Project No. 20-112

A Research Roadmap for Transportation and Public Health

Research Methods and Background Materials Supporting the Research Roadmap

FINAL REPORT

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ABSTRACT

New opportunities are developing within transportation agencies to better integrate public health concepts into transportation processes. With these opportunities come important needs for research, data, and decision-making tools which align transportation goals with improved health outcomes. This Final Report 1) summarizes the research methods used in this project, 2) documents key relationships between transportation and health outcomes such as physical safety, mental/emotional well-being, community health and cohesion, physical activity, exposure to environmental risks (such as air and noise pollution), health equity, and emerging issues, 3) provides background on the usage and effectiveness of existing research, tools, and approaches used by transportation agencies to improve and measure health outcomes, and ascertain how and where evidence-based practices are being utilized; and 4) identifies and provides rationale for areas in need of data, new tools, or guidance on best practice, or where best practices are known but are not fully utilized due to implementation challenges. It is intended to complement the Research Roadmap and support research funding decision-making by a variety of Federal, state, local, and private funding sources and other organizations.

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Glossary of Key Terms and Concepts

This glossary provides definitions for selected terms that are central to this document or merit clarification. These are provided within the context of this report and may not be equivalent to the definitions used by other agencies or in other contexts, though where possible, widely accepted definitions from other organizations are used.

Access: Access is provided when a transportation mode allows individuals to get to destinations. In *The Geography of Urban Transportation*, accessibility is defined as "the ease of reaching potential destinations" and influenced by the number of opportunities available within a certain distance or travel time and the ability to move between different opportunities (e.g., land uses, connectivity or route choices, multimodal transportation options, system delays, etc.). Access is understood as a key health domain in this report and as a social determinant of health and health indicator (see separate definitions). Within the context of the Americans with Disabilities Act (ADA), accessibility is related to access in that it guarantees that the transportation infrastructure can be used by individuals with certain disabilities, thereby allowing them to reach desired destinations. Access can be frequently examined by mode, such as access by walking, bicycle, transit, automobile, or overall. It can be measured from a place perspective or from a person perspective.

Active Travel: The Centers for Disease Control and Prevention (CDC) views active transportation, or active travel, as "any self-propelled, human-powered mode of transportation, such as walking or bicycling." Active travel can contribute to an individual's ability to integrate physical activity into everyday life and/or to access other modes of transportation, such as transit or shared mobility services.

Automated Vehicle: Per a recent Pedestrian and Bicycle Information Center (PBIC) report, "Automation can refer to the automated control of any number of functions within an automobile." For this report, the term "automated vehicles" is used in the most general sense and could refer to vehicles at any level of automation. Interested readers can refer to the PBIC report for a detailed discussion of the defined levels of automation and related terms, such as automated driving systems (ADS) and highly automated vehicles (HAVs) (Sandt and Owens 2017).

Big Data: Extremely large data sets, often gathered by machine or sensor technologies, that are often difficult to analyze without the help of sophisticated computing techniques.

Biometric Data: Data—such as fingerprints, cell or tissue samples, or facial scans-gathered from individuals using sensors or computer processing, and used for a variety of purposes, including facial recognition and health monitoring.

Equity: "The absence of avoidable, unfair, or remediable differences among groups of people, whether those groups are defined socially, economically, demographically or geographically or by other means of stratification."(World Health Organization 2018). See related definitions for *health equity* and *transportation equity*.

Health: The World Health Organization (WHO) presents a basic definition of health: a "state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Others have acknowledged that health is experienced along a spectrum, rather than a steady state, and is a dynamic and evolving phenomenon influenced by spiritual, emotional, vocational, and other factors beyond those recognized in the WHO definition.

Health Determinant: Any factor that influences health status; these could include personal (e.g., biological, genetic), social (e.g., family, peer, vocational, organizational, political, policy factors), economic, and environmental factors. In transportation, several factors have been identified as health determinants, including: exposure to environmental risks (including noise, air, and water pollution), opportunities for active travel (see separate definition), quality and safety of roadway infrastructure, access or lack of access to reach needed services (related to transportation availability and choices, distance, time,

and cost; see separate definition), as well as other policies that affect travel behaviors and transportation-related exposures.

Health Equity: The *Communities in Action : Pathways to Health Equity* resource defines health equity as "The state in which everyone has the opportunity to attain full health potential and no one is disadvantaged from achieving this potential because of social position or any other socially defined circumstance" (National Academies of Sciences, Engineering, and Medicine et al. 2017). See also *equity* and *transportation equity*.

Health Effects or Impacts: Health effects (or health impacts or outcomes) are changes in health resulting from exposure to a factor (which could include a policy, an environmental source, an intervention, etc.). In the transportation context, health impacts are often measured in terms of changes in mortality (i.e., death frequency or rate), morbidity (see separate definition), or the associated costs of these. In fields such as the medical profession and public health community, other health impacts related to quality of life and well-being are increasingly being used. Health effects or impacts can be in the positive or negative direction.

Health Impact Assessment (HIA): An HIA "is a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA provides recommendations on monitoring and managing those effects." (National Research Council (US) Committee on Health Impact Assessment 2011)

Health in All Policies (HiAP): Health in All Policies is defined as "a collaborative approach to improving the health of all people by incorporating health considerations into decision-making across sectors and policy areas" in a report released by the Public Health Institute. The report lists five key elements of HiAP: promoting health and equity, supporting intersectoral collaboration, creating co-benefits for multiple partners, engaging stakeholders, and creating structural or process change (Centers for Disease Control and Prevention and Office of the Associate Director for Policy and Strategy 2016).

Health Indicator: A health indicator is a data point designed to summarize information about population health or system performance, within a defined geographic or organizational boundary. Within the transportation context, these data points could measure how transportation facilities, operations, or services affect health issues such as safety, active travel, environmental quality, access, and other health domains. Health indicators are intended to provide comparable, actionable information and can be used to track progress over time. The Transportation and Health Tool, referenced in this report, provides several transportation-health indicators (Boehmer et al. 2017).

Health Outcome: See *Health Effects or Impacts* definition.

Intervention: any modification made to the built environment, agency policy or practice, or population with the goal of changing behaviors or health outcomes.

Morbidity: Refers to having a medical problem, illness, disease or the symptom of such. Morbidities frequently associated with transportation include diabetes, depression, cardiovascular disease, obesity, cancer, traumatic brain injury, chronic obstructive pulmonary disease (COPD), and others. A person can have multiple morbidities and they can be interrelated.

Mortality: Death; often referred to as a population-level rate per time. A more commonly heard term in the transportation context is fatality, typically associated with a motor vehicle crash. Mortality can be defined as all-cause or can be specific to a disease or injury.

NEPA: Per NEPA.GOV, "The National Environmental Policy Act (NEPA) was enacted to: declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality. Sec. 2 [42 U.S. Code § 4321].

NEPA is a basic national charter for protection of the environment. It establishes policy, sets goals (section 101), and provides means (section 102) for carrying out the policy. Section 102(2) contains "action-

forcing" provisions to make sure that federal agencies act according to the letter and spirit of the Act (Council on Environmental Quality 2019).

Performance Measure: Performance measures are data points used in the transportation performance management process to capture the state of the system, set targets/goals to improve the system, and to evaluate and/or compare the effects of different projects or policies. Certain performance measures are required to be reported under Federal legislation and are tied to Federal funding decisions. Transportation agencies, influenced or mandated by Federal and state policies, often develop performance measures and targets related to convey various features of the transportation system, including safety, the condition/quality of the infrastructure, system reliability, freight movement, economic vitality, environmental sustainability, and congestion reduction. Health indicators (see separate definition) can be used as performance measures and relate to many of the domains traditionally considered in transportation performance measurement.

Resiliency: As defined by a National Academies of Sciences report, this is: "The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events." In this report, it is defined within the context of natural disaster related events (such as floods and hurricanes) that affect transportation as well as other key sectors of government (*Disaster Resilience: A National Imperative* 2012).

Social determinants of health: The CDC considers Social Determinants of Health to be 'the conditions in the places where people live, learn, work and play that affect a wide range of health, functioning, and quality-of-life outcomes and risks" (Healthy People 2020 2018). Examples include availability of resources to meet basic needs, access to education, public safety, the built environment and transportation options, to name a few. See the glossary entry for *Health Determinant* as a related term.

Transportation Equity: The United States Department of Transportation defines transportation equity as "the way in which the needs of all transportation system users, in particular the needs of those traditionally underserved by existing transportation systems, such as low-income and minority households, older adults, and individuals with disabilities, are reflected in the transportation planning and decision-making processes and its services and products. Transportation equity means that transportation decisions deliver equitable benefits to a variety of users and that any associated burdens are avoided, minimized, or mitigated so as not to disproportionately impact disadvantaged populations" (Transportation Planning Capacity Building Program, Federal Highway Administration, and Federal Transit Administration 2017). In the book Bicycle Justice and Urban Transformation, the authors go on to address participation in the process by describing bicycle justice as "not only a distributional paradigm but one based on representation and empowerment" (Golub et al. 2016). The process and the outcomes of transportation equity are central to health equity within the transportation system. See related definitions for *equity* and *health equity*.

Summary

As a result of the increasing visibility of health and equity related issues, many state and local agencies have taken important steps to identify and address the adverse impacts of transportation on health while seeking to leverage the role of transportation in supporting positive health outcomes. Several state departments of transportation (DOT) are working closely with their public health department counterparts to identify opportunities for collaboration and jointly funded initiatives.

The goal of this National Cooperative Highway Research Program (NCHRP) project was to develop a strategic research roadmap that identifies critical research needed to improve the ability of transportation agencies to incorporate health considerations and lead to better health outcomes. This roadmap was informed by stakeholder-engaged research that:

- **Documents key relationships between transportation and health** outcomes at the individual and population level, such as physical safety, mental/emotional well-being, community health and cohesion, physical activity, exposure to environmental risks (such as air and noise pollution), health equity, and emerging issues;
- **Provides background on the usage and effectiveness of existing research, tools, and approaches** used by transportation agencies to improve and measure health outcomes, and evidence on how and where evidence-based practices are being utilized; and
- **Identifies areas in need of data, new tools, or guidance on best practice**, or where best practices are known but are not fully utilized due to implementation challenges.

The purpose of the *Health and Transportation Strategic Research Roadmap* is to build upon this body of literature, strategic agendas, and research needs to provide a strategic plan for funding research over the next ten years that can lead to greater consideration of health issues in transportation contexts. This *Final Report* is a companion piece to the *Research Roadmap* and provides additional rationale and background information supporting the research recommendations and details on the roadmap development process. It is intended to document project methods and provide relevant background information used to inform the Roadmap and achieve the goals stated above. Appendix A describes the process for prioritizing key research gaps and needed research identified in the *Research Roadmap* in order to select the research problem statements that were developed and included in the *Roadmap*.

Both the *Final Report* and *Research Roadmap* are intended to support research funding decision-making by organizations such as:

- State planning and research (SPR) programs.
- The American Association of State Highway Traffic Officials (AASHTO).
- University Transportation Centers (UTCs).
- Federal funders, including the United States Department of Transportation (USDOT), Centers for Disease Control (CDC), Environmental Protection Agency (EPA), National Institute of Health (NIH), Federal Transit Administration (FTA), and National Institute of Environmental Health Sciences (NIEHS), including its Disaster Research Response Program.
- Non-governmental agencies and foundations that fund health-related research.

A synthesis of stakeholder interviews and studies identified in the literature review provided useful insights on a variety of topics, including:

- Research establishing health and transportation pathways and impacts.
- Research around health equity.

- Research and current agency practices related to:
  - Leadership and interagency collaboration.
  - Data collection, integration, and application in various processes.
  - Decision-making tool development and usage.
  - Approaches to quantifying health and transportation costs and impacts.
  - Measuring and evaluating health performance.
- Research connecting health and transit.
- Emerging issues and technology.

In each of these sections, research findings are discussed, and research gaps and needs are identified. These research gaps and needs, along with others identified by stakeholders, are reflected in the *Research Roadmap*.

1. Introduction

In the past decade, a growing body of research has shed light on various health impacts—both positive and negative—associated with transportation infrastructure and/or travel behaviors. The emerging picture is one of a complex set of interrelationships between transportation, physical activity, air pollution intake, injury, obesity, and well-being, which vary by individual, travel mode, and circumstance (van Wee and Ettema 2016). Studies have established and quantified the health effects of walking, bicycling, and transit use and made connections with features of the built environment that can support active travel modes (MacDonald et al. 2010). Similarly, volumes of research are produced each year devoted to understanding the incidence of traffic injuries, fatalities, associated risk factors, and health burdens.

Other research has also examined the prevalence of air and noise quality concerns associated with roads, how travel behaviors affect (and are affected by) air pollution intake, and the negative health effects of exposure to air pollutants (Kaufman et al. 2016; Handy, van Wee, and Kroesen 2014). Beyond physical health, there has been research emerging about the role of transportation and city design in emotional and mental health and well-being. For example, studies have explored the relationship between active transportation and cardiovascular disease, commute times and stress levels, and how active travel to school impacts children's sense of autonomy, mood, and classroom behavior (Sallis et al. 2012; van Wee and Ettema 2016). Recent research has highlighted how urban green space, such as street trees or bioswales along a shared-use path, can reduce stress and violence, improve state of mind and encourage physical activity (Kondo et al. 2018; Mäki-Opas et al. 2016).

There is a strong interest from public health and transportation practitioners in understanding disparities in health outcomes, and how transportation infrastructure and service providers can better serve vulnerable groups within the community. Environmental justice and equity have been prevailing themes at many recent conferences, and several new resources have been released on ways to promote social and/or health equity through land use and transportation planning (Sandt, Combs, and Cohn 2016). The Surgeon General's *Call to Action to Promote Walking and Walkable Communities*, announced in 2015, calls for improved access to safe and convenient places to walk and wheelchair roll as a means to improve population health. This message is reiterated in the Physical Activity Guidelines for Americans (U.S. Department of Health and Human Services 2018).

As a result of the increasing visibility of health and equity related issues, many state and local agencies have taken important steps to identify and address the negative impacts of transportation on health while seeking to leverage the role of transportation in supporting positive health outcomes. Several state departments of transportation are working closely with their public health department counterparts to identify opportunities for collaboration and jointly funded initiatives. Health Impact Assessments (HIAs) as a part of land development projects have become routine transportation planning processes in many places (such as Oregon, Michigan, and Tennessee), and in other areas, such as Richmond, California, communities are taking this a step further with a "Health in All Policies" approach.

At many agencies, and at many levels of transportation decision-making within each agency, further opportunities exist to incorporate health considerations in a way that may lead to better health outcomes. For example, State DOT practices and legislative requirements regarding the interrelationship between roadway design, functional classification, and speed limit setting may incorporate consideration of health goals.

In some areas, lack of data, resources, and strategic coordination with key entities—such as health departments—limits the abilities of transportation departments to fully realize their potential to improve health for all constituents and reduce disparities. However, many DOTs are looking for better ways to measure the impacts of transportation projects on a broad range of community issues that relate to health:

air quality, noise control, water quality, community cohesion, social equity, active travel, and safety. Further, the Federal Highway Administration (FHWA) recently issued a new set of rules, *Highway Safety Improvement Program: National Performance Management Measures*, requiring the use of certain performance measures, many of which relate to health impacts. Thus, states are seeking guidance in how to set targets and report on their progress, opening new opportunities to consider health.

New opportunities, technologies, and practices within transportation agencies are emerging to better imbed public health concepts during transportation processes. With these come important needs for research, data, and decision-making tools.

1.1 Purpose

The primary goals of this project were to:

1. Develop a 10-year strategic research roadmap providing a broad overview of highly relevant research needs at the intersection of transportation and public health in the United States.
2. Identify evidence to support practical and useful information, and implementable tools, for state DOTs and partners.

This *Final Report* is a companion piece to the *Research Roadmap*. It is intended to document project methods and provide relevant background information used to inform the Roadmap and achieve Goal #2 stated above. Appendix A describes the process for selecting the research problem statements included in the Roadmap.

Both the *Final Report* and *Research Roadmap* are intended to support research funding decision-making by organizations such as:

- State planning and research (SPR) programs.
- The American Association of State Highway Traffic Officials (AASHTO).
- University Transportation Centers (UTCs).
- Federal funders, including the United States Department of Transportation (USDOT), Centers for Disease Control (CDC), Environmental Protection Agency (EPA), National Institute of Health (NIH), Federal Transit Administration (FTA), and National Institute of Environmental Health Sciences (NIEHS), including its Disaster Research Response Program.
- Non-governmental agencies and foundations that fund health-related research.

1.2 Study Scope

There are many facets to health and transportation and agencies may define their role in affecting health in different ways. For the purposes of this study, and in accordance with feedback from the NCHRP 20-112 project panel, we placed emphasis on the following six health domains, shown in Figure 1 and described below:

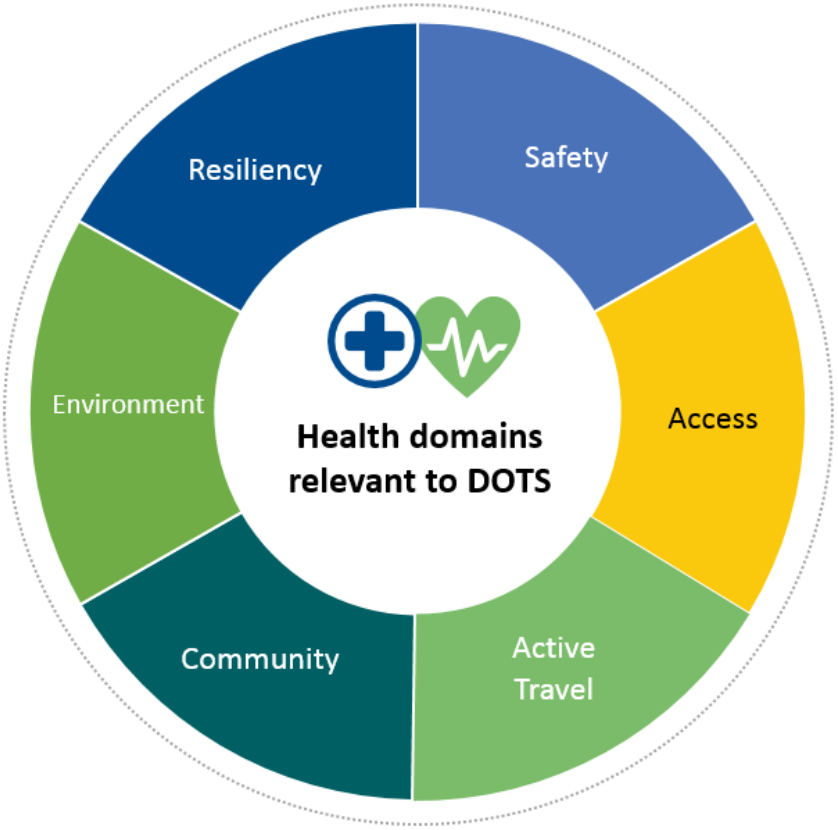

Figure 1 Key domains in which transportation processes and decisions may impact health.

- **Access**: Provision of transportation-related access to basic needs and services (healthy food, healthcare, schools, jobs, community services, etc.).
- **Active travel:** Support for human-powered travel, including pedestrian, and bicycle transportation (for utilitarian and recreational purposes), associated transit ridership, and reduction of personal automobile dependence and associated sedentary time.
- **Community:** Understanding and supporting the role of transportation in community well-being, cohesion, and sustainability, including issues related to affordability, traffic-related stress, mental health, quality of life, social capital, personal security, etc.
- **Environment**: Protection and improvement of environmental quality (air, noise, and water), and reduction of human exposure time to environmental pollutants.
- **Resiliency:** While this term has other uses in different contexts, for the purposes of this document, we refer to activities related to emergency preparedness and disaster response/recovery.
- **Safety:** Efforts to prevent or mitigate traffic-related injuries and crashes for all road users.

The glossary contains more formal and detailed definitions of several of these terms.

These domains, all interrelated, are also those suggested by Widener and Hatzopoulou and by van Wee and Ettema as integral components of a systems approach to health and are discussed further in subsequent sections (Widener and Hatzopoulou 2016; van Wee and Ettema 2016).

Transportation equity is a key concept that must be embedded within each of these six domains of health. The USDOT states that "considering equity early and often through methods such as public participation and data collection and analysis improves the planning process's ability to adequately respond to the needs of the community it serves" (Transportation Planning Capacity Building Program, Federal Highway Administration, and Federal Transit Administration 2017). This approach is mirrored in Towards the Healthy City, where the author argues that 'healthy city planning' must be comprehensive. He states "healthy city planning will require new issue and problem framings, investigative and analytical techniques, and inclusive and deliberative public processes that together can generate new norms, discourses and practices for greater health equity" (Corburn 2009). In this report we devote a specific section (2.2) to document equity-related research and issues but also try to integrate the concept of equity across all other domains explored.

Environmental and safety considerations have been well-established in state department of transportation practices. NCHRP has also produced a Strategic Research Roadmap specific to highway safety (Report 756). So, while safety and environmental issues are acknowledged in this project, this report is focused more heavily on other domains of health—such as active transportation, access, and community—that are often less-well considered as key to DOT functions.

Certain domains, such as resiliency, are rising in importance for DOTs. For example, while other entities such as state Departments of Health and the state disaster recovery coordinators are often largely responsible for emergency preparedness plans, emergency response, and disaster recovery, the impact of weather-related disasters to sectors beyond housing and health and social services is becoming more frequent. In the future, state transportation agencies may have an increasing role to play in disaster preparedness, evacuation planning, and recovery and rebuilding efforts.

While important and related to transportation, we considered occupational health issues to be governed by processes and agencies beyond state DOTs and outside the scope of this project.

1.3 Study Methods

Literature Review

Research team members searched for, gathered, and screened potentially relevant studies and agency reports to identify completed research conducted and existing documentation of research needs. Strategic research agendas published by USDOT, AASHTO, and U.S. Surgeon General were also gathered and reviewed, as well as collected health-related Research Needs Statements. Screened databases included: Transportation Research Board's (TRB) Research Needs Statements, TRB Research in Progress, the Transportation Research International Documentation (TRID) database, Cochrane Library, and Articles+ (via UNC Libraries). Additionally, pertinent documents were extracted from TRB's Health and Transportation Subcommittee and TRB Arterials and Public Health Task Force, including the Transportation Research Circular Number E-C239, *Arterial roadways research needs and concerns: Informing the planning, design, and operation of arterial roadways considering public health*. After screening, more than 200 research articles and 90 grey literature documents collected from online databases, organizational websites, and other sources were included.

The literature gathered contained one or more of the following terms, used in initial keyword searches, combined with AND "health" AND "transport" OR "transportation," as suited to the initial keyword.

