Technical Memorandum
FDOT Master University Agreement BDV29-977-56

Assessing the Health Impacts of Transportation Projects – a Synthesis

Final Report

Prepared For

Planning and Environmental Management Office

Florida Department of Transportation - District 6

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Date

December 2020

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Prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

METRIC CONVERSION CHART

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton)	Mg (or t)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F−32)/9 or (F−32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	pound force	4.45	newton	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or t)	mega grams (or metric ton)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newton	0.225	pound force	lbf
kPa	kilopascals	0.145	pound force per square inch	lbf/in^2

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

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Assessing the Health Impacts of Transportation Projects – a Synthesis		5. Report Date December 2020
		6. Performing Organization Code
7. Author(s) Ming S. Lee and Xia Jin		8. Performing Organization Report No.
9. Performing Organization Name and Address Florida International University 10555 W. Flagler Street Miami, Florida 33174		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. BDV29-977-56
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee St., Tallahassee, FL 32301		13. Type of Report and Period Covered Final Report January 2020 - December 2020
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

To identify the best approach to applying Health Impact Assessment (HIA) for complete street projects in Florida, a comprehensive literature review and case studies were conducted. Existing HIA tools applied in the U.S. and elsewhere in the world were reviewed. It was found that the Integrated Transportation and Health Impacts Model tool (ITHIM) is the best choice for implementation of HIA in Florida, because ITHIM has had successful implementations in the United States, including multiple Metropolitan Planning Organizations (MPO) in California and Nashville in Tennessee. ITHIM's ability of modeling three transportation impacts that are important in Florida, namely physical activity, air pollution, and traffic injuries with pedestrians and cyclists, is also an important criterion for the decision.

Three important ITHIM implementations in the United States were then examined in great detail (i.e., greater Nashville area in Tennessee, five major California MPOs, and counties in Sacramento, California). From these case studies, useful perspectives and modeling techniques that can be replicated for a potential ITHIM application in Florida were identified. The Nashville case demonstrated that ITHIM implementation can be coupled with other regional planning initiatives to increase public support for active transportation investments. The Sacramento case showcased a disaggregate approach that can highlight underlying health disparities in neighborhoods with diverse socioeconomic and racial and ethnic backgrounds. ITHIM implementations for multiple California MPOs provided a modern software architecture that can be replicated in Florida.

Combining the results of literature review and case studies, a modeling framework was developed to integrate transportation and health impact assessment for MPO transportation planning in the United States. This framework combining a regional travel demand model with ITHIM can be integrated into the standard regional transportation planning process. Potential data sources that can be used for implementation of this framework in Florida were also identified.

17. Key Words Health impact assessment, complete street, active transportation, transportation planning		18. Distribution Statement No restrictions	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 91	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) in September 2014 adopted its Complete Street policy and established the Complete Streets Program to oversee implementation of the Policy. Complete Streets are roadways designed and operated to provide safe mobility for all users, including people of all ages and abilities, regardless of their choices of transportation modes (e.g., walking, bicycles, automobiles, or public transits). The Complete Street Policy is an important means for FDOT to drive down fatalities from pedestrian and bicyclist crashes with vehicles on all public roads. In November 2014, the Miami-Dade County (MDC) Commission followed suit with adoption of its own Complete Streets Resolution. MDC's Complete Streets Resolution aims to transform the County's roadway facilities into healthy and sustainable mobility options for all users equally, whether they are walking, biking, riding transit, or driving automobiles.

With the Complete Street Policy in place at both the county and state levels, projects promoting active transportation have been proposed in South Florida and the state in general. However, assessment of the projects' health impacts in terms of increasing participation in active transportation, improving air quality, and reducing traffic crashes has not been attempted. There is generally a lack of information in all relevant planning documents regarding how potential health benefits of a project are factored into its priority in project selection.

To identify the best approach to apply Health Impact Assessment (HIA) for Complete Street projects in South Florida and the state, we conducted a comprehensive literature review and case studies. Results of the literature review and case studies were used to develop a framework that can be used to assess the impacts of transportation on public health.

For literature review, we first reviewed the latest medical evidence on the health benefits of active transportation and guidelines for physical activity. Existing HIA tools applied in the U.S. and elsewhere in the world were then reviewed. We also reviewed specific transportation and public health issues in South Florida. We concluded that transportation plans and projects that promote active transportation can help solve transportation and public health issues facing south Florida, especially stroke, diabetes, and injuries and fatalities involving pedestrians and bicyclists. Latest evidences in medical and public health research show that all-cause mortalities and the prevalence of cardiovascular disease, diabetes, weight gain, dementia, depression and injuries due to falls by the seniors can all be reduced by a greater rate of participation in physical activity by the public. Together, these medical conditions represent a significant amount of economic cost in the U.S.

We also found that conducting HIA for these projects can show the general public what health benefits and associated economic benefits are expected of these projects. As for specific HIA tools that suit the needs of south Florida, we concluded that the Integrated Transportation and Health Impacts Modeling tool (ITHIM) is the best choice for implementation of HIA in this region, because ITHIM has had successful implementations in the United States, including multiple Metropolitan Planning Organizations (MPO) in California and Nashville in Tennessee.

ITHIM's ability of modeling three transportation impacts that are important in south Florida, namely physical activity, air pollution, and traffic injuries with pedestrians and cyclists, is also an important criterion for the decision.

To identify an effective model for applications of ITHIM in the regional transportation planning process for Complete Streets projects, we examined three important ITHIM implementations in the United States (i.e., greater Nashville area in Tennessee, five major California MPOs, and counties in Sacramento, California). Nashville's application of ITHIM was conducted with many other joint efforts by the regional governments to promote public health through active transportation. Results of these efforts helped the region formalize regional transportation planning that take health and active transportation into consideration. The implementation with the five largest MPOs in California was driven by California's policy initiatives targeted for greenhouse gas emissions reduction from vehicular sources. Involvement from several public agencies in the state of California (e.g., California Department of Public Health and California Air Resource Board) in this ITHIM study helped the agencies acquire resources to conduct ITHIM applications for suitable projects in the future. The Sacramento application was a research project that highlighted the potential benefits and technical challenges of disaggregating ITHIM analyses by population groups and small geographic divisions.

From these case studies, we identified useful perspectives and modeling techniques that can be replicated for a potential ITHIM application in South Florida. We learned from the experience in Nashville that an ITHIM implementation can be coupled with other regional planning initiatives to increase public support for active transportation investments. We also recognized that the disaggregate approach demonstrated with the Sacramento implementation has the potential to result in an ITHIM application that can highlight underlying health disparities in Miami's neighborhoods with diverse socioeconomic and race/ethnic backgrounds. In addition, we see technical advantages of running ITHIM analyses with computation apps developed in the R language like those developed for California Air Resource Board.

Combining the results of literature review and case studies, we developed a modeling framework to integrate transportation and health impact assessment for MPO transportation planning in the United States. This framework combining the regional travel demand model with ITHIM can be integrated into the transportation planning process endorsed by the Federal Highway Administration and Federal Transit Administration. We also identified potential data sources that can be used for implementation of this framework in South Florida.

We concluded this research by elaborating the urgent need to develop a functional HIA tool based on the ITHIM architecture for the Miami-Dade Transportation Planning Organization (TPO). The tool can be applied with local data to evaluate the health benefits of Complete Street projects in the most recent long range transportation plan and transportation improvement program of the TPO. The successful experience of ITHIM application in Nashville and MPOs in California can also be replicated by the Miami-Dade TPO. With a successful application of HIA in South Florida, the HIA tool can be adapted for applications by other MPOs in Florida to increase statewide awareness and support for Complete Street projects.

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CHAPTER 1 INTRODUCTION

Transportation is one of the most important functions of the modern society. Transportation projects can have tremendous impacts on the health of the general public through their positive and/or negative effects on physical activity, air quality, and injuries and fatalities from crashes. For a long time, transportation policies and investment decisions gave little attention to public health impacts. Things have begun to change in recent decades. Many states and metropolitan planning organizations (MPOs) now include public health goals and health criteria in transportation planning and project selection processes (USDOT, 2015a). The public health community has also begun to partner with transportation planning agencies to integrate health considerations in transportation work (NASEM, 2019). As a result of collaboration between transportation and public health communities, Health Impact Assessment (HIA), a systematic framework developed by public health researchers, has emerged as a preferred approach for considering how transportation and land use decisions can impact public health (NRC, 2011). Currently, several HIA tools exist, and successful applications of the tools for transportation planning in U.S. metropolitan areas have been reported.

The Florida Department of Transportation (FDOT) in 2014 adopted its Complete Street Policy and established the Complete Streets Program to oversee implementation of the Policy (FDOT, 2019). In adopting the policy, FDOT acknowledges that increasing active transportation participation while reducing pedestrian and bicyclist accidents is important for FDOT to achieve its goal in promoting safety, quality of life and economic development in the state. With the Complete Street Policy in place, projects promoting active transportation are going to be proposed in the state of Florida. However, assessment of the projects' health impacts in terms of increasing participation in active transportation, improving air quality, and reducing traffic crashes has not been attempted in the state.

Recognizing the needs to help the agency identify and evaluate projects that achieve a balance between economic development and public health, this project developed a framework that can assess the relationship between transportation and health. More specifically, the objectives include:

- Conducting a comprehensive review of existing knowledge and experience in HIA methods as well as tool applications.
- Develop a framework for HIA that details the procedures and methodological processes that can help the agency to incorporate health considerations into the planning process.

The objectives were accomplished with three major tasks:

Task 1: Literature Review

We reviewed existing literature on what have been done in the U.S. and other parts of the world in terms of health impact assessment of transportation projects. The review included the most up-to-date evidence in medical research regarding health impacts of active transportation. The results of the literature review showed what aspects of health outcomes can be affected by decisions in the planning and design of transportation systems. We also identified HIA tools developed in the US and other World communities for assessment of health impacts by transportation investments.

Task 2: Case Studies

We identified existing cases of ITHIM applications for transportation projects and conducted in-depth analysis of the cases. Based on results of literature review, we selected three cases (i.e., greater Nashville area in Tennessee, five major California MPOs, and counties in Sacramento, California) of transportation health impacts assessment in the U.S. and examined the context of HIA applications, the assessment methods and data, and regional transportation plans and actions taken after the assessment.

Task 3: Framework Recommendation

Combining the results of the literature review and case studies, we formulated a framework for transportation project HIA in South Florida. The framework includes the procedures and modeling processes that can be effectively integrated in urban transportation planning process in the State of Florida and US in general. We also identified potential data sources to be used for applications of the framework.

CHAPTER 2 LITERATURE REVIEW

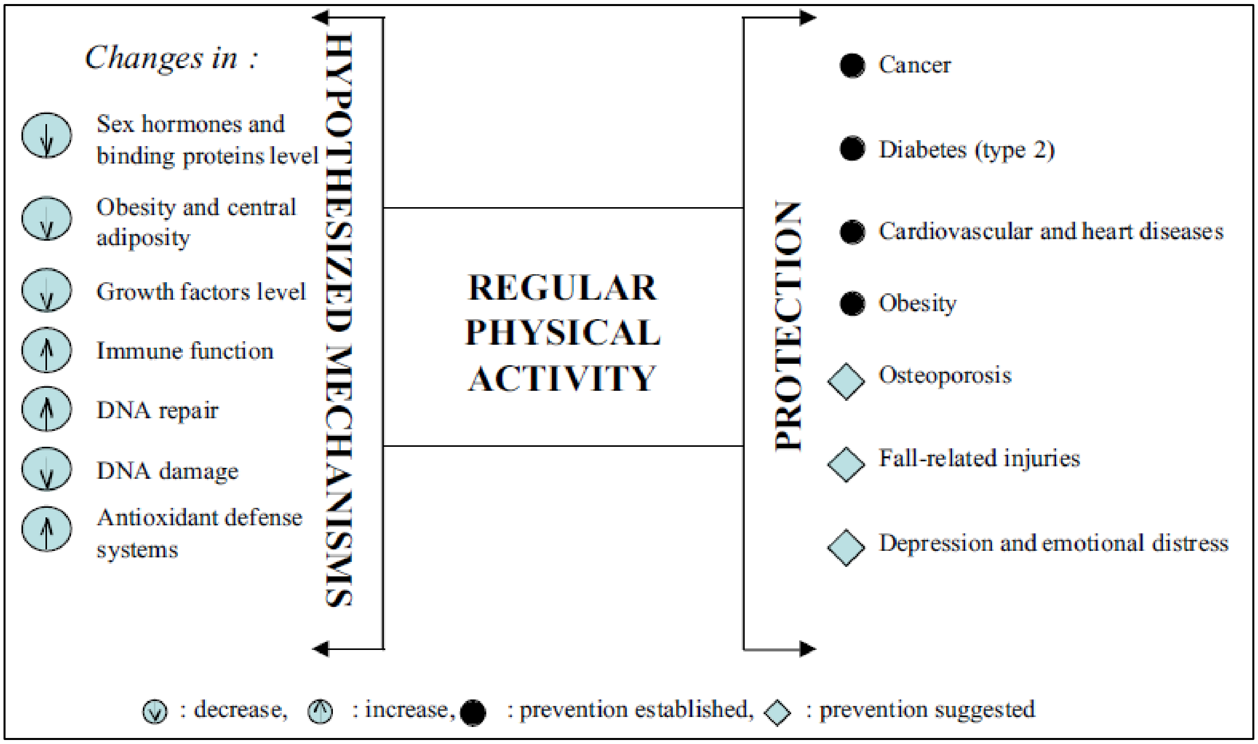
2.1 Health Impacts of Complete Streets Projects

Facilities designed with complete street concept enable safety and support mobility for all users, including people of all ages and abilities, traveling as drivers, pedestrians, bicyclists, or public transportation riders (USDOT, 2015b). Complete streets can reduce vehicle crashes with pedestrians and bicyclists when infrastructures like sidewalks and bike paths are designed and built to protect people who walk and bike (Reynolds, Harris, Teschke, Cripton, Winters, 2009). By providing facilities that are safe for all users, complete streets can promote walking and bicycling as means of transportation, leading to reduced automobile use and reduced mobile-source emissions. Powell, Martin, and Chowdhury (2003) found that 43% of people who had access to a place to walk were significantly more likely to meet current recommendations for physical activity than those reporting no place to walk.

When evaluating benefits of complete street projects, it is necessary to clearly define the health outcomes and associated economic costs/benefits resulting from changes in physical activities, air pollution and crash injuries and fatalities. Injury severities and associated economic costs from vehicle crashes with pedestrians and bicyclists had been described for transportation practices (Eluru, N., Bhat, C., and Hensher, D., 2008; Reynolds et al., 2009; Zahabi, Strauss, Manaugh, and Miranda-Moreno, 2011; Blincoe, Miller, Zaloshnja, and Lawrence, 2015). Although specific health outcomes associated with increased physical activities and exposure to vehicular emissions were well studied in the domain of medicine and public health (Warburton, Nicol, and Bredin, 2006; Kruk, 2007; Warburton and Bredin, 2017), they have not reached the same level of consensus and familiarity in transportation communities.

2.1.1 Health Benefits Associated with Physical Activities

Physical inactivity is a modifiable risk factor for cardiovascular disease and other chronic health conditions, including diabetes mellitus, obesity, hypertension, cancer (colon and breast), bone and joint diseases (osteoporosis), and depression (Warburton, Nicol, and Bredin, 2006). In the fields of medicine and public health, there have been many long-term studies that have assessed the relative risk of premature death from any causes and from specific conditions (e.g., cardiovascular disease) associated with physical inactivity (Warburton and Bredin, 2017). Kruk (2007) summarized findings prior to 2006 on the association between physical activity and risk factors of chronic diseases in Figure 1. Figure 1 shows that evidence-based recommendations or guidelines had been established for the prevention of cancer, diabetes, cardiovascular disease, and obesity by achieving the recommended levels of physical activity. Such recommendations had not been made for osteoporosis, fall-related injuries, and depression, despite evidence for positive association between physical activity and prevention of these three conditions.



Source: Kruk (2007)

Figure 1 Protective effects of physical activity on chronic diseases and hypothesized biological mechanisms for its health benefits

Cardiovascular Diseases

For primary prevention (i.e., preventing diseases from occurring on previously healthy people), studies had shown that regular physical activity and a high fitness level are associated with reduced risk of premature death from any causes and from cardiovascular diseases (Warburton, Nicol, and Bredin, 2006). Systematic reviews have also shown that engaging in regular exercise can attenuate or reverse the disease process in patients with cardiovascular disease (Warburton and Bredin, 2017), providing evidence for effective secondary prevention (i.e., stopping and/or reversing the progression of existing diseases) of cardiovascular disease by participating in regular physical activities.

Diabetes

Prospective studies with follow-ups had shown a strong association between physical activities and reduced rates of death from diabetes (Manson et al., 1992). Moderately intense physical activity and good cardiovascular fitness are protective against the development of type 2 diabetes in middle-aged men, with greater effect among those at high risk (e.g., overweight or obese) for developing diabetes (Lynch, Helmrich, Lakka et al., 1996). In patients with type 2 diabetes, walking more than 2 hours per week was shown to reduce the risk of premature death (Gregg et al., 2003).

Cancer

Existing literature showed that routine physical activity (either for recreation/maintenance or for work) is associated with reductions in the incidence of specific cancers, particularly colon and breast cancer (Thune and Furberg, 2001). Compared with those who were physically inactive, a 30%–40% reduction in the relative risk of colon cancer was observed among physically active men and women, and a 20%–30% reduction in the relative risk of breast cancer was observed for women who exercise regularly (Lee, 2003). Moderate physical activity for about 30–60 minutes per day has a greater protective effect against colon and breast cancer than activities of low intensity (Thune and Furberg, 2001). Studies involving breast and colon cancer patients showed that patients who reported participation in physical activity were associated with a decreased recurrence of cancer and risk of death from cancer, with the greatest benefit observed among cancer survivors who exercised regularly for 3–5 hours per week (Holmes et al., 2005; Haydon et al, 2005).

Obesity

Obesity is a risk factor for developing many medical conditions such as hypertension, cardiovascular disease, type-2 diabetes, colon cancer and breast cancer in women (Carmichael and Bates, 2004). Controlling obesity prevalence in the population can thus help decrease the incidence of those conditions. Based on a study of over 15,000 American adults between 53 and 57 years, Littman, Kristal and White (2005) found that engaging in regular physical activities of various intensity, such as jogging, cycling and aerobics for over 10 years can prevent weight gain associated with aging for people over age 45. Jakicic et al. (2019) conducted a systematic review on the association between physical activity and prevention of weight gain in adults. They identified a dose-response relationship between physical activity and weight loss. Prevention of weight gain is most pronounced with over 150 minutes of moderate-to-vigorous intensity (≥3 Metabolic Equivalent of Task [MET] hours) physical activity per week. Jakicic et al. (2019) concluded that public health initiatives to curb obesity should include physical activity as a means of prevention.

Osteoporosis and Fall-Related Injuries

Osteoporosis is a growing major public health problem, especially in postmenopausal women (Camacho et al., 2020). The disease is associated with increased susceptibility to fractures due to decreased bone density (Renno et al., 2005). Weight-bearing, balance, and resistance exercises have shown to have the greatest effects on bone mineral density and improvement of osteoporosis (Camacho et al., 2020).

Another risk factor leading to injuries and bone fractures in the elderly is the susceptibility to falls (Rubenstein, 2006). Either home-based or group-based exercise programs have been shown effective in preventing falls in the older population (Shier, Trieu, and Ganz, 2016).

Depression and Emotional Stress

Major depression is a highly common mental disorder in the United States (NIH, 2019). It was estimated that 17.3 million adults (i.e., 7.1% of U.S. adult population) in the United States had at least one major depressive episode. The prevalence of major depressive episode was higher among adult females (8.7%) compared to males (5.3%) (NIH, 2019).

A systematic review of literature on physical activity and depression concluded with sufficient evidence that physical activity may prevent depression (Mammem and Faulkner, 2013). All levels of physical activity can potentially prevent future depression. Anxiety disorders is another common mental condition with a lifetime prevalence of nearly 29% in the United States (Kessler et al., 2005). Numerous studies and meta-analyses showed that exercise is also associated with reduced anxiety in clinical settings (Anderson and Shivakumar, 2013).

2.1.2 2018 Physical Activity Guidelines for Americans, 2nd Edition

In 2018, the US Department of Health and Human Services (USDHH) released the Physical Activity Guidelines for Americans (PAG), 2nd Edition (USDHH, 2018a), which updated the first edition released in 2008. The latest general physical activity guideline for adults is at least 150 minutes to 300 minutes a week of moderate-intensity aerobic physical activity; or 75 minutes to 150 minutes a week of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity aerobic physical activity (USDHH, 2018a).

In conjunction with the new PAG, USDHH also released the 2018 Physical Activity Guidelines Advisory Committee Scientific Report (USDHH, 2018b), providing the most up-to-date evidence for the guidelines. The scientific evidence accumulated since 2008 resulted in an expansion of the list of documented health benefits for physical activity (Powell et al., 2019). Table 1 summarizes all health benefits of physical activity in both the 2008 and 2018 PAG.

Table 1 Physical Activity–Related Health Benefits for Adults All Ages

	Conditions	**Benefits from Meeting Physical Activity Guidelines***
Adults, All Ages	All-cause mortality	Lower risk
	Cardiovascular conditions	Lower risk of cardiovascular disease, and cardiovascular disease mortality (including heart disease and stroke)
		Lower risk of hypertension
	Diabetes	Lower risk of type 2 diabetes
	Cancer	Lower risk of **bladder****, breast, colon, **endometrium**, **esophagus**, **kidney**, **stomach**, and **lung cancers**
	Brain health	**Reduced risk of dementia**
		Improved cognitive function
		Improved cognitive function following acute bouts of aerobic activity
		Improved quality of life
		Improved sleep
		Reduced feelings of anxiety and depression in healthy people and in people with existing clinical syndromes
		Reduced risk of depression

Table 1, continued

	Conditions	Benefits from Meeting Physical Activity Guidelines*
Adults, All Ages	Weight status	**Reduced risk of excessive weight gain**
		An additive effect on weight loss when combined with moderate dietary restriction
		Weight loss and the prevention of weight regain when a sufficient dose of moderate-to- vigorous physical activity is attained
Older Adults	Falls	**Reduced risk of falls**
		Reduced risk of fall-related injuries
	Physical function	**Improved physical function in older adults with and without frailty**

*Only benefits with strong or moderate evidence are included in the table. **Benefits in bold are those added in 2018. Source: Powell et al., (2019)

For physical activity benefits in cancer prevention, the 2nd edition of PAG adds documented benefits in lower risks for bladder, endometrium, esophagus, kidney, stomach, and lung cancers. In addition, physical activity benefits in preventing excessive weight gain, depression, anxiety, dementia, and risk of fall in older adults are formally supported in the 2nd edition. However, osteoporosis is not a documented benefit in either 2008 or 2018 editions. Table 2 summarized health benefits of physical activity for those with pre-existing chronic conditions.

