ITHIM USA | Integrated Transport and Health Impact Model

User's Guide and Technical Manual

USA R/Shiny Version

by

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Glossary of Acronyms and Terms

Acronym	Definition
BAU	Business as Usual
BD	Burden of Disease (includes injury)
CRSS	Crash Report Sampling System
CRA	Comparative Risk Assessment
CV	Coefficient of variation (standard deviation/mean)
CVD	Cardiovascular Disease
FARS	Fatality Analysis Reporting System
HHD	Hypertensive heart disease
DALY	Disability Adjusted Life Year = Years of Life Lost + Years Living with Disability
MOVES	MOtor Vehicle Emission Simulator
Facility	Engineers' parlance for a roadway, bridge, highway ramp
GBD	Global Burden of Disease (includes injury)
ICD	International Classification of Diseases (5-digit hierarchical code)
ITHIM	Integrated Travel and Health Impact Model
MET	Metabolic Equivalent Task
mMET	Marginal MET (MET - 1)
MPO	Metropolitan Planning Organization
NHANES	National Health and Nutrition Examination Survey
NHTS	National Household Travel Survey
PA	Physical Activity
PAF	Population Attributable Fraction
PM2.5	Particulate matter with an aerodynamic diameter of 2.5 microns or less
PMT	Personal Miles Traveled (VMT and PMT are related through occupancy)
RR	Relative Risk (ratio of disease/injury rate in population with exposure over rate of disease/injury in a non-exposed population
RTI	Road Traffic Injuries
VMT	Vehicle Miles Traveled
WHO	World Health Organization
YLD	Years Living with Disability
YLL	Years of Life Lost

Introduction

The Integrated Transport and Health Impact Model (ITHIM) is a tool to quantify the health co-benefits of travel-related reductions in greenhouse gas emissions. Health impacts of active transportation and low carbon driving are mediated through changes in population distributions of physical activity, ambient fine particulate matter, and road traffic injuries. Use cases of ITHIM include:

- Quantify health benefits and harms of regional and local transportation and land use plans
- Provide information to policy makers on opportunities to improve the health impacts of their transportation investments
- Evaluate the health impacts of targets and project performance of regional transportation plans
- Provide a tool for students and researchers to learn about the interrelationships between health, transportation, and land use.

ITHIM has been implemented as a suite of related models in the United States and the United Kingdom that differ in platforms and capabilities. The development of ITHIM in the United States has been a partnership of regional transportation and state and federal health agencies in California, Oregon, Maryland, Tennessee, and Vermont.

Purpose and Audience of this Guide

The purpose of this guide is to support users of the web-based United States R/Shiny version of ITHIM (https://ithim.org/ithim). While the *Guide* uses national data to illustrate use, calibration, and integration with travel demand models, the process may be adapted to other locations in the United States and other countries.

This guide is oriented to technical staff of governmental and nongovernmental organizations and academic researchers who want a detailed understanding of comparative risk assessment models, their data, and their implementation in ITHIM USA. The *Guide* will help build a common vocabulary for technical staff from different disciplines – transportation and urban planning, epidemiology, health policy, economics – whose collaboration is an essential ingredient of a successful implementation.

For policy-oriented and less technical users, the ITHIM USA website (https://ithim.org/ithim) offers short video tutorials on website contents and navigation, and workshop slides that describe the health outcomes and mechanics of the model.

Organization of the Guide

The *Users' Guide* has two chapters and 3 technical appendices. Chapter 1 describes comparative risk assessment methodology, which is the conceptual and technical basis of the ITHIM USA model. It also describes the health outcome of disability adjusted life years. Chapter 2 reviews the features of the ITHIM USA website. It describes each web page, how to navigate the website, and how to use the tool page (RunITHIM) to carry out a health impact analysis. This chapter also describes several aspirational and "What if" scenarios that allow you to create scenarios on-the-fly by altering levels of walking, cycling, and transit. Appendix A describes how data were processed from primary sources to create calibration data. Appendix B describes the procedures to process and format outputs of travel demand or activity-based models as inputs for ITHIM USA as user-uploaded scenarios. Appendix C describes how to estimate total walking and bicycling times when increasing transit (and transit-associated active transport) in the Baseline Multiples scenario.

Software History and Versions

ITHIM was originally developed by a research team headed by Dr. James Woodcock at London School of Hygiene and Tropical Medicine in 2010 and later at the University of Cambridge, United Kingdom. The first California version of ITHIM model was implemented as a spreadsheet in Excel using aggregate data for individual regions of California. Adaptations of this software for the United States and California have been co-developed by Dr. Neil Maizlish, affiliated with the California Department of Public Health (2011-2015), and the University of California, Davis (2018-2019). Dr. Woodcock has developed a version (2.5) based on aggregate data using the modeling software called Analytica. Dr. Woodcock's research team is developing R/Shiny versions of ITHIM (3.0) that simulate individuals' travel patterns and health outcomes in populations.

The June 2020 release of ITHIM USA (R/Shiny) represents a significant advance from previous spreadsheet versions (See comparison table next page). The July 9, 2021 version incorporates updated dose-response functions and, for physical activity, a dose scale based on marginal METs (mMET-hr/w). Physical activity for all health outcomes includes active transport and leisure time activities, but excludes occupational physical activity. Lung cancer was also added to the health outcomes for physical activity.

Licensing

We would welcome feedback on the use of this model, including any errors or bugs detected. Send reports to Dr. Neil Maizlish (neil3971@comcast.net).

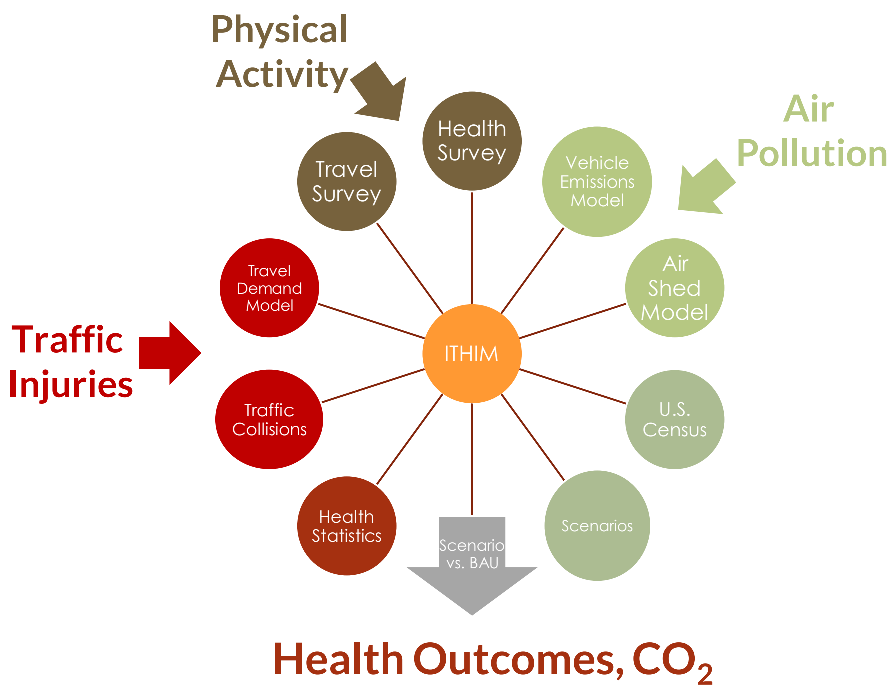
Comparison of Features in the Spreadsheet and R/Shiny Versions of ITHIM USA

Feature	ITHIM USA Version	
	Spread Sheet	R/Shiny
Years in Use	2011-2017	2020-2021
Analytic Engine	Five regional Excel workbooks with 35 Excel worksheets per workbook; formulae and data distributed in thousands of cells	One R program accessing 25 data files
Interface	Rudimentary and difficult to use without training	R/Shiny web-application; easy to use and graphically appealing; tool driven by dropdown menus/radio buttons; background information and decision support materials incorporated into the website
Reporting	Highly detailed outputs distributed in multiple worksheets, specific for each region; statewide analysis require manual pooling of regional results	Outputs include a "mini report"/elevator pitch, infographic, publication-ready tables and graphs at summary, medium, and high level of detail
Scenarios	Regions varied in available scenarios	Travel data standardized for scenarios based on state agency goals, regional transportation plans, or substituting half of short car trips with active travel
Air Pollution (fine particulate matter, PM2.5)	Data only available for SF Bay Area	Data available for entire United States

Chapter 1. Concept

The Integrated Transport and Health Impact Model (ITHIM) integrates travel and health data from multiple sources to predict changes in health and carbon emissions.[1-3]

Figure 1.1 ITHIM Integrates Data on Health and Travel



Health Outcomes

Previous research has identified physical activity, air pollution, and traffic injuries as the main, direct pathways of transportation-related health co-benefits and harms.[4] The model's conceptual basis is comparative risk assessment.[5] It formulates a change in the burden of disease, *BD*, due to the shift in the exposure distribution from a baseline scenario to an alternative. This is an extension of the population attributable fraction (PAF) formula, in which an exposure, x, has a continuous distribution.

$$\Delta BD = \frac{\int_{\text{Xmin}}^{\text{Xmax}} RR(x)P(x)dx - \int_{\text{Xmin}}^{\text{Xmax}} RR(x)Q(x)dx}{\int_{\text{Xmin}}^{\text{Xmax}} RR(x)P(x)dx} \times BD_{Baseline} \cdot$$

where,

$$PAF = \frac{\int_{\text{Xmin}}^{\text{Xmax}} RR(x)P(x)dx - \int_{\text{Xmin}}^{\text{Xmax}} RR(x)Q(x)dx}{\int_{\text{Xmin}}^{\text{Xmax}} RR(x)P(x)dx}$$

The relative risk, RR, at exposure level (x) is weighted by the baseline and alternative population distributions, P(x) and Q(x), respectively, and summed over all exposure levels. The burden of disease can be measured by the number of deaths or a more comprehensive measure called disability adjusted life years (DALY), which are the sum of years of life lost due to premature mortality, YLL, and years of living with disability, YLD. This is illustrated below for a one individual in a population, but the measure is applied to all individuals in a population.

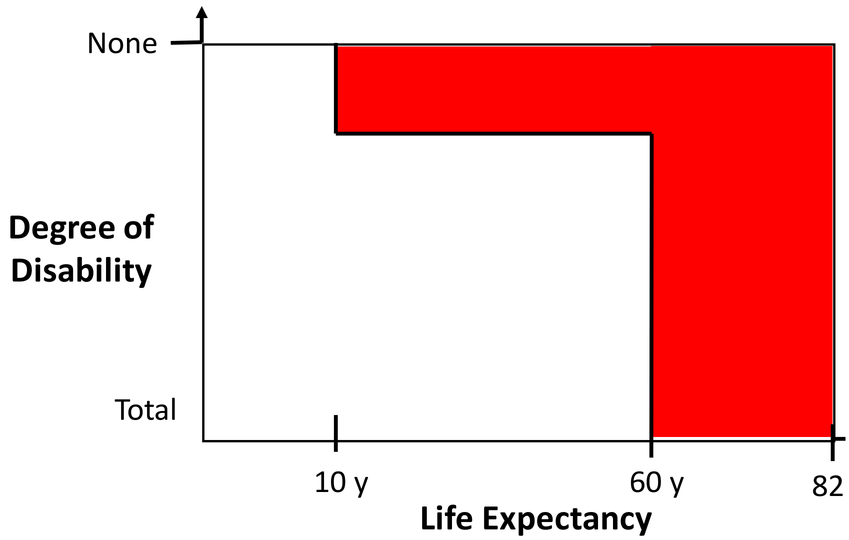


Figure 1.2 A woman who has a brain injury from a traffic collision at age 10 dies prematurely at age 60. Assuming a disability weight for injury at 0.63, her loss in DALYs is:

Years living with disability + years of life lost

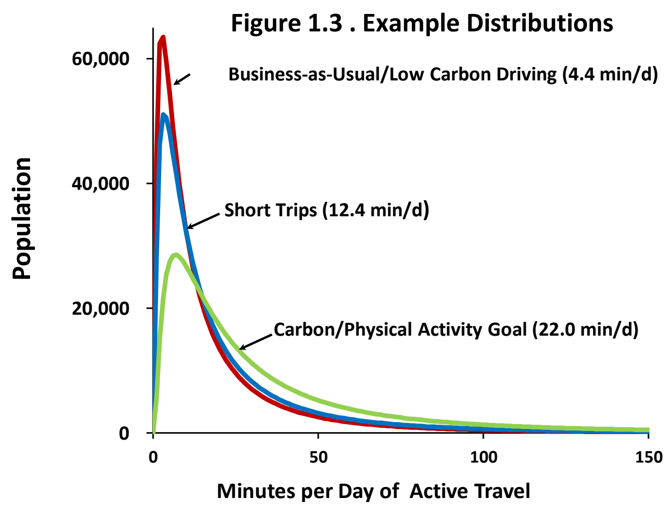
(60y-10y) × 0.63 + (82.5y – 60y) × 1.0 = 15 + 31.5 = 46.5 y

ITHIM incorporates specific causes that have strong evidence of a relative risk (RR)-exposure gradient for physical activity and air pollution, based on systematic reviews. These causes include cardiovascular diseases, colon cancer, breast cancer, lung cancer, respiratory disease, diabetes, and dementia.[6]

Exposure Distributions

Physical Activity

Physical activity includes both travel and non-travel related physical activity (PA). Activity times are multiplied by weights to give metabolic equivalent task hours (METS), which reflect energy expenditures for walking and cycling at average speeds and leisure time activities.[7] Idealized exposure distributions are illustrated in Figure 1.3.



Energetic intensity was rescaled to marginal MET hours per week (mMHW), which discounts physical activity between the states of sleep and rest. The physical activity distribution was derived from the log transformed per capita mean weekly minutes of active travel and its standard deviation. The distribution was approximated in quintiles and stratified by sex and age (0-4, 5-14, 15-29, 30-44, 45-59, 60-69, 70-79, 80+). mMET weights for walking reflected age and sex variation from an average walking speed of 3 miles per hour (~3 mMETS) and those for cycling were based on an average speed of 12 miles per hour (5 mMETS). The change in dose (Δ), reflected changes in the distribution of mMET-weighted walking and cycling times from a baseline, b, to the alternative scenario, s (e.g., electrification, VMT reduction through active travel).

The dose-response function was non-linear,[6] disease-specific, and, as incorporated into the population attributable fraction, PAF, has the form:

$$PAF = 1\text{-RR, where RR} = \frac{rr_s}{rr_b} = \frac{\exp(\beta * \Delta mMHW_s)}{\exp(\beta * \Delta mMHW_b}$$

The PAF is calculated from an overall relative risk, RR, which incorporates relative risks of baseline (rr_b) and scenario (rr_s) at their respective mMHWs on the dose-response curve. Based on meta-analyses of Garcia et al (2021),[8] the dose-response decreased approximately linearly up to 10 mMHW. For higher levels, we set the relative risks to those of 10 mMHW.

Dose-response gradients, e^{β}, (change in relative risk per mMHW) were as follows for ischemic heart disease (0.9764), hypertensive heart disease (0.9764), stroke (0.9697), dementia (0.9666), diabetes (0.9666), depression (0.9695), colon cancer (0.9940), breast cancer (0.9813), and lung cancer (0.9771). The relative risk-physical activity gradient was based on active travel and leisure time physical activity. Age and sex specific leisure physical activity times at quintiles of active transport times were estimated from NHANES data that reported breakdowns of physical activity for leisure activities apart from walking and cycling for transport.[9]

Air Pollution

The distribution of fine particulate air pollution ($PM_{2.5}$) in populations is characterized by its mean, and the population attributable fraction is given by:

eq. 1

$$PAF = 1 - e^{\beta(x_0 - x_1)}$$

Where *β* is the coefficient for the dose-response gradient (*ln* RR) between the health outcome per unit of air pollution (e.g. $\mu g/m^3$) and x_0 is the baseline mean ambient concentration of $PM_{2.5}$ and x_1 is ambient mean concentration of $PM_{2.5}$ under the alternative scenario. (x_0 - x_1 are often represented by Δx, or change in $PM_{2.5}$ concentrations.) The value of β was based on the meta-analysis of Vodonos et al (2018).[10] The means are expressed as population-weighted averages, which are outputs of two modeling processes: transportation emissions and chemical transport models.[11] Emissions models simulate the entire fleet of motorized vehicles and generate primary and secondary constituents of $PM_{2.5}$ (in tons/d). The chemical transport models integrate weather-related movement of air masses, fluid dynamics of the air shed, and photochemical reactions among primary and secondary constituents of transportation and non-transportation-related $PM_{2.5}$.

Because chemical transport models are complex and resource intensive, techniques are available to estimate health impacts as a function of emissions[12] rather than ambient $PM_{2.5}$ concentrations. These techniques take advantage of the observation that, in most air sheds across the United

States, ambient $PM_{2.5}$ levels linearly track emission levels of primary and secondary sources of PM2.5.

The U. S. Environmental Protection Agency has estimated mortality in using incidence per ton (IPT) of specific emissions applied to a 2016 baseline population of the United States.[12]

$$eq.\ 2 \qquad Incidence\ (deaths) = \sum_i^n c_i \times TPD_i$$

where the total incidence of deaths is the sum of product of tons per day (TPD) of pollutant i and a constant, c (Table 1.1). The pollutants of interest are primary emissions of $PM_{2.5}$, including tire and brake wear, nitrogen oxides (NO_x), and sulfate (SO_2).

Table 1.1 Annual Mortality per Ton of PM2.5 Precursors, c_i, On-Road Vehicles

Year	NOx	PM2.5	SO2
2016[a]	0.000890	0.043000	0.002300
2020[b]	0.000920	0.044000	0.002400
2025[c]	0.000980	0.048000	0.002600
2030[d]	0.001000	0.051000	0.002900
2035	0.001049	0.053856	0.003075
2040	0.001090	0.056858	0.003290
2045	0.001132	0.059860	0.003504
2050	0.001173	0.062862	0.003719

Source: Office of Air Quality Planning and Standards[12]
[a] Table 30; [b] Table 30; [c] Table 30; [d] Table 30; 2035-2050 were linearly extrapolated

Through the population attributable fraction (PAF) formula that underlies both the IPT and ITHIM, it is possible to equate emissions and $PM_{2.5}$ concentrations through an equivalency in deaths for the same air basin:

$$eq.\ 3 \qquad PAF \times BD = \Delta BD = \Delta\ Incidence\ (annual\ deaths)$$

where BD is the annual average burden of all-causes mortality (CDC WONDER: 2,744,248 for 2016).

The formula can be solved for change in $PM_{2.5}$ concentration per death:

$$eq.4 \qquad \Delta PM_{2.5} = \frac{\ln(1-\frac{1}{BD})}{\beta}$$

Likewise, the incidence per ton can be expressed per death ($1/c_i$). We can establish the relationship between emissions and air concentrations as a ratio by equating the two expressions (eq. 1 and eq. 4) for an equivalent number of deaths:

$$eq.5 \qquad Ratio_i = \frac{\Delta PM_{2.5}}{\Delta TPD_i} = \frac{\frac{\ln(1-\frac{1}{BD})}{\beta}}{\frac{1}{c_i}}$$

For regulatory purposes, the Office of Air Quality Planning and Standards of the U.S. Environmental Protection Agency calculated the average annual incidence of mortality per ton of U.S. emissions for PM2.5, nitrides of oxygen (NO_x), and sulphate for the on-road mobile sources, using a β (0.005827)from Krewski et al (2019). [13] The terms in equation 5 can be rearranged and summed for $PM_{2.5,}$ $NO_{x,}$ and sulfate:

$$eq.6 \quad \Delta PM_{2.5} = Ratio_{PM25} \times \Delta TPD_{direct\ car\ PM2.5} + Ratio_{NOx} \times \Delta TPD_{car\ NOx} + Ratio_{SO2} \times \Delta TPD_{car\ SO2}$$

The change in car emissions, ΔTPD_i, is directly related to the change in vehicle miles traveled (VMT). By specifying the TPD as per percent change in car VMT, it is possible to predict ambient $PM_{2.5}$ levels as a function of percent change in car VMT (e.g., -1.68 nanograms/m^3 $PM_{2.5}$ per percent reduction in car VMT in 2015 and 0.57 nanograms/m^3 $PM_{2.5}$ per percent reduction in 2050). Estimated car emissions for $PM_{2.5}$, $NO_{x,}$ and SO_2 were obtained between 2015 and 2050 in 5-year increments from the Motor Vehicle Emissions Simulator (MOVES) model.[14]

Carbon Emissions

The MOVES emissions model also estimates carbon dioxide emitted per mile, EF (emissions factor), by vehicle and fuel type, and total vehicle miles traveled. Aggregate emissions are given by:

$$Aggregate\ CO_2\ Emissions = EF\ \times per\ capita\ mean\ car\ VMT\ \times Population.$$

In practice, CO_2 emission rates were VMT-weighted by fuel type (gas, diesel, and electric) of personal passenger vehicles (cars and light duty trucks) at five-year intervals from 2010 to 2050. Corresponding populations were based on projections of the U.S Bureau of the Census.[15]

Road Traffic Injuries

ITHIM-USA takes into account that traffic injuries occur when a pedestrian, cyclist or victim’s vehicle is struck by another vehicle, and that the risk of injury depends on both person miles traveled (PMT) by the victim and vehicle miles traveled (VMT) by the striking vehicle (Figure 1.4).

Figure 1.4 Matrix of Striking Vehicle-Victim Road Traffic Injuries

Number of Injuries/Fatalities							
		Striking Vehicle, SV					
Victim, V		b	p	m	c	d	h
Bicycle	b	r_{bb}	r_{bp}	r_{bm}	r_{bc}	r_{bd}	r_{bb}
Pedestrian	p	r_{pb}	r_{pp}	.	.	.	.
Motorcycle	m	r_{mb}	r_{mp}	r_{mm}	.	.	.
Car	c	r_{cb}	etc	.	.	.	.
Bus	d	r_{db}	.	.	.	.	.
Truck	h	r_{hb}	.	.	.	.	.

