

Technology Review and Roadmap for Inventorying Complete Streets for Integration into Pavement Asset Management Systems

July 2021

A Research Report from the National Center for Sustainable Transportation

April Gadsby, Ph.D., Georgia Institute of Technology

Yichang (James) Tsai, Ph.D., Georgia Institute of Technology

John Harvey, Ph.D., University of California, Davis



National Center
for Sustainable
Transportation

ITS **UCDAVIS**
INSTITUTE OF TRANSPORTATION STUDIES

Georgia Tech **School of Civil and Environmental Engineering**
College of Engineering

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NCST-UCD-RR-21-14	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A	
4. Title and Subtitle Technology Review and Roadmap for Inventorying Complete Streets for Integration into Pavement Asset Management Systems		5. Report Date July 2021	
		6. Performing Organization Code N/A	
7. Author(s) April Gadsby, Ph.D., https://orcid.org/0000-0002-2276-7929 Yichang (James) Tsai, Ph.D., P.E., https://orcid.org/0000-0002-6650-2279 John Harvey, Ph.D., P.E., https://orcid.org/0000-0002-8924-6212		8. Performing Organization Report No. UCD-ITS-RR-21-18	
9. Performing Organization Name and Address University of California, Davis Institute of Transportation Studies 1605 Tilia Street, Suite 100 Davis, CA 95616 Georgia Institute of Technology School of Civil and Environmental Engineering 790 Atlantic Dr, Atlanta, GA 30332		10. Work Unit No. N/A	
		11. Contract or Grant No. Caltrans 65A0686 Task Order 028 USDOT Grant 69A3551747114	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590 California Department of Transportation Division of Research, Innovation and System Information, MS-83 1727 30th Street, Sacramento, CA 95816		13. Type of Report and Period Covered Final Report (February 2020 – January 2021)	
		14. Sponsoring Agency Code USDOT OST-R	
15. Supplementary Notes DOI: https://doi.org/10.7922/G2XW4H3Q Dataset DOI: https://doi.org/10.25338/B8DK9G			
16. Abstract Complete Streets provide mobility for all modes of transportation including active transportation. Complete Streets are being implemented in the US and transportation agencies must maintain these assets, which requires bringing them into asset management systems. Many gaps exist to include Complete Streets in asset management, and there is no comprehensive plan for filling those gaps. This project developed a road map to fill those gaps. To create this roadmap, the study completed the following tasks: 1) develop and refine a survey 2) perform national and in-depth surveys, 3) synthesize survey outcomes, 4) identify current statuses, challenges, and needs, and 5) develop a roadmap for Complete Streets asset management. All 50 state Department of Transportations participated in the national survey while Caltrans, Georgia DOT, and the Atlanta and Washoe County Metropolitan Planning Organizations contributed to the in-depth survey. This report synthesizes the outcomes of the surveys and literature review. The survey results showed that many agencies have some Complete Streets guidance (39/50), but far less have a dedicated liaison or office (15/40), and only seven agencies have Complete Streets performance measures. The three primary challenges are: 1) inadequate funding related to organizational structure 2) the need for a rating system, and 3) the need for improved data accessibility, collection methods, and management techniques. The proposed roadmap includes asset management development and improved data collection and analysis pathways. The roadmap is intended to be used as a starting point for the incorporation of Complete Streets into asset management.			
17. Key Words Complete Streets, Asset Management, Implementation, Challenges/Needs, and Roadmap		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 41	22. Price N/A

About the National Center for Sustainable Transportation

The National Center for Sustainable Transportation is a consortium of leading universities committed to advancing an environmentally sustainable transportation system through cutting-edge research, direct policy engagement, and education of our future leaders. Consortium members include: University of California, Davis; University of California, Riverside; University of Southern California; California State University, Long Beach; Georgia Institute of Technology; and University of Vermont. More information can be found at: ncst.ucdavis.edu.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program and, partially or entirely, by a grant from the State of California. However, the U.S. Government and the State of California assume no liability for the contents or use thereof. Nor does the content necessarily reflect the official views or policies of the U.S. Government or the State of California. This report does not constitute a standard, specification, or regulation. This report does not constitute an endorsement by the California Department of Transportation of any product described herein.

Acknowledgments

This study was funded, partially or entirely, by a grant from the National Center for Sustainable Transportation (NCST), supported by the U.S. Department of Transportation (USDOT) and the California Department of Transportation (Caltrans) through the University Transportation Centers program. The authors would like to thank the NCST, the USDOT, and Caltrans for their support of university-based research in transportation, and especially for the funding provided in support of this project.

The authors would also like to thank Ronald Knezevich and Pingzhou (Lucas) Yu for developing the in-depth interview questionnaire and for providing the methodology map in this report. They would like to thank Qiuhan Chen and Ariel Steele for help in performing the interviews, and other assistance on this study. They would also like to thank the personnel at Georgia DOT, Caltrans, the Atlanta Regional Commission, and Washoe County MPO who participated in our interviews and extra thanks to those who helped to refine the survey (Meg Pirkle, Brent Story, Jack Anninos, Eric Conklin, Daniel Pass, Sam Harris, Andrew Heath, Andy Doyle, Ernay Robinson, Byron Rushing, Scott Gibson, Daniel Doenges, Amy Cummings, Anika Jesi, Tim Sobelman, Joe Holland, Jessica Downing, Bobby Dosanjh, Cathrina Barros, Larry Hernandez, Zhongren Wang, Brian Simi, Loren Turner, Rachel Carpenter). Finally, the authors wish to thank all the state DOTs for responding to the national survey.

Technology Review and Roadmap for Inventorying Complete Streets for Integration into Pavement Asset Management Systems

A National Center for Sustainable Transportation Research Report

July 2021

April Gadsby, Ph.D., Department of Civil Engineering, Georgia Institute of Technology

Yichang (James) Tsai, Ph.D., P.E. Professor, Department of Civil and Environmental Engineering,
Georgia Institute of Technology

John Harvey, Ph.D., P.E., Professor, Department of Civil and Environmental Engineering,
University of California, Davis

TABLE OF CONTENTS

EXECUTIVE SUMMARY	i
Introduction	1
Objectives	2
Tasks.....	3
Methodology for Developing Complete Streets Asset Management Roadmap	4
Survey Development.....	4
Synthesis of Results and Identification of Challenges and Needs	6
Complete Streets Asset Management Roadmap	6
Status of Transportation Agencies’ Complete Streets Implementation and Asset Management .	7
Performance Measures.....	10
Detailed Implementation Status from In-Depth Interviews.....	11
Challenges, Gaps, and Needs for Implementation	12
Funding and Organization Structural Needs.....	12
Rating Systems for Complete Streets Assets	13
Pedestrian and Bicyclist Facility Data Availability, Collection, and Management.....	14
Roadmap for Inventorying Complete Streets Features for Complete Streets Asset Management.....	15
Asset Management Development Pathway	18
Improved Data Collection and Analysis Pathway	19
Detailed Project Descriptions	20
Conclusions and Recommendations.....	22
References	23
Data Management	27
Appendix: Detailed Description of Roadmap Components.....	28
Research.....	28
Development	30
Implementation	31

List of Tables

Table 1. Sections and their titles of the in-depth survey..... 6

Table 2. Table of Performance Measures for the Five State DOTs That Have Them 10

Table 3. Example Detailed Project Descriptions 21

Table 4. Recommended Research Projects 28

Table 5. Recommended Development Projects 30

Table 6. Recommended Implementation Projects 31

List of Figures

Figure 1. Examples of Complete Streets designs made using Streetmix.net.	1
Figure 2. Visual Representation of the Methodology.....	4
Figure 3. (a) Complete Streets guidance implementation, (b) length of time agencies have been implementing Complete Streets (c) agencies with Complete Streets performance measures, (d) agencies with a Complete Streets coordinator.	9
Figure 4. Building the complete streets asset management system from the data foundation up.	16
Figure 5. Roadmap for complete streets asset management.	17
Figure 6. Performance Measures Pathway, products in bold	19
Figure 7. Improved Data Collection and Analysis Pathway, products in bold	20

Technology Review and Roadmap for Inventorying Complete Streets for Integration into Pavement Asset Management Systems

EXECUTIVE SUMMARY

For the nation's interstates and auto-focused assets, neglecting asset management leads to deteriorating facilities, inefficient use of funding, and reactive rather than proactive maintenance. To address this, federal legislation requiring asset maintenance and data collection on asset conditions has been passed starting with MAP-21 in 2012 and the current FAST Act extended one year to last through 2021.

As defined by the National Association of City Transportation Officials (NACTO), Complete Streets are an "approach to roadway design focused on the needs of all transportation users, regardless of their age, ability, or mode of travel". The Complete Streets policies originated in 2003 and have since been adopted by state and local agencies across the nation. As active transportation assets are built, these types of assets need to be incorporated into asset management.

Therefore, the objectives of this study are to understand the implementation status of Complete Streets asset management, identify what agencies need to improve their asset management plans, and develop a road map to move forward with Complete Streets asset management. To accomplish these objectives, surveys and interviews were used to gather information on Complete Streets. First, an initial draft survey was developed. Communication and interviews with GDOT and Caltrans helped refine the in-depth survey. The final survey was divided into 1) a short national survey focused on high-level Complete Streets implementation status, and 2) an in-depth survey to be given via in-person and phone interviews to selected transportation departments. Although the national survey is not within the scope of the project and was conducted in a separate effort at Georgia Institute of Technology, some national survey results were included as needed in this report. Interviews were conducted with GDOT and Caltrans as well as two metropolitan planning organizations (MPOs): Washoe Regional Transportation Commission in Nevada (RTC) and the Atlanta Regional Commission (ARC) in Georgia to fill out the in-depth version of the survey. All 50 state DOTs filled out the national survey. The results from both sets of surveys were synthesized to identify challenges and needs for Complete Streets implementation and asset management and to develop a roadmap to addressing those needs.

Of the national survey respondents, 39 reported that they had some Complete Streets guidance. Although required to have a bike/ped coordinator, only 15 said they had a complete streets coordinator or liaison. Only seven had network level performance measures. Agencies marked safety, usage, and cost-effectiveness as the most important aspects to measure for performance if they were to develop a set of performance measures. Prioritization of Complete Streets is motivated by safety, usage, and cost-effectiveness.

The surveys showed many needs and challenges for implementing complete streets asset management. Some of the biggest challenges include funding and organization structures, lack of rating systems, and bicycle and pedestrian data availability, collection, and management. Challenges within the funding and organization structures include a lack of performance measures, a need for a complete streets coordinator, and needs for both inter- and intra-agency collaboration. The rating systems challenges include the need for a condition rating system for Complete Streets assets including both physical rating systems, long-term performance forecasting, and cost analyses to support performance measures. The bike/ped data section highlights the need for improved safety and count data, data collection methods, and software and databases for storing and managing the data.

