



Photo by Cait McCusker

# A Decade of Research in Walking and Bicycling

## *NITC Research Roadmap: Lit Review*

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What follows is an **excerpt** from the full report “**NITC Research Roadmap: Walking and Bicycling**,” which serves as internal guidance to where our focus on research and workforce development should be applied next in this area. It is one in a series of six reports looking at:

***Transportation and Land Use***

***Multimodal Data and Modeling***

***Walking and Bicycling***

***New Mobility and Technology***

***Transportation Equity***

***Transportation Resiliency***

*These excerpts provide a lookback of the last decade of projects funded by the National Institute for Transportation and Communities, a U.S. DOT University Transportation Center. Through these literature reviews we hope you’ll gain new transportation insights that our researchers and partners have shared.*

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# NITC Research Roadmap: Walking and Bicycling

## *Lit Review*

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# Table of Contents

<b>Acknowledgements</b>	<b>3</b>
<b>Overview</b>	<b>4</b>
Scan of NITC and UTC research on walking and bicycling	5
Approach to this roadmap	6
One in a set of roadmaps	6
Focus on leveraging research to achieve transformation	7
Methods	7
<b>What do we know about walking and bicycling?</b>	<b>8</b>
Bicycling and walking are central to a healthy and sustainable transportation system	8
Designing facilities on which people want to walk and bike	10
Emerging technologies are extending the possibilities for active transportation	13
Work is needed to make walking and bicycling equitable	14
<b>Conclusions</b>	<b>16</b>
<b>References</b>	<b>17</b>

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# Overview

Walking and bicycling are foundational transportation modes, whether serving as the primary or preferred means of movement for work and non-work trips alike, for moving around neighborhoods, or as first- and last-mile connections within larger communities with established transit systems. They are forms of travel that provide positive health, social, environmental, economic, and community benefits. As cities grow and change over time, understanding how to expand and accelerate the benefits of these active transportation modes, while reducing current safety deficiencies, will be an essential task for research seeking to improve both transportation and its connection to these larger environmental, economic, and social goals.

The need for quality research in walking and bicycling is driven home by a number of key factors. First, safety data shows that crashes resulting in fatalities for people walking and bicycling are up dramatically over the past decade, both in raw numbers, increasing from 5,532 non-motorist traffic fatalities (including people walking, bicycling, and other non-motorists) in 2004 to 7,709 in 2020, and as a proportion of all traffic fatalities, increasing from 12.9% in 2004 to 19.9% in 2020 (see Figure 1). The increase of non-motorist fatalities of 39% between 2004 and 2020 is also slightly higher than the 35% estimated increase in walk and bike trips over the closest comparable National Household Transportation Surveys (2001 to 2017). Second, walking and bicycling are critical components of reducing the motor vehicle-produced problems of greenhouse gas emissions, air and water pollution, health impacts from the sedentary nature of driving, society's inability to maintain car-based infrastructure, and more. Third, we know that the automobile congestion that is clogging city streets, disrupting communities and businesses, and absorbing time spent in traffic cannot be fixed by roadway expansion, but can only be effectively addressed by making more space-efficient modes of travel easier, more direct, and safer. Fourth, more walking and bicycling can be a key contributor to healthier people and communities, which is related to safety and pollution but extends to helping people get essential physical activity, improve mental well-being, strengthen social connections, and develop the type of communities that thrive socially and economically.

Making walking and bicycling a real choice for anybody who would like to is also an equity issue. Walking and bicycling can provide the least expensive means of getting around. In many cities, a considerable proportion of people do not own cars; for some this is a choice, for others this is because they cannot afford them. For many of them, the cost of public transportation is also a burden. In terms of safety, it is often in the most underserved neighborhoods and populations who are at the most risk and need the most attention.