The risk of injury is considered for every pairwise combination of victim mode (i) and striking vehicle (j) for baseline (B) and scenario (S) travel, where the modes are walking, cycling, LDPV, motorcycle, bus, and truck. Based on empirical observation the injury risk is non-linear[16] and has the functional form:

$$RR_{i,j} = \sqrt{\frac{PMT_{Si} \times VMT_{Sj}}{PMT_{Bi} \times VMT_{Bj}}}$$

The risk function integrated into the expression for the PAF is:

$$PAF = 1 - \left(\frac{\sum(RR_{i,j} \times B_{i,j})}{\sum B_{i,j}}\right) = 1 - \frac{\sum Injuries_S}{\sum Injuries_B}$$

where $B_{i,j}$ is the number of baseline injuries for combinations of victim and striking vehicle.

Injury severity was categorized as fatal or serious and stratified by roadway type (highway, arterial, or local), which is a surrogate for traffic speed and volume associated with injury risk. Because pedestrian and bicycle travel rarely occur on highways, in the AT scenarios, walking and cycling replaced car travel only on local roads and arterials.

Joint and Total Impacts

Physical activity and $PM_{2.5}$ are both associated with mortality from all causes (combined) and the specific causes of ischemic heart disease, hypertensive heart disease, stroke, and lung cancer. When assessing the overall heath impact of these diseases, the population attributable fraction is based on multiplicative relative risks of physical activity and $PM_{2.5}$:

$$PAF = 1 - (RR_{PA} \times RR_{PM2.5})$$

The total change in the burden of disease combines the results for physical activity, air pollution and road traffic injuries:

$$\Delta BD_{total} = \Delta BD_{PA} + \Delta BD_{PM2.5} + \Delta BD_{RTI}$$

Monetization of Health Outcomes

The health benefits (and harms) due to the change in burden of disease and injury are presented as monetized costs. Costs were estimated using two methods: 1) cost of illness and 2) willingness to pay using the value of a statistical life (VSL). For cost of illness, national estimates of direct medical costs and productivity losses (in constant 2010 dollars), obtained from specialty societies and government agencies, were scaled to the population of the scenario. Disease/injury specific change in PAFs were applied to costs. For VSL, the change in the number of deaths was multiplied by the dollar value of statistical life for VSL values used by different government agencies (Maizlish N, Siegel Z. *Monetizing Health Co-benefits from Transportation Strategies that Reduce Greenhouse Gas Emissions in the San Francisco Bay Area. Presented at the Annual Meeting of the American Public Health, San Francisco, October 21, 2012*. Richmond, CA: California Department of Public Health; 2012). The default value is $9.8 million in 2019 dollars.

Data Sources

Health Outcomes

Deaths and DALYs for the United States in age-, sex- and cause-groups are publicly available from the Global Burden of Disease database for 2015.[17] The GBD was adjusted to take into account trends in population growth and disease rates from 2015 to 2050. The United States population is projected to increase in size and have a proportionately greater share of older age groups. Advances in public health and medical care are projected to decrease age- and sex-specific rates of mortality due to chronic disease and injuries. US. population estimates, broken down by age and sex from 2015 to 2050 in 5 calendar year intervals, were compiled from the U.S. Census Bureau.[15] Estimated average annual percent change in sex- and age-specific disease rates for major chronic diseases and injuries were estimated by Canudas et al[18] from projections from the Social Security Administration and an expert panel. The annual percent change, APC, is applied to the Global Burden of Disease as follows, where t_1 is a future calendar year (up to 2050) and t_{2010} is the base year of 2010.

$$Deaths_{t_1} = Deaths_{2010} \times (1 - APC/100)^{(t_1 - t_{2010})}$$

The APC formula was applied to deaths, years of life lost, years living with disability, and disability adjusted life years.

A complete annual census of fatal roadway injuries in the United (2016) was available in the Fatality Analysis Reporting System.[19] A probability sample of non-fatal serious traffic injuries in the United States was available for 2016 in the Crash Report Sampling System.[20] Each system records information to derive a roadway type associated with the crash, which was categorized as local, arterial, and highway).

Travel Patterns

Age-and sex-specific travel times and distances for walking and bicycling were available from the National Household Travel Survey (NHTS), 2017.[21] Per capita mean annual travel distances for automobiles, buses, and rail were likewise compiled from the NHTS. The ITHIM USA road traffic injury module requires both personal miles traveled (PMT) of victims and vehicle miles traveled (VMT) of striking vehicles. PMT and VMT are related through occupancy (PMT/VMT). Bus PMT was readily available in the NHTS, but bus VMT was not. Nationally published figures for bus occupancy[22] and bus PMT from NHTS were used to estimate bus VMT in 2015.

Likewise, truck travel is not reported in NHTS. However, aggregate truck travel is reported by state transportation agencies and compiled by the Federal Highway Administration.[23] Per capita mean truck VMT was calculated by summing 2015 U.S. truck miles traveled (Single-Unit, 2-Axle 6-Tire or More, and Combination Trucks) and dividing the by the 2015 U.S. population.

Non-Travel Physical Activity

For all physical activity health outcomes, the dose-response relationship is based on total physical activity, which includes leisure and domestic activities. (Occupational physical activity is excluded.) Non-travel leisure time was calculated at quintiles of travel related physical activity. Estimates of non-travel physical activity were derived from the National Health and Nutrition Examination Survey, 2015-2016. [24, 9, 25]

Emissions

For the calculation of ambient $PM_{2.5}$ concentrations, emissions data on $PM_{2.5}$, NO_x, SO_2, and CO_2 were obtained from the MOVES model[14] for all fuel types (gas, diesel, electric) of all personal passenger vehicles (light duty cars and trucks).

Assumptions and Limitations

ITHIM outputs occur at user-specified, steady-state time horizon. Several of the key assumptions of the ITHIM model are:

- The model assumes that the health co-benefits occur in a single "accounting year", although the changes in the physical activity distribution and low carbon driving are likely to gradually occur over time. It is assumed that the co-benefits will be maintained in subsequent years.
- Non-transport physical activity does not vary over time.
- Increases in physical activity due to active transport are not compensated by a decrease in non-transport physical activity (no activity substitution)
- Safety in numbers: the slope of square root relationship is a constant (i.e. does not account for infrastructure, policy, education, etc. that further deflects this slope).

ITHIM USA represents the population distribution of travel distances as means or age-sex quintiles of active travel times for relatively large geographic areas. The calibration data are aggregate and do not provide empirically derived, geographically resolved estimates of travel parameters, or to examine subgroups or geographic heterogeneity within regions. Third generation ITHIM models are being developed in the United Kingdom that simulate individuals within large populations and have potential to provide greater geographic resolution and subgroup analysis.[26]

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Chapter 2. User's Guide to ITHIM USA

Getting and Running the Application

ITHIM USA is a computer program written in the free R programming language (version 3.6.1, July 2019)[27] and its Shiny package (version 1.2.1335).[28] R reads rows and columns of input data and performs mathematical calculations that are stored in output data structures (data frames and lists). Shiny is an extension of the R programming language that generates hypertext markup language (HTML), which is the standard for creating web pages. Shiny, with a standard style sheet (cascading style sheet, CSS) allows the styling and integration of photos, images, narrative text, tables, and graphs as a complete website.

There are two ways you can run ITHIM USA:

1. Interactive Website

Just enter https://ithim.org/ithim into your web browser (Chrome, Edge, Firefox, Internet Explorer, Opera, or Safari).

2. Developer Version

Advanced users may modify the R source code or use their own data files to create customized versions of ITHIM. Chapter 3 provides information on the application's directory structure, file names, and data file formats.

At the User Support page of ITHIM USA (https://ithim.org/ithim/#UserSupport), scroll to R & Shiny Code for Developers. Click on ITHIM USA R/Shiny Application (ZIP). Unzip the file and copy the folders and files to a folder on your desktop computer. Running app.R, requires the prior installation of the R programming language (https://www.r-project.org) and several R packages (shiny, grid, png, markdown, digest, and ggplot2). R programming is facilitated by RStudio (https://www.rstudio.com/products/rstudio/download/), which is an integrated development environment.

Devices that Run ITHIM USA

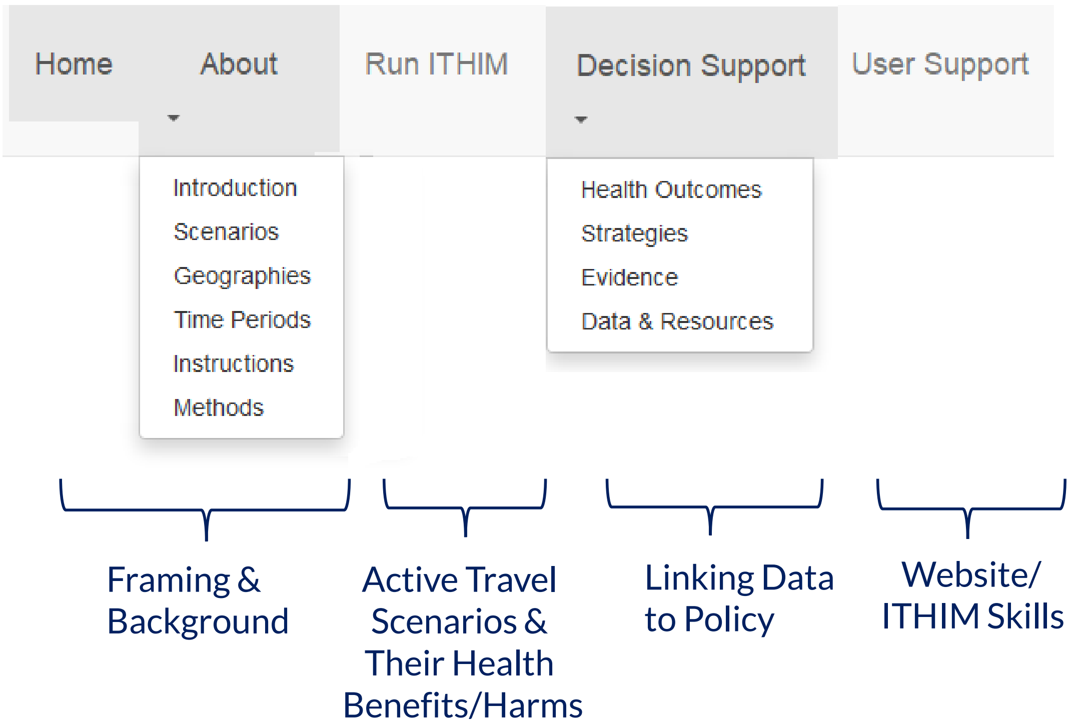
ITHIM USA was designed for desktop and laptop computers running common web browsers (Chrome, Edge, Firefox, Internet Explorer, Opera, and Safari). Web page representations of the Home, About, Decision Support, and User Support pages may be acceptable on some mobile devices; however, the output of the RunITHIM interactive page may not be readable.

Organization of the ITHIM USA Webpages

ITHIM USA website follows a standard organization of web pages:

- Home
- About
- Tool
- Decision Support, and
- User Support (Figure 2.1).

Figure 2.1 Schematic of ITHIM USA Software Application/Website



As you progress from left to right on the main horizontal navigation bar, you learn about: the framing of health, transportation, equity, and climate change; active travel scenarios and health co-benefits or harms; information that a) puts the co-benefits into a broader health and equity context and b) suggests on ways to increase physical activity, improve safety, and decrease air pollution, greenhouse gas emissions, and VMT in the transportation system; and, information to help you navigate the website and develop expertise in health impact analysis.

Website navigation may be done with a mouse or other pointing tool. Keyboard navigation, using the Tab, arrows, and Enter keys, is also available as an accessibility option.

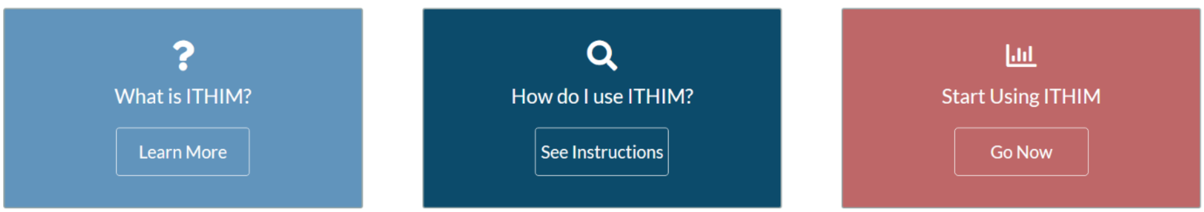
Home Page

The Home Page (https://ithim.org/ithim/) is the main landing page (Figure 2.2). The Home page introduces the website themes, action buttons that directly link to background information or the tool page, and a gallery of images that link to reports and publications featuring ITHIM.

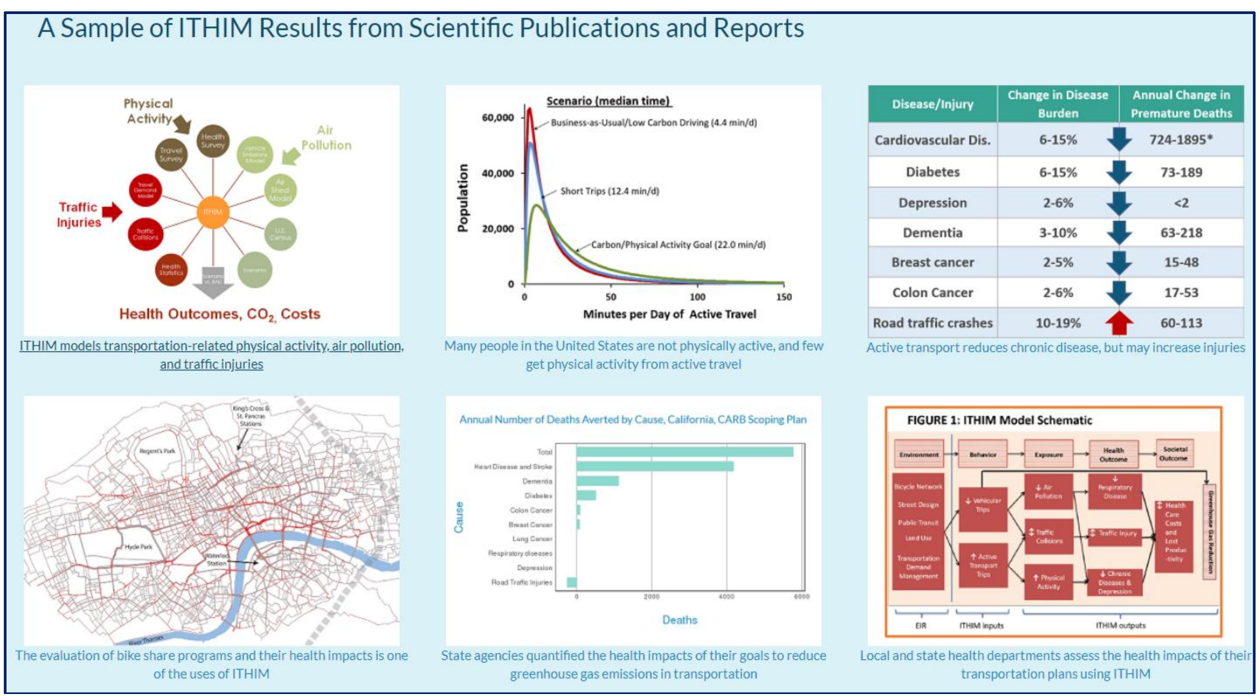
Figure 2.2 Home Page Features of ITHIM USA

Clicking on the action buttons will link you directly to About and the RunITHIM pages.

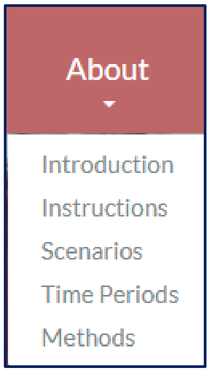
Links: About > Introduction Links: About > Instructions Kinks: RunITHIM (Tool Page)



Clicking on a gallery image will link you to technical reports and scientific publications featuring ITHIM.



About Pages



Clicking the About tab reveals 5 pages that provide an introduction, instructions on how to use the tool page, a description of 2015 baseline travel in the United States and different travel scenarios, time periods between 2015 and 2050 available for analysis, and highlights of the methods used in ITHIM USA (Chapter 1).

Figure 2.3 Features of the About Pages

The About pages introduce the basic graphic style of web pages. A vertical, left side-panel with a light blue background has a menu to navigate between the About pages. The right side-panel with a white background presents narrative content.

Introduction (https://ithim.org/ithim/#Introduction)

About > Introduction is the landing page for the About pages. It describes the purpose and importance of ITHIM, its history, and use cases.

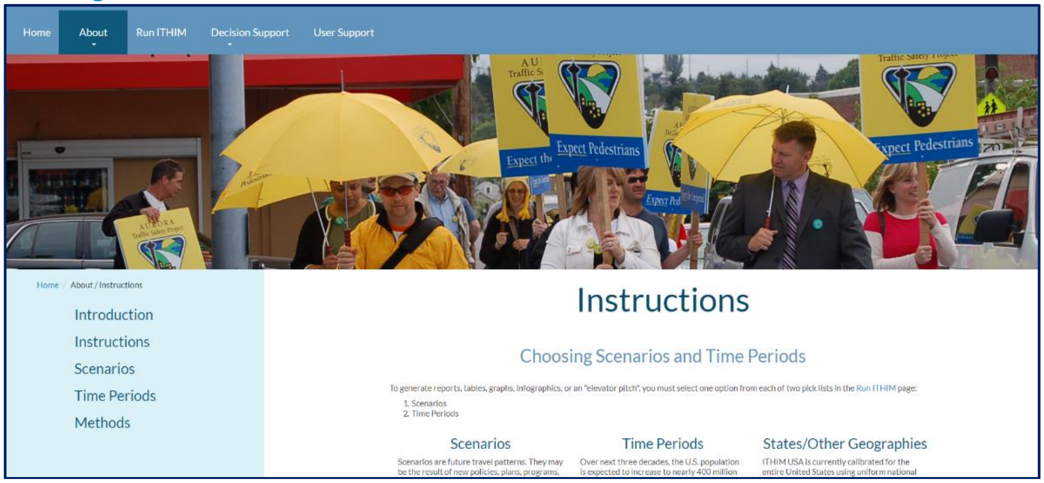
Instructions (https://ithim.org/ithim/#Instructions)

Instructions highlights three user selections that are required to generate output on the RunITHIM Page. These selections are:

- A scenario (among a picklist of 8 options)
- A time period of interest (among a picklist of eight 5-year time periods from 2010 to 2050).

A detailed description of these options is covered in the RunITHIM page below.

Figure 2.4 Features of the About > Instructions



Scenarios (https://ithim.org/ithim/#Scenarios)

The Scenarios page (Figure 2.5) lists and describes the 2015 Baseline and 6 alternative travel scenarios based on national health goals for physical activity, and several "What If" options:

- Increase or decrease walking, cycling, and transit by multiples or a percentage of the baseline
- Increase or decrease walking and/or cycling by a fixed amount of time per week
- Substitute short car trips < 5 miles in the 2015 baseline with walking (<1 mi.) or cycling (1-5 miles).
- Increase the transition to electric vehicles and other low carbon driving strategies.

A summary of the Scenarios is listed in Table 2.1.

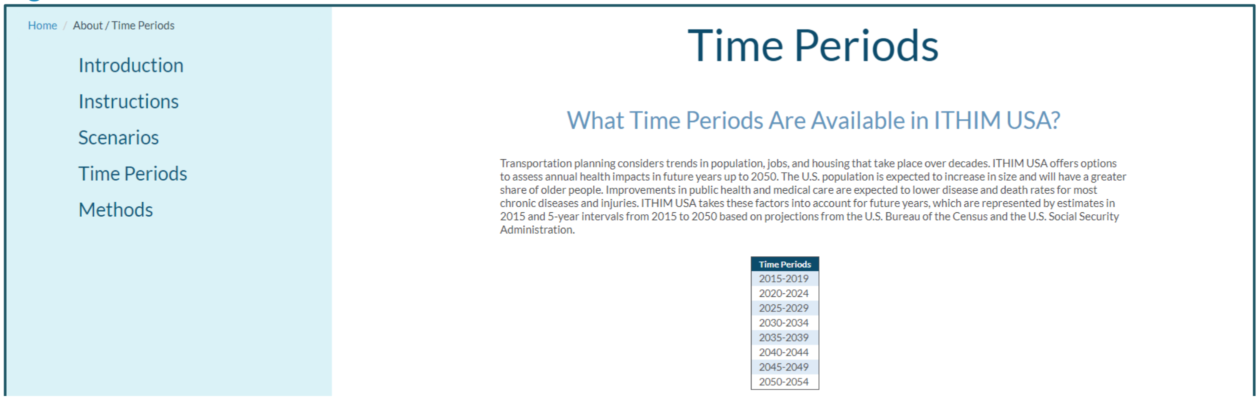
Figure 2.5 Features of the About > Scenarios

Table 2.1 Baseline and Scenarios in ITHIM USA

Scenario Name	Description
Baseline 2015	Scenarios are contrasted against travel patterns of the baseline year of 2015. The National Household Travel Survey, 2017 provided detailed information on walk and bicycle trips taken by a representative cross-section of the U.S. population. Trip distances and times for motorized modes (car, bus, rail, motorcycle) were likewise derived from the NHTS2017. Bus occupancy and truck VMT were based on data of the U.S. Department of Transportation. Unless you upload your own baseline data, the 2015 Baseline will be the comparison for other scenarios, which are briefly described below.
U.S. Surgeon General Recommendations (USSG)	Popularly known as "the Nation's Doctor", the U.S. Surgeon General focuses on improving the country's health. Based on a review of decades of research on the relationship between physical activity and health, the Surgeon General has stated that "engaging in regular physical activity is one of the most important things that people of all ages can do to improve their health." For adults, an optimum level of health can be achieved by engaging in at least 150 minutes of moderate-intensity physical activity each week. For ITHIM USA this recommendation has been translated into a population health goal in which at least 50% of the U.S. population gets 150 minutes per week of moderate physical activity through active transportation. In 2018, 54% of the U.S. adult population met this goal from leisure physical activity.
Baseline Multiples	This is a "What-If" Scenario in which you can assess the health impacts of increasing the average baseline walking and cycling for transport by relative amounts (e.g., 1.05 = 5%). This scenario allows you to input any multiple of the U.S. baseline average of walking, cycling, or transit.
Fixed Time	This is a "What-if" scenario allows you to specify the average weekly minutes of walking and cycling for transport.
Short Trips	Nearly two-thirds of all car trips in the United States are less than 5 miles. In this scenario, we envision half of these trips are walked or bicycled. Trips less than 1 miles are walked (20 minutes per day), and trips 1 to 5 miles are cycled (6 to 30 minutes per day).
Low Carbon Driving (LCD)	Car travel reflects a significant increase in electric vehicles, hybrids, and low carbon fuels. This scenario assumes there is no change from baseline in total car vehicle miles traveled or levels of active transportation. In addition to significantly lowering greenhouse gas emissions from cars, low carbon driving reduces health risks from fine particulate matter.
User Upload and Equity Analyses	If you or your organization have access to a travel or land use model, you can assess the health impacts of your own baseline, business-a-usual, and other scenarios by uploading travel distances and times for different modes of travel. Likewise, data can be uploaded to carry out analyses of population subgroups based on race/ethnicity, income, and other factors that influence health equity. Details on how to prepare files for uploading are described in Chapter 2.

