Transportation Affects Health: Five Indicator Domains Recommended for Tennessee

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7497 words

Submitted August 1, 2023

ACKNOWLEDGEMENTS
The authors would like to acknowledge the support of TDOT staff: their manager, Daniel McDonell, their Division Director, Daniel Pallme, their Bureau Chief, Preston Elliot, the Office of Mobility and Accessible Transportation (OMAT) and the TDH staff: John Vick, M. Sarah Elliott, Harper-Grace Niedermeyer Emily Duchac, Samantha Deal, Jennifer Trail, J.W. Randolph, and Elizabeth Jones. Additional thanks to Dr. Helen Pineo for lending her expertise.

ABSTRACT
Transportation affects public health in complex ways. Quantitative indicators are frequently used to model this relationship and are particularly useful to state agencies for analysis and decision-making. The objective of this study is to identify effective and accurate indicators of transportation's effects on health for usage in state health initiatives. A robust process for developing indicators is necessary for ensuring their effectiveness, and effective indicators are necessary for guiding public policy and preventing negative health outcomes. This study analyzed five "domains" of the relationship between transportation and health and recommended two potential indicators for each domain. The five domains are access, physical activity, pollution and environment, traffic fatalities, and social equity. This research may be replicated by other states' agencies in selecting indicators for transportation and health.
Keywords: transportation, health, indicators, qualitative analysis

INTRODUCTION

Motivation and Objectives

In the past year, the Tennessee Department of Health (TDH) has sought support and assistance from the TN Department of Transportation's (TDOT) Multimodal Planning Office (MMPO) on three separate transportation-related projects. First, TDH published "The State of Health in Tennessee" which examined the relationship of health and transportation using five transportation-related indicators. Secondly, the TN Livability Collaborative, a working group of 20+ state agencies led by TDH, is including five transportation-related indicators in the upcoming TN Livability Index. Lastly, TDH's Vitality Toolkit provides transportation-based information to support the work of County Health Councils. The purpose of this study is to characterize the relationship between transportation and health, including through identifying indicators, to support the work of TDH transportation-related projects.

Considerations

This research was guided by several parameters: TDH requested five indicators, data must be state-wide and readily available, and a heuristic approach was needed due to the vast and complex relationship between transportation and health.

LITERATURE REVIEW

Existing Indicators

There is an extensive body of existing research dedicated to developing, evaluating, and implementing appropriate indicators for measuring this relationship. Initial phases of the literature review focused on articles that review existing and evidence-based indicators. For example, Pineo et al. reviewed 145 urban health indicator tools comprising 8,006 indicators, 984 of which related specifically to transportation (1). The U.S. Transportation and Health Tool (THT) provides a set of 14 indicators developed by an expert panel of transportation and public health professionals (2). This phase of the review also examined similar research undertaken by peer states.

Peer State Review

The peer state review involved identifying similar research efforts or initiatives undertaken by peer state transportation or health departments to potentially model. Nine states with applicable research or initiatives were identified: California (3), Massachusetts (4), Minnesota (5), Nevada (6), New Mexico (7), Oregon (8), Pennsylvania (9), Washington (10), and Utah (11).

Deliali et al.'s "Incorporating Health Related Criteria for Project Scoring in Massachusetts" was the most relevant this research (4). The study sought to update the Massachusetts Department of Transportation (MassDOT) Highway Division's project scoresheet used to approve and prioritize proposed projects as part of the department's decision-making framework to include health-related criteria. Proposed scoring criteria were organized into five groups: air quality, accessibility, equity, physical activity, and safety. This research provides valuable guidance on how peer state transportation departments are approaching the topic.

Domains

Later phases of the literature review focused on qualitative analysis of the basic pathways between transportation and health. Multiple studies, including Deliali et al., identify variations of a few pathways through which transportation impacts health (2,4,12–14). Though exact verbiage and scope varies across different sources, these pathways, or domains, may be generalized as access, physical activity, pollution & environment, traffic casualties, and social equity.