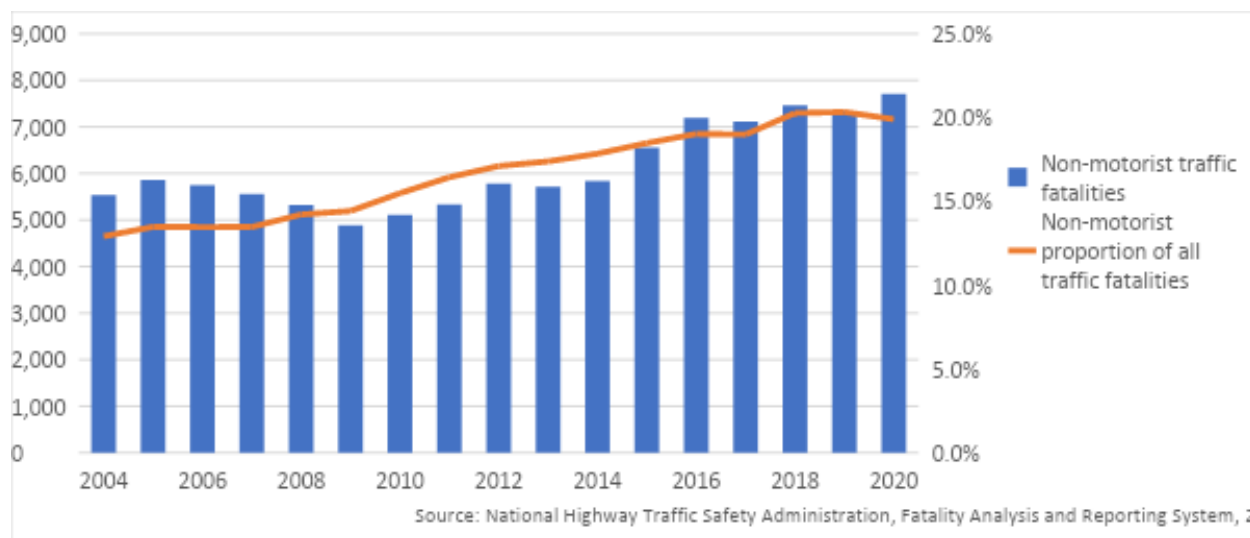


Figure 1 Non-motorist traffic fatalities

As noted in the 2021 AASHTO Council on Active Transportation Research Roadmap<sup>1</sup>, while the number of research publications in the walking and bicycling arena have increased dramatically in recent years (rising from 146 journal articles or book chapters on these topics in Web Of Science in 1992 to 2,488 in 2018), there are still major gaps in the knowledge. The AASHTO Council on Active Transportation (CAT) Roadmap is an essential resource for assessing the state of walking and bicycling research, and details 110 research needs, including in-depth descriptions of 46 medium, high, and highest priority needs. While that roadmap is targeted to a state highway agency audience, the specific needs provide great detail for many ways in which research can help to make walking and bicycling safer and more common. In contrast, this roadmap lays out a research framework that is more focused toward the role of University Transportation Centers (UTCs) generally, and the National Institute for Transportation and Communities (NITC) specifically, and lays out research needs into broader gap areas rather than more specific research project ideas.

## Scan of NITC and UTC research on walking and bicycling

NITC is one of seven national UTCs, and is focused on "improving mobility of people and goods to build strong communities." As a first step in developing the NITC Research Roadmap for Walking and Bicycling, the project team reviewed the relevant scholarship to date emerging from NITC and its predecessor, the Oregon Transportation Research and Education Consortium (OTREC), focusing on research projects that tagged with subjects related to walking or bicycling.

In total, we identified 87 such NITC research projects, including 65 focused on bicycling and 49 focused on walking (many covered both topics). Projects were coded by research theme areas,

<sup>1</sup> Additional information on the CAT Roadmap, including download links for the full roadmap and supporting documents, is available at <https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4808>

including safety, design, travel behavior, equity, access/disability, aging, technology, data and modeling, implementation and practice, economic, policy, and other. As shown in Figure 2, the most common research theme areas for bicycling were data and modeling, travel behavior, design, equity, technology, and safety. For walking, the most common research themes were data and modeling, travel behavior, safety, equity, and access/disability.