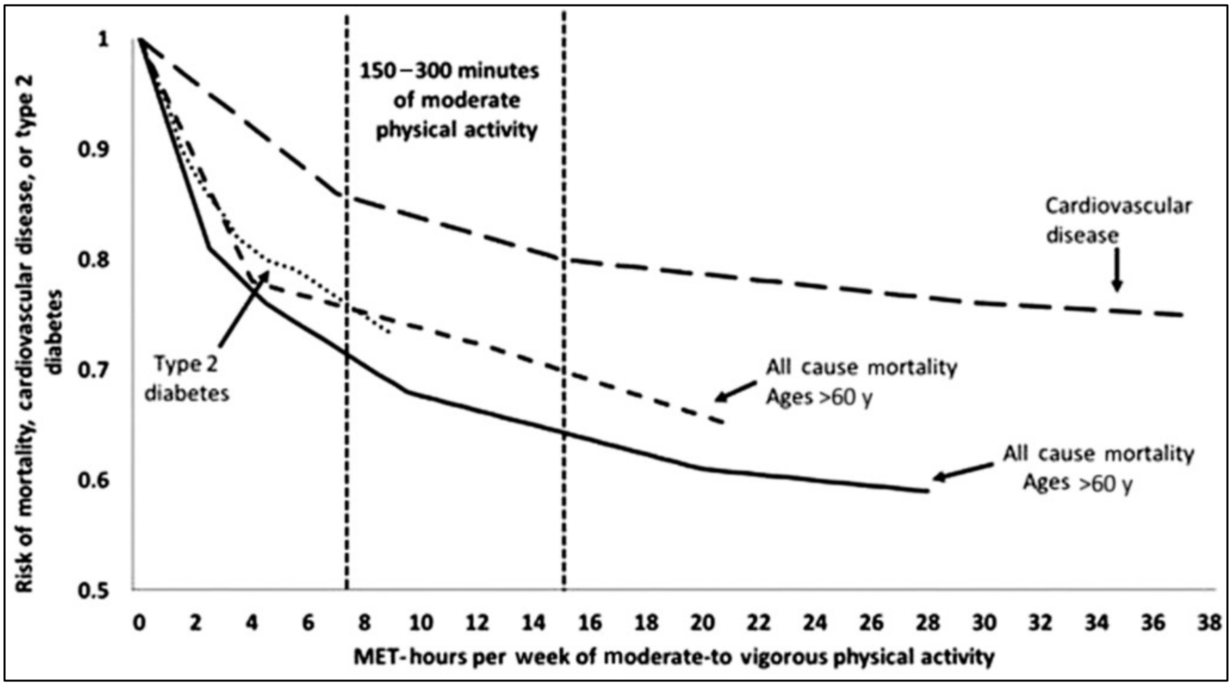
Table 2 Physical Activity–Related Health Benefits for Individuals with a Chronic Condition

Pre-existing Chronic Conditions	Benefits from Meeting Physical Activity Guidelines
Breast cancer	Reduced risk of all-cause and breast cancer mortality
Colorectal cancer	Reduced risk of all-cause and colorectal cancer mortality
Prostate cancer	Reduced risk of prostate cancer mortality
Osteoarthritis	Decreased pain
	Improved function and quality of life
Hypertension	Reduced risk of progression of cardiovascular disease
	Reduced risk of increased blood pressure over time
Type 2 diabetes	Reduced risk of cardiovascular mortality
	Reduced progression of disease indicators: hemoglobin A1c, blood pressure, blood lipids, and body mass index
Recent hip fracture	Improved walking, balance, and activities of daily living
Frailty	Improved walking, balance, and activities of daily living
Stroke	Improved walking, physical fitness, functional independence
	Improved cognition
Spinal cord injury	Improved physical fitness
	Improved walking and wheel-chair skills
Dementia	Improved cognition
Multiple sclerosis	Improved walking
	Improved strength and physical fitness
Parkinson's disease	Improved walking, balance, activities of daily living, and cognition
Schizophrenia	Improved quality of life and cognition
Attention deficit hyperactivity disorder	Improved cognition

Source: Powell et al., (2019)

Dose–Response Relationship Between Physical Activity

Based on the literature review performed for the 2018 Physical Activity Guidelines Advisory Committee Scientific Report (USDHH, 2018b), an inverse relationship between self-reported moderate to vigorous physical activity and all-cause mortality, cardiovascular disease mortality and incidence, and incidence of type 2 diabetes had been identified (see Figure 2).



Source: Powell et al., (2019)

Figure 2 Inverse dose–response relationships between self-reported aerobic moderate-to-vigorous physical activity and risk of all-cause mortality, risk of cardiovascular disease, and risk of type 2 diabetes.

The inverse, curvilinear dose–response curves demonstrate that the largest increase in benefits is observed for originally sedentary people who initiate physical activity. The marginal increases in benefits gradually decline as the amount of physical activity continues to increase, until leveling off after reaching beyond 30 MET-hours per week (see Figure 2). This shape of the dose-response curve is an important feature in the design of HIA tools (see discussions in section 3).

Effective intervention strategies for increasing physical activity are summarized in Table 3 (Powell et al., 2019). Strategies and policies aiming to change the physical environment for physical activity facilitation are most relevant to transportation projects and plans promoting complete streets.

Table 3 Selected Types of Interventions Shown to Increase Physical Activity

Social ecological level	Type of physical activity intervention
Individual	Interventions targeting youth, particularly if families are incorporated
	Behavior theory-based interventions aimed at adults and older adults
	Peer-led behavioral self-management interventions for older adults and individuals with chronic disease
Community	Community-wide interventions including intensive contact with a majority of targeted population School-based interventions that aim to increase physical activity during physical education classes Multicomponent school-based interventions aimed at increasing
	student physical activity throughout the school day
Communication environment	Wearable activity monitors in combination with goal setting and other behavioral strategies Telephone-assisted interventions in the general adult population including older adults Internet-delivered interventions that include educational components
	Computer-tailored print interventions in the general adult population Mobile phone programs that include text messaging for adults Smartphone applications for children and adolescents
Physical environment and policy	Point-of-decision prompts to use stairs versus escalators or elevators
	Built environment infrastructure and elements to enable active transport and support recreational physical activity among children and adults
	Access to parks and outdoor or indoor recreational facilities for children and adults

Source: Powell et al., (2019)

Table 4 shows some of the most common causes of death, prevalent chronic conditions, and expensive medical conditions in the United States that can be effective prevented by regular participation in physical activity (Powell et al., 2019). Effective promotion of physical activity is expected to significantly reduce the burden and cost of these diseases in the United States.

Table 4 Leading Causes of Death, Most Prevalent Chronic Conditions, and Most Expensive Medical Conditions Associated with Insufficient Physical Activity

Ten leading causes of death	Ten most prevalent chronic conditions	Ten most expensive medical conditions
Heart disease	Hypertension	Heart conditions
Cancer	Hyperlipidemia	Trauma disorders
Chronic lung diseases	Upper respiratory conditions	Cancer
Unintentional injuries	Arthritis	Mental disorders
Stroke	Mood disorders	Asthma/COPD
Alzheimer's disease	Diabetes	Hypertension
Diabetes	Anxiety disorders	Type 2 diabetes
Influenza and pneumonia	Asthma	Arthritis
Kidney disease	Coronary artery disease	Back problems
Suicide	Thyroid disorders	Healthy childbirth

Source: Powell, King, Buchner et al., (2019)

It is noted that mental disorders such as depression and anxiety disorders are collectively one of the most expensive medical conditions in the U.S. However, the impacts and economic costs saving of physical activity on reducing the burden of depression and anxiety have not been addressed in any of the existing health impact assessment tools (see discussion in section 3).

2.1.3 Health Impacts of Long-Term Exposure to Mobile-Source Emissions

Long-term exposure to air pollution is associated with many health impacts, including chronic obstructive pulmonary disease (COPD) linked to ozone exposure (O_3) (Li, Wiegman, and Seiffert et al., 2013); acute lower respiratory illness, cerebrovascular disease (e.g., stroke), ischemic heart disease (e.g., angina and myocardial infraction), COPD, and lung cancer linked to $PM_{2.5}$ (Burnett et al., 2014). Lelieveld, Evans, Fnais, Giannadaki and Pozzer (2015) used a global atmospheric chemistry model to study the link between premature mortality and different emission source categories (e.g., agriculture, power generation, industry, and land traffic) in urban and rural environments. The results suggested that land traffic emissions were responsible for about 20% of mortality by ambient $PM_{2.5}$ and O_3 in Germany, the U.K. and the U.S.. Globally, land traffic emissions accounted for approximately 5% of mortality. Emissions of NO_x from land traffic were also estimated to be responsible for 5% mortality globally (Lelieveld et al., 2015).

Hoek et al. (2013) conducted a meta-analysis based on epidemiological studies of long-term exposure to $PM_{2.5}$, PM_{10}, nitrogen dioxide (NO_2), and elemental carbon (i.e., NO_2 and elemental carbon are indicators of land traffic emissions) on mortality from all-cause, cardiovascular disease and respiratory disease. The pooled estimate of excess risk per 10 $\mu g/m^3$ increase in $PM_{2.5}$ exposure was 6% for all-cause and 11% for cardiovascular mortality. Long-term exposure to $PM_{2.5}$ was found to be associated with mortality from cardiovascular disease (particularly ischemic heart disease) more than from nonmalignant respiratory diseases. Hoek et al. (2013) also identified heterogeneity in the mortality effect of $PM_{2.5}$ across studies, likely due to differences in particle composition, infiltration of particles indoors, population characteristics, and the exposure assessment methods used for the studies. In addition, all-cause mortality was found to be significantly associated with elemental carbon (6% excess risk per 1 $\mu g/m^3$) and with NO_2 (5% excess risk per 10 $\mu g/m^3$). Limited by the studies available for the meta-analysis, no evidence was found for association between long-term coarse particulate matter (PM_{10}) exposure and mortality.

Although long-term exposure to ambient NO_2 was found to be associated with increased mortality, it was not clear whether NO_2 exerted the mortality effects independently or in combination with other pollutants, such as $PM_{2.5}$. Faustini, Rapp, and Forastiere (2013) conducted a meta-analysis to estimate pooled estimates for the long-term effects of NO_2 and $PM_{2.5}$ on mortality. A random effects analysis differentiating the effects of NO_2 and $PM_{2.5}$ was used for the analysis. The pooled effect of NO_2 on all-cause mortality was 4% excess risk per 10 $\mu g/m^3$ in the annual NO_2 concentration and 5% for $PM_{2.5}$. The effect on cardiovascular mortality was 13% for NO_2 and 20% $PM_{2.5}$. The NO_2 effect on respiratory mortality was 3% and $PM_{2.5}$ 5%. Faustini, Rapp, and Forastiere (2013) concluded that there is a long-term effect of NO_2 on mortality as great as that of $PM_{2.5}$.

2.2 Health Impact Assessment Tools

HIA is a systematic process for identifying and presenting the potential health impacts of proposed public projects, plans and polices in order to formulate recommendations for improvement of public health (National Research Council, 2011). HIA can be applied to evaluate proposals for future developments that can have potential health impacts to the public, such as transportation projects, land use plans, and economic policies (Cole and Fielding, 2007). Conducting HIAs for these future proposals facilitates collaboration across different sectors of the governments and promotes public engagement on issues important to public health (National Research Council, 2011). Applications of HIA in the United States has increased since first being introduced 20 years ago (Dannenberg, 2016). HIAs for a broad range of projects and policies (e.g., housing, energy, labor policies) have been completed in the United States. Morley, Lindberg, Rogerson, Bever, and Pollack (2016) noted that transportation is one of the most active areas of HIA applications.

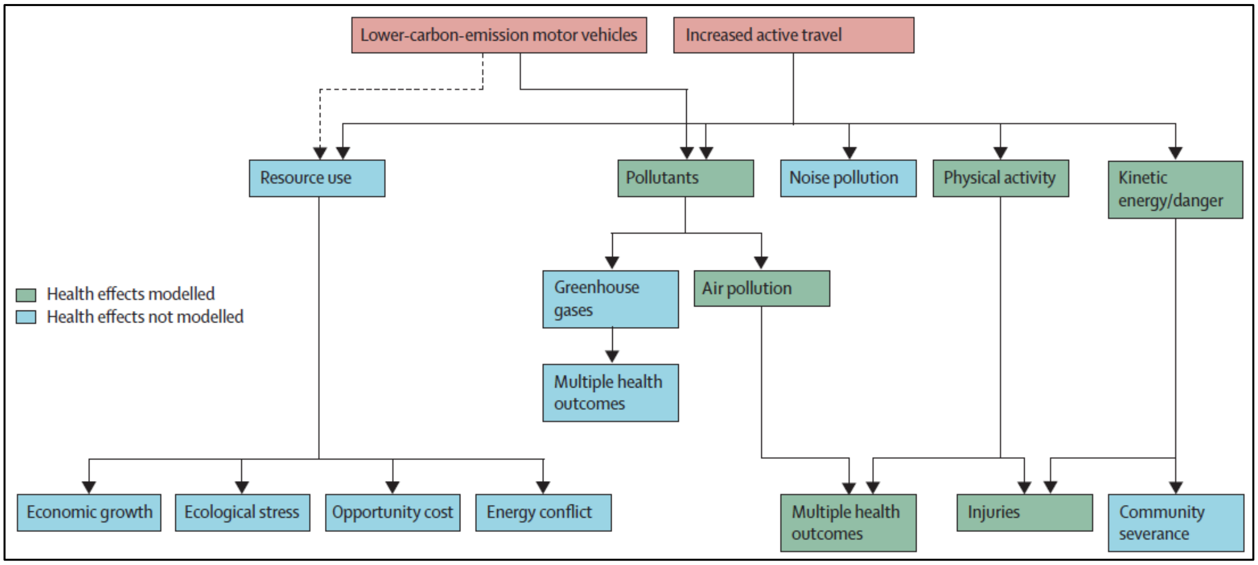
Table 5 summarizes characteristics of four health impact assessment models that had been applied across the world for evaluation of health impacts for active transportation (Karner, Rowangould, Wu, Igbinedion, and London, 2017). Except for the California Public Health Assessment Model (C-PHAM), all models are based on the comparative risk assessment (CRA) methods developed from epidemiological research (Murray, Ezzati, Lopez, Rodgers, and Vander Hoorn, 2003). C-PHAM uses a regression model that relates built environment and demographic variables to health outcomes (SCAG, 2016).

2.2.1 Integrated Transport and Health Impact Tool (ITHIM)

The Integrated Transport and Health Impact Model (ITHIM) is a tool designed to estimate the health impacts of transportation projects through changing levels of physical activity, air pollution, and traffic injuries (Whitfield, Meehan, Maizlish and Wendel, 2017). ITHIM was developed from the work by Woodcock et al (2007) in the United Kingdom for evaluation of strategies to reduce Greenhouse Gas emissions by increasing active transportation. ITHIM's theoretical basis is the method of Comparative Risk Assessment (CRA) (Maizlish et al., 2013), which models a change in disease burden (e.g., mortality) resulting from changes in the exposure distribution from the baseline scenario (i.e., no development) to a project alternative scenario. For transportation projects, it is generally accepted that physical activities, air pollution from vehicular emissions, and injuries from vehicle crashes are the key exposures associated with disease burden attributable to the projects (Woodcock et al, 2007). General relationships between the key exposure and disease burden were obtained from peer-reviewed public health research (Maizlish et al., 2013). Disease burden modeled in ITHIM are presented in four summary measures: total mortality (i.e., deaths per year), premature mortality (i.e., years of life lost), morbidity (i.e., years living with a disability), and disability-adjusted life years (DALYs), which are the sum of years of life lost and years living with a disability. The overall process of an ITHIM evaluation is illustrated in Figure 3.

Table 5 Summary of Health Impact Assessment Models

	Integrated Transport and Health Impact Model (ITHIM)	Health Economic Assessment Tool (HEAT)	California Public Health Assessment Model (CPHAM)	Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA)
Typical spatial scale	County/region	Project/plan	150 m gridcell	Barcelona census tract
Developer/Sponsor	Medical Research Council	World Health Organization	Urban Design 4 Health	US Environmental Protection Agency
Exposure pathways considered	Physical activity from walking and cycling, traffic injuries, air pollution	Physical activity from walking and cycling	Centre for Research in Environmental Epidemiology (CREAL)	Air pollution (particulate matter and ozone)
User Input	Changes in travel activity by mode (aspirational, off-model literature-based estimates, or from travel demand model outputs)	Active travel estimates can be input data from various sources (e.g. travel surveys, observed counts, predictive estimates).	Changes in built environment and transportation characteristics via the Urban Footprint sketch planning tool	Aspirational (compliance with international exposure level recommendations) for all exposure pathways
Built-in data and relationships	Health impacts of physical activity, air pollution (in some calibrations), and collision risks are based on research literature. Region-specific calibrations include baseline health, traffic injury, air quality, and travel behavior data.	Relative risk data are from published studies. Value of a statistical life	Directly estimated from land use and transportation characteristics, demographics, California Household Travel Survey, California Health Interview Survey	Heath impacts of physical activity, air pollution, noise, heat, and access to green space based on research literature. Includes baseline data drawn from the Barcelona Health Survey (PA), land use regression (air quality), Barcelona strategic noise map, central temperature monitor, Urban Atlas (green space)
Outcomes considered	All-cause mortality, disease-specific mortality, disability adjusted life years	All-cause mortality, economic benefits	Prevalence of health outcomes, body mass index, physical activity	All-cause mortality, economic benefits
Methodological approach	Comparative risk assessment	Comparative risk assessment	Direct estimation of health outcomes via regression on urban form, transportation, demographic, and health variables	Comparative risk assessment
Location(s) applied	United Kingdom, United States, India, Brazil, Malaysia	United Kingdom, Spain	California	Barcelona, Spain



Source: Woodcock et al. (2009)

Figure 3 ITHIM modeling process

ITHIM models public participation in physical activity by comparing distributions (i.e., identified from travel survey and health survey data) of weekly physical activity under different scenarios. Walking, cycling and occupational physical activities are combined as Metabolic Equivalent f oTask (MET) hours per week. Health outcomes affected by physical activity participation include cardiovascular diseases, depression, dementia, diabetes, breast cancer, and colon cancer. ITHIM also models health benefits through the all-cause mortality. The effect of changing population physical activity participation on public disease burden is modeled with the comparative risk assessment method (Maizlish et al., 2013).

Traffic injuries are modelled by applying a crash risk model developed from traffic injury data, which describe the relationship among crash incidences, vehicle speeds, and vehicle miles traveled (Woodcock et al., 2007). Differences in risk by gender and age are also included.

Heath impacts from air pollution are modeled by exposure to fine particulate matter ($PM_{2.5}$), which is calculated for the general population and mode specific rates for different transportation modes. The $PM_{2.5}$ exposure changes for population are based on mobile-source emissions predicted by air quality models available for the study area.

ITHIM had been applied in several metropolitan areas in the United States, including San Francisco (Maizlish, Woodcock, Co, Ostro, Fanai, and Fairley, 2013), Los Angeles (Maizlish, 2016), San Diego (Maizlish, 2016), and Sacramento (Karner, Rowangould, Wu, Igbinedion, and London, 2017) in California; Portland in Oregon (Iroz-Elardo, Hamberg, Main, Haggerty, Early-Alberts, and Cude, 2014); and Nashville in Tennessee (Whitfield, Meehan, Maizlish and Wendel, 2017). Results of these ITHIM implementation in the United States demonstrated that health benefits from increased active transportation can be successfully modeled using data sourced from government agencies in the United States (see detailed discussions in section 3).

The earliest operational ITHIM was implemented as a spreadsheet model in Microsoft Excel (Woodcock et al. 2009; Maizlish et al., 2013), which allowed ITHIM to complement regional travel demands by adding a health component for evaluation of strategies for increasing active transportation (Maizlish et al., 2013).

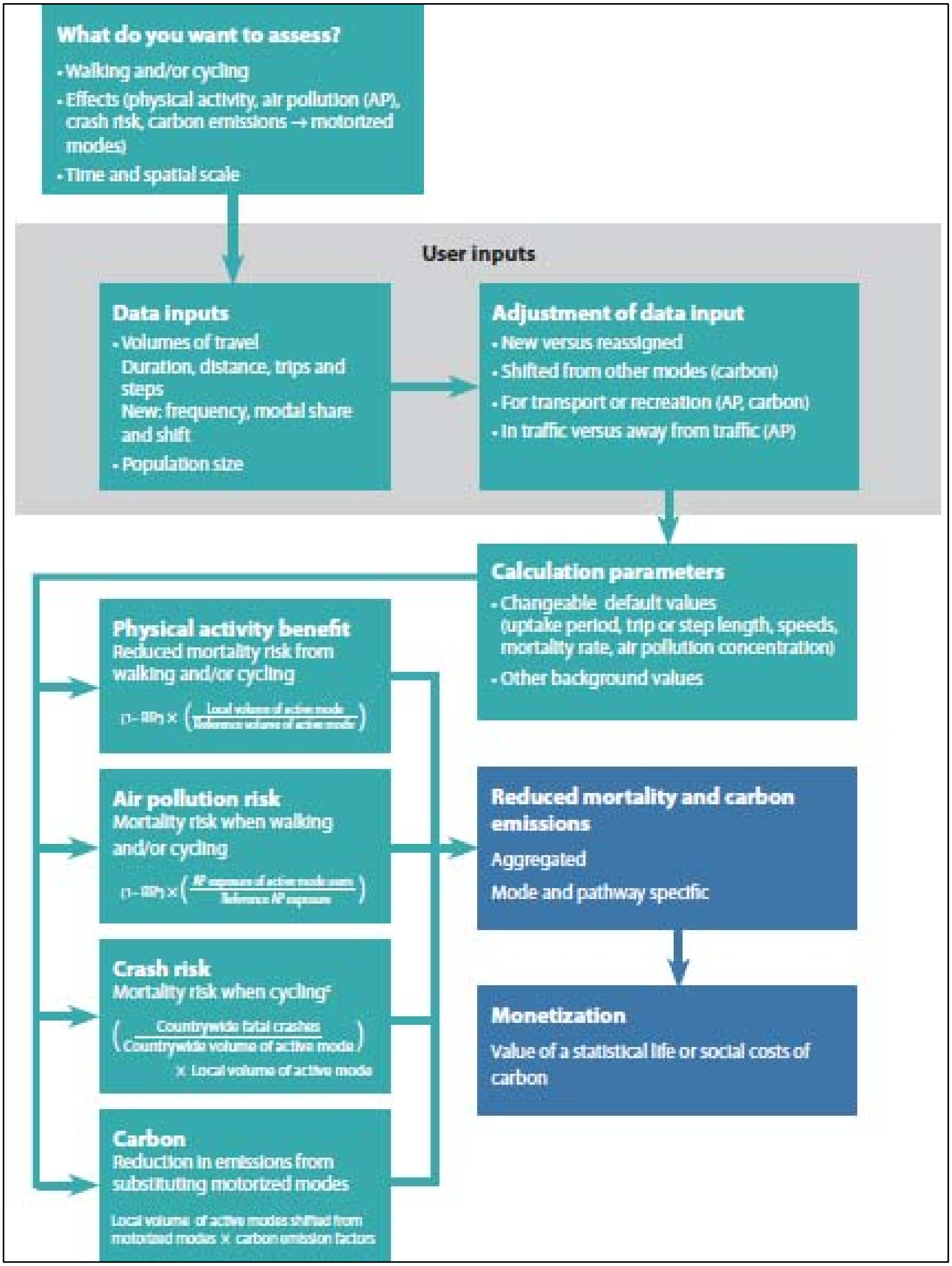
2.2.2 Health Economic Assessment Tool (HEAT)

The development of Health Economic Assessment Tool (HEAT) was sponsored by the World Health Organization (WHO) for economic assessments of the health impacts of walking or cycling (WHO, 2017). Earlier versions of the tool only estimated reduced mortality and associated economic benefits resulting from specified amounts of walking or cycling in a study area. The latest HEAT can also consider health effects from road crashes and air pollution, and effects on carbon emissions (WHO, 2017). Figure 4 shows the modeling process of HEAT.

HEAT applies the same CRA method as ITHIM for evaluation of health benefits from walking and cycling (WHO, 2017). HEAT uses estimates of the relative risk of all-cause deaths among regular cyclists or walkers and compares it with the risk for people who do not cycle or walk regularly. Relative risks for premature deaths or developing certain chronic diseases for those who regularly walk or cycle versus those who do not were derived from meta analyses of published studies.