- Access
- Accessibility
- Active travel
- Air Pollution
- Air quality
- Arterioscler*
- Atheroscler*
- Automated vehicles (automat* autonomous, driverless, self-driving)
- Bicycle
- Built Environment
- Cancer
- Cardiovascular disease
- Crime Prevention Through Community Design
- Cognitive (Cognit*)
- Connectivity
- Complete Streets
- Congestion pricing
- Crash*
- Depression
- Diabetes
- Disparities
- Driving
- E-bikes or electric bikes
- Electric vehicles
- Emissions
- Equity
- Exercise
- Fatality (skipped on TRID)
- Health
- Health care or Healthcare
- Health impacts
- Heart Disease
- Injury (excluded in TRID search)
- Land Use
- Mental health
- Mobility (focus on multimodal/active travel modes)
- Mortality (excluded in TRID search)
- Noise pollution
- Obesity (Obes*)
- Overweight
- Performance measures (and metrics and management) and transportation
- Personal Security
- Physical Activity
- Public health
- Quality of life
- Resilience
- Ride-sharing
- Safety
- Scenario Planning
- Sedentary
- Social capital
- Social determinants
- Sustainable
- Street Lighting
- Stress
- Traffic
- Transit
- Travel
- Transportation
- Urban Health
- Urban Nature
- Vehicle Miles Traveled (VMT)
- Walk*
- Water Quality

The coverage of various health outcomes in this report is heterogeneous. For some domains, like safety and air pollution, lots of work extensive research has been performed so reviewing this literature in detail is unnecessary. Rather, the research team focused on reviewing syntheses, meta-analyses or meta-reviews and other seminal resources. For other domains, such as mental health, stress, and social capital, less work has been done and therefore a more traditional review was conducted.

Research articles and grey literature identified were entered into a citation management tool selected to support primary screening and data extraction for systematic literature reviews. Literature was pre-screened based on abstracts and executive summaries by multiple team members. Documents were excluded from further review if found to be irrelevant, outdated, or covered more in-depth in another document. Additional review and feedback from the project team resulted in categorization of literature as 'primary' and 'secondary' in terms of pertinence to this project.

Literature deemed to be of primary relevance to the project received additional review by research team members and was classified according to study design, transportation process, health outcomes, and other features, according to a tagging system developed by the team. The results of this process, a spreadsheet of literature (title/abstracts) on health topics, which can be searched or sorted by topic, year, study design, geography, health outcomes, mode of travel, etc. can be made available to other researchers and to the health community.

During the review period of this report, additional references were added to the database. Further literature searches were conducted as a result of feedback and input from the advisory panel and team members. Resources were also added as new material was published or as the team was made aware of relevant documents during the course of the study.

Peer-reviewed Literature

Through this process, the team identified four meta-analyses, more than twenty systematic reviews, more than twenty-five narrative reviews, and close to two hundred additional peer reviewed journal articles. Studies identified included various research designs, including case studies, observational studies, quasi-experimental studies, natural experiments, and "other" or mixed method studies. Research focused on populations or issues in the U.S., Canada, other countries, multiple countries, or did not have a focus area described in the abstract. In terms of the primary mode of travel of interest to the study, there were more than sixty that were "multimodal" in nature, less than ten focusing on vehicle users, less than ten on bicyclists, and under five on "emerging" modes of travel, three bus studies, and one on rail in the initial group of literature reviewed. Based on this, additional efforts were made in subsequent targeted literature searches to pursue research on particular topics or transportation modes.

Seventy five percent of the initial primary research articles reviewed covered at least one health issue/outcome and at least one stage of the transportation decision-making process. Within the research articles, planning/policy and tools (such as HIAs) were the most frequently occurring process topics that were tagged, with sixty-two and forty-one research studies on these topics, respectively. Another twenty-two examined features of the built environment and/or design process. Fewer than ten research articles focused on maintenance, operations, prioritization, public engagement, or inter-agency cooperation. These topics also came up less often during stakeholder interviews (see next section) than the topics of planning and design processes, data, and tools.

Grey Literature

The team identified more than one hundred grey literature documents. These studies tended to be reports, from agencies or task forces assessing the state of practice or making the case for better health integration in transportation. A few tools were identified, including the Integrated Transportation Health Impacts Model (ITHIM), which was mentioned in several of the stakeholder interviews. Much of the grey literature was focused generally on the connection between health and transportation without relating specifically to stages of the transportation decision-making process. These resources often contained recommendations and research needs for a variety of audiences (e.g., practitioners, policymakers, researchers). Similar to the research studies, most of the grey literature focused on elements of the transportation planning/design and policy processes, with a couple more on other topics including operations and performance monitoring.

TRB Research Needs Statements

Research team members also searched the TRB website and TRB committee/subcommittee webpages for Research Needs Statements that mentioned health, and incorporated documents recommended by the panel and other stakeholders. We retrieved and tagged forty-two Research Needs Statements and an additional four research in progress records. In general, the Research Needs Statements reflect a need for:

- Forecasting tools/models to quantify outcomes or impacts (program/facility use, health costs, air quality, etc.) and communicate with the public/elected officials.
- Improved data systems to support health decision-making and understanding of data options (including linking crash data to medical data).
- Synthesis of best practices by transportation and transit agencies (e.g., planning/community engagement to improve facility design/use by/for vulnerable road users (VRUs)).
- Models/guidance for implementation, such as:
  - Models for partnerships between health, transportation, and other stakeholders.

- Methods for accelerating project delivery.
- Guidebook for transit agencies on when/how to incorporate health.

These themes are also reflected in the structure of this Report.

Strategic agendas

During the literature review, more than a dozen Strategic Plans or Agendas were identified, from agencies including USDOT, EPA, Department of Health and Human Services (DHHS), National Institute on Aging, NIH, and the Surgeon General's *Call to Action to Promote Walking and Walkable Communities*. A summary of common themes from these is included in the Introduction section of this document.

Stakeholder Interviews

To supplement the literature review, research team members conducted interviews with stakeholders from a variety of federal, state, and local organizations. These organizations were selected based on their role in prior health and transportation related efforts, as identified by documents obtained in the literature review, knowledge of project team members, or referrals made by other stakeholders interviewed. They represented a range of geographic coverage areas across the US, perspectives (including research and practitioners), and roles in relation to transportation (including planning or analysis, policy, engineering design, construction, program evaluation, maintenance, etc.). Key informants interviewed represented the following organizations:

- State agencies, including:
  - Massachusetts Department of Transportation.
  - Florida Department of Transportation.
  - California Department of Transportation.
  - North Carolina Department of Transportation.
  - Iowa Department of Transportation.
  - Oregon Department of Public Health.
  - Minnesota Department of Public Health.
- City or regional agencies, including:
  - Arlington County, Virginia.
  - Kane County, Illinois.
  - Washington County, Oregon.
  - Delaware County, Pennsylvania.
  - San Francisco Department of Public Health.
  - Centralina Council of Governments (Charlotte, North Carolina, region).
  - Columbus, Indiana.
  - LA Metro (the Los Angeles, CA Transit Authority).
- Members of TRB's Health and Transportation Subcommittee.
- Members of TRB's Arterials and Health Task Force.
- USDOT Office of Secretary.
- Volpe National Transportation Systems Center, a research arm of USDOT.
- CDC (including representatives from physical activity, policy, and injury prevention branches).
- Private consulting firms (working with municipalities on transportation plans and projects).

For each stakeholder or group of stakeholders, screening calls/emails were first placed with contacts at the agencies, and a pre-interview set of questions was provided in order to extract basic information about the contact and/or agency practices. Then, researchers held one-hour calls with a semi-structured set of questions designed to draw out insights about resources, best practices, barriers and limitations, and knowledge gaps related to transportation and health issues.

After several interviews were conducted, the project team met to discuss the interview process, themes that were emerging, and whether similar topics were also being identified in the literature search. The team updated its interview process with insights from the team and input from NCHRP panel members and identified and conducted additional interviews and key word searches to identify relevant literature or resources.

2. Literature Review and Stakeholder Interview Findings

A synthesis of stakeholder interviews and studies identified in the literature review provided useful insights on a variety of topics, including:

1. Research establishing health and transportation pathways and impacts.
2. Research around health equity.
3. Research and current agency practices related to :
    a. Leadership and interagency collaboration.
    b. Data collection, integration, and application in various processes.
    c. Decision-making tool development and usage.
    d. Approaches to quantifying health and transportation costs and impacts.
4. Research and guidance for measuring and evaluating health performance.
5. Research connecting health and transit.
6. Emerging issues and technology.

In each of these sections, research findings are discussed, and research gaps and needs are identified. These research gaps and needs, along with others identified by stakeholders, are also reflected in the *Research Roadmap*.

2.1 Establishing the Health and Transportation Pathways and Impacts

A number of studies identified in this project documented how transportation choices and the roadway environment are key determinants (or influencers) of health. While the transportation system connects communities and provides access and opportunity for many, corresponding negative externalities of transportation planning decisions impact several key health risks, including cancer, cardiovascular disease, respiratory disease, car crashes, and other sources of morbidity and mortality (Subramanian 2005). Many studies have noted myriad ways in which motor vehicle use impacts air and water pollution, wildlife and ecosystems, injuries, sedentary behaviors, stress, mental health, household costs, and public costs (Fang and Volker 2017; *How Does Transportation Impact Health?* 2012). Land use, roadway design, and transportation operations can influence behaviors—factors such as trip, time, mode, and route choices—and act as support or barriers to access critical services that can impact individual and population health in a variety of ways.

There are numerous pathways, or linkages, between transportation processes/infrastructure/networks and health determinants (or, factors that influence health) and health impacts or outcomes (see glossary for more detailed definitions of these terms). While there are many individual research studies on components of the relationship between transportation and health, few studies have provided a comprehensive overview. Two studies identified in this project provided a conceptual framework for examining the numerous relationships between transportation and health (van Wee and Ettema 2016; Widener and Hatzopoulou 2016). Both models are similar in that they identify direct, or first-order, relationships between health and transportation-related:

- Levels of physical activity (part of the active travel domain used here).

- Air-pollution intake (part of the environmental domain).
- Morbidity and/or mortality related to collisions (part of the safety domain).
- Well-being and/or stress (part of the community domain).

The Widener model also acknowledges direct pathways to personal health related to access to goods, services, as well as health goods and services (part of the access domain used here). Both models identify, indirectly, the role of land use and/or residential choice in relation to travel behavior as well as other second order relationships between health and travel.

These models are presented in the context of routine transportation, and do not depict relationships between health and transportation during/after disasters, and thus do not acknowledge the role of transportation processes and facilities for supporting health and resiliency to widespread emergency events, or short- or long-term health and transportation impacts of these events.

Combined, these models articulate the complicated and interconnected issues related to transportation and health determinants or outcomes. While they underscore the complexity and challenges for research in this area, they also highlight the numerous potential leverage points and pathways for transportation agencies to more positively impact health.

Innumerable studies have sought to quantify transportation-related health impacts, particularly in the last decade. While a comprehensive review of literature across all domains of health and transportation is infeasible here, we attempt to highlight the most recent key studies relevant to the health domains within the scope of this *Roadmap*, particularly systematic reviews and studies with rigorous research designs.

Access: Access to destinations and access to modes of transportation which enable a person to reach desired destinations are two fundamental components of access. The ability of transportation to provide or limit access to key destinations and services is an important determinant of health. Furthermore, case studies have shown accessibility to transportation options may be particularly critical for specific vulnerable populations. Two studies analyzing the impact of transportation on access to health care among older adults found that access to multiple transit options reduced the likelihood of missing or delaying appointments. Although social networks can help fill the transportation gap, older adults who do not or cannot drive are at a transportation disadvantage to accessing health care and other basic needs. In particular, transit operations such as routes, schedules, and headways can pose serious barriers to healthcare access (Battista et al. 2015; Mattson 2011). A case study examination of transportation and healthcare access among older adults in Vermont identified several often-overlooked and unmet needs of older adults, some of which may be shared among other population subgroups, that may impact transit use (Mattson 2011).

Active Travel: There has also been extensive research into the relationship between active travel behaviors, transportation infrastructure, and health outcomes. For example, a 2014 meta-analysis shows, after accounting for other forms of physical activity, walking and biking for transportation can reduce all-cause mortality by eleven percent and ten percent respectively, with greatest gains among persons who spend less time walking and biking in general (less than one hundred twenty minutes of walking per week and less than one hundred minutes of biking per week)(Kelly et al. 2014). A recent systematic review analyzing the relationship between the built environment and physical activity found an association between transportation-related physical activity and infrastructure that supports biking, walking, and transit – particularly trails. The review also found the built environment and accessibility to be positively linked with physical activity levels (Kärmeniemi et al. 2018). Another literature review of 400+ scientific and grey literature documents concluded that designing "activity-friendly" environments has many health co-benefits (Sallis et al. 2015). A systematic review of quasi-experimental studies pertaining to the built environment found walkability interventions have consistently increased levels of physical activity and active travel (M. Smith et al. 2017). A systematic review of active transportation HIAs by Mueller et al. found that regardless of geographical scale, interventions that increase active travel are associated with lower rates of mortality, mental health issues, type 2 diabetes, cardiovascular disease, injuries, or weight gain. While air quality impacts on health varied by population, a net positive gain was expected because the general population

benefits, even though the subpopulation of active travelers is exposed to higher levels of pollution (Mueller et al. 2015). Questions have long been raised as to how crime and fear of crime might affect active transportation and mode choice, in particular for women (Appleyard and Ferrell 2017; Loukaitou-Sideris and Eck 2007; Lynch and Atkins 1988).

Community: The direct or indirect linkages between transportation systems and broader community health (i.e., well-being, cohesion, and quality of life) are less well-established in the current literature but have often been documented anecdotally. A case study analysis of subjective well-being as related to transportation among residents in Denver, Colorado found a positive connection between transportation options and quality of life. Importantly, while vehicle ownership was also positively linked with quality of life, it was not found to be a statistically significant indicator (Makarewicz and Németh 2018). A 2016 report from the Project for Public Spaces highlighted the need for additional research that explores the relationship between place attachment, social capital, and health (Project for Public Spaces 2016). Community cohesion is understood to be a key component of Crime Prevention through Environmental Design, which utilizes "the design, management and use of the built environment to reduce crime and fear of crime and to promote public health, sustainability and quality of life" (Cozens and Love 2015).

Environment: Nearly forty scientific articles included in this review pertain to air quality. Among the findings, these studies show there is a significantly higher risk of asthma among children exposed to transportation air pollution (TRAP); elevated risk of breast cancer among women who, as children, lived on or near roads with a barrier or median; and an association between long-term exposure to TRAP and high blood pressure as well as hypertension (Foraster et al. 2014; Khreis et al. 2017; Shmuel, White, and Sandler 2017). A recent study of bicyclists in Minneapolis found the majority of bicycling activity is in areas with high exposure to air pollution and that shifting to nearby streets with less traffic could reduce exposure by approximately 15 percent (Hankey, Lindsey, and Marshall 2017). Minet et al. suggests nuanced air pollution assessments may improve network design as an analysis of Toronto finds the highest exposure to air pollution along cycle tracks, and the city's planned bike facilities will exceed air pollution levels on the existing network (Minet et al. 2018). Work has also been done to show positive effects of urban green space and green infrastructure on health outcomes (Nieuwenhuijsen et al. 2017; Kondo et al. 2018).

Resiliency: The role of transportation infrastructure and services in affecting health during and after a large disaster cannot be over-emphasized. As illustrated in the National Academies of Science report, *Healthy, Resilient, and Sustainable Communities After Disasters: Strategies, Opportunities, and Planning for Recovery*, state and local transportation agencies play a critical part in evacuation planning, public communication, intra-agency coordination, emergency service delivery, and other activities aimed at mitigating injuries and fatalities during disaster events (Committee on Post-Disaster Recovery of a Community's Public Health, Medical, and Social Services, Board on Health Sciences Policy, and Institute of Medicine 2015). After a disaster, the quality of a transportation agency's network, disaster planning, policies, and ability to provide coordinated leadership can impact access to healthcare services, food/water and medical supplies, shelter, and the speed of disaster relief. How an agency approaches recovery, and their ability to incorporate equity and health considerations, can affect both short- and long-term health outcomes.

Safety: A comprehensive 2015 report released by the National Highway Traffic Safety Administration (NHTSA) documented the social and economic costs of traffic crashes in the U.S. In a single year (2010), there were nearly 33,000 fatalities and 3.9 million injuries, with an economic cost totaling $242 billion (considering losses in productivity, medical costs, legal/court costs, emergency response costs, congestion, property damage, and other costs)(Blincoe et al. 2015). Beyond lasting physical and economic impacts, motor vehicle collisions have been found to increase psychological strain for at least three years following the crash (Craig et al. 2016). Many studies have documented the long-term quality of life impacts of vehicle injuries; increasingly, research is identifying the associations between traffic-related injuries and other social and mental health consequences stemming from vehicle crashes, including depression and opioid prescription misuse or abuse. A large body of research indicates the severe and direct impacts that

transportation decisions and infrastructure may have on safety, or the likelihood of injury or fatality as a result of a crash.

As previously mentioned, the above domains of health and transportation are interrelated. For example, a narrative review by Boniface notes the casual relationship between morbidity and social networks, a component of social capital, which has been positively, albeit sometimes weakly, associated with walkability (2015). The authors note that traffic and transportation infrastructure can present serious barriers to health through reduced access to health facilities, fragmented informal care networks, and impaired mental health and social cohesion.

These studies and others highlight a wide body of evidence on the health and transportation connection that could be used to inform transportation decision-making, and in many agencies is being directly incorporated into tools, models, and processes used to support transportation project, policy, and plan development and evaluation (described in subsequent sections of this report).

2.2 Health Equity

The World Health Organization defines health equity as "the absence of avoidable, unfair, or remediable differences among groups of people, whether those groups are defined socially, economically, demographically or geographically or by other means of stratification. 'Health equity' or 'equity in health' means that everyone should have a fair opportunity to attain their full health potential and that no one should be disadvantaged from achieving this potential" (World Health Organization 2018). WHO includes transport under the broad list of 'social determinants of health,' noting that the social/structural determinants of public health have received less attention than the biomedical/disease prevention sector in recent years. Health equity is designated a guiding principal towards achieving sustainable transportation systems in the long term (Albrecht et al. 2011). The Robert Wood Johnson Foundation further discusses the definition of health equity in a recent paper titled *What is Health Equity?* The report puts forward a framework for action, which includes "fostering cross-sector collaborations to improve well-being" (Braverman et al. 2017).

The USDOT has identified health equity as a topic of concern for the transportation field and recommends targeting improvements towards traditionally underserved community members. The current *Planning Process Briefing Book* underscores state agencies' responsibility to "ensure that all segments of the population have been included in the planning process regardless of race, national origin, income, age, sex or disability"'(Transportation Planning Capacity Building Program, Federal Highway Administration, and Federal Transit Administration 2017), per Title VI of the Civil Rights Act of 1964. Recognizing the need to mitigate the harmful effects the transportation system can have on public health, the USDOT collaborated with the CDC and the American Public Health Association (APHA) to create the Transportation and Health Tool, which highlights equity as one of five pathways through which transportation can influence health (Boehmer et al. 2017).

Examining health equity from a bicycle and pedestrian planning perspective, a recent Pedestrian and Bicycle Information Center report describes a goal of transportation equity "to facilitate social and economic opportunities through equitable levels of access to affordable and reliable transportation options based on the needs of the populations being served, particularly populations that are traditionally underserved." The report goes on to say that underserved, or vulnerable populations include: low income, minority, older adults, limited English proficiency, or persons with disabilities (Sandt, Combs, and Cohn 2016). A key concept the report highlights is that "equity can be considered both a process and an outcome."

The Prevention Institute/Robert Wood Johnson Foundation report *Countering the Production of Inequities to Achieve an Equitable Culture of Health: Extended Summary* summarizes health inequities that have been produced over time as a result of policies, laws, and practices across a number of sectors. The document suggests a systemic approach to creating change, consisting of multi-sector collaboration, and highlights multiple paths of action to achieve health equity (Davis et al. 2016).

The following sections summarize recent research on equity outcomes in relation to several health domains, as well as processes identified that relate to advancing equity through health considerations.

Measuring the distribution of health outcomes

Evidence shows that there are health-related disparities in many of the domains central to this project:

Access: An equitable transportation system provides not only mobility but also accessibility and connections to "jobs, schools, health care services, faith entities, social gatherings, and other destinations" (Sandt, Combs, and Cohn 2016). A study by Jeekel and Martens makes the case for codifying mobility as a basic human right and argues for a shift in framing from simply mobility to accessibility and warns of the risk of 'accessibility poverty'. They maintain that equitable mobility is as important to human health as health care, education and housing, and call out the urgent need to introduce equity principles similar to those in the above fields into the transportation realm (2017).

Transportation policy and its effect on the built environment plays a role in the ability of many to secure affordable housing in locations which enable access. When affordable housing is removed from convenient, efficient transportation connections, access to jobs, services and community connections decline. (*Where We Live Matters for Our Health: Neighborhoods and Health* 2008).

Neutens and Mattson document various shortcomings in equitable access to healthcare (2015; 2011). In a case-study of low-income residents of Austin, TX, Clifton presents barriers to securing healthy, reasonably priced food for those who travel by means other than a personal automobile (2004). A study conducted in San Diego found that accessibility to low-wage jobs was far greater by car and examined options for improving travel time in first mile/last mile solutions (Boarnet et al. 2017).

Active travel: Research documents the relationship between equity and transportation facilities, including those related to active travel. Not only are certain types of transportation facilities inequitably distributed, but development of new facilities has been shown to trigger or exacerbate equity issues. A recent comparison of bicycle networks in Portland and Chicago found inequitable spatial distribution of bike infrastructure, with disproportionately fewer facilities in neighborhoods of low income, low home prices, or low educational attainment (Flanagan, Lachapelle, and El-Geneidy 2016). James found that walkability was associated with higher quality of life in well-off neighborhoods, while walkability was associated with lower quality of life in deprived neighborhoods (2017). Increased property values, a factor of gentrification, have been documented in areas near new facilities following implementation of bike share in Pittsburgh, the Beltline multi-use path in Atlanta, and have been forecast to occur near Transit Oriented Development in Washington, D.C. (Immergluck 2009; Dawkins and Moeckel 2016; Pelechrinis et al. 2017). Chriqui examined the association between zoning policies and active transportation and found disparities in built environment features that support walking, biking, and transit (2017). Another study looking at inclusion of active transportation plans among DOTs found levels of support for active travel design and planning to be related to percentages of the states' population in urban areas, and integration of more innovative policies was low overall (Dill, Smith, and Howe 2017).

Community: Boniface provides an overview of literature detailing the transport system's impact on health in terms of social interactions, an umbrella term used to describe social exclusion, social capital, social cohesion and social networks (2015). According to Waygood et al., evidence exists that transport options affect social well-being of children in the physical, psychological, cognitive, social and economic domains (2017). Leyden explored the question of social capital and walkability and found that a pedestrian friendly environment had a positive effect on social capital for residents in those neighborhoods (2003). Van Wee and Geurs provides an overview of the relationships between travel behavior and subjective well-being, detailing both the direct effect of personal exposure physical and social surroundings, and the more indirect social inclusion which may influenced by travel (2011). Mackett and Thoreau examined a variety of ways that transportation-related social exclusion coupled with greater exposure to negative externalities of transportation can lead to poor health outcomes in the United Kingdom (2015). In an innovative but

small-sample photo voice project, Ward, Freeman and McGee observed that walking, cycling or taking the bus provided social and mental well-being in a group of older adolescents (2015). Less clear is how to quantify non-participation, for example when the transportation system environment is perceived as unwelcoming or unsafe, some members of the public may opt not to travel.