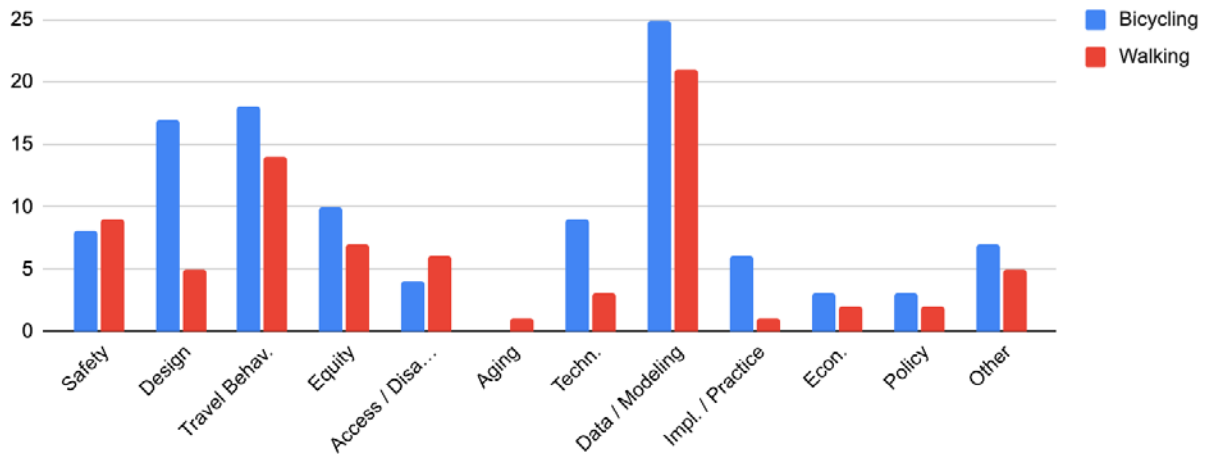


Figure 2. NITC Walking- and bicycling-related research projects, by thematic area

The project team scanned available reports from the NITC walking- and bicycling-related research, documenting suggestions for future research, key implications of the research for practice, along with key findings and limitations. This information was used to inform the *What We Know* about walking and bicycling section of this roadmap, along with the identification of key research gap areas.

A scan of other University Transportation Centers around the United States found that most UTCs have at least some research focused on walking and bicycling. For example, five out of six national UTCs (besides NITC) have projects focused on walking-related research, while all six had projects focused on bicycling. For Regional and Tier 1 UTCs, we identified walking-related research projects at 15 of 29, and bicycle-related research at 14 of 29.

## Approach to this roadmap

### *One in a set of roadmaps*

This roadmap for walking and bicycling was developed as one of a set of NITC Research Roadmaps, and it is important to note that some important gaps that pertain to walking and bicycling fall under those roadmaps. For example, having better exposure and safety data for walking and bicycling is crucial for many planning needs, and while not covered directly in this roadmap, is covered in the Data and Modeling Roadmap. Other roadmaps covering transportation and land use, advancing equity in transportation, technology and new mobility, and resiliency all overlap to some degree with walking and bicycling.



## ***Focus on leveraging research to achieve transformation***

The existing research provides a clear picture of the many benefits of walking and bicycling, including their role in attaining sustainable and livable communities. Based on the available research, input from practitioners, and the experience of the project team, there is a clear sense that future research needs to help tackle the challenge of how to put what we know about walking and bicycling into practice, and assess how to make the leap to broader adoption of these modes. The gaps described in this roadmap seek to respond to this challenge.

### ***Methods***

This roadmap was developed by an inter-campus team of NITC researchers, with the assistance of a graduate research assistant. The project team conducted an extensive review of NITC-funded projects and reports under the subject areas of “bicycling” and “walking,” including identifying themes, key findings, applications of research, along with noted research gaps or future research needs. The project team scanned other University Transportation Center (UTC) webpages and reports to identify where research on walking and bicycling is taking place, along with the type of research taking place in these areas. Pulling from the NITC and UTC review, the roadmap team identified 15 research needs in walking and bicycling. A group of six practitioners working on walking and bicycling was assembled to help review, prioritize and discuss the research needs through an initial ranking survey followed by a focus group. The rankings and input from the practitioner group were used to develop the gaps presented in this roadmap.

# What do we know about walking and bicycling?

The 2021 *AASHTO Council on Active Transportation's Research Roadmap* included a detailed research review, which summarized active transportation research across 22 topics and 166 pages. We encourage readers interested in a broad summary of research related to walking and bicycling to review that document. With that in mind, this section will focus on research in several key theme areas from NITC-affiliated researchers, along with findings from other University Transportation Center research and other scholarship to place the NITC research. The key theme areas are focused around understanding what research is needed in the coming years.