Because ITHIM and HEAT are both based on the CRA method, the application processes and data requirements are similar between the two. The major difference between ITHIM and HEAT is that HEAT assumes a linear relationship between walking or cycling and mortality, while ITHIM posits a non-linear relationship (WHO, 2017; Maizlish et al., 2013). There are studies (e.g., Woodcock, Franco, Orsini, and Roberts, 2011; Powell et al., 2019) suggesting that the dose–response relationship between physical activity and all-cause mortality is most likely non-linear. However, the meta-analysis carried out for HEAT development (Kelly et al., 2014) showed that differences between various dose–response curves (i.e., linear vs, non-linear) were modest. A linear approximation is often adequate within the foreseen range of activity for analysis with HEAT. In addition, the linear relationship assumption also avoids additional data requirements on baseline activity levels (WHO, 2017).

Existing applications of HEAT were all by European countries (WHO, 2020). There is no HEAT application by any U.S. government agencies.

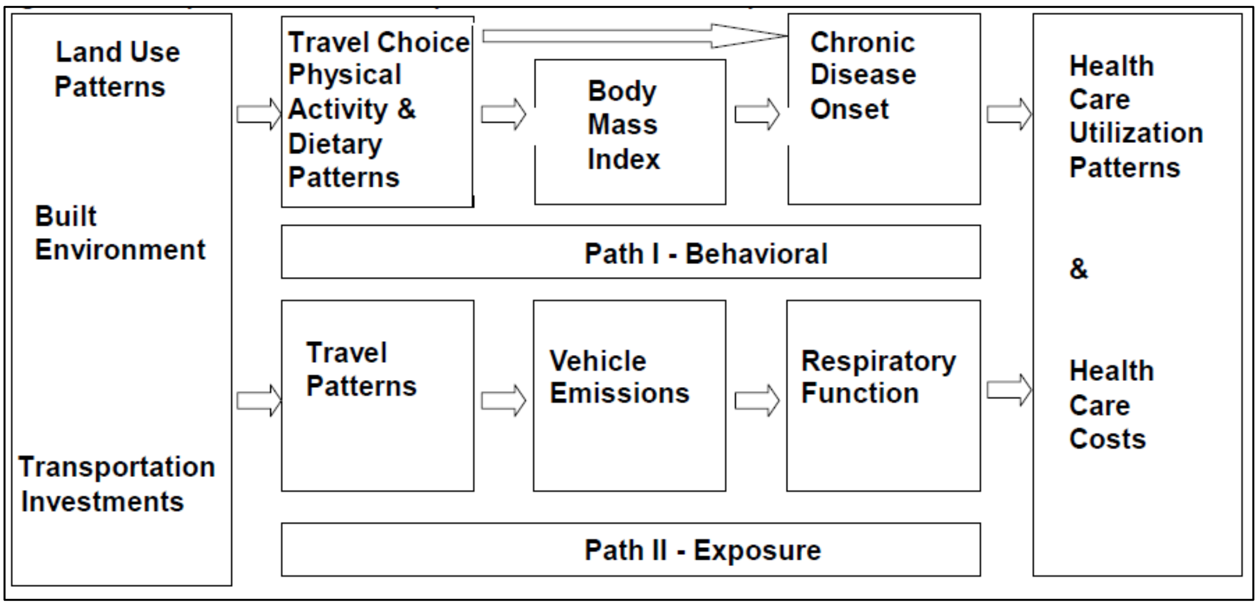


Source: WHO (2017)

Figure 4 The modeling process of HEAT

2.2.3 California Public Health Assessment Model (CPHAM)

The California Public Health Assessment Model (C-PHAM) was developed by Urban Design 4 Health (UD4H) for planning applications in the State of California (SCAG, 2016). C-PHAM was developed with a variety of survey data in California, including land use, socio-demographic, travel behavior, physical activity, and health conditions. These data were used to derive equations that predict health outcomes based on health-related behaviors and built-environment characteristics of the study area (SCAG, 2016). The relationships among these different variables and health outcomes are depicted in Figure 5.



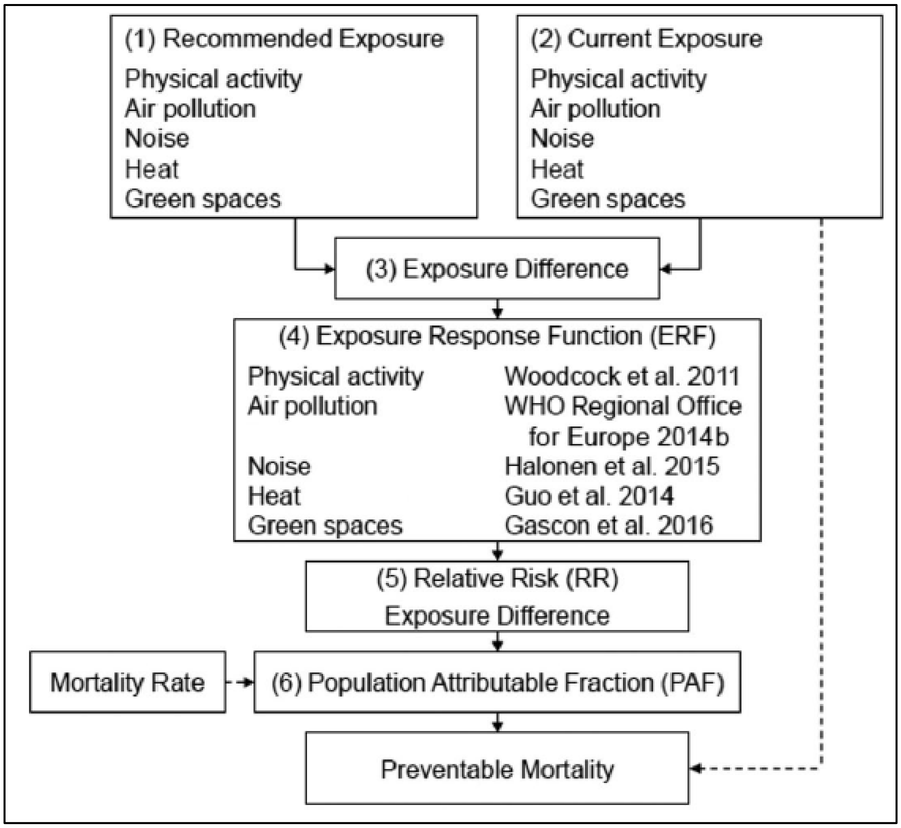
Source: SCAR (2016)

Figure 5 The C-PHAM conceptual model.

The modeling process of C-PHAM consists of two sets of equations. The first set predicts the amount of physical activities that are likely to be induced by specific demographic and land use variables. The second set then relates the predicted physical activity levels to health outcomes such as body mass index, diabetes, high blood pressure, and cardiovascular disease The first set of equations were derived from California Household Travel Survey and the second set California Health Interview Survey (SCAG, 2016). Because the model was based entirely on California data, C-PHAM cannot be applied in any other states in the United States without re-estimating all predictive equations again.

2.2.4 Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA)

The Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) model was developed by European researchers to estimate the mortality burden associated with exposures common to urban living, including physical activity, air pollution, noise, heat, and green spaces (Mueller et al., 2017). UTOPHIA was used for a health impact assessment (HIA) in Barcelona, Spain. Health benefits and economic savings associated with meeting the international recommendations for physical activity participation; exposure to air pollution, noise and heat, and access to green spaces in the city of Barcelona were estimated with UTOPHIA (Mueller et al., 2017). Figure 6 shows the modeling process of UTOPHIA application in Barcelona.



Source: Mueller et al. (2017)

Figure 6 Conceptual framework of the UTOPHIA tool.

UTOPHIA adopted the same CRA methodology as ITHIM and HEAT. The difference in UTOPHIA and the two other models is in the exposure-response functions (i.e., referred to as dose-response in references for the two other models) adopted. In addition to physical activity and air pollution, UTOPHIA also models noise, heat, and green spaces, which are not assessed in the other two models.

2.3. Applications of Health Impact Assessment in the United States

2.3.1 San Francisco Bay Area

In 2006, the State of California enacted legislation (i.e., California Global Warming Solutions Act of 2006) aiming to achieve the goal of reducing greenhouse gas emissions (GHGE) to its 1990 level by 2020 (CARB, 2018). The GHGE reduction goal has been updated every five years. The latest goal, approved in 2017, sets a target of 40 percent emissions reductions below 1990 levels by 2030 (CARB, 2018). Strategies for reducing GHGE include increasing share of low carbon fuel vehicles (i.e., biofuels, advanced diesel, natural gas, hydrogen fuel cells, gas-electric hybrids, and electricity plug-ins) and reducing total vehicle miles traveled in California (CARB, 2020a). In order to reduce vehicle miles traveled, shares of alternative modes, such as public transits, bicycles, and walking, need to be increased in major urban areas in California. Because using these modes for transportation increase physical activity participation, increasing transit and active transportation use can also improve public health.

Maizlish et al. (2013) used ITHIM to quantify potential health benefits of different strategies to reduce transport-related GHGE in the San Francisco Bay Area, California. The area is made up of nine counties surrounding the San Francisco Bay with a population of 7.1 million in 2010. The cities of San Francisco, Oakland, and San Jose are major employment hubs in the area. The Metropolitan Transportation Commission (MTC) is the Metropolitan Planning Organization (MPO) responsible for transportation planning in the area.

2.3.1.1 Data Sources

ITHIM required 14 calibration data items covering underlying disease burdens, travel habits, physical activity participation, air pollution levels, and traffic injuries and fatalities in the study area. Table 6 summarizes the data items and the sources.

Table 6 Sources of Data for ITHIM Implementation in San Francisco Bay Area

Source	Calibration Data Item	Units	Stratification
San Francisco Bay Area Travel Survey 2000 Regional Travel Characteristics (MTC, 2004)	Per capita mean daily travel distance	Miles/person/day	Travel mode
	Per capita mean daily travel time	Minutes/person/day	Travel mode
	Ratio: per capita mean daily active transportation time		Walk, bike, age, and sex
	Standard deviation of mean daily active transportation time	Minutes/person/day	
	Walking speed	Miles/hour	
	Ratio of daily per capita bicycling time to walking time		
	Personal auto travel distance and time	Miles and hours/day	Driver and passenger
MTC's Travel demand model (MTC, 2017)	Vehicle miles traveled (VMT) by facility type	Miles/day	Travel mode and road type
US Census	Distribution of population by age and gender	%	Age and sex
California Health Interview Survey (UCLA, 2008)	Per capita weekly non-travel related physical activity, expressed in Metabolic Equivalent Task (MET) hours	MET-hours/ week	Age and sex
	Age-sex specific ratio of disease-specific mortality rate between the Bay area and USA.		Disease group, age, and sex
	Proportion of colon cancers from all colorectal cancers		

Table 6, continued

Source	Calibration Data Item	Units	Stratification
California Highway Patrol (CHP, 2008) and Transportation Injury Mapping System (SafeTREC, 2020)	Serious and fatal injuries between a striking vehicle and a victim vehicle in road traffic collisions	Injuries	Severity, striking mode, victim mode, and road type
EMFAC 2007 (CARB, 2020b)	Emissions of $PM_{2.5}$ attributable to light-duty vehicles	Tons/day	

2.3.1.2 *Analysis Scenarios*

The *Business-as-usual* (BAU) scenario corresponded to 2035 population and Vehicle Miles Traveled (VMT) projection in MTC's 2035 long-range transportation plan. This scenario assumed that certain level of improvement to passenger vehicles carbon emission rates would result by 2035 from incrementally improved fuel economy. The *Low-carbon driving* (LCD) scenario assumed the same VMT as the BAU scenario. Carbon emissions by automobiles and light trucks (i.e., light-duty vehicles) were assumed to be lower than in other scenarios owing to increased adoption of LCD fleets, including gas-electric hybrid vehicles and light-duty diesel, biofuel, and electric plug-in vehicles.

Two active transportation scenarios (*short trip* and *carbon and physical activity goal*) assumed the same total travel distances by all modes as the BAU scenario while assuming increased shares in active transportation. The *short trip* (ST) scenario assumed a shift of 50% of BAU miles traveled in automobiles for less than 1.5 miles to walking and 50% of BAU miles traveled in automobiles for 1.5 to 5 miles to bicycling. The 2000 Bay Area Travel Survey identified that 24% of car trips in the area were less than 1.5 miles and 33.8% were between 1.5 and 5 miles. The *carbon/physical activity goal* (C/PAG) scenario optimized both physical activity participation and vehicular CO_2 emission reductions by setting the time for participation in walking and bicycling to the median commute times identified in the journey to work data of the American Community Survey for the San Francisco Bay area (U.S. Census Bureau, 2020).

To estimate CO_2 emissions for all scenarios, the amount of CO_2 emissions for a 2010 baseline scenario corresponding to MTC's 2035 long-range transportation plan was first estimated using MTC's travel demand model (Brazil and Purvis, 2009). To determine CO_2 emission reductions for the BAU and LCD scenarios, percent reductions of CO_2 emissions estimated by Lutsey (2010) for low-carbon vehicles were applied to the baseline CO_2 emissions based on the shares of low-carbon vehicles assumed in the BAU and LCD scenarios. For the active transport scenarios, estimation of CO_2 emissions was based on the reduced annual vehicle miles resulting from increases in active transport miles assumed for the scenarios. For each active transport scenario, only VMT of light-duty vehicles (i.e., passenger cars and light trucks) were changed, holding constant for VMT for all other vehicle classes and estimates for nonmobile sources. Table 7 shows the assumed per capita daily travel time, travel distances, and the estimated region-wide % reduction in CO_2 emissions for the four analysis scenarios.

Table 7 Per Capita Daily Travel Distances and Times and Region-wide Percent Reduction in Carbon Dioxide Emissions

Scenario	Travel Time, Min/D, Median		Travel Distance,[a] Miles/D, Mean			Reductions in Carbon Emissions,[c] %
	Walk	Bicycle	Walk	Bicycle	Car[b]	
Business as usual	3.7	0.7	0.35	0.17	22.6	-16.5
Low-carbon driving	3.7	0.7	0.35	0.17	22.6	-33.5
Short trips	6.4	6.0	0.63	1.58	20.9	-0.7
Carbon/physical activity goal	11.3	10.7	1.10	2.74	16.6	-14.5

[a]Other modes and total distance mi/person/d: bus = 0.62; rail = 0.79; heavy good vehicles = 1.0; total = 25.6.
[b]Passenger vehicles include automobiles, light trucks, and motorcycles
[c]2000 baseline of 27.9 million metric tons of carbon dioxide.

Source: Maizlish et al. (2013)

2.3.1.3 Analysis Results

Table 8 shows the ITHIM predicted health benefits of the two active transportation scenarios. The numbers of change in burden of disease and the % attributable benefits are both compared to the corresponding numbers of the BAU scenario. Table 9 shows the comparison of benefits between the LCD and C/PAG scenarios.

Compared with the BAU scenario, the ITHIM model for the C/PAG scenario predicted a reduction in the number of premature deaths by 2,404 and a reduction of 44,866 total DALYs (i.e., the sum of years of life lost and years living with disability) per year (see Table 8). The burden resulting from road traffic injuries increased for the ST scenario by 11% (3,320 DALYs) and 19% (5,907 DALYs) for the C/PAG scenario, compared with BAU, as a result of an increase in collisions involving cars, bicyclists, and pedestrians.

Compared with LCD, the C/PAG scenario had the larger net decrease in total disease (see (Table 9). The reduced $PM_{2.5}$ concentrations associated with LCD compared with BAU resulted in 22 (1%<) premature deaths and 232 (1%<) years of life lost as a result of cardiovascular diseases, lung cancer, and nonmalignant respiratory diseases, suggesting the relatively smaller risk for these diseases from $PM_{2.5}$ exposure when compared with physical inactivity.

The ITHIM implementation in the Bay area demonstrated that active transportation has the potential to substantially lower both the carbon emissions and burden of disease. By committing to a modal shift in favor of active transportation with LCD technologies, a significant level of GHGE reduction goals can be achieved with better public health status for a region. It also demonstrated that ITHIM can be used with a regional travel demand model to estimate and predict the health benefits associated with proposed transportation projects and/or long-range transportation plans for the region.

It is important to note that the presentation of estimated health benefits unrealistically assumed that the reductions in premature deaths and DAYLs occur in the planning horizon year (e.g., 2035). However, the achievement of health benefits such as reduction in the prevalence of chronic diseases from increased physical activities requires some time to manifest in the population. In future implementations of ITHIM. According to WHO (2017), based on expert consensus, five years is a reasonable assumption for newly initiated physical activities to reach full benefits, with an increase of 20% each year.

Table 8 Predicted Annual Change in Burden of Disease From Physical Activity and Road Traffic Injuries Compared With Business as Usual

	Change in Burden of Disease		Attributable Fraction (%)	
Cobenefit Source by Cause[a]	Short Trips	Carbon Goal	Short Trips	Carbon Goal
Physical Activity				
Premature deaths				
Cardiovascular disease	-1195	-1985	-8.5	-13.4
Diabetes	-122	-189	-8.6	-13.3
Dementia	-121	-218	-5.4	-9.6
Breast cancer	-31	-48	-3.1	-4.9
Colon cancer	-31	-53	-3.2	-5.6
Depression	-1	-1	-4.1	-7.4
Total	-1501	-2404	-3.0	-4.8
Years life lost				
Cardiovascular disease	-13 842	-21 503	-9.5	-14.8
Diabetes	-1902	-2961	-9.3	-14.4
Dementia	-808	-1387	-5.6	-9.6
Breast cancer	-614	-955	-3.3	-5.1
Colon cancer	-427	-728	-3.2	-5.5
Depression	-7	-11	-4.4	-7.5
Total	-17 600	-27 545	-2.4	-3.8
Years living with disability				
Cardiovascular disease	-2726	-4295	-9.9	-15.2
Diabetes	-2303	-3707	-9.4	-15.1
Dementia	-2414	-4029	-5.8	-9.6
Breast cancer	-158	-250	-3.2	-5.0
Colon cancer	-98	-166	-3.2	-5.5
Depression	-2703	-4784	-3.2	-5.7
Total	-10 402	-17 321	-1.7	-2.9
Injuries				
Deaths	61	113	9	17
Years life lost	2456	4524	9	17
Years living with disability	864	1382	19	31
Disability-adjusted life years	3320	5907	11	19

Source: Maizlish et al. (2013)

Table 9 Predicted Annual Health Benefits by Source of Benefits and Scenarios Compared With Business as Usual

	Counts			Rate per Million Population		
Risk Factor or Burden	LCD	Active Transport, C/PAG	LCD + C/PAG	LCD	Active Transport, C/PAG	LCD + C/PAG
Physical activity						
Premature deaths	0	-2404	-2404	0	-319	-319
YLL	0	-27 544	-27 544	0	-3653	-3653
YLD	0	-17 231	-17 231	0	-2285	-2285
DALYs	0	-44 776	-44 776	0	-5939	-5939
Air pollution ($PM_{2.5}$)						
Premature deaths	-22	-9	-29	-3	-1	-4
YLL	-232	-101	-317	-31	-13	-42
YLD	0	0	0	0	0	0
DALYs	-232	-101	-317	-31	-13	-42
Road traffic crashes						
Premature deaths	0	113	113	0	15	15
YLL	0	4524	4524	0	600	600
YLD	0	1382	1382	0	183	183
DALYs	0	5907	5907	0	783	783
Total						
Premature deaths	-22	-2300	-2321	-3	-305	-308
YLL	-232	-23 121	-23 337	-31	-3067	-3095
YLD		-15 849	-15 849	0	-2102	-2102
DALYs	-232	-38 971	-39 186	-31	-5169	-5197

Source: Maizlish et al. (2013)

2.3.2 Nashville Area Metropolitan Planning Organization

The Nashville Area Metropolitan Planning Organization (NAMPO) oversees transportation planning in a region of seven counties in north central Tennessee (TN), which has approximately 1.5 million residents with the city of Nashville being the capital of Tennessee. With 62% of adults failing to meet the physical activity guidelines (i.e., at least 150 minutes of moderate-intensity aerobic physical activity or 75 minutes of vigorous-intensity physical activity per week) of the United States Center of Disease Control and Prevention (CDC), the state of Tennessee ranks second in the U.S. for adult inactivity (CDC, 2016). In addition, 37% of adult Tennessee residents are overweight (ranked third among states) and 29% are obese (ranked 15th among states) (CDC, 2016). The NAMPO has recognized the potential for transportation to address these health issues and is actively engaging in the planning and implementation of active transportation (i.e., walking and bicycling) in the region (Meehan and Whitfield, 2017). The NAMPO has officially included elements of Complete Streets design standards as one of its project selection criteria. The NAMPO has also set up dedicated funding for active transportation and public transit-related projects. In the planning phase of these projects, NAMPO used ITHIM to evaluate the potential economic and health benefits of the projects (Whitfield et al., 2017). The results of ITHIM analyses are then used to educate stakeholders and the general public on the relationship between transportation and health.

2.3.2.1 Data Sources

Table 10 list the data items used for NAMPO's implementation of ITHIM.

Table 10 Data Sources for ITHIM Implementation by NAMPO

Source	Calibration Data Item	Units	Strata
Middle TN Transportation and Health Study	Per capita mean daily travel distance	Miles/person/day	Travel mode
	Per capita mean daily travel time	Min/person/day	Travel mode
	Ratio: per capita mean daily active transportation time(reference group: females aged 15–29 years)	Dimensionless	Walk, bike, age, sex
	Standard deviation of mean daily active transportation time	Min/person/day	None
	Walking speed	Miles/hour	None
	Ratio of daily per capita bicycling time to walking time	Dimensionless	Bicycle, walk
	Personal auto travel distance and time	Miles and hours/day	Driver, passenger
Travel Demand Model	Vehicle miles traveled (VMT) by facility type	Miles/day	Travel mode and road type4
US Census	Distribution of population by age and gender	%	Age, sex
NHANES	Per capita weekly non-travel related physical activity	MET-hours/week	Median of quintile of walk +bicycle METs, by age and sex
TN Department of Health	Age-sex specific ratio of disease-specific mortality rate between Nashville metro and USA.	Dimensionless	Disease group5, age, sex
	Proportion of colon cancers from all colorectal cancers	Dimensionless	None
TN Department of Safety	Serious and fatal injuries between a striking vehicle and a victim vehicle in road traffic collisions	Injuries	Severity, striking mode x victim mode, road type
TN Department of Environment and Conservation	Emissions of PM2.5 attributable to light-duty vehicles	Tons/day	None

Source: Whitfield et al. (2017)

The Middle Tennessee Transportation and Health Study (MTTHS) was NAMPO's regional household travel survey conducted in 2012 (Lee et al., 2013). The MTTHS contained questions for residents in the MPO area regarding the origins, destinations, purposes, travel modes (including walking and cycling), start time, and end time of all trips in a 24-hour period. The travel distance between a pair of origin and destination was estimated with recommend travel route on Google Maps (Whitfield et al., 2017). Vehicle miles traveled by roadway types were obtained from the NAMPO's travel demand models.

The 2010 US Census provided data for the study area population by age and sex. Participation in non-travel related physical activities (i.e., leisure, domestic, and occupational physical activity) were obtained from the National Health and Nutrition Examination Survey 2011–2012 (CDC, 2013). The most recent (2008-2010) mortality data for all diseases in the study area were provided by the Tennessee Department of Health (Whitfield et al., 2017). Table 11 shows the specific disease groups modeled in ITHIM by the International Classification of Diseases, version 10 codes (ICD-10).

