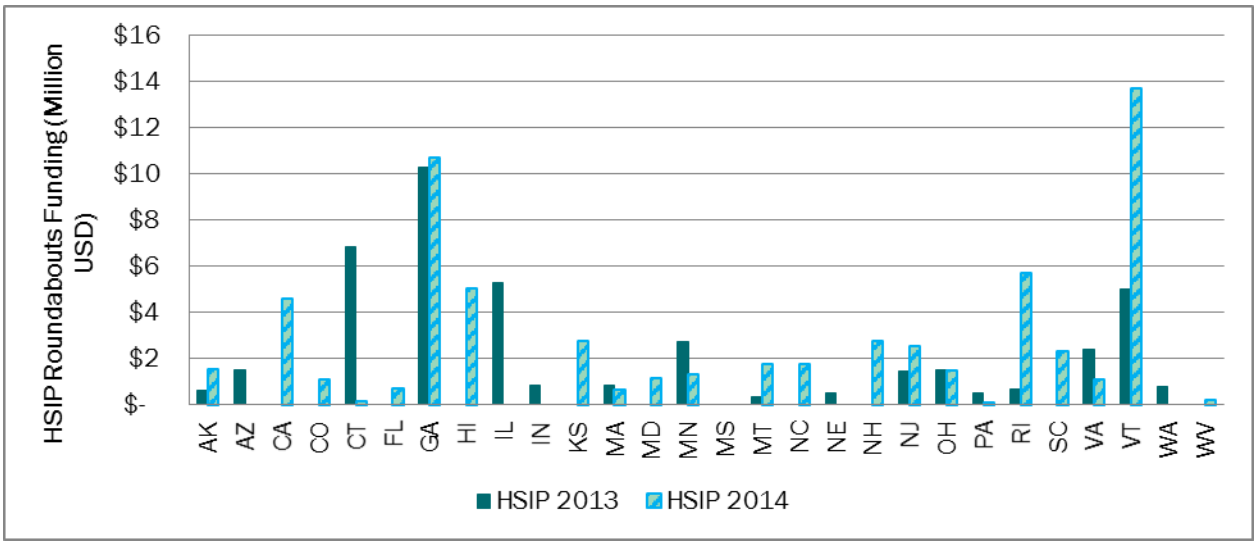
Source: FHWA.

Figure 9. Graph. Cumulative CMAQ roundabout funding by State (1995–2013) and number of roundabouts funded.

In addition to CMAQ, FHWA offered funding through the HSIP. HSIP was established in 2005 as a core Federal program by SAFETEA-LU, and was continued through MAP-21 in 2009. Together with CMAQ, the funding data show how roundabouts have become well-established safety countermeasures in terms of funding and implementation; the sustained spending in recent years verifies the effectiveness of FHWA intra-agency communication.

HSIP spending covered 100 percent of the costs for 71 roundabout projects from 2013–2014, and covered roughly 65 percent of the funding for the remaining 42 roundabouts projects. Total HSIP funding for roundabouts increased from approximately $42 million in 2013 to $63 million in 2014.

Figure 10 shows the total HSIP funding for roundabouts by State and year. Six States (Connecticut, Georgia, Hawaii, Kentucky, Michigan, Montana, and West Virginia) used such HSIP funding for roundabouts despite not incorporating roundabouts as a countermeasure in any SHSP. Four States (Arizona, Florida, Indiana, and Massachusetts) received funding for roundabouts in 2013–2014, without roundabouts in their most recent SHSPs.



Source: FHWA.

Figure 10. Graph. HSIP spending per State (2013–2014).[11]

It is possible, but unlikely, that consideration of roundabouts as a traffic-flow or safety solution by local and State officials was driven exclusively by funding availability. Making funds available creates or limits options for local and State governments seeking outcomes, not necessarily solutions. Capitalizing on HSIP and CMAQ funding does not necessarily imply that a given roundabout would not have been otherwise built.

Twenty-three States built their first roundabout during or after 2000. Of those, 10 received HSIP funding for a roundabout and to date have built fewer than 30 roundabouts. Two others have more than 80 roundabouts each. This suggests that FHWA funding support increased the consideration and implementation of roundabouts in States not otherwise constructing them.

[11]Table 13 in appendix A provides the number of projects as well as the total funding amounts.

Eleven of the 15 States that first adopted roundabouts prior to the NCHRP 264 report used funding from HSIP in 2013 to 2014.(13) This shows that the availability of funding also continues to play a role in the adoption of roundabouts in States with abundant roundabout experience.

Beyond FHWA's continued research and funding to date, FHWA also increased the number of roundabouts through targeted assistance and communication from Safety R&D, the Office of Safety, and the Resource Center. As discussed in section 3.2, FHWA remains committed to engaging with local and State traffic agencies (since its *2000 Informational Guide*). Two activities have considerably influenced State and local agencies' consideration of roundabouts: the roundabouts workshop and training (by FHWA staff and NHI) and the Peer-to-Peer Technical Assistance and Exchange Program. Late adopters, such as Ohio, Pennsylvania, Kentucky, and Illinois, have benefited from the NHI trainings. Of the 30 States with fewer than 30 roundabouts deployed, 20 have been a part of the peer-to-peer assistance training.[12](36)

FHWA targeted States with the highest potential for safety benefits based on how States assess their own levels of risk. Further FHWA research focused on data-driven analysis of safety by using the HSM 2010 models to assess safety potential. When States were directly seeking assistance for specific sites, roundabouts were consistently a solution because of their safety.

The Resource Center sought to move agencies from skepticism about whether roundabouts were safe, operationally efficient and different than other circular intersection designs, to consideration about whether roundabouts were appropriate to satisfy agencies' needs, and finally to adoption. Agencies don't want to change an intersection and do more damage, particularly without Federal data, and FHWA alleviated liability concerns and "gave cover" to agencies. One FHWA interviewee noted that agencies need someone who "has their back," and in many cases FHWA leadership and investment in initial products provided that necessary confidence.

FHWA staff shared that that the vast majority of stakeholders now know what roundabouts are; the challenge is communicating that their benefits of roundabouts are broader than unique situations. Staff hold the position that not only are roundabouts a solution, however, as put by one FHWA interviewee, "You need to provide reasons why you're not doing it." FHWA has provided the research and tools to move States and agencies past the barriers and obstacles they face when adopting roundabouts, and has seen a concomitant widespread adoption of roundabouts.

Finding: Initial capital costs and public attitudes remain barriers to roundabout adoption.

In recent years, the rate of growth in adoption of roundabouts has slowed despite the fact that the United States still is behind many European and other countries in the number of roundabouts as compared with traditional intersections. There appear to be two major barriers to adoption: negative public attitudes and high initial capital costs.

Many adopters have faced significant opposition from the public. One roundabout expert interviewed said of local feedback that "…our chief of police [said] 'if I'm chasing a suspect at 100 mph I don't want a roundabout,'" and that, referring to a roundabout near a school, "…our athletic department was against it… saying 'we'll lose fans,' or 'people won't send kids to a place with roundabouts.'"