## **Bicycling and walking are central to a healthy and sustainable transportation system**

Research at NITC and elsewhere has shown that walking and bicycling are key components and building blocks of healthy people and communities.

On an individual level, travel by walking and biking results in people being more likely to meet recommended daily physical activity levels than those who travel by other modes (e.g., see Woodward and Wild, 2020; Dill, 2009). More directly tied to health outcomes, studies have found travel by walking and biking to be associated with reductions in cholesterol, obesity, hypertension, and diabetes (e.g., Lorenzo et al., 2020; Schuader and Foley, 2015), and that positive health benefits from physical activity outweigh risks associated with traffic violence or exposure to vehicle emissions (Mueller et al., 2015).

NITC research builds off the individual benefit of travel by active transportation modes in several ways. Several studies have focused on the impact of active transportation on personal sense of well-being. For example, Smith (2017) surveyed “people about their subjective satisfaction with their travel to and from work, and found that people who bike and walk to work are happier with their commutes and are relatively unaffected by traffic congestion compared to bus and car commuters” (p. 246). Another study explored “positive utility of travel,” (PUT) or the idea that travel can provide benefits or motivations such as travel-based multitasking, positive emotions, or fulfillment, in contrast to the typical view that travel time is a negative value in a travel model (Singleton, 2017). The PUT idea assembles concepts relevant to travel behavior such as utility maximization, multitasking and well-being. Notably, the study found that people engaged in active modes like walking and bicycling actually felt that their commute times were positive experiences, rather than costs to be endured to get to a destination. The study results suggest that PUT can greatly increase the explanatory power of the mode choice model, and can be used for transportation policies to promote non-automobile travel and planning for autonomous vehicles (Singleton, 2017). Perhaps one of the reasons for the positive utility of active travel can

be found in other NITC-sponsored research. Yang et al. (2018) used a combination of surveys and cortisol (a stress-induced hormone) level testing to examine the stress levels throughout a day for people who commuted to and from work by different modes, controlling for overall levels of physical activity. They found that active travel commute modes were associated with lower levels of stress at home and at work, and further, reduced the transfer of stress from home-to-work and vice versa.

Walking can be an effective means of accessing destinations when the built environment is supportive; walking and transit together can make most of an urban area accessible. Bicycling has been shown to greatly expand access to destinations over walking (e.g., McNeil, 2011), and bicycling as a first- and last-mile solution improves accessibility to jobs via transit, particularly for low-income and minority residents (Zuo et al., 2020). Bicycling and bike share can also be a means of meeting transportation needs while spending less money, particularly when combined with supportive programming. A NITC study of people who participated in equity-related bike share programs found that bike share participants were spending less on transportation such as public transit or taxi rides and driving a personal car (McNeil et al., 2017).

NITC research has also examined the impact of building out bicycle networks on access to destinations. Liu and Shi (2018) studied Portland's planned "City Greenway" network, and found that it decreased the travel cost of active transportation due to a well-connected network, provided higher comfort and safety to cyclists, as well as increased accessibility to important destinations within the same distances at lower stress levels. This plan was beneficial for the disadvantaged communities as it improved accessibility due to the development of more bicycle infrastructure; however, that didn't result in better access to important destinations without complementary economic development and land use policies expansions among the transportation infrastructures. All these measures were identified using three sets of bicycle accessibility measures (BAMs)- distance-based BAM, destination-based BAM and low-stress network-based BAM (Liu and Shi, 2018).

Active transportation is important for people who are more limited in their transportation options due to age and disability. Walking can be an important means of reaching essential stores and services for seniors (Garcia et al., 2019). While many older adults feel reliant on having a car or knowing someone who does, this study found that, with a supportive walking environment, some older adults living in senior housing are able to achieve most of their daily needs by walking (Garcia et al., 2019). For people who rely on accessible features such as curb ramps for their mobility, researchers are pushing to enhance data standards and availability by using data sources such as LIDAR, Open Streets, and aerial photos to fill in missing environmental data to provide people with limited mobility the access to tools to determine a safe and pleasant urban route (Deitz, 2021).