Table 11 Diseases included in the ITHIM model and their respective ICD-10 codes

Condition	ICD-10 Code(s)
Cancers	
Breast	C50
Colorectal	C18–C21
Trachea, bronchus, and lung	C33–C34
Cardiovascular diseases	
Hypertensive heart disease	I10–I13
Ischemic heart disease	I20–I25
Inflammatory heart disease	I30–I33, I38, I40, I42
Cerebrovascular disease	I60–I69
Alzheimer's and other dementias	F01, F03, G30–G31
Depression (Unipolar depressive disorders)	F32–F33
Road traffic injuries	V01–V89, Y85
Respiratory conditions	
Lower and upper respiratory infections	J00–J06, J10–J18, J20–J22
COPD, asthma, other respiratory diseases	J30–J39, J40–J98

Source: (Whitfield et al., 2017)

Three-year average mortality rate by age and sex was calculated for each disease condition. Traffic injuries and fatalities by roadway types (local, arterial, and highway) and by the modes involved (opposing and victim vehicle) for 2010–2012 were provided by the Tennessee Department of Safety. Injuries and fatalities resulted from collision between pedestrians and bicycles were not included as these accidents were not typically recorded in accident reports (Whitfield et al., 2017). The Tennessee Department of Environment and Conservation provided average annual $PM_{2.5}$ (particulate matter smaller than 2.5 micrometers in diameter) concentrations and the estimated proportion of regional $PM_{2.5}$ from light-duty vehicles.

To estimate economic cost saving associated with reduced injuries and chronic disease incidence, published US estimates of the direct costs of treatment and indirect costs of lost worker productivity for relevant medical conditions were compiled from various references (Table 12). Nashville-specific costs were then calculated by multiplying the national estimates with the proportion (0.48%) of the US population living in NAMPO area (Whitfield et al., 2017). The Nashville-estimated costs were then multiplied by the ITHIM-predicted change in disease burden to arrive at the estimated change in cost for each condition.

Table 12 Conditions Included in the Economic Benefits Calculations and Estimated National Cost of the Conditions

Condition	Base Year	National Cost of Illness, Base Year ($, millions)	Inflation factor	National Cost of Illness, 2012 ($, millions)	References
Cancers					
Breast	2010	27,379	1.05	28,748	(Bradley et al., 2008; Mariotto et al., 2011)
Colorectal	2010	26,942	1.05	28,289	(Bradley et al., 2008; Mariotto et al., 2011)
Lung	2010	51,073	1.05	53,627	(Bradley et al., 2008; Mariotto et al., 2011)
Cardiovascular					
Stroke	2007	40,900	1.11	45,399	(Roger et al., 2011)
Heart disease	2007	177,500	1.11	197,025	(Roger et al., 2011)
Respiratory					
Asthma	2007	56,000	1.11	62,160	(Barnett and Nurmagambetov, 2011)
Mental Illness					
Dementia	2010	172,000	1.05	180,600	(Wimo and Prince, 2010)
Depression	2000	83,100	1.33	110,523	(Greenberg et al., 2003)
Other					
Diabetes	2007	174,000	1.11	193,140	(American Diabetes, 2008)
Traffic Injuries	2005	99,319	1.18	117,196	(Naumann et al., 2010)

Source: (Whitfield et al., 2017)

2.3.2.2 Analysis Scenarios

To estimate the health impacts of increasing amount of walking and bicycling for transportation in the region, NAMPO created three analysis scenarios (conservative, moderate, and aggressive), each with progressively higher average active transportation (walking and bicycling) participation, while holding total miles traveled by all modes constant (see Table 13). It's noted that the miles of walking and bicycling of the aggressive scenario correspond to the minimum physical activity recommendation (i.e., at least 150 minutes per week of moderate-intensity aerobic physical activity) in the 2008 Physical Activity Guidelines of US Department of Health and Human Services (2008). A fourth scenario, injury-neutral, was created to determine the reduction in vehicle miles that would be needed to offset additional injuries and fatalities incurred by increasing the average weekly walking and bicycling per person by 1 mile each.

2.3.2.3 Analysis Results

With the assembly of data as described above, NAMPO calibrated the ITHIM model for the MPO region. Results of the model runs for the baseline and the four analysis scenarios are shown in Table 13.

Table 13 NAMPO ITHIM Analysis Scenarios and Results

	Baseline	**Conservative**	**Moderate**	**Aggressive**	**Injury-neutral**
Per capita miles per week					
Walk	0.7	1.7	3.7	5.7	1.7
Bike	0.3	1.0	1.5	3.0	1.3
Vehicles	195.9	194.2	191.6	188.1	175.1
Driver	151.8	150.5	148.5	145.8	142.9
Passenger	44.1	43.7	43.1	42.3	32.2
Total1	225.0	225.0	225.0	225.0	206.2
Per capita minutes per week					
Walk	18.4	37.8	82.2	126.7	37.8
Bike	2.6	8.0	12.0	24.0	10.4
Vehicles	418.1	414.6	409.2	401.7	373.7
Driver	324.0	321.3	317.1	311.3	305.1
Passenger	94.1	93.3	92.1	90.4	68.6
Total2	494.5	515.7	558.8	607.8	477.3
Results-DALYs					
Chronic Diseases		1,124	2,793	4,375	1212
Injuries / Fatalities		−552	−1,240	−1,733	1
Net Change		572	1,552	2,642	1213
Results-Deaths					
Chronic Diseases		38	109	165	41
Injuries / Fatalities		−14	−31	−43	−2
Net Change		24	71	123	39
Economic Cost Savings (Millions)		$10	$32	$63	$46

Source: (Whitfield et al., 2017)

For the conservative scenario, ITHIM predicted 38 deaths avoided due to reduction in chronic disease incidence (1.1% reduction in diabetes and 1.0% in cardiovascular disease) (Whitfield et al., 2017). However, 14 additional traffic fatalities incurred as a result of increasing walking and bicycling, resulting in a net 24 deaths averted per year for the conservative scenario. The estimation of DALYs shows a net improvement of 572 averted DALYs. After multiplying the chronic disease and injuries/fatalities estimates with the economic cost estimates (see Table 12), approximately $10 million was predicted to be saved through decreased direct healthcare expenses and indirect productivity losses. Whitfield et al. (2017) noted that ITHIM results in all analysis scenarios revealed that the economic benefits of increasing active transportation attained through increased physical activity were significantly greater than the benefits attained from reduced air pollution.

Under the moderate scenario, the predicted benefits also outweighed the predicted harms with net reduction of 71 deaths and 1552 DALYs avoided per year (see Table 13). The cost estimates for the moderate scenario suggested a saving of $32 million in direct and indirect costs. The aggressive scenario resulted in a net decrease of 123 deaths and 2,642 averted DALYs per year. The economic cost savings of the aggressive scenario was estimated to be $63 million in direct and indirect costs.

For the injury-neutral scenario, after an increase in both walking and bicycling of 1.0 mile per person per week, the analysis suggested that an 11% decrease in vehicle miles per person per week (175.1 versus 195.9 miles per week, Table 4) would offset the DALYs incurred by increased pedestrian and bicyclist injuries and fatalities. With this amount of reduction in vehicle miles, the analysis suggested that 1,212 DALYs could be avoided due by reducing chronic disease incidence and 1 DALY could be averted due to reduced injuries and fatalities. The estimated economic cost savings for this scenario was approximately $46 million.

ITHIM implementation in Nashville was one of several steps that NAMPO had taken to improve public health through transportation planning. NAMPO's decision in running ITHIM was to quantify and present the health benefits of active transportation to the stakeholders and the general public. Whitfield et al. (2017) noted that ITHIM outputs were well-received and the results were included in the NAMPO 2040 Regional Transportation Plan. As a result, sidewalk mileage in NAMPO region increased by 57 percent, bikeway mileage by 19 percent, and greenway mileage by 36 percent between 2009 and 2014 (NCHRP, 2019).

2.3.3 Sacramento Area Council of Governments

Similar to the San Francisco Bay Area and NAMPO implementations, most existing implementations of ITHIM involved aggregate analyses for a region (Wu, Rowangould, London, and Karner, 2019). Aggregated regional results are not able to show potential health disparities that may occur to certain population groups in the region. Wu et al. (2019) conducted a study that explicit modeled the potential health impacts of transportation projects and plans on population subgroups in a region. They used ITHIM to assess health equity of transportation plans in the Sacramento Area Council of Governments (SACOG) region for population groups with different race/ethnicity mixes and income levels. The SACOG region consists of six counties surrounding the city of Sacramento, the capital of California. SACOG, being the MPO for the region, developed and maintained the regional travel demand model SACSIM15, which is an activity-based model that simulates the travel behaviors of the region on a disaggregated basis (SACOG, 2015).

Wu et al. (2019) used ITHIM to evaluate the health benefits resulting from changes in physical activity and traffic injury that will result from future alternative scenarios under SACOG's 2016 Metropolitan Transportation Plan and Sustainable Communities Strategy (MTP/SCS) (SACOG, 2016). SCS is as a component of regional long-range transportation plans (RTPs) required by California Senate Bill 375 (SB 375), under which SACOG's 2016 MTP/SCS was required to demonstrate viable plans to achieve per-capita reductions in future GHG emissions by changing residents' travel behaviors (e.g., shifting car trips to public transits and active transportation) (SACOG, 2016). In the physical activity module of ITHIM, modeling of health outcomes and changes in travel behavior were disaggregated by age-gender-race/ethnicity and age-gender-income categories. Due to data limitation, the traffic injury health benefits were disaggregated for only two race/ethnicity groups (i.e., non-Hispanic white and people of color, which includes Black, Hispanic, and other residents). Analysis of health benefits from air pollution reduction was not performed for the SACOG study.

2.3.3.1 Data Sources

Table 14 shows the data items and sources for ITHIM SACOG implementation.

Rather than obtaining travel behavior data from regional travel surveys like the implementations in San Francisco Bay Area and NAMPO, Wu et al. (2019) sourced travel behavior data from SACSIM15, which is an activity-based model built and calibrated to produce disaggregate travel data at the individual level (SACOG, 2015). SACSIM15 outputs for the 2016 MTP/SCS were used to estimate the average active transportation (walking and cycling) time (i.e., minutes per day) and average distance (i.e., miles per day) for each demographic group for all analysis scenarios. VMT outputs from SACSIM15 for each travel mode was estimated.

Health data for all-cause mortality statistics were obtained from the California Department of Public Health (CDPH) vital records data and statistics (CDPH, 2020). Average annual all-cause mortality rates by age-sex-race/ethnicity and age-sex income level categories were calculated for each county in the SACOG region. Due to small African-American population in some counties, annual all-cause mortality rate for the Black population is only available for the entire region rather than for each county. The U.S. disease burden data for all age-sex categories were derived from the Global Burden of Disease (GBD) database (Institute for Health Metrics and Evaluation, 2017). The California Health Interview Survey (UCLA, 2012) data were used to identify characteristics of non-transport physical activities for residents of SACOG. MET-hours per week are calculated for occupational and exercise physical activity (non-travel METs) in the same way as the San Francisco Bay Area study by Maizlish et al. (2013).

Table 14 Data Sources for ITHIM SACOG Implementation

Source	Calibration Data Item	Units	Stratification
Sacramento Activity-Based Travel Simulation Model (SACSIM15) (SACOG, 2015)	Per capita mean daily travel distance	Miles/person/day	Travel mode
	Per capita mean daily travel time	Minutes/person/day	Travel mode
	Ratio: per capita mean daily active transportation time		Walk, bike, age, and sex
	Standard deviation of mean daily active transportation time	Minutes/person/day	
	Walking speed	Miles/hour	
	Ratio of daily per capita bicycling time to walking time		
	Personal auto travel distance and time	Miles and hours/day	Driver and passenger
	Vehicle miles traveled (VMT) by facility type	Miles/day	Travel mode and road type
US Census	Distribution of population by age and gender	%	Age and sex
California Health Interview Survey (UCLA, 2008)	Per capita weekly non-travel related physical activity, expressed in Metabolic Equivalent Task (MET) hours	MET-hours/week	Age and sex
	Proportion of colon cancers from all colorectal cancers		
California Department of Public Health (CDPH) Vital Records Data and Statistics (CDPH, 2020)	Age-sex specific ratio of disease-specific mortality rate between the SACOG area and USA.		Disease group, age, and sex
Transportation Injury Mapping System (SafeTREC, 2020)	Serious and fatal injuries between a striking vehicle and a victim vehicle in road traffic collisions	Injuries	Severity, striking mode, victim mode, and road type

Source: Wu et al. (2019)

Traffic injury data for the Sacramento region were obtained from the Transportation Injury Mapping System from the Statewide Integrated Traffic System (SWITRS) geocoded by University of California, Berkeley Safety Transportation Resource and Education Center (SafeTREC, 2020). Due to data limitation, mortality and disease burden of traffic injures can only be disaggregated by race/ethnicity categories without income level differentiation.

To perform equity analysis, travel behavior and health data for each race/ethnicity group and household income group are required (Wu et al., 2019). Due to unavailability of race/ethnicity and income variables in required datasets, the hot deck imputation method (D'Orazio et al., 2006), a type of data fusion, was used to synthesize the missing variables. The hot deck imputation method synthesized the race/ethnicity statistics for the entire SACOG region based on the limited number of samples in the 2012 American Community Survey Public Use Microdata Sample (ACS PUMS) and SACSIM15 as the recipient. Hot deck imputation was performed for the race/ethnicity variable in travel behavior data and mortality rate variables in health data.

2.3.3.2 *Analysis Scenarios*

Three unadopted future alternatives (i.e.,S1, S2, and S3) documented in SACOG's 2016 MTP/SCS were evaluated for the planning horizon year of 2036. The scenarios vary by the amount of investment in facilities for automobile vs. alternative transportation (i.e., public transit and active transportation) and by development densities for residential units and employment. For the MTP/SCS plan adopted in 2016, evaluation for future impacts was performed for year 2020, 2027, and 2036 to see how health benefits are expected to progress over the years. A detailed comparison of the alternatives and the adopted plan is shown in Table 15.

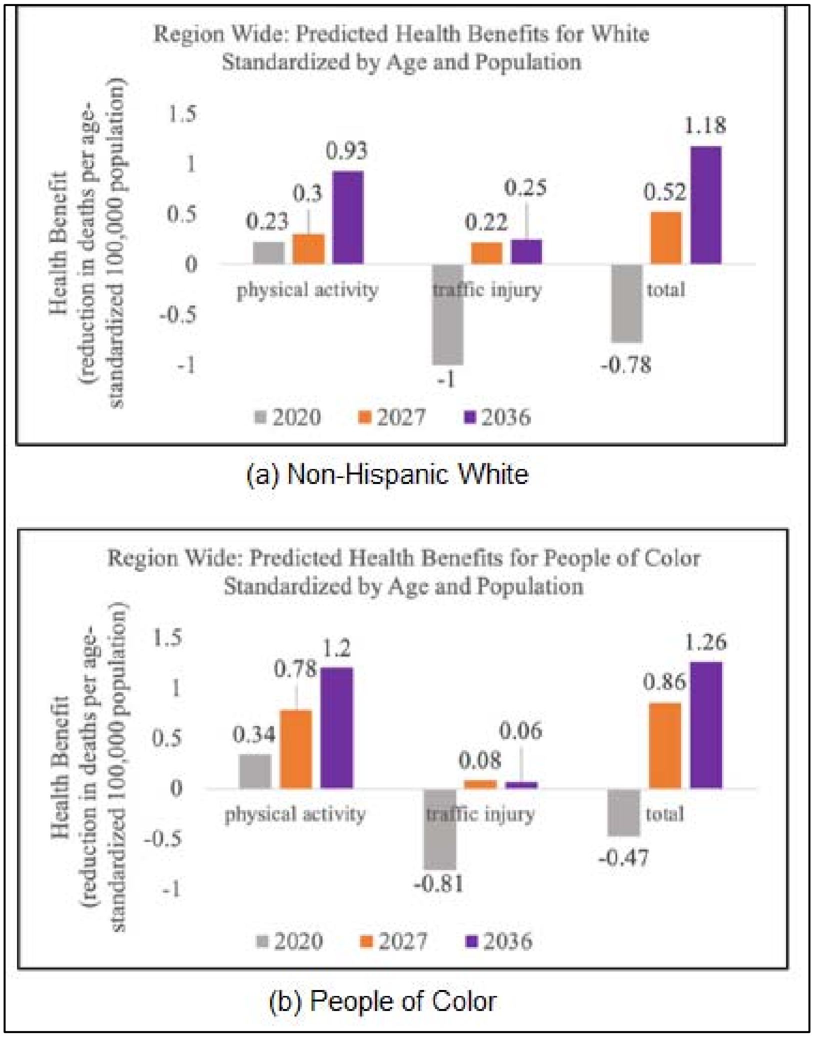
Table 15 SACOG 2016 MTP/SCS Alternatives and Adopted 2016 Plan

Transportation inputs	S1	S2	S3	Adopted 2016 plan
New or expanded roads (lane miles, percent increase from 2008)	34%	31%	25%	32%
Transit service (vehicle service hours, percent increase from 2008)	54%	88%	127%	98%
Funding for maintaining and operating the road and highway ($ in billions)	$10.9	$11.5	$11.0	$11.5
Funding for maintaining and operating the transit system ($ in billions)	$7.5	$7.9	$9.6	$7.9
Funding for bike and pedestrian routes, trails and paths ($ in billions)	$2.8	$2.8	$3.0	$2.8
Funding for new or expanded bus and light rail lines ($ in billions)	$3.2	$3.4	$4.1	$3.4
Land use inputs	**S1**	**S2**	**S3**	**Adopted 2016 plan**
Share of growth in "Center and Corridor Communities"				
Percent of new homes	20%	31%	36%	30%
Percent of new jobs	27%	36%	35%	29%
Share of growth in "Established Communities"				
Percent of new homes	29%	25%	27%	26%
Percent of new jobs	57%	49%	53%	52%
Share of growth in "Developing Communities"				
Percent of new homes	47%	42%	36%	42%
Percent of new jobs	15%	14%	12%	18%

Source: Wu et al. (2019)

2.3.3.3 *Analysis Results*

Figure 7 shows the results of region-wide predicted health benefits from both physical activity and traffic injury under the adopted 2016 plan for non-Hispanic white and people of color. Figure 8 shows the comparison of region-wide predicted health benefits of the three future alternatives compared with base year 2012.

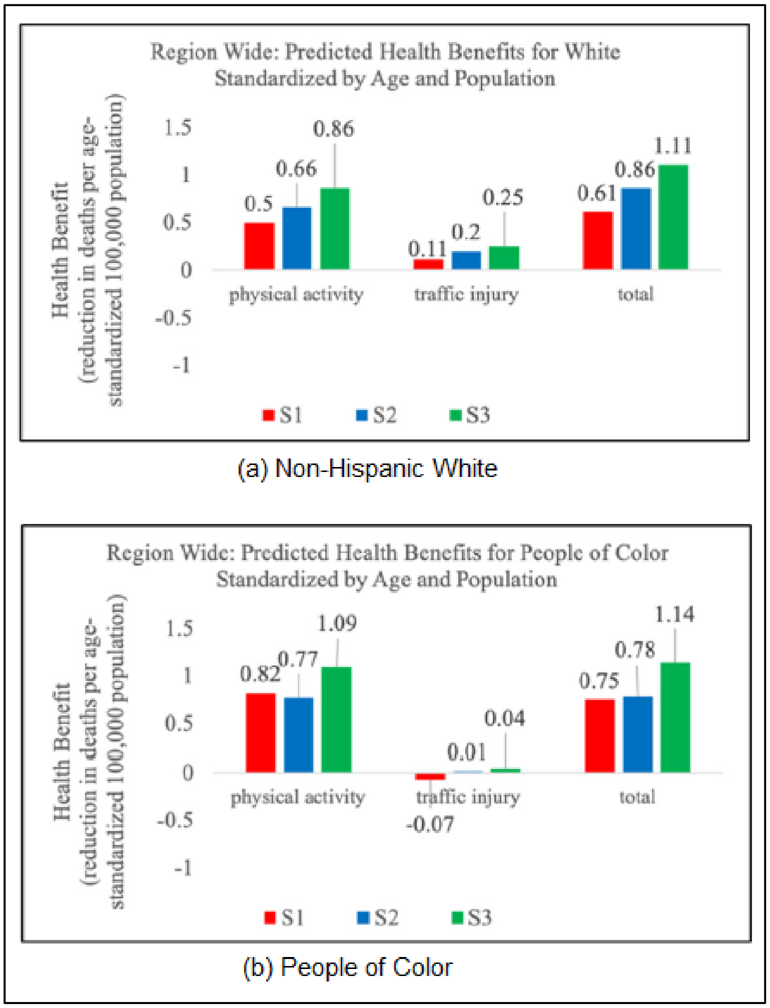


Source: Wu et al. (2019)

Figure 7 Predicted health benefits of the adopted 2016 MTP/SCS from physical activity and traffic injury compared with baseline year 2012.

It can be seen in Figure 7 that both race groups exhibit a negative value in premature death reduction in 2020, which is caused by predicted increase in traffic injuries from increased non-motorized travel distances from 2012 to 2020. For 2027 and 2036, reductions in premature deaths are predicted for both physical activity and traffic injury, because that active travel time increases and motorized travel distance decreases. The reduction in premature deaths from increased physical activities (i.e., reduction in chronic disease incidence) exceeds deaths due to traffic injuries for the years 2027 and 2036. Thus, the net effect is an overall reduction in premature death for 2027 and 2036.

For three alternative scenarios in **Error! Reference source not found.**, non-Hispanic white population shows increasing health benefits for all categories (physical activity, traffic injury, and total) from S1 to S2 and S3, resulting from increased active transportation time and distance. However, for people of color, the reduction in premature deaths from physical activity in S1 is larger than S2, although the overall active travel time in S1 is actually smaller than S2. This is caused by the larger portion of older adults in the people of color category than in the non-Hispanic white category. If a subcategory that exhibits an increase in active travel has a high baseline health burden (e.g., older adults) it will affect the estimated health outcome more than age/gender subgroups with a lower baseline health burden (e.g., younger generations). If the health benefits of the entire region were aggregated, the difference in health benefits or costs for subgroups of the population cannot be discovered. Such results demonstrate the value of performing health impacts assessment for different subgroups of the population.



(a) Non-Hispanic White

(b) People of Color

Source: Wu et al. (2019)

Figure 8 Predicted health benefits of future alternatives from physical activity and traffic injury compared with baseline year 2012.

This study is subject to the same limitation as other ITHIM implementations mentioned earlier. In addition, due to missing race/ethnicity and other detailed variables, imputation was needed to synthesize data for population subgroup analysis. In future efforts regarding data collection and modeling for transportation and health impacts, data necessary for differentiation of subgroups in the population need to be collected and analyzed.

2.4 Transportation and Public Health Issues in South Florida

To identify the most effective approaches to implementing health impacts assessment for transportation projects in South Florida, it is important to assess the specific issues for transportation and public health planning in this region.

2.4.1 Public Health Issues

According to information released by the U.S. CDC, the Miami-Dade County (MDC) has been dealing with obesity in the community (CDC, 2013). The county has seen a high rate (67.4%) of obesity and overweight for adults in the county. The obesity rate for high-school students were 13%, but only 12% of them attended regular physical-education classes at school, which is significantly lower than the state average of 44%. Physical inactivity and poor diet are the main causes for the obesity problem. Approximately 24.5% of the county's adults reported no physical activity in the last 30 days and only 22.1% of them met the Federal government's guidelines for fruit and vegetable consumption (CDC, 2013). Table 16 shows the top 10 leading causes of death in MDC (FDHMDC, 2019).