Time Periods (https://ithim.org/ithim/#TimePeriods)

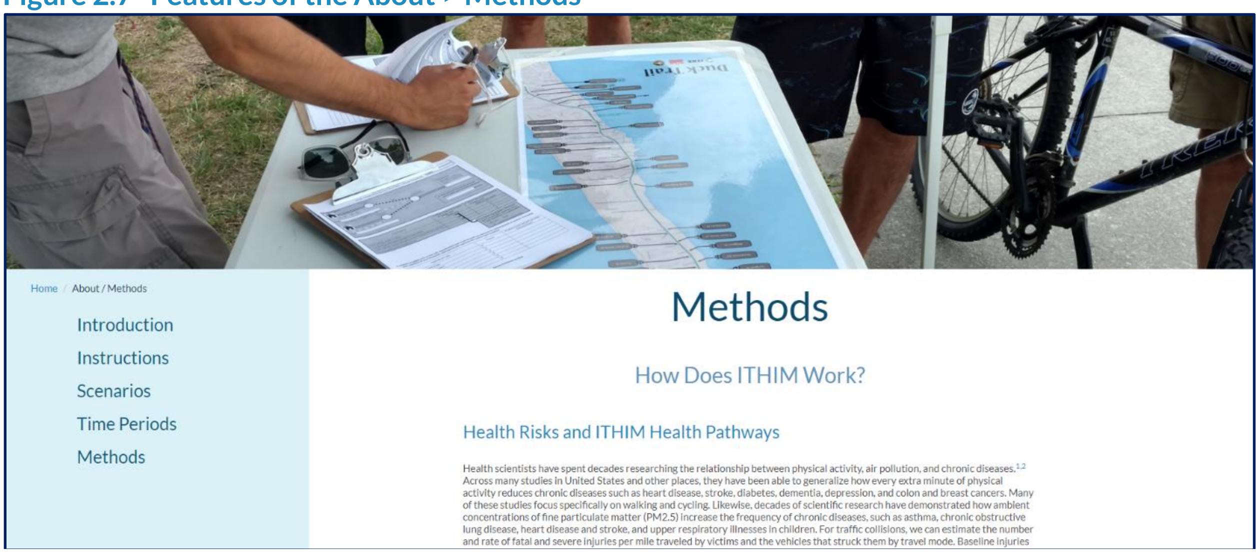
Figure 2.6 Features of the About > Time Periods



ITHIM USA incorporates expected U.S. population growth, demographic trends of aging, and mortality trends over time. These changes impact both travel patterns and the U.S. burden of burden of disease. In 5-year time intervals between 2015 and 2050, users can match the time period of scenario implementation with the expected population and disease trends.

Methods (https://ithim.org/ithim/#Methods)

Figure 2.7 Features of the About > Methods



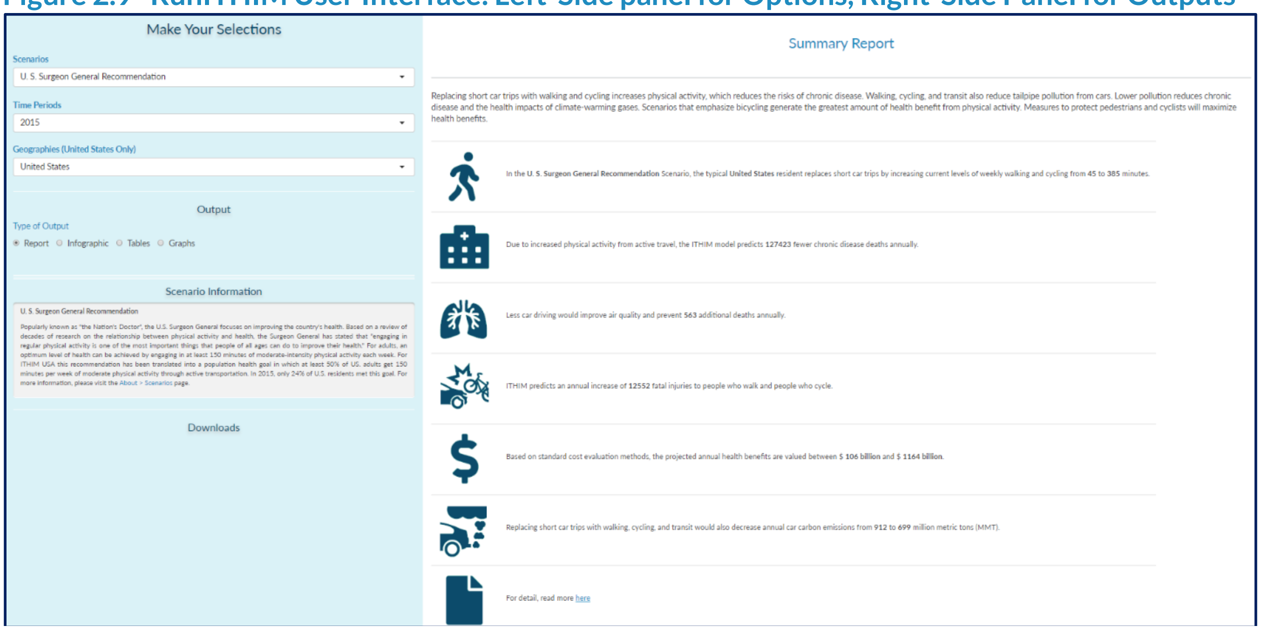
The Methods page gives an overview of the statistical methods used to quantify the health impacts of changes in the distribution of physical activity, air pollution, and traffic collision due to changes in travel patterns from a baseline to the scenario chosen by the user. The methods also highlight key assumptions and limitations. Additional details of the methods appear in Chapter 1 of this *User's Guide*.

RunITHIM Page

Figure 2.8 Features of the RunITHIM page

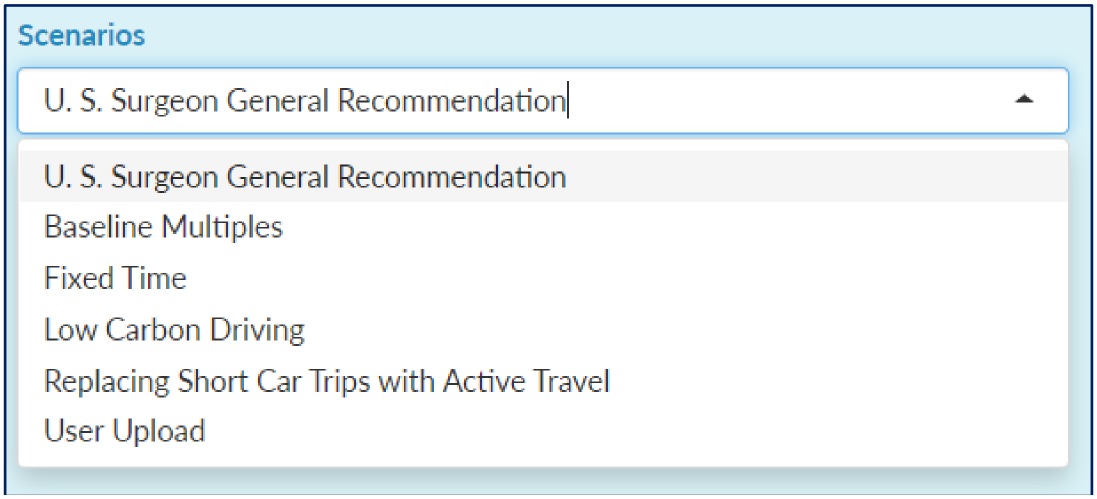
The RunITHIM page (https://ithim.org/ithim/#RunITHIM) is an interactive tool in which user-selected options drive the type and level of detail of outputs. The screen is divided into a blue-shaded left side-panel with user options and a wider right side-panel for outputs. To generate output, users must select a scenario and a time period. The defaults are set for the U.S. Surgeon General's Recommendations with the Baseline 2015), evaluated in the year 2015 for the entire United States.

Figure 2.9 RunITHIM User Interface: Left-Side panel for Options, Right-Side Panel for Outputs

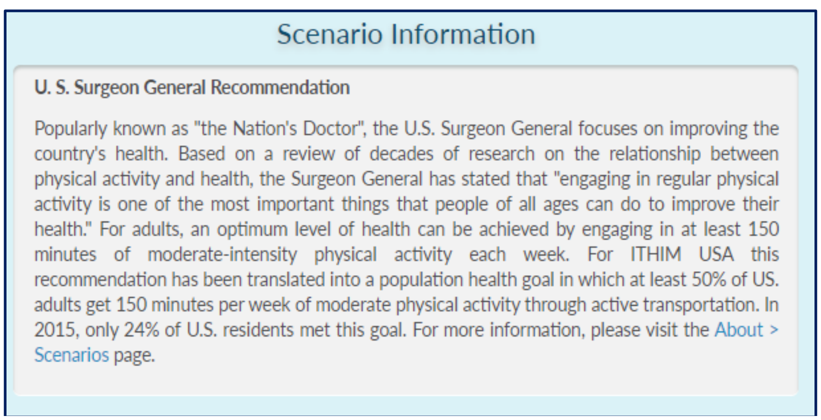


Scenarios

The scenario list is revealed by clicking on the arrow at the end of the **Scenarios** dialogue box. Use the scroll bar to the right side of the dialogue box to scroll through the entire list.



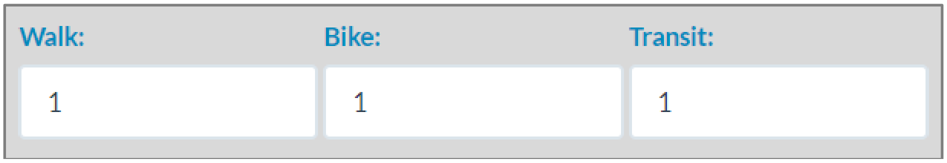
You can move through the list with your mouse (which moves the cursor) or press the down arrow key on your keyboard. When the focus changes, the background of specific list items turns gray. When you click on an item or press the <Enter> key, the choice is activated and the Scenarios dialogue box will close and show the selection. The same scenario description that appeared in the About pages will also appear in the left side-panel.



This sequence for selecting a scenario applies to all the scenarios. However, "Baseline Multiples", "Fixed Time", and "User Upload" require additional user inputs.

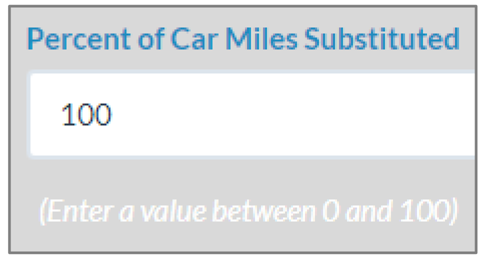
Baseline Multiples

This scenario allows you to make increases in per capita mean walking, bicycling, or transit relative to levels of those in the Baseline 2015. When you select this scenario, an additional dialogue box appears.



The default multiples are 1, meaning the scenario starts off with baseline levels of walking, cycling, and transit. If you would like to explore the health impacts of <u>doubling</u> walking, enter <u>2</u> in the box under Walk. For three times the baseline, enter 3. For an increase of 25%, enter 1.25, and for an increase of 1%, enter 1.01. Bike and transit work the same way. Transit means bus, trains, and light rail.

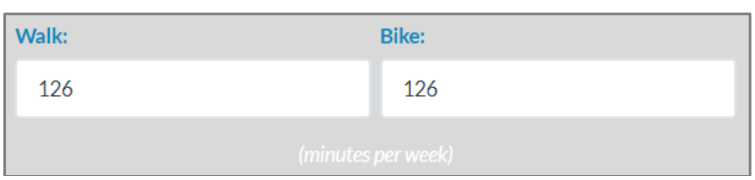
By default, the increases in active travel in "Baseline Multiples" replace car trips mile-for-mile. This is indicated in the dialogue box, as 100% of Car Miles Substituted. However, you may modify the scenario for less than a mile-for-mile replacement. For example, if only half of car trips were substituted by active travel, you would enter 50 into the dialogue box.



By default, total distances traveled across all modes are the same in in baseline and scenario. Also, by default, transit-associated walking and cycling is not automatically added scenario's active transport. Appendix C and an auxiliary worksheet at User Support (https://ithim.org/ithim/#UserSupport) provide instructions on how to add transit-related walking and cycling to the scenario multiples for walking and cycling. This is particularly important in scenarios that rely on large transit increases to promote walking and cycling and/or to reduce car carbon emissions.

<u>Fixed Time</u>

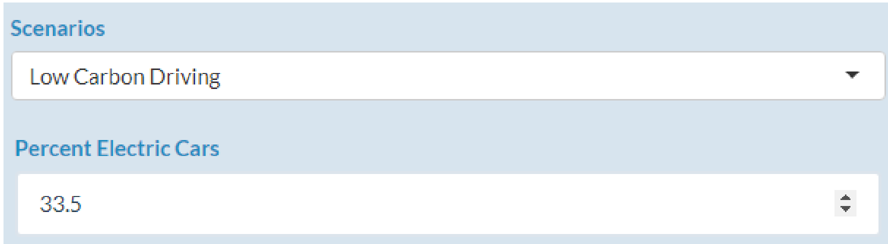
In addition to relative changes in baseline levels, you can indicate a specific amount of walking or cycling time in your population (geography) of interest. The amount is expressed as per capita mean minutes per week. When you select "Fixed Time", another dialogue box will appear below the Scenario.



You can enter any amount of time for walking or cycling up to 150 minutes per person per week. This upper limit reflects concerns that exceeding this limit may place a serious time burden on a large share of the population and compete with economic and social necessities.

<u>Low Carbon Driving</u>

You may indicate the degree of carbon reduction mediated through car VMT that has been decarbonized through electrification (e.g. a 10% increase in fully electric car VMT replaces 10% of conventional car VMT and its associated emissions contributing to $PM_{2.5}$ and to CO_2.

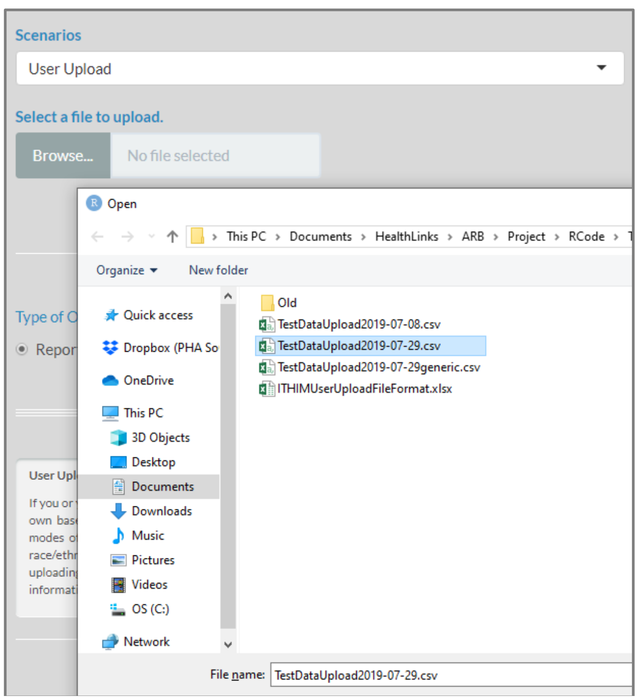


The default value is set to 33.5%. Because electric cars generate road dust from tire and brake wear, 100% electrification will not completely eliminate emissions from $PM_{2.5}$.The formula that predicts PM2.5 levels from tailpipe emissions, do not include tire and brake wear.

User Upload

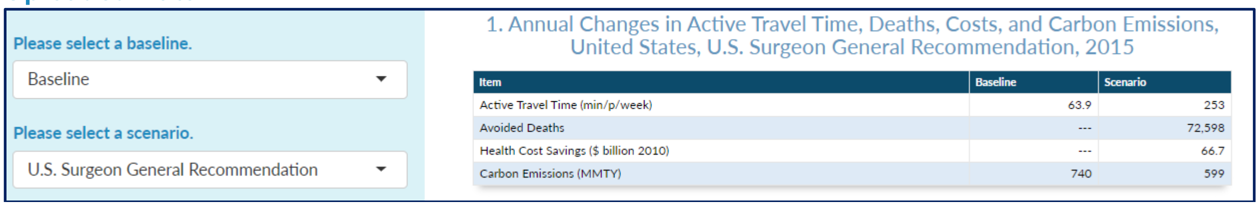
For users with their own data on baseline, business-as-usual, or alternative scenarios, this option allows you to upload data from your desktop computer. Uploading data for equity analyses follow the same steps, but with data specific to the equity group of interest (e.g., race/ethnicity, income, etc.). When you chose this option, a new dialogue box will appear.

Figure 2.10 Dialogue Box for Uploading a File with Baseline, Business-as-Usual, and Scenario Data



When you click on the Browse button, you will open a directory of file folders on your desktop computer. Use the commands in your computer's operating system to navigate to the folder that contains the file you would like to upload. In the example above (from Windows 10 operating system), you can click on the file and the Open button to load the data into ITHIM USA. The format of the data must follow a standard template as a CSV (commas separated values) file. Files in other formats cannot be read into ITHIM USA. The file format and template are presented in Tables 2. 3 and 2. 4, respectively (next page). If the files do not contain format errors, new buttons will appear in the dialogue so you can indicate the ID numbers of the Baseline/BAU and Scenario data. (Baseline usually indicates empirical data from a specific year. Business-as-Usual (BAU) usually means travel projections to a future year based on current trends or plans, not new travel scenarios). After you make selections, a table will appear with the selected data. For uploaded files that contain errors or missing data, messages will appear to help users identify problematic fields or unreadable data (Table 2.5).

Figure 2.11 Selecting the Baseline, Business-As-Usual, and Alternative Scenario from User Uploaded Data



Item	Baseline	Scenario
Active Travel Time (min/p/week)	63.9	253
Avoided Deaths	---	72,598
Health Cost Savings ($ billion 2010)	---	66.7
Carbon Emissions (MMTY)	740	599

Table 2.3 Template of a File to Upload Data on Baseline, Business as Usual and Scenario Travel Patterns

	A	B	C	D	E	F
1	Region	Item_Name	Scenario_ID	Mode	Strata	Item_Result
2	United States	Per Capita Mean Daily Travel Distance	Baseline	Bike		0.16849172
3	United States	Per Capita Mean Daily Travel Distance	Baseline	Bus		0.80429886

The data dictionary for the template is presented below.

Table 2.4 Data Dictionary for Uploaded Data Files

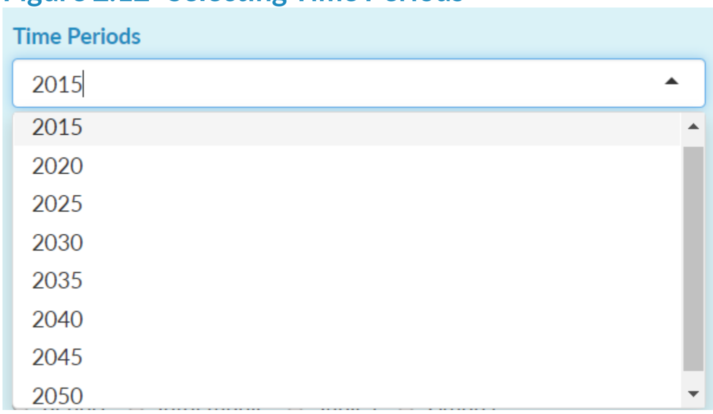
Variable Name	Definition	Code Levels
Region	Entire geography of the United States	United STates
Item_Name	Distance Travel by mode or Proportion of Distance by Facility Type	"Per Capita Mean Daily Travel Distance" or "Proportion of Vehicle Miles by Mode and Facility Type"
Scenario_ID	User defined alphanumeric string to identify baseline, BAU, or scenario	
Mode	Travel mode	Walk, Bike, CarDriver, CarPassenger, Bus, Rail, Motorcycle, Truck
Strata	Facility type for Item_Name Proportion of Vehicle Miles by Mode and Facility Type	local, arterial, highway for bus, car, truck modes only
Item_Result	Per capita mean miles/p/day by mode	10 decimal digit precision

Table 2.5. Examples of Errors and Warning Messages in User Data Uploads

Type of Error/Warning	Example Warning Message	Data File
Column headings	User Error: Headers are incorrect. Missing Mode.	C D E Scenario_ID Strata Baseline Bike Baseline Bus Baseline CarDriver
Item_Name	User Error: Missing "Per Capita Mean Daily Travel Distance" for Baseline in user uploaded data (csv).	Item_Name Per Capita Mean Daily Travel Distances Per Capita Mean Daily Travel Distance Per Capita Mean Daily Travel Distance
Region (misspell/ missing)	User Error: The Scenario_ID "Baseline" has either a missing Region value, or contains multiple values in Region.csv).	Region United States United State U.S.
Mode duplicated/ missing	User Error: The Scenario_ID "Baseline" has an excess or missing "Mode" in Distances in user uploaded data (csv)."	D E F Mode Strata Item_Result 0.168492 Bus 0.804299 CarDriver 15.57071
Item_Result missing (or missing row)	User Error: The Scenario_ID "Baseline" is missing or duplicating mode: Bike.	Mode Strata Item_Result Bike Bus 0.804299
Missing motorcycle/bus	Warning: The Scenario_ID "Baseline" is missing values for mode: Bus. Thus, substituting values from ITHIM TOOL's Baseline 2015.	D E F [redacted]

Time Periods

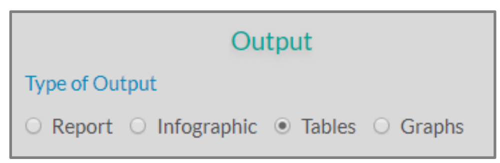
Figure 2.12 Selecting Time Periods



You may choose one time period from the Time Periods pick list. The time period aligns the projected time period for implementing the scenario and projected population characteristics. The default time period is 2015, which is the first item in the list. The pick list then presents eight years in 5-year intervals from 2020 to 2050. You can use the scroll bar on the right side of the pick list box to review all the items. Clicking on an item (or pressing the <Enter> key, will cause the pick list to close and reveal your choice in the selection box.