NITC-supported research has also explored youths' attitudes toward walking and bicycling, providing information about what kids' views on transportation are and informing potential interventions to promote walking and biking over time. The study found that while study participants generally view walking and bicycling positively, and as good ways to get around for

the time being, most felt they wanted to shift to driving once they were old enough (Shafer and Macary, 2018). Most participants responded positively to appeals to autonomy.

Aside from benefits that would generally be considered individual benefits like improved physical and mental health, active transportation also offers the potential for benefits accrued to the broader community. At the community level, walking and bicycling offer the potential to reduce vehicle miles traveled and emissions associated with air pollution and climate change, (e.g., Alessio et al., 2021; Frank et al., 2010); offer economic benefits (e.g., McDonald et al., 2016; Clifton et al., 2013); as well as benefits related to improved social cohesion (Sallis et al., 2015).

Researchers followed a systematic framework to evaluate the economic effects of corridor-level bicycle or pedestrian street improvements across several corridors in multiple cities. They found street improvements to have positive impacts or non-significant impact on corridor economic and business performance (Liu and Shi, 2020).

However, better data is still needed on how levels of bicycling and walking affect health, pollution, congestion, and other individual and community impacts. Relatedly, further research is needed into documenting, in practice, what level of intervention yields what level of walking or bicycling, which can help further document and quantify the contributions these interventions make. This need includes generating specific measurable relationships to guide investment and planning. Further, even though many of these benefits are generally known, and can contribute to goals around shifting transportation to greener and healthier systems, NITC research has also documented that “current transportation governance and finance structures can impose significant barriers to making transportation investments that effectively advance goals” (Lewis et al., 2018, p. 2).

## **Designing facilities on which people want to walk and bike**

Many people who could walk or bike choose not to, at least in part because they don't feel comfortable walking or riding on the streets around them. However, existing research provides a good roadmap for the types of walking and bicycling facilities that are most likely to improve safety and encourage walking and bicycling.

Several NITC research studies have reinforced the idea that the type of bicycle infrastructure that will make people feel more comfortable riding is infrastructure that separates them from people driving motor vehicles, whether along segments via separated bike lanes or trails completely separated from cars, or at intersections via maintaining some form of separation all the way up to the intersection and/or separating out movements through signalization.

A national study of separated bike lanes found that the installation of such lanes made people feel safer riding and feel that they would ride more (Monsere et al., 2014). The study evaluated separated bike lanes in five cities and found an increase in ridership after the lanes were installed. Surveys found that 10% of riders switched from other modes and 24% switched from other bicycle routes, and over a quarter of riders indicated they were riding more because of the

new lanes. The surveys showed that any type of buffer or separation showed an increase in comfort levels over a striped bike lane, but that designs with physical separation had the highest scores. Surveys of community residents, including many non-cyclists, found that most residents would bike more if bicycles were separated by a barrier from people driving motor vehicles. Nearly three times as many residents felt that having a bicycle lane would increase the desirability of living in the neighborhood. A complementary study developed a level-of-service model for bike lanes, and found that protected bike lanes resulted in a significant increase in the expected comfort of people bicycling (Foster et al., 2015).

Another study sought to understand how people, including those who don't currently ride bicycles, would feel riding through different intersection designs (Monsere et al., 2019). In particular, the study looked at the perceived level of comfort of people when riding through mixing zones, lateral shifts, bend-on, bend-out, protected intersection designs, as well as phase separated (bicycle signal) locations, using ratings of 26 first-person videos of cyclists riding through the locations. The study found that designs that minimized the interaction of people bicycling and cars, such as fully separated signal phases and protected intersections, were rated as most comfortable, and that comfort levels for other designs dropped even lower with interacting at all with turning vehicles. Another important finding was that as the exposure distance increased, or the non-separated area in which a cyclist might have to mix with traffic or cross traffic, comfort decreased. A prior study of bike boxes at intersections in Portland found that three-quarters of surveyed cyclists thought bike boxes made intersections safer (Dill et al., 2011), which is likely due in large part to the provision of a separate space away from motor vehicles.