These gaps and challenges were compiled into a road map to implementing asset management for complete streets. Two major pathways were developed for this road map: the asset management development pathway and the improved data collection and analysis pathway. Both pathways progress from concept to implementation, incorporating many of the gaps and challenges noted in the surveys and interviews.

This report uses a national survey and interviews with various offices in Caltrans, GDOT, RTC, and ARC to identify the gaps and needs for implementing asset management for Complete Streets assets. With those gaps and needs, a road map with two pathways was devised to aid agencies in progressing and identifying future research projects. The contributions of this report, including both the needs identification and road map, are critical to agencies moving forward with asset management for complete streets. This is the first proposed roadmap for Complete Streets asset management. It can act as a starting point for conversation or research about incorporating complete streets into asset management. The final deliverables in this research project include 1) identified needs and challenges of Complete Streets asset management, 2) a Complete Streets asset management roadmap, 3) two Complete Streets pathways (a. asset management development and b. improved data collection and analysis), and 4) recommended projects for Complete Streets asset management research, development and implementation. Based on the roadmap, recommendations for next steps include:

1. It is recommended to perform follow-up interviews with states with network level Complete Streets performance measures and targets to better describe the best practices.
2. It is suggested to survey and interview city and county officials to understand the local-level needs and challenges for Complete Streets asset management for fine-tuning the roadmap.
3. It is recommended to develop research needs statements (RNS) for the projects to address the needs related to Complete Streets asset management. Recommended initial studies are developing a condition rating system for Complete Streets assets with defined performance measures, and pilot testing technologies for Complete Streets data collection.

Introduction

Recognizing the importance of asset maintenance and rehabilitation, the federal government has passed a series of policies requiring asset management based on data collection on asset conditions, including the federal MAP-21 act in 2012 (1) and the current FAST Act extended one year to expire in late 2021 (2).

Transportation agencies have an interest in increasing the use of active modes of transportation due to the potential benefits for public health and air quality. Active transportation requires the building, and then the maintenance and rehabilitation of infrastructure features to enhance the safety and appeal of active transportation. Complete Streets is a set of design principles for active transportation infrastructure that also bring other benefits. As defined by the National Association of City Transportation Officials (NACTO), Complete Streets policies are an “approach to roadway design focused on the needs of all transportation users, regardless of their age, ability, or mode of travel” (3). Figure 1 depicts examples of Complete Streets design with varying amounts of bicycle, pedestrian, and transit dedicated space. Bicycle advocates in the United States had been using the term “routine accommodation” since the 1970s, but in 2003 coined the term Complete Streets as a more impactful and inclusive phrase (4, 5). NACTO published their initial Complete Streets guidance in 2011 (6). Since then, Complete Streets are increasingly being adopted by state and local agencies into transportation infrastructure across the nation. According to Smart Growth America’s Complete Streets Coalition in 2018, 35 states had adopted some level of Complete Streets policy (7).



Figure 1. Examples of Complete Streets designs made using Streetmix.net.

Complete Streets policies provide many benefits including increased numbers of people walking, biking, and taking transit; improved safety; improved public health; and reduced emissions. It has been shown repeatedly that if municipalities build infrastructure to support active transportation, more people will use these modes (8–13). There is also evidence that building Complete Streets increases cycling numbers but keeps fatality rates constant resulting in a net lower fatality risk per cyclist (14, 15). One Complete Streets project in Massachusetts increased bicycle volumes by 929% while dropping crash rates from 2.5 to 0.6 per 100 trips (15). A city in Iowa restriped a roadway during routine maintenance from lanes, to two lanes with a center left turn lane and two bike lanes which reduced crashes by 57 percent while carrying 6% more motor vehicles (15).

These projects show Complete Streets designs can improve cycling numbers and traffic flow while reducing crash rates. But injuries and fatalities also have associated costs. A report by Anderson et al. found that across the 34 projects in the study, \$18.1 million was saved in averted costs from collisions in the first year (15). They also found that in some cases these averted cost savings were higher than the project cost. For example, in Nevada a project added bike lanes and widened sidewalks, which resulted in a 45% reduction in crashes and 62% reduction in injuries. They calculated that this saved them \$5.8 million in the first year, more than the \$4.5 million project cost (15). Active and public transportation also have associated health benefits (including cardiovascular, respiratory, and mental health) due to the increased daily activity of their users (16–18). Encouraging low-emissions forms of transportation can also reduce greenhouse gas emissions (17, 18). As agencies continue to build Complete Streets infrastructure to take advantage of these benefits, we need to be planning how to maintain this newly built infrastructure.

The Federal Highway Administration (FHWA) defines asset management as “a strategic approach to managing transportation infrastructure assets [which] provides a systematic process for maintaining, upgrading, and operating physical assets cost effectively” (19). They list the benefits of asset management to include cost savings, more rational resource allocation decisions, simplified cost estimating and budget processes, improved data access, and improved safety. To reap these benefits, the government has passed numerous policies requiring asset maintenance and data collection on asset conditions in the USA starting with MAP-21 (1) in 2012 and the current FAST Act (2) set to expire in late 2020. The USA is not unique in the development of asset management policies; increased focus on asset management policies by transportation agencies has occurred globally (20–22).

Complete Streets assets are components of a street designed to accommodate the needs of all users. This definition includes a broad array of assets including the driving lane, bicycle lanes, sidewalk, crosswalks, transit stops, and so on. This report focuses primarily on active transportation (bicycling and walking) assets.

Objectives

Asset management has proven to be an effective means to manage roadway assets that has been widely adopted by state and local transportation agencies (19, 20, 23). However, agencies

do not typically include Complete Streets in mainstream asset management systems, including the pavement asset management systems. Limited research was found on measuring the condition of bicycle and pedestrian facilities (24–27), and none was found on incorporating these facilities into existing asset management systems in the United States. Therefore, the objectives of this study were:

- Understand the status of Complete Streets asset management and implementation
- Identify what agencies need to improve their asset management plans
- Develop a road map addressing those needs to advance progress with Complete Streets asset management

The road map is intended to be used as a starting point and prompt for conversation that guides researchers and agencies to develop the framework, data, analysis, and decision support needed to fully incorporate Complete Streets into asset management processes. Information in this study was developed from the synthesis of a national survey, interviews, and in-depth discussions with transportation agency personnel. This study contributes to practice by identifying critical action steps and future research needs to move Complete Streets asset management from an idea to implementation.

Tasks

The tasks completed were:

1. Develop and conduct interviews with the California Department of Transportation (Caltrans), the Georgia Department of Transportation (GDOT), the Atlanta Regional Commission (ARC), and the Regional Transportation Commission of Washoe County (RTC) to gain an in-depth understanding of the challenges and needs for Complete Streets implementation¹
2. Review Complete Streets implementation status and the challenges and needs for moving forward with Complete Streets asset management
3. Develop a roadmap to incorporate Complete Streets assets into asset management systems.
4. Write the final report

¹ Survey data can be found at Gadsby, April; Tsai, Yichang (James); Harvey, John (2021), Technology Review and Roadmap for Inventorying Complete Streets for Integration into Pavement Asset Management Systems, Dryad, Dataset, <https://doi.org/10.25338/B8DK9G>

Methodology for Developing Complete Streets Asset Management Roadmap

The goals of the methodology were to gain both a depth and breadth of understanding of Complete Streets implementation and asset management. The end product is a research road map to guide discussion on research, development, and implementation of asset management for Complete Streets. This was accomplished primarily through synthesis of results from a national survey and in-depth online interviews with GDOT, Caltrans, ARC, and RTC. Figure 2 presents our methodology for developing the Complete Streets asset management roadmap. The methodology has the following major components: 1) Survey Development and Deployment, 2) Synthesis of Results and Identification of Challenges and Needs, and 3) Creation of the Roadmap.

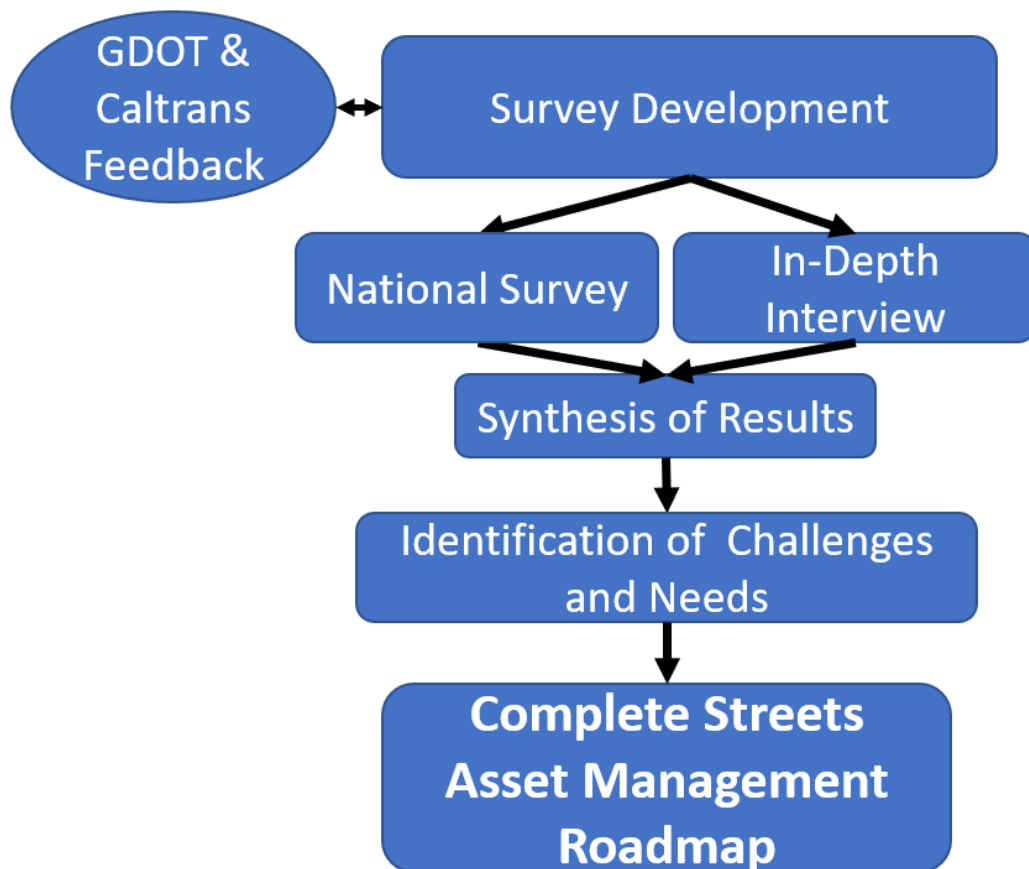


Figure 2. Visual Representation of the Methodology

Survey Development

The initial survey was developed based on our background knowledge of asset management and Complete Streets based on experience. To improve the survey, it was sent to personnel at GDOT, ARC, and the RTC, and later Caltrans for discussion, feedback, and refinement. After

multiple meetings with personnel at the four agencies, the ninth and final edition of the in-depth survey was ready for deployment. However, by the ninth iteration, the survey was very detailed and in-depth, beyond any single person's expertise. Therefore, two versions of the survey were used. The original, in-depth survey and a focused survey to be deployed nationally.