Output Formats

Figure 2.13 Choices for Outputs



By clicking on a radio button, you may choose among four options for output formats.

<u>Report</u>

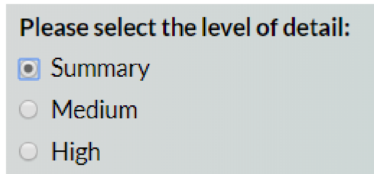
The Report the default output format and appears in the right side-panel (Figure 2.14). The Report is a graphical mini-report similar in content to a bulleted list of talking points, or an elevator pitch. It is prefaced by a general statement on the health impacts of increases in active travel, and describes the main findings of the health impact analysis: changes in active travel from the baseline to the chosen scenario, annual health impacts, and emissions of carbon dioxide and $PM_{2.5}$. The "breadcrumbs" of selection –scenario, geography, and time period – are embedded in the first line after the preface.

<u>Infographic</u>

The infographic is a graphic that weaves together narrative, images, and the health and environmental impacts of a selected scenario and time period (Figure 2.15, next page). The impacts are compared with those of two other scenarios that approximate 1) the upper limit of optimal health gains from following the U.S. Surgeon General physical activity guidelines and 2) the upper limit of carbon and air pollution reductions by implementation of low carbon driving strategies (e.g. electrification of the automobile fleet, low carbon fuel standard, etc.).

Tables and Graphs

The Tables selection generates formatted tables for the selected scenario, geography, and time period. Likewise, The Graphs selection generates bar graphs and multi-series line graphs for the selected scenario, geography, and time period. When Tables or Graphs are selected, another set of radio buttons will appear below.



Use these radio buttons to select the level of detail in the tables and graphs that appears in the right side-panel. Each level of detail is represented by 4 to 6 different tables or graphs (Figure 2.16-17).

Figure 2.14 Example of a Report

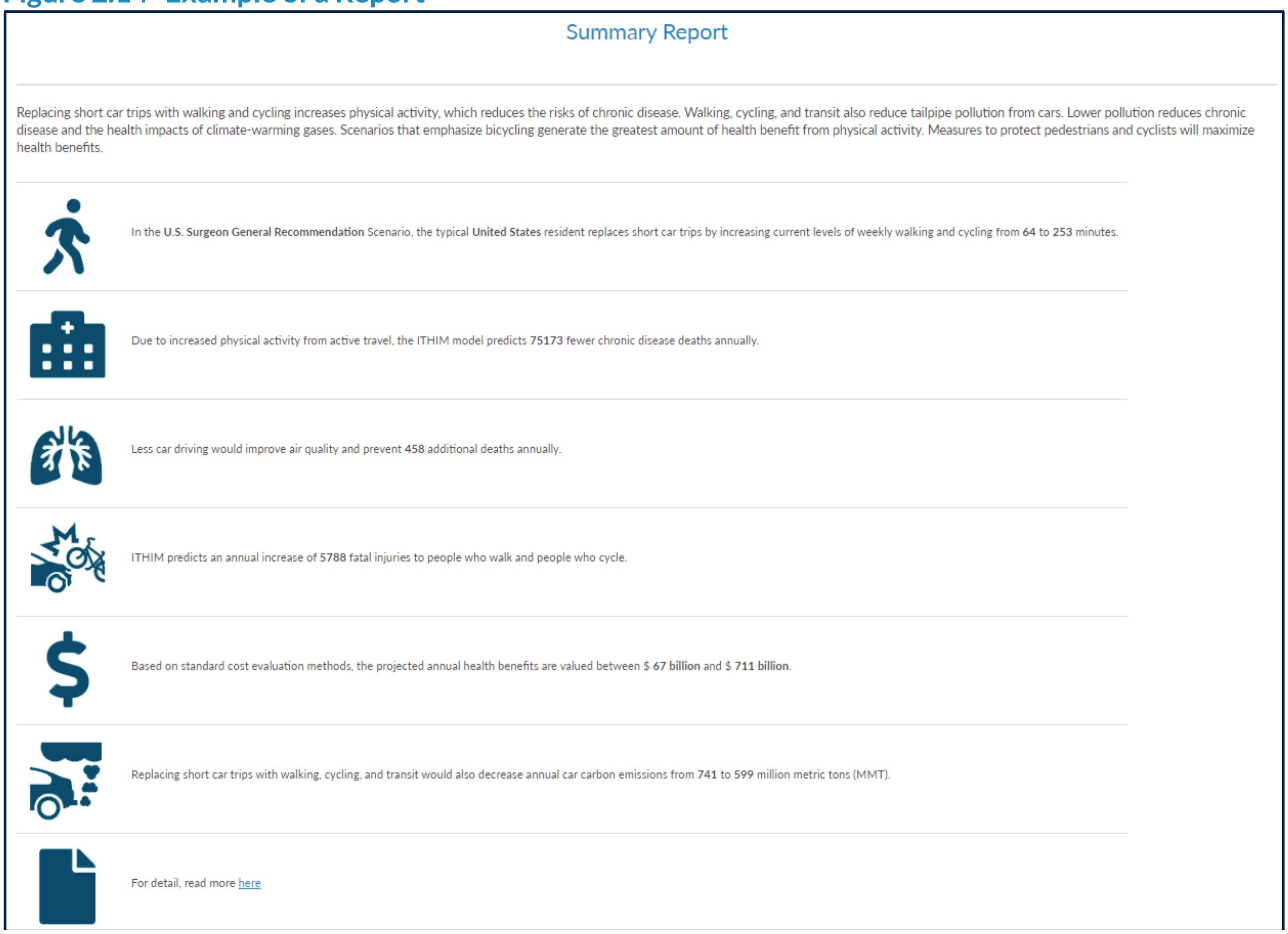
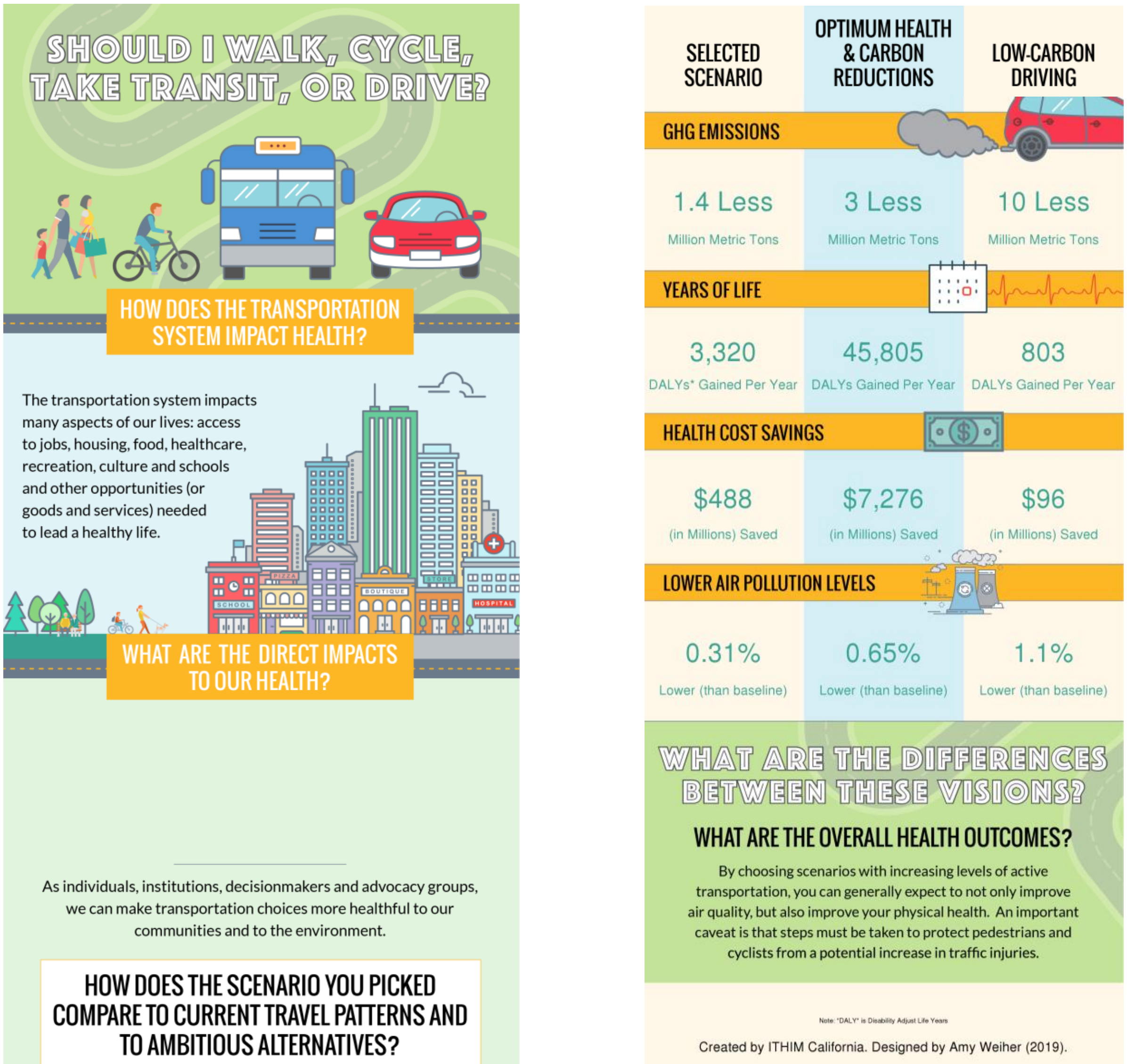


Figure 2.15 Example of the Infographic*



* On computer screens, the infographic is one column wide, but is displayed above to fit this page.

Figure 2.16 Example of Table Output (Summary Level)

1. Annual Changes in Active Travel Time, Deaths, Costs, and Carbon Emissions, United States, U. S. Surgeon General Recommendation, 2015

Item	Baseline	Scenario
Active Travel Time (min/p/week)	44.5	384
Avoided Deaths	---	118,786
Health Cost Savings ($ billion 2010)	---	106
Carbon Emissions (MMTY)	912	698

min/p/week, per capita weekly mean minutes; MMTY, million metric tons per year; Note, negative values indicate an increase in deaths, DALYs, or costs.

2. Per Capita Mean Weekly Active Travel Times (minutes), United States, U. S. Surgeon General Recommendation, 2015

Mode	Baseline	Scenario
Walk	39.5	192
Bike	5.0	192
Total	44.5	384

3. Per Capita Mean Annual Travel Distance (Miles) by Mode, United States, U. S. Surgeon General Recommendation, 2015

Mode	Baseline	Scenario
Active	364	2,334
Car	10,070	7,713
Transit	251	251
Total (incl. Truck & Motorcycle)	11,667	11,667

4. Annual Change in the Burden of Disease by Health Pathway, United States, U. S. Surgeon General Recommendation, 2015

Pathway	Deaths		DALYs	
	PAF (%)	Count	PAF (%)	Value
Physical Activity	11.2	127,423	13.1	2,928,751
Air Pollution	< 0.1	562	< 0.1	8,663
Road Traffic Injuries	-16.8	-9,155.3	-16.8	-413,627.1
Total	5.0	118,830	5.2	2,523,787

ths, PAF, population attributable fraction; DALY, disability adjusted life year; Note, negative values indicate an increase in dea DALYs, or costs.

tates, 5. Annual Cost Savings of Health Benefits (billions of 2010 dollars), United S U. S. Surgeon General Recommendation, 2015

	Method	Dollars
106	Cost of Illness	
1,164	Value of a Statistical Life	

6. Annual Car Carbon Emissions, United States, U. S. Surgeon General Recommendation, 2015

CO2 Emissions	Baseline	Scenario
Aggregate (Million Metric Tons)	912	698
Per Capita (Metric Tons)	2.8	2.2

Figure 2.16 Example of Table Output (Medium Level)

1. Per Capita Mean Weekly Active Travel Time (minutes) by Age, United States, U. S. Surgeon General Recommendation, 2015

Age Gender	Baseline	Scenario
00-04	0.0	0.0
05-14	37.2	398
15-29	45.3	409
30-44	48.3	498
45-59	44.9	417
60-69	47.5	396
70-79	45.2	303
80+	28.7	186
Male	44.1	477
Female	39.1	296

2. Per Capita Mean Annual Travel Distance (Miles) by Mode, United States, U. S. Surgeon General Recommendation, 2015

Mode	Baseline	Scenario
Bike	28.2	1,997
Bus	336	336
CarDriver	7,002	5,363
CarPassenger	3,068	2,350
Motorcycle	32.1	32.1
Rail	218	218
Truck	871	871
Walk	112	499

3. Annual Number of Deaths Averted by Cause, United States, U. S. Surgeon General Recommendation, 2015

Cause	PAF %	Deaths
Heart Disease and Stroke	12.5	92,425
Dementia	8.3	20,779
Diabetes	13.6	8,621
Colon Cancer	6.3	4,048
Breast Cancer	4.0	1,852
Respiratory diseases	< 0.1	130
Lung Cancer	< 0.1	84.9
Depression	0.0	0.0
Road Traffic Injuries	-21.9	-9,155.3
Total	7.1	118,786

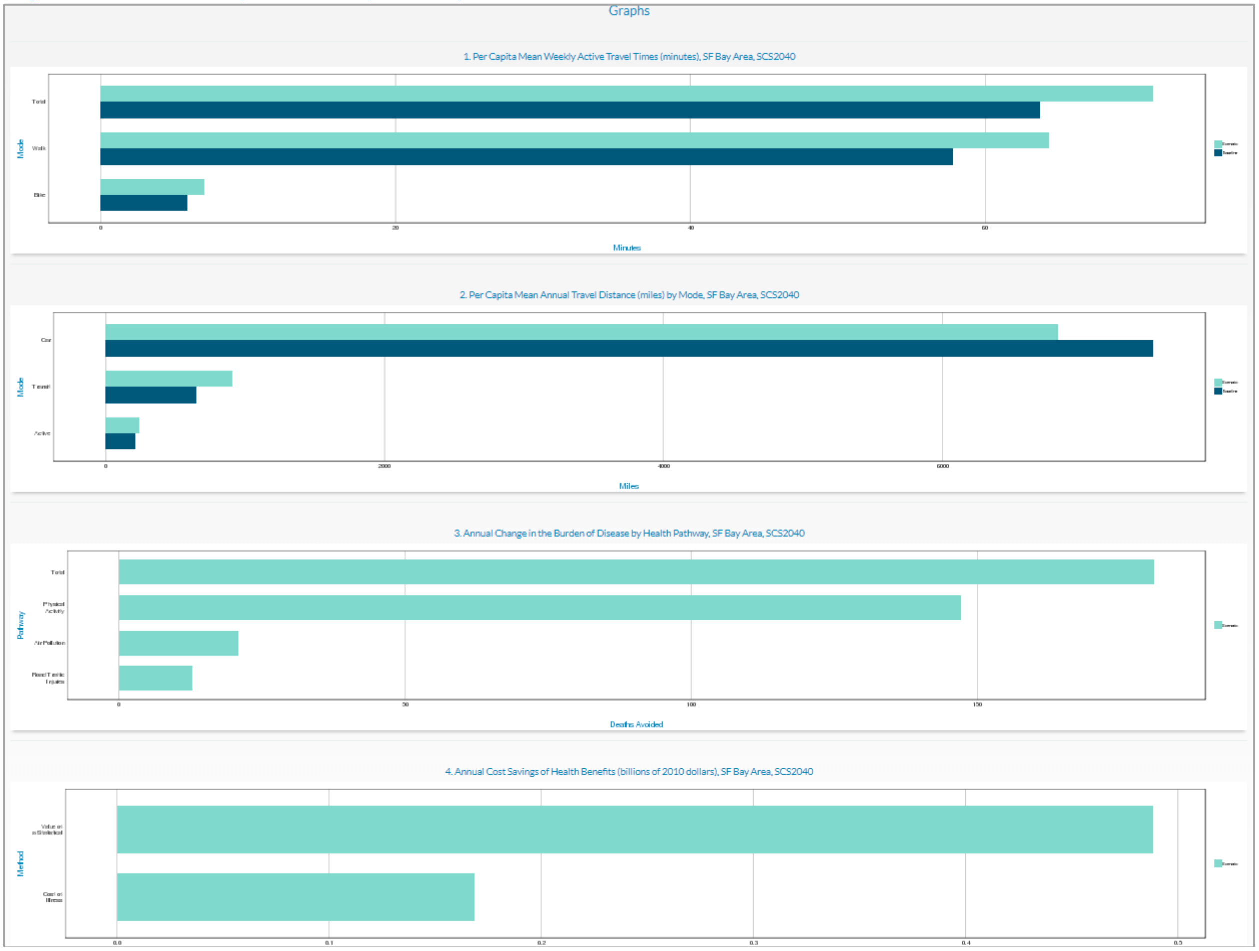
Note, negative values indicate an increase in deaths, DALYs, or costs.

4. Annual Cost Savings of Health Benefits (millions of 2010 dollars), United States, U. S. Surgeon General Recommendation, 2015

Cause	COI	VSL
Heart Disease	63,638	711,936
Dementia	15,438	203,635
Stroke	6,447	193,708
Diabetes	29,506	84,490
Colon Cancer	1,900	39,676
Breast Cancer	1,184	18,150
Asthma and COPD	12.4	1,276
Lung Cancer	24.5	832
Depression	7,148	0.0
Road Traffic Injuries	-19,041.8	-89,722.0
Total	106,256	1,163,981

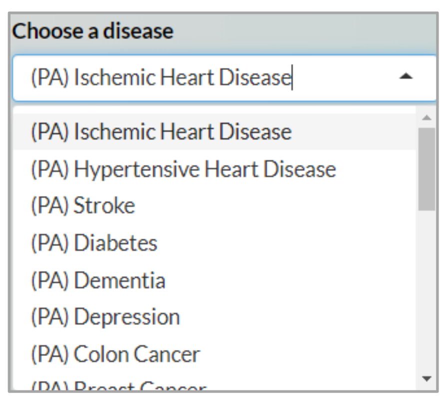
COI, cost of illness; VSL, value of a statistical life; COPD, Chronic Obstructive Pulmonary Disease; Note, negative values indicate an increase in deaths, DALYs, or costs.

Figure 2.17 Example of Graph Output (Summary Level)



The Summary group of tables/figures provides an overview of results that include a basic description of per capita mean active travel time, per capita mean distances traveled by mode, annual change in health outcomes and their monetized value, and annual change in carbon emissions. The Medium level of detail breaks down active travel by age and gender and travel distances by mode (car, bus, truck, rail, walk, bicycle, motorcycle). It also provides annual number of deaths, their costs, and the population attributable fraction for specific diseases. The High level of detail breaks down active travel by age, gender, and mode. Deaths, years of life lost, years living with disability, and disability life years are presented for specific diseases.

When the High level of detail is selected, another pick list of diseases and their pathways appears (at right).



Each selection generates a detailed health outcomes table/graph broken down by age and gender for deaths, YLL, YLD, DALYs and their population attributable fractions. The specific health pathway – physical activity (PA), $PM_{2.5}$ (PM), and road traffic injuries (RTI) – are indicated for each disease. Four diseases – all causes, ischemic heart disease, hypertensive heart disease, and stroke – are related to <u>both</u>

physical activity and $PM_{2.5}$ (PA + PM). The pick list allows users to select disease- and pathway-specific health impacts, and, for the four diseases, the combined effects of physical activity and $PM_{2.5}$.

Figure 2.18 Example of Health Outcomes by Age and Gender for a Specific Disease (Ischemic Heart Disease) and Pathway (Physical Activity)

3. (PA) Ischemic Heart Disease-Specific Change in Burden of Disease by Age and Sex, United States, U. S. Surgeon General Recommendation, 2015

Cause	Pathway	Sex	Age	Deaths	YLL	YLD	DALY	PAF (%)			
								Deaths	YLL	YLD	DALY
Ischemic Heart Disease	PA	M	00-04	0.0	0.0	0.0	0.0	0	0	0	0
Ischemic Heart Disease	PA	M	05-14	0.0	0.0	0.0	0.0	0	0	0	0
Ischemic Heart Disease	PA	M	15-29	124	7,788	131	7,918	21.3	21.3	21.3	21.3
Ischemic Heart Disease	PA	M	30-44	1,290	62,876	1,007	63,883	24.5	24.5	24.5	24.5
Ischemic Heart Disease	PA	M	45-59	8,535	294,725	5,390	300,115	23.4	23.4	23.4	23.4
Ischemic Heart Disease	PA	M	60-69	10,815	265,458	7,128	272,586	21.0	21.0	21.0	21.0
Ischemic Heart Disease	PA	M	70-79	9,237	147,997	5,425	153,422	15.7	15.7	15.7	15.7
Ischemic Heart Disease	PA	M	80+	15,074	109,273	4,066	113,339	13.1	13.1	13.1	13.1
Ischemic Heart Disease	PA	F	00-04	0.0	0.0	0.0	0.0	0	0	0	0
Ischemic Heart Disease	PA	F	05-14	0.0	0.0	0.0	0.0	0	0	0	0
Ischemic Heart Disease	PA	F	15-29	36.5	2,296	80.1	2,376	15.6	15.6	15.6	15.6
Ischemic Heart Disease	PA	F	30-44	336	16,385	496	16,880	16.6	16.6	16.6	16.6
Ischemic Heart Disease	PA	F	45-59	1,993	68,738	1,907	70,645	13.9	13.9	13.9	13.9
Ischemic Heart Disease	PA	F	60-69	3,168	77,191	2,667	79,858	13.3	13.3	13.3	13.3
Ischemic Heart Disease	PA	F	70-79	4,526	71,415	2,916	74,331	11.6	11.6	11.6	11.6
Ischemic Heart Disease	PA	F	80+	11,490	72,223	2,807	75,029	7.2	7.2	7.2	7.2
Ischemic Heart Disease	PA	Both	Total	66,623	1,196,364	34,019	1,230,384	13.1	16.2	14.9	16.1

PA, physical activity, PM, fine particulate matter, PM2.5, RTI, road traffic injuries; YLL, years of life lost; YLD, years living with disability; DALY, disability adjusted life year; PAF, population attributable fraction; Note, negative values indicate an increase in deaths, DALYs, or costs.