Environment: A review of literature on health effects associated with proximity to traffic examined twenty-nine studies. Of these, twenty-five reported statistically significant associations between residential proximity and at least one of the following adverse health effects: symptoms of asthma or other respiratory, diminished lung function, adverse birth outcomes, childhood cancer, increased mortality risks (Boothe 2008). The authors argue that the weight of evidence is enough to consider close proximity to traffic to be a public health threat. Rowangould calculated that of the almost 20 percent of U.S. population who live near high volume roadways where "the concentration of mobile air source pollutants is typically elevated…greater traffic volume and density are associated with larger shares of non-white residents and lower median household incomes." Moreover, he found that "very few monitors used to enforce the National Ambient Air Quality Standards (NAAQS) are co-located with near road populations" (2013). Modeling smart growth planning scenarios in Albuquerque revealed significantly higher air pollution exposure among lower-income households but no significant difference among households based on race/ethnicity. The study concludes that aggregation methods for regional air quality analyses as prescribed by the EPA may mask environmental justice issues and are too coarse for infill or smart growth plans. The authors call for more disaggregated data in order to assess where higher levels of air pollution exist on a more granular level (Tayarani et al. 2016). Exposure to traffic noise has also been linked to both physiological and psychological health outcomes (Recio et al. 2016).

Resiliency: A report titled *Healthy, Resilient and Sustainable Communities After Disasters* was issued by the National Academy of Sciences in 2015. The report seeks to draw attention to the many opportunities to advance the goal of building better, healthier communities by leveraging the unique circumstances and resources available after a natural disaster. The report takes a strong stance on the linkages between health and equity, stating that "health, equity, resilience and sustainability are interdependent and mutually reinforcing – part of the same virtuous cycle." Recognizing that many disasters can exacerbate social disparities and hit those with limited means the hardest, the authors warn that those who are most vulnerable can also be the least resilient. Actions discussed which promote equitable post-disaster recovery include development of affordable housing, provision of accessible housing for older adults and disabled, establishment of community centers, workforce development and creation of initiatives to address food deserts, to name a few. Recommendations place a strong emphasis on 'place-based' recovery, which entails integrating the components of a communities' overall vision setting and comprehensive planning process to bear on pre- and post- disaster strategizing, and ensuring that the central systems within the community, such as the transportation system, are designed to support the resiliency and long-term well-being of the entire population (Committee on Post-Disaster Recovery of a Community's Public Health, Medical, and Social Services, Board on Health Sciences Policy, and Institute of Medicine 2015).

Safety: The Pedestrian and Bicycle Information Center (PBIC) report *Pursuing Equity in Pedestrian and Bicycle Planning* provides an overview of evidence that shows that underserved populations have greater need for safe facilities and often face a challenging travel environment lacking access to quality transportation facilities. "Residents of underserved communities are less likely to live near or travel along roads with safe, accessible and high-quality pedestrian and bicycle facilities … [and] the risk of crashes with motorized vehicles increases when pedestrians are forced onto substandard or nonexistent facilities" (Sandt, Combs, and Cohn 2016). A variety of studies detail how the distribution of transportation infrastructure can influence the transportation safety of specific disadvantaged populations. For example, a 2012 study from Canada found that the roadway environment in less wealthy parts of Montreal could explain excess traffic crashes in those areas (Morency et al. 2012). Research has found that crash injuries within Native American communities were significantly higher than among whites and other races in the U.S., and a recent series of case studies highlighted opportunities for collaboration between tribal and non-

tribal governments around road safety concerns, among other things (Shinstine and Ksaibati 2013; Fu et al. 2007). McAndrews studied crashes in the state of Wisconsin, where the data revealed higher risk for some ethnic and racial groups as bicyclists and pedestrians. She argues that the transportation practice lacks data, policy tools, and funding to ensure equitable protection of road users (2017).

Practices around equity

A comprehensive review of practices pertaining to equity in transportation was beyond the bounds of this study but highlights from the grey literature collected are presented here.

Laws central to governing the Department of Transportation's equity work are: Title VI of the Civil Rights Act of 1964 and Executive Order 12898. Title VI prohibits exclusion from the process and the benefits of the decisions made regarding the transportation system, stating that "…no person shall, on the grounds of race, color, or national origin, be excluded from participation in, be denied benefits of, or be otherwise subjected to discrimination under any program or activity for which the recipient receives Federal assistance from the Department of Transportation" (Transportation Planning Capacity Building Program, Federal Highway Administration, and Federal Transit Administration 2017).

Executive order 12898 mandates environmental justice as part of every federal agency's mission and specifically identifies minority populations and low-income groups as protected groups. The order mandates that Federal agencies ensure that they are:

- Avoiding, minimizing, or mitigating disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority and low-income populations;
- Ensuring the full, fair, and meaningful participation in the transportation decisionmaking process by all potentially affected communities; and
- Preventing the denial of, reduction in, or significant delay in the receipt of benefits by minority and low-income populations.

Additional guidance from the FHWA specifies a strategy to, "Reduce adverse human health and environmental effects on minority and low-income populations," in its efforts to address environmental justice (*Moving Healthy: Linking FHWA Programs and Health* 2013). This recognition of the need to mitigate the harmful effects the transportation system can have on public health, led the USDOT to collaborate with the CDC and the APHA to create the Transportation and Health Tool, which highlights equity as one of five pathways through which transportation can influence health (Boehmer et al. 2017).

In many places across the U.S. equity concepts are being integrated into transportation and public health planning efforts. For example, the Minnesota Department of Health is working to update their statewide physical activity plan around the theme "Transportation is a health equity issue," with reference to the relationship between transportation, affordable housing, access to jobs/food/education, and importance of transit. The FHWA report *Statewide Transportation Planning for Healthy Communities* contains further examples of state agencies' efforts to include health equity in their processes (Lyons et al. 2014).

The Massachusetts Department of Transportation (MassDOT) applies a social determinants of health model to fully analyze equity in transportation projects. They recognize the broad impacts land use, economic development, and access to jobs, health care, and housing can have on health and transportation equity. It is necessary to understand and measure these impacts to identify the full spectrum of health burdens and benefits of transportation projects and work to mitigate disproportionate burdens and distribute benefits. MassDOT has developed strategies to quantify these relationships with available data.

Delaware Valley Regional Planning Commission's Equity Through Access project led to the City of Camden Transportation Gaps Study, which analyzed the local transit network for gaps in access to "healthy" destinations like parks, grocery stores, and hospitals. A 2009 report funded by the USDOT

examined women's personal security concerns in certain transportation environments, and suggested some best practices to address these problems (Loukaitou-Sideris et al. 2009).

The 2017 National Academies Press report *Communities in Action: Pathways to Health Equity* provides a recent and thorough literature review of the transportation and health relationship, and places transportation within overall context of health components of equity (National Academies of Sciences, Engineering, and Medicine et al. 2017).

A report produced by the PBIC for FHWA, documented the need for equity considerations in all transportation agency processes, including: 1) Staff hiring and training practices and communication strategies; 2) Infrastructure planning, goal-setting, and project prioritization; 3) Inclusive public outreach; 4) Utilizing data to identify concerns and opportunities; and 5) Design and engineering for everyone. The document includes example practices in each of these areas and links to additional resources (Sandt, Combs, and Cohn 2016).

Stakeholder Perspectives

Several stakeholders interviewed described efforts to integrate equity issues into their plans or practices. One stated: "Transportation inequities ARE health inequities. Active transportation is linked to transit, and affordable transportation is linked to affordable housing."

Future Research Needs

Work by Manaugh and El- Geneidy, Lee, and Evenson reveals that equity impacts are often not accounted for in transportation planning in North America. Evenson and Lee both reviewed pedestrian and bicycle plans and found that equity was rarely a consideration (2012; 2016; 2005). Lee suggests that clear performance measures for social equity would increase incorporation of equity concerns into planning. Manaugh and El-Geneidy discusses the fact that equity outcomes in transportation can be less tangible, and less explicitly factors of "health" and suggests that measures should be easily operationalize, while stressing that they need to be robust enough to "capture the meaning of related objectives" (2012).

Data and fundamental research

Clear understanding of who experiences positive or negative health outcomes as a consequence of policy, planning, design, and implementation is essential to ensuring equitable distribution of resources. Accessibility and functionality of robust, enriched data sources with disaggregated socio-economic and demographic characteristics at a variety of geographies from macro to street-scale will aid practitioners as they work to provide for everyone equitably. In a 2017 article that discusses opportunities and challenges for research on the associations between public space and physical activity, Harvey and Rodriguez question how broadly human-scale metrics are generalizable across populations (Harvey and Rodriguez 2017). Further work to identify the transportation system's direct and indirect health impacts on a wide set of subgroups (including seniors, people in rural contexts, etc.) will reveal systemic properties of current and future courses of action.

Victoria Transport Policy Institute's (VTPI) *Evaluating Transportation Equity* touches on many facets of the question of equity within transportation and suggests that solutions can be categorized as structural or programmatic in nature. The report breaks down types of equity, such as horizontal or vertical, and a myriad impacts and measurement units to be considered in an equity analysis. No one approach is all encompassing, but exploration of these with health outcomes and community goals in mind will bolster the body of knowledge on the subject (Litman 2018c).

Program and policy evaluations

Exploration of root causes of health inequities within and external to transportation is a priority. *Communities in Action* stresses that transportation is multifaceted, and points to the need to recognize externalities from many perspectives (National Academies of Sciences, Engineering, and Medicine et al. 2017).

Development and advancement of policies and programs which more equitably distribute both the benefits and burdens of the transportation system, from a health perspective, are required. Evaluation of program and policies pertaining not only to transportation but also to land use, economic development, the design of public space and how these affect diverse populations, though the lens of key health domains of health related to transportation will be crucial. Considering the positive and negative impacts of pricing techniques (congestion pricing, parking pricing, gas tax increases, etc.), in relation to business as usual, will be important.

The document *Healthy Equitable Transportation: Policy Recommendations and Research* offers an overview of current policy challenges and proposes that new transportation policy at federal, state and local levels be aligned with top health and environmental goals, prioritize distressed populations, emphasize accessibility and ensure meaningful participation from diverging interests (Malekafzali). Research can step in to formulate a framework for achieving these goals.

Stakeholder Perspectives

Many stakeholders interviewed indicated the importance of executive-level action, but also the necessity of transportation and health staff capacity to operationalize or translate legislative action into practice. They also acknowledged the role of the advocacy community and others in providing grass-roots support for initiatives long before they were formalized through executive action.

Recommendations for practice and policy

Case studies on application of health equity processes and principles in urban and rural contexts are needed to call attention to successes and struggles. Best practices should be tested on a variety of scales and scenarios. In particular, documentation of DOT approaches to integrate and align health equity considerations into all methods and processes is needed.

2.3 Leadership and Interagency Collaboration

From the literature review and stakeholder interviews, the project team identified the following approaches currently being taken by transportation agencies, often in conjunction with others, to advance health:

- Executive or legislative initiatives.
- Interagency project development and prioritization.
- Policy-making and programming.
- Grassroots engagement.
- Data sharing and usage agreements.
- Embedded staff.

- Creative financing and funding.

Many of these activities or opportunities for collaborative leadership fit within a conceptual framework based on network-theory, presented by Li, Casey and Brewer on the key characteristics of successful network collaboration. The following sections provide brief examples, drawn from the interviews or case studies, illustrating these approaches in relation to various health domains and highlight challenges, lessons, and implications for research (2015).

Executive or legislative initiatives

At the state level, the formal beginnings of collaboration between transportation and health agencies is often marked by an executive or legislative initiative. This top-down approach creates a policy or understanding to formally recognize the important connections between health and transportation and create a common vision for agencies to work towards together. Even if the initiative is not lasting, it can help foster or establish a culture of collaboration and integration between agencies that may not occur organically.

Massachusetts is one example of a state where health considerations are incorporated into transportation projects and decision-making using a top-down approach. The Healthy Transportation Compact of 2009 consolidated agencies into a single department and resulted in embedding health goals into existing transportation processes. That was followed by the 2013 Health Transportation Policy Directive, which "formalized the agency's multimodal focus and mode shift goal" (*Healthy Transportation Policy Directive* 2013).

Stakeholder Perspectives

State transportation and health department representatives interviewed frequently mentioned that they required a period of time to informally "get to know each other." This stage could require months or years of frequent communication to learn roles, terminology, and common interests in order to identify opportunities for collaboration. A "bridge" staffer with expertise in both areas could reduce the learning curve. Overall, this informal coordination allowed the agencies to break down traditional silos before programs and policies could formalize.

In Oregon, executive-level interest from the DOT Commissioner led to a memorandum of understanding (MOU) between the Oregon Department of Transportation and the Oregon Public Health Division to foster collaboration, communication, planning, data collection, and research. The 2015 Public Health Modernization legislation provided additional state-level directive to integrate public health and active travel measures and metrics (Oregon Health Authority Public Health Division and Oregon Department of Transportation 2013).

In California, two laws related to climate change spurred efforts to reduce vehicle miles traveled, Senate Bill 375 passed in 2008 and Senate Bill 743, set targets for emissions reductions, develop multimodal networks, and diversify land uses (Fang and Volker 2017). These mandates effectively shifted the state's transportation performance measures from aiming to measure and reduce automobile delay to instead measure and reduce vehicle miles traveled. It also acknowledged the many health and cost-saving co-benefits of reducing VMT (e.g., reductions of air pollution, water pollution, wildlife mortality, congestion, crashes).

An additional law, Assembly Bill 2800 passed in California in 2016, requires "state agencies to take into account the current and future impacts of climate change when planning, designing, building, operating, maintaining, and investing in state infrastructure" and establishes a Climate Safe Infrastructure Working

Group. The Working Group is still in the process of gathering data, looking at research and existing models, and identifying practices from health and transportation agencies to see how climate change considerations can be factored into design of infrastructure. LA Metro, for example, could factor in climate change when evaluating transit and bus shelter level of service and comfort; a location with no tree canopy or bus shelter, anticipated to experience a significant number of high heat days, may be deemed to have inadequate service for users unless alternative accommodations are made.

In a review of forty-three case studies of planning and public health agency collaboration, Li et al. noted that "about half of the case studies explicitly mentioned that collaborations were in response or to comply with mandate requirements." Formal mandates were also regarded as an opportunity to overcome regulatory dissimilarities across agencies that were viewed as a barrier to collaboration (Li, Casey, and Brewer 2015).

In many examples identified, executive level actions often resulted in or provided support for some of the following models of collaboration.

Interagency project development and prioritization

In Minnesota, an Interagency Advisory Group (including staff from tourism, commerce, education, economic development, health, natural resources, public safety, and pollution control) developed a corridor investment management strategy (CIMS). The intent is to prioritize project selection around projects that support Minnesota Department of Transportation goals for quality of life, economic competitiveness, and environmental health. Projects selected using these criteria have generally involved roadway improvements that support safe, multimodal use.

Likewise, Metro (Portland, Oregon's Metropolitan Planning Organization (MPO)) incentivizes transportation projects that are likely to increase walking and biking trips through its Regional Flexible Funds (RFF) program (which uses Congestion Mitigation and Air Quality Improvement (CMAQ), Surface Transportation Block Grants (STBG), and Transportation Alternatives Program (TAP) funds) and also provides funding specifically for active transportation and transit-oriented projects (Carpenter 2017). The agency collaborates closely with the Oregon Public Health Institute, Upstream Public Health, Enders in Action, and other organizations concerned with health and social equity to participate in community engagement and to evaluate design criteria and components of RFF projects. In a separate report, Transportation for America provided a series of case studies on how regional entities, including Portland, Oregon and communities in Tennessee, Texas, North Carolina, Minnesota, Oklahoma, Ohio, and California are prioritizing and evaluating projects through the health lens (Carpenter and Zaccaro 2018).

At a more local level, interagency or departmental collaboration can incentivize specific projects as well. For example, in Kane County, Illinois, the Kane County Cooperative stemmed from an interagency group brought together to work on the Public Health Department's Fit Kids 2020 program. The Cooperative now works to incorporate health outcomes into a variety of programs and funding opportunities. This includes project funding prioritization, where points are awarded to projects that encourage active transportation, such as sidewalks, side paths, and transit improvements. Funding—for infrastructure and related programs—is a powerful way for agencies at all levels to encourage a focus on health outcomes, across disciplines. Umstattd and colleagues found that the most common community-level strategy used in rural areas seeking to prevent obesity was to improve infrastructure that supports walking (2016).

Further, many communities are incorporating structured interfaces, such as multidisciplinary advisory committees, to inform decisions at the project level. Another major effort by the Kane County Cooperative has been in the County development process. A forty percent discount is offered on the current development impact fee for including elements that benefit public health; these are usually active transportation oriented.

In rural communities, interagency or departmental partnerships are often a central strategy, more so than policy. There are numerous examples of partnerships between local and regional governments, the business and faith community, and/or non-governmental entities (including foundations) to secure grants and funding sources for local programs geared toward health. Quick and Narváez emphasize the need to

improve interagency coordination between tribal and non – tribal agencies in order to improve road safety in tribal jurisdictions (2018).

Policymaking and programming

Complete Streets, Vision Zero, Safe Routes to School (SRTS), and Health in All Policies efforts and programs have often facilitated discussions around health in the transportation planning process and enabled inter-agency collaboration (Lyons et al. 2014). These programs were broadly recognized in stakeholder interviews as approaches that require and enable cross-agency communications in advance of and during broader public engagement processes. These efforts are also often closely tied to grassroots engagement, embedded staff, data sharing, and project development.

At the state level, Arkansas Department of Transportation works with public health staff in their Toward Zero Deaths initiative, pooling staff and resources to analyze data and develop an outreach campaign. Similarly, in Massachusetts, interagency collaboration through the Healthy Transportation Compact led to the establishment of a Complete Streets program and the incorporation of public health into design guidelines. For examples at the regional level, Transportation for America provides case studies of several MPO-led Complete Streets programs or projects and describes the involvement of public health and other interagency partners (Carpenter and Zaccaro 2018; Carpenter 2017).

Regarding the issues of access to goods and services (including health-related), Mattson provides a Vermont-based case study examining the challenges and possible collaborative solutions in providing access to health care via public transport. Mattson notes the need for greater coordination between health and transportation agencies, as well as the need to restructure states' systems of mileage reimbursement for nonemergency medical trips made by Medicaid-eligible persons, in order to maximize usage of public transport programs to access health care (Mattson 2011).

At the local level, the variety of organizational structures and funding sources can lead to collaborations beyond the traditional transportation and public health department. In Columbus, Indiana, the push to consider health in transportation has come from a section of Columbus Regional Health, the local hospital network, called the Healthy Communities initiative (HC). HC's initial involvement in the policy and activities of the Columbus planning department (which oversees transportation) came when they received a $2 million CDC Communities Putting Prevention to Work (CPPW) grant to address obesity prevention. Since 2010, the HC has also been directly involved in creating and implementing Complete Streets and Safe Routes to School policies in Columbus. For example, work done by HC for the SRTS program demonstrated that elevated pollution levels in the local schools were directly tied to bus and car idling. This resulted in a Young Lungs at Work campaign to decrease idling near Columbus City Schools.

In addition to the above practices identified in the stakeholder interviews, additional policy-related practices—or recommendations for practice—were found in the published literature. For example, the resource *Metrics for Planning Healthy Communities* provides a list of policies to support health across various domains (including active living, healthy food systems, environmental exposures, emergency preparedness, and social cohesion) and guidance on how to measure performance of plans and policies in these areas (Ricklin and Shah 2017).

Stakeholder Perspectives

Stakeholders interviewed indicated that policies and programs are where the "rubber meets the road" in terms of incorporating health into transportation processes. Operationalizing a policy, working within the existing regulatory framework, and utilizing research to inform policy-making were all highlighted as challenges and/or opportunities for research.

In the article, *If Health Matters: Integrating Public Health Objectives in Transportation Planning*, Litman raises the issue that traditional safety programs seek to mitigate the risks associated with driving, rather than reduce the overall rate of driving, or exposure to risks (2017). He cites several studies showing that mobility management, transportation demand management, or general efforts to reduce vehicle travel do significantly reduce crashes and may provide opportunities for other health benefits by shifting travel from vehicles to transit or active modes. He presents several conventional strategies to improve safety, air quality, physical activity, and access and recommends additional strategies and often-overlooked impacts to consider in policymaking. In a complementary study, Fang and Volker provide a framework for considering the health benefits of reducing vehicle miles traveled and an extensive summary of literature documenting the relationship of reducing VMT to various health outcomes (Fang and Volker 2017).

In an overall review of transport policies, Khreis, May, and Nieuwenhuijsen conclude that land use and travel pricing measures may possibly have the most positive effect on public health by reducing the need to travel, enhancing green space, and facilitating shorter distance travel by active modes (2017). This point was also made by Manville and Goldman, whose research provided evidence that revenue provided by congestion pricing could offset the burden to poor drivers harmed, while roads without congestion pricing still burden poor drivers and do nothing to mitigate harms. Additional research may be warranted (see section below) to comprehensively describe how frequently these policy approaches are being used and to what extent they have been evaluated in terms of health outcomes (2017).

Stakeholder Perspectives

State transportation and health department agency representatives were asked during the interviews how they framed health issues, or whether they focused on specific domains. The mindset tended to vary, based on organizational mission and boundaries. Some agencies reported using the term broadly, or focusing on the areas in which audiences were most familiar (such as air quality or safety) and then gradually bringing attention to other aspects of health such as opportunities for active travel and community well-being. In some places a framing around health equity issues or vulnerable populations has been key. For collaborative partnerships shared framing across departments and consistent communications with the public was deemed critical.

Grassroots engagement

Grassroots engagement, separate or in addition to top-down leadership, is an opportunity for health issues to arise in transportation conversations. For example, Arkansas DOT works with public health staff in their Toward Zero Death initiative pooling staff and resources to analyze data and develop an outreach campaign. Vision Zero programs were broadly recognized in stakeholder interviews as an approach that requires and enables cross-agency communications in advance of and during broader public engagement processes.

Columbus, Indiana, has spent time gathering community support for transportation projects and programs that are health oriented. Community engagement approaches have included the GoHealthy Columbus website, newsletters, bike month and Walktober events, and outreach events such as a breakfast and "handlebar" happy hours, to gather contact information. Policy education events have also been important in building a network of support within the community, with speakers from organizations like America Walks and Walkable Communities. These events have been critical in turning public opinion from stiff opposition to actively asking for traffic calming and bicycle/pedestrian projects. A focus on building

community support has also kept active transportation relevant, even without a mandate or the support of the City and County administration.

Oakland, California, offers another model for grassroots engagement through electoral processes. There, a coalition of transportation professionals organized and provided an early endorsement of a (then) relatively unknown mayoral candidate—Libby Schaff—who promised to make sustainable, equitable transportation an important pillar of her agenda. The grassroots support was critical, and she won. Following on her campaign promises, she elevated transportation to a city cabinet level position, which resulted in the formation of the Oakland Department of Transportation and the hiring of the City's first transportation policy director. Many new funding and policy provisions have since arisen, relating to the department's mission to "envision, plan, build, operate and maintain a transportation system for the City of Oakland and assure safe, equitable, and sustainable access and mobility."

At both the city and the state level, community and grassroots engagement is a key part in the local planning and infrastructure delivery process and involves not only individual citizens but business groups and employers of all sizes. In cities and states that have made progress in incorporating health considerations, it has been recognized that there is a valuable role for the medical community, and hospitals in particular, in having a seat at the table, as early as possible in the community engagement process. In some places, the presence of and engagement with major medical research centers (such as the Mayo Clinic in Rochester, Minnesota and the Cleveland Clinic in Cleveland, Ohio) has facilitated conversation around the importance of moving beyond providing health care to providing healthy places, which also provide health care as well as broader community benefits.