Table 16 Leading Causes of Death (Age-adjusted Death Rate per 100,000) in Miami-Dade County Compared to Florida and the United States

Causes of Death	Miami-Dade County	Florida	United States
Heart Disease	148.4	148.5	165.6
Cancer	128.2	149.4	155.8
Stroke	43.1	39.6	37.3
Chronic Lower Respiratory Disease	29.6	40.0	40.6
Unintentional Injury	30.6	56.0	47.4
Alzheimer's Disease	23.8	21.0	30.3
Diabetes	22.4	20.7	21.0
Influenza and Pneumonia	9.1	9.8	13.5
Nephritis, Nephrotic, Syndrome, & Nephrosis	9.1	10.3	13.1
Parkinson's Disease	7.6	8.1	N/A

Source: Florida Department of Health in Miami-Dade County (FDHMDC, 2019)

Table 16 shows that, when compared to the state and the U.S., MDC has slightly below average rates for most health conditions leading to death, except for stroke and diabetes, which are actually higher than the U.S. averages. With our review of health benefits of physical activity presented in Table 1, increasing physical activity can help reduce the incidence of stroke and diabetes. The rates of death caused by cancer and chronic lower respiratory disease for MDC are both significantly lower than the averages for the state and the U.S..

Table 17 shows the years of potential life lost (YPLL) before age 75 by different causes leading to death. YPLL is a measure of premature mortality defined as the number of years of life lost among persons who die prematurely before their life expectancy. It can be seen that stroke has seen a dramatic incidence of stroke as the cause of YPLL has increased in MDC since 2015. So did heart disease and unintentional injuries. All three conditions (i.e., heart disease, stroke, and unintentional injuries) can benefits from increase physical activity and reducing vehicle crashes on the streets, both of which are features of complete streets.

Table 17 Years of Potential Life Lost before Age 75 to Leading Causes of Death (Single-Year Rate per 100,000 population in Miami-Dade County, FL)

All Causes	2015	2016	2017
All Causes	5,635.8	5,821.8	5,651.3
Cancer	1,207.7	1,241.0	1,197.7
Unintentional Injuries	793.3	974.2	955.5
Heart Disease	803.6	851.2	822.6
Stroke	157.3	151.2	194.2
Chronic Lower Respiratory Disease	98.6	101.4	111.1

Source: FDHMDC (2019)

2.4.2 Transportation Issues

Congestions is clearly the most significant transportation issue facing south Florida. Miami was ranked as the fifth most congested urban area in the U.S., with commuters spending approximately 64 hours a year in traffic jam (Sun Sentinel, 2018). Pedestrian fatalities is another transportation issue for south Florida and the entire state of Florida. The state of Florida has had a very high pedestrian fatality rate over the years (GHSA, 2020). Increasing active transportation and public transit use via complete street projects appear to be a solution that can address both issues (USDOT, 2015b).

2.5 Summary

For literature review, we addressed the following items:

- Latest medical evidence on the health benefits of active transportation and guidelines for physical activity
- Existing HIA tools
- Existing implementations of HIA for transportation projects and plans in the United States
- Specific transportation and public health issues in South Florida

Latest evidences in medical and public health research show that all-cause mortalities and the prevalence of cardiovascular disease, diabetes, weight gain, dementia, depression and injuries due to falls by the seniors can all be reduced by a greater rate of participation in physical activity by the public. Together, these medical conditions represent a significant amount of economic cost in the U.S. Transportation plans and projects that promote active transportation can help solve transportation and public health issues facing South Florida, especially stroke, diabetes, and injuries and fatalities involving pedestrians and bicyclists. Conducting HIA for Complete Streets projects can show the general public what health benefits and associated economic benefits are expected of these projects.

After reviewing existing HIA tools and applications, we found that ITHIM is the best choice for implementation of HIA in this region, because ITHIM has had successful implementations in the United States, including multiple MPOs in California and Nashville in Tennessee. ITHIM's ability of modeling three transportation impacts in physical activity, air pollution, and traffic injuries with pedestrians and cyclists also meets the need for applications in South Florida and the state in general.

Chapter 3 Case Studies

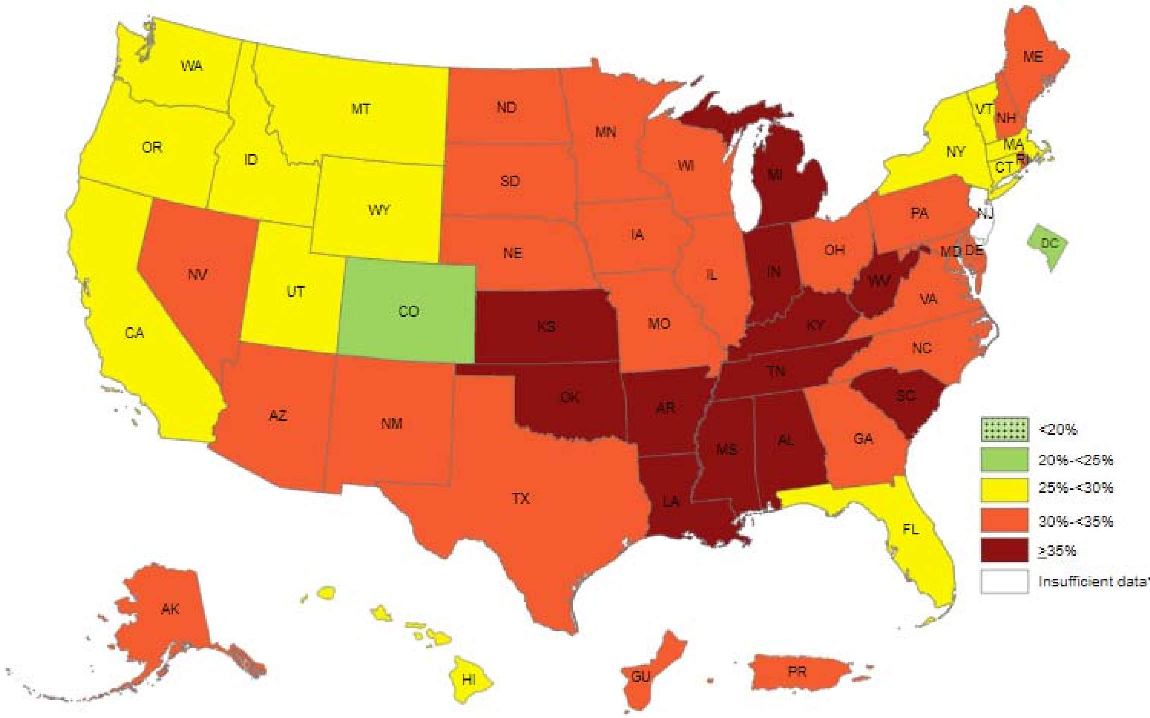
After conclusion of literature review for this project, we determined that the Integrated Transport and Health Impact Tool (ITHIM) is the most appropriate tool for conducting health impact assessment in Miami-Dade county. In this chapter, we documented results from our comprehensive review of ITHIM implementation cases in the United States, including implementations in greater Nashville area in Tennessee, five major California Metropolitan Planning Organizations (MPO), and counties in Sacramento, California. The case studies examined details of the ITHIM implementations in terms of contexts of the applications, calibration data, assessment scenarios, health outcomes assessed, results of the assessment, and plans and actions after ITHIM implementations. Note that discussions of ITHIM case studies in this chapter cover only technical details relevant to the implementation. ITHIM methodologies are covered in the literature review chapter.

3.1 Greater Nashville Regional Council

3.1.1 Application Context

The Greater Nashville Regional Council (GNRC), formerly known as the Nashville Area MPO, serves as the administrator of the federally-mandated MPO for the Nashville area, which consists of 19 counties and 52 cities in middle Tennessee, in accordance with federal regulations and supervisions by the Tennessee Department of Transportation, Federal Highway Administration, and Federal Transit Administration (GNRC, 2020). The MPO region of GNRC has experienced rapid growth in the last two decades. The region's population grew from 1.14 million in 2000 to 1.98 million in 2015 with an annual growth rate of 3.8% (GNRC, 2016). Because of rapid population growth, traffic congestion had become an important issue in the region. According to a report from Texas A&M Transportation Institute (Schrank, Eisele, and Lomax, 2019), Nashville currently ranks as the 24th most congested city in the U.S., with an average daily commuter spending 58 hours in traffic every year.

In addition to traffic problems, residents in the region have also been dealing with a significant public health challenge in high prevalence of obesity and physical inactivity. According to data from the Behavioral Risk Factor Surveillance System (CDC, 2019a), more than 35% of adults in the state of Tennessee rated themselves as obese (see Figure 9). Tennessee also has more than 30% of adults who are physically inactive (CDC, 2019b). It was reported that more than half of the residents in the greater Nashville region never walked for transportation and only one in five walked for transportation for more than four days per week (Westat, 2013).



Source: CDC (2019a)

Figure 9 Prevalence of self-reported obesity among U.S. adults by state and territory.

3.1.1.1 Project Scoring Criteria with Considerations in Health, Safety, and Social Equity

In the lats decade, GNRC initiated innovative planning and programming efforts that resulted in increased investment in the region's active transportation infrastructures (i.e., walking and bicycling) in places where the most benefits on public health and social equity could be achieved (GNRC, 2010). The MPO incorporated consideration of health, safety, and social equity into its prioritization and selection process for transportation projects. A 100-point transportation project scoring process was first developed for the MPO's 2035 long-range transportation plan (GNRC, 2010) and further refined in its 2040 plan (GNRC, 2016). For the 2040 plan, 80 of the available 100 points for a project's score are related to public health, safety, or social equity, giving active transportation projects higher chance of being selected in areas where most health benefits from participation in activity transportation can be gained by the residents. Table 18 shows the project scoring criteria for GNRC's 2035 and 2040 long-range transportation plans (Meehan and Whitfield, 2017).

Table 18 Project Scoring Criteria, and Selected Health-Related Sub-Criteria From the 2035 and 2040 Regional Transportation Plans

	Points per category	
	2035 Plan	**2040 Plan**
1. System preservation and enhancement	15	10
2. Quality growth, sustainable development, and economic prosperity	15	15
Project improves accessibility/connection to residential population		
Project improves accessibility/connection to existing jobs		
Project incorporates streetscaping / enhancements		
3. Multi-modal options	15	15
Project includes sidewalk improvements		
Project includes bicycle facility improvements		
Project includes multi-modal treatments (cross-walks, shelters, etc)		
4. Congestion Management	10	15
Project addresses corridor congestion		
Project provides additional non-motorized mode capacity		
Project improves transit capacity		
5. Safety and Security	10	20
Primary project purpose is to improve safety		
Project is on local/state high crash corridor designation		
Project addresses specific location with high crash prevalence		
6. Freight and goods movement	10	5
7. Health and environment	10	15
Project located in high health impact area		
Project provides alt. transportation choices for underserved groups		
Project provides multi-modal options near schools		
8. Project history	15	5
Total points:	**100**	**100**

Source: Meehan and Whitfield (2017)

In conjunction with creation of the project scoring criteria, GNRC engaged in two additional planning processes to identify areas to invest in active transportation projects:

1. Determine which areas in the region have the greatest need to improve their residents' health.
2. Identify where active transportation infrastructure projects would most likely be utilized.

3.1.1.2 Middle Tennessee Transportation and Health Study

To determine the areas where health benefits from active transportation are most needed, GNRC conducted the Middle Tennessee Transportation and Health Study (MTTHS), which collected data on travel behavior and public health in the MPO areas (Westat, 2013). Approximately 11,000 individuals from 5,000 households participated in MTTHS. In addition to a one-day travel diary, all respondents answered six health questions related to average daily sitting time, physical activity, self-reported diet and health status, and height and weight (see Table 19). A 10% subsample of adult respondents was recruited to participate in an expanded study that included four days of physical activity tracking with accelerometer and GPS device, as well as a food diary and additional health questions (Westat, 2013).

Table 19 Health Questions for the Middle Tennessee Transportation and Health Study

General Health Question Text	Response Options
During the last 7 days, how much time did you usually spend ***sitting*** on a **weekday?** (Please report in hours; for example: 8.5 h)	Number of hours
Which of the following statements best describes how physically active you are in a typical week.	• I rarely or never do any physical activity • I do some light or moderate physical activities • I do some vigorous physical activities
In general, how healthy is your overall diet? Would you say that, in general, your health is:	• Excellent • very good • good • fair • poor
About how much do you weigh without shoes? About how tall are you without shoes?	Open ended

Source: Meehan and Whitfield (2017)

Based on results of the MTTHS, GNRC identified four demographic characteristics associated with worse health outcomes:

1. Low income, defined by annual household income of $24,300 or less for a family of four
2. Being unemployed
3. Older adults age of 65 and above
4. Zero-car households

Census block groups in GNRC region that have higher than average rates for at least three out of the four characteristics are identified as "Health Priority Areas" in GNRC's 2040 long-range transportation plan (GNRC, 2016). The GNRC's project scoring process awards more points to active transportation projects (i.e., including features for walking and/or bicycling) that serve the health priority areas.

3.1.1.3 Regional Bicycle and Pedestrian Study

The purpose of GNRC's regional bicycle and pedestrian study (RBPS) is to establish an overall strategy to accommodate walking and bicycling opportunities in the greater Nashville region (GNRC, 2015). The strategy provides the basis in the GNRC's long-range transportation plan by which selection priorities for active transportation projects are established.

GNRC's RBPS was first conducted in 2009 and updated in 2014 (GNRC, 2015). The RBPS began by establishing an inventory of bicycle and pedestrian facilities in the MPO region. The inventory was combined with other regional data for analyses on the demand, level of services, physical activity promotion (i.e., health priority areas), crash propensity, and corridor congestion relief for new pedestrian and bicycle facilities in different areas in the region (see Table 20). The results of the analyses enabled the GNRC to identify geographic areas where more bicycling and walking trips were most likely to occur. More points were awarded in the scoring and selection process to walking and bicycling projects in these areas.

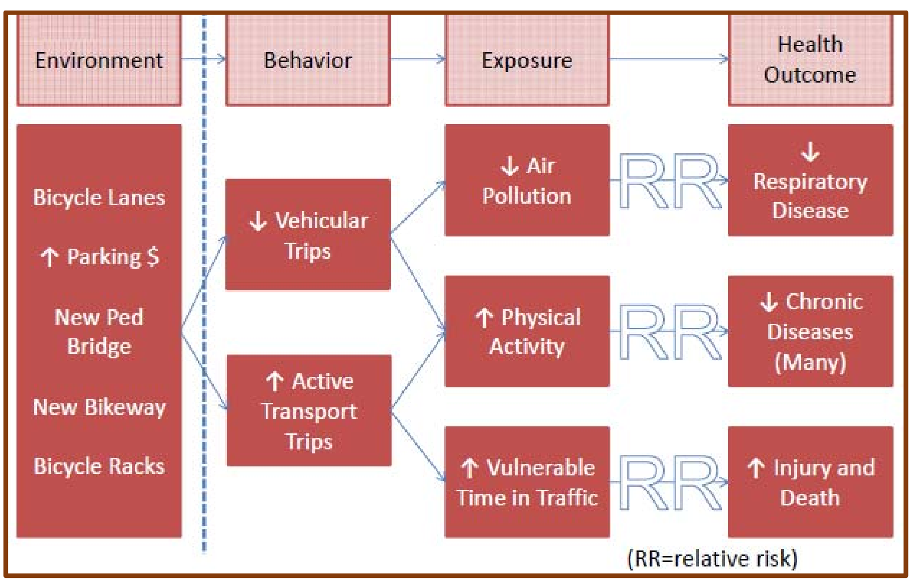
Table 20 Components of the 2009 and 2014 Regional Bicycle and Pedestrian Studies

Analysis	Description	Results
Bicycle/Pedestrian latent demand model	Uses parcel-level information on housing, land use, employment, and destination proximity to predict the number of bicycling and walking trips that might be expected if walking and bicycling infrastructure were already in place	Identified parts of the region that might produce the most users for bicycle and pedestrian infrastructure
Bicycle/pedestrian level of service	Based on the Transportation Research Board's 2010 Highway Capacity Manual (Centers for Disease Control and Prevention, 2016) Considers multiple factors such as shoulder width, traffic volume, and separation from vehicles to provide an index of pedestrian and bicyclist comfort for a given corridor or street segment Assigns a score of A (best) through F (worst)	Approximately two-thirds of arterials and collectors scored at least a C Identified corridors that are not appealing to bicyclists and pedestrians
Health priority areas	Four demographic characteristics were shown to be associated with poor health: low income, high unemployment, age > 65 years, and lack of car ownership Areas with three or more of the above factors were classified as having high health needs and were priorities for healthy transportation infrastructure	Identified areas of the city with demographics that suggest poor population health
Dangerous corridors	Created a map all recorded pedestrian and bicycle crashes in the area	Identified areas that would most benefit from safety improvements
Congested corridors	Classified vehicle corridors according to volume to capacity ratios	Identified corridors that would most benefit from shifting mode share away from personal automobiles

Source: Meehan and Whitfield (2017)

3.1.2 ITHIM Implementation

To communicate the public health benefits of active transportation projects to the residents in the region, GNRC worked with the Centers for Disease Control and Prevention (CDC) to estimate the monetary value of the benefits by using the Integrated Transportation and Health Impact Modeling Tool (ITHIM) (Meehan and Whitfield, 2017). Technical details of ITHIM and the calibration data used for the Nashville implementation had been described in the literature review chapter. Figure 10 provides an overview of the ITHIM modeling process for the Nashville implementation (Meehan, 2015).



Source: Meehan (2015)

Figure 10 The ITHIM modeling process.

Health outcomes resulting from investments in pedestrian and bicycle facilities are estimated by ITHIM with the relative risk method, which predicts the risk of developing respiratory and chronic diseases based on the amount of exposure to air pollution and physical activity involvement (Meehan and Whitfield, 2017). Active transportation increases physical activity and reduces air pollution. However, increasing pedestrian and bicyclist activities can also increase risk of traffic injuries and fatalities. Table 21 shows that lists of diseases whose risks of development are modeled in ITHIM with exposures to physical activity and air pollution (Meehan, 2015).

Table 21 Exposures and Diseases Modeled by ITHIM

Exposure to Physical Activity	Exposure to Air Pollution
Ischemic Heart Disease	Respiratory Infections
Depression	Cardiovascular Disease
Dementia	Hypertensive Heart Disease
Diabetes	Inflammatory Heart Disease
Colon Cancer	Lung Cancer
Breast Cancer	Respiratory Disease (kids)
All-Cause Mortality	Stroke

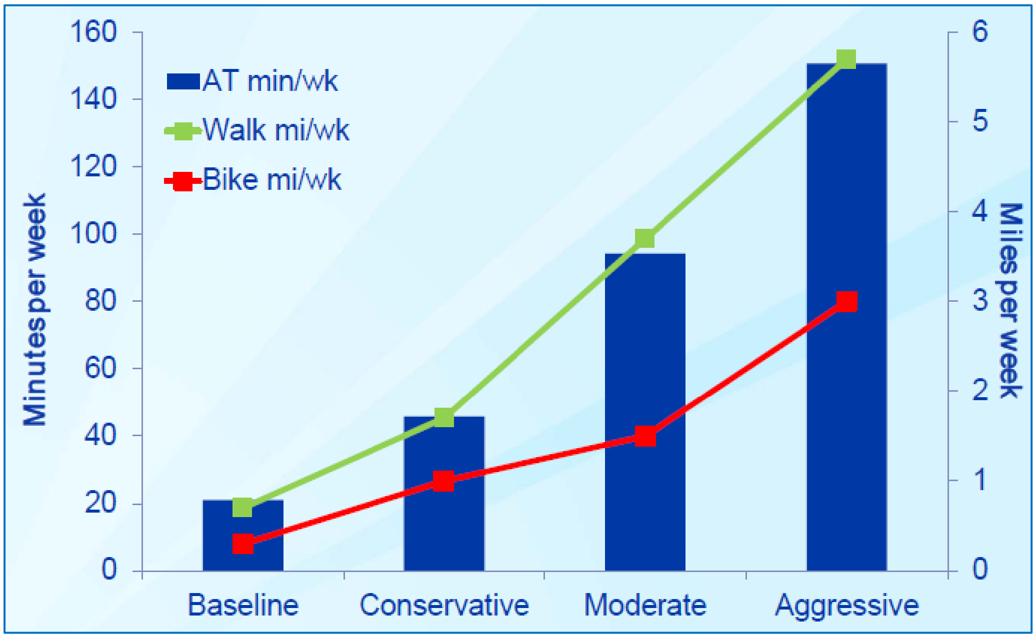
Adapted from Meehan (2015)

3.1.2.1 Calibration Data

Calibration of ITHIM for the Nashville implementation involved data on baseline demographics, travel behavior, vehicle miles traveled, emissions of particulate matter smaller than 2.5 µm in diameter ($PM_{2.5}$), roadway injuries, physical activity participation, and current disease burdens (Meehan and Whitfield, 2017). Demographic data were sourced from U.S. Census, while the MTTHS provided most of the travel-related data, including travel by means of walking and bicycles. The Tennessee Department of Safety provided data on traffic injuries and Tennessee Department of Environment and Conservation $PM_{2.5}$ data. Data on the incidences of diseases shown in Table 21 were provided by the Tennessee Department of Health.

3.1.2.2 Analysis Scenarios

Once the Nashville ITHIM model was calibrated, three scenarios (i.e., conservative, moderate, and aggressive) were developed, each with progressively higher average active transportation (walking and bicycling) participation, while holding total miles traveled by all modes constant. Data from MTTHS showed that residents in the greater Nashville area engaged in an average of 0.7 mile per week of active transportation by walking and 0.3 mile by bicycling (Meehan and Whitfield, 2017). In the conservative scenario, average distance of walking for transportation was increased to 1.7 miles per capita per week and 1.0 mile for biking. In the moderate scenario, average walking distance was increased to 3.7 miles and bicycling 1.5 miles per capita miles per week, which were translated to roughly 10 additional minutes or walking or biking per day based on average walking and cycling speeds. The aggressive scenario was constructed such that miles of walking or bicycling correspond to the minimum physical activity recommendation (i.e., at least 150 minutes per week of moderate-intensity aerobic physical activity) in the 2018 Physical Activity Guidelines of U.S. Department of Health and Human Services (USDHH, 2018), which translated to 5.7 miles of walking or 3.0 miles of cycling per capita per week. Figure 11 shows the comparison of walking and biking distances and minutes by scenarios.



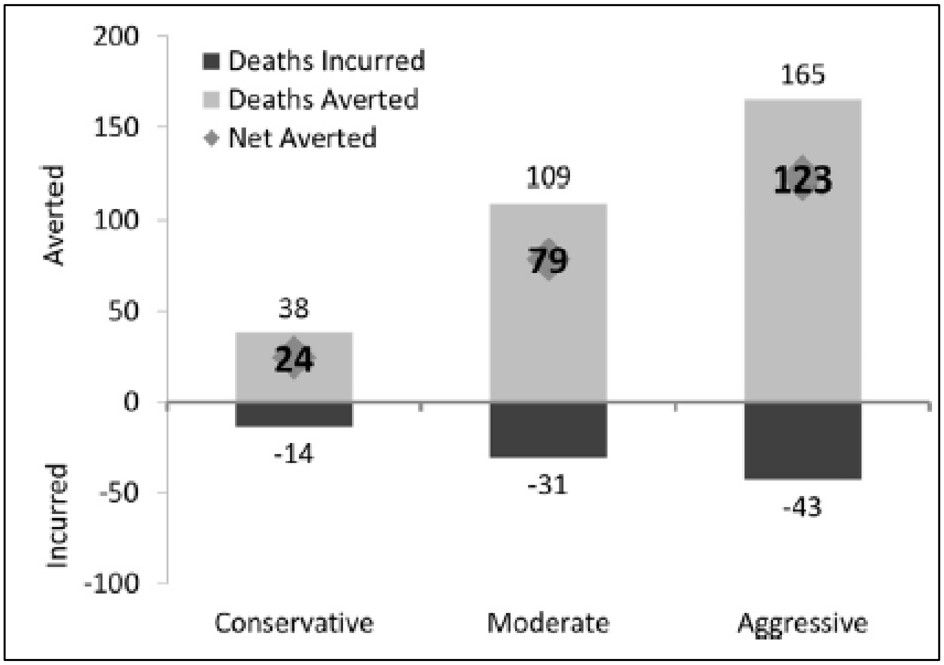
Source: Meehan (2015); AT: Active Transportation

Figure 11 Active transportation participation by scenarios.