Time and Distance Units

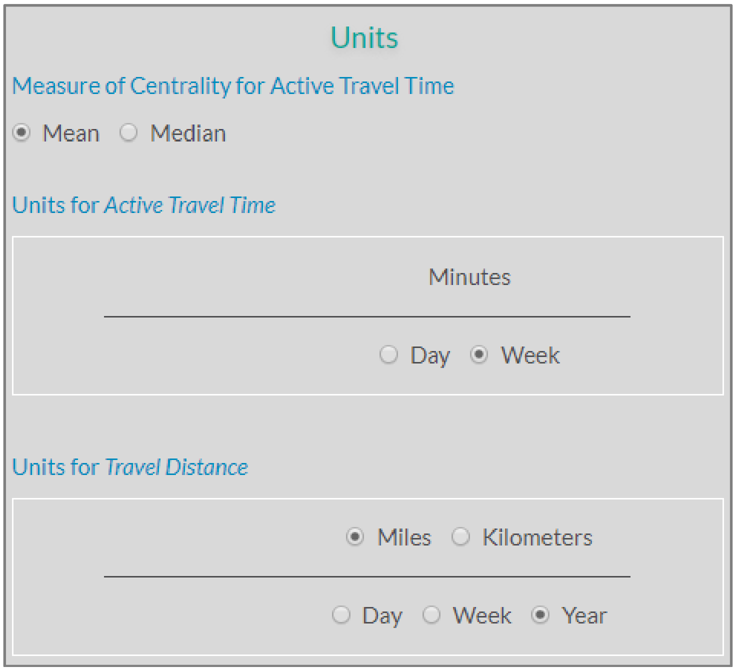
Active Travel Time

Users have the option of expressing per capita active travel time as a population mean or median or in units of minutes per day or minutes per week (Figure 2.19). Underlying the choice of mean or median is the observation that the distribution of active travel time in most populations is lopsided: a large percentage of the population engages in very little active travel and a small percentage are very active. This gives rise to a log-normal or humped distribution rather than a symmetrical bell shaped or normal distribution. For log normally distributed characteristics, such as active travel time, the population median (50% point of observations ordered from smallest to largest) may better represent the central tendency of the population. Means will be larger than medians.

Travel Distances

Users can express travel distances units of miles or kilometers, and the time basis for these distances can be expressed per day, per week, or per year. The choice of units were designed to

Figure 2.19 Choices for Units for Active Travel Time and Travel Distances

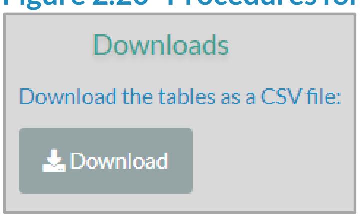


align with the conventions of different disciplines (urban planning, travel modeling, and health sciences).

Saving Outputs

Users have several options to save to their desktop computers the outputs that appear in the right side panel of the RunITHIM page. First is a comma separated file of the series of tables that has been selected (Summary, Medium, or High detail).

Figure 2.20 Procedures for Downloading Outputs as a CSV File



Clicking on the download button will open a dialogue box with a folder directory of your computer. Using the commands of your computer's operating system, you can save the file to a specific directory. An example of the file format is presented below.

Figure 2.22 Example of a downloaded CSV file for the Summary Level of Detail

Baseline	Scenario	Level of Detail	Evaluation Year	Table Title	Row Item Name	Table Values			
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Changes in Active Travel Time, Deaths, Costs, and Carbon Emissions	Item	Baseline	Scenario		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Changes in Active Travel Time, Deaths, Costs, and Carbon Emissions	Active Travel Time (min/p/week)	44	384		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Changes in Active Travel Time, Deaths, Costs, and Carbon Emissions	Avoided Deaths	NA	118786		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Changes in Active Travel Time, Deaths, Costs, and Carbon Emissions	Health Cost Savings ($ billion 2010)	NA	106		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Changes in Active Travel Time, Deaths, Costs, and Carbon Emissions	Carbon Emissions (MMTY)	912	698		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Weekly Active Travel Times (minutes)	Mode	Baseline	Scenario		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Weekly Active Travel Times (minutes)	Walk	40	192		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Weekly Active Travel Times (minutes)	Bike	5	192		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Weekly Active Travel Times (minutes)	Total	44	384		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Annual Travel Distance (Miles) by Mode	Mode	Baseline	Scenario		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Annual Travel Distance (Miles) by Mode	Active	364	2333		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Annual Travel Distance (Miles) by Mode	Car	10070	7713		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Annual Travel Distance (Miles) by Mode	Transit	251	251		
Baseline2015	U. S. Surgeon General	Summary	2015	Per Capita Mean Annual Travel Distance (Miles) by Mode	Total (incl. Truck & Motorcycle)	11667	11667		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Change in the Burden of Disease by Health Pathway	Pathway	PAF.Death	Deaths.Av	PAF.Dalys	Dalys.Avoided
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Change in the Burden of Disease by Health Pathway	Physical Activity	11	127423	13	2928751
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Change in the Burden of Disease by Health Pathway	Air Pollution	0	562	0	8663
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Change in the Burden of Disease by Health Pathway	Road Traffic Injuries	-17	-9155	-17	-413627
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Change in the Burden of Disease by Health Pathway	Total	5	118830	5	2523787
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Cost Savings of Health Benefits (billions of 2010 dollars)	Method	Dollars			
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Cost Savings of Health Benefits (billions of 2010 dollars)	Cost of Illness	106			
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Cost Savings of Health Benefits (billions of 2010 dollars)	Value of a Statistical Life	1164			
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Car Carbon Emissions	CO2 Emissions	Baseline	Scenario		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Car Carbon Emissions	Aggregate (Million Metric Tons)	912	698		
Baseline2015	U. S. Surgeon General	Summary	2015	Annual Car Carbon Emissions	Per Capita (Metric Tons)	3	2		

The title of the table is given for each row of table data. "Item" is the contents of the first table column(a), and b, c, d, and e refer to successive columns. You can open the CSV table in Excel or other spreadsheet application to make further edits or format changes.

Outputs can be printed or saved to the hard drive a desktop computer. To print the current webpage, use your browser tool by selecting Print or type <Ctrl> + P. You will have the option of saving the page as a PDF or printing it as a hard copy on a printer.

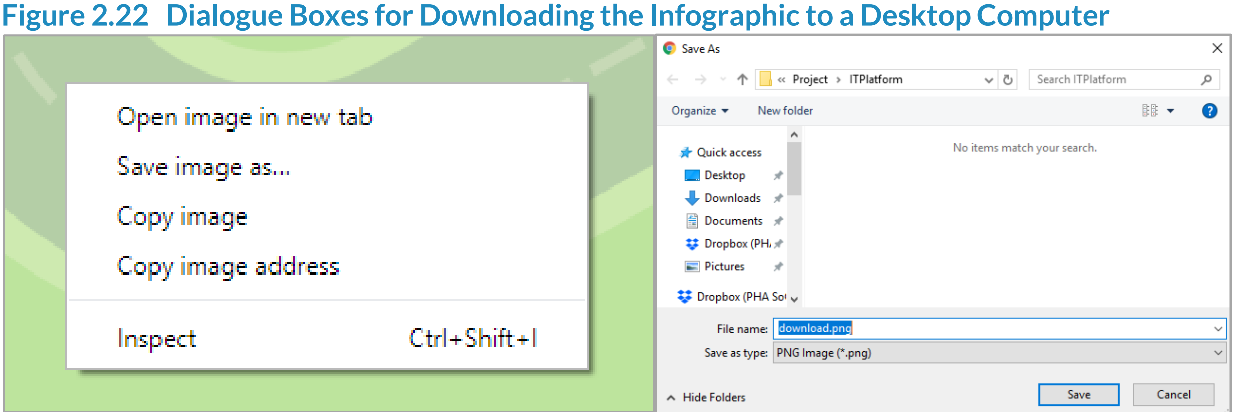
<u>Summary Report</u>

To save the Summary Report as editable text, highlight the icons and text of the report and then cut-and-paste the selection into a Word document.

<u>Infographic</u>

The infographic is downloadable as a PNG file with the default name of "download.png. Right click on the Infographic to initiate the dialogue box (left below). Select "Save image as" to open a new dialogue box (right below) that displays the file folder directory of your desktop. Navigate to the folder of your choice and save and/or rename the file.

Figure 2.22 Dialogue Boxes for Downloading the Infographic to a Desktop Computer



Tables

Tables can be saved as editable, formatted text by highlighting the table (title and rows and columns), and cutting-and-pasting into an Excel or Word document. HTML5 using Shiny will preserve the tabular format and the color scheme of the web-based table.

Graphs

Graphs follow the same steps as the infographic. Right click on the graph to initiate the dialogue box (left below). Select "Save image as" to open a new dialogue box (right below) that displays the file folder directory of your desktop. Navigate to the folder of your choice and save and/or rename the file. Remember to save the corresponding title.

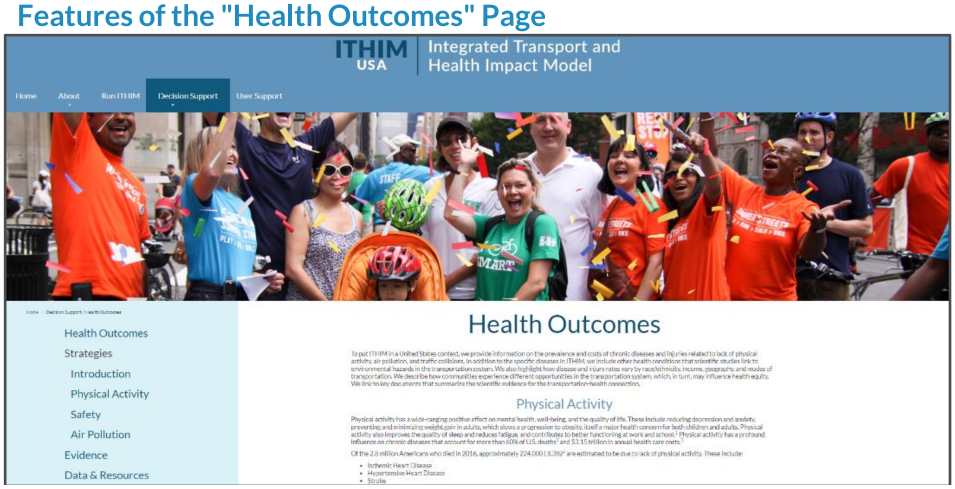
Decision Support Pages

The Decision Support are comprised of 7 subpages that help users put the outputs of the RunITHIM page into a broader public health context and help users identify strategies to increase transportation-related physical activity, increase traffic safety, and reduce vehicle-related air pollution, carbon emissions, and miles traveled (VMT).

Health Outcomes

"Health Outcomes" is the first Decision Support page and has style elements in common with all Decision Support pages. The left side-panel has a navigation menu that allows you to rapidly access other decision support pages (Figure 2.23).

Figure 2.23 Features of the "Health Outcomes" Page

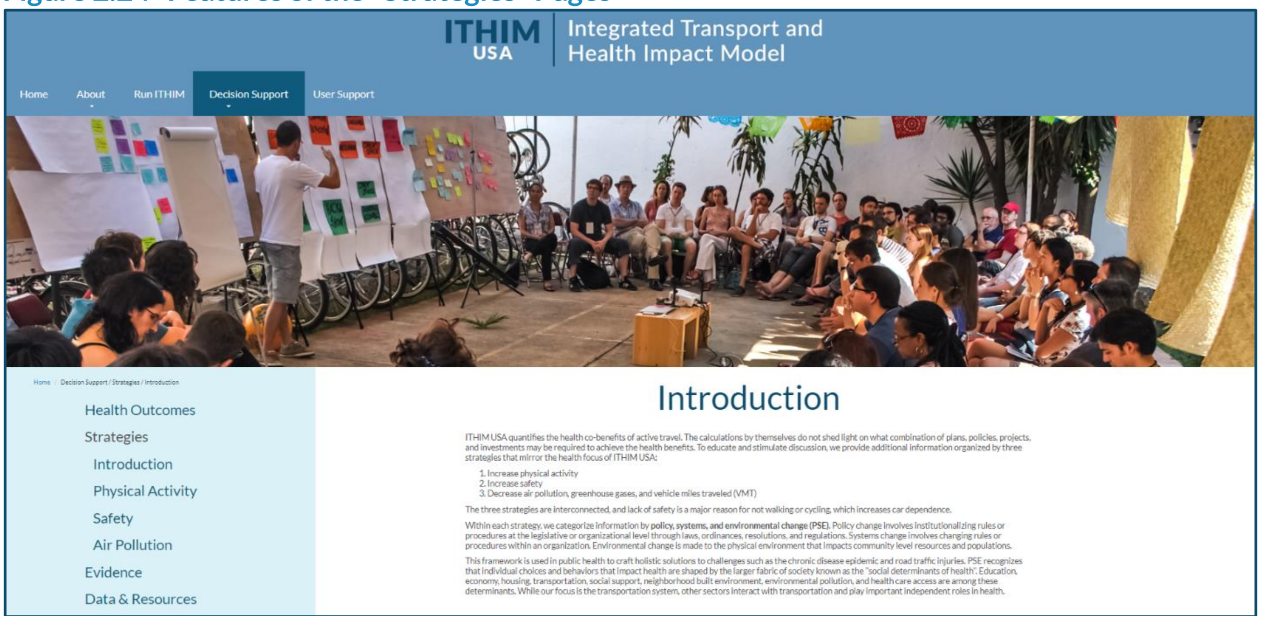


The "Health Outcomes" page has information on the prevalence and costs of chronic diseases and injuries related to lack of physical activity, air pollution, and traffic collisions.

These include the specific diseases modeled in ITHIM and other health conditions that scientific studies link to environmental hazards in the transportation system. To inform users about health equity, variation in disease and injury rates are presented by race/ethnicity, income, geography, and modes of transportation. A reference section provides links to U.S. health statistics and scientific evidence for the health impacts and costs of physical inactivity, air pollution, and traffic injuries.

Strategies

Figure 2.24 Features of the "Strategies" Pages

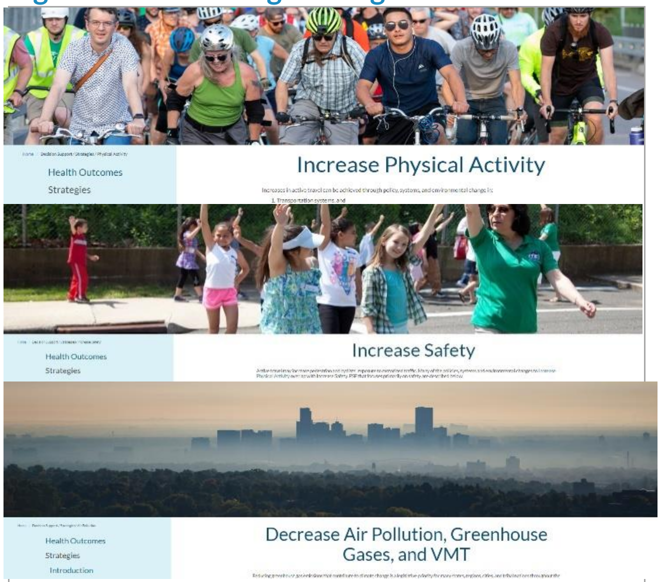


The Introduction is the first of three strategies pages, each of which corresponds to the strategies to:

1. Increase physical activity
2. Increase safety
3. Decrease air pollution, greenhouse gases, and vehicle miles traveled (VMT)

The Introduction lays out the public health framework for presenting strategies. The framework is **policy, systems, and environmental change (PSE)**. Policy change involves institutionalizing rules or procedures at the legislative or organizational level through laws, ordinances, resolutions, and regulations. Systems change involves changing rules or procedures within an organization. Environmental change is made to the physical environment that impacts community level resources and populations.

Figure 2.26 "Strategies" Pages

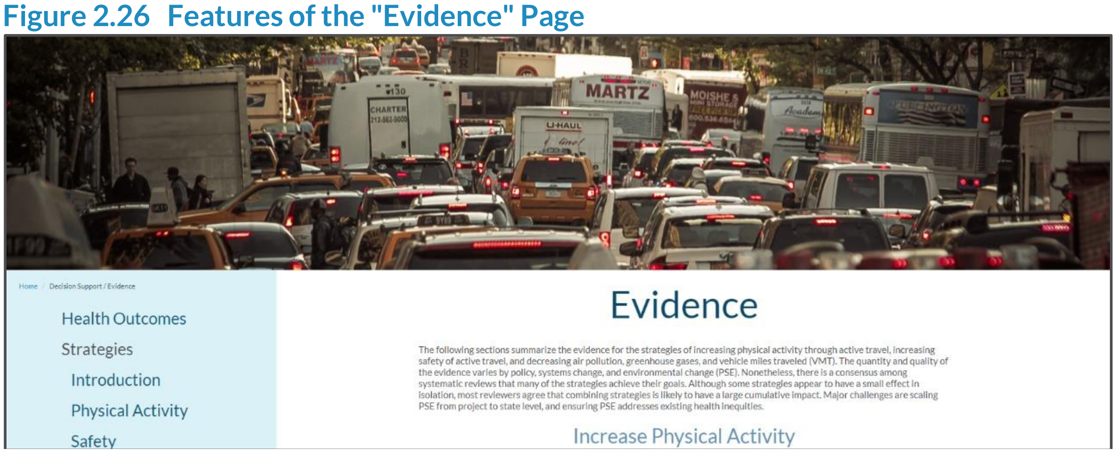


The Policy section of each strategy page has descriptions and links to legislation and policies discussed or implemented. The Systems sections focuses on change within systems of governmental agencies or coordination between agencies that does not require legislative action. The Environmental section describes infrastructure investments and engineering solutions to the transportation system or built environment that promote the strategies.

Links are provided to guidelines, best practices, and exemplary programs.

Evidence

Figure 2.26 Features of the "Evidence" Page



The "Evidence" page summarizes and references the scientific evidence for the strategies of increasing physical activity through active travel, increasing safety of active travel, and decreasing air pollution, greenhouse gases, and vehicle miles traveled (VMT).

Data & Resources

The "Data & Resources" page (Figure 2.27) provides information on the following:

- Description of data sources used in ITHIM USA
- Links to obtain a copy of the ITHIM USA data files (ITHIM USA_Data.zip)
- Street, bikeway, transit design best practices from national professional organizations
- Safety countermeasures from federal transportation authorities

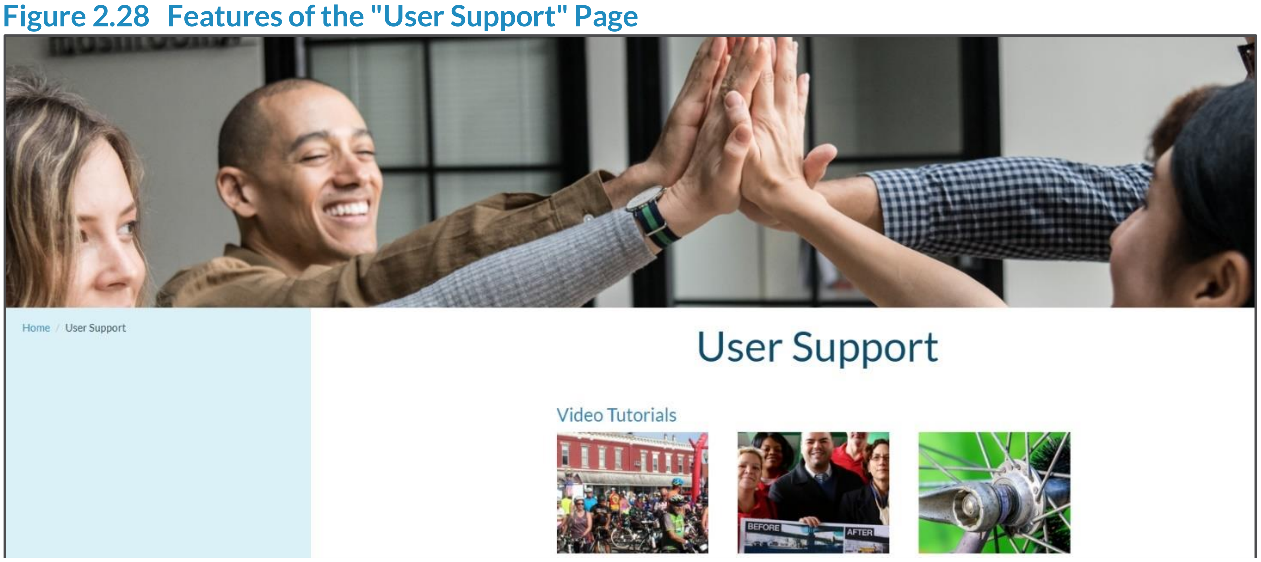
- Neighborhood design standards from national organizations

Figure 2.27 Features of the "Data & Resource" Page

- National community-based organizations for active travel and safety
- Programmatic approaches and materials to promote health equity in transportation systems
- Guides for physicians, nurses, and public health practitioners on climate change and health
- Indicator projects/mapping tools with transportation and health information for census tracts
- Links to international ITHIM developers and other transportation-health impact models.

User Support Page

Figure 2.28 Features of the "User Support" Page



The "User Support" page provides information on how to navigate the ITHIM USA website and information for software developers, and analysts who wish to deepen their knowledge of the operational details of ITHIM USA. The materials include:

- Short video clips introducing the website and use of the tool in the RunITHIM page
- Links to a quick navigation guide in PDF format (ITHIM_quickguide.pdf)
- Links to this User's Guide (THIMUsersGuide.pdf)
- Instructions in pdf format on how to upload scenario and equity data (ITHIM_upload.pdf)
- R code and supporting files of the ITHIM USA R application
- R Code that formats outputs of travel models as inputs for ITHIM USA scenarios (contributed by California MPOs)
- A glossary of acronyms used in the website and User's Manual (ITHIM_glossary.pdf).