METHODOLOGY

Indicators reviewed during the initial phase of the literature review were categorized based on shared characteristics. There were eleven categories, including accessibility and proximity (i.e., to roads, transit, and other services), costs, crashes and casualties, infrastructure, and modal type. Categorization helped to identify the most frequent topics and concerns that researchers tend to focus on in terms of indicators. Synthesis of this categorization with the peer state review and conceptualization of domains allowed for selection of potential indicators. The domains serve as the basic framework for indicator selection. For each of the five domains, two potential indicators are proposed and supported by the literature review.

RESULTS

1. Access

Overview

Transportation directly affects one's ability to reach basic needs and services, including food, healthcare, education, and employment.

Food insecurity is impacted by a number of complex factors such as consumer behavior, food affordability, and transportation. Glazener et al. summarized the impact of transportation access on food insecurity: "…Accessibility to healthy food could be unpredictable for people dependent on public transportation due to the variability of public transportation services. This leaves individuals who do not live within walking or cycling distance of a grocery store nor have access to a private vehicle vulnerable to inadequate nutrition" (15). Food insecurity has a range of harmful physical and psychological effects. These effects include higher probability of chronic diseases such as hypertension, coronary heart disease, hepatitis, stroke, cancer, asthma, diabetes, arthritis, chronic obstructive pulmonary disease, and kidney disease (16).

Similarly, transportation affects one's ability to access healthcare. According to Syed et al., "transportation barriers lead to rescheduled or missed appointments, delayed care, and missed or delayed medication use. These consequences may lead to poorer management of chronic illness and thus poorer health outcomes" (17), also noting that these problems disproportionately affect those with lower incomes and the under/uninsured. Wolfe et al. quantified this barrier, finding that in 2017, 5.8 million people in the United States delayed medical care due to having no transportation (18).

This relationship plays out similarly across education and employment (19), and while these sectors affect health less directly than food and healthcare, they are strong social determinants of health.

Quantifying access is difficult, as it encompasses a wide range of pathways that all operate somewhat differently from one another. Access is both economic and spatial in nature, so an appropriate indicator will incorporate these aspects. Potential indicators within this domain include household transportation costs relative to annual income and households with no access to a vehicle.

Potential Indicator 1.1: Annual Household Transportation Costs Relative to Annual Income

Transportation access is highly dependent on socioeconomic factors, and socioeconomic factors are similarly among the strongest predictors of health. Capturing this complex relationship may be accomplished through the measurement of household transportation costs relative to annual income.

In 2021, U.S. households spent an average of $10,961 or 16.4% of their total income on transportation, accounting for the second largest expenditure behind only housing. The average share of income spent on transportation is increasing and is intensely stratified in relation to socioeconomic class. The lowest income quintile spent the least overall on transportation ($4,273 compared to $19,204 for the highest income quintile) but spent a much larger share of their total income (26.9% compared to 10.4% for the highest income quintile). Rural households experienced a similar cost burden, spending $13,665 or 17.3% of their income compared to $10,362 or 13.2% of urban household expenditure (20).

The cost of transportation is often cited as a barrier to healthcare access (17,18,21), as well as to food (22). Therefore, measuring annual transportation costs can provide insight into the cost burden communities face in relation to healthcare, food, and other social determinants of health. Measuring it as a percentage of annual income controls for variations in socioeconomic status and allowing for even comparison throughout a whole community. A lower share of annual income spent on transportation is expected to reflect better health outcomes in relation to access.

Household transportation costs as a percentage of income are tracked by the Center for Neighborhood Technology (CNT) and published through the Housing and Transportation Affordability Index. The CNT uses a variety of data sources to compile the index and provides data downloads by various spatial scales. The index is accessible at https://htaindex.cnt.org/.

Potential Indicator 1.2: Households with No Access to Vehicle

Access to a vehicle is an alternative indicator for transportation's effect on health within the domain of access. Many studies have identified correlations between limited vehicle access and various negative effects on healthcare access, health outcomes, and food security. Limited or no access to a vehicle has been found to be a common cause of missed or delayed healthcare appointments (17), as well as being a strong predictor for having unmet care needs (23). This is exacerbated among vulnerable populations such as inner-city children (24).