In interviews and a survey conducted of FHWA Division Offices and State transportation departments for the 2013 Evaluation of the Office of Safety Intersection Safety program, many respondents noted that public opposition was a challenge in moving forward with roundabout adoption. Many noted

[12]Internal data provided by Kittelson & Associates.

strong resistance to roundabout adoption, and encouraged Office of Safety to continue outreach efforts to publically emphasize the safety benefits of roundabouts.[49]

In this case, committee agencies or States engaged the public with awareness and information campaigns. FHWA staff participated in public meetings and participated in sessions of local government. NCHRP Synthesis 488 reports 77 percent of surveyed States as developing a roundabouts website, 85 percent developing a flyer or pamphlet, and 54 percent have developed a roundabouts video.[4] The extent to which these were successful or necessary may have affected whether a State or local agency considered additional roundabouts or roundabouts funding for local governments. FHWA gave local and State agencies ways to handle an oppositional public by gathering best practices in a 2013 release with the Montana Department of Transportation called Information Education Synthesis on Roundabouts.[79] Washington State Department of Transporation has a website focused on public opinion of roundabouts directed at drivers, providing survey research showing that the public warms to roundabouts following installation.[80] The Office of Safety Intersection Safety Program also provides a Roundabout Outreach and Education toolbox that allows users to browse by a number of attributes, including roundabout complexity, implementation stage, target audience, geographic region, and outreach strategy.[38]

Still, it is clear that States continue to face opposition from the public and from local elected officials when attempting to install roundabouts, despite the demonstrated safety benefits. NCHRP Synthesis 488 survey respondents reported that 78 percent of respondents “seldom” or “never” install a roundabout as a response to a State elected official, and few respondents indicated that they frequently install roundabouts in response to requests from residents.[4] Many threads of the Roundabouts Listserv have been and continue to be devoted to the discussion of negative news articles or public reaction to roundabouts, as well as promoting positive reactions to roundabouts to counteract negative public reaction.

High roundabout capital costs represent another barrier to adoption. The NCHRP 488 survey of State transportation departments reported that, when considering building a roundabout, very few States reported lower initial capital costs as a reason to build a roundabout (with 69 percent reporting “seldom” or “never”).[4] While mini- and single-lane roundabouts do not require traffic signal equipment and therefore intuitively have less capital and operating expenses than a traditional intersection, high planning costs have made roundabouts frequently more expensive than traditional intersection forms. One FHWA interviewee, described a concern that roundabouts appeared to be too costly—in many cases they were costing $500 thousand to $1 million up to double what might be expected.

NCHRP 488 respondents similarly listed very high costs associated with roundabouts planning.[4] The study authors noted that respondents may have been unclear what was meant by “planning costs,” demonstrated by the wide variation in reported costs. Panel experts were particularly concerned about the reported costs of mini-roundabouts as indicating some level of confusion regarding the definitions of either mini-roundabouts or planning costs. State respondents did report an average cost of upward of $1 million for single-lane roundabouts. The range of costs reported in that study is included in table 9.

Table 9. Reported roundabout cost by roundabout type.[4]

Cost or Number of Responses	Single-Lane Roundabout	Multilane Roundabout
Number of responses	29	25
Minimum	$100,000	$200,000
Average	$1,296,034	$2,048,000
Maximum	$5,000,000	$6,000,000

--Information not applicable.

The FHWA Intersection Safety program evaluation cited low budgets as a chief concern for State and local transportation agencies looking to adopt safety interventions. If capital costs are too high, in addition to public and possible political distrust, it can be difficult to implement roundabouts as a safety countermeasure.

One possible explanation for high roundabout costs is jurisdictions overbuilding for vehicle demand. One approach to address this was described in NCHRP Synthesis 488.[4] States can adopt a phased approach to roundabout construction where a roundabout is built for current demand and can be expanded if demand grows. There have also been State efforts to conduct low-cost roundabout intersection conversions that have a fixed, low budget. In any respect, the high planning costs associated with roundabouts present another barrier to adoption by State agencies.

While State roundabout adoption has risen dramatically in the past 20 years, the rate of growth has slowed. Even if State decisionmakers are convinced by the safety benefits for roundabouts, high capital costs and public opposition remain barriers to adoption in locations where roundabouts would be safety beneficial.

3.4 Evaluation Area 4: Safety, Operational, Environmental, and Economic Impacts of Roundabouts

Hypothesis: The extent to which the growth in the number of roundabouts in the United States contributed to improved safety, operational, environmental, and cost savings.

The evaluation team found that FHWA was responsible for some increase in the number of roundabouts in the United States. This increase in roundabout implementation led to direct impacts of increased safety, operational efficiency, and environmental improvement.

The ultimate impacts of FHWA roundabout research in the United States must include benefits derived from roundabouts installed in the United States. Roundabouts have historically been promoted chiefly as a safety countermeasure by HSA and Safety R&D, and safety benefits are the primary focus of this evaluation. The safety benefits of roundabouts are defined as fewer crashes and reduced crash severity compared with the rate of crashes and crash severity at traditional intersections. Roundabout advocates also point to operational performance benefits of increased throughput compared with traditional intersections. Roundabouts have also been promoted as "greener" than traditional intersections. Roundabouts (in part due to increased throughput) claim to

improve automotive emissions relative to traditional intersections and improved landuse relative to same.

This evaluation does not include a thorough accounting of the benefits of roundabouts in the United States. However, to the extent that roundabouts have been installed because of FHWA's research and promotion, any benefits that accrue from them are at least partially attributable to FHWA.

A summary of findings for this evaluation area overall is presented next, followed by more detailed analysis of each related hypothesis. Where it made sense, the evaluation team grouped related hypotheses for discussion.

Overview of Findings

FHWA's promotion of roundabouts in the United States resulted in an increase in the number of roundabouts in the United States. Although evaluating the complete extent of safety, environmental, operational, and lifecycle cost impacts of the roundabouts installed because of FHWA's influence is beyond the scope of this evaluation, the evaluation team's review of the literature confirms significant benefits from installing modern roundabouts in place of traditional intersection controls. Any roundabout adoption influenced by FHWA likely reduced emissions and improved operational flow, and continues to do so. Most importantly, FHWA's successful promotion of roundabouts has resulted in increased adoption, and consequently has reduced the frequency and severity of crashes at U.S. intersections, which has decreased serious injuries and fatalities.[13] A rough calculation of the safety effect of roundabouts installed in the Unites States between 1990 and 2014 concludes that roundabouts averted between 38,000 and 53,000 crashes, with a societal cost savings of over $9 billion in that period. This estimate is likely conservative when considering the total social impact of roundabouts, as this does not include environmental and operational benefits. Furthermore, the Kittelson & Associates database likely underestimates recent roundabout construction. While FHWA cannot claim direct responsibility for this, their continued research and promotion of roundabouts has had a significant, positive impact on roadway safety in the United States.