These studies are consistent with other research showing that people want and will choose to ride on higher-quality bicycle facilities (e.g., Dill and Carr, 2003; Broach, Dill and Gliebe, 2012; and Blanc and Figliozzi, 2016), and that those who fall into the "interested but concerned" category (people who might ride or ride more if they felt safe doing so) appear to particularly prefer separated facilities (e.g., Dill and McNeil, 2016; McNeil et al., 2015). A study looking at bike share in low-income communities of color found that concerns about the danger posed by riding in traffic is the top barrier to bicycling (McNeil et al., 2017a), and that among people who do use bike share, the perceived lack of better-quality bicycle infrastructure and routes has been identified as a key barrier that is preventing them from using bike share more (McNeil et al., 2017b).

Several NITC studies have examined how to manage signalization strategies to reduce conflicts for people walking and bicycling, including innovative ways to reduce concurrent movements by people driving motor vehicles and these vulnerable road users. One study utilized software-in-the-loop (SITL) simulation to evaluate various pedestrian crossing signalization approaches such as coordination, actuated coordination, free operation, short cycle lengths, leading pedestrian interval (LPI), Barnes Dance (also known as a "scramble," in which all traffic entering an intersection has a red signal phase during which people walking can cross in any direction including diagonally) and a pedestrian priority algorithm (Kothuri et al., 2017). The findings provide details on how to reduce delay for people walking without negatively impacting motor vehicle delay. (Note that motor vehicle delay is currently an important factor in how many

transportation agencies approach decision-making – see Gap 3 for research needed to understand how to update decision-making processes to prioritize walking and bicycling.) Several approaches that are found to improve safety for people walking, including leading pedestrian intervals and Barnes Dance, although both increase delay for vehicles, with the latter also increasing delay for people walking. The study suggests deploying LPIs at high-crash locations.

The same team also utilized video conflict analysis and microsimulation to examine innovative signal treatments that can better accommodate bicycle traffic, such as leading bicycle intervals (Kothuri et al., 2018). The study made recommendations for when to apply such treatments, noting that leading bike intervals (or LBIs) can be an effective treatment when bicycle and motor vehicle volumes are medium to high; while exclusive bike phases are appropriate when volumes of bicycle and motor vehicles are high. The research also notes that LBIs can shift potential conflicts to the latter, or stale, portion of a green phase, and further research may be needed to assess the safety implications of that shift (Kothuri et al., 2018).

NITC researcher-led teams have also been at the forefront of developing and documenting guidance for bicycle signals in the United States. A 2013 report reviewed engineering guidelines for design of bicycle-specific traffic signals and developed operational guidelines for timing and phasing of bicycle-specific traffic signals or modifications that can be made to existing signals to better accommodate people bicycling (Monsere et al., 2013). A 2019 NCHRP project summarized the use of bicycle signals in the United States, and examined additional comprehension and compliance research needs for furthering the effective application of such signals (Monsere et al., 2019).

Signals for people driving motor vehicles also clearly play a role in safety for people walking and bicycling. NITC research has contributed to knowledge around how to maximize safety for people walking when applying innovative signal features such as flashing yellow arrows (e.g., Hurwitz et al., 2013). This simulator study found an increase in the number of people walking led drivers to focus more attention on them, while an increase in the number of opposing vehicles led drivers to spend less time fixating on people walking.

Aside from comfort, another way to make bicycling more appealing is to make it more convenient. A series of NITC-funded research projects has focused on exploring ways for people bicycling to communicate with signals, such as through smart phone signals to “request” green phasing, is a way that eases their flow, such as via a green wave (Fickas, 2019a; Fickas, 2019b; Fickas and Schlossberg, 2019).

NITC research has also extended into the health implications of the physical exertion required of active transportation, including the increased rate of breathing required for human-powered travel, in an environment shaped by motor vehicles and their emissions. Bigazzi (2014) collected and integrated data from an instrumented bicycle, rider, along with environmental data, to document uptake exhaled breath concentrations, respiratory physiology and travel characteristics on a range of facilities. The research identified estimated uptake of volatile organic compounds based on factors such as average daily traffic, and the exertion by roadway and travel characteristics of people who are bicycling.