In terms of actual health outcomes, one study specifically analyzing mortality following myocardial infarction found that lower vehicle ownership was associated with increased all-cause mortality, while there was no such increase for those living in neighborhoods with higher vehicle ownership (25). Similarly, a recent study suggests that there is a positive correlation between vehicle ownership and level of food security (26).

Therefore, vehicle ownership, measured as a percentage of households with access to zero vehicles, may be a strong indicator for measuring access. A greater percentage is expected to reflect better health outcomes, at least within the context of access; however, a key weakness of this indicator is that it may not necessarily reflect the negative effects of vehicle ownership and usage, as discussed in the other domains. In addition, the necessity of vehicle ownership is also context-dependent in terms of urban form and presence of alternative transportation modes. The greater the modal share a household has, that is the number of modes of transportation that is available, the less there is a need for access to a vehicle.

Vehicle ownership is tracked by the American Community Survey (ACS), based on 1 and 5-year estimates. The 5-year estimate data is the most spatially detailed, providing data down to the census block group level. The ACS is likely to be the most readily available data for communities, though while 5-year estimates are more reliable and spatially detailed, they are also the least current in comparison to 1-year estimates. Researchers should pay close attention to the margins of error in any survey and the ACS is no exception. Finally, note that 3-year estimates previously tracked by the ACS have been discontinued.

2. Physical Activity

Overview

In the United States, over half of adults aged 18 and older do not meet the U.S. Department of Health and Human Services' physical activity guidelines for aerobic activities (27). Physical inactivity is linked to a wide range of adverse health effects, including cardiovascular disease, obesity, and poor mental health.

In terms of transportation, use of cars as a primary mode of transportation is associated with greater prevalence of sedentary behavior and decreased likelihood of meeting these physical activity guidelines (28–30). Conversely, many studies support active transportation (i.e. walking and cycling) and use of public transit as modes that increase physical activity and increase the likelihood of meeting activity guidelines (31–33), resulting in subsequent health benefits.

Therefore, an appropriate indicator is needed to track the role of transportation in physical activity. Potential indicators within this domain include modal share and miles of roadways with sidewalks and/or bike lanes per 10,000 people.

Potential Indicator 2.1: Modal Share

Modal share (also referred to as “modal split”) measures the percentage of travelers and/or number of trips using a particular type of transportation (mode). Generally, these modes include walking, cycling, public transit, rideshare (i.e., carpool, taxi, etc.), and private vehicle, and reflects commuting trips.

Modal share is an indicator of transportation’s role in physical activity as it allows high-level approximations of physical activity rates; a higher share of private vehicle usage indicates that the public likely has lower physical activity rates (34,35), while a higher share of walking, cycling, and/or public transit indicates that the public likely has higher physical activity rates (33,36–38). A recent Dutch study modeled a more direct correlation between modal share and health, finding that “walking and cycling modal shares are consistently negatively associated with the prevalence of obesity and diabetes” (39). As such, a higher share of active transportation modes is expected to reflect better health in terms of physical activity.

Furthermore, modal share serves as a heuristic for whether active transportation infrastructure (e.g., sidewalks, bicycle lanes, cycle tracks, etc.) and/or public transit systems within a given area are adequate. Studies have shown that implementation of safer and more robust active transportation and public transit systems induces greater usage of these modes, and subsequently higher levels of physical activity (40–42); conversely, active transportation and public transit mode share is reduced or limited in areas where such infrastructure is not present or where it is not as safe or robust.

One weakness is that modal share typically only tracks commutes, which account for less than 20% of all trips nationwide (though it may be assumed that the majority of travelers use the same mode for other trips as they do for commuting).

Commute modal share is tracked by the ACS, based on 1 and 5-year estimates; see Potential Indicator 1.2 for further considerations in regards ACS data.

Potential Indicator 2.2: Miles of Sidewalks and Bike Lanes Per 10,000 People

As previously discussed, there is a correlation between the presence and/or implementation of active transportation infrastructure and increased usage of active transportation modes. One study found that neighborhood sidewalk length and walkability were positively associated with an increase in walking for transportation (43). Similarly, a systematic review of 21 studies found that bike lane access was significantly correlated with physical activity levels in children and adolescents (44).