Detailed Findings Summary

Finding: The literature demonstrates significant safety benefits of roundabouts.

FHWA rates the quality of supporting research for various safety countermeasures using CMFs[14] to accurately compare countermeasures and to inform stakeholders. CMFs are point values that express the fraction of crashes expected to occur following the deployment of a safety countermeasure. FHWA has reviewed eight roundabouts studies that form the basis of the roundabout safety countermeasure CMF. These studies are briefly described below.

The first major U.S. study on the safety benefits for roundabouts was performed by Safety R&D by Aimee Flannery and Tapan Datta in 1996, which studied six early U.S. roundabout installations. They found crashes were reduced by 60–70 percent at all but one site.(41) One of the most notable studies on roundabout safety is a frequently cited 2001 study (sponsored by Insurance Institute for Highway Safety) that found a 90-percent reduction for fatal crashes in intersections converted to roundabouts, an 80-percent reduction in injury crashes, and a 40-percent reduction overall.(81) This study evaluated 23 roundabout conversions in the United States. A follow-up study was performed in 2012 by Frank Gross; it focused exclusively on conversions from signalized intersections in urban and suburban areas (as the earlier study had included stop-sign intersections as well). This study found a total crash reduction of 21 percent (CMF of 0.792) and an injury reduction of 66 percent

[13]It should be noted that some improperly designed roundabouts have increased crash frequency.
[14]See section 3.1 for a more detailed description.

(CMF of 0.342).[82] These studies have found that benefits diminish as average daily traffic increases, though they still find consistent improvements in all cases.

Studies performed with simulation software specified which instances roundabouts can provide the most benefit and identified traffic conditions and weather conditions where safety benefits are most likely to occur.[83] Studies have also been performed on bicyclist and pedestrian safety. A 2002 study found that roundabouts held promise for reducing pedestrian injury, although later studies found challenges for vision-impaired pedestrians.[84] A study on bicyclists in Belgian roundabouts found crash reductions for overall traffic, but poor outcomes for bicyclists.[85] NCHRP 572, *Roundabouts in the United States*, conducted a meta-study of roundabout safety data, resulting in a collection of five-star rated CMFs, demonstrating certainty in the benefit of roundabouts on intersection safety.[22] FHWA partially funded this study.

The quality of the CMF ratings ensure that inferences made using these data are valid. The evaluation team estimated the safety benefits of current roundabout deployment across the United States to assess the impact of FHWA's research and awareness efforts. The total safety performance benefits were calculated using external data on deployment and an average estimate of crash reduction (from eight studies). It is unclear how many roundabout deployments can be credited in whole or part to FHWA research and outreach (particularly those built prior to research efforts).

However, the potential for bias exists for these studies. Bias could occur from the selection of a roundabout for a study due to a number of factors. For instance, bias could be introduced because the intersections studied could have been selected for roundabout conversion because the previous design was particularly dangerous. The roundabouts selected for these studies may have been installed because the previous intersection design was known to carry significant safety risk. If so, there may have been other intersection designs that would have had the same safety impact as roundabouts. NCHRP Synthesis 488 reported that 61 percent of roundabouts were installed at locations that had previously experienced one or more fatal crashes.[4] If intersections converted to roundabouts had systematically experienced more fatalities prior to conversion, evaluating the resulting roundabouts would lead to an overestimate of crash reduction for the average intersection conversion. It is possible that the safety impacts of roundabout conversion will have diminishing returns as the most dangerous intersections are converted first. In addition, some roundabouts may have been used in multiple studies causing oversampling and potentially introducing bias.

An equal-weight average of the eight studies results in a pre-conversion intersection having an expected 2.73 injuries or fatal crashes and 6.56 PDO crashes per year, and a post-roundabout-conversion intersection having an expected 0.66 injuries or fatal crashes and 4.57 PDO crashes. This translates to a CMF of 0.24 for injury or fatal crashes (reduction of 2.07 crashes per year), and 0.70 for PDO crashes (reduction of 1.99 PDO crashes per year). For example, the standard error of injury or fatal crash rate before roundabout installation was 0.131 crashes per year, and a range of 2.47 to 2.99 using 2 standard deviations. The injury or fatal crash rate after roundabout construction is estimated to be between 0.60 and 0.72.

High and low approximations were calculated for the number of injury and fatal crashes prevented per roundabout. The high approximation was calculated by subtracting the upper limit (2 standard deviations above the average) of the pre-roundabout crash rate from the lower limit (2 standard deviations below the average) of the post-roundabout conversion. The low approximation was calculated by subtracting the lower limit (2 standard deviations below average) of the pre-roundabout crash rate from the upper limit (2 standard deviations above the average) of the post-roundabout crash rate. Thus, the evaluation team estimated that an average roundabout prevents between 1.74 and 2.39 injury or fatal crashes per year. Using the same method for PDO crashes, the average roundabout prevents between 0.48 and 3.49 PDO crashes per year.

Table 10 shows the estimated number of crashes prevented by roundabouts from 1990 to 2014. The evaluation team estimates that roundabouts prevented 38,762 to 53,242 injury or fatal crashes and 10,693 to 77,747 PDO crashes.

Table 10. Estimated number of crashes prevented by roundabouts.

Year	Cumulative Roundabouts in the United States	Injury Crashes Prevented Lower Bound	Injury Crashes Prevented Upper Bound	PDO Crashes Prevented Lower Bound	PDO Crashes Prevented Upper Bound
1990	2	4	5	1	7
1991	4	7	10	2	14
1992	9	16	22	4	31
1993	12	21	29	6	42
1994	20	35	48	10	70
1995	40	70	96	19	140
1996	51	89	122	25	178
1997	82	143	196	39	286
1998	120	209	287	58	419
1999	174	303	416	84	607
2000	265	461	633	127	925
2001	390	679	932	187	1,361
2002	510	887	1,219	245	1,780
2003	656	1,141	1,568	315	2,289
2004	831	1,446	1,986	399	2,900
2005	1,050	1,827	2,510	504	3,665
2006	1,283	2,232	3,066	616	4,478
2007	1,522	2,648	3,638	731	5,312
2008	1,748	3,042	4,178	839	6,101
2009	1,971	3,430	4,711	946	6,879
2010	2,158	3,755	5,158	1,036	7,531
2011	2,267	3,945	5,418	1,088	7,912
2012	2,348	4,086	5,612	1,127	8,195
2013	2,381	4,143	5,691	1,143	8,310
2014	2,383	4,146	5,695	1,144	8,317
Total	2,383	38,762	53,242	10,693	77,747

To value the estimated reduction in crashes, the evaluation team apportioned the prevented crases (table 10) into the six categories of bodily harm (minor, moderate, serious, severe, critical, and unsurvivable) by using historical national values of the frequence of occurrence for each crash severity. The crash costs associated with the six categories of bodily harm are derived as proportions of USDOT's 2014 VSL ($9.1 million). VSL is the additional cost that individuals would be willing to pay for safety (that is, for reductions in risks) that, in the aggregate, reduce the expected number of fatalities by 1 VSL.[39] The National Highway Traffic Safety Administration proportions of the six types of injury crashes using data from all 2014 injury crashes in the United States. This study also reported the average value of a property damage crash reported to insurers to be $3,927 (in 2013

U.S. dollars).[39] While these proportions are for all crashes, not simply intersection crashes, they are valid assumptions for this simple analysis. A future and past growth rate of 1.0107 was used for both VSL and PDO, as per USDOT 2014 guidance, and values were discounted using a 7-percent discount rate.