3.1.2.3 Analysis Results

The ITHIM results indicated that increased participation in active transportation can result in reduced premature death due to reduced incidence in chronic disease and respiratory conditions prevented by increased physical activity and reduced air pollution (Figure 12). For example, the conservative scenario showed that 38 premature deaths from the diseased can be averted by increasing the average per capita walking and cycling distance for transportation. However, the increased active transportation inevitably incurs an estimated 14 roadway fatalities. This resulted in a net prediction of 24 deaths averted. The aggressive scenario shows that engagement in active transportation for 150 minutes per capita per week per, as recommended in the 2018 Physical Activity Guidelines, the region can see a net reduction of 123 premature death averted (Meehan and Whitfield, 2017).

ITHIM also provided disease-specific benefits by active transportation (see Table 22). For example, under the moderate scenario, the model predicts a 4% reduction in disease burden (i.e., measured by premature deaths) for cardiovascular disease and 3.9% in diabetes, as well as between 1% and 2% of reductions in depression, dementia, breast cancer, and colon cancer (Transportation for America, 2016).



Source: Meehan and Whitfield (2017)

Figure 12 Changes in premature death by scenarios.

Table 22 Predicted Decrease in Chronic Diseases Due to Increased Active Transportation

Moderate Scenario	**Changes in Premature Death/Year**	**% Change**	**Changes in Direct and Indirect Costs (Millions)**
Cardiovascular Diseases	-84.0	-3.0%	-$44.4
Diabetes	-9.3	-3.0%	-$35.8
Depression	0.0	-1.1%	-$5.7
Dementia	-11.6	-1.3%	-$15.0
Breast Cancer	-2.2	-1.2%	-$1.9
Colon Cancer	-2.0	-1.1%	-$1.7
Road Traffic Crashes	30.6	15.4%	-$72.7
Total	-78.7	-0.7%	-$31.8

Source: Whitfield, Meehan, Maizlish, and Wendel (2017)

Table 22 also shows the estimated direct and indirect costs saved from reduced disease burden of the moderate scenario. The estimated financial cost savings of improved health through active transportation in the region were intended to be presented to policy makers, stakeholders, and citizens. The direct costs for the diseases modeled in ITHIM and the associated indirect costs of lost productivity were estimated by scaling the national estimates to the population of GNRC (Meehan and Whitfield, 2017). The direct and indirect costs of each of the disease were then multiplied by the change in incidence of the disease predicted by ITHIM.

The results showed annual cost reductions of $10 million, $32 million, and $63 million for the conservative, moderate, and aggressive scenarios, respectively.

3.1.3 Subsequent Plans and Actions

Implementing ITHIM for the greater Nashville region was one of several steps that GNRC took to improve public health through transportation planning. GNRC's primary purpose in running ITHIM was to communicate to stakeholders and the public the potential benefits of active transportation. GNRC's experience with ITHIM implementation and associated planning processes had been featured in many professional presentations and publications (Transportation for America, 2016; Meehan, 2015). Consequently, GNRC had received national recognition for its commitment to improving public heath through transportation planning. It is noted that GNRC's efforts resulted in significant increase in the region's active transportation facilities between 2009 and 2014 (NASEM, 2019).

GNRC is continuing to pursue transportation policies and projects that can improve public health outcomes. One of the specific goals in GNRC's 2040 long-range transportation plan is to "integrate healthy community design strategies and promote active transportation to improve the public health outcomes of the built environment" (GNRC, 2016). To achieve this goal, GNRC will continue its efforts to evaluate health impacts of proposed transportation policies, plans, and programs through three inter-related endeavors (GNRC, 2016):

- Traditional roadway safety and crash data analyses
- Health impact assessment practices
- Development of a new regional model that forecasts health savings resulting from changes in travel behaviors and pollution levels

Although not specified in its 2040 transportation plan, judged by the amount of resources that had been dedicated to ITHIM implementation, it is expected that GNRC will continue to utilize ITHIM for health impact assessment for transportation planning applications.

3.2 MPOs in California

3.2.1 Application Context

The U.S. state of California was once the 15th largest emitter of greenhouse gas worldwide (CARB, 2008). California's transportation sector is the largest source of greenhouse gas emissions (GHGE), accounting for 38% of the state's total GHGE, of which passenger vehicles represent the largest source of emissions. In 2008, California enacted the Climate Change Scoping Plan, setting the goal of reducing GHGE to 80% below its 1990 level (CARB, 2008). In addition to transitioning to technologies for lower carbon fuels and alternative-fuel vehicles (i.e., electric, fuel cell, and gas/electric hybrids), reducing total vehicle miles traveled is another important means of achieving the GHGE reduction goal. It was recognized that a large proportion of urban automobile trips could be made by combinations of walking, bicycling, and public transit, which also provide opportunities for increasing physical activity in the public and reducing GHGE (Maizlish et al., 2013).

In conjunction with the Climate Change Scoping Plan, California enacted the Sustainable Communities and Climate Protection Act of 2008 (CARB, 2020c) that obligates MPOs in California to meet specific GHGE reduction goals through land use strategies, which may include increasing development density, land use mix, job-housing balance, street network connectivity, and accessibility via all relevant modes (i.e., walking, bicycling, and transit). Each MPO in California is required to submit a Preferred Sustainable Communities Strategy (SCS) that specifies strategies for meeting regional GHGE reduction goals. To justify the effectiveness of the SCSs, MPOs in California use regional travel demand models to quantify GHGE reductions that could be achieved by land use strategies proposed in the SCS. The preferred SCSs is reviewed by the California Air Resources Board (CARB), which examines the outputs of the MPO models for the reasonableness of assumptions regarding achievable GHGE reductions from the proposed land use strategies (). Vehicular GHGE and other toxic contaminants had been the focus of these reviews (Zapata, Muller, and Kleeman, 2013), but the health benefits of active transportation, which is the underlying mechanism for automobile trip reduction by increasing land use densities and diversities, had not been adequately addressed in the land use plans (Maizlish, Linesch, and Woodcock, 2017).

Maizlish et al. (2013) conducted the first ITHIM implementation in California to quantify potential health benefits of different strategies for reducing transportation GHGE in the San Francisco Bay Area. The ITHIM implementation in the Bay Area was conducted in conjunction with the California Department of Public Health and the Metropolitan Transportation Commission (MTC), the MPO responsible for transportation planning in the Bay Area. Carrying on the same approach with the Bay Area implementation, Maizlish, Linesch, and Woodcock (2017) conducted another ITHIM study for the California Department of Public Health to quantify GHGE reductions and concurrent health benefits from active transportation documented in several California MPOs' preferred SCSs. The study included five largest California MPOs, including San Francisco Bay Area (i.e., Metropolitan Transportation Commissions), Sacramento (i.e., Sacramento Area Council of Governments), San Joaquin Valley (i.e., Fresno Council of Governments), Southern California (i.e., Southern California Association of Governments), and San Diego (i.e., San Diego Association of Governments). These regions comprised 97% of the state's population.

3.2.2 ITHIM Implementation

3.2.2.1 Calibration Data

Travel behavior data such as average daily distances traveled by walking and bicycling were derived from the 2012 California Household Travel Survey (CHTS) (NuStats, 2013). Travel demand models of the MPOs (i.e., San Francisco Bay Area, Southern California, and San Joaquin Valley) as well as the California Statewide Travel Demand Model (i.e., for Sacramento

Area and San Diego County) (West, 2016) provided estimates of daily vehicle miles traveled (VMT) for cars and trucks.

Burden of disease of the study area was measured by deaths and disability adjusted life years (DALYs), which represent the sum of years of life lost to premature death and years of living with disability. Data on deaths and DALYs were obtained from the 2010 U.S. Global Burden of Disease, GBD (IHME, 2019). The disease burden data for each of the California MPOs were derived by adjusting the U.S. data with the ratio of mortality rates between counties in the MPO and the U.S. Data on weekly non-travel physical activity for leisure and occupational activities were obtained from the California Health Interview Survey (UCLA Center for Health Policy Research, 2012).

Data on traffic fatalities and injuries were obtained from a statewide database of traffic collisions in California (SafeTREC, 2011). GHGE from cars and light trucks were estimated for each MPO region from modeled emission factors in 2010 (CARB, 2020b).

3.2.2.2 Analysis Scenarios

2010 Baseline and Preferred SCS

A 2010 baseline scenario was first constructed with 2010 population and baseline travel behavior data of the five study MPOs. The baseline scenario was to be compared to results according to the Preferred SCSs of the five MPOs. The projected daily vehicle miles traveled for motorized modes, and the annual or daily number of trips for transit, walking, and cycling based on land use strategies of the SCSs were used to calculate results for the preferred SCSs scenario.

Ambitious Scenarios

Four additional 2010 scenarios that reflect ambitious replacement of walking, cycling, and/or transit ridership for automobile trips. In each of the f our scenarios, the total miles traveled across all modes were held constant, while increased distances of active transportation and transit trips replaced automobile VMTs by the same distances. The four scenarios include:

1. The "Walk" scenario increased the per capita average time of walking for transportation to 283 minutes per week while holding the per capita time for transportation bicycling, non-travel physical activity, and riding transit at their 2010 baseline levels. The 283 minutes of average per capita walking time per week was chosen with statistical reference to the travel behavior data of the MPOs. Because the population mean of active transportation time was greater than the median in the study areas (i.e., active transportation time data skewed to the right), setting the weekly per capita average walking time to 283 minutes resulted in half of the study population meeting the 150 minutes of physical activity recommended in the 2018 physical activity guideline (USDHH, 2018). The total distances increased by walking (i.e., estimated with

assumptions of an average walking speed for the population) were then subtracted from the distances traveled by automobiles on local roads and arterials, keeping the total distances traveled by all modes constant.

2. The "Cycle" scenario increased the per capita average transportation bicycling time to 283 minutes per week while holding the per capita time for transportation bicycling, non-travel physical activity, and riding transit at their 2010 baseline levels. The total distances increased by cycling (i.e., estimated with assumptions of an average bicycling speed for the population) were also subtracted from the distances traveled by automobiles on local roads and arterials.

3. The "Transit" scenario considers the time spent on transit trips, which can also include time spent on getting to and from the stations by walking and bicycling. Ratios of minutes walked per transit minute and minutes on bicycles per transit minute were derived from the CHTS. These ratios were multiplied by an increased transit duration to estimate the time spent on active transportation associated with transit trips. The total travel time for the combined transit and active transportation was limited to a total of 283 minutes per person per week.

4. The "Blend" scenario increased the per capita mean daily duration of walking, bicycling, and transit each to 70 minutes per person per week. An equivalent amount of transit, walking, and bicycled miles was subtracted from VMT of passenger vehicles.

3.2.2.3 Analysis Results

Table 23 shows travel distances by travel modes for the baseline and ambitious scenarios. At baseline, the population mean of active transport duration in California was 40.5 minutes per person per week. Active transport and transit comprised approximately 4.9% of all distance traveled in the state in 2010. The distances traveled by different modes varied across MPOs in California due to the patterns of land development. The San Francisco Bay Area has the highest walking and cycling distances owing to its moderate to high development densities. The San Joaquin Valley is partially rural while Southern California and San Diego are known for sprawling land developments.

Table **24** shows the percent increase of active transportation and transit usage according to the MPO’s preferred SCSs, as compared to the 2010 baseline condition.

Table 25 shows the reduction (i.e., compared to the 2010 baseline scenario) in death and DALYs, predicted by ITHIM, of the preferred SCSs of the MPOs. Table 27 shows the reduction in death and DALYs by specific health conditions of the preferred SCSs, while Table 27 for the four ambitious scenarios.

Table 23 Per Capita Travel Distance and Active Travel Times by Modes and Scenarios

	Annual Distance (mi person^{-1} y^{-1})									Travel Time		
			Car		Transit					Mean (median) min person^{-1} w^{-1}		
Scenario	Walk	Cycle	Driver	Pas-senger	Bus	Rail	Motor-cycle	Truck	Total	Walk	Cycle	Total
Baseline												
California, 2010	96	38	6,880	3,503	297	147	34	662	11,657	36.9 (17)	3.6 (2)	40.5 (19)
SF Bay Area[a]	151	61	5,683	1,824	294	354	48	677	9,093	57.8 (30)	5.9 (3)	63.7 (33)
San Joaquin Valley	73	18	6,207	3,257	398	8	23	1,108	11,092	27.8 (10)	1.8 (1)	29.6 (11)
Southern California	85	29	7,967	4,182	304	120	27	464	13,178	32.6 (15)	2.8 (1)	35.4 (16)
San Diego County	77	42	4,841	3,062	235	95	49	1,272	9,673	29.5 (15)	4.0 (2)	33.5 (17)
Sacramento Area	84	61	5,653	4,227	160	33	47	622	10,886	32.4 (15)	5.8 (2)	38.2 (17)
SCS, California	125	57	6,319	3,228	386	244	34	662	11,055	48.0 (23)	5.4 (3)	53.4 (26)
Ambitious Scenarios												
Walk	727	38	6,461	3,291	297	147	34	662	11,657	279 (152)	4 (2)	283 (154)
Cycle	96	2,563	5,205	2,653	297	147	34	662	11,657	43 (21)	240 (133)	283 (154)
Transit	188	72	5,195	2,692	1,923	891	34	662	11,657	73 (35)	6 (3)	79 (39)
Blend	245	981	5,284	2,722	1,178	551	34	662	11,657	105 (48)	84 (48)	188 (96)

Source: Maizlish, Linesch, and Woodcock (2017)

Table 24 Changes in Trips by Modes According to California MPOs' Preferred SCSs as Compared to 2010 Baseline

Mode	Metric	Bay Area	Sacramento Area	San Joaquin Valley	Southern California	San Diego Co.
Walk	Trips/p	+11%	+16%	+31.7%	+27%	+88%
Bicycle	Trips/p	+19%	+11%	+31.7%	+69%	+88%
Car	VMT/p	−9%	−10%	−11%	−7%	−11%
Bus	Trips/p	+40%	+145%	+50%	+7%	+73%
Rail	Trips/p	+40%	+145%	+50%	+94%	+73%

Source: Maizlish, Linesch, and Woodcock (2017)

Table 25 Reduction in Number and Rate of Deaths and DALYs of the Preferred SCSs

Change in Burden of Disease	Bay Area		San Joaquin Valley		Southern California		San Diego		Sacramento Area		Total	
	N	*Rate*	N	*Rate*	N	*Rate*	N	*Rate*	N	*Rate*	N	*Rate*
Deaths, Total	−101	*−1.4*	−122	*−2.9*	−581	*−3.02*	−114	*−3.7*	−22	*−0.9*	−940	*−2.59*
Chronic Disease	−88	*−1.2*	−116	*−2.7*	−583	*−3.04*	−124	*−4.0*	−11	*−0.5*	−923	*−2.55*
Road Traffic Injuries	−13	*−0.2*	−6	*−0.1*	2	*0.01*	10	*0.3*	−10	*−0.4*	−17	*−0.05*
DALYs, Total	−2,727	*−37.1*	−2,509	*−59.4*	−8,607	*−44.8*	−2,138	*−69.1*	−781	*−32.9*	−16,763	*−46.2*
Chronic Disease	−2,057	*−28.0*	−2,148	*−50.8*	−8,769	*−45.7*	−2,604	*−84.1*	−270	*−11.4*	−15,847	*−43.7*
Road Traffic Injuries	−670	*−9.1*	−362	*−8.6*	161	*0.8*	466	*15.1*	−511	*−21.5*	−916	*−2.5*

Source: Maizlish, Linesch, and Woodcock (2017); Note: Rate is for every 100,000 people.

Table 26 Specific Health Benefits with the MPOs' Preferred SCSs

	Deaths		DALYS	
	PAF, %	N	PAF, %	N
Cardiovascular Disease	−1.1	−623	−1.1	−9,682
Diabetes	−1.0	−68	−1.1	−2,343
Dementia	−1.1	−174	−1.0	−1,908
Depression	0.0	0	−0.2	−814
Colon Cancer	−0.4	−15	−0.3	−203
Breast Cancer	−0.3	−12	−0.2	−223
Chronic Disease (above)		−892		−15,173
Road Traffic Injuries	−0.5	−17	−0.5	−916
Total		−909		−16,089
Rate $\times 10^5$ population		−2.5		−44.4

PAF, Population Attributable Fraction
DALYs, Disability Adjusted Life Years.

Source: Maizlish, Linesch, and Woodcock (2017)

Table 27 Change in the Burden of Disease and Injury by Scenarios of Walking, Cycling, and Transit

	Walk				Cycle			
	Deaths		DALY[b]		Deaths		DALY	
	PAF[a], %	N	PAF, %	N	PAF, %	N	PAF, %	N
Cardiovascular disease	−10.3	−6,152	−11.5	−103,200	−10.5	−6,223	−13.8	−124,122
Diabetes	−10.4	−742	−11.7	−26,551	−11.2	−794	−14.1	−31,978
Dementia	−8.5	−1,457	−8.1	−16,882	−6.1	−1,048	−6.4	−13,271
Depression	0.0	0	−3.5	−12,355	0.0	0	−4.2	−14,764
Colon Cancer	−4.0	−162	−3.5	−2,679	−4.4	−179	−4.7	−3,555
Breast Cancer	−3.5	−143	−3.1	−3,219	−2.1	−86	−2.0	−2,144
Sum of Above		−8,656		−164,886		−8,331		−189,834
Road Traffic Injuries	17.0	551	15.8	27,800	−6.5	−213	−2.4	−4,199
Net		−8,104		−137,086		−8,543		−194,033

	Transit				Blend			
Disease Category	Deaths		DALY		Deaths		DALY	
	PAF, %	N	PAF, %	N	PAF, %	N	PAF, %	N
Cardiovascular disease	−2.4	−1,401	−2.5	−22,861	−7.7	−4,554	−9.5	−85,938
Diabetes	−2.3	−165	−2.6	−5,838	−8.0	−569	−9.7	−22,077
Dementia	−2.4	−415	−2.2	−4,670	−5.4	−918	−5.3	−10,958
Depression	0.0	0	−0.7	−2,381	0.0	0	−2.5	−9,046
Colon Cancer	−1.0	−41	−0.8	−603	−3.0	−121	−2.9	−2,173
Breast Cancer	−0.8	−31	−0.6	−633	−1.8	−76	−1.6	−1,712
Sum of Above		−2,054		−36,987		−6,238		−131,902
Road Traffic Injuries	−6.2	−203	−7.0	−12,336	−3.8	−125	−2.1	−3,714
Net		−2,257		−49,322		−6,363		−135,616

Source: Maizlish, Linesch, and Woodcock (2017)

Table 25 shows that health benefits of California MPO's SCSs follow respective increases in active transportation and transit. The SCSs of San Diego and Southern California had the largest increases in active travel (see Table 24) and the largest decrease in DALY rates. These two regions had net positive DALY rates for road traffic injuries. The preferred SCS of Sacramento consists of significantly ambitious transit expansion but modest increase in active transport (see Table 24), resulting in large decreases in DALY rates from fatalities and injuries from traffic crashes.

Table 26 shows that all six MPO SCSs combined can decrease the annual number of deaths by 909 and DALYs by 16,089. The population attributable fraction (PAF) is the proportional reduction in death or DALYs that would occur if active transportation (i.e., physical activity) were increased to the levels assumed by the SCSs. Cardiovascular diseases accounted for the largest share of the reduced disease burden as measured by death and DALYs.

Table 27 shows that, of all ambitious scenarios, Cycle had the largest reduction in deaths and DALYs. Cardiovascular disease, diabetes, and dementia were important contributors to the reduction. The health benefits of the Walk scenario are similar to those of Cycle. However, increased pedestrians on the roads increase death and injuries from traffic accidents, but increasing bicyclists are expected to decrease traffic deaths and injuries. This reflects the difference in the average travel speeds between pedestrians and bicycles. Traffic injuries were estimated by multiplying the baseline crash rates of victim modes with a composite of the changes in miles traveled by both the victim modes (i.e., pedestrians or bicyclists) and striking modes (i.e., automobiles). To engage in the same 283 minutes of active transportation, bicyclists can travel much longer distances than pedestrians, resulting in significantly more automobile VMT being replaced by bicycles than pedestrians. Thus, in the Cycle scenario, the probability for increased bicyclists to increase traffic death and injuries is offset by decreased automobile VMT on the roads (i.e., replaced by bicycles).

The Transit scenario does not produce as much chronic disease reduction as the Walk and Cycle scenarios. It is noted that, unlike the Walk and Cycle scenarios, in which half of the study population are assumed to engage in physical activity meeting the physical activity guidelines, the assumption of Transit scenario does not result in sufficient level of physical activity (i.e., by walking or cycling) involvement. Thus, the health benefits from cardiovascular disease and diabetes are relatively small when compared to rest of the scenarios. However, like the Cycle scenario, increasing transit ridership can also reduce traffic accidents with less automobiles on the road. The Blend scenario is indeed a combination of the other three scenarios, thus showing reduction in all health benefits that are less than Cycle or Walk scenario, but higher than Transit. Nevertheless, the Blend scenario with equal amount engagement in walking, cycling, and transit use represents a more likely scenario for the future than the Walk or Cycle scenario.

Table 28 shows that, with the projected 2040 population, the preferred SCSs of all five MPOs combined cannot keep carbon emissions below the 2010 baseline condition. It was noted that, despite meeting per capita targets (CARB, 2010), the increase in MPO-wise walking and cycling specified in the preferred SCSs was not sufficient to meet the goals of the California Department of Transportation (Caltrans), which seeks to double walking miles and triple cycling from 2010 numbers by 2020 (Caltrans, 2015). Southern California with its vast sprawling land developments generates significantly higher carbon emissions (i.e., estimated by projected VMT) than the other four MPOs. However, the Cycle and Transit scenarios are the most effective in reducing carbon emissions among all scenarios. The San Francisco Bay Area was the only MPO with consistent reductions in carbon emissions in the Cycle, Transit, and Blend scenarios owing to higher baseline transit ridership and active transportation participation as well as a lower VMT per vehicle when compared to other MPOs.

Table 28 Forecasted 2040 Annual Automobile Carbon Emissions by Scenarios

Region	Carbon Emissions ($MMTy^{-1}$)[a]					
	Baseline 2010	Scenario[b]				
		SCS	Walk	Cycle	Transit	Blend
California	105.1	115.4	130.9	105.6	105.6	107.3
San Francisco Bay Area	16.4	19.4	20.5	16.1	12.5	14.1
San Joaquin Valley	11.0	12.7	9.2	9.9	9.7	12.7
Southern California	65.8	70.3	81.8	67.9	70.2	70.4
San Diego County	6.4	6.9	8.2	6.2	6.4	6.5
Sacramento Area	5.5	6.5	7.8	6.2	6.7	6.6

a. $MMTy^{-1}$ = Million Metric Tons per year
b. Forecasts based on projected 2040 population, car VMT replaced by increased active travel and transit, and emission factors held at 2010 levels.