National Survey

Although outside of the project scope of this project, the national survey was designed and conducted with the purpose of gaining a broad perspective about the implementation of Complete Streets at a national level. The survey asked whether agencies had a policy or plan for Complete Streets, funding sources, project prioritization, performance measures, and challenges with implementation. The survey contained 17 questions and took under 10 minutes to complete. DOTs were encouraged to fill out the survey online but were also given the option to fill out a pdf or word version of the survey. All 50 state DOTs responded to the survey.

In-Depth Survey/Interviews

The in-depth survey/interview was designed with the purpose of delving deeper into the challenges and needs of agencies wanting to implement Complete Streets asset management. The final version of the in-depth survey comprised three categories of questions: Complete Streets Design and Implementation, Complete Streets Safety and Operations, and Inventorying Complete Streets for Integration into Pavement Asset Management. Each category comprised multiple parts for a total of 13 sections. Table 1 shows the sections and their titles.

The length and breadth of the survey necessitated sending it to a variety of people in each organization. Agency members that agreed to partake could review the survey and brief descriptions of each section, then were interviewed to get their answers in the most efficient manner possible. Several people at GDOT, Caltrans, Atlanta Regional Commission (ARC), and Regional Transportation Commission of Washoe County (RTC) were interviewed by phone or in-person for one hour each. 12 interviews were conducted. They were informed that their responses would be presented as that of the agency. When responses from an agency disagreed, the most common response was taken as the final answer for that agency.

Table 1. Sections and their titles of the in-depth survey

<i>Section</i>	<i>Title</i>
Category 1	Complete Streets Design and Implementation
Part I	Complete Streets policy adoption and implementation
Part II	Motivation for Complete Streets Implementation
Part III	Funding for Complete Streets Implementation
Category 2	Complete Streets Safety and Operation
Part IV	Complete Streets Implementation Strategy and Its Safety Impact
Part V	Bike Lane Physical Condition Assessment
Part VI	Bicyclists' Sense of Safety/Level of Comfort
Part VII	Sidewalk Physical Condition Assessment
Part VIII	Sidewalk Level of Comfort/Walkability Assessment
Part IX	Sidewalk/American with Disabilities Act (ADA) Compliance Assessment
Part X	Scooter Safety
Part XI	Automated Vehicle (AV) Operation in Complete Streets
Category 3	Inventorying Complete Streets for Integration into Pavement Asset Management
Part XII	Pavement Condition Assessment and Complete Streets Asset Inventory
Part XIII	Qualitative and Quantitative Value of Complete Streets Implementation

Synthesis of Results and Identification of Challenges and Needs

The survey and interview responses were gathered in spreadsheets for comparison, and the in-depth interview recordings were reviewed for additional information. Once thoroughly familiarized with the data, the team identified challenges and needs for the roadmap from a combination of stated challenges and needs from the national survey and interview responses. In this step, the national survey and in-depth interviews were synthesized into an understanding of the current implementation status of Complete Streets and a final comprehensive set of challenges and needs.

Complete Streets Asset Management Roadmap

The final product of the research is a roadmap for research, development, implementation to achieve the vision of full integration of Complete Streets into asset management. The roadmap is displayed in two pathways that address the identified challenges and needs. The final products of from completion of the steps in the roadmaps should put agencies in position to implement asset management for Complete Streets.

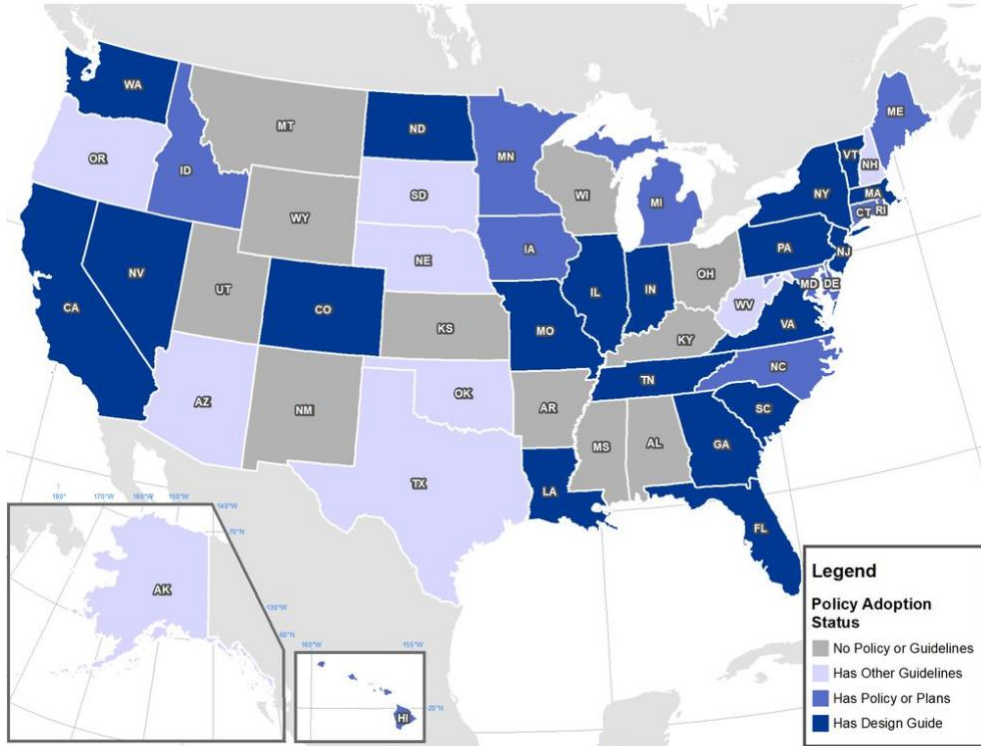
Status of Transportation Agencies' Complete Streets Implementation and Asset Management

According to the national survey, 39 states have enacted some amount of Complete Streets guidance. Some of the 11 without published guidance noted that they had context-sensitive solutions or bike and pedestrian guidelines, but no specific Complete Streets guidance. These results are shown in Figure 3a, which splits guidance up into having a design guide, a policy or plan, some other form of guidance, or no guidance. This split was based on the implementation history at GDOT and Caltrans. These agencies developed a policy or plan before a design guide, and a design guide was necessary for widespread implementation. This may not be accurate for all state DOTs.

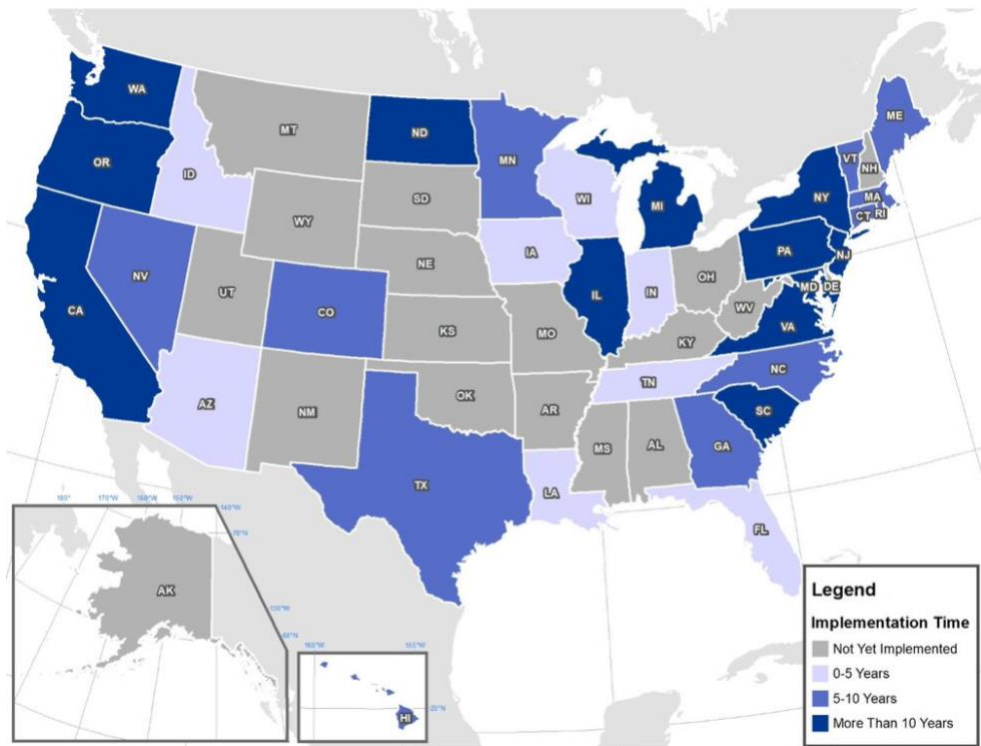
Figure 3b shows the temporal spread of Complete Streets implementation according to the survey, with twelve having implemented them for over ten years, 24 for over five, and the remainder for less than five years. This shows that Complete Streets and active transportation are being increasingly implemented. The primary motivation for implementing Complete Streets was safety, followed by mobility for bicyclists and pedestrians. Development of communities, increased usage of active transportation, improved quality of life, and vehicular safety were all stated as other motivators by transportation agencies.

Although agencies have enacted Complete Streets guidance throughout the country, they've made little progress on implementing asset management performance measures or targets for Complete Streets. As shown in Figure 3c, only seven agencies indicated they have Complete Streets performance measures at the network level, and another three at the project level. Twelve agencies responded they were developing performance measures and targets, suggesting that this is an urgent need for agencies.