Table 11 shows the the lower bound of the economic value of injury crashes prevented. The evaluation team estimates that from 1990–2014, roundabouts have saved between $9.15 billion and $12.5 billion in injury or fatal crashes, and $58.7 to $427 million in PDO crashes.

Table 11. Lower bound for economic value of injury crashes prevented by roundabouts from 1990–2014.

Severity	Frequency of Occurrence	Fraction of VSL	Cost per Crash	Number of Crashes	Total Cost per Crash Type
Minor	0.8473	0.003	$27,300	32846	$868,917,073
Moderate	0.1037	0.047	$427,700	4020	$1,666,082,427
Serious	0.0273	0.105	$955,500	1058	$979,877,567
Severe	0.0061	0.266	$2,420,600	236	$554,665,739
Critical	0.0018	0.593	$5,396,300	70	$364,877,487
Unsurvivable	0.0138	1	$9,100,000	535	$868,917,073
Total	--	--	--	--	$9,151,779,591

--Information not applicable.

These estimates are sensitive to the frequency of occurrence assumptions. The evaluation team calculated two alternative frequency of occurrence schedules for the six categories of bodily harm using the results of a 2007 study, *Pre-crash Scenario Typology for Crash Avoidance Research*.[37] The study looked at crash rates across a number of pre-crash scenarios for the purposes of estimating reduction in crashes from connected vehicle technology. Pre-crash scenarios were defined in part by whether they occurred at an intersection. In addition, a percentage of crashes occurring at an intersection were calculated for each pre-crash scenario, independent of whether the pre-crash scenario was defined to occur at an intersection. Thus, a frequency of occurrence schedule for the six categories of bodily harm could be calculated two ways. The first averaged the values for pre-crash scenarios defined to occur at intersections, while the second method uses the averages of the values for all scenarios weighted by the percent of crashes that occur at an intersection. These methods produce total benefits for the lower- and upper-bound crash reduction assumptions of roughly $6 billion and $9 billion, respectively. This sensitivity result shows that, while estimates may vary on percentage terms by as much as 35 percent, the order of magnitude of the results (billions) remains the same.

With additional information, the safety benefit calculation could further explore the relationship between the safety impacts and the location, number of lanes and other design features of the roundabouts; however, relevant design features of roundabouts were not readily available in the data sources available. In addition, this calculation only includes safety benefits. It ignores other benefits such as operational or environmental impacts. Therefore, the result likely underestimates the total benefits of roundabouts. With information such as the costs associated with roundabouts, including design and construction costs, a fuller picture of the benefit of roundabouts deployed may be developed.

Finding: The literature demonstrates operational, environmental, and lifecycle cost impacts of roundabouts.

There is extensive literature on the environmental and operational impacts of roundabouts. Roundabout studies typically use one of two methods: observation or computer modeling. Observational studies review converted intersections and compare rates of crashes or observational approaches. Computer models simulate geometries and conditions.

Operational Research

Less operational research has been done than safety research, due to the high priority given to safety (particularly, in regard to fatality reduction) and the justification of roundabouts primarily as a safety countermeasure. The operational research that has been done has shown benefit, although there is less agreement on how much, and there are few studies on specific scenarios (e.g., different types of conversions and different levels of urbanization).

Operational studies typically track intersection delay, although some, particularly the early studies concerned with identifying optimal geometry, also track the extent to which motorists must slow down and the following distances they keep. Aimee Flannery (funded by FHWA), performed an observational study in 1998 that found lower average delay times after roundabouts deployment.(44) A 2001 study using SIDRA (a traffic simulation program), found that the operational benefits of roundabouts were most promising in high-demand intersections and those with high left-turn percentages.(86) In a 2005 study that mixed videotaped with SIDRA analysis, Eugene Russell examined Kansas roundabouts and found average intersection delay reduced by 65 percent and queue length reduced by 44 percent.(87)

Environmental Research

Fewer studies of the environmental benefits of roundabouts have been conducted. These studies focus on emissions reductions, and secondary benefits to reduce speed and improved operational efficiency. An international study from 2002 found decreased fuel consumption and carbon monoxide and mono-nitrogen oxides emissions in roundabouts that replaced signalized intersections (results that were duplicated for stop-sign intersections in a SIDRA-based study in 2008), but slight increases in emissions and fuel consumption versus yield-sign intersections.(88,89) A 2006 study found no significant improvement in emissions with roundabouts.(90) Using modeling software, the authors actually found greater fuel consumption while vehicles were in the intersection, but operational benefits cancelled out this effect. Research indicates a reduction in emissions, although they are situationally dependent.

Lifecycle Costs

While it was not possible to collect all the information necessary for a full-benefit cost analysis of the R&T roundabout evaluation, some progress can be made in understanding the full potential impact of the program beyond the safety benefits calculation above. A recent NHCRP document, *Estimating the Life-Cycle Cost of Intersection Designs,* details a number of case studies that consider the selection of intersection infrastructure.(5) These case studies provide full benefit–cost information for the roundabout design compared with a number of alternatives, including the relative magnitude of safety benefits to other benefit and cost categories. The analysis results were presented as the net present value of total costs for each intersection design for a given project such that the design with the lowest value had the most benefit relative to the others. Three of the studies were developed from real world cases and the fourth was a hypothetical case testing various capabilities of the benefit–cost tool developed for the analyses.

Eagle Road/State Street—Eagle, Idaho: The multilane roundabout design was compared with the base case (existing signalized intersection) and an alternative enhanced signalized intersection over a 20-year horizon. Virtually all of the relative benefits (roughly $45 million) for the roundabout design accrued from vehicle delay reduction. The relative safety benefits were marginal, roughly $5–10 million for any given project in which the alternatives to the roundabout design's total costs were upward of $130 million. Relative to the enhanced signalized design, the roundabout design had roughly twice the right-of-way cost, while planning and engineering costs and construction costs were roughly 10 percent lower. The benefit–cost ratio for the roundabout design was 13.03 compared with 1.14 for the enhanced signalized intersection design.

Powell Butte Highway/Neff Road—Deschutes County, Oregon: The single-lane roundabout design was compared with the base intersection (existing unsignalized intersection) and an alternative two-offset intersection design (with two-way stop control). The benefit–cost ratio of the roundabout design was 0.94 compared with 0.26 for the two-offset intersection design, meaning that the base case would be preferred in a benefit–cost framework. The roundabout planning and engineering, right-of-way, and construction costs were roughly 65 percent that of the two-offset intersections designs. The roundabout design's safety benefits relative to the base case and two-offset intersections design were roughly $2 million and $1.5 million, respectively, in which the total costs of all projects were below $6 million.