Measuring the amount and availability of active transportation infrastructure such as sidewalks, bike lanes, cycle tracks, etc. is a strong indicator for physical activity; more mileage of infrastructure is expected to indicate better health in terms of physical activity. However, one weakness of this indicator is that it does not account for infrastructure quality; infrastructure quality and user comfort are key determinants in usage. For example, sidewalks on a 7-lane highway will not have the same effect as sidewalks on a 2-lane road. Level of Traffic Stress for pedestrians and/or bicyclists is a common tool found in many studies to evaluate the comfort and safety risk a user will experience on a given facility. This stands in contrast to Level of Service for vehicles in that the user’s comfort is given priority, not the throughput of the user’s vehicle.

In the state of Tennessee, sidewalk and bike lane data may be accessed through the Enhanced Tennessee Roadway Information Management System (E-TRIMS) provided by TDOT.

3. Pollution & Environment

Overview

The effect of transportation on the natural environment and its pollution is well studied. Certain transportation modes emit a multitude of harmful pollutants and negatively impact the environment. Motor vehicles specifically emit pollutants such as nitrogen dioxide, carbon monoxide, hydrocarbons, benzene, and formaldehyde, in addition to particulate emissions from tire and brake wear. These pollutants have a profound effect on the health of both the public and the environment; a meta-analysis of 353 studies found a wide range of negative health outcomes associated with long-term exposure to traffic-related air pollution, including all-cause mortality, circulatory mortality, ischemic heart disease mortality, lung-cancer mortality, and asthma onset (45).

Transportation-related pollution also causes large-scale environmental changes. According to the US Environmental Protection Agency (EPA), transportation accounted for 28% of greenhouse gas emissions in the United States in 2021, the highest share of all sectors (46). The resulting global warming can have a vast range of health effects, including increased illnesses and deaths from extreme weather and heat, changes in vector ecology, water quality and food supply impacts, and socioeconomic impacts of environmental degradation (47).

Transportation's effect on health through pollution is large, with some estimates showing transportation-related air pollution causes a similar number of premature deaths as traffic crashes (48). Given this impact, an appropriate indicator for transportation's effect on health in the domain of pollution and the environment is vital. Potential indicators in this domain include proximity to major roadways and vehicle miles traveled per capita.

Potential Indicator 3.1: Percent of Population in Close Proximity to Major Roadways

Proximity to roadways is a significant factor in the magnitude of transportation-related air pollution's effect on health. Increased proximity to roads is associated with increased negative health outcomes, occurring through a variety of factors (49).

The high traffic volume and congestion of highways and major roadways result in elevated emissions and traffic-related air pollution, with the highest concentrations of pollutants occurring in the immediate vicinity of roadways and only dissipating to baseline levels beyond 500 to 600 feet of a roadway (though this varies depending on the specific pollutant). Therefore, people living within this range are subject to exacerbated health impacts of motor vehicle emissions. The U.S. Environmental Protection Agency (EPA) estimated in 2009 that more than 45 million people in the United States were living, working, or attending school within 300 feet of a major road, airport, or railroad (50). This number is likely to have increased since then given the United States' rate of urbanization.

The correlation between proximity to roadways and increased negative health effects is well-researched. Proximity to roadways has been consistently associated with increased risk of a wide range of negative health impacts, including all-cause, circulatory, pulmonary, and cardiovascular mortalities, coronary heart disease, lung cancer, leukemia, asthma, and adverse birth outcomes (45,51,52). Children tend to be more susceptible to these effects, especially respiratory disease symptoms (53). There is also some evidence of increased incidence of neurodegenerative conditions such as non-Alzheimer's dementia, Parkinson's disease, Alzheimer's disease, and multiple sclerosis (54).

Given the outsized impact of transportation-related air pollution on health with increased proximity to roads and the number of people living within close proximity to roads, measuring proximity is a strong indicator of transportation's effect on health in any given area.

Proximity to major roadways is a commonly used indicator for measuring the impact of transportation on health. It one of the fourteen indicators chosen by an expert panel for usage in the USDOT THT. The definition used by USDOT is the percentage of people who live within 200 meters of a high traffic roadway that carries over 125,000 per day (2).