Data sharing and usage agreements

Data integration and sharing, both horizontally (e.g., between state and local agencies) and vertically (e.g., between different departments within an agency) was also identified in stakeholder interviews as an important component of health-transportation interagency partnerships and opportunity for collaboration and a support for policy development and evaluation.

San Francisco's Vision Zero program, for example, relies on a data-driven team to develop common safety and equity metrics and to integrate data available from various departments, including police-reported crash data, transit data, hospital data, and other sources. The program used its pooled data to identify "communities of concern"—areas of the City that are particularly low-income, transit dependent, have a high ratio of seniors, etc.—in order to prioritize resources for programs and policies to serve them. Shared data across the departments was useful in creating a common definition of the areas of concern and the geography, as well as for mapping high-injury networks, validating injury data from police reported crashes with hospital data sources, and communicating safety concerns back to the public. It resulted also in an open source data platform, funded in-part by CDC, called TransBASESF, which provides transportation, land use, and safety data in one location (San Francisco Department of Public Health 2018).

In San Francisco, the Vision Zero program was viewed by staff as a way to elevate the need for more resources, data sharing, and intra-agency collaboration. Its Department of Public Health (DPH) epidemiologist is funded by a work order with the San Francisco Metropolitan Transit Authority (SFMTA), which enables the DPH to access their data and use it for Vision Zero related safety analyses.

San Francisco's health and transportation efforts are also supported by the Indicator Project (formerly known as the Sustainable Communities Index (SCI) and the Healthy Development Measurement Tool (HDMT)). This project, which originated from a Health Impact Assessment process, offers an "online framework and data repository that examines how San Francisco neighborhoods perform across eight dimensions of a vision for a healthy, equitable community"(San Francisco Department of Public Health and City & County of San Francisco 2018).

Beyond the City, the State of California took efforts to encourage data sharing, organizing its California Household Travel Survey data to be accessible by all the National Renewable Energy Labs; this has

facilitated the ability of approved researchers to incorporate transportation data into health studies, including those focusing on transit use as a source for adolescent physical activity and other studies on transport-related physical activity (Durand et al. 2016; Durand, Zhang, and Salvo 2017).

Austin, Texas, provides another model for data sharing and use through its Vision Zero program. The City maintains an interactive, crowdsourced input map and has coordinated with multiple entities to create and present a series of maps documenting its high-injury roadways. The City as a whole has been part of an open data initiative aimed at improving access to key data sources, including transportation and health related data.

The Nashville Area Metropolitan Planning Organization (NAMPO) coordinated with the Public Health Department for the 2035 Regional Transportation Plan. As sidewalks and bikeways became priority tenets of the plan, NAMPO wanted to prioritize the placement of the facilities in areas with the highest rates of health disparities and chronic diseases. To accomplish this task, they adapted the ITHIM tool to quantify the change in health status as a result of transportation behaviors. To run the model, NAMPO collected information on travel behaviors, health status, and air pollution from several data source including health studies; the U.S. Census Bureau; and Tennessee Departments of Health, Safety, and Environment and Conservation. This represented local, regional, state, and federal partners.

Embedded staff

Another method to ensure health considerations are incorporated into transportation plans and decisions described in the interviews we conducted, is to embed a staff member of one agency to work directly with the other agency. In Minnesota, there is no formal mandate for collaboration between the Department of Health and Department of Transportation. Instead, a staff person from the Department of Public Health works at the DOT 1-2 days a week. This staffing agreement helps to facilitate collaboration on a range of projects and programs, including the CIMS example above as well as Safe Routes to School, Transportation Alternatives, HIAs, and other projects.

The San Francisco Vision Zero program (described in the previous section) provides another model of embedding and/or cross-funding staff to work on health and transportation related efforts.

Creative or coordinated financing and funding efforts

Across the board, transportation and health agencies are struggling with limited resources, and to some degree the perception that limited resources cannot be creatively overcome.

Some agencies, such as LA Metro, have developed alternative forms of transportation project financing that can help them realize the benefits of sustainable transportation projects and strategies. For example, they use part of their transit revenues to reinvest in training and building capacity amongst their workforce and buy-in amongst the public, using an environmental management system framework. This has involved consolidating best practices into one structure/system, developing staff training programs to help staff become “green professionals,” and expanding training programs to accommodate all city employees, non-profits, and the public at large. Funding used in this way is important for creating a shared language around the issues, reducing silos, facilitating planning, and protecting and building institutional memory and technical skills.

In addition to investing in the transportation workforce, there is a need for continued hard infrastructure investment. Transportation for America provided a series of case studies on how regional entities are creating dedicated revenue streams to support projects related to active travel (Carpenter 2017). Litman recommended various transportation strategies to improve public health (Litman 2017). Among these are a call for transportation pricing reform. This may involve reducing fuel subsidies or increasing fuel taxes; unbundling parking provisions from building space rental; and increasing parking fees.

Much of the work the Kane County, Illinois Planning Cooperative initially did was searching for grants to fund health and transportation projects. They have also found ways to funnel federal funds to active transportation projects by incorporating Congestion Mitigation and Air Quality Improvement Program goals into their project prioritization point system. In the near future, up to twenty-five percent of points will align with CMAQ planning processes in order to fully capture available CMAQ funds.

In post-disaster recovery, there are significant opportunities for new funding mechanisms to be used to support local health, resiliency, and transportation planning. The Federal Emergency Management Agency's (FEMA) *Long Term Community Recovery Planning Process* guide, referenced by FHWA, acknowledges the importance of integrating recovery plans with existing transportation plans prepared by MPOs, rural planning organization (RPOs), and state DOTs, and funding streams for infrastructure, particularly the Statewide Transportation Improvement Program (STIP). It also includes a description of numerous private and federal funding sources (including FEMA public assistance, hazard mitigation and pre-disaster mitigation funds) that can be used to implement plans and projects. FHWA's website also includes a section on leveraging funding sources for recovery planning and rebuilding. However, as more than one community has noted, coordinating and leveraging funding streams during a crisis can be challenging, at best (Nolen 2014). Communities with a history of strong collaborations, existing partnerships, grassroots engagement, and health-oriented leadership may be better positioned to leverage available funds in the wake of a disaster.

Future Research Needs

Cross-sector collaboration tools/training

Developing a shared language and learning the jargon and acronyms from another discipline takes time, communication, and desire to learn (conditions which are sometimes not supported by employers). Few resources were found to help provide common terminology or explanation of routine processes from transportation and health fields to bridge the divide. Anecdotally, several interviewees reported reliance on a "bridge" staffer with a dual-degree background or cross-disciplinary training. To foster more leadership and interagency coordination, there is a need for resources and/or training for current and future professionals that can help build a shared language and understanding of terminology, processes, and tools from both transportation and health fields. This could involve the creation of more cross-disciplinary education programs (between public health and transportation planning or engineering programs), internship programs between Master of Public Health (MPH) and Planning/Transportation degree programs, on-the-job leadership/cross-disciplinary training programs, or embedded or rotational positions across agencies. These could be complimented with print resources that convey key terms, agency structures and processes, data sources and tools, and frame key issues and opportunities for cross-sector collaboration. APHA released a *Transportation and Health Toolkit* in 2011 to specifically help enable transportation and public health partners to communicate more easily; the toolkit has since been removed from the website. The AASHTO Committee on Environment and Sustainability, through the NCHRP, recently published a guidebook to help USDOT, state DOTs, MPOs and other transportation agencies effectively communicate with health practitioners and stakeholders, entitled *Connecting Transportation & Health: A Guide to Communication and Collaboration* (Steedly et al. 2019).

Stakeholder Perspectives

While many stakeholders noted the need for more case examples, they also indicated the need for examples from different community types and sizes, including those they could identify as peers. For example, small, conservative, Midwestern towns may not look to case studies from big cities such as Portland or New York, as being relevant or applicable.

Funding examples

There is a need for more case studies and/or research on how agencies can establish jointly funded programs (including training) and projects. Currently, funding sources remain heavily siloed. In Oregon, for example, much of the funding available to the Oregon Health Authority is from tobacco sales, while Department of Transportation funding comes from gas tax revenues. According to staff that were interviewed, this separation in funding streams makes it difficult to integrate health and transportation initiatives in the long-term. Innovative project funding mechanisms could help pool funds for staff, data collection and sharing, or other initiatives.

In particular, there is a need for case studies to document the funding challenges, opportunities, and noteworthy practices among states and communities that have gone through disaster recovery efforts, and to detail how these efforts were coordinated with the state and other key entities involved. There is also a need for funding examples that focus on rural contexts, particularly around how innovative funding streams, such as using Medicaid travel reimbursements, can be leveraged through agency partnerships to improve transportation services and access to healthcare or other basic needs.

Stakeholder Perspectives

Interviewees from transportation departments expressed a need to better understand the language, terminology, data from health departments, and how to interpret it before partnerships and data can be leveraged. For example, it took some time in one agency to understand that when the health department referred to an "odds ratio for adverse transportation outcomes," they were sharing statistics on what the DOT might consider a safety risk. Once language barriers were overcome, the departments were able to combine information sources to secure additional grant funding.

Tools/resources for framing health issues

Many communities have a low health literacy and little knowledge around transportation-related determinants of health, or others. Several agencies stated a need to compile talking points and education resources that can be used for transportation (and health department) staff to use to communicate and/or promote specific health issues or behaviors, with the public or internally, or provide an entry point into other transportation processes. As described in Nolen, the "evidence has to be ready to go, at the right moment, and communicated as an opportunity" (Nolen 2014). There may also be a need for more (and diverse) case studies describing how an integrated approach to health and transportation can benefit communities. There is already a proposed Research Needs Statement suggesting the need to create case studies to highlight city/county ordinances that support vibrant pedestrian networks.

Policy evaluations

A number of studies have been conducted to evaluate the outcomes of policies designed to improve health. For example, study of travel costs on various travel behavior outcomes found parking fees more effective than fuel prices for increasing walking trips (Yang et al. 2015). A separate study in Australia observed that fuel tax increases can generate small, individual-level health benefits through changes in work-related trips (V Brown et al. 2017). Litman summarizes more than eight studies of pricing reforms and their impact on health, safety, emissions, and driving behaviors. Additional policy evaluations, specific to quantifying health impacts and costs, are also covered in section 2.6 (2017).

Stakeholder Perspectives

One stakeholder interviewed put it bluntly: "More data does not mean better information." The collection and application of health and transportation data needs to be purposeful and targeted to the needs identified. Another stakeholder noted, "what gets measured gets done," and that often the more innovative efforts are limited by the data available. Many communities reported trying to "get by" with whatever limited data they have to run models or set performance targets, while at the same time aspiring to do more. Finally, many recognized that it is not enough to collect data. In order to appropriately use that data in tools and models, staff from both the corresponding transportation and health agencies must understand how to use the tools and interpret the results responsibly.

Complete Streets policies have been passed in more than thirty states and 1,000 municipalities or regions, according to the National Complete Streets Coalition. Many of these have been evaluated at various levels of scientific rigor, most focusing on specific sites or countermeasures related to Complete Streets. One of the most robust, statewide crash-based evaluations was performed by Porter et al. (2018). This study used a multimethod design to evaluate pedestrian crash rates from 1975 to 2015 in relation to the passage and implementation of a Complete Streets policy in Florida, an early Complete Streets adopter. It found that pedestrian crash rates decreased significantly, resulting in 3,500 lives saved over the twenty-nine-year period.

One systematic review of systematic reviews noted that most analyses of transport and health costs are simulated via modeling rather than observation. As such, there is a need for natural experiment studies on the economic impact of environmental or policy interventions at the population-level (Abu-Omar et al. 2017). Systematic reviews of studies about changes in travel behavior (i.e., mode shift) found that interventions, including economic tools, showed promise for positively impacting mode shift away from motor vehicle use, but often lacked rigor (Scheepers et al. 2014; Petrunoff, Rissel, and Wen 2016).

Robust policy evaluations tended to be sparse in the published and gray literature, and additional research is needed to conduct longitudinal research on the short and long-term impacts. There is also a need for such studies to consider how policies can impact different aspects of health, including safety, subjective well-being, physical activity, and exposure to environmental risks. For example, a systematized evaluation of the short-term and long-term impacts of street sweeping policies could take into account particulate matter and air quality, as suggested by Amato et al., as well as perceived safety and quality of bicycle lanes and bike ridership levels (Amato et al. 2010). A systems science approach may be needed to take into account the dynamics of policies that shift travel behaviors over time and unintended consequences, particularly in relation to equity. Proust et al. note that complexity, contingency, and uncertainty impede the development of adaptive strategies and policies needed to promote health in the face of climate change (Proust et al. 2012). They suggest the use of collaboratively developed conceptual models to identify key policy levers and provide a case study focusing on the issue of automobile dependence. The authors provide a rationale

for why a siloed approach looking at individual transportation or health issues is often ineffective or misleading and propose a process. Health Impact Assessments, described in practice further in section 4, are also an approach to policy evaluation that could be further put to use.

As many experts have indicated, the relationship between land use, development, and roadway design and performance is continually evolving over time but often in a disconnected fashion. There is a need for policies related to context sensitive design to be evaluated in terms of their ability to provide continuity and flexibility for adaptation, and for the effects of developments on various health outcomes to be evaluated over longer time horizons (e.g., short- and long-term effects of a mixed-use development near a corridor).

2.4 Data Improvement and Integration

Quality data are integral for transportation and health, used to support research and agency decision-making at all levels. Data to support integration of health considerations in transportation processes come from a variety of sources and depend heavily on the domain of health being considered (e.g., safety, active travel, environment, access, etc.) and how the data are applied. This section places emphasis on the data sources and collection methods identified that are most relevant to supporting transportation and health decision-making processes described in Sections 2.5, 2.6, and 2.7. They are organized in the following way and described in the sections below:

- Data sources for health determinants.
- Data sources for health outcomes.
- Data sources for health determinants and/or outcomes.
- Emerging data sources.
- Data integration efforts.

Data sources for health determinants

GIS-based infrastructure and network data (relevant to all health domains): Motivated by an interest to create healthier, safer options for travel, many communities are mapping their roadway and bicycle facility networks and key destinations to analyze how the networks can be improved to support safer, more equitable, comfortable, and accessible travel systems. Transportation for America provides an in-depth case study of network mapping efforts performed by the Corpus Christi, Texas MPO (Carpenter 2017). PeopleForBikes led a series of efforts to support communities in mapping and improving their bicycle networks, including the Green Lanes Project, the Big Jump, and the development of a bicycle network analysis tool. Network infrastructure data are also used in safety applications, such as mapping high injury networks to address in Vision Zero programs (as San Francisco has done). Collecting and aggregating infrastructure inventory or network data typically follows one of two approaches. A top-down approach involves state or city agencies gathering the data, which could be driven by external or internal mandates or guidance. A bottom-up approach includes those shown by PeopleForBikes and others, involving crowd-sourced efforts and or open-source data platforms such as Open Street Maps. These crowd-sourcing approaches are fundamentally altering the amount and nature of information available about the presence of infrastructure, though methods are still evolving and have room for improvement.

Social determinants of health data: Transportation practitioners are, in general, much less familiar with data sources around Social determinants of health than are public health staff. Many transportation agencies rely on data from administrative databases such as the Census or data collected and used by the state or local health departments. GIS-based mapping of social determinants of health is often an important step in planning (including pre- and post-disaster recovery planning) and HIA processes and community/grassroots engagement (discussed elsewhere in this document).

Air quality monitoring data (relevant to environmental and active travel health domains): Air quality issues in relation to transportation and health have been extensively researched and other efforts have cataloged existing research and data needs. The Center for Advancing Research in Transportation Emissions, Energy and Health (CARTEEH) created a Transportation Emissions, Air Pollution, Exposures, and Health Literature Library that includes more than 500 scientific studies on the topic, many of which relate to air quality data collection, methods, and quality control and are thus not repeated here.

Noise quality monitoring data (relevant to environmental and potentially other health domains): The relationship between traffic-related noise levels and health outcomes is mixed, dependent upon the volume of noise, duration of exposure, and individual factors and adjustments to ambient noise. In March 2017, USDOT's Bureau of Transportation Statistics released an interactive map of traffic-related noise data from across the U.S., designed for use in tracking trends (only the first year of data is currently available) rather than evaluating impacts. FHWA maintains a traffic noise model, based on measured vehicle count data. Other studies have determined that ambient noise levels are highly associated with measured traffic counts, thus highlighting the importance of vehicle count data on traffic facilities (E. Y. Lee et al. 2014).

Data sources for health outcomes

Access: Measures of accessibility are complex and multifaceted, and no one approach is understood as all encompassing. Current research aiming to pin down a definition of accessibility frequently references Handy and Niemeier's paper called *Measuring Accessibility: An Exploration of Issues and Alternatives*, where she reviews three classes of commonly applied measures, and discusses issues of specification, calibration and interpretation, and underlines the gap between research and practical application (1997). In 2018, Eric Miller of the University of Toronto goes on to say that we "do not currently have a comparable, standard way of measuring *accessibility* benefit of the opportunity or potential to interact at various levels of access" (2018). Access to destinations from a state level perspective is captured in the Transportation and Health Tool via a set of higher-level indicators, such as mode share, person miles traveled by mode, vehicle miles traveled, land use mix, complete streets policies, funding for bicycle and pedestrian infrastructure and public transportation trips per capita. Both Khreis, May, and Nieuwenhuijsen and Neutens discuss measures of accessibility and suggest that the most common and widely comprehendible metrics are based on distance and / or travel time to destinations. Neutens takes a close look at a selection of accessibility measures in terms of equitable access to healthcare and proposes research directions for transportation geographers (2017; 2015).

Community: There is no consensus on how to measure community or individual "well-being" or characteristics related to quality of life and social cohesion. This is a very active and emerging area of research. The studies identified to date have used a range of methods to examine this issue. These include employing concepts such as social cohesion, social exclusion, social interaction, exposure to the social environment, and more. Van Wee and Ettema describe how subjective well-being should be understood as a broader term than mental well-being, arguing that subjective well-being encompasses a wider spectrum of mental states, not only those which are considered symptoms of mental illness (2016). Waygood et al. measured well-being in children based on five key domains: physical, psychological, cognitive social, and economic (2017). Chihurri et al.'s 2016 review of studies on driving cessation and depression found research measuring general health, physical health, social health, cognitive decline, depressive symptoms, entry into long term care, and risk of mortality (2016). Leyden measured social capital by assessing how well individuals knew their neighbors, their political participation, their faith in others, and their social engagement (2003). In each of these studies, the source of data to measure these constructs varied widely; most were not considered data sources typically used by or available to transportation agencies.

Safety: The key data sources used to monitor traffic-related injuries and fatalities have been well-established. These include the Fatality Analysis Reporting System (FARS), General Estimating System (GES), CDC's Web-based Injury Statistics Query and Reporting System (WISQARS) and state-level crash,

injury, and fatality reporting systems. For all-cause mortality and morbidity, beyond the transportation sector, the Global Burden of Disease database has been used to estimate disease burden. A recent UTC report by Christopher Cherry, *Completing the Picture of Traffic Injuries: Understanding Data Needs and Opportunities for Road Safety*, describes the strengths and limitations of traditional datasets as well as many complementary datasets that can provide a more complete picture of road safety, and identifies opportunities and methods for data integration (Cherry et al. 2018).

While NHTSA's crash data sources are a key resource, many have noted needed improvements in the data and the definitions used. For example, NHTSA's classification of "rural" and "urban" crashes relies on state-level determinations, which typically use Census Bureau classifications. Census defines different levels of urbanization but defines "rural" as encompassing "all population, housing, and territory not included within an urban area." This basic dichotomy may limit research seeking to take a more nuanced approach to understanding health and transportation determinants and outcomes in different contexts.

Data sources for both health determinants and outcomes

Transportation and Health Tool (THT): This standalone data tool, funded by USDOT and CDC, is a key source of data related to health determinants and outcomes across multiple domains (including safety, access/connectivity, active travel, and environmental risk exposure). Through a rigorous research-informed and stakeholder-driven process, tool developers identified an initial set of one hundred ninety potential transportation-related health indicators (Boehmer et al. 2017). They narrowed these down to fourteen indicators that met the conditions for having either state and/or metro level data available and other key criteria. For each indicator, data were compiled for all U.S. states, three hundred eighty-one metropolitan statistical areas, and four hundred eighty-seven urbanized areas and made available through the tool. These include:

- Alcohol-Impaired Fatalities (state and metro area level).
- Commute Mode Shares (state and metro area level).
- Complete Streets Policies (state and metro area level).
- Housing and Transportation Affordability (metro area level only).
- Land Use Mix (metro area level only).
- Person Miles Traveled by Mode (state level only).
- Physical Activity from Transportation (state level only).
- Proximity to Major Roadways (state and metro area level).
- Public Transportation Trips per Capita (state and urbanized area level).
- Road Traffic Fatalities by Mode (state and metro area level).
- Road Traffic Fatalities Exposure Rate (state and metro area level).
- Seat Belt Use (state level only).
- Use of Federal Funds for Bicycle and Pedestrian Efforts (state level only).
- VMT per Capita (state and urbanized area level).

Data sources underlying the tool include data from FARS, National Household Travel Survey (NHTS), the Census including the American Community Survey (ACS), the U.S. Department of Housing and Urban Development (HUD), the National Transportation Atlas Database, and data gathered by organizations such as the National Complete Streets Coalition, the American Public Transit Association, and others. For more on the tool and its applications, see section 2.5.

Active Travel: Active travel can be seen as both a health determinant (in relation to chronic diseases, respiratory ailments, safety, and morbidity outcomes), and a health outcome in and of itself, related to policy decisions and infrastructure investments. The data sources used to measure active travel vary widely, depending on the research context or application. Many resources, guidance, research, and programs exist

on the topic of measuring physical activity and/or counting pedestrians and bicyclists. Some key existing resources geared to and used by transportation agencies include the NCHRP *Guidebook on Pedestrian and Bicycle Volume Data Collection* (NCHRP Report 797), Chapter 4 of the Federal Highway Administration's Traffic Monitoring Guide (TMG) and FHWA's guide on *Exploring Pedestrian Counting Procedures* (Ryus et al. 2014; Federal Highway Administration 2016; Nordback et al. 2016). Grasser et al. performed a study to "investigate which GIS-based measures of walkability (density, land-use mix, connectivity and walkability indexes) in urban and suburban neighborhoods are used in research and which of them are consistently associated with walking and cycling for transport" (2013).

The Delaware Valley Regional Planning Commission (DVRPC) is an often-referenced agency due to its robust nonmotorized count program. The DVRPC uses a variety of counting methods, many of which are now reflected in FHWA's TMG, and has developed an integrated publicly available database to store, analyze, and share results. The Philadelphia Department of Public Health provides support for the count program, utilizes its data, and participates on a multi-agency Healthy Communities Task Force (Carpenter 2017).

Beyond count programs and survey-based approaches (described later), much research has been undertaken to develop methods to indirectly measure active travel of various forms. For example, Mansfield and MacDonald Gibson estimated non-commute transportation-related physical activity for a specific geographical area. The same authors created models to estimate physical activity impacts from bus ridership; they noted that this research can be confounded by park and ride lots and also may underestimate transit use (2015).