Jackson School Road/Scotch Church Road/Meek Road—Washington County, Oregon: The scenario compared the roundabout design against the base intersection (off-set T-intersection) and a signalized intersection. Capital costs were not included in this case study. The roundabout design greatly outperformed the other designs on benefits with roughly $10-12 million in crash reduction benefits relatively. The roundabout design also out-performed the base case and signalized intersection designs in auto passenger time by upward of $1.5 million.

Hypothetical Example: A roundabout design was compared with the base case (existing all-way stop-controlled intersection) and a signalized intersection design. The benefit–cost ratio of the roundabout design was 0.96 compared with –8.20 for the signalized design. The roundabout design showed higher safety benefits than the signalized intersection, but had higher capital costs (roughly $2.5 million).

The results of these benefit–cost case studies lend support to the finding that there are significant safety benefits of roundabouts relative to other intersection designs. Further, they show that roundabouts may have higher mobility benefits than other designs in many cases, measured by auto passenger time. In the Eagle Road/State Street case such mobility benefits were substantial, totaling approximately $45 million in mobility benefits. While roundabouts were better performing on mobility and safety, the capital costs reduced the total value of the roundabout design, despite strong safety and mobility benefits compared with the base case, which had no capital costs by definition. More research is needed to study the benefit–cost ratio of the roundabout intersection, but evidence so far suggests that the total benefits are positive and potentially significant.

4. Conclusions and Recommendations

This evaluation found strong evidence of FHWA's influence on the acceptance, consideration, and adoption of roundabouts. The findings suggest that acceptance, consideration, and adoption are higher now than would have occurred without FHWA research and activities. FHWA laid the foundation for national adoption of roundabouts by providing empirical evidence of their safety and operational benefits, increasing awareness of and confidence in them among stakeholders, and contributing to the development of the design standards for implementation.

FHWA initially selected roundabouts for research based on clearly demonstrated international benefits. In the early years of roundabout research at FHWA, staff that engaged with the topic benefited from internal support and funding to conduct internal research, and FHWA partnered with lead adopter States to evaluate if similar benefits would accrue domestically and to study the needs for adaptation to the U.S. context. FHWA also provided support for the findings of this early research to be presented and disseminated. Looking forward, FHWA should lend the same type of support during the foundational research period for other countermeasures, while continuing to monitor the international and domestic landscape for other promising innovations.

Following the early years of roundabout research at FHWA, the agency took a strong national leadership role across the technology lifecycle, including research and standards development, funding, and implementation across all States. FHWA developed, funded, and served on the technical panels for cornerstone roundabout documents including the first national *Roundabouts Informational Guide*, NCHRP 572, and the revised *Roundabouts Informational Guide*.[2,3,22] Evidence clearly demonstrates cross-cutting use of these and other documents by State and local agencies to develop their own roundabouts design manuals and SHDMs. These documents informed State intersection project planning and design and encouraged the consideration of roundabouts as an intersection project alternative.

Throughout the long history of roundabout activity, FHWA has coordinated internally, especially across Safety R&D, Office of Safety, and the Resource Center. FHWA also consistently shared information about the benefits of roundabouts through their inclusion in major initiatives and programs from the 2008 and 2012 Proven Safety Countermeasures, to HSIP and CMAQ eligibility, and EDC-2. FHWA's influence and reach were further enhanced by active participation and exchange with the research and stakeholder communities through participation as members on NCHRP panels and the Roundabouts TRB Committee, and by providing training and technical assistance to transportation professionals. In its leadership role, FHWA benefited significantly from a set of engaged, active, and highly coordinated roundabout champions, including consultants, academics, and State and local agencies, a community that flourishes today. The existence of this community is also likely due in part to roundabouts as an "open source" safety intervention, compared with technologies in a market with proprietary systems and competing vendors.

Although the growth in the number of roundabouts has been significant in the United States, room for improvement remains. Adoption of roundabouts in the United States (over 3,200 roundabouts) still significantly lags behind leading adopter nations like France (estimated 30,000 roundabouts). Barriers include the cost of roundabouts, continued public opposition, and misperception of roundabouts. To increase the adoption of roundabouts and promote other emerging safety countermeasures like other alternative intersection designs, FHWA should maintain its cooperation

and partnership across safety disciplines and the broader stakeholder community to ensure support to States throughout the adoption cycle.

While it is difficult to quantitatively estimate the overall contribution of FHWA to the growth in roundabouts, HSIP and CMAQ data show direct funding for such projects and evidence strongly points to FHWA furthering the growth in roundabouts nationwide. Literature assessing the impacts of roundabouts verifies that roundabout adoption reduced crashes of all kinds at U.S. intersections, including those resulting in serious injuries and fatalities, and has also likely reduced emissions and improved operations over traditional intersections. While FHWA cannot claim direct responsibility for this impact, the continued research and promotion of roundabouts has significantly and positively enhanced roadway safety in the United States.

The findings from this evaluation underscore the importance of both foundational and ongoing research, dissemination of resources, and FHWA national leadership on a topic with internal and external stakeholders, leaders, and other decisionmakers.

4.1 Recommendations

FHWA R&T roundabout research and related activities took place over two decades and spanned the range of the technology adoption lifecycle. The number of roundabouts significantly increased over this time period. However, as previously noted, despite this significant growth, room for improvement remains with roundabout adoption in the United States lagging behind leading adopter nations. To further increase the value of FHWA safety research to FHWA and to its wider community of partners and stakeholders, the evaluation team offers the following recommendations for FHWA's consideration.

Recommendation: Begin investing in data collection on research diffusion and technology adoption during the early years of technology implementation.

A lack of data frequently limits attempts to evaluate the adoption and especially the impact of new transportation technologies. The early support for and existence of the Roundabout Inventory enabled analysis of roundabout adoption trends in near-real time by stakeholders. The data also enables analyses such as the safety analysis conducted as part of this evaluation. In some cases, there is an individual or organizational initiative to collect this information. For example, the website divergingdiamond.com, presented by a private consultant, tracks the construction of diverging diamonds nationwide. Given the resource intensity required for such an effort, FHWA could strategically select a subset of technologies for which it would invest in systematic adoption data collection. Simultaneously, FHWA should track internal metrics related to research investment and the location and reach of outreach and technical assistance activities.

Recommendation: Research and promote information on roundabout costs and strategies for reducing roundabout costs.

As discussed under Evaluation Area 3, initial roundabout capital costs appear to be a barrier to roundabout adoption. NCHRP Synthesis 488 notes that multiple State agencies expressed an interest in information and strategies related to reducing the cost to install roundabouts.(4) Additional research should be undertaken to identify the underlying cause for the high costs and in which the potential for cost savings may exist without compromising safety and performance benefits—both for individual components and the planning, design, and construction processes. FHWA investment in

mini-roundabout research already represents a step in this direction, but there is additional progress to be made in identifying and disseminating helpful strategies to enable adoption.