To give practitioners and agencies a vision for how streets can be transformed to better meet the needs of people rather than cars, NITC researchers have compiled several books that lay out myriad examples of transformation to make Complete Streets, streets for bicycles, and streets that accommodate physical distancing (Schlossberg et al., 2014; Schlossberg et al., 2019; Schlossberg et al., 2021).

NITC research also helps to inform the types of culture that may need to be sought to value safety, and moving people over moving cars and the speed of private motor vehicles. Goddard (2017) explored drivers' attitudes, including implicit bias and social attitudes, towards people bicycling using an online survey. Among key findings were that implicit attitudes were distinct from but related to explicit attitudes toward people bicycling, and helped understand behaviors toward them. Personal bicycling experience often improved both attitudes and behaviors toward people bicycling. Other findings of note were that there was broad general support for investing in bicycle infrastructure. A safety challenge to overcome is the findings that many people feel a perceived pressure to overtake someone who is bicycling, and this feeling was not related to personal travel behavior, the built environment, or most sociodemographic factors.

NITC research around how to design facilities that work better for people walking and bicycling, along with some of the tools that can help agencies understand the challenges that need to be overcome, provides many of the details about what needs to happen to make walking and bicycling better. While there are still new types of facilities to evaluate and further details to understand, the research provides a direction to travel and a roadmap for how to get there.

## **Emerging technologies are extending the possibilities for active transportation**

Although there is a separate NITC Research Roadmap on Technology and New Mobility, these themes are also very relevant to the Walking and Bicycling Research Roadmap. New technologies and services are expanding our conception of what bicycle transportation can be and, in turn, expanding both the market of people who might travel by bicycle and the need to design facilities for this changing landscape. NITC research has undertaken considerable research into the question of who is participating in the new mobility landscape, particularly around e-bikes, e-scooters, and bike share.

NITC researchers have led the way in understanding how people are currently and could potentially use e-bikes. A 2017 study involved providing e-bikes to people for a period of 10 weeks, and surveying them before, during and after that period to understand how their views of and participation in bicycling changed. The study found that people tended to bike more, and view themselves as more confident bicyclists (MacArthur et al., 2017). Not surprisingly, the e-bikes helped them overcome barriers related to hills and concerns about sweat.

A national survey of e-bike owners found that e-bikes expand both the number of people who can ride a bicycle, and also the number, types and lengths of trips that they are able to make (MacArthur et al., 2018). The study found that key motivators for the purchase of e-bikes were to reduce physical exertion, be able to navigate challenging topography, and to replace car trips.

Motivations were somewhat different for different groups, with older adults appreciating the opportunity to ride for fitness and recreation, while they might not have been able to do so without the e-assist. For younger adults, e-bikes allowed them to replace car trips and carry cargo and children on rides. Riders also felt a safety benefit from being more willing to go out of their way (at less of a cost in time and exertion) to ride in safe locations, along with the ability to accelerate more quickly to escape potentially dangerous situations (MacArthur et al., 2018). Additional studies by the team have explored the potential of e-bikes to serve as a tool for regions to reduce greenhouse gas emissions (McQueen et al., 2020), as well as documenting e-bike purchase incentive programs around the country (McQueen et al., 2019).

Bike share represents both a technological and programmatic innovation that can make bicycling a possibility for people who don't own a bike or don't want to ride or park a personal bicycle. NITC researchers have partnered with foundations and local partners around the country to seek to better understand the potential for bike share to help people in low-income communities have improved mobility and recreation opportunities (e.g., McNeil et al., 2017a; McNeil et al., 2017b; McNeil et al., 2019).

NITC research is also seeking to understand how cities and agencies are preparing for new mobility. For example, a 2019 report sought to analyze potential impacts and recommendations for new mobility technologies to help jurisdictions to prepare for policy and programmatic responses. The report compiled a catalog of items that a new mobility strategy should cover, ranging from community values and goals, data management and privacy through to educating the public and decision-makers about the potential impact of new mobility technologies (Lewis et al., 2019). Another project collected and developed model policies and codes to guide communities in navigating and respond to the emergence of new technologies such as scooter and bike share systems, ride hailing, and autonomous vehicles (Schlossberg et al., 2020), with the goal of helping communities to encourage the beneficial potential impacts of these technologies. Another project identified that policies and programs around connected vehicles (CVs) have largely overlooked bicycle applications and the potential to increase bicycling, and outlined the potential for bicycles in the CV landscape (MacArthur et al., 2019).