A limitation of this indicator is that it has limited actionability. Reducing residential proximity to roadways is likely to be especially difficult, and increased urbanization will only cause increased average proximity. Nevertheless, promotion of active transportation and limiting expansion of major roadways in these areas could prove to be beneficial to health outcomes. Another limitation is that the efficacy of proximity to roadways as an indicator is dependent on the demarcations used for both “major” roadways and “close” proximity, and variations in these demarcations will produce varying results. When demarcating this indicator, roadway capacity and proximity should generally be scaled inversely; as roadway capacity increases, the threshold for distance to a road should decrease. As a general baseline, however, this indicator may be measured as the percentage of people living within 500 feet of a road with annual average daily traffic (AADT) of 50,000 or more. Additionally, it should be determined if the edge of the roadway or the roadway’s centerline is the unit of analysis as this will significantly affect the outputs.

Data on roadway traffic rates may be examined in conjunction with population census data using geographic information system (GIS) applications. In the state of Tennessee, roadway data may be accessed through E-TRIMS.

Potential Indicator 3.2: Vehicle Miles Traveled Per Capita

Vehicle miles traveled (VMT) is a frequently used indicator of transportation’s effect on pollution and the environment. There is a direct correlation between VMT and polluting emissions output, and the benefits of reducing VMT are well-researched (55–57). VMT per capita as an indicator is beneficial due to connections with other health-related domains; higher VMT is associated with increases in traffic crash casualties crash severity, as well as sedentary behavior (55). Therefore, decreases in VMT will additionally forecast reductions in negative health outcomes from traffic deaths, injuries, and lack of physical activity.

There are some weaknesses involved with VMT as an indicator. For one, the relationship between VMT and emissions is complex and not easily modeled due to a variety of factors. These factors include traffic dynamics and changes in vehicle fuel efficiency technologies.

4. Traffic Casualties

Overview

Traffic casualties are deaths or injuries resulting from incidents involving at least one motor vehicle. In 2022, an estimated 42,795 people died from motor vehicle traffic crashes in the United States (58). This represents a slight decrease compared to 42,939 fatalities in 2021, which was a 16-year high. 2021 saw rising fatalities among non-motorists, with pedestrian fatalities increasing 13% and bicyclist fatalities increasing 5% compared to 2020, also marking multi-year highs (59).

Similarly, injuries on U.S. roads increased in 2021 to an estimated 2.5 million people injured. Though often overlooked in comparison to traffic deaths, traffic injuries lead to many short-term and long-term health consequences, with studies showing that traffic-related injuries can result in significantly lowered health-related quality of life, regardless of severity (60).

Traffic casualties are a growing issue. Some estimates project that road traffic injuries will be the seventh leading cause death globally by 2030 (61), which is a troubling trend particularly in the United States where traffic casualty rates continue to far exceed those in similarly developed countries (13). There are a myriad of reasons for this disparity, though recently there is increasing scrutiny around deference to motor vehicles in infrastructure design and policy (62) and increasing vehicle size and weight (63).

Measuring traffic casualties is fairly straightforward compared to the other domains and are typically already documented. Potential indicators include traffic casualties per capita and traffic deaths in a specific year relative to largest annual number recorded. The primary limitations to this source are the inconsistent reporting in police data and the lack of data from people who were in a crash, went to a hospital but did not report the crash to the police. TDOT is currently working with TDH to address this data gap.

Potential Indicator 4.1: Traffic Casualties Per Capita

Conventional analysis in the United States measures traffic deaths in terms of vehicle miles traveled (VMT), but this method is severely limited by its failure to account for changes or fluctuations in travel trends. As discussed by Litman, death rates by VMT in the United States declined drastically between 1965 and 2010, leading to the perception that traffic safety had improved. In actuality, per capita vehicle travel had more than doubled within the same timeframe, offsetting the actual decline in death rates. Meanwhile, death rates per capita for the same time period showed much more modest improvement (13). Per capita measurement also has the benefit of being sensitive to population changes.