Recommendation: Build cooperation across FHWA safety disciplines and the broader stakeholder community.

Throughout the long history of roundabout activity, FHWA's successful internal coordination, especially across the safety discipline (Safety R&D, Office of Safety, and the Resource Center), resulted in a highly visible and unified message to stakeholders. Documenting the coordination mechanisms, strategies, and activities that made this process successful and replicating them (as appropriate) across other programs and offices within FHWA could provide organization-wide benefits.

Appendix A. Roundabout Adoption Data

This appendix provides additional data from the observations on roundabout adoptions by State based on data from the Kittelson & Associates Roundabouts Inventory Dataset through 2013. Data presented in table 12 includes the year of the first roundabout built by State, the total number of roundabouts by State, and additional information on FHWA HSIP funding for roundabout projects. Table 13 details the HSIP funding and projects from 2013–2014.

Table 12. First roundabout and total presently installed by State.[1]

State	First Year	Roundabouts Installed to Date
DC	N/A	18
NV	1990	27
CA	1992	206
FL	1992	302
MI	1992	68
NE	1992	35
WA	1992	279
MA	1993	95
AZ	1994	80
CO	1994	182
IN	1995	87
MN	1995	36
VT	1995	4
SC	1996	15
TX	1996	59
UT	1996	67
CT	1997	14
KS	1997	107
ME	1997	15
MS	1997	15
WI	1997	271
GA	1998	122
HI	1999	14
IA	1999	36
KY	1999	4
MA	1999	25

[1]Not every roundabout in the Kittelson & Associates database can be attributed to a specific State due to the way some of the data are collected. Therefore, these totals will not match the totals elsewhere in the report.

State	First Year	Roundabouts Installed to Date
NA	1999	96
OR	1999	109
MO	2000	12
NY	2000	80
VA	2000	89
AK	2001	15
AR	2001	4
LA	2001	12
NJ	2001	9
TN	2001	7
NH	2002	10
NM	2002	12
RI	2002	4
DE	2003	4
ID	2003	10
MT	2003	26
AL	2004	17
IL	2004	8
OH	2005	29
OK	2005	4
PA	2005	17
ND	2007	2
SD	2008	2
WY	2008	7
WV	2010	2
Total	1999[2]	2770

[2]This is the average first year of adoption across all States.

Table 13. HSIP funding and projects (2013–2014).

State	2013 Projects	2013 Funding	2014 Projects	2014 Funding
AK	2	$652,156.00	1	$1,552,924.00
AZ	3	$1,529,743.00	--	--
CA	--	--	2	$4,589,000.00
CO	--	--	2	$1,098,000.00
CT	6	$6,856,996.00	2	$185,000.00
FL	--	--	2	$730,917.00
GA	10	$10,282,240.00	13	$10,705,578.71
HI	--	--	1	$5,066,751.00
IL	1	$5,283,000.00	--	--
IN	1	$844,309.00	--	--
IN	--	--	1	$2,085,670.95
KS	--	--	1	$2,753,662.70
MA	3	$861,597.00	2	$641,760.00
MD	--	--	1	$1,165,058.00
MN	3	$2,740,079.00	3	$1,349,469.07
MS	2	$0.00	1	$0.00
MT	1	$352,517.00	4	$1,769,506.00
NC	--	--	6	$1,771,500.00
NE	1	$531,467.00	--	--
NH	--	--	1	$2,795,000.00
NJ	1	$1,451,000.00	2	$2,555,000.00
OH	1	$1,504,510.18	2	$1,497,019.55
PA	2	$550,309.51	1	$120,021.00
RI	1	$665,000.00	2	$5,724,409.00
SC	--	--	11	$2,329,696.85
VA	4	$2,410,549.00	2	$1,131,596.00
VT	2	$5,022,839.00	5	$13,704,839.00
WA	1	$800,000.00	--	--
WV	--	--	1	$216,000.00
Grand Total	45	$42,338,311.69	69	$65,538,378.83

--Information not applicable.

Appendix B. Evaluation Interviewees and FHWA Research Outputs

Section B.1 (table 14) of this appendix provides a list of the interviewees for this evaluation. Given the breadth and depth of roundabout-related resources available, the evaluation team did not use interviews as a primary source of data collection, but rather relied on them to further understand FHWA and research community activities from the 1990s to the present.

Section B.2 (table 15) of this appendix summarizes FHWA research and outputs from 1994–2015.

B.1 Evaluation Interview List

Table 14. Evaluation interviewees.

Interviewee	Organization	Date Interviewed
John McFadden	FHWA	4/21/2015
Eugene Russell	Kansas State University (Retired)	6/3/2015
Jeff Shaw	FHWA	4/2/2015
Joe Bared	FHWA	3/25/2015
Hillary Isebrands	FHWA	4/1/2015
Karen Scurry	FHWA	5/15/2015
Wei Zhang	FHWA	3/20/2015

B.2 FHWA Research and Products Summary

Table 15. Summary of FHWA research and outputs (1994–2015).

Author	Year	Document Title
Sabra, Z.A. and Halkias, J.A.	1994	"TRAF-NETSIM: A Practical Tool for Traffic Preemption and Roundabout Intersection Control Modeling"[91]
Ourston, L. and Bared, J.G.	1995	"Roundabouts: A Direct Way To Safer Highways"[10]
Courage, K.G. and Wise, J.	1996	*Design Guide and Evaluation Plan for Modern Roundabouts in Florida*[45]
Bared, J.G., Prosser, W. and Esse, C.T.	1997	"State-of-the-Art Design of Roundabouts"[11]
Bared, J.	1997	"Roundabouts: Improving Road Safety and Increasing Capacity"[12]
Jacquemart, G.	1998	*Modern Roundabout Practice in the United States*[13]
FHWA	2000	*Roundabouts: An Informational Guide*[92]