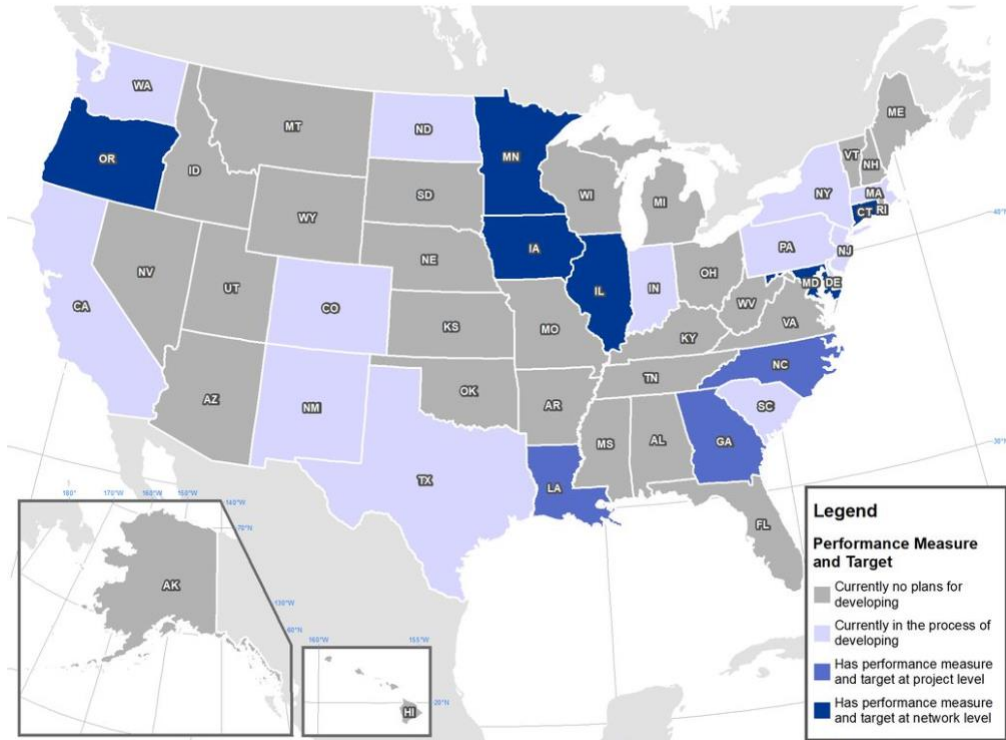
As Complete Streets cover multiple offices in most DOTs, a liaison or Complete Streets office aids in coordinating efforts to implement Complete Streets. Although the Federal Highway Administration requires all states to have a bike/ped coordinator (28), as seen in Figure 3d, only 15 agencies have instituted what they would call a Complete Streets coordinator. Based on feedback about the national survey, the survey sparked conversation within agencies as they review their policies and practices. These conversations have included discussions of organizational structure, policy shifts, and focused debates around topics such as including freight in Complete Streets plans.



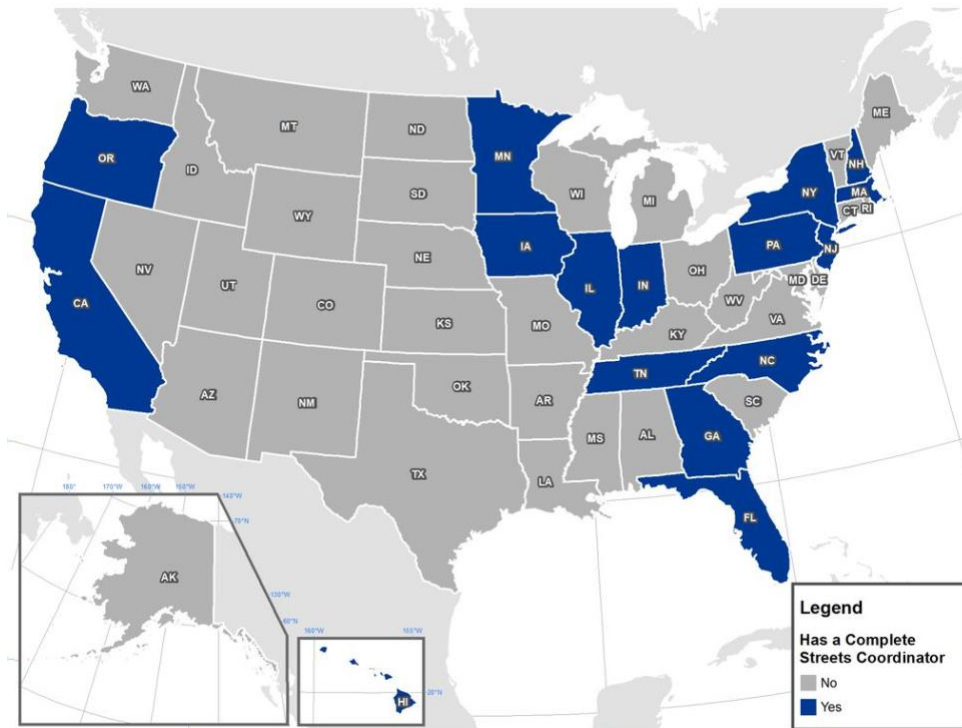
(a)



(b)



(c)



(d)

Figure 3. (a) Complete Streets guidance implementation, (b) length of time agencies have been implementing Complete Streets (c) agencies with Complete Streets performance measures, (d) agencies with a Complete Streets coordinator.

Performance Measures

Of the seven agencies that indicated they had Complete Streets performance measures, five could provide them to us. Table 2 provides summary of those five agencies' Complete Streets performance measures. Based on the national survey, the top three guiding criteria for these performance measures are safety, usage (e.g., bike/pedestrian counts), and condition, but the most common measures in use were pavement condition, ADA compliance, and existence of pedestrian and bicycle facilities. Upon further review of the provided performance measures, no agency had maintenance-focused performance measures for bicycle and pedestrian specific assets. All condition-based measures were taken using the adjacent travel lane(s). Agencies measured bike/ped injuries and/or fatalities as their safety measures. The measures in the usage category typically measured the amount of bike/ped trips, but each agency selected a different metric. Although the definition of suitable varied, there were efforts to make accessibility measures focused on the suitability of roads for use by cyclists.

These five agencies did not all specify targets in their reports besides a desire for an increase (i.e., bike/ped mode share) or a decrease (i.e., # of accidents). Maryland and Oregon both had some performance measures, but Maryland is the only state that consistently defined performance targets for each of their measures from the review of their documents. It is recommended that agencies set both performance measures and targets to track progress.

Table 2. Table of Performance Measures for the Five State DOTs That Have Them

<i>DOT</i>	Usage	Safety	Condition	Accessibility	Network	Other
<i>Connecticut (29)</i>						Fulfillment of steps in their plan (building pieces of the network, safety audits, manual updates, etc.)
<i>Iowa (30)</i>	Bike and pedestrian mode share	# of accidents, # of accidents involving children	N/A	% of rural and urban network suitable for bike and ped	# of miles of bicycle facility added	% of Transportation Alternatives Program funds used for bike/ped; # of MPOs, counties, and cities adopting Complete Streets policies

DOT	Usage	Safety	Condition	Accessibility	Network	Other
<i>Maryland</i> (31)	Vehicle miles travelled, transit ridership	# of fatalities and injuries, perception of safety (general)	Road condition (not bike specific)	% of network with acceptable Level of Traffic Stress score, access to transit, perceptions of connectivity	N/A	
<i>Minnesota</i> (32)	% of residents who bike 1x/week, transit ridership	# of fatalities	Ride quality (not bike-specific), curb ramp condition	ADA compliance, accessible pedestrian signals installed	Projects addressing bike, ped, transit, and freight needs (one measure each)	
<i>Oregon</i> (33)	% of commute trips less than 20 minutes made by bike and by walking (1 measure each)	# of fatalities, # of injuries, Perception of safety of walking and cycling		% of streets within a 1/2 mile of a transit stops with sidewalk, % of network with Level of Traffic Stress 3 or lower, % of streets within 1 mile of a transit stop with bike Level of Traffic Stress 2 or lower		Recognition measures (i.e., state ranking for bike friendliness)

Detailed Implementation Status from In-Depth Interviews

The in-depth interviews gathered more detail on the Complete Streets' implementation status and history for the two DOTs interviewed. Both GDOT and Caltrans have policies directing the implementation of Complete Streets. Caltrans issued its initial directive (Deputy Directive 64) in 2008 and updated it in 2014 (34). This directive requires the consideration of bike/ped/transit improvements in all projects, including construction and rehabilitation projects. In 2019, the California Senate passed Senate Bill 127 requiring funding for addition of pedestrian and bicycle facilities on most transportation facilities or rehabilitation of existing facilities, but it was vetoed by the governor (35). In contrast to Deputy Directive 64, SB 127 was more explicit, detailed, and went a step further in implementation by specifying the need for asset management, targets, and performance measures. Although it was not passed, Caltrans indicated that they are endeavoring to meet some requirements set forth in it. Towards this end, Caltrans has created a Complete Streets office and is working on developing an asset management plan with performance targets and measures.

A State Transportation Board Resolution mandated the Georgia DOT's Complete Streets policy in 2012 and requires consideration of bike/ped/transit facilities in all new construction, reconstruction, and capacity-adding projects (36). Chapter 9 of the GDOT Design Policy Manual (37) outlines this. However, they have not reached the implementation level of setting performance targets and measures for their assets. Both agencies are implementing at the project level but see benefits of incorporating more of a network perspective to their Complete Streets policies. GDOT and Caltrans' initial steps were similar, but Caltrans is a step ahead by working on developing Complete Streets associated targets, performance measures, and an asset management plan.

Challenges, Gaps, and Needs for Implementation

Funding and Organization Structural Needs

Of all the challenges to implementing Complete Streets, the national survey indicated that funding was the primary challenge. 25 agencies responded that funding and lack of resources were their primary challenges to implementing Complete Streets. Right of way and construction costs were the main costs.

Lack of performance measures for building and maintaining Complete Streets' assets contributes to the lack of funding. Our interviewees suggested that without organizational Complete Streets performance measures in place there is not enough priority given to Complete Streets to solicit dedicated funding. Building Complete Streets is typically funded as part of a project and future maintenance is usually not considered once the project is complete. Agencies that have performance measures focused on building (miles of bike lanes, ADA compliance, counts when available, etc.), but did not have maintenance-related performance measures (cracking and other deterioration measures). Agencies that checked pavement quality of bike lanes did so in combination with the vehicle travel lane. The vehicle travel lane which will naturally accrue more wear than a bike lane due to heavier loading. Additionally, aspects of condition (e.g., debris, cracking, texture, etc.) may matter more to cyclists than drivers (24, 38). Bicycle and pedestrian-specific performance measures are needed. Creating performance measures regarding both the building and maintenance of Complete Streets assets will assist in predicting needs and acquiring funding.

The survey also indicated that lack of a dedicated organizational structure around Complete Streets also contributes to the lack of funding. Complete Streets cover many jurisdictions, crossing from state to city or county owned roads and do not fit neatly into one existing office at most DOTs. For example, personnel from traffic operations, planning, data, and design divisions in the DOTs participated in the interviews, all with some contribution to Complete Streets building and maintenance. The interviews suggested that a coordinator or liaison is beneficial to help coordinate Complete Streets between offices within an agency and between agencies. 15 respondents marked that they have a Complete Streets Coordinator or liaison. Besides a coordinator, the interviewees explain that for successful implementation Complete Streets asset management, it is also essential to establish organization performance measures that various offices (e.g., planning, maintenance, traffic operations, etc.) can respond to. As for

collaboration with the cities and counties that state roads pass through, only eight agencies responded they implemented Complete Streets at the network level with inter-agency collaboration. Complete Streets require higher levels of collaboration both within DOT and with other agencies, which will require new organizational structures and operation procedures to be effective.