Source: Maizlish, Linesch, and Woodcock (2017)

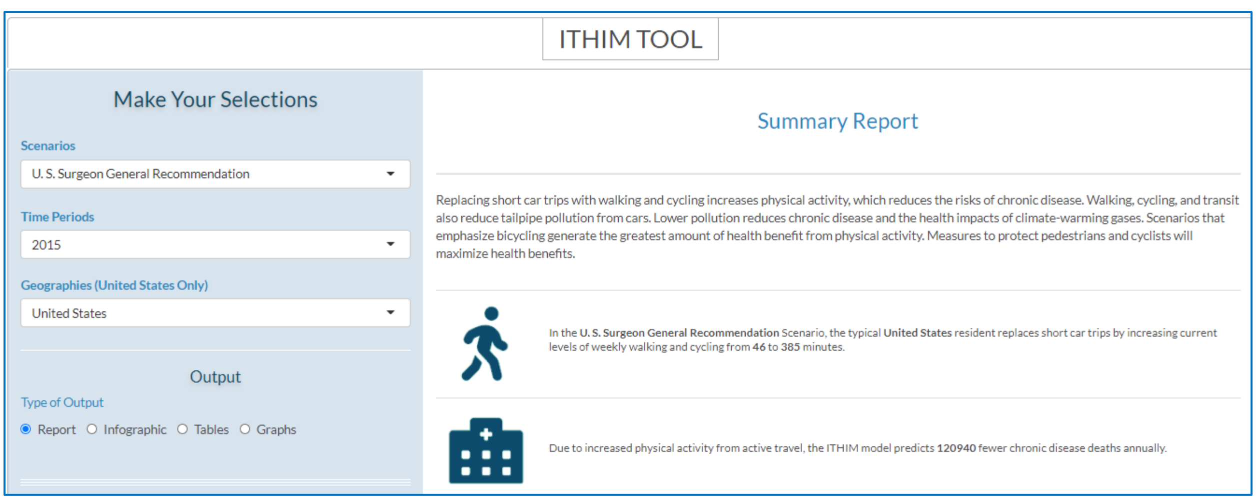
3.2.2.4 Strength and limitation

Using data from the Global Burden of Disease (GBD) Project (Institute for Health Metrics and Evaluation, 2014), this implementation of ITHIM calculates health benefits on disease-specific deaths and DALYs for which the relationships between physical activity and associated health benefits are well established in medical and public health research. In addition to premature mortalities, DALYs also incorporates the concept of morbidities (i.e., measured by years living with disability0 for assessment of the burden of disease, realistically reflecting potential impacts on quality of life and overall economic costs incurred. The method for calculating expected numbers of traffic fatalities and injuries used in this implementation of ITHIM considers that miles traveled by the victims (i.e., pedestrians and bicyclists) and striking vehicles. The miles traveled by increased pedestrians and bicyclists were subtracted from automobile VMTs. In addition, crash risks used in calculation also differentiate by roadway types (i.e., arterials vs. local roads). Thus, increasing bicycle and transit miles can reasonably show decreased traffic fatalities and injuries when substantial VMTs were replaced by active transportation and transit.

Currently, all existing implementations of ITHIM do not consider the differential travel behavior and health impacts by age and gender, which in reality influence travel patterns and health outcomes significantly. Future implementations of ITHIM may need to incorporate additional data to address this issue. Similarly, substitution of travel-related for non-travel related (i.e., leisure-time) physical activity is not considered. That is, leisure time physical activity data used in health benefit calculation were not adjusted in scenarios that increased walking or cycling for transportation. It is reasonable to expected that additional time used for active transportation may diminish the time available for leisure time physical activity. Future research needs to identify the extent to which active transportation substitutes leisure time physical activity to properly adjust the baseline leisure time activity levels in the population.

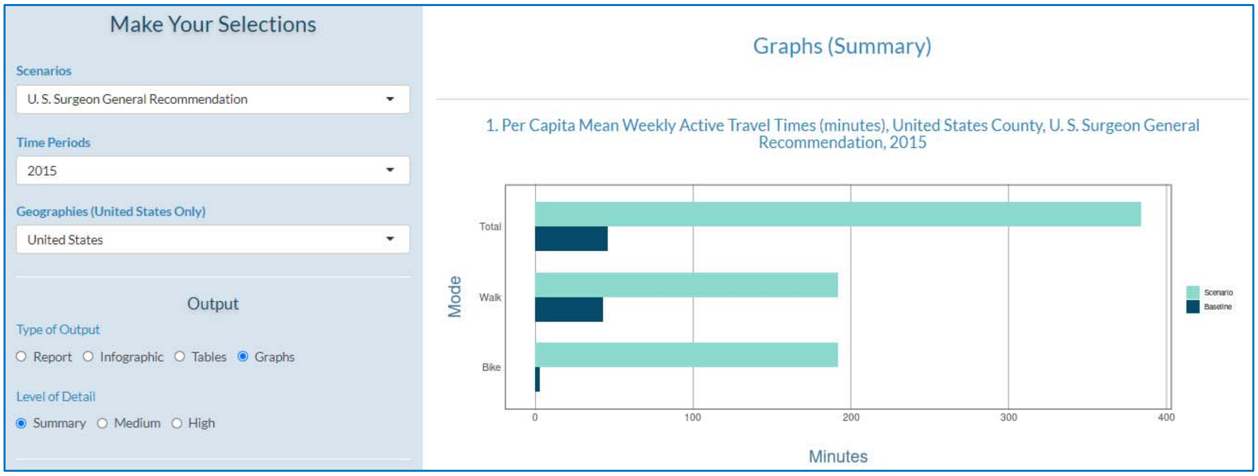
3.2.3 Subsequent Plans and Actions

Prior to 2019, existing implementations of ITHIM in the U.S. were based on an Excel spreadsheet tool that was first developed for implementation in the San Francisco Bay Area in 2011 (see Maizlish et al., 2013). Led by the University of California, Davis (UCD), an open source version of ITHIM was created with sponsorship from the CARB and the California Environmental Protection Agency (Maizlish and London, 2019). Inputs for the development of the Web-based ITHIM was provided by current and potential ITHIM users from small MPOs, state agencies, local health departments, and other stakeholders via participation in an advisory group. Computation formulation in the Excel spreadsheet was coded in the R programming language into an analytic engine, which performs the calculations of comparative risk analysis. A HTML-based user interface (see Figure 13 and Figure 14) was then created for users to run ITHIM calculation over the Internet (ITHIM USA, 2020). It is expected that CARB staff will be able to perform analysis and maintain the website over the 3 to 5 years, before updating of calibration data becomes necessary.



Source: ITHIM USA (2020)

Figure 13 The ITHIM USA user interface



Source: ITHIM USA (2020)

Figure 14 The ITHIM USA presentation of result graphs.

Several directions for future enhancement of the Web-based ITHIM were recommended by the advisory group (Maizlish and London, 2019). Current ITHIM implementations are based on aggregate zones such as Census geographies. Users expressed interest in performing ITHIM analysis with higher geographic resolution in the same way as activity-based travel demand models, in which individual travel patterns are micro-simulated at distinct origins and destinations. Maizlish and London (2019) noted that such efforts are currently being undertaken by ITHIM development team at the University of Cambridge, UK, which is attempting to couple individual-level population simulation with individual level transportation simulation to facilitate more detailed analyses of population subgroups. In addition, a separate effort undertaken by researchers at UCD had developed a disaggregate implementation of ITHIM based on data from the Sacramento region in California for equity analyses involving race/ethnicity subgroups (Wu, Rowangould, Karner, and London, 2019).

Representatives of small MPOs reported barriers in assembling their own calibration data for ITHIM implementation. These MPOs expressed interest in identifying funding for such applications. In addition, these users inquired how the aggregate zones of California ITHIM implementations can be applied to small communities or other situations in which data limitations may hinder applications of ITHIM.

3.3 Disaggregated ITHIM Implementation for the Sacramento Region

3.3.1 Application Context

Health benefits associated with active transportation can vary greatly across subgroups of the population as well as small geographic areas within a region. For example, age is an important factor determining a person's ability of walking and/or bicycling for transportation. Low-income neighborhoods ridden with crime can also deter residents from walking to stores. Understanding differential health outcomes by population subgroups and subareas can help design policies and interventions that bring health to every citizen in every neighborhood. Existing ITHIM applications are based on aggregate zones (e.g., counties), which do not distinguish health risks and benefits by subgroups of the study population. Karner, Rowangould, Wu, Igbinedion, and London (2017) created a version of ITHIM that disaggregated health outcomes by race, ethnicity, and income levels. This research project was sponsored by the National Centers for Sustainable Transportation (NCST), funded by the University Transportation Center program of the U.S. Department of Transportation (NCST, 2020). Although this research was based on the Sacramento Area Council of Governments' (SACOG) Metropolitan Transportation Plan/Sustainable Communities Strategy (SACOG, 2017), SACOG was not involved in the research other than providing data. Technical details of this ITHIM Sacramento implementation are described in chapter 2 literature review.

In 2019, building on the ITHIM Sacramento implementation, the same research team produced another version of ITHIM that is disaggregated by ZIP code areas within the SACOG region (Rowangould, Karner, Wu, Igbinedion, and London, 2017). The purpose of this project was to demonstrate how ITHIM can be adapted to model demographically explicit health outcomes at the neighborhood scale based on transportation plan scenarios. The regional transportation plan for the six-county SACOG region was used as the basis for this project.

3.3.2 ITHIM Implementation

3.3.2.1 Calibration Data

Baseline disease burden data were obtained from the 2010 U.S. Global Burden of Disease, data (IHME, 2015), using DALYs as the measure of disease burden. Baseline all-cause mortality rates for the Sacramento region were based on the 2008-2010 California Department of Public Health (CDPH) Vital Records Data and Statistics (CDPH, 2020). Baseline leisure time physical activity data are from the California Health Interview Survey (UCLA, 2008). Baseline and scenario-specific data on travel distance by automobiles, trucks, and active transportation were derived from Sacramento Activity-Based Travel Simulation Model (SACSIM15) (SACOG, 2015), SACOG's regional travel demand model. Baseline traffic fatalities and injuries for the Sacramento region were obtained from the Statewide Integrated Traffic Records System and the Transportation Injury Mapping System (TIMS) (SafeTREC, 2020).

To disaggregate regional data to ZIP code areas, demographic (i.e., population, age, and gender) data at the ZIP code level were obtained from the 2010 U.S. Census for all zip code tabulation areas (ZCTA) within the SACOG region. Baseline mortality rates for each ZCTA are estimated by multiplying the ZCTA's number of people in each age-gender category with corresponding Sacramento region-wide mortality rate for the same category. Leisure time physical activity data were estimated for each ZCTA with the same method.

Data on scenario-specific active transportation activities were available at the traffic analysis zone (TAZ) level from SACSIM15 outputs. While most TAZ boundaries were identical to

ZCTA, some TAZs were larger than ZCTAs. For TAZs that cover more than one ZCTA, the data of the TAZ were proportionally distributed to the ZCTAs based on the respective ZCTA areas covered by the TAZ. Baseline injury data were first stratified by striking and victim modes, severities, and road types (Rowangould, Karner, Wu, Igbinedion, and London, 2017). Region-wide fatality and injury rates for each stratum were factored into each ZCTA based on the ratio of miles traveled for each mode between each ZCTA and the region.

3.3.2.2 Analysis Scenarios

This study evaluated the health outcomes of the adopted SACOG's 2016 Metropolitan Transportation Plan/Sustainable Communities Strategy for three future years (i.e., 2020, 2027, and 2036). Additionally, three alternative scenarios (i.e., S1, S2, and S3) were also evaluated for health impacts for year 2036. The three scenarios vary in percent increase (i.e., as compared to the 2012 baseline) of land use and transportation investments (Table 29). S2 is the scenario preferred by SACOG. Results of all scenarios are presented as changes with respect to the 2012 baseline conditions.

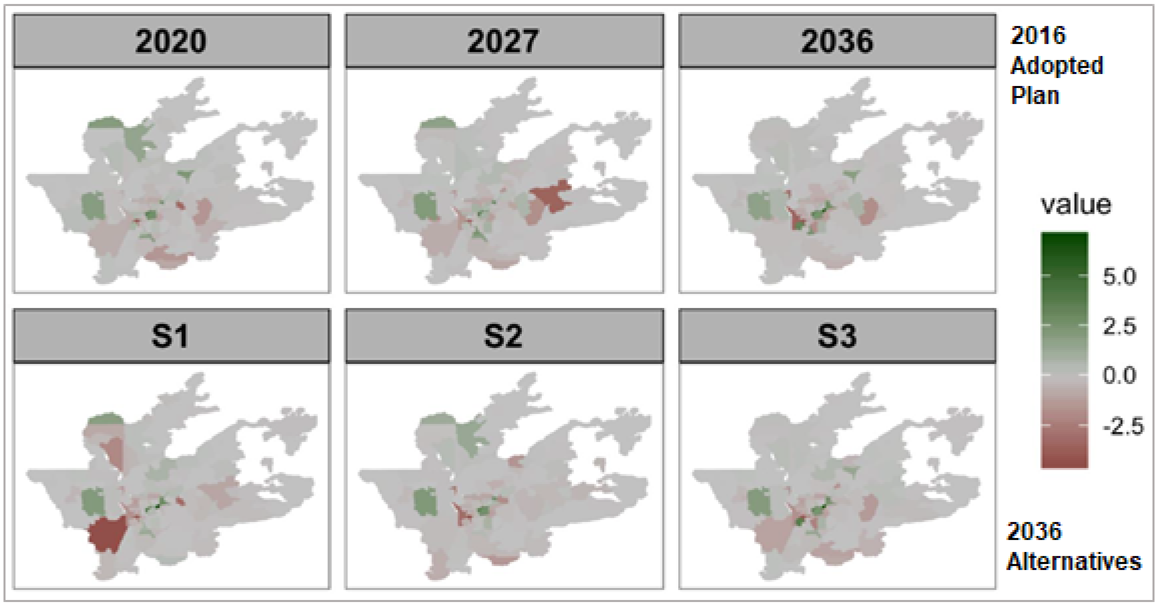
Table 29 Description of the Analysis Scenario for Disaggregated ITHIM Implementation for SACOG MTC/SCS

	S1	S2	S3	Adopted 2016 plan
Transportation investments				
New or expanded roads (lane miles, % increase from 2012)	**31%**	27%	23%	24%
Transit service (vehicle service hours, % increase from 2012)	54%	109%	**143%**	122%
Bike and pedestrian improvements ($ in billions)	$2.8	$2.8	**$3.0**	$2.8
Land use planning				
Share of growth in "Center and Corridor Communities" (percent of homes)	20%	31%	**36%**	30%
Share of growth in "Established Communities" (percent of homes)	**29%**	25%	27%	28%
Share of growth in "Developing Communities" (percent of homes)	**47%**	42%	36%	40%
Newly developed land (acres of development, % increase from 2012)	**11%**	7%	5%	7%
Transportation outcomes				
Vehicle miles traveled (per person per day)	**17.6**	17.2	16.0	17.0
Mode share for transit, walking, bicycling (percent of all person-trips)	12%	12%	**14%**	13%

Source: Rowangould, Karner, Wu, Igbinedion, and London (2017)

3.3.2.3 Analysis Results

Figure 15 through Figure 20 show the respective reductions in DALYs. These maps demonstrate the variation in total death and DALYs reductions driven by variations in differences in demographics and /travel health behavior in the ZIP code areas.

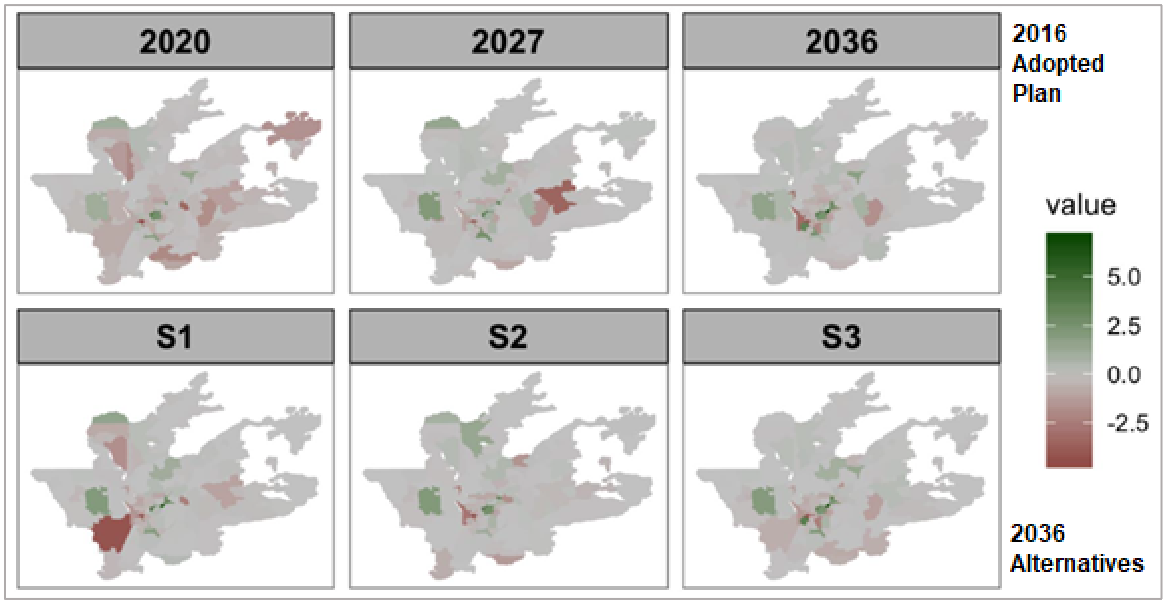


Adapted from: Rowangould, Karner, Wu, Igbinedion, and London (2017)

Figure 15 Total expected reduction in deaths from changes in physical activity.

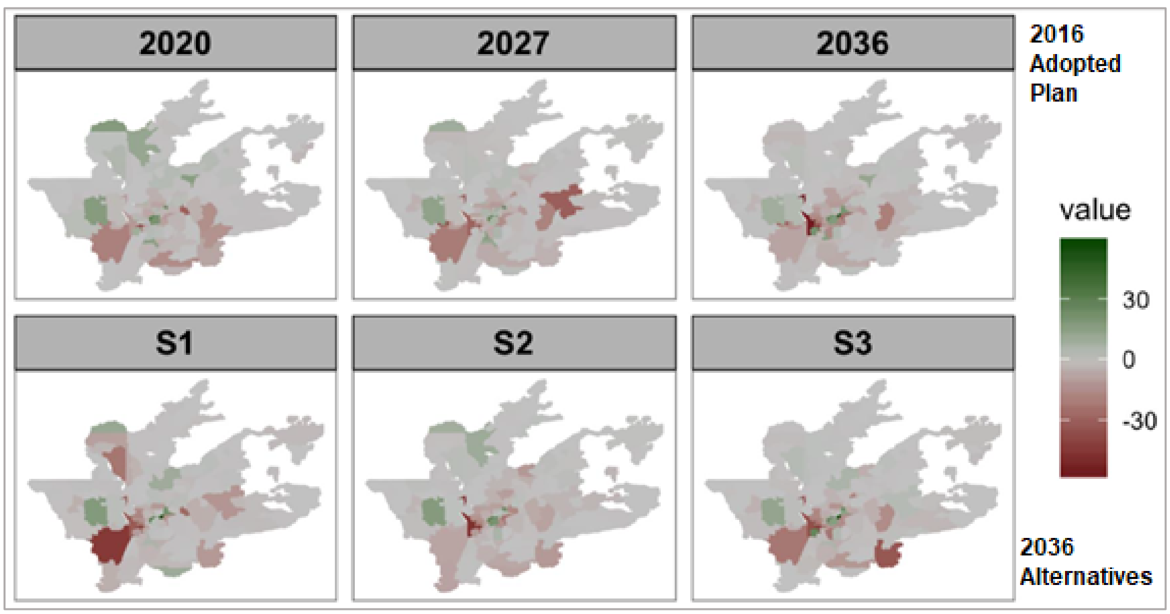
Adapted from: Rowangould, Karner, Wu, Igbinedion, and London (2017)

Figure 16 Total expected reduction in deaths from traffic injury.



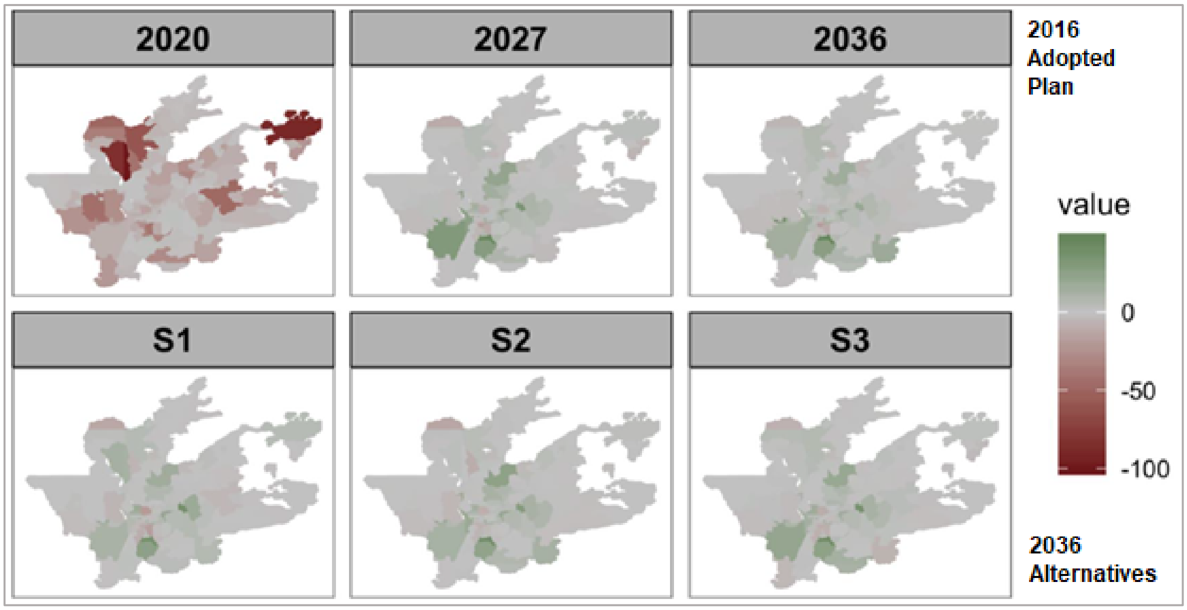
Adapted from: Rowangould, Karner, Wu, Igbinedion, and London (2017)

Figure 17 Total expected reduction in death from physical activity and traffic injury combined.



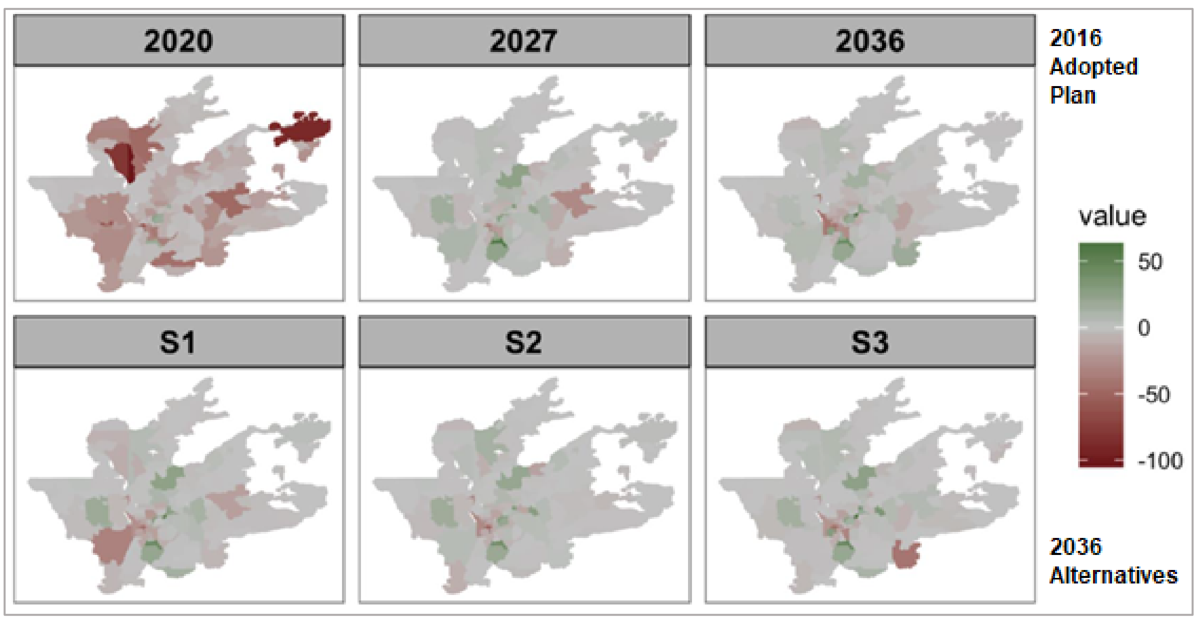
Adapted from: Rowangould, Karner, Wu, Igbinedion, and London (2017)

Figure 18 Total expected reduction in DALYs from changes in physical activity



Adapted from: Rowangould, Karner, Wu, Igbinedion, and London (2017)

Figure 19 Total expected reduction in DALYs from changes in physical activity.