Travel and/or health surveys: Several of the agencies interviewed spoke about the importance of collecting detailed travel survey data to assist with understanding the transportation-related factors impacting health, and also to directly measure health outcomes. The Behavioral Risk Factor Surveillance System (BRFSS) is one of the few national data sources that collects information on physical activity among other questions covering health-related risk behaviors and chronic health conditions. It is managed by the CDC and covers all states (with an option to buy add on data), with continuously conducted health surveys of more than 400,000 adults each year. The National Household Travel Survey is another source for data. Mansfield and MacDonald Gibson showed regression estimates generated from NHTS data can be effective for generating baseline estimates of physical activity within a neighborhood or region (to then use for Health Impact Assessments) (2016).

The Bureau of Labor Statistics' American Time Use Survey (ATUS) is a survey, conducted by the U.S. Census Bureau, aimed at measuring time spent on various activities, including working, socializing, exercising, leisure, childcare, and household activities. ATUS data have been used in studies examining well-being, family activities, eating and drinking habits, other health behaviors, and may be a source for examining the role of transportation on various aspects of time use.

Local travel surveys are also useful for estimating relationships between transportation and health at smaller geographic scales (metros and regions), as well as for gauging public opinion around health and transportation related issues. They can be routinely administered, for surveillance purposes, or designed as part of specific research studies. Nashville is an often-referenced example of a community that added health questions to their household travel survey, which was first administered by the Nashville Area MPO in 2009; results from the survey were used to inform and ultimately shift public policy toward greater support for active travel modes (Meehan and Whitfield 2017). In a separate example, a 2010 study in Charlotte, North Carolina evaluated the health impacts of its new light rail system using a pre/post phone survey to collect data related to physical activity, body weight, and other health measures of residents near the new system (MacDonald et al. 2010).

Online tools from the public health sector may include useful transportation data. County Health Rankings also has easily accessible information about long commutes, driving alone, air pollution, and social associations (among other information) that may be relevant. The Equity Atlas is another potential

source for indicators (such as car access and commute time) that may be utilized (Policy Link and USC Program for Environmental and Regional Equity (PERE) 2018).

Qualitative data sources: Qualitative data sources for identifying health and transportation concerns are both frequently used and frequently undervalued. Field-based visits or observations (sometimes called road safety audits or community health assessments, depending on their purpose) are often conducted and recommended as a data-collection approach and public engagement process. These typically involve participation from key stakeholder groups, which could include underserved community members, city council members, agency staff, etc. to observe conditions on the ground to assess where/how people use facilities and what adjustments are needed. The FHWA has long supported pedestrian and bicycle road safety audits (RSAs) and provided guidance and support for conducting them in numerous states, cataloging examples of use. NHTSA recently funded the development of a behavioral road safety assessment, to augment the infrastructure-oriented data gathered in the FHWA audit with additional behavioral components. Some states, such as North Carolina, have tailored the federal RSA guidance into a local process and program (Thomas et al. 2018). Beyond the data, the process of bringing people together, may be the most rewarding opportunity.

Relatedly, participatory photography, or Photovoice, has been an approach used to engage those with seemingly little power or status to support community needs assessments (Ward, Freeman, and McGee 2015). In this study, Photovoice was used among sixteen-year-old students in New Zealand to discuss themes concerning transportation and well-being through photography. The photos and resulting discussions suggested that "transport infrastructure played a key role in supporting well-being among participants." In the US, Photovoice projects have been used extensively by advocacy organizations such as America Walks and other entities working in underserved communities.

Emerging data sources

There are many emerging data sources that hold potential to improve the ability of practitioners and researchers to capture health determinants and outcomes, in particular accessibility, active travel, and environmental exposures. These include GIS data gathered from app-based sensing technology (such as Strava and Waze), that can track individuals and aggregate the travel behaviors and routes of some populations. Some, such as Google Fit, are also capable of integrating travel and health data. A 2015 report describes the technologies and methods by which pedestrian and bicyclist activity data can be crowdsourced to support research and planning. The report describes four different types of crowdsourced data (in situ, thematic, thumbtack, and spatial inventory data), and provides various applications and examples (A. Smith 2015).

Other emerging data sources with health applications include biometric data, available through in-vehicle technology to measure driver stress levels and other conditions, such as intoxication, and to monitor for situations such as heart attacks, seizures, and diabetic-related blackouts affecting driver safety and performance. Ridella, Kang and Kitazaki describe the potential for various in-vehicle biomedical and biometric monitoring devices (2009). It is not currently widely known to what degree these technologies have been tested or implemented. Biometric data have also been used to measure pedestrian stress and are being applied in a current UC-Berkeley study, performed in collaboration with Stanford, to examine cyclist stress (Chrisinger and King 2018).

Big data can be defined as extremely large data sets, often gathered by machine or sensor technologies, that is often difficult to analyze without the help of sophisticated computing techniques. Common sources of big data in transportation come from traffic camera footage, or the personal apps collecting travel data described in earlier paragraphs. One current project, NCHRP IDEA 20-30, is developing a data collection system for inventorying pedestrian facilities via satellite imagery and machine learning. Cell phone data is becoming more widespread, robust, and available for research and analysis. For example, it has become more common for transportation agencies to purchase data from communication companies and data-

processing companies to describe real-time travel patterns. This data is most often applied to study motor vehicle traffic, but it may also be used to describe pedestrian and bicycle travel patterns. As big data storage, management, security, and analytic practices evolve, there may be more opportunities for harnessing these data sources for health and transportation research opportunities.

Data integration efforts

Cherry et al. provides an in-depth literature review on transportation and medical data linkage efforts to date, methods and technical challenges, as well as applied case studies. Many sources for this report indicated obstacles regarding integrating data across the health and transportation fields that need to be overcome in future efforts (2018). CDC's *Assessment of Characteristics of State Data Linkage Systems* found reporting lag time to be the primary barrier to data linkage across agencies. Other major issues in linking data included having capable staff, data quality, and lack of unique identifiers (Milani et al. 2015). Above all, the organizational structure of most state, regional, and local agencies may lead to siloed efforts that can be difficult to combine for a variety of reasons. The interview with the Oregon DOT and Health Authority, for instance, highlighted the difficulty of integrating data collection because of differing responsibilities and funding sources. Moreover, when deciding how to incorporate health data into transportation decision-making processes, it can be difficult to navigate between potentially opposing priorities for the public health and transportation agency, a difficulty mentioned by more than one state DOT.

Stakeholder Perspectives

Stakeholders commented that while data integration can be difficult and time-consuming, it is not impossible. It can also be a good place to bring people to the table to begin relationship building. Often, what is needed to enable the work is a broader policy initiative, such as Vision Zero, that provides motivation, political cover, resources, and opportunities for the cross-agency coordination needed to facilitate data integration.

Another major issue is that some forms of public health data come from geographies larger than the transportation data. Public health data is often geared at the county level, while transportation data can get as detailed as an individual intersection. Most of the interviewed agencies emphasized a need for more localized, granular public health data.

Future Research Needs

Improvement of data collection methods and adoption of best practices

Researchers and practitioners alike demonstrated a strong desire for research that would bolster data collection efforts and adoption of data collection best practices. This may entail funding research to:

Improve data coverage/quality: Improved data are needed, particularly in relation to key health determinants or outcomes needed in modeling tools. For example, widespread usage of the Health Economic Assessment Tool (HEAT) is limited by lack of data for several factors, including lack of morbidity data, the non-linear relationship between mortality and active transportation, lack of data on the long-term health effects of active transportation on children, health effects of active travel by gender and age group, and non-fatal crash data (Kahlmeier, Goetschi, and Cavill 2017). Other studies or stakeholders

have reported the need for more quantitative data in general, to augment qualitative health data. It may be particularly important to consider where these data are collected and where additional data should be gathered. For example, the National Ambient Air Quality Monitoring Network, a network of air quality monitoring stations around the country, lacks monitoring stations in counties with populations living near high-volume roads (Rowangould 2013), which limits the ability to effectively study health and equity concerns in those areas. Several existing Research Needs Statements indicated the need for better data related to air quality in relation to diesel, tailpipe, and non-tailpipe sources.

Ensure equity in data: Establishing guidelines and best practices around ensuring that data do not underrepresent persons or populations which have been traditionally underserved or under counted is critical.

Share innovations for using existing data/tools: In some cases, existing data may need to be manipulated or adjusted for use in available health and transportation tools. For example, Wu et al. and the National Center for Sustainable Transportation provide some potential case studies to illustrate how to fill data gaps related to race/ethnicity and income in transportation/health datasets, using data fusion to infer demographic variables for several counties to use in ITHIM (2018; Niemeier and Qian 2018).

Assess innovations in collecting data: This might include the need to assess passive data collection techniques (e.g., GPS-based apps) for use in measuring travel behavior and physical activity, or to develop guidance on how to derive ped/bike counts from existing technologies.

Provide guidance for data formatting, standardization, and aggregation: One scientific article noted the need for more studies that account for the modifiable areal unit problem or MAUP (aggregating geographic units causes data variations) and the uncertain geographic context problem or UGCoP (when perceived/self-reported geographical boundaries do not match formal boundaries) (Badland et al. 2015). An existing Research Needs Statement suggests the development of a "database of data" to be able to understand the health effect of transportation projects at various geographic scales. This same Research Needs Statement includes developing strategies for sharing data across policy sectors. It is worth noting that such an archive, for household travel surveys, was started. It does not seem to be up to date, and it is not clear or easy to identify studies that have leveraged it.

Provide guidance on how to institutionalize collection of key data sources, such as pedestrian and bicycle counts or other methods to measure exposure and active travel activity across a network (and for purposes beyond just commuting)**.**

Improved data granularity/specificity to the unit of analysis needed

Related to the above research need around data improvement, there was an expressed need for data collected at scales that are meaningful and useful for a fine-grained analysis (e.g., at the sub-county unit or sub-population level). Specifics of the data needed at finer levels of analysis varied, but included:

- Pedestrian/bike activity data by population subgroups (e.g., gender and age groups) as well as intensity of physical exertion, available for discrete transportation facility types. The THT developers. specifically acknowledged the lack of non-motorized travel/physical activity data at the Metropolitan Statistical Area (MSA) level (Boehmer et al. 2017).
- Data regarding different types of transit (e.g., the ACS lumps all transit together at block group level, which is particularly an issue for research in rural areas).
- Tayarani et al., 2016 highlighted the need for guidance for more fine-grained air quality analyses, as the methods the EPA requires for regional analyses obscure issues due data aggregation (2016).

It is worth mentioning that efforts are ongoing to do small-scale estimation for a variety of national level data sources. For example, using BRFSS, CDC is working on promising approaches (Pierannunzi et al. 2016).

Data integration

Linking and integrating data has been identified as a key goal of TRB's Health and Transportation Committee. More than one existing Research Needs Statement describes the need to link crashes and medical data (including emergency room and/or trauma registry data). Given some of the emerging issues referenced in section 2.9, there is a need, and opportunity, for data integration to support the ability to gather data needed to investigate the relationship between opioids, cannabis, other classes of drugs and synthetics, and transportation safety outcomes. Beyond linkage, there is a need to manage and utilize linked data surveillance systems and demonstrate the value of such data integration.

Spatial linkage is an important aspect of data integration. There is a desire to be able to link key data sources, such as National Household Travel Survey, using Global Position System (GPS) survey methods to collect more detailed activity data.

Another area ripe for data integration and innovation lies in the area of transit-related data. Transit providers are owners of key data sources, including transit ridership counts and surveys, as well as transit infrastructure inventories (such as spatially referenced bus stops and shelters) that could be useful for planning and integrating health and transportation considerations. There is a need for guidance and examples on how to integrate public health data collection into existing transit data collection and management, and vice versa.

Data visualization and application

As a trend in data visualization and mapping continues, there is a need for research to detail how communities are funding, using, and maintaining online mapping forums (i.e., via Vision Zero) and how such data are being integrated into safety and transportation planning practices. Documentation of processes to develop open source data sharing platforms, or coordination of efforts to combine data platforms, may reduce redundancies across states and cities that are undertaking these efforts.

2.5 Decision-Making Tools and Processes

A wide variety of health and transportation decision-making tools were identified through the process of the literature review and stakeholder interviews. A few were deemed key opportunities to trigger conversations about health and integrate health considerations into the transportation process. These are organized and presented according to the following categories:

- Data modeling/forecasting tools.
- Data visualization (estimators and mapping) tools.
- Health scoring/assessment tools and checklists.
- Frameworks/processes.

Data modeling/forecasting tools

Most health and transportation tools fall into two categories: those that use comparative risk assessment (CRA) methods and those that use a regression models to "directly" link certain factors to health outcomes. Relationships that are fundamental to regression model can change over time (e.g., density) so models can't simply apply current conditions to the future; they need to be re-calibrated over time. CRA-based tools are less likely to need to be adjusted over time because they rely on robust epidemiological evidence about the relationship between behavioral risk factors and health outcomes (e.g., daily exercise and morbidity).

However, CRA tools require high-quality local data about affected populations and behavior change. Four tools were repeatedly described and have been applied in various contexts. These include:

Integrated Transport and Health Impact Model (ITHIM): This is a comparative risk assessment that estimates changes in mortality and disease burden due to changes in travel behavior. ITHIM is based on air quality, physical activity, and road traffic injuries (measured by disability adjusted life years). ITHIM has been used by communities and can be tailored to local context and to specific population segments (e.g., Sacramento, Nashville, Massachusetts, and California). This is important as several scientific articles pointed out that substituting estimates from other locations or from the literature limits confidence in model results, because much of what is studied through these models is context specific. The model has gone through several iterations and is the basis for ITHIM Global, which aids ITHIM assessment in urban areas of middle to low-income countries. Several case studies were identified involving applying or calibrating ITHIM. For example, one Nashville study has been extensively cited. Using ITHIM, Nashville's MPO estimated $10-63 million in annual savings due to reduced disease burden from decreased car travel and increased walking and biking (Whitfield et al. 2017). Sacramento's case study was documented by Wu et al. and in the National Center for Sustainable Transportation report (2018; Niemeier and Qian 2018). There, the City adapted ITHIM to account for equity considerations by interpolating demographic data (referred to as "data fusion"). Examples from California, and its Bay Area have also been documented (Maizlish et al. 2013; Carpenter 2017). In their interview with project team members, MassDOT referenced work underway to calibrate ITHIM for its context.

Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE): This is an open-source computer program designed to estimate both frequency and cost of air-quality related deaths and illnesses. Several applications of its use have been documented. BenMAP generates county-level estimates from state or national data. Results can be displayed as a map, tabular data, or a text summary.

Community Multiscale Air Quality Modeling System (CMAQ): This is an open-source modeling tool developed by the EPA to estimate current and future pollutant concentrations. The output of this tool is often an input for other tools, such as BenMAP.

Health Economic Assessment Tool (HEAT): This model, developed by the World Health Organization, aims to generate a comparative risk assessment of health economic benefits based on value of a statistical life (VSL), from an intervention that results in changes to walking and biking (Kahlmeier, Goetschi, and Cavill 2017). HEAT has been criticized for its inability to take into account changes over time to population health; it is being refined through ongoing research such as Gerike et al. (2016). Several case studies applying the HEAT tool where identified. A Barcelona project applied HEAT during its HIA and estimated a €9.3 billion per year savings modeled under the scenario where the city's residents met requirements for physical activity, green space, air pollution, etc. (Mueller et al. 2017; Pérez et al. 2017). Other studies have compared HEAT to complementary tools, including to CMAQ and EPA's BenMAP in the Midwest, to the Physical Inactivity Calculator in Arlington, VA, and to the Dynamic Modeling for Health Impact Assessment (DYNAMO) in North Carolina (Soneji et al. 2014; Mansfield and MacDonald Gibson 2015; Grabow et al. 2012). The comparison of HEAT to DYNAMO in NC found estimates from HEAT were three times greater than the estimates from DYNAMO-HIA for same data, because HEAT cannot account for population changes over time.

Beyond these four open-source tools, a number of more general data analysis/modeling techniques were also identified in the literature review. Modeling approaches ranged from using probit models to estimate travel behavior, to pricing models to determine impacts on real estate, to agent-based models to examine walking behavior among sub-populations. Poisson and negative binomial regression models were commonly used in studies to estimate impacts (such as crashes/safety) from transportation interventions.

Data visualization (estimators and mapping) tools

While some of the above tools can also support data visualization, a number of resources have been created with the specific goal of enhancing data visualization. These are traditionally used to support community engagement and education, as well as provide estimators and mapping tools useful in the planning process. Example tools identified include:

- **City Health Dashboard**: An online tool developed by New York University with funding from the Robert Wood Johnson Foundation that shows health and population metrics by zip codes/census blocks for the 500 largest cities in the U.S.
- **U.S. Health Map:** An online map and data visualization tool to show health risks and causes of mortality/morbidity by state and county over time. The U.S. Health Map, maintained by the Institute for Health Metrics and Evaluation, a research center at the University of Washington, also provides data visualization for several health indicators and outcomes for countries around the world.
- **North Carolina Social Determinants of Health Map:** This is a state-level example of an online mapping tool, developed by the North Carolina Department of Health and Human Services with data from the Census and the USDA's Food and Nutrition Service. It is designed to illustrate health trends and disparities by region of the state.
- **Physical Inactivity Cost Calculator:** An online tool developed by Active Living Leadership to estimate health costs (lost productivity, medical care, and workers' compensation) due to changes in physical activity. This tool generates a quick estimate from only a few inputs, most of which are available through the U.S. Census Bureau.
- **Housing and Transportation Affordability Index**: Haas et al. developed a model for estimating average household transportation costs (at the Census block level) based on Census-based information on vehicle miles traveled, auto ownership, and transit use. The model has since been expanded and refined into the Housing and Transportation Affordability Index, a data visualization tool to support policy makers, planners, and housing professionals. It has been applied in a number of cities and states to support planning and benchmarking (Haas et al. 2008).

Health scoring/assessment tools and checklists

Scoring tools and checklists provide an opportunity and structured method to consider key elements of health during critical stages of transportation infrastructure planning and design. Following are four health-oriented checklists. Others, like Road Safety Audits that focus specifically on safety, are described in the section 2.4 discussion of qualitative data sources. Both these and RSA checklists contain links to guidance documents that are heavily used for decision-making (e.g., American Planning Association (APA) *Healthy Communities Policy Guide*, National Association of City Transportation Officials (NACTO) guides, *Small Town and Rural Multimodal Networks* (STAR) guide, Federal resources, etc.). A limitation on most checklists and scoring tools is that they are often considered as subjective, qualitative, and/or often outside the realm of required activities by transportation decision-makers. They are most powerful as a tool for grassroots engagement.

- **Healthy Living and Active Design Scorecard:** This is a tool developed for use in Delaware to score comprehensive plans based on policies that support health. University of Michigan used this tool as a template for the Healthy Rural Community Design: A Scorecard for Comprehensive Plans (Maiden et al., 2017).
- **AARP walkability audit tool:** An example of a tool designed to support community engagement and discussions around walkability and document community needs.

- **Rural Active Living Assessment** (RALA): This resource provides a framework to assess how supportive rural communities are for physical activity based on built environment, community programs, and policy.. A case study of RALA in North Carolina is provided in Hege et al. (2017).
- **FHWA Health in Transportation Corridor Planning Framework :** This document supports the integration of health into the corridor planning process, at state, regional and local scales. Components of the framework include air quality, bicycle and pedestrian issues, health equity, community engagement, safety and transit.

Qualitative approaches, such as concept mapping (to identify potential solutions based on collective experience of community members), logic flow models (to develop shared understanding and documentation of data and decision-making processes), and systems diagrams (to surface assumptions and develop shared understanding of system goals and components, and structures) were also processes described in the literature, often used in tandem with quantitative and data visualization approaches described above.

Frameworks/processes

Health Impact Assessment: HIAs focus on identifying potential health impacts of proposed policies and projects and provide recommendations to improve those policies/projects by mitigating adverse health impacts and promoting positive health impacts. Often, they include several health indicators, such as physical activity, air quality, safety, or others.

A large number of HIA-related research has been published. Studies range from a review of one hundred fifty-eight transportation-related HIAs, case studies that demonstrate possible data sources for HIAs, and a case study of an HIA on the City Comprehensive Plan performed in the aftermath of Galveston's disaster (Hurricane Ike), to finally a review of seventy-three transportation related HIAs which includes a collection of case studies that emphasize the importance of public health and transportation interagency collaboration (Dannenberg 2016; Mansfield and Gibson 2016; Waheed et al. 2018; Nolen 2014). A systematic review of twenty-nine active travel HIAs determined that evidence shows it is plausible that there is no substitution effect between travel related physical activity and non-travel physical activity, a common concern with HIA methods (Mueller et al. 2015). One tool, Dynamic Modeling for Health Impact Assessment (DYNAMO-HIA), is an HIA-related tool that uses Markov Chain modeling to account for population health changes over time and address this common critique of HIAs. See Mansfield and MacDonald Gibson for a comparison of DYNAMO to HEAT, referenced above (2015).

A recent synthesis of data from evaluations of multiple HIAs argues that HIAs are effective in promoting health and preventing decisions made in non-health sectors from having negative impacts. Moreover, the study suggests that the efforts made to engage community stakeholders during the HIA process can be as valuable as the outcome itself (Dannenberg 2016).

While many studies have evaluated HIAs as an approach and demonstrated value, challenges in implementation remain. In their review, Waheed, et al. found a general need for improved clarity and rigor in transportation HIAs (2018). In some cases, poorly timed, badly articulated and under resourced HIAs were less successful. Some transportation agency staff have expressed concerns that HIAs are one more "add-on" that require additional resources that aren't available, and that they are aren't integrated or can't be integrated into routine DOT processes such as NEPA without a significant paradigm shift or funded legislative action. One study noted that HIA actions typically come "from the outside," leaving uncertainty around the uptake of recommendations. There are also concerns HIAs don't consider the realities of building a transportation system (Dannenberg 2016).

National Environmental Policy Act Review Process: This is a Federally mandated process that requires agencies to evaluate the environmental and related social and economic effects of any federally funded activities in the public realm which change the physical environment.

In an article discussing the integration of health into the Environmental Impact Assessment (EIA) process, a process within NEPA, Bhatia and Wernham emphasize the comprehensive nature of NEPA and its influence on a wide range of federal and state activities which impact human health. He stresses that 'protecting human health and welfare' along with the 'interdependence of environmental quality and human health' underpins the NEPA regulation. He notes, however, that health has been traditionally less of a focus in the NEPA process, as in practice NEPA has often been in the purview of agencies which are more directly tasked with environmental protection and management (2008).

The report *Integration of Health & Health Impact Assessments via Environmental Policy Acts*, issued by the Network for Public Health Law, details multiple legal pathways for further integrating health and health analyses into the NEPA process, as well as into processes mandated by State Environmental Policy Acts (SEPAs) in seventeen states. The authors note that while health considerations are legally embedded in NEPA, and that some agencies use Human Health Risk Assessments (HRAs) or Life Cycle Assessments (LCAs) to address potential health impacts of projects, HIAs are broader in scope and enable consideration of a wider range of community and population specific health effects. The report goes into depth describing potential entry points during the NEPA or SEPA process for health analyses (Hodge, Widenaar, and Barraza 2016).