Additionally, conventional analysis tends to overemphasize traffic deaths over traffic casualties. Given that non-fatal injuries from traffic incidents still have a significant effect on health, measuring traffic casualties per capita is a more holistic approach.

There are some limitations to this indicator. Road crash reporting is rarely complete, accurate, or reliable. Beyond fatality and serious injuries, there are no federal standards in the United States for injury or property damage only crash reporting, meaning states use different frameworks for collecting and reporting data, and what crash reports that do occur depend heavily on police officer discretion (64). Studies show that incidents involving cyclists and pedestrians in particular are underreported (65). Recommendations for improving traffic crash reporting include developing and utilizing standardized crash reporting guidelines (64) and integrating hospital discharge data with crash report data for more complete documentation (66).

Spatialized traffic casualty data is typically easily accessible from local and state authorities. TDOT and the Tennessee Department of Safety & Homeland Security maintain several crash data platforms for the state of Tennessee, accessible at https://www.tn.gov/content/tn/safety/stats/dashboards.html.

Potential Indicator 4.2: Traffic Deaths in a Specific Year Relative to Largest Annual Number Recorded

Evans (67) proposes a new measure for tracking changes in traffic safety: traffic deaths in a specific year relative to largest annual number recorded. Evans describes a number of benefits to this measure. Firstly, it requires only one reference year, the year in which the largest number of deaths occurred. Secondly, it is dimensionless, which reduces the number of complicating variables. Finally, it is a self-referential measurement, meaning that "if jurisdiction's data are systematically biased," each year is operating on the same bias and significant changes are still evident. This is a new opportunity for addressing the limitations in more conventional measurements of traffic casualties.

5. Social Equity

Overview

Social equity in terms of transportation and health refers to the ways in which transportation can improve and/or impair the health of socioeconomically disadvantaged populations. While social equity is listed here as a distinct domain, it in fact operates parallel to each of the other four domains; that is, social equity is at play in relation to the mechanisms of the other domains and their impact on health, potentially augmenting the negative effects and minimizing the negative effects. For example, populations living near roadways in urban settings generally tend to be comprised of non-white residents and of lower median household incomes, and are therefore disproportionately affected by the negative impacts of proximity to traffic-related air pollution (68). In fact, disadvantaged populations are disproportionately affected by nearly all of the health outcomes discussed in this study. Disabled individuals are especially vulnerable to transport-related burdens.

Glazener et al. emphasizes that a key consideration for equity is where certain populations live in relation to major transportation infrastructure and that some factors do not impact different populations in the same way (15). For example, healthcare access is often limited for rural populations, and proximity to a major roadway may improve that access. Conversely, urban populations will likely see negative effects from such proximity, far outweighing any benefits seen within the domain of access. These relationships require further research tailored to the populations in question in order to understand them more fully, but they serve to illustrate the complexity of how social equity operates across domains.

In MassDOT's update of the department's project scoring process, chosen indicators were designed to emphasize "vertical equity" over "horizontal equity." A horizontal equity approach applies equal allocation of resources or treatment to all users, whereas vertical equity allocates resources or treatments according to actual need. In the context of transportation, this may mean greater investment in more affordable modes of transportation (i.e., walking, biking, transit) and greater community engagement in transportation planning (4).

An appropriate indicator for social equity will capture how transportation-related resources are allocated in relation to socioeconomically disadvantaged populations. Potential indicators for the domain of social equity include share of transportation budget allocated for active transportation or public transit projects.

Potential Indicator 5.1: Percent of Census Tracts Identified as Transportation Disadvantaged

USDOT maintains an interactive mapping tool called the Equitable Transportation Community (ETC) Explorer. This tool allows users to view data on transportation disadvantaged census tracts. USDOT identifies such tracts based on data for a range of sub-indicators falling into categories related to climate & disaster, environment, health vulnerability, social vulnerability, and transportation insecurity, and provides an overall score for each category. Data can be viewed at various geographical scales. The sub-indicators provided for each category provide greater detail on the factors influencing transportation disadvantage, allowing users to gain a better understanding of how the scoring is assigned.