Adapted from: Rowangould, Karner, Wu, Igbinedion, and London (2017)

Figure 20 Total expected reduction in DALYs from traffic injury.

3.3.2.4 Strengths and Limitations

As demonstrated with Figure 15 to Figure 20, one of the strengths of the disaggregate approach is that ZIP code areas with increased deaths and DALYs that could be results of underlying socioeconomic and health environment inequity in the neighborhoods can be identified geographically. Such inequities cannot be identified with aggregate approach at the regional level. A geospatially disaggregated ITHIM tool can help visualize the health impacts of different planning scenarios, which can help planners and policy makers reach informed decisions about the region's future that address the well-beings of every citizen. However, spatial resolution of such analysis is limited by available resources at the neighborhood levels. For example, Rowangould, Karner, Wu, Igbinedion, and London (2017) noted difficulties in obtaining health and leisure time physical activity data at the ZIP code level. Instead, simplified assumptions were made to approximate values for these ZIP codes based on regional statistics. Thus, the study could not fully address the benefits and challenges inherent in modeling disaggregate health outcomes. The research team recommended performing sensitivity analysis to various model formulations to identify the potential range of uncertainties resulting from the data limitation.

3.3.3 Subsequent Plans and Actions

After conclusion of the research project, the research team of the ITHIM Sacramento study made the resources developed for this study available via public access Web sites (Karner, 2020), which include all relevant reports and the R-programming source codes used to run the analysis. The results shown in Figure 15 to Figure 20 can also be viewed interactively over another Web site developed by the research team (Wu, Rowangould, Karner, Igbinedion, and London, 2020).

3.4 Summary

We examined three prominent ITHIM implementations in the United States: GNRC, five major California MPOs, and SACOG in California. GNRC's application of ITHIM was conducted as one of the many efforts of the regional governments to promote public health through active transportation. As a result, GNRC established a regional transportation planning process that takes health and active transportation into consideration. California's policy initiatives targeted for GHGE reduction from vehicular sources was the major incentive behind the implementation with the five largest MPOs in California. Several public agencies in the state of California (e.g., California Department of Public Health and California Air Resource Board) acquired resources to conduct ITHIM applications for suitable projects in the future. The Sacramento application showcased the potential benefits and technical challenges of disaggregating ITHIM analyses by population groups and geographic divisions.

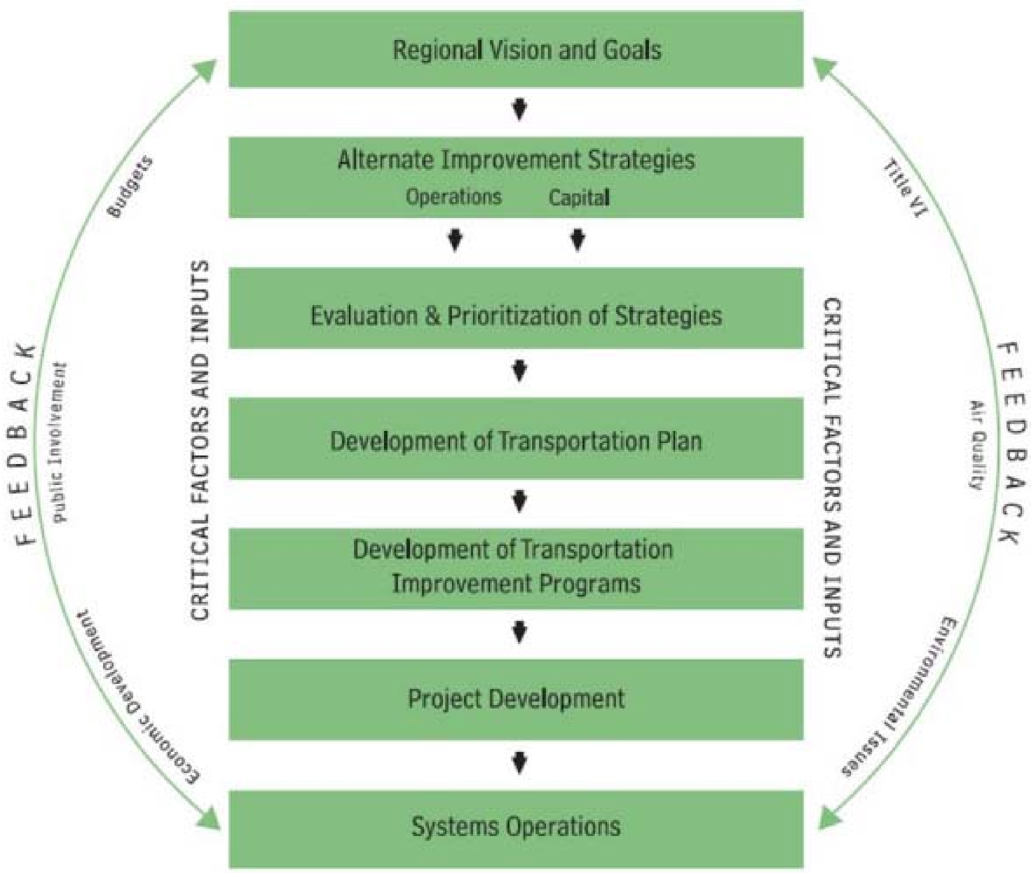
These three ITHIM case studies offered useful perspectives and modeling techniques that can be followed by a similar application in South Florida. We learned from the GNRC's experience that public support for active transportation investments can be increased by coupling an ITHIM implementation with other regional planning initiatives. The disaggregate approach demonstrated with the Sacramento implementation has the potential to result in an ITHIM application that can highlight underlying health disparities in Miami's neighborhoods with diverse socioeconomic and race/ethnic backgrounds. We also recognize technical advantages of running ITHIM analyses with computation apps developed in the R language like those developed for California Air Resource Board.

CHAPTER 4 FRAMEWORK RECOMMENDATION

Combining the results of literature review and case studies, we formulated a framework for transportation project health impact assessment (HIA). The framework includes the procedures and modeling processes that can be integrated in the transportation planning process by metropolitan planning organizations (MPO) in the State of Florida and US in general. We also documented available data sources to be used for applications of the framework in South Florida.

4.1 Metropolitan Transportation Planning Process

Transportation planning for a metropolitan area in the United States is a cooperative process led by the federally designated MPO for the area with involvement from the stakeholders, including state transportation agencies, environmental agencies, transit operators, freight operators, and concerned members from the local communities. The transportation planning process of a MPO determines long- and short-range transportation improvement strategies and priorities for the area (FHWA, 2019). Figure 21 shows individual steps in the metropolitan transportation planning process.



Source: FHWA (2019)

Figure 21 The transportation planning process.

The transportation planning process begins with establishment of overall vision and goals for the region's transportation systems such as congestion relief, safety improvement, economic development, or environmental conservation. Attainment of the goals is determined by a set of performance measures defined with inputs from the stakeholders. Performance measures of the existing transportation systems are surveyed and the baseline condition representing current transportation systems inventory and performance is then established. Future demand for the transportation systems in terms of population and employments in the region are then projected for both short-term future (e.g., 3 to 5 years) and long-term (e.g., 25 years). Performance measures of the transportation systems are then evaluated for the short- and long-term future and compared to the baseline condition. If problems with respect to the regional goals are anticipated, improvement strategies are devised and evaluated for performance measures. These strategies are the prioritized and selected for future implementation according to criteria agreed upon by stakeholders.

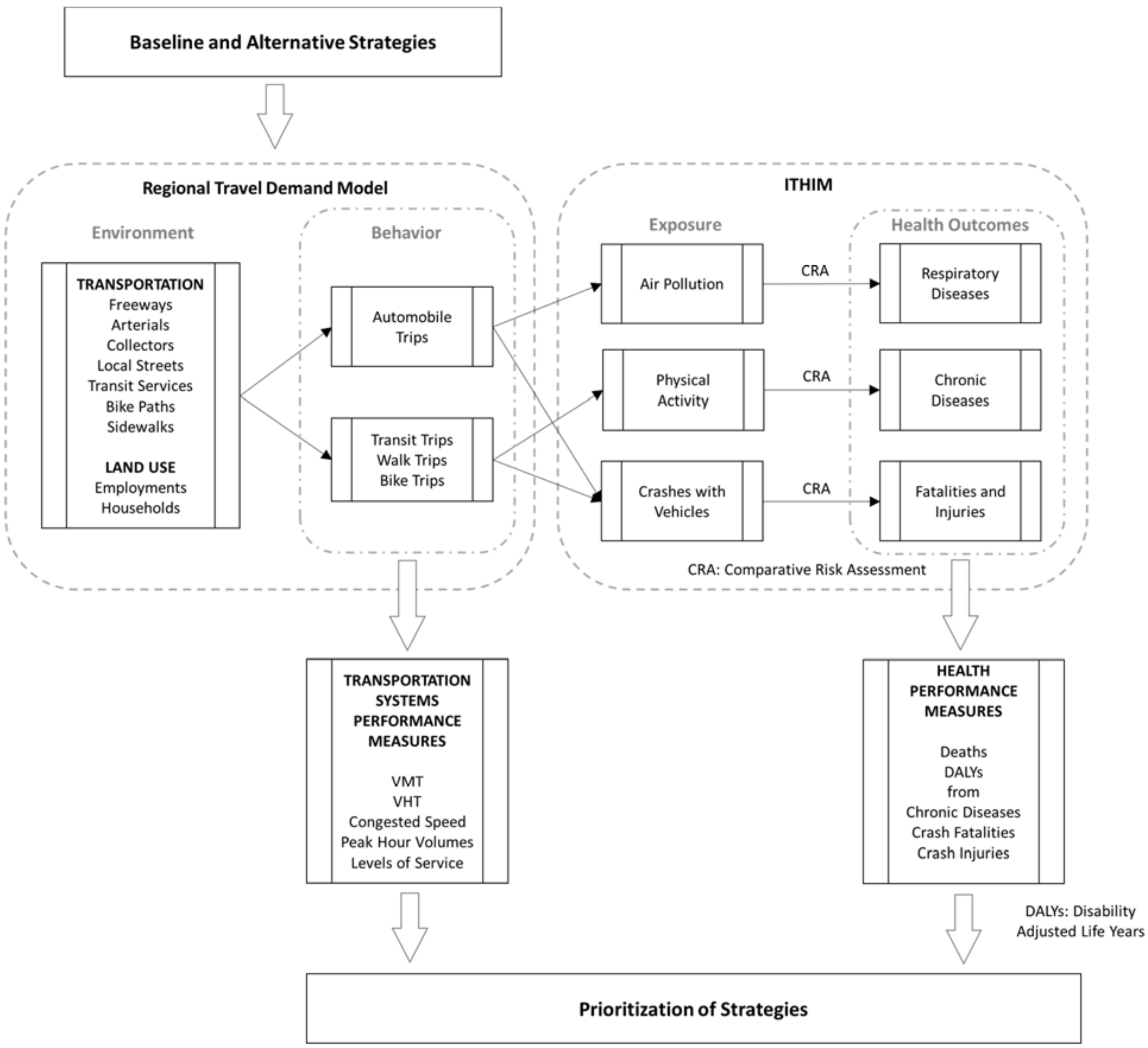
Strategies chosen for long-term improvement are contained in the long-range transportation plan for the region while those for short-term future in the transportation improvement program. Attainment of the regional vision and goals by he chosen long- and short-term strategies are evaluated. The long-range transportation plan and the short-term transportation improvement program are approved if attainment of regional goals can be expected. A financial plan is then developed to cover the cost of implementing the short- and long-term strategies.

The transportation planning process discussed above is implemented accordingly by all MPOs in the United States. The long-range transportation plan and short-term transportation improvement program need to be updated periodically by a MPO to satisfy requirements set forth by FHWA and FTA for funding purpose (FHWA, 2019).

4.2 Integrated Transportation and Health Evaluation

As shown in Figure 21, evaluation of a transportation improvement strategy for performance measures is carried out in the step, Evaluation & Prioritization of Strategies. A travel demand model for the MPO is developed for the purpose of evaluating systems performance with respect to the projected future population and employment (FHWA, 2019). The Integrated Transport and Health Impact Modelling Tool (ITHIM) can be integrated with the MPO's travel demand model to add performance measures related to health impacts due to changes in physical activity participation and crash frequency. Figure 22 shows the integrated process adapted from the implementation process of ITHIM for the Nashville area MPO (Meehan, 2015).

Evaluation of the improvement strategies' performance measures begins after the baseline condition and alternative strategies are defined. On the left-hand side of Figure 22 is the travel demand modeling process that produces traditional system-wide or corridor-level performance measures such as Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), average congested speed, peak hour volumes, and level of services. These metrics can be further processed with emissions models to produce air quality projections for the alternative strategies. For MPOs designated as air quality non-attainment areas by the U.S. Environmental Protection Agency (EPA), the air quality projection is one of the most critical criteria to determine the priority of a strategy (FHWA, 2019).



Note: Adapted from Meehan (2015)

Figure 22 Integrated transportation and health evaluation framework.

The right-hand side of Figure 22 shows how ITHIM can be integrated with the MPO's travel demand model to produce performance measures related to the public health in the region. When combined with health data for the MPO region, the outputs of the travel demand model in terms of overall vehicle volumes and VMT on the region's roadway networks as well as the proportions of travelers who walk, bike, or use transit can be entered into ITHIM calculation for health-related performance measures corresponding to the alternative strategies. The health performance measures can also be factored into the prioritization process and communicated to the stakeholders for informed decision-making.

4.3 Potential Data Sources for ITHIM Implementation in South Florida

Table 30 shows potential data sources for ITHIM implementation in South Florida.

Table 30 Potential Data Sources for ITHIM Implementation in South Florida

Source	Calibration Data Item	Units	Strata
Southeast Florida Household Travel Survey (WSP, 2017) and Southeast Florida Regional Planning Model (SERPM 8) (FSUTMS, 2020)	Per capita mean daily travel distance	Miles/person/day	Travel mode
	Per capita mean daily travel time	Min/person/day	Travel mode
	Ratio: per capita mean daily active transportation time (reference group: females aged 15–29 years)	Dimensionless	Walk, bike, age, sex
	Standard deviation of mean daily active transportation time	Min/person/day	None
	Walking speed	Miles/hour	None
	Ratio of daily per capita bicycling time to walking time	Dimensionless	Bicycle, walk
	Personal auto travel distance and time	Miles and hours/day	Driver, passenger
SERPM 8 (FSUTMS, 2020)	Vehicle miles traveled (VMT) by facility type	Miles/day	Travel mode and road type
US Census	Distribution of population by age and gender	%	Age, sex
Florida Behavioral Risk Factor Surveillance System (BRFSS) Data (FDH, 2017)	Per capita weekly non-travel related physical activity	MET-hours/week	Median of quintile of walk +bicycle METs, by age and sex
	Age-sex specific ratio of disease-specific mortality rate between South Florida and USA.	Dimensionless	Disease group, age, sex
	Proportion of colon cancers from all colorectal cancers	Dimensionless	None
Florida Crash Report (FLHSMV, 2020)	Serious and fatal injuries between a striking vehicle and a victim vehicle in road traffic collisions	Injuries	Severity, striking mode x victim mode, road type
Florida's Air Quality System (FDEP, 2020)	Emissions of PM2.5 attributable to light-duty vehicles	Tons/day	None

Adapted from Whitfield et al. (2017)

The Southeast Florida Household Travel Survey (SEFHTS) is the regional household travel survey conducted in the spring of 2017 (WSP, 2017). The SEFHTS was designed to provide data for development and calibration of the latest regional travel demand model, version 8 of the Southeast Florida Regional Planning Model (SERPM 8) that covers Miami-Dade, Broward, and Palm Beach counties in South Florida. SERPM 8 is an activity-based model that uses microsimulation to produce individual travel patterns for the synthetic population of the three-county region (FSUTMS, 2020). Travel behavior data required for ITHIM calculations for the baseline conditions can be provided by SEFHTS data while those for the alternative strategies by SERPM 8 results.

Most recent data on the study area's population by age and sex can be provide by the U.S. Census. Participation in non-travel related physical activities (i.e., leisure, domestic, and occupational physical activity) as well as mortality by diseases can be obtained from the Florida Behavioral Risk Factor Surveillance System (BRFSS) (FDPH, 2017), which is the Florida state branch of the national BRFSS sponsored by the Centers for Disease Control and Prevention (CDC). Traffic injuries and fatalities by roadway types (i.e., local, arterial, and highway) and by the modes involved (i.e., striking and victim vehicle) can be obtained from the Florida Crash Report compiled annually by the Florida Highway Safety and Motor Vehicles (FLHSMV, 2020). The Florida Department of Environmental Protection (FDEP) can provide average annual $PM_{2.5}$ (i.e., particulate matter smaller than 2.5 micrometers in diameter) concentrations (FDEP, 2020).

CHAPTER 5 SUMMARIES AND CONCLUSIONS

We accomplished the objectives of this research by completing three tasks: literature review, case studies, and framework development. For literature review, we concluded that transportation plans and projects that promote active transportation can help solve transportation and public health issues facing south Florida, especially stroke, diabetes, and injuries and fatalities involving pedestrians and bicyclists. Latest evidences in medical and public health research show that all-cause mortalities and the prevalence of cardiovascular disease, diabetes, weight gain, dementia, depression and injuries due to falls by the seniors can all be reduced by a greater rate of participation in physical activity by the public. Together, these medical conditions represent a significant amount of economic cost in the U.S.

To promote Complete Streets projects, conducting HIA for these projects can show the general public what health benefits and associated economic benefits are expected of these projects. As for specific HIA tools that suit the needs of south Florida, we conclude that ITHIM is the best choice for implementation of HIA in this region, because ITHIM has had successful implementations in the United States, including multiple MPOs in California and Nashville in Tennessee. ITHIM's ability of modeling three transportation impacts that are important in south Florida, namely physical activity, air pollution, and traffic injuries with pedestrians and cyclists, is also an important criterion for the decision.

For case studies, we examined three prominent ITHIM implementations in the United States (i.e., greater Nashville area in Tennessee, five major California MPOs, and counties in Sacramento, California). Nashville's application of ITHIM was conducted with many other joint efforts of the regional governments to promote public health through active transportation. Results of these efforts helped the region formalize regional transportation planning that take health and active transportation into consideration. The implementation with the five largest MPOs in California was driven by California's policy initiatives targeted for greenhouse gas emissions reduction from vehicular sources. Involvement from several public agencies in the state of California (e.g., California Department of Public Health and California Air Resource Board) in this ITHIM study helped the agencies acquire resources to conduct ITHIM applications for suitable projects in the future. The Sacramento application was a research project that highlighted the potential benefits and technical challenges of disaggregating ITHIM analyses by population groups and small geographic divisions.

All three ITHIM case studies offer useful perspectives and modeling techniques that can be followed by a similar application in South Florida. For example, we learned from the GNRC's experience that an ITHIM implementation can be coupled with other regional planning initiatives to increase public support for active transportation investments. We also recognized that the disaggregate approach demonstrated with the Sacramento implementation has the potential to result in an ITHIM application that can highlight underlying health disparities in Miami's neighborhoods with diverse socioeconomic and race/ethnic backgrounds. In addition, we see technical advantages of running ITHIM analyses with computation apps developed in the R language like those developed for California Air Resource Board.

We also identified a specific area of improvement for future ITHIM implementation in South Florida. Unlike travel behavior or health data, vehicle crash data are often geocoded by the exact locations. Future ITHIM applications may incorporate local crash data to develop crash fatalities and injuries rates at a local scale. In addition, using distance-based crash rates developed from existing crash data may over-predict the numbers of pedestrian and bicyclist fatalities and injuries for future smart growth facilities that will be designed and enhanced with safety features. One way to address this issue is to incorporate crash modification factors suitable for smart growth facilities in the estimation and prediction of future pedestrian and bicycle facilities.

Based on the results of our literature review and case studies, we developed a modeling framework to integrate transportation and health impact assessment for MPO transportation planning in the United States. This framework can be integrated into the transportation planning process endorsed by FHWA and FTA. We also identified potential data sources that can be used for implementation of this framework in South Florida.

In November 2014, the Miami-Dade County (MDC) Commission adopted its own Complete Streets policy through Resolution 995-14 (MDC, 2020). MDC's Complete Streets Resolution aims to transform the County's roadway facilities into healthy and sustainable mobility options for all users equally whether they are walking, biking, riding transit, or driving automobiles. To facilitate effective design and construction of Complete Street projects in the county, the official Miami-Dade County Complete Streets Design Guidelines (MDC, 2020) was later created and adopted with funding from the U.S. Centers for Disease Control and Preventions (CDC). As a result of all the ongoing efforts, Complete Street projects are now included in the latest 2045 Long Range Transportation Plan (Miami-Dade TPO, 2020a) as well as the 2012-2015 Transportation Improvement Program (Miami-Dade TPO, 2020b) by the Miami-Dade Transportation Planning Organization (TPO). However, although these projects were strategically planned with extensive resources from the county, assessment of these projects' health benefits in terms of increasing participation in active transportation, improving air quality, and reducing pedestrian and bicyclist crashes has not been attempted. There is generally a lack of information in all relevant planning documents regarding how potential health benefits of a project are factored into its priority in project selection. To support efforts for the planning and programming of Complete Street projects in MDC and elsewhere in Florida, there is a urgent need to begin developing and applying a HIA tool that can quantify and communicate the health benefits of these projects to the public.

Within the context of promoting Complete Street projects, there is a urgent need to develop a functional HIA tool based on the ITHIM architecture for the Miami-Dade TPO and apply local data to evaluate the health benefits of Complete Street projects in the most recent long range transportation plan and transportation improvement program of the TPO. The successful experience by the GNRC and MPOs in California can be replicated by the Miami-Dade TPO. In addition, the most recent travel demand model for South Florida, Version 8 of the Southeast Florida Regional Planning Model (SERPM), is an activity-based model that uses micro-simulation to produce individual travel pattern for the synthetic population of the region (FSUTMS, 2020). Integrating SERPM with an ITHIM analysis app coded in the R language has the potential of producing health outcome projection for a future transportation investment scenario immediately after completing the SERPM model run. It is expected that a ITHIM application for Miami-Dade TPO as discussed above can offer the following benefits to the transportation planning processes in the region:

1. A functional tool for quantification and communication of health benefits of Complete Street projects to the public.
2. Addition of health metrics (e.g., reduced fatalities, injuries, and chronic disease incidences) as criteria for transportation project prioritization.
3. Effective planning and prioritization of Complete Street projects.
4. Increased public awareness of the health benefits of, and support for Complete Street projects and active transportation.
5. Increased Complete Street projects and public participation in active transportation in MDC, leading to increased public health and environmental sustainability.

With a successful application of HIA in South Florida, the HIA tool can be adapted for applications by other MPOs in Florida to increase statewide awareness and support for Complete Street projects. Furthermore, consultation and support from U.S. CDC can be sought to make the products of this research transferable to other U.S. urban areas interested in conducting HIA for transportation projects, effectively making Miami-Dade TPO and Florida leaders in HIA for transportation projects in the United States.

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