A publication from the Association of State and Territorial Health Officials (ASTHO) provides a set of case studies of agencies who have used HIAs as a part of or alongside the NEPA process. The researchers present similar findings, HIAs can broaden and enhance the scope of health considerations which are inherent in NEPA. In addition, the case studies reiterated the work of Dannenberg, above, in the finding that HIAs strengthen and foster community engagement around health outcomes of projects (Dolan et al. 2017).

Resiliency and recovery planning and frameworks: Disasters and extreme weather events such as hurricanes, tornadoes, wildfires, and floods can profoundly impact population health and transportation infrastructure. Some studies have indicated that the frequency of these events is on the rise in the U.S. and globally (Hoeppe 2016). These events are disproportionately impactful on vulnerable populations, including seniors, low-income households, and people with poor health or social status. While often performed under devastating conditions, disaster recovery planning offers unique processes for communities to consider health as they develop plans to rebuild.

The National Transportation Recovery Strategy provides a broad outline of recommended practices for Federal, state, and local stakeholders to consider before and after a disaster event. It is intended to complement FEMA's National Response Framework, the guiding resource for response and recovery planning. The National Transportation Recovery strategy highlights the need for considering active, sustainable transportation that can "reduce the high public cost of building, maintaining, and repairing roads, overpasses, and bridges—infrastructure that is often damaged in a natural disaster." It encourages states and communities to review transportation plans and policies and consider efforts to give people more transportation options (such as active travel and transit), encourage denser development patterns, provide higher quality public transit in both rural and urban areas, and identify opportunities during recovery planning to advance sustainable infrastructure (*Recovering from the Disasters: The National Transportation Strategy* 2009).

Healthy, Resilient, and Sustainable Communities After Disasters: Strategies, Opportunities, and Planning for Recovery provides a comprehensive, 500+ page review of the importance of health planning post-disaster. It highlights opportunities to take a "Health in All Policies" approach to integrating health into all aspects of recovery planning and design, and to build community engagement, collaboration, and support. It puts forth a recommended strategy to consider health and transportation initiatives through a disaster lens, in order to consider pre-disaster planning opportunities that can accelerate recovery, as well as to approach post-disaster planning and recovery efforts through a health lens. The report emphasizes the collection of data indicators related to health and health equity, which have even more pronounced effects after a disaster. Notably, while the role of transportation providers is acknowledged throughout the

document, none of the authors or review committee represented state or local transportation departments; there may be a need to distill key guidance from this document for specific transportation audiences to accelerate usage and implementation of recommended practices (Committee on Post-Disaster Recovery of a Community's Public Health, Medical, and Social Services, Board on Health Sciences Policy, and Institute of Medicine 2015).

Future Research Needs

HIA-related research needs

While the process for HIAs and findings have been extensively documented in the literature, questions still remain regarding whether or not HIAs can support better health through transportation, and how the process can be more routine and aligned with existing transportation processes without causing undue burden. Alternatively, if HIAs are conducted separately, there is interest in guidance on expedited HIAs or condensed, lighter versions that are less resource intensive. There is a need to examine the use of HIAs in longer-term studies and validate whether HIAs can capture the long-term impacts of a transportation project, or to improve the underlying sources of data so that HIAs can better capture long-term impacts. Agencies are also seeking guidance on the appropriate time and place for an HIA and how to make them more participatory and aligned with transportation best practices.

Existing modeling/forecasting tool needs

With the many tools that currently exist that have been applied to various contexts, several research needs have emerged around evaluating and further refining these tools. These needs generally fell into the following categories:

- **Validate tools and underlying assumptions**: There is a need to assess available models, especially the most commonly used ones, for how they account for documented research challenges, including self-selection bias, non-linearity, system feedback, and the relationship between regular physical activity and travel-related physical activity.
- **Enhance tool specificity:** Section 2.4 describes the need for improved data at the sub-county level; this is a prerequisite for improving the tools and models so that they can also be enhanced in order to model specific subsets of the population and specific projects/interventions below the county level.
- **Better incorporate equity measures**: As data and research improve, there is a need for guidance on equity indicators, and how these can be integrated into existing tools.
- **Document and assess tool usage**: There is a need to synthesize the applications of certain tools (such as ITHIM and HEAT) and to evaluate the effectiveness, application, and customization in different agency contexts. This effort could also examine why certain tools are or, more importantly, are not being used and develop guidance, training, or additional resources that can enhance tool usage.
- **Develop more comprehensive or complementary tools**: Ultimately, practitioners seem to be seeking a model or research that can provide a comprehensive overview of health impacts for different kinds of transportation projects (including transit). This could include spreadsheets or tables that provide quick numbers estimating impacts such as emission reductions, cost-benefits, and others at different geographic scales.

In particular, two scientific articles and one governmental report cited the need for more research and underlying data regarding the non-linear relationship between mortality and active transport, and preferably by population subgroup (Kahlmeier, Goetschi, and Cavill 2017; Abu-Omar et al. 2017; Kelly et al. 2014) .

This will also help inform future iterations of HEAT (described above), which is currently based on a linear dose-response function because that is the data available, even though research shows the relationship is likely non-linear (Kahlmeier, Goetschi, and Cavill 2017).

Other travel demand model research needs

With major changes in health and emerging modes of travel (described more in section 2.9), there is a need for more careful examination of existing travel demand models, and their underlying assumptions. Research is needed to develop more robust tools for travel demand modeling, in particular around estimating pedestrian and bicycle travel demand, and demand for walking to transit, in various contexts. Estimating travel demands and needs among hospital or clinic patients, and incorporating travel needs and travel time into the transportation planning and design processes, is also an important area where little research currently exists.

2.6 Quantifying Health and Transportation Costs

With transportation agencies operating in a resource-constrained context, there is considerable pressure to prioritize project selection based on quantitative information that can be transparently and routinely applied. Return on investment (ROI), or benefit/cost ratio (B/C), are key figures considered by transportation agencies during project prioritization and selection.

This section describes the approach that agencies are taking to conduct economic evaluations, and research that provides evidence of the economic costs or benefits of health-related transportation projects. The majority of studies identified revolved around assessment of active travel-related interventions or quantifying environmental risk related impacts (air and noise pollution, etc.). Specific tools/models used and frequently applied to quantify health impacts and costs were described in Section 2.5. The literature below reflects the broader collection of research and findings on this topic.

Stakeholder Perspectives

Many stakeholders interviewed indicated the difficulty in communicating a specific benefit from a project or approach, or quantifying the exact health benefits for a single project (such as widening or extending a sidewalk), while more economic studies are emerging, particularly studies for trail projects, a widely expressed concern was having enough studies or data to convince people of the value of certain facility types, particularly related to active transportation. As one interviewee noted: "Engineers are trained and comfortable with methods such as Level of Service for measuring vehicle-related roadway performance; they are defendable models and it's hard to argue with the math. Anything we put forward that is less quantifiable will lose the engineer's, and possibly the public's confidence."

Active travel: The VTPI report titled *Evaluating Active Transport Benefits and Costs* is a combined literature review and guidance document that explains various costs and benefits of active transportation with associated performance measures, indicators, evaluation, and monetization techniques (Litman 2018a). A systematic review of systematic reviews related to costs of physical activity interventions included five reviews that considered travel-related interventions. Four of the five found travel-related interventions to increase physical activity to be

either cost-saving (intervention benefits outweighed intervention costs) or cost-effective (intervention less costly than other options, but not necessarily cost-saving). Nearly all of the reviews with a transport component reported wide ranges in costs and benefits. One review, from 2012, found school-based transport interventions not to be cost-effective (Martin, Suhrcke, and Ogilvie 2012). However, a 2008 review by Cavill et al. focused entirely on active travel, and found interventions to be cost-saving (2008). Sonali et al., analyzed Transportation Demand Management (TDM) efforts in Arlington, Virginia and estimated a 200 percent ROI on TDM implementation, assuming 1 percent of the population shifted from inactivity to CDC recommended activity levels (2014). A systematic review regarding economic impacts from active transportation by Brown et al. found scientific literature tends to focus on economic benefit from physical activity, whereas grey literature takes a more comprehensive approach. The majority of studies reviewed utilized cost benefit analysis (thirty-two of thirty-six), considered a hypothetical intervention (seventeen of thirty-six), and analyzed a facility or facilities (twenty-nine of thirty-six). All studies were from Europe, the U.S., Australia, or New Zealand and none considered subgroups of their target population. While findings were limited by the variety of methods and time periods used for estimating impact, in comparison to a systematic review on the same topic from 2008, there has been a marked improvement in standardization of methods (2016).

Environmental: The Organisation for Economic Development's (OECD) 2014 report of the cost of air pollution shows the magnitude of health impacts from air pollution "could easily outweigh the monetary costs of investments in more ambitious programs to reduce pollution" (*The Cost of Air Pollution* 2014). The report also supports use and development of standard methods for calculating health impacts for morbidity (e.g. Value of Statistical Life for mortality)(*The Cost of Air Pollution* 2014). Analysis of a light rail project in Houston, TX showed reduced environmental exposure to motor vehicle related air pollution to the population immediately around a new light rail station, suggesting health benefits (Park and Sener 2017). Modeling of health impacts of congestion in eighty-three cities shows that monetized value of premature deaths from exposure to particulate matter, while less than economic costs due to time/fuel wasted, is a significant proportion of the total costs of congestion (Levy, Buonocore, and von Stackelberg 2010). Application of the Pavement Environmental Impact Model (PEIM) in Quebec revealed that noise costs constituted the majority of environmental costs related to pavement management. This tool can help DOTs add environmental costs to their maintenance cost-benefit estimates (Pellecuer, Assaf, and St-Jacques 2014). Grabow et al. provide a case study for estimating health costs under various air pollution scenarios. The study used CMAQ to model potential changes to air pollution and estimated the associated health economic impact from such changes using BenMAP and HEAT (2012).

Multiple health outcomes: APHA's report titled *The Hidden Health Costs of Transportation* provides estimates (in 2008 dollars) for the public health costs of transportation and health savings from urban design. A 2018 report from North Carolina Department of Transportation (NCDOT) utilized the Implan modeling tool and the Alta Benefit Impact Model to estimate the post-implementation economic impact of shared use paths in both rural and urban areas of the state. Intercept surveys and trip counts were used to estimate health benefits of increased physical activity, air pollution reduction benefits, and safety benefits from reduced crashes. These impacts were monetized via Disability Adjusted Life Years and Value of Statistical Life (O'Brien et al. 2018).

Future Research Needs

Accuracy, consistency, and standards for incorporating intervention costs into evaluations

A systematic review of the health impacts of built environment interventions found reports of intervention costs were uncommon, inconsistent (in terms of what costs were reported and when), and exhibited a wide range (Smith et al., 2017). There may be a need for high-quality research regarding the costs of interventions as well as guidance of what costs should be included in cost-benefit or other economic

analyses of transportation projects to ensure a more standardized approach. The Benefit Cost Analysis of Bicycle Facilities Tool has long been hosted by the Pedestrian and Bicycle Information Center and still receives regular visits and inquiries, but there is no longer a funding mechanism to support tool updates and maintenance. The site now refers to a resource by Bushell et al., *Costs for Pedestrian and Bicycle Infrastructure Improvements*, that contains a lengthy summary of the range of costs for various infrastructure treatments and key assumptions to guide the application of the data (2013). Future research could revisit or build upon these or other efforts to provide common and consistent sources of information on intervention costs.

Consistency/standards for measuring health impacts

As illustrated by the volume of research studies noted above, there are many different approaches currently in use to measure various health impacts. WHO's 2017 guidebook to the HEAT tool (*Health Economic Assessment Tool for Walking and for Cycling*) notes the variance in the preferred economic valuation of health impacts by discipline. For example, the transportation sector typically uses Value of Statistical Life, while years of life lost or health care costs are more common among the health field. Numbers for VSL differ vastly across countries and WHO recommends using a local VSL for HEAT.

While there are few documented techniques for valuing equity, a 2017 report by the Victoria Transport Policy Institute offers a crude method that is based on willingness-to-pay. There is a need for continued documentation of the approaches taken to quantify health impacts and costs, particularly concerning equity, and as the research evolves, to move toward more consistent standards or approaches.

Examples and research of rigorous economic evaluations

Many existing Research Needs Statements identified, and stakeholder interviews conducted, contained a theme related to the desire to have more, and defendable, examples of return on investment studies that incorporate health costs or savings. There was also recognition that some of the benefits of transportation investments, such as health care costs avoided by having more pedestrian/bicycle infrastructure, may accrue in sectors outside the one paying for the costs. Agencies expressed desire for research or examples of cost-benefit analyses comparing various investment scenarios, including those showing active travel projects as compared to highway projects. Quantitative data are needed on health benefits/impacts associated with individual transportation projects and "place-scale" factors such as streetscape, public space destinations, wayfinding, etc. There is also a demand for research to quantify the costs and benefits (including health cost savings) of policies or approaches related to aging in place, safety, air quality, and mental health. For rural transportation providers, developing better definitions for return on investment that incorporate health care cost savings provided by increased access to services, was deemed important. Some practitioners identified a need for a siloed approach to economic evaluations (i.e., measuring the individual economic benefit/cost contributed by discrete elements in an investment strategy) and others highlighted the need for an integrated evaluation approach.

Stakeholder Perspectives

Several stakeholders noted that in addition to measuring the cost of doing something, such as implementing a new roadway facility, agencies need to find ways to take into account the cost of *not* doing something (i.e., maintaining the status quo).

Several challenges remain inherent in economic evaluations which may require additional research and documentation of best practices to overcome:

- **Monetization challenges:** Several health outcomes (such as stress, quality of life, mental health, etc.) are not easily monetized, or it may be inappropriate to do so, and thus are often ignored in economic evaluations. As noted earlier, there is also limited research related to monetization of equity-related factors in cost-benefit analysis; this has been a Research Needs Statement submitted in 2007 and again in 2012.
- **Data limitations:** As one study noted, "Bike/ped forecasting methodologies are not well developed, and supporting data are not always available" (Aoun et al. 2015). This presents a challenge to estimating the benefits of projects that may increase walking and biking.
- **Lack of consistency/standards:** The sections above speak to these issues and how they may impact the ability to monetize certain health outcomes or scenarios.

Structural silos: Many transportation departments, particularly their safety offices, are familiar with benefit/cost approaches that relate to their area of expertise (e.g., crashes and infrastructure with associated crash modification factors and cost data) but may be reluctant to incorporate costs (or use underlying data) of health domains beyond safety (such as air quality or physical activity) if they are not operating in an environment where cross-silo work is encouraged and enabled.

As a start, synthesis research may be needed to identify economic evaluation approaches used (by type of project and health domain), data sources/methods, key challenges, and stakeholders necessary to engage in future research in order for it to be effectively integrated into practice.

2.7 Setting Goals and Performance Measures

Fundamentally, performance measures are tied to Federal funding. Understanding how agencies are incorporating health-related transportation performance measures, and whether this strengthens the work that is funded and increases chances of integrating health, is an important research area.

Moving Ahead for Progress in the 21st Century (MAP-21), enacted in 2012, required transportation agencies to begin reporting a wide range of performance measures to track surface transportation investments. This was a major shift for many DOTs as well as some MPOs, and they are still trying to navigate the requirements and understand how decision-making is impacted.

Quality performance measures, and research/evidence to guide implementation, are important for planning efforts—such as Strategic Highway Safety Plans, Vision Zero, or related safety initiatives—that have clear connections to health and offer important opportunities to bring new partners and data to the table.

The following sections document practices and research around measuring and evaluating health-related performance. Perhaps in part due to federal requirements, there is a large body of evidence regarding transportation and safety performance measurement. This section specifically did not pursue studies in which safety was the *only* component of health performance measurement. It does include studies where traffic deaths and injuries were included as one of many related health performance metrics used or recommended. The section includes the following:

- Existing guidance on health performance measures.
- Research and evaluation of performance measures.

Existing guidance on health performance measures

FHWA's *Guidebook for Developing Pedestrian and Bicycle Performance Measures* provides a toolbox of performance measures for pedestrian and bicycle transportation. Fifteen out of the thirty identified measures are related to a “health” goal and can be used to evaluate health performance. Many of these

measures could also be used to address other goals such as connectivity, economic health, safety, and equity. For each performance measure, FHWA offers examples from peer communities, implementation recommendations based on geography (state, region, or local) and land use type (urban, suburban, or rural), and potential data sources. The guide also provides different ways that communities could develop these measures and use it to track their goals. This guidebook lacks specific values for most performance measures; with values and target ranges appropriate for different contexts, this document could serve as a national framework for assessing active transportation and other health-related concerns (Semler et al. 2016).

The Alliance for Biking and Walking endeavored to collect and track data on bicycling and walking beginning in 2003. Their primary mission was to support efforts to increase biking and walking, a key objective of which included making the connection between active transportation and healthy communities. The *2016 Bicycling and Walking in the United States Benchmarking Report* , which was shepherded by the League of American Bicyclists, was developed into an online resource principally funded by the CDC. The site features a deep dive into relevant current knowledge, interviews with practitioners in the active transportation field, and importantly, a robust data exploration interface, drawing from over twenty data sources, with a useful toolbox to assist communities in "making their case". Among the notable limitations are the fact that many data sources exist only for the most populous cities, and the question of which active transportation trips remain unmeasured by current data collection methods (League of American Bicyclists 2016). The report was updated in 2018 (League of American Bicyclists 2018).

APA's *Metrics for Planning Healthy Communities* provides a list of built environment indicators and planning policies for many aspects of a healthy community. The main purpose of this report is to help communities assess, measure, monitor, and report progress towards health performance goals. Among the five major domains identified in the report, four fall within the scope of this report – active transportation, access to basic needs and services, environmental quality, and community well-being, cohesion, and sustainability. These metrics are not meant to be prescriptive in nature and thus do not provide guidance on what values/ranges to aim for within each indicator (Ricklin and Shah 2017). APA's *Healthy Community Policy Guide*, which is based on the Metrics report, also includes a list of policies across various domains. It seems that the intent of these performance measures is to provide a menu of options as a starting point. Additional rationale, background evidence, and guidance on applying the performance measures are needed (*Healthy Communities Policy Guide* 2017).

The *Developing Public Health Performance Measures to Capture the Effects of Transportation Facilities on Multiple Public Health Outcomes* report develops public health performance measures for transportation infrastructure with a focus on safety, physical activity, and air quality. It provides examples of performance measures to evaluate transportation infrastructure and their impact on health. The purpose is to allow decision-makers to evaluate and prioritize transportation infrastructure investments such that those investments benefit not single, but multiple health outcomes (Casey et al. 2016). Similarly, to evaluate the performance of transportation investments, Transportation for America has developed data-driven measures that could be used by MPOs. They also provide case studies on several communities – including the San Francisco Bay Area, Sacramento, California, Nashville, Tennessee, and Greensboro, North Carolina (Carpenter and Zaccaro 2018).

Research and evaluation of performance measures

A systematic review of twenty-five long-range regional transportation plans found that the health-related components in those plans did not address all aspects of health. Most of the plans lacked health-related performance measures for general health and physical activity. The plans also fell short of including direct performance measure of population health (such as obesity), and thus tools such as ITHIM could be helpful. In many cases, the population-specific goals were not accompanied by population-specific measures (Singleton and Clifton 2017).

Healthy Living and Active Design Scorecard was created to score comprehensive plans for their ability to incorporate health. It consists of fifty comprehensive plan measures and twenty-nine implementation measures. A study that evaluated the effectiveness of the Scorecard found it to be a reliable tool for measuring how land use plans and plan implementation address health. Twenty-five of the fifty measures for land use plans and eleven of the twenty-nine implementation measures are related to transportation or connectivity. The tool was created to focus on built environment strategies that could reduce obesity, and thus has a restricted scope (Maiden et al. 2017).

A review of twenty-six studies showed that the three most commonly used strategies used by the rural communities to prevent obesity are "enhance infrastructure supporting walking," "increase opportunities for extracurricular physical activity," and "increasing physical activity opportunities at school outside of physical education." This study, however, could not say for certain that these measures were successfully implemented and that they were effective in decreasing obesity (Umstattd Meyer, Perry, et al. 2016) Another systematic review of GIS-based walkability measures showed a consistent relationship of walking and cycling for transport with gross population density, housing unit density, intersection density, and walkability indexes (Grasser et al. 2017). However, due to the presence of measurement issues (too many measures to measure the built environment), the connection between these measures and walking for transport requires further investigation.

Stakeholder Perspectives

Many agencies interviewed spoke to the need for performance measurement to better align with policy and plan goals and anticipated outcomes or noted a mismatch in performance measures used by different coordinating agencies (e.g., health department vs. transportation department).

Future Research Needs

Evaluation of paradigm shifts in what agencies measure

There is a need to understand current practices regarding to what degree states utilize Level of Service (LOS) and other auto-oriented measures of performance against measures that are more aligned with multiple health co-benefits, such as Multimodal Level of Service (MMLOS) or reductions in vehicle miles traveled (VMT). Relatedly, there is a need for research on the cost of VMT on a per-distance traveled basis (Fang and Volker 2017). This research should consider what factors have prompted a shift in what performance measures are made (e.g., California's executive level action as described in section 2.3, or other approaches related to Federal policy, etc.).

There may also be a need to reflect on how evaluations related to transportation are performed altogether, taking a systems perspective to uncover and test basic assumptions and examine whether the processes used to evaluate health projects and programs are designed appropriately.

Evaluation of plans/policies/programs for their impact on health outcomes

Most of the studies that assess transportation-related plans, policies, or programs focus on the inclusion of health or health-related aspects in them rather than their impact on population health. There is a need to develop performance measures or studies that evaluate the effect of such plans or policies on health outcomes such as physical activity, obesity, environmental exposure, and quality of life. Longitudinal before-and-after natural experiments can be valuable in addressing this issue, but such studies are few. The

resources required to conduct such studies including time and funding can be an impediment. Also, it is difficult to measure the true impact of a plan or a strategy on health using such tools in the presence of other community efforts.

Standardization of health indicators

A systematic review of built environment and physical activity studies showed an inconsistency of evaluation in terms of performance measures used and time horizons for application (M. Smith et al. 2017). There is a need to provide guidance on standardizing the application of performance measures to help communities select, develop, or use the measures that best suit their context. Using an appropriate performance measure and best evaluation technique will also help in effective policymaking because it will translate the reality more accurately. Following is a list of criteria that could be standardized to make the evaluation process more relevant:

- Need for guidance on when and how often the plans or policies are evaluated depending on the geographic size of the community and scale of the project.
- Need to synthesize and compare performance measures for major aspects of transportation and health such as walkability, built environment, health outcome, and natural environment.
- Need to develop shared or complimentary performance measures for various agencies based on their type (city, county, state) and area of focus.
- Need to create a consensus around the standard definition(s) and the way to measure the performance measures and health indicators.
- Need to compare different health indicators such as disability-adjusted life years (DALYs), all-cause mortality (ACM), value of a statistical life (VSL), disease burden, and metabolic equivalent of task (MET).
- Need a standard for morbidity that measures the economic cost of morbidity as a coefficient of the economic cost of mortality. This would increase the use of morbidity costs as outcome in many tools such as ITHIM, HEAT, and BenMAP (described in section 2.6), which at present uses mortality and associated economic costs.
- Need for guidance on how to modify and select performance measures by geographic scale in a way that accounts for the modifiable areal unit problem or MAUP (aggregating geographic units causes data variations) and the uncertain geographic context problem or UGCoP (when perceived/self-reported geographical boundaries do not match formal boundaries)
- Need to develop a standard geographic unit or buffer size for monitoring the impact of the built environment interventions on active travel.