The tool also allows users to spatially identify where communities are disadvantaged and the degree to which they are disadvantaged. Within the Nashville, TN Area MPO, for example, 18% of the census tracts are transportation disadvantaged, representing roughly 289,600 of the 1.7 million area population. The greatest contribution to this disadvantage is attributable to environmental burdens.

A key weakness of the use of this tool as an indicator is its lack of actionability. Many of the factors used to determine disadvantage are deeply systemic and cannot be easily addressed. For example, the social vulnerability category includes unemployment as an indicator, which itself is the product of a hugely complex set of factors. Nevertheless, the tool may be highly useful for its diagnostic abilities and will be used at TDOT during grant applications, GIS analysis, and more. The tool may be accessed at https://www.transportation.gov/priorities/equity/justice40/etc-explorer.

Potential Indicator 5.2: Share of Transportation Budget Allocated for Active Transportation or Public Transit Projects

Active transportation and public transit modes play a key role in addressing health impacts across all four of the previous domains. Disadvantaged populations tend to rely more heavily on active transportation modes (69), including those with disabilities (70). However, inadequate infrastructure can prevent usage of these modes among the same populations (71).

Litman recently lamented the lack of equitability in conventional transportation planning and funding in North America, finding that private vehicles receive a disproportionately large amount of space, infrastructure, and funding relative to travel demand and cost efficiency. Litman proposes a "fair share" approach that places greater emphasis on investment in walking, biking, and transit systems (69,72). Allotting greater share of funding to these systems, proportional to travel demand and cost efficiency, would improve transportation equity for disadvantaged populations.

DISCUSSION AND RECOMMENDATIONS

State of Tennessee Agency Usage

This study is intended to provide guidance for TDH and the Livability Collaborative on potential indicators and areas of focus in the State of Health Report, the Livability Index, and the Tennessee Vitality Toolkit. Through continued collaboration and input from health experts, a final set of five indicators will be discussed with these projects to determine how they will be incorporated into each. Future usage by state agencies in Tennessee may include modeling MassDOT's integration of transportation and health-related indicators in project scoring processes, ensuring that transportation planning and funding consider health in new projects. In any case, state agencies will ideally solicit feedback from local agencies to help determine the usefulness of these indicators.

Limitations

This study faced some limitations. Time was the most significant limitation; the research timeframe was limited to the duration of the internship program for the primary author, which was approximately two months. This meant that the breadth and depth of analysis was reduced.

The target of five final indicators presented a significant challenge in choosing which aspects of the relationship between transportation and health to focus on. Given the complexity of this relationship, it is impossible to fully capture this relationship through only five indicators. As such, it was best to adopt a heuristic approach in selecting indicators. Each of the proposed indicators will only capture a portion of the intended domains, though they will also overlap across domains.

Additionally, the existing literature on transportation, health, and related indicators tends to focus primarily on urban settings. The proposed indicators may reflect this shortcoming in the literature, and result in reduced usefulness in rural areas.

This study also focused primarily on personal automobiles, bicycles, pedestrians, and public transit. Aviation, maritime, and rail transportation were generally not strongly considered in the development of the proposed indicators. Communication with offices that oversee these modes did occur, but more work is needed in order to fully incorporate these into this research.

Future Research

This study presents several opportunities for future research. The validity of these indicators for measuring the impact of transportation on health may be verified through empirical analysis. A potential method for this analysis could involve geographically weighted regression (GWR) using GIS software, comparing the proposed indicators with health data of residents. This would result in a visualization of specific locations where transportation and health can be improved.

Another potential opportunity is to analyze of the impact of indicator usage, particularly within state and local agencies. This analysis may focus on how specifically the indicators are used and incorporated into transportation and/or health improvement efforts. It is important to establish a clear pathway from the proposal of indicators to their incorporation into state agency processes and implementation of policy and infrastructure.

Future research may also seek to comprehensively address the gaps in understanding transportation's effect on health in rural settings. A separate set of indicators may be developed catering specifically to these areas so that local agencies can choose depending on their location and level of development. Additionally, future proposed indicators might consider aviation, maritime, and rail transportation.

This study may be modeled by other state agencies seeking to develop their own indicators in relation to transportation and health, as well as demonstrate a successful collaboration between state agencies for the improvement of public well-being.

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