Chapter References

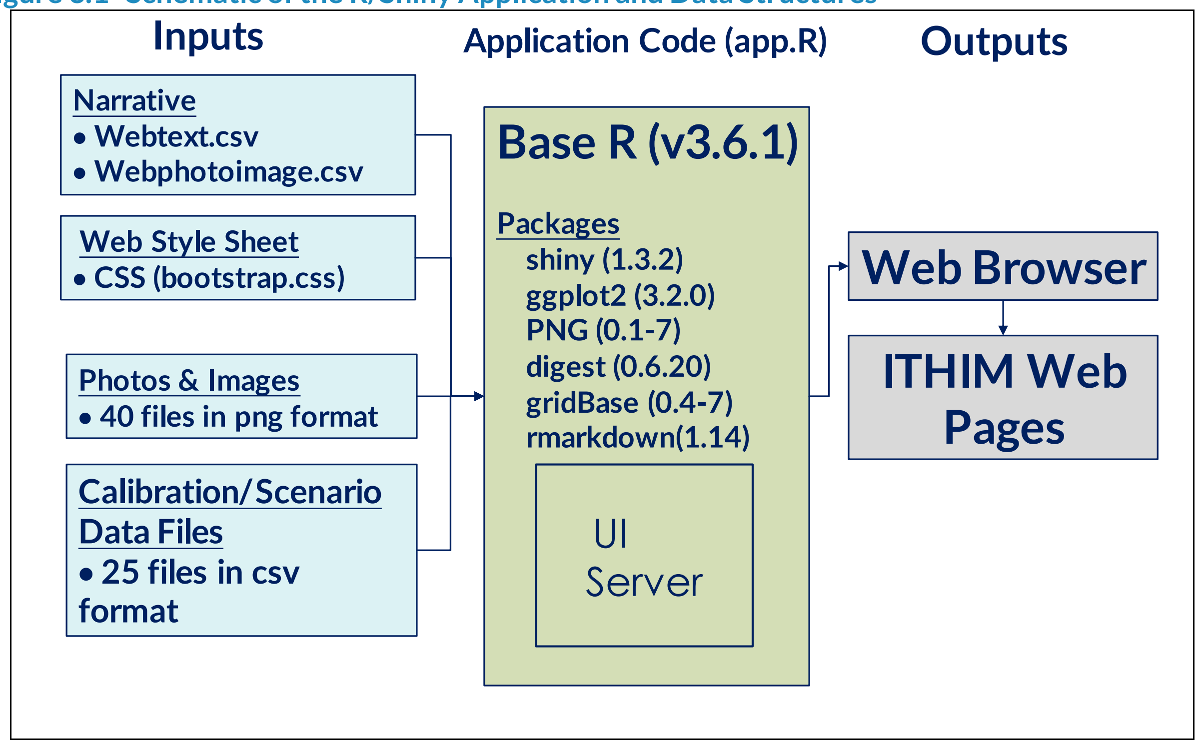
27. R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2016.http://www.R-project.org/. Accessed April 4, 2019.
28. R Studio. *Shiny R Package*. Boston, MA: R Studio; 2019.http://shiny.rstudio.com/. Accessed April 4, 2019.

Chapter 3. Programmer's Guide to ITHIM USA

Schematic of Process and Data Structures

The ITHIM USA R/Shiny software application combines R commands; web narrative (text) and HTML commands; photos, icons, and other images and corresponding text for accessibility text readers; a cascading style sheet (CSS) based on the Bootswatch Flatly template;[29, 30] and calibration and scenario data files (Figure 3.1). The application was initially developed on desktop computers using RStudio,[28] which is an interactive development environment (IDE).

Figure 3.1 Schematic of the R/Shiny Application and Data Structures



Input Files

There are five categories of inputs to the R application (app.R), which generates the HTML interpreted by the web browser on your desktop/laptop computer and displays web pages.

Text and Image Management

The "webtext.csv" file has web page narrative and formatting commands called HTML tags and occasional CSS styling instructions. The file is a look-up table linked to the R application by the unique entries in column 1 called "Element". When an R command is executed, the text of the "Contents" (column 2) populates the web page. This approach adds flexibility to web page maintenance, so that changes to the wording of web pages can be done without knowledge of R programming or the need to modify the R codes itself (hard coding). There is an additional column for notes, mostly pertaining to HTML representation of special characters (©, no-break spaces - , Greek letters, etc.). Webstext.csv and its layout are presented below.

Table 3.1 Sample of Text from "webstext.csv" File

Element	Content
hp.versiontext	DRAFT FOR DISCUSSION ONLY - Website Under Construction - April 22, 2020
hp.bannertext	Transportation Planning for Health, Equity, and Climate Change
hp.bannercaption	Replacing short car trips with walking, cycling, and transit increases physical activity and cuts air pollution and climate-warming emissions
hp.bannersubcaption	Every year, more than 292,000 Americans die prematurely from traffic injuries and chronic diseases linked to physical inactivity and air pollution. Learn about active travel health benefits, harms, and potential cost savings of transportation plans and for goals in your own community.
hp.leftbutton	What is ITHIM?
hp.centerbutton	How do I use ITHIM?
hp.rightbutton	Start Using ITHIM
hp.leftsubbutton	Learn More
hp.centersubbutton	See Instructions
hp.rightsubbutton	Go Now
hp.pithyquote	"The idea that we can cure ourselves and the planet by simply walking or riding a bicycle is both obvious and daunting given our current transportation system. ITHIM makes the case that active travel has a prominent role in solving the twin crises of chronic disease and climate change."
hp.pithyquoteauthor	ITHIM USA Development Team
hp.gallerytitle	A Sample of ITHIM Results from Scientific Publications and Reports
hp.galleryintro	Since 2009, ITHIM has played a role in elucidating the health co-benefits of active travel as a strategy to reduce greenhouse gas emissions. The model has been used by regional transportation planning agencies, state departments of health, transportation, and air pollution control, and local health departments to evaluate their strategic goals.
hp.galleryfig1	<a href = "https://doi.org/10.1016/S0140-6736(09)61714-1"
hp.galleryfigcap1	ITHIM models transportation-related physical activity, air pollution, and traffic injuries
hp.galleryfig2	<a href = "https://data.chhs.ca.gov/dataset/adults-meeting-physical-activity-guidelines-lghc-indicator-16"
hp.galleryfigcap2	Many people in the United States are not physically active, and few get physical activity from active travel
hp.galleryfig3	<a href = "https://www.ncbi.nlm.nih.gov/pubmed/25900805"
hp.galleryfigcap3	Active transport reduces chronic disease, but may increase injuries
hp.galleryfig4	<a href = "https://www.bmj.com/content/348/bmj.g425"
hp.galleryfigcap4	The evaluation of bike share programs and their health impacts is one of the uses of ITHIM

Table 3.2 File Layout of the "webtext.csv" file

Variable	Definition	Coding levels
Element	Unique identifier for an element on a web page	First two or three characters identify the web page that the element is part of: hp = Home Page ap = About Page > Introduction in = About Page > Instructions sc = About Page > Scenarios geo = About Page > Geographies (not used) tm = About Page > Time Periods me = About Page >Methods rp = RunITHIM tt = tool tip on Run Pages ds = Decision Support ds.ho = Decision Support > Health Outcomes ds.st = Decision Support > Strategies ds.ev = Decision Support > Evidence ds.dr = Decision Support > Data & Resources us = User Support
Contents	Text and HTML tags for the content of a web page	= begin and end of paragraph text>= hypertext linkage </u> = begin/end of unordered list = begin/end of ordered list = begin/end of line entry in unordered list = begin/end of bold text = begin/end of superscripted character - begin/end of subscripted character <u></u> = begin/end of underline =apply HTML command to items within the span tags <th></th> = begin/end of a table column headers <tr></tr> =beginning/end of table row <td></td> = beginning/end of data points of a table row = beginning/end of third level header text = beginning/end of fourth level header text
Notes	Special characters or instructions for HTML or CSS codes	&#215 = multiply sign &#181 = micro (μ) symbol = no break space &copy = copyright symbol

The "webphotoimage.csv" file is also a look-up table linked to the R application by the unique entries in column 1 called "Element". When an R command is executed, the photo or image file name listed in "Filename" (column 2) populates the web page. The contents of "Alttext" are also incorporated into the website so that text readers can provide visually impaired users with a description of the image. This approach adds flexibility to web page maintenance, so that photographs can be easily exchanged without knowledge of R programming.

Table 3.3 Sample of Data from "webphotoimage.csv" File

Element	Filename	Alttext	Title
hp.wordmark	ITHIMUSAWordmark_725by115.png	ITHIM wordmark	ITHIM wordmark
hp.banner	background-image: url('home_page_banner2000by750.png');	Bicycle riders congregating	Bicycle riders congregating
hp.gallery1	ITHIMbubble375by250.png	ITHIM pathway diagram	ITHIM pathway diagram
hp.gallery2	figure375by250.png	Line graph of active travel time	Line graph of active travel time
hp.gallery3	ITHIMPAFDx375by250.png	Table of change in burden of disease and road traffic injuries	Table of change in burden of disease and road traffic injuries
hp.gallery4	LondonBikeShare375by250.png	London Bike share route map	London Bike share route map
hp.gallery5	CalCO2Goals375by250.png	Bar charts of health impacts of California greenhouse reduction goals	Bar charts of health impacts of California greenhouse reduction goals
hp.gallery6	LACountyHIA375by250.png	Los Angeles County health impact assessment	Los Angeles County health impact assessment
hp.sponsor	Sponsor01_250by200.png	Sponsor 01 - Neil Maizlish	Sponsor 01 - Neil Maizlish
hp.sponsor2	Sponsor02_250by200.png	Sponsor 02 - Weiher Creative	Sponsor 02 - Weiher Creative
hp.sponsor3	Sponsor03_250by200.png	Sponsor 03 - Chensheng Jiang	Sponsor 03 - Chensheng Jiang
hp.sponsor3	background-image: url('WalkingManhatan2000by400.png');	Pedestrians in crosswalk, Manhatan	Pedestrians in crosswalk, Manhatan
ap.intro	background-image: url('ExpectPedestrians2000by400.png');	City officials walking in crosswalk with umbrellas	City officials walking in crosswalk with umbrellas
ap.instruct	background-image: url('Scenarios2000by400.png');	Transportation officials with before-after pictures road safety intervention	Transportation officials with before-after pictures road safety intervention
ap.scenbanner	Baseline2015_200by200.png	Baseline 2015	Baseline 2015
ap.scenario1	CARBScopingPlan200by200.png	California Air Resources Board (not used)	California Air Resources Board
ap.scenario2	Caltrans2020SMP200by200.png	Caltrans (not used)	Caltrans
ap.scenario3	SCS2040_200by200.png	Sustainable Community Strategies	Sustainable Community Strategies
ap.scenario4	USSG200by200.png	US Surgeon General	US Surgeon General
ap.scenario5	BaselineMultiples200by200.png	Multiples of baseline	Multiples of baseline
ap.scenario6	FixedTime200by200.png	Fixed amount of time	Fixed amount of time

The "webphotoimage.csv" file follows the same convention as the "Element" field in the "webtetx.csv" file regarding the first 2 or 3 letters that reference the web page of photo or image. The file also has a column "Size", which provides the dimensions in pixels of the image. “Webtext.csv” and “webphotoimage.csv” were adapted from corresponding files of California ITHIM. Rows referring to a Geographies web pages have not been removed and serve as place holders for potential addition of regional or state versions. Geography-related rows in the main R program (app.R) have been inactivated using comments (#).

Web Style Sheet

Modern web programming uses HTML tags in conjunction with a styling commands that are consolidated in a text file called a cascading style sheet (CSS). ITHIM USA uses a free and open-source CSS template called Bootswatch "Flatly" (https://bootswatch.com/flatly/), which is based on the Bootstrap family of style sheets. Bootstrap design templates encompass typography, forms, buttons, navigation and other interface components. The Flatly style sheet (148 KB, 7100 lines) was modified to incorporate the Lato family of fonts and the color palette in the CARB website style guidelines.

Table 3.3 Selected Style Elements in Bootswatch.css File

Style Element	HTML Tag	CSS Element	Pixels
First header level	h1	color: #0C4B6B (dark blue)	32
Second header level	h2	color: #6194BC (medium blue)	24
Third header level	h3	color: #1F8BBF (light blue)	18
Paragraph	p	color: #4D4D4F (dark grey)	16
Table heading background	th	color: #0C4B6B (dark blue)	
Table row color	tr	color: #deeaf6 (pale blue)	

Comments were inserted in the "bootstrap.css" file to indicate where changes were made to the original CSS. For example, changes in the style for tables was documented by the sequence below.

```
/* Change Table header background dark blue, formerly CARB green*/
th }
    background-color: #0C4B6B;
    color: white;
    border: 1px solid white;
     padding: 0;
)
/* Light blue zebra alternating rows */
tr:nth-child(even) {background-color: #deeaf6;
   }
```

Style elements unique to ITHIM USA appear at the end of the bootstrap.css file (lines 7238 - 7581).

Calibration/Scenario

ITHIM USA has 21 data files in CSV format that are used to calibrate the model for baseline conditions in 2015 and two files for travel patterns of two scenarios: Short Trips and US Surgeon

General Physical Activity Recommendations (USSG). The names of the files are presented in Table 3.4 (next page) and their layout is presented in Table 3.5.

Meta-Data Dictionary and Data Files

File names (Table 3.4), variables within each file, and definitions and coding levels of each variable (Table 3.5) were presented in previous pages.

Default Values

Table 3.6 presents the default values in the file 'ParameterDefaults.csv', which are constants used in calculating distances/times, population attributable fractions for physical-activity related diseases, the value of a statistic life, safety in numbers, and other inputs.

Table 3.6 Default Values for Key parameters of ITHIM USA

Variable Name	Definition	Default Values
Walkspeed	Average walking speed in miles/hour	3
Bikespeed	Average bicycling speed in miles/hour	12
SiN	Safety in Numbers coefficient	0.5
PAChronicBeta	Slope of the dose-response function between physical activity and chronic diseases, exclusive of all causes	0.5
PAAllCauseBeta	Slope of the dose-response function between physical activity and all-causes mortality	0.25
NQtiles	Number of quantiles of modeled physical activity distribution	5
VSL	Value of a Statistical Life in dollars, 2010	9800000

ITHIM USA uses walk speed and bike speed to determine active travel times. Mean active travel time was derived by dividing mean distances for walking and cycling by estimated average speed. Active travel distances were calculated from origin-destination data points (in the National Household Travel Survey) linked by an assumed Google Maps route by mode. Self-reported travel times for walking and cycling are reported by survey respondents, but they regularly spike at times ending in 0 or 5, suggesting a rounding up digit bias. Walk speeds and bike speeds based on self-reported travel times and distances often leads to unrealistically low travel speeds.

Of note, the 'default_narratives.csv' file contains travel distances by mode for the baseline 2015 and scenario distances by mode for the Short Trips and U.S. Surgeon General scenarios.

Safety in numbers refers to the observation that the rate of bicycle and pedestrian injuries appears to follow a function of bicycle and pedestrian mode share – the higher the mode share

Table 3.4 Calibration and Scenario data File Names, Descriptions, and Primary Source by Class of Information, ITHIM USA

Category	File Name	Description	Primary Source
Burden of Disease	BurdenDisease2010.csv	Age-sex-cause-region specific deaths, yll, yld, dalys	Institute for Health Metrics and Evaluation
Burden of Disease	APC_Disease_Rates.csv	Age-sex-cause specific annual change in mortality rates	Canudas et al, 2017
Burden of Disease	DiseaseRiskAdjuster.csv	Age-sex-cause specific adjustment factor to population subgroup (equity analysis)	User-defined (e.g. race/ethnicity, income, etc.)
Car CO2	CO2g_mi.csv	Grams of CO2 per car mile traveled	US EPA-MOVES2014b
Costs	COI2010USD.csv	Cause-specific per capita costs of illness	MEPS, NCI, medical specialty societies
Exposure	ATmean_min_week_age_sex_baseline.csv	Age-sex-region-specific minutes of walking and cycling/p/y by mode	NHTS, 2017
Exposure	bike_walk_cv.csv	Region-specific coefficient of variation for mean active travel (mi/p/y)	NHANES, 2016-2017
Exposure	METminWalk_Bike.csv	Age-sex-mode (walk/bike) specific MET weights for active travel	James Woodcock, 2011
Exposure	nonTravelMETS.csv	Age-sex-quintile specific min/p/w of non-travel METs	NHANES 2016-2017, R CVnonTravelMETS2020-01-13.R
Exposure	default_narratives_2019_07_10.csv	Region-specific travel miles/p/y by mode for 2015 baseline and built-in scenarios: Short trips, US Surgeon General (USSG).	NHTS 2017. For USSG, baseline motorized modes + 75 med min bike/walk converted to mean and then 3 and 12 mph speed; For Short Trips and USSG, increase in active travel is offset by reduction in car miles maintaining baseline occupancy .
Exposure	Baseline_distance_by_facility_type.csv	Percentage of VMT by mode and facility type	California average of large MPO and California Statewide travel demand models

Category	File Name	Description	Primary Source
Exposure	PM252010_2050.csv	Change in airborne PM2.5 concentration with car emissions as a function of change in car VMT, 2015 to 2050 in 5-year intervals	MOVES2014b, US EPA methodology for mortality per ton of emissions
Exposure	WalkBikeTransitRatios.csv	Mode (bike/walk)-specific ratio of transit travel time (min/p/y)	NHTS, 2017
Exposure	Bus_occupancy.csv	Region-specific bus occupancy	US DOT, 2016
Parameters	ParameterDefaults.csv	Default constants (e.g., walk, speed, bike speed, VSL, etc.)	Constants for travel, health outcomes, costs
Population	age_sex_regionUSA.csv	Age-sex-population proportions for baseline year 2010	USCensus_2010_SF1_QTP1
Population	age_sex_region_county2010-2050.csv	Age-sex-county population projections in 5 calendar year bands from 2015-2050	USCensus_2010_SF1_QTP1, US Census NP2014 projections
Risk	PA_RR.csv	Disease-specific RR per METhr-wk	Garcia et al, 2021
Risk	PM25_RR.csv	Disease-specific RR per $\mu g/m^3$ of PM2.5	Vodonos et al, 2018 value for cardio-pulmonary disease, Woodcock 2013 for acute respiratory illness in children
Risk	rti_baseline.csv	Severity-facility specific RTIs by striking and victim mode for baseline year	FARS, 2016; CRSS, 2016

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration and Scenario Data Files, ITHIM USA

File Name	Variable Name	Definition	Code Levels
BurdenDisease.csv	Region		United States
	Year	Year of death	
	Cause	Cause of death	Ischemic Heart Disease, Stroke, Hypertensive Heart Disease, Diabetes, Breast Cancer, Colon Cancer, Dementia, Depression, Inflammatory Heart Disease, Lung Cancer, Respiratory diseases, Acute resp infections, Road Traffic Injuries
	Sex	Gender	1=M, 2=F
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+
	pop	Population	DOF
	deaths	Number of deaths	Global Burden of Disease for US adjusted to mortality ratio of region to US for age-sex deaths >10
	yll	Years of life lost	Global Burden of Disease for US adjusted to mortality ratio of region to US for age-sex deaths >10
	yld	Years living with disability	Global Burden of Disease for US adjusted to mortality ratio of region to US for age-sex deaths >10
	daly	Disability-adjusted life years	Global Burden of Disease for US adjusted to mortality ratio of region to US for age-sex deaths >10
APC_Disease_Rates.csv	Cause	Specific cause of disease	Ischemic Heart Disease, Stroke, Hypertensive Heart Disease, Inflammatory Heart Disease, Lung Cancer, Respiratory diseases, Acute resp infections
	Sex	Gender	1=M, 2=F
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+
	APC	Annual percent change in mortality rate	0 to 100

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration and Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
DiseaseRiskAdjuster.csv	Region	United States	United States
	Cause	Cause of death	Ischemic Heart Disease, Stroke, Hypertensive Heart Disease, Diabetes, Breast Cancer, Colon Cancer, Dementia, Depression, Inflammatory Heart Disease, Lung Cancer, Respiratory diseases, Acute resp infections, Road Traffic Injuries
	Sex	Gender	1=M, 2=F
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+
	Rradj	Relative risk adjustment for co-variate	1 for deaths < 10
CO2_gmi.csv	Region		United States
	Year	Year of Projection	2015 and 5-year intervals to 2050
	CO2g_mi	Grams of CO2 emitted per mile of car travel	Averaged over gas, diesel, and electric cars and light trucks
COI2010USD.csv	Cause	Specific cause of disease	Ischemic Heart Disease, Stroke, Hypertensive Heart Disease, Diabetes, Breast Cancer, Colon Cancer, Dementia, Depression, Inflammatory Heart Disease, Lung Cancer, Respiratory diseases, Acute resp infections, Road Traffic Injuries
	Specific cause	Cause mentioned in cost literature	Heart Disease, Diabetes, Breast Cancer, Colon Cancer, Dementia, Depression, Lung Cancer, Asthma and COPDs, Road Traffic Injuries
	USCost2010	National cost in constant 2010 USD	
	PerCapita2010USD	Cost per capita in constant 2010 USD	

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration and Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
ATmean_min_week_age_sex_baseline.csv	Region	United States	United States
	Sex	Gender of traveler	1=M, 2=F, Both=Both
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+, Total
	Mode	Active mode of travel	Walk, Bike
	Baseline	Mean minutes/person/week of active travel at baseline	NHTS2017 mean distance/p/d converted to times using 3 mph average for walking and 12 mph for cycling
	Source	Source(s) of data	NHTS2017
ParameterDefaults	VariableName	Variable name of parameter	Walkspeed, Bikespeed, SiN, PAChronicBeta, PAAllCauseBeta, Nqtiles, VSL
	Definition	Definition of parameter	
	Default	Default value of parameter	3, 12, 0.5, 1, 0. 3333,5, 9800000
WalkBikeTransitRatios.csv	Region	United States	United States
	BikeTRatio	Ratio of Bike to Transit minutes	
	WalkTRatio	Ratio of Walk to Transit minutes	
	TransitMin	Baseline Transit Minutes per week	