Development of new performance metrics

The current literature and existing research need statements identified highlight the need to develop the following additional performance measures that could enhance future analysis and help provide a better understanding of the connection between transportation and health. These include:

- Measures to evaluate equity, including the economic impacts for cost-benefit analysis.
- Measures to evaluate the feasibility of infrastructure for autonomous vehicles.
- Measures to track active transportation at the county level or lower.
- Measures of environment and social impacts of pavement management systems.
- Measures to quantify the impact of transportation funding decisions.
- Measures to estimate and monitor cost-benefit of reducing greenhouse gas (GHG) emissions.

- Measures to track the change in attitudes/perception/preferences towards health and travel behavior.
- Measures to evaluate the impact of increased driving and congestion on crashes and emergency transport to trauma facilities.

2.8 Connecting Health and Transit

Public transit is key to providing access to medical services, schools, work sites, grocery stores, and other community services. It is also a critical tool in addressing transportation-related inequities. Transit is closely associated with walking and bicycling travel, and associated health benefits. Many transit providers have affirmed a common saying, "every transit trip begins and ends on foot." The CDC recently released a series of case studies on transit and its connection to health, highlighting what can be accomplished to improve public health in five years via various transit programs (Centers for Disease Control and Prevention 2019).

Transit planning and operational decision-making are often made in separate silos, or organizational structures, from other surface transportation processes. For example, a state DOT may have a Division of Transit that is separate from its Divisions related to Safety, Land Use, Long Range Planning, and Multimodal Division. Locally, a separate agency may have jurisdiction over transit services. This is not to say that these entities do not coordinate or collaborate regularly with each other. However, there may be unique needs, challenges, and opportunities for transit and health considerations, beyond the general transportation and health needs and issues raised in the other sections of this *Report*. The following sections document key research and practices surrounding transit and highlight potential research needs.

Several studies have shown a relationship between transit availability/placement and the ability to meet physical activity goals, reduce the risk of chronic diseases, or access transit by active modes of travel (Besser and Dannenberg 2005; Lachapelle and Frank 2009; Durand et al. 2016; MacDonald et al. 2010). Some of these findings indicate that minority and lower-income populations benefitted the most from walking to transit.

Stakeholder Perspectives

Many stakeholders interviewed indicated that transit was an often overlooked or under-considered opportunity to incorporate health. The decision-making nexus between land use, transit route/stop planning, and coordination of services related to health care access was seen as a difficult but critical opportunity for coordination.

In an overall review of transport policies, Khreis, May, and Nieuwenhuijsen single out several transit related policies that could have a positive effect on health outcomes, primarily those that improve transit service and overall accessibility to destinations. The authors reiterate that good public transit can produce increased physical activity, reduced noise and air pollution, climate change effects and possibly crashes, and facilitate more exposure to green space, reduction in social exclusion and inequalities (2017).

Personal security is a topic of concern with regards to transit. While violence committed on transit can affect both men and women, women express more fear of harassment while using transit, and may choose not to use transit or to change routes (Ceccato 2017). Policy has been slow to address women's mobility needs; Loukaitou-Sideris and Fink found that, of one hundred thirty-one transit agencies surveyed, only one-third had identified the need for specific women-friendly transit services, and only three had implemented such a program (2009).

Locally, many communities and regions are seeing the connection between transit and health and making intra-agency collaborations more explicit. Transportation for America documents several case studies of regions working to improve access to transit and overall health outcomes (Carpenter and Zaccaro 2018). It details the Denver Regional Council of Governments work to improve first and last mile connections to transit to support walking/biking trips; efforts by the Atlanta Regional Council to invest in transit-oriented

and multi-modal projects to help meet the region's air quality improvement needs; and North Decatur, Georgia's plans to establish "wellness districts" as part of its Medline Plan. It is likely that many regions have similar success stories and efforts underway—such as efforts this project team learned about through stakeholder interviews with Kane County, Illinois to utilize rural transit to improve access to food, and San Francisco's work to coordinate transit stops and services with a local health clinic—that are not as thoroughly documented as these.

The Victoria Transport Policy Institute summarizes several best practices related to building transit-supportive systems which include transit-oriented development, bus priority lanes, first/last mile improvements, provision of funding for newer/cleaner transit vehicles, improved user information, bus stop and station improvements. The organization also details the positive benefits of high quality Transit on public health, including crash reductions, increased physical activity, improved well-being, and better access to needs such as healthy food and health care, and reduced financial stress (Litman 2010; Litman 2017).

At the state level, transit planning and provision may not be as closely planned or coordinated with surface transportation projects or health initiatives. A white paper issued by USDOT and the Volpe Center noted that "human services transportation is often coordinated at the state level and is commonly separate from the statewide transportation planning process "(Lyons et al. 2014).

Measuring transit and health connections

Modeling can be used to estimate health outcomes around transit systems. Using a health impact assessment methodology, Mahendra and Rajagopalan estimated that ninety-six lives could be saved over the course of five years as a result of increased walking or cycling, decreased private vehicle use and a reduction in air pollution exposure along a bus rapid transit (BRT) corridor in Indore, India, as compared to a business as usual scenario in which current trends in motorization continued (2015). Mansfield and MacDonald Gibson created models for active transportation using the NHTS, and found, among other things, that changes in the built environment that induced more transit use prevented a number of estimated deaths in the given area per year (2016).

Many HIAs (also discussed in section 2.5) have been conducted on transit projects. Dannenberg et al. examined seventy-three selected HIAs that had been used to analyze transportation projects around the country, highlighting the diversity of types of projects on which HIAs can be conducted. The proposed fourteen-mile long Red Line Light Rail project in Baltimore was assessed, and findings showed positive effects on health via increased physical activity, improved air quality, better access to jobs, and improved neighborhood connection (Dannenberg et al. 2014).

Several studies quantified health impacts of specific transit projects using before-and-after evaluations. Objective and self-reported measures have been used to determine changes in the environment, physical activity, and health outcomes after implementation of a transit project. One investigation looked at health impacts of a light rail transit (LRT) project in Houston and showed measurable health benefits to residents near the LRT as compared to those further away from the location of the project, showing both a reduction in air pollution in the area surrounding the light rail and a decrease in stroke mortality for the group nearest the same area (Park and Sener 2017). MacDonald examined users and non-users of a LRT system in Charlotte, North Carolina, and found a reduction in Body Mass Index to be associated with use of the light rail (2010). In separate studies, Brown et al. and Miller et al. used GPS and accelerometer data to determine change in physical activity after construction of new transit projects (2017; 2015). Other research looked at walking times for transit users captured in the NHTS data, in order to assess the proportion of transit users who obtain 30 minutes or more of daily physical activity (Besser and Dannenberg 2005).

Future Research Needs

Communicating the broader health benefits of transit

Research and guidance on how states and localities are achieving and communicating the benefits of transit, from a health connection perspective, may broaden understanding and support for integration of transit into the transportation network. Linking transit improvements to larger public heath goals beyond simply air-quality—such as improved well-being, better placemaking, and improved and more equitably distributed accessibility for the community, and even to reduced vehicle crashes and loss of life—can tie transit to overall quality of life. In addition, there is a need for demonstrating how agencies are linking land use, built environment, and pedestrian improvements to transit ridership and coordinating with other entities to share knowledge, data, and coordinate communications with the public.

Stakeholder Perspectives

From the interviews conducted, there is a sense that some transit agencies don't see their impact on health as much as pedestrian and bicycle advocacy groups do. Research could highlight policy outcomes that lead to mode shift and thus better health outcomes, including equity. Articulating the health benefits of transit to the general public could build support for transit.

Quantifying the health benefits of transit

Studies show a positive connection between health outcomes and transit, but there are gaps in knowledge of how to measure health benefits derived from transit use. Literature on the effects of transit use on specific attributes of health—such as health equity, social cohesion, air quality—is still growing. Individual findings point to reductions in vehicle crashes, reduced exposure to pollutants, increased physical fitness, and improved accessibility based on increased transit use, but little work has been synthesized to show the complete picture in a systems-oriented perspective, and how the different health issues interrelate. One noteworthy example of research that has taken a systems approach is Procter et al.; this study created and subsequently performed simulations on a conceptual model of transit and light rail policies in relation to other key transportation, land use, energy, and economic factors. The model, and simulation output, showed how policies set in one sector were impacted by other sectors and how these affected health outcomes, including air quality, and vehicle miles traveled (2017). This type of work could further be expanded to show safety, physical activity, and other health outcomes. Research that provides a wide-ranging overview of health impacts of transit, and conceptual framework, may enhance transit agencies' ability to consider health outcomes in transit planning.

Data inaccessibility, lack of granularity, inability to link datasets, and so forth may obscure the full story and limit the research recommended above. Refer to section 2.4 for research recommendations in these areas that also relate to transit.

Quantifying health cost savings of transit implementation, on both a macro and micro level, especially in comparison to other motorized and non-motorized means of travel, would support higher prioritization for including efficient transit into the transportation system. Analyses of economic gains made through transit should be conducted in both urban and rural settings. A synthesis of current state of the practice for transit ridership to medical facilities would yield important findings for those working to improve this particular service.

Standardized metrics with which to assess, quantify, and forecast health outcomes as transit planning is taking place would provide concrete guidance for practitioners. Performance measures that help the transportation field align heath objectives with transportation goals need to be developed. Many DOTs may

have worked to develop such performance measures, and evaluation of their application and how well the health measures integrate into the planning process would inform future efforts.

Assessing the role of new technologies in supporting health through increased transit access/use

Technology advancements endeavor to deliver service information to transit users in new ways. There are numerous emerging technologies, phone-based apps, and services that transit agencies are pilot testing and adopting. For example, NCDOT's transit division is partnering with Uber and a local startup TransLoc in a current pilot to examine the ways in which car and rail transit service and payment can be more seamlessly integrated. Many transit agencies, including those in New York City, Massachusetts, Nashville, Tennessee, Durham, NC, and others are examining innovations in providing on-demand paratransit services, with the support of apps and partners such as Uber and Lyft.

In-depth studies on the emerging technologies associated with transit could expand on this work, and add to future adoption of innovation (Khreis, May, and Nieuwenhuijsen 2017). The extent to which these pilots are motivated by health interests, informed using health related data, and engaging with health partners is needed.

Guidance/case studies

Several guidance documents already exist on how transit agencies can improve the safety, access, and integration of transit with other modes, and coordinate with other entities responsible for the broader transportation network. For example, FHWA offers a Pedestrian Safety Guide for Transit Agencies as well as a more recent guidebook on Achieving Multimodal Networks. NACTO produced a Transit Street Design Guide that references the role of transit in creating healthy cities in its foreword. FTA's *Manual on Pedestrian and Bicycle Connections to Transit* is an additional helpful resources on connecting active travel modes to transit.

Stakeholder Perspectives

Agency representatives interviewed explained that they have observed connections between drug addiction, mental health, and traffic crashes. As a result, they are searching for data to focus interventions and public safety messaging. These connections span many sectors of public health and transportation safety.

However, it is not clear how often these resources have been used by transit agencies, particularly at the state level, or how well they address the needs and challenges of these agencies in incorporating or communicating health considerations. In particular, these resources may be more oriented to urban transit providers and may not address the many opportunities for more rural entities to improve health. Development of a synthesis resource, with documentation of transit-related case studies for how to integrate public health considerations into planning, development, and operations of transit, may be warranted. This is also the topic of an existing Research Needs Statement from 2013.

2.9 Emerging Issues and Technology

Society is observing major shifts in demographic, cultural, and behavioral trends related to transportation and health. Some of these, but not all, are intertwined with emerging technologies and scientific innovations that have occurred in transportation and other sectors. These changes present new challenges and often opportunities for further integrating health and transportation.

The following sections present a snapshot of emerging issues, both demographic, cultural, and technological, that may need to be accounted for in future transportation and health endeavors and research. Data-related technologies and emerging issues are described elsewhere in section 2.4.

Demographic, cultural, and travel behavior shifts

While many societal changes are occurring, the following trends may have direct or indirect impact for state and local transportation agencies and for policymaking.

Aging: The population makeup as a whole in the United States is aging; by 2040, twenty percent of the population will be over the age of sixty-five, up from thirteen percent in 2010. The long-term impact on this demographic shift in terms of transportation and health-related outcomes is unknown. Chihuri et al. examined research on aging populations and driving cessation in the U.S. and found that driving cessation was associated with a number of poor health outcomes, including a doubling of the risks of depressive symptoms (2016). Safety-related studies have shown mixed results; while a number of studies have documented that senior drivers (and pedestrians) are more cautious and less likely to be involved in a crash (in terms of individual risk), seniors account for a growing percentage of the fatal vehicle-vehicle and vehicle-pedestrian crashes.

Impairment: Alcohol misuse, and its impact on transportation safety as well as numerous other health domains, continues to be a major problem in the U.S. Alcohol-involved crashes represent nearly twenty-eight percent of all fatal crashes, and the trends in alcohol fatalities appears to be on the rise (National Highway Traffic Safety Administration 2017). In addition, the opioid epidemic has emerged as a major health crisis in the U.S. Emergency room visits and unintentional deaths due to controlled substances have increased at alarming rates in recent years (Manchikanti and Singh 2008). A review of epidemiologic evidence concluded that there is a clear association between opioid use by drivers and significantly increased risks of crash involvement and crash culpability (Chihuri and Li 2017). Impairment of driver performance is one possible contributor to increased road fatalities (Wickens et al. 2017). Additionally, there have been major policy shifts in many states regarding marijuana that have affected its distribution, cost, quality, and accessibility; the impacts on changes in marijuana usage—particularly in relation to other legally or illegally available substances—and on transportation safety and related behaviors is an ongoing topic of discussion and research.

Mental health: Factors affecting mental health and the role of transportation, is an under-studied issue. Within this realm, concern for transportation-related suicide has been raised as a potential topic of import. Of particular concern is whether vehicle-assisted suicide is under-reported, and what transportation agencies may do to improve programming, as well as data collection and reporting of traffic incidents related to mental health concerns. Some transportation agencies have developed programs to support suicide prevention program, in particular programs related to rail transit and bridges.

Urbanization: On the whole, populations are moving from rural to urban living. In 2015, ‘millennials’, those born in the last two decades of the Twentieth century, represented the largest portion of all Americans, numbering seventy-five million, and many tend to live in more urbanized areas. Studies show a steady decrease in automobility in this generation, which is producing a marked shift in travel demand. McDonald argues that while their travel patterns may show fewer trips made by this group today, their travel patterns may shift once they reach new life milestones, and government has an opportunity now to set policy which will shape the form of their future mobility (McDonald 2015). Another factor of changing urban landscapes is rising housing values, displacement and gentrification, which are identified as a concern in multiple studies looking at implementation of major transportation infrastructure, such as the Atlanta Beltline and various Transit Oriented Development projects. Innovative policies which encourage investment while not excluding some residents in all facets of a community need to be explored and advanced. Finally, as some residents choose to live outside of town or are priced out of urban cores, questions remain as to whether demand on the rural transportation system will meet their health needs.

Aging, impairment, mental health, and urbanization issues are also inherently intertwined, with associations with health all documented in the literature; some trends may be balancing or reinforcing others. For example, mental health and well-being can be affected by changing environments. In a report titled *Urban Sanity*, VTPI discusses some of the impacts of urban living on mental health, including those of transportation conditions, stating that, for example, a transportation system which enables safe walking and biking can produce positive mental health benefits for a community (Litman 2018b). Robertson et al. looked at studies on walking and concluded that the evidence is clear that walking has a large positive effect on the symptoms of depression (2012).

Consumer vehicle preferences: An emerging trend, identified in recent studies and media coverage, has related to a recent uptick amongst U.S. consumers in purchasing larger vehicles, including light trucks and SUVs. The impetus for this trend, whether associated with gas prices, social forces, or other factors, is not clear. However, the safety and health implications—for safety and air quality in particular—are striking. For example, a recent report by the Insurance Institute for Highway Safety (IIHS) examined the recent rise in pedestrian deaths, from 2009 to 2016. The report raises questions about the increase in the number of larger vehicles (sport utility vehicles, or SUVs) involved in pedestrian crashes, and points to the larger vehicle design as a possible factor in higher risks of death or severe injury to the pedestrian (Hu and Cicchino 2018). Research is needed to better understand trends in vehicle marketing, consumer demand, and safety for road users both inside of and outside of larger personal vehicles, and the role of health departments and DOTs in curbing demand for particularly unsafe or unhealthy forms of travel.

Access to healthcare in rural areas: A 2016 publication by Kaufman et al. documented the rising rate of rural hospital closures, higher in the South, which "show no signs of abating."(2016) The health and broader economic impacts of hospital closures are large. For rural transportation providers in particular, whose primary mission is often to connect its users to health care services, this trend presents a key challenge in providing affordable access to healthcare. For rural residents it also has important implications on the quality and speed of providing post-crash emergency care and treatment. There is a need for additional research on the impacts of hospital closures on health and transportation costs in rural areas and guidance for state DOTs regarding transportation funding and policymaking.

Stakeholder Perspectives

Stakeholders interviewed expressed optimism about the opportunities presented by shared mobility services, but also a widespread concern that policy making, and demands for policy making, were outpacing research available. There was also concern for how all of the emerging issues and technologies could be, or were being, communicated to the public.

Emerging forms of transportation and mobility

Known by some as 'three revolutions,' the emerging technologies of shared mobility, vehicle electrification, and automation are positioned to radically alter the transportation landscape (Fulton, Mason, and Meroux 2017).

Shared mobility: The shared use of a vehicle, bicycle, or other travel mode, has expanded rapidly in recent years. Work by researchers at UC Berkeley's Transportation Sustainability Research Center and Institute of Transportation Studies explore impacts of shared mobility, and find that, in general, use of this mode can lead to reduced VMT, increased accessibility for carless households, reduced greenhouse gasses and some increased use of active modes of travel. However, though studies have shown that use of shared mobility services can increase mobility for disadvantaged households, the lack of credit cards and smartphones remains a challenge for some populations (Shaheen, Cohen, and Zohdy 2016).

A systematic review of active transportation interventions included two studies that demonstrated self-reported mode shift due to implementation of bike sharing systems. Survey participants reported substituting motor vehicle trips with bike share trips, with a six percent substitution in London and an eight to ten percent substitution in Montreal (Scheepers et al. 2014). Woodcock et al. also looked at Bike share in London and found positive health effects for some, but not all user groups and suggests that creating safer cycling infrastructure would further increase likely benefits (2014). Additional studies have identified positive impacts on physical activity in Montreal, Melbourne, Brisbane, Washington D.C. and Minneapolis/St. Paul (Fuller et al. 2013; Fishman, Washington, and Haworth 2015). The safety literature examining net safety changes or even individual mode-based changes in crash frequency, has not yet caught up to explore these issues but several crash-based evaluations looking at the introduction of shared mobility services in a community are underway.

With the entry of more shared mobility providers, there are opportunities to create public-private partnerships to improve health equity and mobility. For example, the Centralina Council of Governments, an MPO in the Charlotte, North Carolina region, is working with Uber to identify volunteer drivers to support a transportation service for vulnerable populations. They provide training and umbrella insurance to participating drivers, with a shared goal of increasing access for patients to preventive visits; anecdotal evidence suggests that the program has seen positive mental health improvements.

Electric vehicles: Electric vehicles (EVs), those with either a hybridized internal combustion and battery powered engine or a full battery powered engine, have exploded in popularity around the globe, with some estimating that around two million electric and plug in hybrid passenger cars and around two hundred million electric two-wheelers were on the roads as of 2017 (Hall, Cui, and Lutsey 2017).

Electric vehicles are quieter than vehicles with combustion engines. While this may reduce ambient traffic-related noise pollution, it also has raised concern about the ability of bicyclists and pedestrians, particularly those with hearing impairments, to detect and avoid vehicles. In 2016, NHTSA announced new regulation requires hybrid and electric vehicles to produce sound to enable better audible detection of the vehicles by pedestrians and bicyclists on the roads (Karush 2017). Testing of optimal sound levels, tone, and pitch was conducted, but NHTSA suggested there is room for further refinement of the minimum effective audible warning (Hastings, Guthy, and Pollard 2012). The new regulations will come into place in September 2018, offering future opportunities for testing the quality and impact of these regulations.

Sales of electric bicycles, or ‘e-bikes’, are also on the rise. In Switzerland, electric bicycle crashes have been tracked since 2011, and a recent study analyzed single-vehicle e-bikes crashes, and found that, among other things, common causes for crashes were speed, road surface, and in some cases rider experience (Hertach et al. 2018). Survey results from the UK concluded that e-bike purchases were partly motivated by perceived health and well-being benefits, and the use of an e-bike, while it replaced the use of a conventional bicycle often replaced the use of a motor vehicle (Jones, Harms, and Heinen 2016). Recently published research found that e-bikes do provide moderate physical activity for all users in general and increase physical activity for those using an e-bike instead of a car or a bus (Langford, Chen, and Cherry 2015). Although e-bikes have been shown to make biking more accessible to a variety of people, more research is needed to understand how e-bikes affect travel behavior and physical and mental health (Jones, Harms, and Heinen 2016).

A doctoral thesis from University of Tennessee, Knoxville looked at health and equity impacts of both electric vehicles and two wheelers in China, which have dramatically increased in use in the country. Among other things, the study found that EVs do not necessarily perform better than conventional cars in terms of environmental health impacts, though e-bikes do. Heavy particulate matter emissions resulting from electricity production required to charge EVs reflect China’s reliance on coal. In contrast, e-bikes lead to fewer negative environmental health impacts, due to the fact that they are lighter and require less energy overall (Ji et al. 2012).

The collaborative Light Electric Vehicle Education and Research Initiative (LEVER) is tackling a wide-ranging set of research questions in relation to e-bikes and small electric vehicles (which include

skateboards, scooters, and even roller skates). The group have identified five central thrusts for future research: Behavioral Analysis of Light Electric Vehicles (LEVs), System Impacts of LEVs, Health Impacts from E-bike Use, Urban Freight Logistics, and Shared LEV systems.

Automation: With the recent burst in efforts to develop and also regulate highly-automated vehicles (HAVs), Crayton and Meier note that it will be necessary for public health actors to participate in policy debates and reforms, considering all the ways that health can be impacted through zoning, licensing, privacy, costs, and liability. They make the case for a research agenda that focuses on the public health effects of Automated Vehicles (AVs) on 1) roadway injuries, 2) environmental health and air quality, 3) mobility and equity issues for seniors and other mobility-limited populations, 4) sedentary lifestyles and travel behavior shifts, 5) changes to roadway design and land use regulation and planning, and 6) labor market disruption (in particular taxi, bus, freight, delivery, licensing, and insurance markets) (2017).

The report *Public Health and Health Equity Considerations of Autonomous Vehicles in California* reviews potential health and equity impacts of widespread use of AVs and puts forward policy recommendations for moderating the worst outcomes. Determinants of the degree/magnitude of the impacts include the degree to which transportation is shared, the degree to which transportation is electrified, and additional public policies. Health impacts fall under the key domains of support of active transportation, effect on environment, traffic safety, and mental health, and the additional question of how use of 5G technology and its attendant radiofrequency radiation might affect human health (Snyder, Torres, and Wu 2018).