Rating Systems for Complete Streets Assets

According to the survey, agencies had little information regarding the condition of their complete streets assets. An agency's ultimate goal is to have a facility rating system that can both determine treatment options and timing as well as communicate the need to decision makers for funding allocation. Agencies need to know what aspects of performance are necessary to collect data for. Respondents identified four categories of performance for identifying and prioritizing maintenance and rehabilitation: safety, comfort, deterioration rate, and utilization. Agencies also need a prioritization approach to provide a weight to the rating for a final prioritization. Experience in asset management shows that prioritization requires some knowledge of the deterioration rate for the assets (performance models), and a conceptual identification of appropriate treatment(s) (decision trees). The rest of this section will discuss the steps agencies need to take to develop a prioritization approach based on experience in pavement asset management.

A life cycle cost analysis (LCCA) can contribute to both project and network level asset management. At the project level, LCCA can assess initial, maintenance, and rehabilitation costs over the life cycle of different construction alternatives (39). LCCA can also be used for project level selection of the best maintenance or rehabilitation (M&R) treatment (39). These are both important because they can address the difficulty of getting funding addressed in the surveys by accounting for the later M&R costs of alternative designs or treatments.

At the network level, LCCA is generally not used for several reasons, primarily because the optimization approach using LCCA has only recently been developed (40). Based on experience working with DOTs on their pavement management systems, most pavement management systems use decision trees to identify the most appropriate level of treatment (preservation, maintenance, rehabilitation, or reconstruction) for a set of condition variable states. They then use a cost/benefit analysis rather than an LCCA analysis to prioritize projects that are to receive a treatment. However, LCCA can improve the decision trees that trigger and then select the category of treatment. Agencies need performance measures and cost information on treatments for Complete Streets to use LCCA at the project level and decision trees at the network level.

Finally, the interviews indicated that agencies need an encompassing condition rating system around which performance models can be built. This rating system is a critical need for agencies to start incorporating Complete Streets into asset management and prioritization for maintenance funding. A multi-criteria objective decision framework, considering asset condition deterioration, life cycle cost, safety, utilization, and accessibility, needs to be further formulated and developed to support Complete Streets M&R prioritization decision. In

addition, cross-asset decision making in terms of the funding allocation and distribution among different assets (e.g., travel lane pavements, bridges, sidewalks, traffic congestion reduction, etc.) still need to be properly formulated and developed to support a comprehensive Complete Streets asset management system.

Pedestrian and Bicyclist Facility Data Availability, Collection, and Management

According to the survey, transportation agencies see the need for data on the presence, condition, usage, comfort, and safety of their pedestrian and bicyclist facilities on a network level. Agencies believe these data are necessary for them to identify planning and maintenance needs within a network.

However, they currently have limited availability of these data due to both limited data collection and cost-effective methods to collect the data. For example, the interview results indicated that agencies assess sidewalks only for ADA compliance, not condition, on a project by project basis. Bicyclist facility condition data is not being assessed or assessed as part of pavement condition surveys in asset management systems together with the vehicle travel lanes. This makes it impossible to determine bike facility-specific treatments. Both types of data have methods to collect them, but the respondents indicated that the current data collection methods are too costly and labor intensive to be used extensively. The survey responses mentioned measures for safety and usage as the most difficult to collect due to data inaccuracy and limited data collection capacity at a network level, respectively. Improvement of safety data and usage data were the most highly requested data improvements.

Safety Data

All agencies surveyed who have a prioritization system for building Complete Streets listed safety as one of their top three factors in prioritization of Complete Streets projects. However, crashes involving a pedestrian or cyclist often go unreported, except in cases of severe injury, due to the lack of police involvement in these types of incidents (41). The limited crash data leaves transportation agencies wondering where improvement is needed and without a means to quantify the effects of the improvements they make.

Network Level Pedestrian and Bicyclist Usage Data

The survey and interviews indicated that agencies consider pedestrian and bicycle usage data difficult to collect at the network level. Of the 21 agencies that responded to an open-ended question about their data collection challenges, 18 listed network level usage data as their biggest data collection challenge. Although spot counts are possible, it is challenging to collect usage data at a network level. Nevertheless, this data is important for transportation agencies to prioritize locations to implement Complete Streets.

Optimize Data Collection Process for Complete Streets Data Inventory

The surveys and interviews indicated that agencies need a cost-effective means of collecting their Complete Streets data for maintenance and asset management. Often agencies collect pavement surface data for the vehicle travel lanes automatically using high speed vans. They

then do the subsequent data processing and analyses for pavement distress information extraction automatically or semi-automatically. However, many agencies manually survey their bike/ped assets, which are slow, costly, and subject to human variability. The interviewed agencies show strong interest in improving cost-efficiency and data quality by combining additional Complete Streets data collection items into existing pavement condition data collection. Although combining data collection sounds appealing to the agencies, they are unsure of the feasibility without some evidence of its practical effectiveness. Some agencies foresee significant challenges in aligning different objectives from different offices while utilizing limited data collection resources. Other agencies believe that the specialized equipment designed for vehicle lane pavement data collection cannot adapt and capture the features and condition data on bike lanes and sidewalks. Experimentation and testing of data collection procedures suitable for bike lanes and sidewalks, either as part of street data collection systems or as separate systems, is needed.

Database Management and User Interfaces

Agencies surveyed identified the need for a database system and database management plan for their Complete Streets data. The interviews uncovered a need for a database that includes Complete Streets asset information with consistent data that multiple departments in the agency could use. Additionally, agencies identified the necessity of improved user interfaces for both inputting and extracting data from the database. GIS software is one tool that has been used for this task, however; GIS software typically requires a license and training to operate, limiting the number of employees who can interact with the data. GIS also does not use the typical postmile/lane location referencing system (LRS) used by most state and county DOTs or the street/cross street LRS used by most cities. This is especially challenging when considering that Complete Streets spans multiple departments/offices. Therefore, agencies need a database to house the new data, a simple method to input and analyze data that is accessible by multiple departments/offices, and a workable LRS.

Roadmap for Inventorying Complete Streets Features for Complete Streets Asset Management

Based on our review, we have developed a roadmap of actions and projects recommended for moving Complete Streets asset management forward. At the upper right, the roadmap begins with a vision of where completion of the road map leads. The roadmap journey starts on the left of the figure at conceptual development and progresses through the entire research arc to implementation. The research arc allows for the agency to develop their data sources, then models, then software and implementation strategies. This allows the agency to create a strong foundation to build upon. This concept is portrayed in Figure 4. To aid in progressing through the road map shown in Figure 5, it was divided into two pathways: the asset management development pathway (blue boxes) and the improved data collection and analysis pathway (green boxes). These are shown in Figure 6 and Figure 7, respectively. These pathways can be completed in parallel. Both must be completed before the implementation projects and map completion.

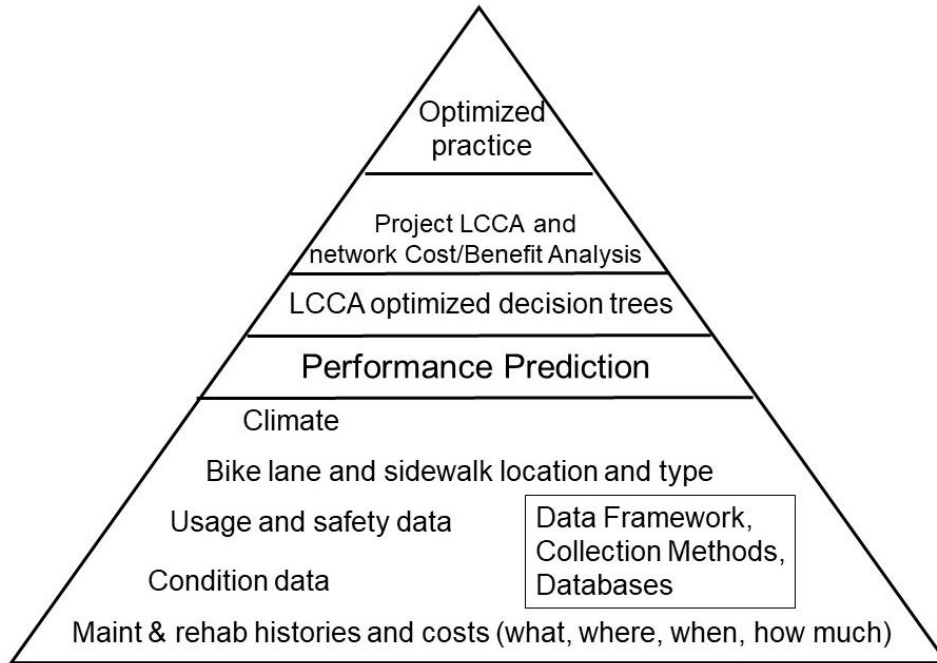


Figure 4. Building the complete streets asset management system from the data foundation up.