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration and Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
bike_walk_cv.csv	Region	United States	United States
	CV	Coefficient of variation of active travel time	CVnonTravelMETS2021-07-05NoOccMarginalMETS.R
METminWalk_Bike.csv	Sex	Gender of traveler	1=M, 2=F, Both=Both
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+, Total
	METminWalk	Age-sex adjusted marginal METS for walking	Average velocity of 3 mph, Woodcock age-sex ratios from Europe, and Ainsworth 2011 regression relationships using mMETs
	METminBike	Age-sex adjusted marginal METS for cycling	Constant of 5 METS (no age-sex variation)
nonTravel_METS.csv	Region	United States	United States
	Sex	Gender of traveler	1=M, 2=F
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+
	q1	1st quintile of non-travel METS	0 - 33
	q2	2nd quintile of non-travel METS	0 - 33
	q3	3rd quintile of non-travel METS	0 - 33
	q4	4th quintile of non-travel METS	0 - 33
	q5	5th quintile of non-travel METS	0 - 33

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration ND Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
default_narratives_2019_07_10.csv	Region	United States	United States
	Item_Name	Description of item	Distances (miles/person/year)
	Scenario_ID	2015 Baseline and built-in scenario names	Baseline2015, Replacing Short Car Trips with Active Travel, U. S. Surgeon General Recommendation
	Mode	Travel mode	Walk, Bike, CarDriver, CarPassenger, Bus, Rail, Motorcycle, Truck
	Baseline	Per capita mean miles/p/yr	TBD edit checks specific to mode
PA_RR.csv	Cause	Specific cause of disease	Ischemic Heart Disease, Diabetes, Breast Cancer, Colon Cancer, Dementia, Depression, Stroke, Hypertensive Heart Disease, All causes, Lung Cancer
	Sex	Gender	1=M, 2=F
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+
	RR	Change in RR per mMET-hr/w	0.89 - 0.99999
PM25_RR.csv	Cause	Specific cause of disease	Ischemic Heart Disease, Stroke, Hypertensive Heart Disease, Inflammatory Heart Disease, Lung Cancer, Respiratory diseases, Acute resp infections
	coefficient	ln(RR per µg/m3 PM2.5)	CVD, 0.014494446; Lung Cancer, 0.01212618; respiratory disease, 0.011236632; Acute resp infections, 0.009758033

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration and Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
PM252010_2050.csv	Region	United States	United States
	pm25	Population weighted annual average PM2.5 levels, background, 2010	5-25
	slope	change in PM2.5/change car VMT	
	DPM_TPD	PM2.5 Emissions in tons per day	
	NOX_TPD	NO_x Emissions in tons per day	
	SO2_TPD	SO_2 Emissions in tons per day	
age_sex_regionUSA.csv	Region	United States	United States
	Sex	Gender	1=M, 2=F, Both
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+, Total
	Population	Population count in 2010	
	Percent	Percent of age-sex population	0 to 1

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration ND Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
age_sex_region_county2010-2050	Geography	United States	United States
	Region	Name of region (based on MPOs)	United States
	Sex	Gender	1=M, 2=F
	Age	Age group identifier	0=0-4, 5=5-14, 15=15-29, 30=30-49, 50=50-59, 60=60-69, 70=70-70, 80=80+
	Year	Year of estimate	2010, and 5-year annual average for 2015-2019, 2020-2024, 2025-2029,2030-2034,2035-2039,2040-2044,2045-2049,2050-2054
	Population	Population estimate	5-year annual average population based on Cal Dept. of Finance Projections
Baseline_distance_by_facility_type.csv	Region	United States	United States
	Mode	Travel mode	Walk, Bike, Ca, Bus, Motorcycle, Truck
	local_pct_b	Percent of travel on local roads	0 to 1
	art_pct_b	Percent of travel on arterials	0 to 1
	hwyl_pct_b	Percent of travel on highways	0 to 1

Table 3.5 Variable Names, Definitions, and Coding Levels of Calibration and Scenario Data Files, ITHIM USA (cont'd)

File Name	Variable Name	Definition	Code Levels
rti_baseline.csv	Region	United States	United States
	Severity	Severity of injury	Fatal, Serious
	Roadway	Roadway type	Local, Arterial, Highway
	VictimMode	Mode of victim	walk, bike, car, bus, rail, motorcycle, truck
	walk	Number of injuries, walk striking mode	Non-negative or 0
	bike	Number of injuries, bike striking mode	Non-negative or 0
	bus	Number of injuries, bus striking mode	Non-negative or 0
	car	Number of injuries, car striking mode	Non-negative or 0
	truck	Number of injuries, truck striking mode	Non-negative or 0
	motorcycle	Number of injuries, motorcycle striking mode	Non-negative or 0
	NOV	No other vehicle involved in collision	Non-negative or 0
bus_occupancy.csv	Region	United States	United States
	Occupancy	Occupancy (PMT/VMT)	Non-negative or 0

the lower the rate of injuries.[16] The function follows an inverse power relationship: injuries = mode share^n, where n is 0.5.

'PAChronicBeta' describes the functional form of the physical activity-disease dose response relationship for specific causes modeled in ITHIM USA.[6] This follows from the observation that risk reduction is sharpest at the low dose end of the dose-response curve (i.e. a 5 minute increase in physical activity will have a bigger population health impact for the population with low levels of physical activity than the population with already with high levels. 'PAAllCauseBeta' describes the same phenomenon for 'PAChronicBeta', but for all causes of disease combined, where this effect is stronger.

The active travel time distribution is modeled in quintiles by default (NQtiles, 5). The value of a statistical life is based on US. EPA values $9.8 million in 2016 USD).[31]

The amount of carbon reductions in the Low Carbon Driving scenario is user specified. The baseline reduction follows Lutsey[32], who estimated a 33.5% reduction in carbon emissions from a 2000 baseline by 2045 due to electrification of the auto fleet and adoption of low carbon fuels. He projected an additional 16% reduction from other engineering improvements (drive train, accessories, etc.).

ITHIM USA Application (app.R)

Directory and File Structure

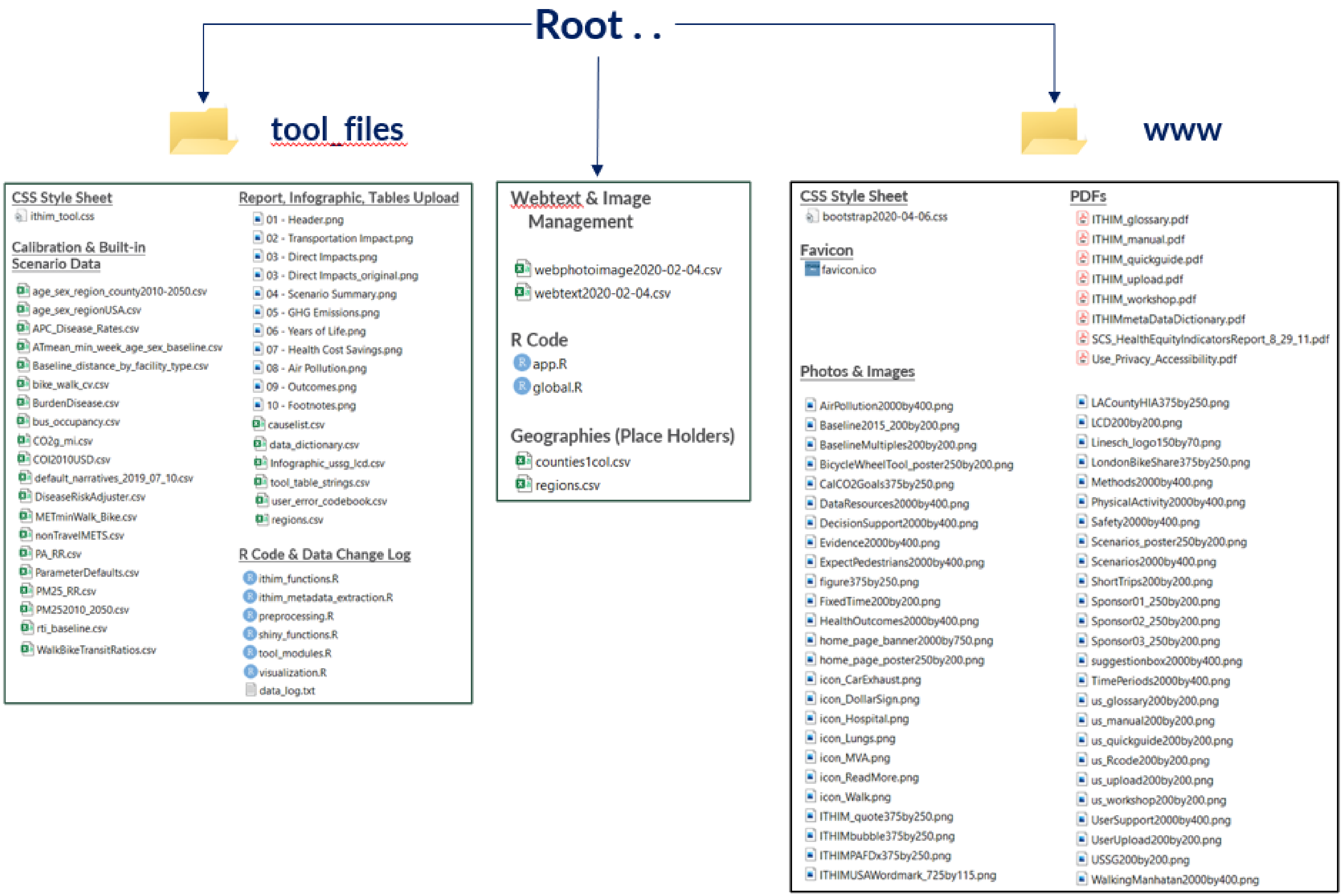
R applications follow several file and folder naming conventions (Figure 3.2). The application itself must be named "app.R", and be located in a root file directory (folder). The app.R file can be accessed from the Github repository[33] and uses R Markdown for documentation. File directories must be created ahead of time and can then be referenced within the R application. An R default directory called "www" is the location of the CSS style sheet, the favicon for the website title tab, pdfs of documents stored at the website, and photos and image files. Video tutorial files are hosted by CARB at its YouTube site (https://www.youtube.com/watch?v=sFsNd3yQo5M&feature= youtu.be). Calibration and scenario data are stored in a separate directory called "tool_files."

In addition to the base R program (version 3.6.1), ITHIM USA utilizes several packages that are listed below with their function.

Table 3.7 R Packages Used in ITHIM USA

Package Name (version)	Function
Shiny (1.3.2)	Generates HTML for website presentation
ggplot2 (3.2.0)	Grammar of graphic for display of bar and line charts
png (0. 1-7)	Reads and writes png images (for infographic)
Digest (0.6.20)	Creates compact hash digests of R objects (data integrity checks)
grid (0.4-7)	Integrates base and grid graphics (display of tables/graphs)
Rmarkdown (1.14)	Creates dynamic documents for R (documentation of R code)

Figure 3.2 Directory Structure and File Locations



Schematic Input-Output Diagram

An overview of the functional inputs and outputs of ITHIM USA are presented in Figure 3.3. The inputs include calibration and built in scenario data and constants, which the analytic engine converts to outputs covering changes in the burden of disease by pathway (physical activity, PM2.5, road traffic injuries), monetized costs of the health outcomes, and CO_2 emissions of cars. Figure 3.4 describes the basic program flow and the major functions of the analytic engine. Table 3.7 gives the mathematical formulae for the key functions.

Overview of the Structure of the R Application (app.R)

The development of the California R/Shiny application was guided by the following:

- Programming with basic R and the Shiny package with other packages used sparingly and only when to achieve a specific functional requirement of the application

- "Top-down" programming of functional components, which were broken down into a sequence of steps. This contrasts with more advanced programming techniques such as object-oriented programming.

Thus, the guiding philosophy of application development emphasized a reduction in complexity commensurate with skills sets that could maintain the code until the program and its data undergo significant updating. Several key data sources (U.S. Census, National Household Travel Survey, Global Burden of Disease) are scheduled for updating within a few years of 2020.

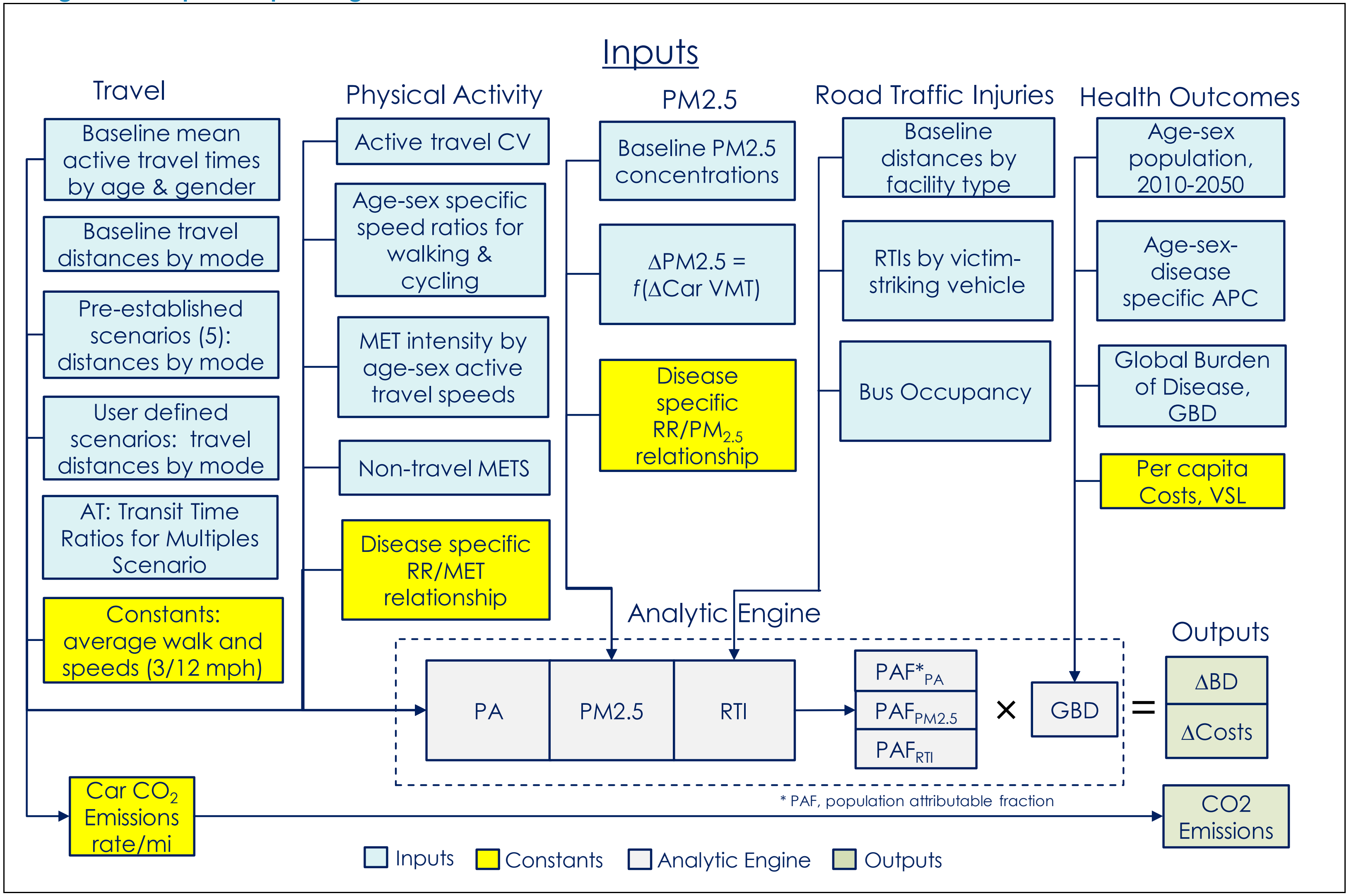
A schematic outline of the R/Shiny program is presented in Table 3.8. R Shiny applications are divided into two sections: 1) user interface (ui) and 2) server. The "ui" section contains the design elements of ITHIM USA website and the "server" contains the commands for the analytic engine through the tool module.

ITHIM Tool

A key element of design is modularization. The website can be functionally divided into two components: 1) the core analytic and interactive tool appearing below ITHIM TOOL on the RunITHIM page, and 2) all the other webpages, which have static text and images. Detailed documentation of the Tool module and its R code are available at https://ithim.org/ithim/CA_ITHIM_Tool_Documentation.pdf.

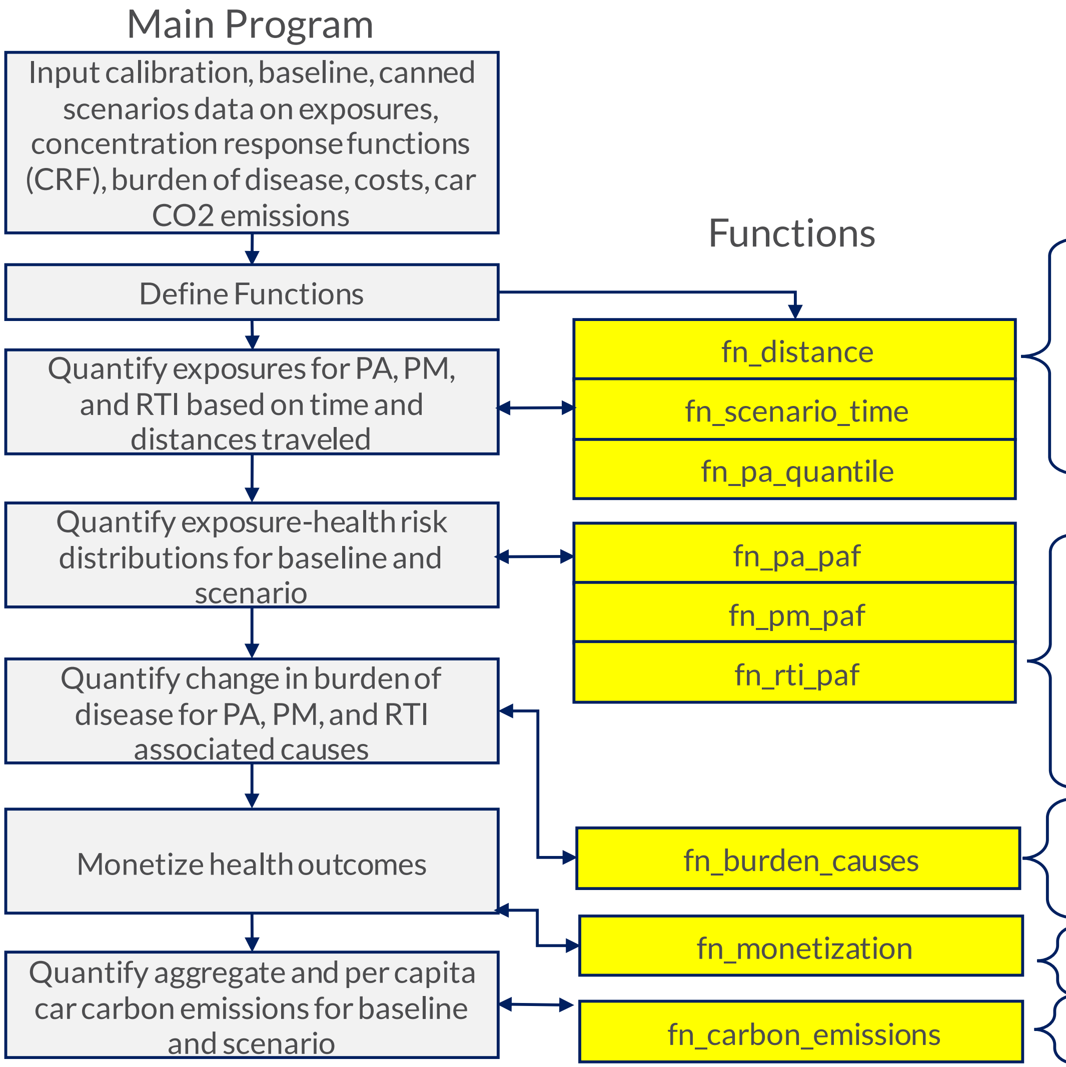
The Tool module is accessed in the Shiny interface in the RunITHIM tab panel [ithim_toolUI("TOOL")] and in the server [callModule(ithim_tool, "TOOL")]. This approach keeps the R code used to maintain the website's static narrative text and images apart from the dynamic and reactive R code that generates outputs (summary report, infographic, tables, and graphs). This also minimizes the risk of the application being rendered inoperable by unintentional changes in the tool portion when there is website maintenance for the Home, About, Decision Support and User Support pages.