A resource developed by the Federal Highway Administration's Pedestrian and Bicycle Information Center, *Discussion Guide for Automated and Connected Vehicles*, provides a basic glossary of key AV-related terminology and focuses on the research needs and policy implications of automated and connected technologies as it relates to active travel. Primary issues and potentially emerging concerns center around AVs' abilities to detect and prevent crashes with VRUs, effective communication between AVs and nonmotorized users, and current inconsistencies with the laws that may dictate AV operations and interactions with other road users. The problem of the human-in-the-loop/driver hand off (whereby the vehicle reverts control back to the driver, or, a safety driver in the case of AV testing), is also discussed. Detection and handoff were key issues in the first documented fatal crash in the U.S. involving an AV and a pedestrian (walking with a bicycle) that occurred in 2018, and challenges are likely to persist. Challenges and research needs related to AV testing, data sharing, and, in the long term, how mode share and urban form will evolve to incorporate AVs, are also raised (Sandt and Owens 2017).

Between the issues of automation and electrification, questions remain as to how trends in vehicle electrification will affect greenhouse gas emissions, and whether electrification of automated vehicles will offset expected increases in GHG via a growth in VMT.

Future Research Needs

Documentation of innovative practices and use of new technologies

With the range of new technologies, including automation, EVs and LEVs, shared mobility services, etc., being integrated into different contexts (with their own shifting social and demographic trends) there is a need to continue monitoring plans, the role of community engagement and literacy around these topics, and implementation. As opportunities arise, there is a need for research to re-examine health determinants and evaluate the health and transportation impacts from the standpoint of:

- Impacts of policies and the role of Federal, state, and local governments in regulating usage or testing of innovative technologies and fostering public engagement.

- Direct health impacts (personal and population) from use, as well as documentation of health disparities among different population subgroups.
- Systems impacts, including mode shift/substitution and environmental outcomes. This may also include data systems, and changes needed to health and safety surveillance.
- Behavioral adaptation (including safety, health, social interaction, etc.).
- Implications for resiliency and disaster planning.

As more data and research are available, there will be a need for translational research and efforts to bring knowledge to practitioners, in particular around the best practices for planning, community engagement, and policymaking to support health equity. There is also a need to document the role of collaborations and partnerships in testing new programs and technology that can support healthy and equitable mobility.

2.10 Conclusions

Based on the studies described within this report, there appears to be substantial evidence documenting the linkages between transportation and health, which also hold implications for practice. For example, roughly twenty-five systematic reviews were identified that estimate health impacts of various transportation facilities or policies. These studies also highlight the challenges, limitations, and complexity inherent in research in this arena. Nearly all systematic reviews noted the difficulty in drawing quantitative conclusions regarding relationships between health and transportation due to the wide range of methods, results, and settings within the existing body of research. Major weaknesses in the literature were often attributed to data aggregation, substituting data from elsewhere for local estimates, the lack of post-intervention evaluation, self-selection bias, and the general body of knowledge being based almost entirely on studies from developed countries (North America, Europe, and Australasia). Furthermore, only a few studies demonstrated statistical significance of findings.

Both the research and practices documented in this report highlight myriad, often piecemeal ways that states and cities are working toward meeting health needs through transportation improvements. A theme amongst stakeholders interviewed was the need for practical research that can capture and communicate best practices, provide quantitative evidence, and provide immediate value to practitioners. This is a high bar for any individual research project to meet; thus, in many cases opportunities for synthesis research projects emerged. In general, a need was expressed for more studies from low-middle income neighborhoods and communities, and more case studies from diverse geographic regions, including rural areas.

In many instances, we noted tension across different stakeholder interests. For example, there was simultaneously a call for research to show combined health effects of various approaches, and for research to disaggregate the effects at a very fine-grain level. Both are needed and important. The source of this tension may be the variation in context in which this information may be used in different transportation decision-making processes.

More broadly, there appears to be a need for practitioner-oriented guidance on how to apply findings from health/transportation research for planning and prioritization through tools and partnerships. Much research and guidance exist that are underutilized; thus, there is a need to showcase how the existing tools can be translated into baseline indicators or performance measures and build capacity or other supports for agencies to act upon the information, incorporate new research, and institutionalize best practices.

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List of Abbreviations and Acronyms

AASHTO	American Association of State Highway Traffic Officials
ACM	All-cause Mortality
ADS	Automated Driving Systems
APA	American Planning Association
ASTHO	Association of State and Territorial Health Officials
ATUS	American Time Use Survey
AV	Automated Vehicle (see glossary for definition)
B/C	Benefit/cost
BenMAP-CE	Environmental Benefits Mapping and Analysis Program - Community Edition
BMI	Body Mass Index
BRFSS	Behavioral Risk Factor Surveillance System
BRT	Bus Rapid Transit
CDC	Centers for Disease Control and Prevention
CEQA	California Environmental Quality Act
CIMS	Corridor Investment Management Strategy
CMAQ	Community Multiscale Air Quality Model; see also entry below
CMAQ	Congestion Mitigation and Air Quality Improvement; see also entry above
COPD	Chronic Obstructive Pulmonary Disease
CPPW	Communities Putting Prevention to Work
CRA	Comparative Risk Assessment
DALY	Disability-adjusted Life Years
DHHS	Department of Health and Human Services
DOT	Department of Transportation
DVRPC	Delaware Valley Regional Planning Commission
DYNAMO	Dynamic Modeling for Health Impact Assessment
EIA	Environmental Impact Analysis
EIR	Environmental Impact Report
EPA	Environmental Protection Agency
EV	Electric Vehicle
FARS	Fatality Analysis Reporting System
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GES	General Estimates System
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Position System
HAV	Highly Automated Vehicle
HC	Healthy Communities
HDMT	Healthy Development Measurement Tool; same as SCI
HEAT	Health Economic Assessment Tool
HIA	Health Impact Assessment (see glossary for definition)

HiAP	Health in All Policies (see glossary for definition)
HRA	Human Health Risk Assessments
HUD	Department of Housing and Urban Development
ITE	Institute of Transportation Engineers
ITHIM	Integrated Transport and Health Impact Model
IIHS	Insurance Institute for Highway Safety
LCA	Life Cycle Assessment
LEV	Light Electric Vehicle
LRT	Light Rail Transit
MAUP	Modifiable Areal Unit Problem
MET	Metabolic Equivalent of Task
MMLOS	Multi-Modal Level of Service
MOU	Memorandum of Understanding
MPO/C	Metropolitan Planning Organization/Commission
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standards
NACTO	National Association of City Transportation Officials
NAMPO	Nashville Area Metropolitan Planning Organization
NAS	National Academies of Sciences, Engineering, and Medicine
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act Review Process (see glossary for definition)
NHTS	National Household Travel Survey
NIA	National Institute on Aging
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institute of Health
OECD	Organization for Economic Co-operation and Development
PBIC	Pedestrian and Bicycle Information Center
PEIM	Pavement Environmental Impact Model
RALA	Rural Active Living Assessment
RFF	Regional Flexible Funds
RNS	Research Needs Statement
ROI	Return on Investment
RPO/C	Rural Planning Organization/Commission
RSA	Road Safety Audit
SCI	Sustainable Communities Index; same as HDMT
SEPA	State Environmental Policy Act
SFDPH	San Francisco Department of Public Health
SFMTA	San Francisco Metropolitan Transit Authority
SPR	State planning and research
SRTS	Safe Routes to School
SUV	Sport Utility Vehicle
TDM	Transportation Demand Management
THT	Transportation and Health Tool
TIP	Transportation Improvement Program
TMG	Traffic Monitoring Guide
TRAP	Transportation Air Pollution
TRB	Transportation Research Board
TRID	Transportation Research International Documentation

UGCoP	Uncertain Geographic Context Problem
USDOT	U.S. Department of Transportation
UTC	University Transportation Center
VMT	Vehicle Miles Traveled
VSL	Value of Statistical Life
VTPI	Victorian Transport Policy Institute
WHO	World Health Organization

Appendix A: Research Problem Statement Selection Process

To select the set of research needs topics to develop into more detailed project statements from the list of needs identified in the Research Roadmap, the team developed a process in coordination with the panel to prioritize high value topics. The steps and outcomes for this process are described below.

Step 1a: Input was sought from the panel to identify the research GAPS with the greatest significance/urgency to address. The panel was asked to respond directly on the research roadmap and/or respond to a Qualtrics survey. A similar survey was also sent to stakeholders who had been engaged in the project previously and results were compared to but not combined with what the panel members submitted. The survey included a 7-point Likert scale to rate each research gap identified by urgency, as well as open text fields to collect additional commentary. Panel members could rank all sections from the Research Roadmap or select specific areas of interest to respond to. A total of 6 panel members completed the survey and a 7th panelist submitted comments that were incorporated to the ranked list.

From this process, the top ranked research gaps identified included (in ranked order):

Topic Section	Section Number	Research Gap
DATA AND INTEGRATION	2.5.1	Agency Processes Data improvement and integration - Lack of integrated data needed for systematic monitoring of transportation and health outcomes.
DEMOGRAPHICS	4.2.3	Specific Topics and Emerging Issues: Demographic, cultural, and travel behavior shifts - Unknown or missed opportunities in transportation planning and other activities to advance health equity.
EMERGING DATA	4.4.1	Specific Topics and Emerging Issues: Emerging data sources - Deficiency in knowledge as to how emerging data sources can be utilized to advance health in transportation.
DEMOGRAPHICS	4.2.1	Specific Topics and Emerging Issues: Demographic, cultural, and travel behavior shifts - Insufficient understanding of which populations experience positive or negative health outcomes related to transportation, and the magnitude of such impacts on general public health, particularly in the face of shifting demographic trends.
PLANNING	2.2.5	Agency Processes Planning - Lack of guidance on opportunities to integrate health consideration during prioritization, programming, and pre-scoping processes.
POLICY	2.1.1	Agency Processes Policy-Making - Lack of quality research on the effect of policies at various stages of transportation agency activities (planning, design, project delivery, maintenance, spending, and other procedural policies) on short and long-term health and equity outcomes.

Topic Section	Section Number	Research Gap
PLANNING	2.2.2	Agency Processes Planning - Lack of guidance on how travel surveys can be used to integrate health questions.
MONITORING	2.4.1	Agency Processes Monitoring and evaluation - Lack of detailed, disaggregate morbidity data needed for health and injury monitoring.
SETTING GOALS	3.1.6	Transportation Agency Practices and Research Translation Setting goals and performance measures - Lack of guidance on how agencies should measure success in incorporating health into transportation policies, particularly performance measurement.
MONITORING	2.4.3	Agency Processes Monitoring and evaluation - Lack of tools and performance measures for plan evaluation.
PLANNING	2.2.4	Agency Processes Planning - Lack of research on equity considerations and outcomes in planning processes.
POLICY	2.1.2	Agency Processes Policy-Making - Limited knowledge about the application of land use, travel pricing, and other travel demand management tools and the extent to which these have been evaluated in relation to health and equity outcomes.
TRANSIT	4.1.1	Specific Topics and Emerging Issues: Transit - Deficiency in research measuring the overall health benefits of transit.
CAPITAL PROJECTS	2.3.1	Agency Processes Capital programs, projects, and implementation - Lack of guidance for addressing health as part of a project's environmental document.
DATA AND INTEGRATION	2.5.2	Agency Processes Data improvement and integration - Lack of documentation of best practices in data collection, improvement, integration, and application.
SETTING GOALS	3.1.7	Transportation Agency Practices and Research Translation Setting goals and performance measures - Lack of basic research on data sources and the role of transportation agencies in measuring community well-being, and how agencies should incorporate community well-being as a performance measurement.
PLANNING	2.2.6	Agency Processes Planning - Lack of research to evaluate and refine key decision-making tools and support implementation.
SETTING GOALS	3.1.3	Transportation Agency Practices and Research Translation Setting goals and performance measures - Lack of commonly accepted tools for measuring access and planning for improved equity in access.
TRANSIT	4.1.5	Specific Topics and Emerging Issues: Transit - Deficit in knowledge on how transit projects positively or adversely affect health equity.
CAPITAL PROJECTS	2.3.2	Agency Processes Capital programs, projects, and implementation - Lack of data and methods for assessing short- and long-term health impacts and associated economic evaluation.

Step 1b: The project team applied a quantitative score to the specific research NEEDS within each of the identified gaps, using an excel spreadsheet. The team used the guidance in the table below on attribute values to help score needs according to the six attributes (on a 1-10 scale). Each attribute was scored across all needs by the same reviewer in order to improve scoring consistency, and attribute scores were compiled to produce a total score.

Attribute	Attribute Values	Attribute Score (0-10)
Practical Implementation Potential	Research results can be easily integrated into existing practices/processes and/or enhance practices	10
	Practitioners can apply results with some additional work (e.g. guidebook)	5
	Useful to researchers, but not to practitioners	1
Innovative/Transformative	Research results may transform or innovate practice, methods, or technology	10
	Research results might lead to future innovations or transformations	5
	Research not transformative/innovative in nature	1
Applicability	Research results are applicable/transferrable to all state DOTs and local agencies	10
	Research results are applicable to some state DOTS or local agencies	5
	Research results are limited in application	1
Addresses Multiple Health Outcomes	Research clearly supports multiple pathways to health (e.g., safety, access, community, resiliency, active travel, environment)	10
	Research has potential to support multiple pathways to health	5
	Research focuses on only one pathway to health	1
Takes a Multimodal Approach	Research clearly benefits multiple travel modes (transit, bicycle, pedestrian, automobile, other)	10
	Research has the potential to benefit multiple travel modes	5
	Research focuses on only one mode of travel	1
Focuses on Underserved Populations	Research process and/or results directly benefit or focus on traditionally underserved populations (including seniors, low income groups, people of color, people with disabilities, etc.)	10
	Research process and/or results potentially or indirectly benefit or focus on traditionally underserved populations	5
	Research process and/or results have no clear benefit or focus on traditionally underserved populations	1

From this process, the top ranked research needs included (in order of ranking):

Topic Section	Section Number	Research Need
Monitoring	2.4.1. b	Research to explore state practices in consistently reporting non-fatal crashes and other morbidities and develop recommendations on how to collect nationally comparable morbidity data, such as non-fatal injuries sustained by people using active travel modes.
Policy	2.1.4. b	Synthesis research to identify transportation policies designed to adapt to or mitigate against impending health effects of flooding, urban heat island effects, and drought.
Planning	2.2.1.c	Studies to assess objective data collection techniques (such as with mobile device Bluetooth tracking) for use in measuring physical activity and travel behaviors, and where they take place, and develop guidance on how to derive pedestrian and bicycle counts from existing technologies. For example, studies are needed to validate mobile device trackers with calibrated bicycle and pedestrian counters and identify and adjust for sources of bias (underrepresented groups, etc.)
Data and integration	2.5.1. b	Guidance and training/capacity building for state and local agency staff on how to institutionalize collection and integration of key data sources (such as active travel measures or pedestrian and bicycle counts). This may include guidance for data formatting, standardization, and aggregation.
Policy	2.1.4. a	Synthesis research to identify examples of transportation policies related to resiliency and disaster planning and how they account for and are related to health impacts.
Planning	2.2.3. b	Research to describe the role of public engagement and grassroots support in the adoption of health-related plans and documentation of agency planning practices to support inclusive and equitable engagement.
Emerging mobility	4.3.3. b	Analysis of public health impacts of policies and actions designed to regulate or test new technologies or forms of transportation.
Capital Projects	2.3.3. a	Research to detail how communities are funding, using, and maintaining online mapping or data visualization forums, and other innovative experiential ways of community involvement (e.g., from temporary pop-ups to virtual reality) and how new data are being integrated into transportation practices and public engagement.
Emerging data	4.1.1. a	Sound approaches for integrating determinants of health into emerging transportation data sources.
Policy	2.1.2.c	Research to describe the degree to which state and local transportation agencies—and related societal sectors such as chambers of commerce, school districts, public health agencies, legislative bodies, etc.—are implementing the guidance from prior research and existing resources that have identified specific policies to support health across a variety of domains (e.g., safety/injury prevention, active travel, environmental health, access, etc.), documentation of the barriers and

Topic Section	Section Number	Research Need
		challenges to implementation, and recommendations to support more rapid diffusion of best practices.
Demographics	4.2.3. e	Basic research to estimate the relationship between changes in land use, population and job growth, availability or lack of affordable housing and effects on travel/commute times by mode.
Policy	2.1.2. b	Synthesis of practice to describe how federal, state, and or local entities are aligning policy goals related to travel demand and travel performance metrics (such as vehicle miles traveled) to advance health and equity (building upon the guidance provided by Malekafazali, n.d.). This should include case studies from urban and rural contexts.
Capital Projects	2.3.4. a	Checklists for data sources that can be used to generate performance measures around health and wellness per the scale of impact transportation project.
Emerging mobility	4.3.4. a	Exploration of interactions of emerging technologies and disaster planning / hazard mitigation.
Emerging data	4.1.1. d	Consideration of how new forms of data can be used to improve public engagement, data visualization, and messaging for better communication around transportation and health.
Transit	4.1.2.c	Research that provides wide-ranging overview of health impacts of transit, and conceptual framework to enhance agencies ability to consider health outcomes in transit planning.
Planning	2.2.5. a	Synthesis of practices where MPOs or State DOTs included health indicators in transportation project prioritization criteria.
Emerging mobility	4.3.1. d	Research systems impacts, including mode shift/substitution, safety, and environmental outcomes related to emerging technologies. Consider the net impact of car-shedding and the emergence of mobility as a service on population health.
Data and integration	2.5.1.c	Fund the existing RNS (from 2012) calling for a “database of data” to be able to examine the effects of transportation projects at various geographic scales and develop strategies for sharing data across policy sectors.
Data and integration	2.5.1. d	Research to identify, test, and recommend methods to link or overlay key national data sets, such as National Household Travel Data and American Time Use Survey, to better contextualize trips and health behaviors.
Setting goals	3.1.3. a	Studies to develop holistic measures of access (e.g., travel time/network distance to certain destinations using different modes) that can be used in a comparable, standardized way to evaluate projects, plans, and equity outcomes.

Step 2: The ranked list of most urgent/priority research needs and gaps produced by the team in steps 1a and 1b and shown above were reviewed and compared by the project team. The team sought to identify high-scoring research needs that were within highly rated research gaps identified as priorities by the panel. The team then made additional assessments regarding the portfolio of research needs/gaps in relation to the coverage of topics in the roadmap and known research priorities/opportunities of key funding sources. We also reviewed and incorporated feedback from a select set of stakeholders who were engaged earlier in the project during the interviews/literature review tasks and completed the survey. The resulting list of priority topics that emerged from integrating team, panel, and stakeholder feedback included:

1. Monitoring	NEED 2.4.1. b	Research to explore state practices in consistently reporting non-fatal crashes and other morbidities and develop recommendations on how to collect nationally comparable morbidity data, such as non-fatal injuries sustained by people using active travel modes.	a. GAP 2.4.1 Agency Processes - Monitoring and evaluation - Lack of detailed, disaggregate morbidity data needed for health and injury monitoring.
2. Data and integration	NEED 2.5.1. b	Guidance and training/capacity building for state and local agency staff on how to institutionalize collection and integration of key data sources (such as active travel measures or pedestrian and bicycle counts). This may include guidance for data formatting, standardization, and aggregation.	GAP 2.5.1 Agency Processes Data improvement and integration - Lack of integrated data needed for systematic monitoring of transportation and health outcomes.
3. Demographics	NEED 4.2.3. e	Basic research to estimate the relationship between changes in land use, population and job growth, availability or lack of affordable housing and effects on travel/commute times by mode.	GAP 4.2.3 Specific Topics and Emerging Issues Demographic, cultural, and travel behavior shifts - Unknown or missed opportunities in transportation planning and other activities to advance health equity.
4. Policy	NEED 2.1.2. b	Synthesis of practice to describe how federal, state, and or local entities are aligning policy goals related to travel demand and travel performance metrics (such as vehicle miles traveled) to	GAP 2.1.2 Agency Processes Policy-Making - Limited knowledge about the application of land use, travel pricing, and other travel demand management tools and the extent to which these

			advance health and equity (building upon the guidance provided by Malekafazali, n.d.). This should include case studies from urban and rural contexts.	have been evaluated in relation to health and equity outcomes.
5.	Transit	NEED 4.1.2.c	Research that provides wide-ranging overview of health impacts of transit, and conceptual framework to enhance agencies ability to consider health outcomes in transit planning.	GAP 4.1.1 Specific Topics and Emerging Issues Transit - Deficiency in research measuring the overall health benefits of transit.
6.	Emerging data	NEED 4.4.1. a	Sound approaches for integrating determinants of health into emerging transportation data sources.	GAP 4.4.1 Specific Topics and Emerging Issues Emerging data sources - Deficiency in knowledge as to how emerging data sources can be utilized to advance health in transportation.
7.	Policy	NEED 2.1.2.c	Research to describe the degree to which state and local transportation agencies—and related societal sectors such as chambers of commerce, school districts, public health agencies, legislative bodies, etc.—are implementing the guidance from prior research and existing resources that have identified specific policies to support health across a variety of domains (e.g., safety/injury prevention, active travel, environmental health, access, etc.), documentation of the barriers and challenges to implementation, and recommendations to support more rapid diffusion of best practices.	GAP 2.1.2 Agency Processes Policy-Making - Limited knowledge about the application of land use, travel pricing, and other travel demand management tools and the extent to which these have been evaluated in relation to health and equity outcomes.
8.	Planning	NEED 2.2.5. a	Synthesis of practices where MPOs or State DOTs included health indicators in transportation project prioritization criteria.	GAP 2.25 Agency Processes Planning - Lack of guidance on opportunities to integrate health consideration during prioritization, programming, and pre-scoping processes.

9.	Capital Projects	NEED 2.3.4.c	Checklists for data sources that can be used to generate performance measures around health and wellness per the scale of impact transportation project.	GAP 2.3.1 Agency Processes Capital programs, projects, and implementation - Lack of guidance for addressing health as part of a project's environmental document GAP 2.3.2 Agency Processes Capital programs, projects, and implementation - Lack of data and methods for assessing short- and long-term health impacts and associated economic evaluation.
10.	Planning	NEED 2.2.1.c	Studies to assess objective data collection techniques (such as with mobile device Bluetooth tracking) for use in measuring physical activity and travel behaviors, and where they take place, and develop guidance on how to derive pedestrian and bicycle counts from existing technologies. For example, studies are needed to validate mobile device trackers with calibrated bicycle and pedestrian counters and identify and adjust for sources of bias (underrepresented groups, etc.)	GAP 2.2.1 Agency Processes Planning - Lack of available data and research methods for planning/forecasting active travel and the exposures that result from it. GAP 2.2.4 Agency Processes Planning - Lack of research on equity considerations and outcomes in planning processes.

Step 3: The above list was considered as a starting point for team members to then create more detailed research problem statements (as shown in the *Research Roadmap* Appendix A for these). The team held a series of internal meetings to tighten the focus of each problem statement, incorporate documentation from the Final Report and input from panel members, and reduce overlap with other research problem statements while aiming to preserve the ideas around research needs reflected in the tables above. Not all of the ideas in the above table were incorporated directly into the research problem statements developed, but these and many others are reflected in the Research Roadmap.