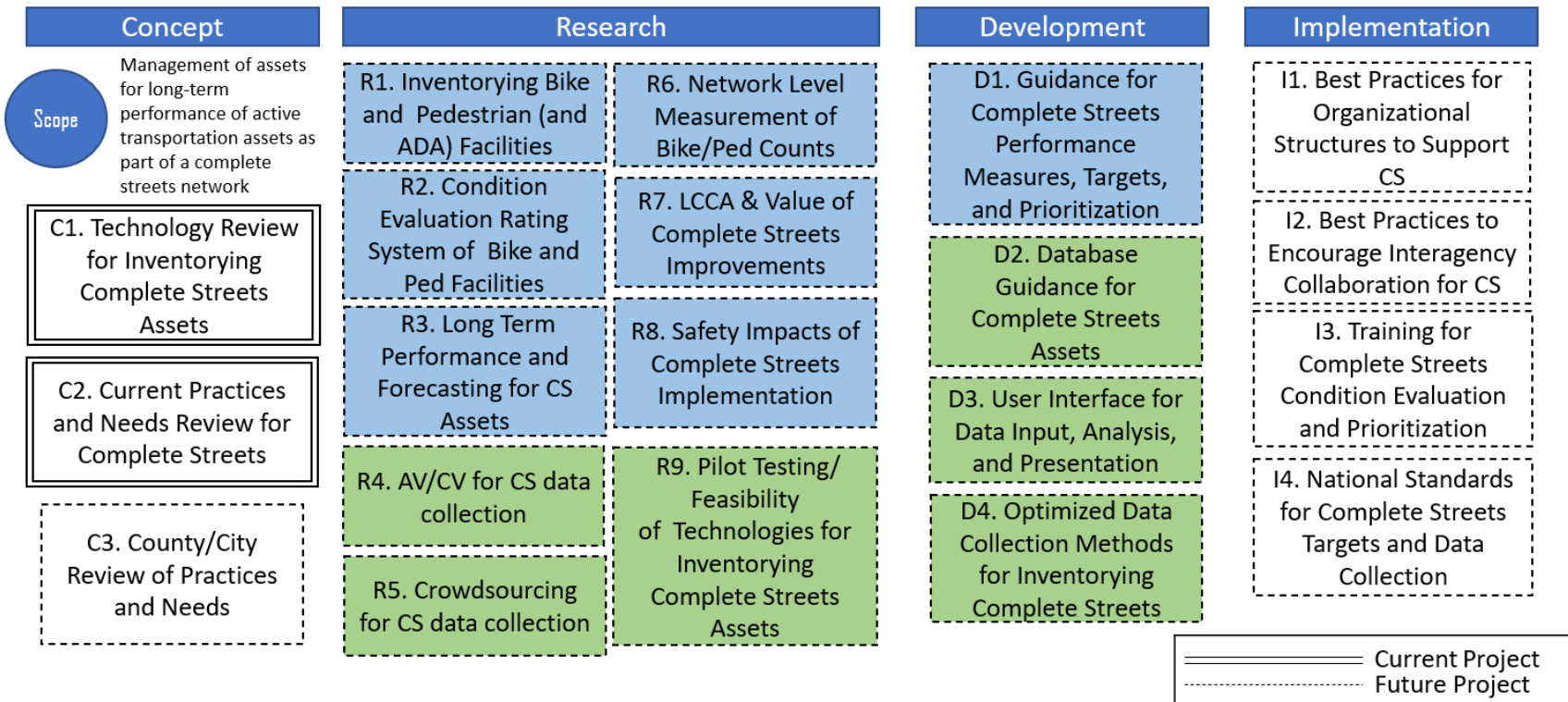


Figure 5. Roadmap for complete streets asset management. The blue boxes are associated with the asset management development pathway and the green boxes with the improved data collection and analysis pathway.

In addition to the road map, some good practices for Complete Streets implementation were identified by the surveys. These include:

1. Appoint a person/create an office to facilitate coordination between offices and agencies
2. Establish Complete Streets performance measures and targets to allow for initiation of a cohesive data collection and prioritization scheme
3. Incorporate Complete Streets into routine maintenance projects such as restriping/resurfacing projects to minimize costs
4. Collaborate with cyclists and cyclist advocacy groups. Strong relations with them can foster mutual benefits such as bike comfort or network maps and promotion of crowdsourcing platforms

Asset Management Development Pathway

The asset management development pathway includes condition assessment, network level usage measures, safety impacts, and economic impacts. These lead to improved guidance for Complete Streets performance measures, targets, and prioritization. The final output of this pathway is guidance for Complete Streets performance measures, targets, and prioritization. Agencies mentioned an urgent need for initial asset management performance targets, so preliminary performance target setting begins the map. Agencies would refine these targets through research and experience. The map then splits into three tracks, condition/economics, usage, comfort/safety, representing the three main categories to include in the performance measures. The condition/economics path identifies, based on our experience and the survey/interview responses, the essential pieces needed to include Complete Streets in asset management:

- Identification of what assets need to be inventoried and an appropriate location referencing system (LRS) to consistently tie data to the location of those assets
- A framework for how to collect data, meaning a condition rating system and equipment and procedures
- Performance models that forecast long-term performance
- Decision trees to trigger treatment timing and identify preliminary type selection
- Benefits equations for cost/benefit analysis
- Prioritization indices or other prioritization methods in the usual case of constrained budgets where not all triggered projects can be funded
- Methods for combining prioritization of projects triggered by the vehicle travel lane with prioritization of active transportation features

Safety and mobility were the primary motivations for developing Complete Streets, so measuring their usage and their impact on safety is critical. The interview and survey responses characterized both usage and safety as data streams that need improved data collection methods. Therefore, projects to address those needs have been included in this roadmap as well.

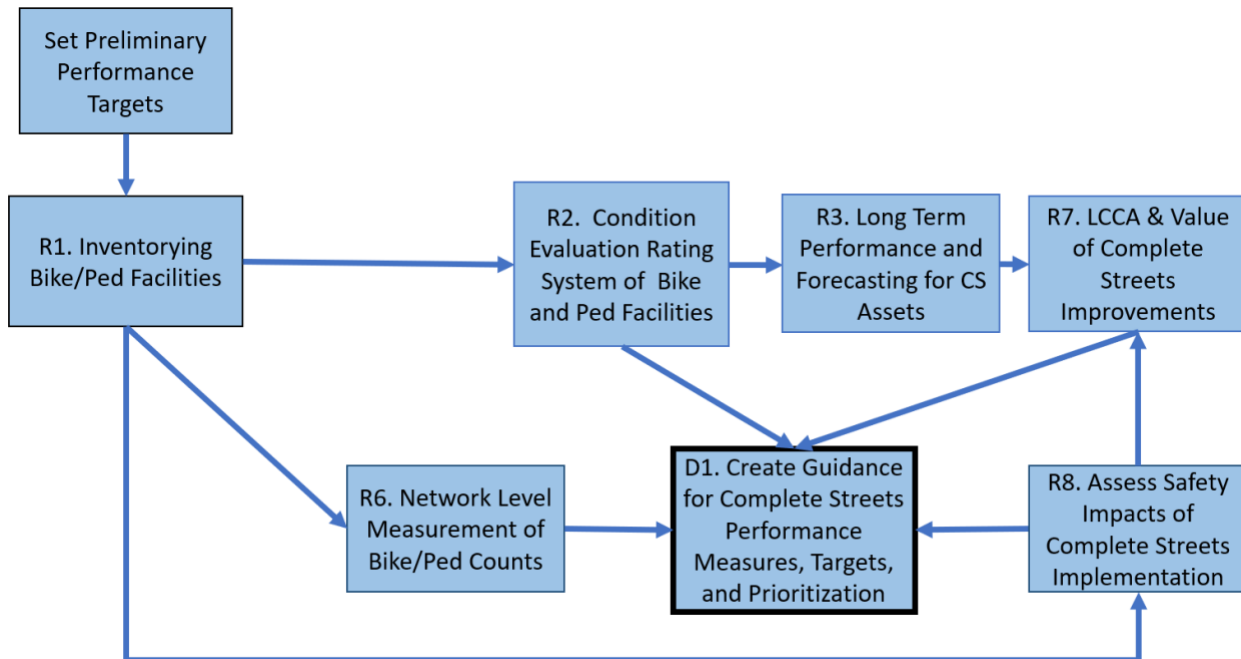


Figure 6. Performance Measures Pathway, products in bold

Improved Data Collection and Analysis Pathway

The improved data collection and analysis pathway covers how to collect, store, and interact with the data. The final outputs from this pathway include a selection of optimal technologies/methods for data collection, a database for the Complete Streets data, and an improved interface for interacting with and inputting the data.

Once data needs are identified, there will be a phase where manual/existing data collection techniques continue while an exploration of improved data collection techniques proceeds. Some ideas for the improved data collection techniques include existing technology such as the light detection and ranging (LiDAR) technology and future technology such as autonomous vehicles or crowdsourcing.

Crowdsourcing offers the opportunity to gather high volumes of data frequently. However, an exploration is needed to identify the best measurement technology audience and items to inventory for acceptable accuracy and resolution. This source of data is uncalibrated, which could be acceptable with sufficiently high volumes of unbiased data. Crowdsourcing would logically also require people to engage in the long term. These aspects need to be assessed to determine crowdsourcing’s potential for asset management data collection. Similarly, transportation agencies believe that Line Detection and Ranging (LiDAR) from autonomous vehicles has the potential to improve their data collection of aspects such as pavement markings, bike lane widths, debris on bike lanes, pavement condition, and presence of all roadway features. This would be high frequency data, but it is unknown whether the data have sufficient accuracy or resolution and the amount of required calibration. Data collection could

entail the use of in-house AV/CVs or a partnership with companies that own connected and automated vehicles such as rideshare, trucking, or delivery companies.

The surveys and interviews indicated that pilot tests are needed to demonstrate the effectiveness of new data collection technologies to aid agencies in defining their bid specifications for technology vendors. Besides how to collect the data, agencies cited needs for data storage and access. Many offices will need the data collected, so the database needs to address all offices' needs. In addition, the interviews unveiled a need for software for data input, analysis, and presentation that is user friendly and accessible by many agency members/offices without license limitations. Therefore, technology testing, database guidance, and user-friendly software development are included in the road map.

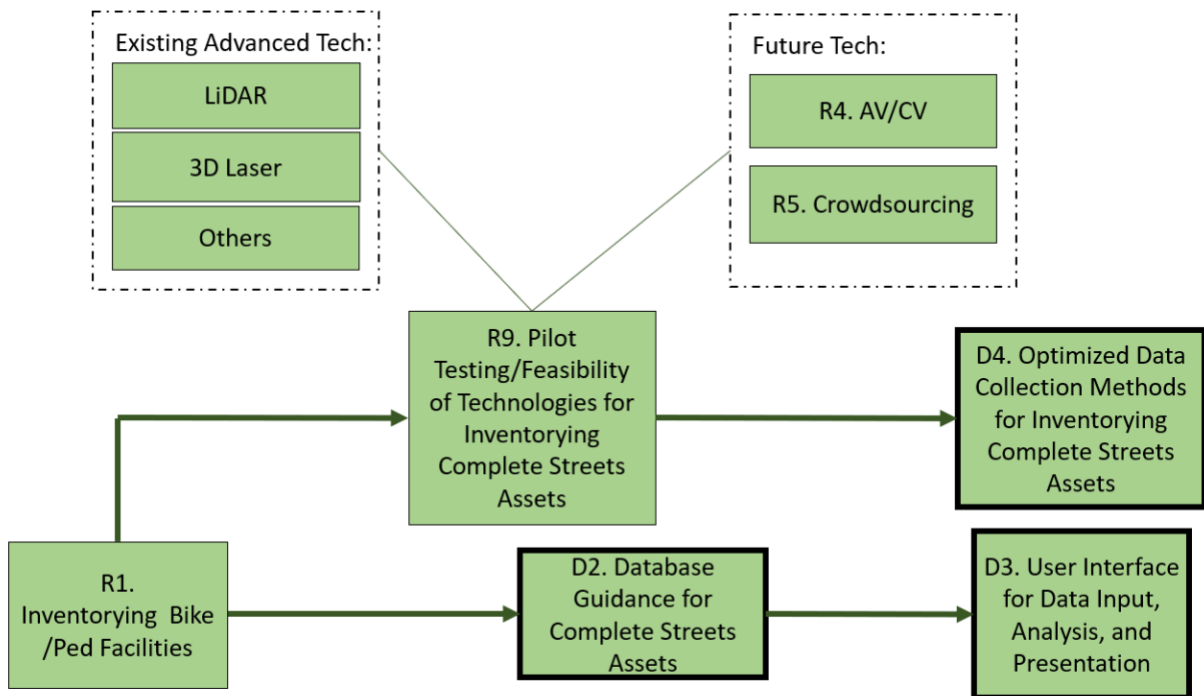


Figure 7. Improved Data Collection and Analysis Pathway, products in bold

Detailed Project Descriptions

Each project listed in the roadmap has an accompanying detailed description with the identified needs addressed and a brief description of the project. Table 3 shows an example of this for the condition evaluation rating system of bike and ped facilities and forecasting and long-term performance of Complete Streets assets projects. The complete set is in the appendix.