## **Work is needed to make walking and bicycling equitable**

Walking and bicycling can be the cornerstone of equitable transportation, providing low-cost transportation, physical activity and contributing to healthy communities. However, research has demonstrated that, in practice, efforts to improve these modes have not always served underrepresented racial/ethnic and low-income communities.

Recent scholarship has found that common practitioner conceptions of walkability and walkable environments may fail to consider that different groups, including lower-income and minority populations, may interact with the built environment in different ways (Adkins et al., 2017). These groups appear to walk relatively more than other groups in environments typically viewed as less supportive of walkability, and relatively less in environments viewed as more supportive of walkability, perhaps because they are doing so more out of necessity than out of choice.

Traditional definitions of walkability based around the built environment need to be expanded to account for the types of needs and barriers these communities encounter.

On the bicycling front, a study based on interviews with women and minorities in Portland found that for these people, barriers to bicycling include the concerns about infrastructure, as well as concern about being vulnerable to harassment and/or violence while riding (Lubitow, 2017). The study also noted the unique position of parents and caregivers who face challenges transporting their children. These findings indicate how the mobilities of the cyclists are critically linked to their intersecting and overlapping identities.

A study of bike share in disadvantaged communities found that lower-income and minority residents face greater and more barriers to using the bike share systems, ranging from affordability, comfort bicycling, through to knowledge about how to use the systems or what programming exists to help them access the system (McNeil et al., 2017a). Further, many bike share programs struggle to fund ongoing equity programs, and have limited systems in place to document the efficacy of their programs (McNeil et al., 2019). Responding to the latter problem, McNeil et al. produced a national scan of equity programs to document types of programs and metrics used to evaluate programs.

Black, Indigenous and other People of Color (BIPOC) are fatally injured at a higher rate while walking than white people, with contributing factors tied to higher levels of walking, including to transit, and much of that activity occurring in harsher pedestrian environments, including streets with more traffic and higher-speeds (Roll and McNeil, 2021). A further potential contributor to these disparities in pedestrian safety may be related to driver yielding behavior. A 2014 study looked at driver yielding based on the race of the person seeking to cross the street; the researchers conducted a field study at an unsignalized, midblock, marked crosswalk in downtown Portland (Goddard et al., 2014). They found Black people were passed by twice as many cars and their wait times were 32% longer than the White people. Their results supported their hypothesis on the discriminatory treatment faced by minority pedestrians. A follow-up study consisting of focus groups supported the findings of the field experiment, with African American and Black participants indicating that drivers were less likely to stop for them (Kahn, 2017).

# Conclusions

This roadmap seeks to help inform and guide walking and bicycling research to effectively address the needs and challenges facing communities and practitioners as they seek to make these modes more comfortable, safer and ubiquitous. Several key points deserve to be emphasized in considering how walking and bicycling research meet these objectives:

- **Ongoing research will be key as the mobility landscape, built environment, and transportation needs are all changing.** The fluctuating environment will require iterative testing of new programs and infrastructure, evaluations, and case studies to identify and replicate best practices, both for interventions that are designed for walking and bicycling, but also to understand how other interventions impact these modes.
- **Research cannot be done in any one place.** In order to capture the innovation of numerous agencies trying different approaches and tackling different problems in different contexts, the intercampus approach of UTCs is essential, and work across UTCs can help to expand that advantage even further.
- **The research can't be effective if communities and practitioners are not able to implement known successful practices.** Overcoming roadblocks and influencing the decision-making at various levels will be a key challenge for the coming years.
- **There needs to be ongoing efforts to connect research to practitioners and decision-makers.** The research has to be relevant and presented in manageable ways. Ongoing efforts to document how research can successfully influence policy and outcomes would be beneficial to make this aspect more effective.
- **Some of the needed work requires a focus or skills in areas beyond traditional transportation research.** Marketing, psychology and political/social science researchers should be brought into the mix, especially for Gaps 1 and 3.

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