Author	Year	Document Title
Robinson, B.W., Rodegerdts, L., Scarborough, W., Kittelson, W., Troutbeck, R., Brilon, W., Bondzio, L., Courage, K., Kyte, M., Mason, J., Flannery, A., Myers, E., Bunker, J., and Jacquemart, G.	2000	*Roundabouts: An Informational Guide*[2]
Bared, J.G. and Kaisar, E.I.	2000	*Comparison of Diamond Interchanges with Roundabout Interchanges*[93]
FHWA	2000	*Roundabouts: An Informational Guide* (brochure)[92]
FHWA	2000	*Your Community Deserves a Lot Less: Roundabouts: The More You Build, the Less You Get* (pamphlet)[94]
Flannery, A.	2001	"Geometric Design and Safety Aspects of Roundabouts"[95]
FHWA	2001	"The Case for Roundabouts" (videorecording)[52]
Bared, J.G. and Kaisar, E.I.	2002	"Does Your Interchange Design Have You Going Around in Circles?"[96]
Robinson, B.W.	2002	*FHWA Guidelines for Safety of Roundabouts*[97]
Inman, V.W., Shafer, T., Katz, B.J., Bared, J.G., and Davis, G.W.	2003	*Field Observations of Path and Speed of Motorists at Double-Lane Roundabouts*[98]
Lee, J.C., Robinson, B., Kidd, B.D., and Scarbrough, W.	2003	*Roundabouts: An Arizona Case Study and Design Guidelines*[34]
Davis, G.W., Inman, V.W., Shafer, T., and Katz, B.J.	2003	*A Simulation Study of Path and Speed Through Double-Lane Roundabouts*[99]
FHWA	2004	*Roundabouts*[100]
Saito, M. and Lowry, M.	2004	*Evaluation of Recent Traffic and Safety Initiatives, Volume I: Developing Guidelines for Roundabouts*[101]
Katz, B.J., Hanscom, F.R., and Inman, V.W.	2004	*Navigation Signing for Roundabouts*[102]
NCHRP	2005	*Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*[103]
Lutkevich, P. and Hasson, P.	2005	*An Examination and Recommendation for Current Practices in Roundabout Lighting*[104]
Schurr, K.S. and Abos-Sanchez, J.	2005	*Effects of Central Island Landscape Treatments at Single-Lane Roundabouts*[105]
Katz, B.J., Hanscom, F.R., and Inman, V.W.	2005	*Navigation Signing for Roundabouts*[106]
Inman, V.W., Davis, G.W., and Sauerburger, D.	2005	*Roundabout Access for Visually Impaired Pedestrians: Evaluation of a Yielding Vehicle Alerting System for Double-Lane Roundabouts*[107]

Author	Year	Document Title
Bared, J.G. and Edara, P.K.	2005	*Simulated Capacity of Roundabouts and Impact of Roundabout Within a Progressed Signalized Road*[108]
FHWA	2006	*Roundabouts*[109]
Rodegerdts, L., Blogg, M., Wemple, E., Myers, E., Kyte, M., Dixon, M.P., List, G.F., Flannery, A., Troutbeck, R., Brilon, W., Wu, N., Persaud, B.N., Lyon, C., Harkey, D.L., and Carter, D.	2006	*Web-only Document 94: Appendixes to NCHRP Report 572: Roundabouts in the United States*[110]
Inman, V.W., Katz, B.J., and Hanscom, F.R.	2006	"Navigation Signing for Roundabouts"[111]
Inman, V.W., Davis, G.W., and Sauerburger, D.	2006	*Pedestrian Access to Roundabouts: Assessment of Motorists' Yielding to Visually Impaired Pedestrians and Potential Treatments to Improve Access*[112]
Molino, J.A., Inman, V.W., Katz, B.J., and Emo, A.	2007	*Lane Restriction Signing and Marking For Double-Lane Roundabouts*[113]
Rodegerdts, L., Blogg, M., Wemple, E., Myers, E., Kyte, M., Dixon, M.P., List, G.F., Flannery, A., Troutbeck, R., Brilon, W., Wu, N., Persaud, B.N., Lyon, C., Harkey, D.L., and Carter, D.	2007	*NCHRP Report 572: Roundabouts in the United States*[22]
Molino, J.A., Inman, V.W., Katz, B.J., and Emo, A.	2007	*Lane Restriction Signing and Marking For Double-Lane Roundabouts*[114]
Joerger, M.	2007	*Adjustment of Driver Behavior to an Urban Multi-Lane Roundabout*[115]
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Doctor, M. and Mousseau, A.	2007	*Operational Analysis of Proposed Roundabouts in Gorham, Maine*[117]
Inman, V.W. and Davis, G.W.	2007	*Synthesis of Literature Relevant to Roundabout Signalization to Provide Pedestrian Access*[118]
FHWA	2008	*Roundabouts: A Safer Choice* (pamphlet)[119]
Roundabout Lighting Subcommittee of the Illumination Engineering Society Roadway Lighting Committee	2008	*Design Guide for Roundabout Lighting*[23]
ITE	2008	*Enhancing Intersection Safety Through Roundabouts*[24]
Benekohal, R.F. and Atluri, V.	2009	*Roundabout Evaluation and Design: A Site Selection Procedure*[120]

Author	Year	Document Title
Khattak, Bishu, R., A., Schurr, K., and McKnight, G.	2009	*Investigation and Mitigation of Driver Confusion at Modern Roundabouts*[121]
Shaw, J. and Moler, S.	2009	"Bicyclist- and Pedestrian-Only Roundabouts"[122]
FHWA	2009	*Roundabouts: A Proven Safety Solution that Reduces the Number and Severity of Intersection Crashes*[123]
Bared, J.G. and Afshar, A.M.	2009	"Using Simulation to Plan Capacity Models by Lane for Two- and Three-Lane Roundabouts"[124]
FHWA	2010	*Summary Report: An Evaluation of Signing for Three-Lane Roundabouts*[125]
Arnold, L.S.	2010	*Identifying Factors That Determine Bicycle and Pedestrian-Involved Collision Rates That Affect Bicycle and Pedestrian Demand at Multi-Lane Roundabouts*[126]
FHWA	2010	*Mini-Roundabouts*[127]
FHWA	2010	*Minnesota Roundabout : A Scott County Success Story*[128]
FHWA	2010	*Modern Roundabouts: A Safer Choice* (videorecording)[72]
Lee, M.	2010	*Performance Analysis of the Dowling Multi-Lane Roundabouts in Anchorage, Alaska*[129]
FHWA	2010	*Roundabouts*[130]
FHWA	2010	*Roundabouts–The Maryland Experience : A Maryland Success Story*[131]
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Schroeder, B., Hughes, R., Rouphail, N., Cunningham, C., Salamati, K., Long, R., Guth, D., Emerson, R.W., Kim, D., Barlow, J., Bentzen, B.L., Rodegerdts, L., and Myers, E.	2010	*NCHRP Web-Only Document 160: Supporting Material to NCHRP Report 674*[132]
Rodegerdts, L., Bansen, J., Tiesler, C., Knudsen, J., Myers, E., Johnson, M., Moule, M., Persaud, B., Lyon, C., Hallmark, S., Isebrands, H., Crown, R.B., Guichet, B., and O'Brien, A.	2011	*Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*[133]
FHWA	2011	*DMV Reaches Out to Drivers in Wisconsin with Roundabout Flyers in Mailings Background*[134]