Table 3. Example Detailed Project Descriptions

Gap/Need	Project	Description
<p>1. <i>Assets will deteriorate, but there is no measurement of their condition</i></p> <p>2. <i>Agencies need a condition rating system that is descriptive enough to support maintenance decisions</i></p>	R2. Condition evaluation rating system of bike and ped facilities	Define data collection purposes for prioritization, maintenance and rehabilitation planning, and communicated to the public/decisionmakers. Develop rating systems for bike/ped assets.
<p>3. <i>Forecasting is needed to properly support complete streets asset maintenance in the budget</i></p>	R3. Forecasting and long-term performance of complete streets assets	Values for the service life of different bike/ped assets and recommendations of when to treat them based on performance and cost. Forecasting for future funding prediction.

Note: R2 and R3 refer to projects identified in Figure 6.

Conclusions and Recommendations

Incorporation of Complete Streets assets into mainstream asset management is a critical need as agencies build out their Complete Streets networks. This report has used a national survey and in-depth interviews with various offices in Caltrans and GDOT and two MPOs to identify the gaps and needs for implementing asset management for Complete Streets assets. Future work should also include more local-level agencies, but the gaps and needs identified here are based on state DOTs and two big MPOs. With the identified gaps and needs, a road map with two pathways was devised to aid agencies in progressing and in identifying future research projects. The first steps are to set preliminary performance measures and targets and identify what aspects of bike and pedestrian facilities need to be inventoried. From there, agencies can begin monitoring their assets and exploring rating system, performance, and alternative data collection strategies.

The contributions of this study include 1) an understanding of the implementation status of Complete Streets nationally, 2) the identification of needs and challenges for Complete Streets asset management, 3) a roadmap to implementing it, and 4) sparking discussion within agencies about Complete Streets policies and asset management. These contributions are critical to agencies moving forward with asset management for Complete Streets. The final deliverables in this research project include 1) identified needs and challenges of Complete Streets asset management, 2) a Complete Streets asset management roadmap, 3) two Complete Street pathways (a. asset management development and b. improved data collection and analysis), and 4) recommended projects for Complete Streets asset management research, development and implementation.

Based on the roadmap, the following are recommended:

1. It is recommended to perform follow-up interviews with the states with network level Complete Streets performance measures and targets to further develop the best practices cases.
2. It is suggested to survey and interview more city and county level officials, and especially include small and medium sized agencies, to understand the local-level needs and challenges for Complete Streets asset management for fine-tuning the roadmap with local level.
3. It is recommended to develop research needs statements (RNS) for the projects to address the needs related to Complete Streets asset management. Recommended studies to begin with are R1 Inventorying Bike/Ped Facilities and R9 Pilot testing/feasibility of technologies for inventorying Complete Streets assets. a collection.

References

1. FHWA. *MAP-21 | Federal Highway Administration*. 2012. <https://www.fhwa.dot.gov/map21/>. Accessed Aug. 30, 2017.
2. FHWA. Fixing America’s Surface Transportation Act or the FAST Act - FHWA | Federal Highway Administration. <https://www.fhwa.dot.gov/fastact/>. Accessed Aug. 30, 2017.
3. Complete Streets Policies – Active Transportation Policy. <http://atpolicy.org/complete-streets-policies-index/>. Accessed May 6, 2020.
4. McCann, B. Happy Anniversary, Complete Streets! Smart Growth America. <https://smartgrowthamerica.org/happy-anniversary-complete-streets/>. Accessed Jul. 30, 2020.
5. New Jersey Bicycle and Pedestrian Resource Center. History of Complete Streets in the United States. <http://njbikeped.org/services/history-of-complete-streets-in-the-united-states/>. Accessed Nov. 10, 2020.
6. Urban Bikeway Design Guide. National Association of City Transportation Officials. <https://nacto.org/publication/urban-bikeway-design-guide/>. Accessed Jul. 30, 2020.
7. Complete Streets Policies Nationwide. Smart Growth America. <https://smartgrowthamerica.org/program/national-complete-streets-coalition/publications/policy-development/policy-atlas/>. Accessed May 6, 2020.
8. Félix, R., P. Cambra, and F. Moura. Build It and Give ‘em Bikes, and They Will Come: The Effects of Cycling Infrastructure and Bike-Sharing System in Lisbon. *Case Studies on Transport Policy*, Vol. 8, No. 2, 2020, pp. 672–682. <https://doi.org/10.1016/j.cstp.2020.03.002>.
9. Dill, J., and T. Carr. Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them. *Transportation Research Record*, National Research Council, 1828, , 2003, pp. 116–123.
10. Buehler, R., and J. Pucher. Cycling to Work in 90 Large American Cities: New Evidence on the Role of Bike Paths and Lanes. *Transportation*, Vol. 39, No. 2, 2012, pp. 409–432. <https://doi.org/10.1007/s11116-011-9355-8>.
11. Marqués, R., V. Hernández-Herrador, M. Calvo-Salazar, and J. A. García-Cebrián. How Infrastructure Can Promote Cycling in Cities: Lessons from Seville. *Research in Transportation Economics*, Vol. 53, 2015, pp. 31–44. <https://doi.org/10.1016/j.retrec.2015.10.017>.
12. Panter, J., E. Heinen, R. Mackett, and D. Ogilvie. Impact of New Transport Infrastructure on Walking, Cycling, and Physical Activity. *American Journal of Preventive Medicine*, Vol. 50, No. 2, 2016, pp. e45–e53. <https://doi.org/10.1016/j.amepre.2015.09.021>.
13. Santos, G., H. Maoh, D. Potoglou, and T. von Brunn. Factors Influencing Modal Split of Commuting Journeys in Medium-Size European Cities. *Journal of Transport Geography*, Vol. 30, 2013, pp. 127–137. <https://doi.org/10.1016/j.jtrangeo.2013.04.005>.

14. Mooney, S. J., C. Magee, K. Dang, J. C. Leonard, J. Yang, F. P. Rivara, B. E. Ebel, A. Rowhani-Rahbar, and D. A. Quistberg. "Complete Streets" and Adult Bicyclist Fatalities: Applying G-Computation to Evaluate an Intervention That Affects the Size of a Population at Risk. *American Journal of Epidemiology*, Vol. 187, No. 9, 2018, pp. 2038–2045. <https://doi.org/10.1093/aje/kwy100>.
15. Anderson, G., L. Searfoss, A. Cox, E. Schilling, S. Seskin, and C. Zimmerman. Safer Streets, Stronger Economies: Complete Streets Project Outcomes From Across the United States - ProQuest. *Institute of Transportation Engineers ITE Journal*, Vol. 85, No. 6, 2015, pp. 29–36.
16. Ewing, R., and R. Krutetzer. Understanding the Relationship Between Public Health and the Built Environment. <https://www.usgbc.org/resources/understanding-relationship-between-public-health-and-built-environment-report-prepared-lee>. Accessed Nov. 13, 2020.
17. Maizlish, N., J. Woodcock, S. Co, B. Ostro, A. Fanai, and D. Fairley. Health Cobenefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the San Francisco Bay Area. *American Journal of Public Health*, Vol. 103, No. 4, 2013, pp. 703–709. <https://doi.org/10.2105/AJPH.2012.300939>.
18. Mizdrak, A., T. Blakely, C. L. Cleghorn, and L. J. Cobiac. Potential of Active Transport to Improve Health, Reduce Healthcare Costs, and Reduce Greenhouse Gas Emissions: A Modelling Study. *PLOS ONE*, Vol. 14, No. 7, 2019, p. e0219316. <https://doi.org/10.1371/journal.pone.0219316>.
19. FHWA. *Why Your Agency Should Consider Asset Management Systems for Roadway Safety*. FHWA-HRT-05-077. <https://www.fhwa.dot.gov/publications/research/safety/05077/index.cfm> (Accessed Jul. 12, 2021)
20. Shah, R., O. McMann, and F. Borthwick. Challenges and Prospects of Applying Asset Management Principles to Highway Maintenance: A Case Study of the UK. *Transportation Research Part A: Policy and Practice*, Vol. 97, 2017, pp. 231–243. <https://doi.org/10.1016/j.tra.2017.01.011>.
21. Too, E. Infrastructure Asset: Developing Maintenance Management Capability. *Facilities*, Vol. 30, No. 5–6, 2012, pp. 234–253. <https://doi.org/10.1108/02632771211208503>.
22. van der Velde, J., L. Klatter, and J. Bakker. A Holistic Approach to Asset Management in the Netherlands. *Structure and Infrastructure Engineering*, Vol. 9, No. 4, 2013, pp. 340–348. <https://doi.org/10.1080/15732479.2012.657650>.
23. Sinha, K. C., S. Labi, and B. R. D. K. Agbelie. Transportation Infrastructure Asset Management in the New Millennium: Continuing Issues, and Emerging Challenges and Opportunities. *Transportmetrica A: Transport Science*, Vol. 13, No. 7, 2017, pp. 591–606. <https://doi.org/10.1080/23249935.2017.1308977>.

24. Li, H., J. Harvey, Z. Chen, Y. He, T. J. Holland, S. Price, and K. McClain. Measurement of Pavement Treatment Macrottexture and Its Effect on Bicycle Ride Quality. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2525, No. 1, 2015, pp. 43–53. <https://doi.org/10.3141/2525-05>.
25. Bíl, M., R. Andrášik, and J. Kubeček. How Comfortable Are Your Cycling Tracks? A New Method for Objective Bicycle Vibration Measurement. *Transportation Research Part C: Emerging Technologies*, Vol. 56, 2015, pp. 415–425. <https://doi.org/10.1016/J.TRC.2015.05.007>.
26. Frackelton, A., A. Grossman, E. Palinginis, F. Castrillon, V. Elango, and R. Guensler. Measuring Walkability: Development of an Automated Sidewalk Quality Assessment Tool. *Suburban Sustainability*, Vol. 1, No. 1, 2013. <https://doi.org/10.5038/2164-0866.1.1.4>.
27. Sousa, N., J. Coutinho-Rodrigues, and E. Natividade-Jesus. Sidewalk Infrastructure Assessment Using a Multicriteria Methodology for Maintenance Planning. *Journal of Infrastructure Systems*, Vol. 23, No. 4, 2017, p. 05017002. [https://doi.org/10.1061/\(asce\)is.1943-555x.0000362](https://doi.org/10.1061/(asce)is.1943-555x.0000362).
28. FHWA. *ACTION: Designation of Bicycle and Pedestrian Coordinators within State Departments of Transportation - Legislation - Bicycle and Pedestrian Program - Environment - FHWA*. US DOT Memorandum, 1992.
29. ConnDOT. Connecticut Active Transportation Plan. http://www.ctbikepedplan.org/documents/CTActiveTransPlan_01-09-2019.pdf. Accessed May 25, 2021.
30. Iowa DOT. Chapter 8: Implementation. *Iowa Bike/Ped Plan*. <https://iowadot.gov/iowainmotion/files/bike-ped-plan-chapter8.pdf>. Accessed May 25, 2021.
31. Maryland DOT. Maryland DOT Attainment Report. https://www.mdot.maryland.gov/OPCP/2021_Attainment_Report_2021_1_19_LowRes.pdf. Accessed May 25, 2021.
32. Minnesota DOT. Annual Minnesota Complete Streets Performance Snapshot 2017 <http://www.dot.state.mn.us/planning/completestreets/pdf/2017-complete-streets-scorecard.pdf>
33. Oregon DOT. Oregon DOT Annual Performance Progress Report. [https://www.oregon.gov/odot/PerformMang/Documents/Annual Performance Progress Report/ODOT 2021 APPR.pdf](https://www.oregon.gov/odot/PerformMang/Documents/Annual%20Performance%20Progress%20Report/ODOT%202021%20APPR.pdf). Accessed May 25, 2021.
34. Ajise, K. *Deputy Directive 64 Complete Streets - Integrating the Transportation System*. Deputy Directive 64-2, 2014. <https://dot.ca.gov/programs/transportation-planning/office-of-smart-mobility-climate-change/smart-mobility-active-transportation/complete-streets> (Accessed Jul. 12, 2021)
35. Weiner, Bloom, Boerner Horvath, Chiu, Friedman, Eduardo Garcia, and Gonzalez. *Bill Text - SB-127 Transportation Funding: Active Transportation: Complete Streets*. CA Senate Bill 127, 2019. https://leginfo.ca.gov/faces/billNavClient.xhtml?bill_id=201920200SB127 (Accessed Jul. 12, 2021)

36. Ross, G. *GDOT Complete Streets Policy*. GDOT Interdepartment Correspondence, 2012. [http://www.dot.ga.gov/PartnerSmart/DesignManuals/PolicyAnnouncements/Complete%20Streets%20Policy%20-Chief%20Engineer%20\(9-20-12\).pdf](http://www.dot.ga.gov/PartnerSmart/DesignManuals/PolicyAnnouncements/Complete%20Streets%20Policy%20-Chief%20Engineer%20(9-20-12).pdf) (Accessed Jul. 12, 2021)
37. Georgia Department of Transportation. *Design Policy Manual*. 2020. <http://www.dot.ga.gov/PS/DesignManuals> (Accessed Jul. 12, 2021)
38. Li, H., J. Buscheck, J. Harvey, D. Fitch, D. Reger, R. Wu, R. Ketchell, J. Hernandez, B. Haynes, and C. Thigpen. *Development of Recommended Guidelines for Preservation Treatments for Bicycle Routes Part of Partnered Pavement Research Program (PPRC) Strategic Plan Element 4.57: Development of Guidelines for Preservation Treatments for Bicycle Routes*. 2017.
39. Federal Highway Administration. 2002. Life Cycle Cost Analysis Primer. Office of Asset Management. <https://www.fhwa.dot.gov/asset/lcca/010621.pdf> (Accessed Jul. 12, 2021)
40. Sathaye, N. and S. Madanat. A Bottom-up Optimal Pavement Resurfacing Solution Approach for Large-scale Networks. *Transportation Research Part B: Methodological*. Vol. 46, No. 4, 2012, pp. 520-528.
41. Hendrie, D., and G. A. Ryan. Estimates of Bicycle Crashes and Injuries Using Different Sources of Data. *Annual proceedings of the Association for the Advancement of Automotive Medicine*, Vol. 38, 1994, pp. 221–234.

Data Management

Products of Research

The data collected for this project consisted of documentation of interviews followed a scripted questionnaire that included both written and transcribed verbal responses to the questions. Multiple interviews were completed for the California Department of Transportation and the Georgia Department of Transportation. Single interviews were completed for the regional transportation authorities for Atlanta, Georgia and Washoe County, Nevada.

Data Format and Content

The data are contained in MS Word files, with one file for each interview/response.

Data Access and Sharing

The data can be accessed through the Dryad data repository at <https://doi.org/10.25338/B8DK9G>.

Reuse and Redistribution

Data can be freely accessed as long as the users cite the data, this report, and/or subsequent paper to follow. Citation to dataset is:

Gadsby, April; Tsai, Yichang (James); Harvey, John (2021), Technology Review and Roadmap for Inventorying Complete Streets for Integration into Pavement Asset Management Systems, Dryad, Dataset, <https://doi.org/10.25338/B8DK9G>

Appendix: Detailed Description of Roadmap Components

This appendix has the complete set of detailed projects. The concept projects are not included as they are this project and the accompanying technology review.

Research

The research addresses the needs identified in the concept projects. There were many needs associated with data collection as well how to set up performance measures for complete streets assets. The needs are paired with projects, project deliverables, and project approach in Table 4.

Table 4. Recommended Research Projects

Need	Project	Description
<ol style="list-style-type: none"> Some agencies are not inventorying their Complete Streets assets No standard set of assets to inventory to support Complete Streets Need cost-effective and efficient technologies to inventory 	R1. Inventorying bike and pedestrian/ ADA assets	Two focuses: one is to identify and set up performance measures (attributes) and the second is technology to inventory and measure performance (e.g., conditions)
<ol style="list-style-type: none"> Assets will deteriorate, but there is no measurement of their condition Agencies need a condition rating system that is descriptive enough to support maintenance decisions Forecasting is needed to properly support Complete Streets asset maintenance in the budget 	R2. Condition evaluation rating system of bike and ped facilities	Define data collection purposes for prioritization, maintenance and rehabilitation planning, and communicated to the public/decisionmakers. Develop rating systems for bike/ped assets.
	R3. Forecasting and long -term performance of Complete Streets assets	Values for the service life of different bike/ped assets and recommendations of when to treat them based on performance and cost. Forecasting for future funding prediction.
<ol style="list-style-type: none"> The impacts of Complete Streets projects (i.e., economic, safety, etc.) have been assumed, but not quantified. Quantified values for the impacts of Complete Streets would influence project prioritization. 	R4. Life cycle cost analysis and value of Complete Streets assets	Quantify the economic impacts of building Complete Streets assets over its lifetime and the impact on surrounding development/return on investment
	R5. Safety impacts of Complete Streets implementation	Quantify the effect of adding Complete Streets assets on reducing injuries and fatalities

Need	Project	Description
<ol style="list-style-type: none"> 1. Usage numbers are needed to support project prioritization 2. Agencies have no cost-effective, efficient, and reliable means of assessing ped/bike counts at network level. 3. Their typical asset management data collection technologies are not useful for this 	<p>R6. Network level measurement of bike/ped counts</p>	<p>A methodology for measuring ped/bike counts at network level throughout an agency's jurisdiction</p>
<ol style="list-style-type: none"> 1. Agencies need improved data collection technologies 2. AV/CV present an opportunity to collect data cost-effectively and frequently, but how effectively is unclear 	<p>R7. AV/CV for Complete Streets data collection</p>	<p>Recommendations/guidance for utilizing/requesting data from AV/CV for Complete Streets inventory data collection</p>
<ol style="list-style-type: none"> 1. Agencies need improved data collection technologies 2. Crowdsourcing presents an opportunity to collect data cost-effectively and frequently, but how effective is unclear 	<p>R8. Crowdsourcing for Complete Streets data collection</p>	<p>Recommendations/guidance for utilizing data from crowdsourcing for Complete Streets inventory data collection</p>
<ol style="list-style-type: none"> 1. Agencies don't know which technologies will be most cost-effective for data collection of Complete Streets inventories 2. Agencies may not trust technologies/be willing to invest in them until they have tested/experienced them. 3. Agencies need to know how to set up adequate bidding specification for certain technologies 	<p>R9. Pilot testing/ feasibility of technologies for inventorying Complete Streets assets</p>	<p>A technology demonstration that can be shared with agencies. Evidence of the costs/benefits and strengths/weaknesses of various data collection technologies.</p>

Development

The development phase takes the research from ideas to product and creates or refines products for implementation. These projects are described in Table 5.

Table 5. Recommended Development Projects

Need	Project	Deliverable
1. Agencies need performance measures, targets, and a prioritization scheme for Complete Streets projects	D1. Guidance/ best practices for Complete Streets performance measures, targets, and prioritization	Guide to setting targets, performance measures, and prioritization for Complete Streets projects for use by many different agencies
1. Complete Streets inventory data requirements need to be established. 2. Databases are not set up for or are insufficient for incorporating Complete Streets into asset management due to the multi-office collaboration required	D2. Database guidance for Complete Streets assets	Guide on data requirements and listing required components in a database that incorporates Complete Streets
1. Agencies need a means of inputting and working with the data 2. GIS software can be complex, and require licensing and training, limiting the staff able to work with data stored in them	D3. User friendly software for data input, analysis and presentation	Develop a software that is simple (without GIS license and can display GIS) and works with a database following the database guidance to do data input, analysis, and presentation.
1. Once agencies have identified potential technologies, they need to know the most efficient and cost-effective data collection method	D4. Optimized Data Collection Methods for Inventorying Complete Streets	Test data collection methods with the identified feasible technologies. The goal is to collect as much data in a single pass as possible. The deliverable will be a data collection strategy for Complete Streets assets.

Implementation

The implementation phase is focused on bringing the research in to practice. These projects are described in Table 6.

Table 6. Recommended Implementation Projects

Need	Project	Deliverable
1. One of the largest hinderances to implementation of Complete Streets asset management is internal fragmentation of oversight and funding for Complete Streets. Additionally, there are no agency-wide performance measures or targets, so inventorying Complete Streets assets is not a priority.	I1. Best practices for internal organizational practices for Complete Streets	A guide of the best practices for addressing organizational constraints to Complete Streets asset management implementation
1. When trying to build a Complete Streets network, projects cross jurisdictions (state/local boundaries) 2. Multiple agencies need to collaborate from the planning stage 3. There are no consistent data collection or prioritization schemes across agencies	I2. Best practices for encouraging interagency collaboration	A guide of the best practices for addressing interagency collaboration constraints to Complete Streets asset management implementation
1. The previous projects will produce new tools, methods, and concepts for agencies	I3. Training for Complete Streets condition evaluation and prioritization	A training workshop for implementing the results of the previous projects
1. Agencies need performance measures, targets, and a prioritization scheme for Complete Streets projects	I4. National Guidance for Complete Streets Targets and Data Collection	Guide to setting targets, performance measures, and prioritization for Complete Streets projects for use by many different agencies