Author	Year	Document Title
FHWA	2011	*Engaging the Public Through Print and Web Outreach: How Carmel, Indiana, Uses Innovative Media to Shape Public Perception of Roundabouts*[135]
FHWA	2011	*In Florida, Clearwater's Public Charrettes Produce Strong Support for Roundabouts*[136]
FHWA	2011	*Iowa Transportation Department Provides "Expert-on-Hand" Technical Assistance to Promote Roundabouts Across the State*[137]
Valdez, M., Cheu, R.L., and Duran, C.	2011	"Operations of Modern Roundabout with Unbalanced Approach Volumes"[138]
Uddin, W.	2011	*Performance Evaluation of Roundabouts for Traffic Delay and Crash Reductions in Oxford, MS*[47]
FHWA	2011	*Seeing Is Believing: Missouri DOT Convinces Skeptics That Roundabouts Work Background*[139]
FHWA	2011	*Sioux Falls, South Dakota Conducts Roundabout Rodeo*[140]
FHWA	2011	*Teaching Through Children: How Bend, Oregon Used Coloring Books to Communicate About Roundabouts*[141]
Mills, A., Duthie, J., Machemehl, R., and Waller, T.	2011	*Texas Roundabout Guidelines*[142]
FHWA	2011	*VDOT's Roundabouts Review Committee Spearheads Internal and External Outreach Efforts*[143]
Cicu, F., Illotta, P.F., Bared, J.G., and Isebrands, H.N.	2011	*VISSIM Calibration of Roundabout Traffic Performance*[144]
FHWA	2011	*Washington County, MN Educates Drivers Through Roundabout U*[145]
FHWA	2011	*Washington State Focuses on Outreach, Illustrates How to Drive a Roundabout*[146]
FHWA	2011	*Wisconsin Roundabouts Calm Traffic, Improve School Zone Safety*[147]
Isebrands, H. and Hallmark, S.	2012	*Statistical Analysis and Development of Crash Prediction Model for Roundabouts on High-Speed Rural Roadways*[148]
Lochrane, T.W.P., Zhang, W., and Bared, J.	2012	"Mini-Roundabouts for the United States and Traffic Capacity Models"[149]
Bullough, J.D., Rea, M.S., Snyder, J.D., Skinner, N.P., Capó, R.I., Rizzo, P., and Besenecker, U.	2012	*Demonstration of Roundabout Lighting Based on the Ecoluminance Approach*[150]
Engstrom, D.	2012	*Modern Roundabouts: More Than Just an Intersection* (presentation)[151]
Woodmansey, A. and Spalding, K.	2012	"Montana's Roundabout Corridor"[152]

Author	Year	Document Title
FHWA	2012	*Proven Safety Countermeasures: Roundabouts*[153]
Zhang, W., Bared, J., and Jagannathan, R.	2012	"They're Small But Powerful"[52]
Zirkel, B., Park, S., McFadden, J., Angelastro, M., and McCarthy, L.	2013	"Analysis of sight Distance, Crash Rate, and Operating Speed Relationships for Low-Volume Single-Lane Roundabouts in the United States"[154]
Day, C.M., Hainen, A.M., and Bullock, D.M.	2013	*Best Practices for Roundabouts on State Highways*[56]
Dixon, K. and Zheng, J.	2013	*Developing Safety Performance Measures for Roundabout Applications in the State of Oregon*[155]
Veneziano, D., Ewan, L., and Stephens, J.	2013	*Information/Education Synthesis on Roundabouts*[79]
Lochrane, T.W.P., Kronprasert, N., Bared, J.G., Dailey, D.J., and Zhang, W.	2013	*Traffic Capacity Models for Mini-Roundabouts in the United States: Calibration of Driver Performance in Simulation*[156]
Lochrane, T.W.P., Kronprasert, N., Bared, J., Dailey, D.J., and Zhang, W.	2014	"Determination of Mini-Roundabout Capacity in the United States"[157]
Isebrands, H., Hallmark, S., and Hawkins, N.	2014	"Effects of Approach Speed at Rural High-Speed Intersections: Roundabouts versus Two-Way-Stop Control"[158]
Rodegerdts, L.A., Jenior, P.M., Bugg, Z.H., Ray, B.L., Schroeder, B.J., and Brewer, M.A.	2014	*NCHRP: Report 772: Evaluating the Performance of Corridors with Roundabouts*[159]
Meyers, E., Sides, K., McCulloch, H., and Shaw, J.	2014	*Evolution of Roundabout Practice in the United States – A Conversational Panel with Audience Participation* (presentation)[160]
Isebrands, H.	2014	"Implementing Modern Roundabouts in the United States"[46]
Zhang, W.	2014	*Mini-Roundabout Case Studies*[161]
Woodmansey, A.	2014	*Montana's Roundabout Corridor: Convincing the Stakeholders and Ourselves* (presentation)[162]
Isebrands, H.	2014	*The Multi-Lane Roundabout PDO Dilemma*[163]
Isebrands, H.N., Hallmark, S., and Hawkins, N.	2014	*The True Story of Roundabouts with High Speed Approaches* (presentation)[164]
Zhang, W., Kronprasert, N., and Gustafson, J.	2014	*Unclog Local Network Congestion Using High Capacity Mini-Roundabout: A Feasibility Study*[165]
Griffith, M.	2014	*Welcome and Remarks from Federal Highway Administration* (presentation)[166]
FHWA	2014	*NCHRP Report 772: Evaluating the Performance of Corridors with Roundabouts*[27]

Author	Year	Document Title
FHWA	2015	*Accelerating Roundabout Implementation in the United States*[28]
FHWA	2016	*Roundabout Outreach and Education Toolbox*[38]
Shaw, J.	Undated	*Overview of the Northeast U.S. Roundabouts Peer Exchange* (presentation)[167]
FHWA	Undated	*Safety Aspects of Roundabouts*[168]

Appendix C. State SHSPs Used for SHSP Analysis

Table 16 summarizes the SHSPs used by State and year. Current SHSPs are available at https://safety.fhwa.dot.gov/shsp/other_resources.cfm. Contact the state DOT for prior year reports.

Table 16. State SHSPs used for SHSP analysis.

State	Years of SHSPs used in Analysis
Alabama	2012[169]
Alaska	2012, 2013[170,171]
Arizona	2005, 2007[172,173]
Arkansas	2007, 2013 [174,175]
California	2010, 2015[176,177]
Colorado	2014[178]
Delaware	2010[179]
Florida	2006[180]
Idaho	2007, 2010, 2013[181–183]
Illinois	2005, 2009[184,185]
Indiana	2006[186]
Iowa	2006[187]
Kansas	2006, 2009, 2014[188–190]
Louisiana	2006[191]
Maine	2011, 2014[192,193]
Maryland	2003[194]
Massachusetts	2006[195]
Minnesota	2014[196]
Mississippi	2014[197]
Missouri	2008, 2012[198,199]
Nebraska	2007, 2012[200,201]
Nevada	2006, 2011[202,203]
New Hampshire	2012[204]
New Jersey	2007[205]
New York	2007, 2010[206,207]
North Carolina	2007, 2015[208,209]
North Dakota	2010, 2013[210,211]
Oregon	2011[212]
Pennsylvania	2006, 2012[213,214]
Rhode Island	2007, 2012[215,216]
South Carolina	2007, 2015[217,218]

South Dakota	2014[219]
Tennessee	2014[220]
Texas	2006, 2009, 2014[221–223]
Utah	2014[224]
Vermont	2006, 2012[225,226]
Virginia	2006, 2012[227,228]
Washington	2007, 2010, 2013[229–231]
Wisconsin	2006, 2011[232,233]

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