Figure 3.3 Input-Output Diagram for ITHIM USA



APC, annual percent change; BD, burden of disease; CV, coefficient of variation of active travel time; GBD, global burden of disease; METS, Metabolic equivalent task; PA, physical activity; PM2.5, fine particulate matter with aerodynamic diameter of 2.5 microns; RR, relative risk; RTI, road traffic injuries; VMT, vehicle miles traveled; VSL value of a statistical life; mph, miles per hour constants

Figure 3.4 Schematic of Functions of the Analytic Engine of ITHIM USA



Inputs	Outputs
Baseline distances by mode	Scenario distances for multiples of baseline
Baseline mean AT times (age-sex-mode)	Scenario mean AT times via baseline age-sex ratios
Scenario distances by mode	
METs wtd. AT/total time, ΔRR/METhr-wk	$RR_{PA\text{-}causes}$
PM2.5 = f(carVMT), ΔRR/µg PM2.5/m^3	$RR_{PM2.5\text{-}causes}$
Baseline injuries, miles traveled by victim (PMT) and striking vehicle (VMT)	RR_{RTI} Injury rates per 10^8 miles traveled baseline & scenario
RR/PAFs (PA, PM2.5, RTI), population projections, APC in diseases, disease lists	Δ Deaths, YLL, YLD, dalys for PA, PM, RTI, and PA-PM associated causes
Per capita costs, VSL, population, PAFs	Δ COI and VSL by cause
Car CO_2 g/mi, Δ car VMT/p/y, population	MMTY CO_2 baseline & scenario

Table 3.7 Mathematical Basis for Functions in ITHIM USA (app.R)

Functions "fn_scenario_time " and "fn_pa_quantile"	
Strata: *i*, age 1 to 8; *j*, gender (M, F); *k*, mode (walk, bike); *l* quintile (1 to 5); b = baseline, s = scenario	
$\boldsymbol{x}$, per capita mean weekly active travel minutes reported from National Household Travel Survey, NHTS, 2017	
$\boldsymbol{r}$, age-sex ratio of mean travel times ($\boldsymbol{x}$) by mode, $\boldsymbol{r_{ijk}} = \frac{x_{ijk}}{x_{F15-29,k}}$	
$\boldsymbol{t}$, population mean active travel time by mode derived from mean distance, d, and velocity, v, $\boldsymbol{t_k} = \frac{d_{ijk}}{v_k}$ where v_{walk}, 3; v_{bike}, 12mph Distance, *d*, is based on origin-destination coordinates in CHTS, 2012; velocities, *v*, are MPO conventions	
CV, coefficient of variation in total active travel time (bike + walk)	
sd, standard deviation of active travel mean, $\boldsymbol{sd_{ijk} = CV * t_{ijk}}$	
P, proportion of population in the *ith-* , *jth* age-gender group	
vc, Age-sex walk velocity adjustment constants, $\boldsymbol{vc_{ijk}} = \frac{v_{ijk}}{v_{..k}}$	
p, percentile of the active travel physical activity time distribution (0.1, 0.3, 0.5 [median], 0.7, 0.9)	
Preprocessed inputs	
Baseline	Scenario
$\boldsymbol{t(b)_{ijk} = f(r_{ijk}, P_{ij}, t_{..k})}$ CV $\boldsymbol{MET_{ij,walk} = f[\frac{METS}{v}(Ainsworth), vc_{ij,walk}]}$# $\boldsymbol{MET_{ij,bike} = 6}$	$\boldsymbol{t(s)_{..k} = \frac{d(s)_k}{v_k}}$
Program Functions	
Baseline	Scenario
e1: $\boldsymbol{t(b)_{ijkl} = f(exp[normalinv(\ln(t(b)_{ijk}), \ln(sd(b)_{ijk}, p_l), t_{ij.}])}$	$\boldsymbol{t(s)_{ijk} = f(r(b)_{ijk}, P_{ij}, t(s)_{..k})}$† $\boldsymbol{CV(s) = CV(b) - 0.0015429 * [t(s)_{...} - t(b)_{...}]}$ $\boldsymbol{t(s)_{ijkl} =}$ $\boldsymbol{f(exp[normalinv(\ln(t(s)_{ijk}), \ln(sd(s)_{ijk}, p_l), t_{ij.}])}$
e2: $\boldsymbol{METhrwk(b)_{ijkl} = t(b)_{ijkl} * MET_{ij,k}}$	$\boldsymbol{METhrwk(s)_{ijkl} = t(s)_{ijkl} * MET_{ij,k}}$

Processed input that could be a program function; † $t(s)_{ijk}$ could be based on user input or a user specified $r(s)_{ijk}$

Table 3.7 Mathematical Basis for Functions in ITHIM USA (app.R) continued

Functions "fn_pa_paf ", "fn_pm_paf", and "fn_burden causes"

Strata: *i*, age 1 to 8; *j*, gender (M, F); *k*, mode (walk, bike); *l* quintile (1 to 5); b = baseline, s = scenario; d = disease; n = exponent describing slope of dose-response curve; RR is the disease specific mortality risk per marginal MET-hr/week

A. PAF for Physical Activity

For all causes, marginal *MET-hr/wk* = travel MET-hr/w + non-travel MET-hr/w. Non travel physical activity includes leisure time, but not occupational.

$$PAF_{ijd} = 1 - \frac{\Sigma\, RR_{ijld}^{(mMEThrswk,scenario)^n}}{\Sigma\, RR_{ijld}^{(mMEThrswk,baseline)^n}} = 1 - RR_{ijd}^{PA}$$

If RR < 1 then PAF = -PAF (change sign so to indicate decrease in burden of disease)
RR = 1 for ages 0-4 and 5-14

B. PAF for PM2.5

Where β = 0.014494446 for ischemic heart disease, hypertensive heart disease, stroke, and respiratory
β = 0.01212618 for lung cancer
β = 0.009758 for acute respiratory infections in children < 5 years
β = 0.012817504 for all-causes
PM2.5 is ambient concentration as a function of car VMT [PM2.5 = f(car VMT, Region)]

$$PAF_{ijd} = 1 - RR^{\beta_d (PM2.5_{Scenario} - PM2.5_{Baseline})}$$

C. PAF for combined pathways of ischemic heart disease, hypertensive heart disease, and stroke (other PA-related $RR^{PM2.5}$ = 1)

$$PAF_{ijd} = 1 - (RR_{ijd}^{PA} \times RR_{ijd}^{PM2.5})$$

D. Burden of disease, BD

Strata: *i*, age 1 to 8; *j*, gender (M, F); d = disease, yr = accounting year,

$$BD_{i,j,d,yr} = localpop_{ij,yr} \times r_{i,j,d,baseline} \times (1 - APC_{i,j,d})^{(yr - yr_{baseline})}$$

Where, *localpop* = user-selected regional or county (within region)
r = regional rate (x 10^5 Regional reference population) and regional deaths, yll, yld, and daly
APC = annual percent change in age-, sex-, cause-specific mortality rate

E. Change in the Burden of disease, BD

$$\Delta BD_{i,j,d,yr} = PAF_{ij,d} \times BD_{ijd,yr}$$

Functions "fn_pa_paf ", "fn_pm_paf", and "fn_burden causes"

Strata: *i*, age 1 to 8; *j*, gender (M, F); b = baseline, s = scenario; st = striking vehicle mode, v=victim mode, VMT = vehicle miles traveled (striking vehicle), PMT = personal miles traveled (victim), sev = severity (fatal, serious), f = facility type (local, arterial, highway), n = safety in numbers exponent (default set at 0.5)

A. RR/PAF

$$RR_{sev} = \frac{\sum_{fac}\sum_{st,v} Injuries_s}{\sum_{fac}\sum_{st,v} Injuries_b}$$

Where $Injuries_s = ((VMT_{s,st} \times PMT_{s,v})^n \times Injuries_{b)}/\left(VMT_{b,st} \times PMT_{b,v}\right)^n$

B. Burden of disease, BD for RTIs

Strata: *i*, age 1 to 8; *j*, gender (M, F); yr = accounting year,

$$BD_{i,j,d,yr} = localpop_{ij,yr} \times r_{i,j,baseline} \times (1 - APC_{i,j})^{(yr - yr_{baseline})}$$

Where, *localpop* = user-selected regional or county (within region)

r = regional rate (x 10^5 Regional reference population) and regional deaths, yll, yld, and daly

APC = annual percent change in age-, sex-, cause-specific mortality rate

C. Change in the Burden of disease, BD

$$\Delta\, Deaths = -(1 - RR_{fatal}) \times BD_{deaths}$$
$$\Delta\, YLL = -(1 - RR_{fatal}) \times BD_{yll}$$
$$\Delta\, YLD = -(1 - RR_{serious}) \times BD_{yld}$$
$$\Delta\, DALY = \Delta YLL + \Delta YLD$$

Table 3.8 Outline of the R Shiny Application (app.R), ITHIM USA (Key Shiny Commands)

I. General Set-Up
- A. Read R libraries for Shiny, ggplot2, and other packages (library)
- B. Read input (csv) text and image management, and geographies for About >Geographies tables (read)

II. Shiny User Interface (ui)
- A. Title Panel (titlePanel)
- B. Main horizontal navigation bar and footer (navbarPage)
- C. Home page (tabPanel)
  - 1. Content and action buttons (actionButton)
- D. About page menu (navbarMenu)
  - 1. Introduction (tabPanel)
    - a. Content (drawn from webtext.csv and webphotoimage.csv)
  - 2. Instructions (tabPanel)
    - a. Content
  - 3. Scenarios (tabPanel)
    - a. Content
  - 4. Geographies (tabPanel)
    - a. Content
  - 5. Time Periods (tabPanel)
    - a. Content
  - 6. Methods (tabPanel)
    - a. Content
- E. RunITHIM Page
  - 1. ithim_toolUI("TOOL")
- F. Decision Support page menu (navbarMenu)
  - 1. Health Outcomes (tabPanel)
    - a. Content
  - 2. Strategies - Introduction (tabPanel)
    - a. Content
  - 3. Strategies - Physical Activity (tabPanel)
    - a. Content
  - 4. Strategies - Safety (tabPanel)
    - a. Content
  - 5. Strategies - Air Pollution, greenhouse gas emissions, car VMT (tabPanel)
    - a. Content
  - 6. Evidence (tabPanel)
    - a. Content

Table 3.8 Schematic Outline of the R Shiny application (app.R) for ITHIM USA with Key R Shiny Commands (continued)

7. Data & Resources (tabPanel)
   a. Content
8. Evidence (tabPanel)
   a. Content

G. User Support page (tabPanel)

III. Shiny Server

A. callModule(ithim_tool, "TOOL")

B. Generate tables for About > Geographies (renderTable)

C. Execute Home page action buttons (updateNavbarPage)

D. Navigate between pages on website (updateTabsetPanel)

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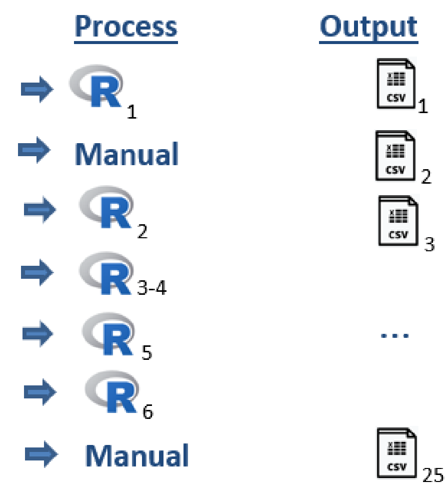
Appendix A. Creating ITHIM USA Data Files from Primary Sources

Calibration data for the 2015 baseline and several scenarios was created by an automated process (Figure A.1) using batch programs in R that read disaggregated data from the source, usually as a downloadable file from the Internet.

Figure A.1 Schematic of Data Processing for Model Parameters

Class of Parameter	Raw Data (8 sources)
Baseline travel distance by mode (motorized & active)	Travel Surveys (NHTS, 2017)
PMT/VMT by facility type	California Statewide & Regional Travel Demand Models
Population projections	US Census (np2014)
Road traffic injuries	FARS & CRSS
Non-travel physical activity	Health Surveys (NHANES)
Deaths and DALYs	IHME GBD
Input to air shed models	PM2.5, CO_2 (MOVES2014b)



The programs carried out statistical analyses and created output in a standardized format, which was edited to the file specifications in Tables 3.4 and 3.5. The correspondence between the R and the ITHIM USA calibration data files is presented in Table A. 1. Copies of the R programs are freely available and located at the Github repository of this project (https://github.com/nmaizlish/neiltest).

Table A.2 Correspondence between ITHIM USA Calibration Files and SAS/R Batch Programs That Processed Primary Data

File Name	Data Processing Batch File/Method	Key Metric(s)
BurdenDisease.csv	USGBD2015format2020-01-26.R	Age-sex-disease specific adjustment factors for deaths, yll, yld, dalys
APC_Disease_Rates.csv	Manual extraction of data from Canudas et al,[18] compiled in spreadsheet ITHIM 'Disease Rates'	Annual average percent change in age-sex-disease specific mortality rates
DiseaseRiskAdjuster.csv	User-supplied data	Ratio of age-sex-disease specific mortality rate to age-sex-disease risk adjuster mortality rate
CO2g_mi.csv	Manual reformatting (CO2MOVES2010-2050_2020-01-05.xlsx) of MOVES2014b output	CO_2/mi
COI2010USD.csv	Manual extraction of data from Maizlish and Siegel[34] ; compiled from spreadsheet ITHIM 'Costs'	Disease-specific costs per capita, 2010
ATmean_min_week_age_sex_baseline.csv	NHTS2017DistTimeMode2020-02-06.R	Age-sex and mode (walk, bike) specific ratios of active travel time/p/w
bike_walk_cv.csv	CVnonTravelMETS2020-01-13.R	Coefficient of variation of the mean active travel time in the baseline year
METminWalk_Bike.csv	Manual extraction from spreadsheet ITHIM ('Baseline'!AD6:AG13) based on Ainsworth[35]	Age-sex-walk/bike mMETS
nonTravelMETS.csv	CVnonTravelMETS2020-01-13.R	Age-sex-quintile specific mMETS
Distances_mi_year_baseline.csv	NHTS2017DistTimeMode2020-02-06.R	Mode-specific mi/p/y
Distances_mi_yr_strip.csv	NHTS2017DistTimeMode2020-02-06.R	Mode-specific mi/p/y
Distances_mi_yr_ussg.csv	NHTS2017DistTimeMode2020-02-06.R 'What If' calculation for walk and bike were set to 75 median min/p/wk and distances calculated using walk at 3 mph and cycling at 12 mph	Walk and bike mi/p/w

File Name	Data Processing Batch File/Method	Key Metric(s)
Baseline_distance_by_facility_type.csv	Manual extraction of outputs of MPO and California Statewide Travel Demand model[36]	Percent of car, bus, truck travel by roadway (facility type)
PM252010_2050.csv	Excel spreadsheet (EPApopulation2010-2050PM25_IPT2020-01-03.xlsx) of MOVES2014b outputs and mortality incidence per ton data	Change in annual average ambient PM2.5 per percent change in car VMT
WalkBikeTransitRatios.csv	NHTS2017DistTimeMode2020-02-06.R	Ratio walk/bike minutes to transit minutes
Bus_occupancy.csv	US DOT estimate, 10.1	PMT/VMT for buses
ParameterDefaults.csv	Constants for travel, health outcomes, costs (Table 3.6)	Constants for travel, health outcomes, costs
age_sex_regionUSA.csv	USPopAgeSex2015-2050.R	USCensus_2010_SF1_QTP1
age_sex_region_county2010-2050.csv	USPopAgeSex2015-2050.R	US Census (np2014), 2010-2050
PA_RR.csv	For specific causes, linear slope of RR per 8.75 mMET-hr/w for mMET-hr/w between 0 and 10, and RR at 10 mMET-hr/w for >10 mMET-hr/w (Garcia et al[8]). Data tables at: https://github.com/meta-analyses/drpa/tree/master/inst/extdata	Disease specific RR/mMET-hr/w
PM25_RR.csv	Vodonos et al 2018[10] for cardio-respiratory disease, and lung cancer. Acute respiratory infections in children (Woodcock et al 2013)[37]	Coefficient of concentration-response function for cardiopulmonary disease, lung cancer and acute respiratory infections in children
rti_baseline.csv	CRSS2020-01-20.R FARS2020-01-18.R	CRSS, 2016 FARS, 2016

Data Quality

The statistical stability of parameters derived from probability samples in survey data (e.g. mean walk or bicycle distances and times stratified by age and sex) was assessed by examining their relative standard error, RSE (sometimes called coefficient of variation). Parameters with an RSE greater than 0.3 were considered potentially unstable. In NHTS 2017 data, RSEs for age-sex specific per capita mean daily walking were less than 0.11. RSEs for male age-specific per capita mean daily cycling were less than 0.03. Female bicyclists aged 70-79 and 80+ years were most likely to have sparse and statistically unstable data (CV 0.45, 0.67, respectively).

The following section provides detailed description for each of baseline calibration parameter.

Per Capita Mean Daily Travel Distance

The National Household Travel Survey, 2017, was the source of calibration data for per capita mean annual miles traveled by walking, cycling, and driving by cars (driver and passengers), motorcycles, buses, and rail.[21] The NHTS is a probability sample of 129,696 of 130 million U.S. households, and captures 923,572 daily trips taken by 264,234 sample persons.

2015 Baseline Travel

An R program (NHTS2017DistTimeMode2020-02-06.R) applied person sample weights to daily trip distances by mode aggregated to persons within households. Trip distances reflected the shortest route through a gridded network based on geocoded origin and destination addresses submitted to Google Maps. Modes in the travel survey were cross-walked (lookup_ithim_mode.csv) to a smaller number of ITHIM categories. Baseline travel was expressed as per capita annual mean miles by walking, cycling, car (driver and passenger), bus, rail, truck, and motorcycle.

US Surgeon General Scenario

To promote optimum health, the US Surgeon General (USSG) recommends that adults should engage in at least 150 minutes per week of moderate intensity physical activity. As a population (rather than individual's) goal, ITHIM USA translates this recommendation as the U.S. adult population achieving a median of 150 minutes per week of active transport, split evenly between walking (75 min) and cycling (75 min).

In two steps, an R Program (NHTS2017DistTimeMode2020-02-06.R) estimated the per capita mean annual miles of walking and cycling associated with the median active travel time of 150 weekly minutes. In the first step, a subprogram (Mean2median.R) applied an inverse normal transform to estimate a median when (the log) mean active transport time and (the log) coefficient of variation (CV) are known. The CV of baseline travel was estimated from NHANES data (see below) based on per capita weekly minutes of active transport physical activity. For the scenario, the program segment was run iteratively until the repeatedly guessed means generated a back transformed median of 150.0000 minutes (error at the 5th decimal digit). The program segment incorporated a regression relationship based on European data (Woodcock, personal communication 2010) that decreases the CV as active travel increases. In the second step, the overall per capita mean minutes (384.08866) was divided by 2 and converted to walk miles/yr (at 3 mph) and bicycle miles/yr at 12 mph. The CarDriver and Car Passenger annual miles in the scenario were reduced by the difference in baseline and added scenario miles, and maintained

Short Trips Scenario

This scenario recognizes that many car trips are of short lengths that could be substituted by walking and cycling. In the U.S., car trips less than 5 miles in length comprised 13% of all car miles traveled in 2016. Using NHTS data and the R program (NHTS2017DistTimeMode2020-02-06.R) , total (weighted) car miles were broken down by trip distance categories (<1.5, 1.5-5, >5 miles) and divided by the entire US population (per capita mean daily car miles by distance category). Half the value of per capita car miles in the <1.5 mile category were added to baseline walking, and Half the value of per capita car miles in the 1.5 to 5 mile category was added to the cycling baseline. The miles added to active transport were subtracted from cars (CarDriver, CarPassenger) to maintain baseline occupancy. Scenario distances overall all modes were also the same as baseline.

Walk Transit Ratios for the Baseline Multiples Scenario

For the 'Baseline Multiples' scenario, users specify the relative change from the 2015 Baseline in distances walked, biked, and ridden in transit. For the transit component, the ratio, R, of walk time to transit time and the ratio of bicycle time to transit time were used to estimate transit-associated walking and cycling. This was calculated from the trip file in the National Household Travel Survey, which numbers trips in sequence and includes the mode for each trip. Each trip, n, before (n-1) and after (n+1) a bus or rail trip that was a walk trip (or bike trip) could be identified. The minutes associated with all walk trips (before and after) transit trips were summed as were minutes of those transit trips.

$$R_i = \frac{\sum min_{i,n}}{\sum min_{transit,n}}$$

where *i* is the *i*th mode (walk, bike).

Thus, by using these ratios, walking and cycling times associated with increases in transit time could be estimated. This ratio approach assumes that the relationship between increased active travel time increases linearly with increase transit times (i.e. people will walk and bike further to regional transit than local transit). The R batch file NHTS2017DistTimeMode2020-02-06.R' carried out the calculations and the output was incorporated into 'WalkBikeTransitRatios.csv.'

Age, Sex, and Mode-Specific Per Capita Mean Daily Active Travel Time (Baseline)

Walking, bicycling, and health outcomes are strongly influenced by the age and gender distribution of a population. This parameter is the "Baseline" variable in the "ATmean_min_week_age_sex_baseline.csv" data file, and was generated by NHTS2017DistTimeMode2020-02-06.R for active modes of travel from the National Household Travel Survey.[21] The numerator is the sum of daily active travel time (min.) for each person in an age-sex stratum for each mode. The denominator is the count of persons of each age-sex stratum in the population, which includes the entire population, even those who did not travel.

$$Mean_{i,j,k} = \frac{\sum min_{i,j,k} \times wt_{i,j,k}}{\sum Population_{i,j,k} \times w_{i,j,k}},$$

where *i* = age group, *j* = gender and *k*= mode (walk, bicycle), and wt is the sample weight

To project per capita mean age-sex- and walk (and bicycle) travel time for future populations and scenarios, the ratio, R, of age-sex- and walk (and bicycle) specific per capita mean baseline travel time relative to females aged 25 years was used to derive age-sex and mode-specific per capita means for the scenario from the scenario's overall mode-specific per capita mean travel time and the age-sex distribution of the scenario population.

$$R_{i,j,k,0} = \frac{min_{i,j,k,0}}{min_{f25,k,0}}$$

where $min_{f25,k,0}$ is the per capita mean minutes of the k^{th} mode (walk, bicycle) for women aged 15-29 years at baseline, 0 .

The sum of the ratios is given by:

$$R_{..k,0} = \sum R_{i,j,k,0}$$

The scenario age-sex and mode per capita mean minutes of active travel is derived from the overall scenario per capita mean active travel time and the age-sex population percentages of the scenario population. The mode-specific overall per capita mean for the scenario is represented by:

$$Scenario\ per\ capita\ mean\ travel\ time = min..k1$$

where k is the mode (walk, bicycle) and 1 represents the scenario. The age-sex stratum specific per capita mean active travel time for scenario and kth mode is:

$$min_{i,j,k1} = R_{i,j,k,0} \times \left({\frac{n_{i,j}}{n..}} \Big/ {R_{..k0}} \right) \times \left({min_{..k1}} \Big/ {\frac{n_{i,j}}{n_{..}}} \right)$$

Where $n_{i,j}$ is the age-sex stratum population count and n.. is the population total.

In ITHIM USA the overall scenario mean walking and bicycling times were derived from their scenario distances and assumed average speed of 3 mi/h and 12 mi/h, respectively. This approach was taken due to limitations in predicting or modeling age-sex specific active travel time in future populations. Some MPO travel models do not allocate bicycle trips by gender, and there are no readily available data that reliably predict demonstrate the relationship between mean age-sex travel times and changes in bicycle mode share. In countries with high active travel mode shares, women are as likely as men to ride bicycles and a cycling is common across age groups. This contrasts with the United States experience for cycling, which tends to be more common in young adult males than other age-sex groups.

This approach for deriving age-sex active travel times for scenarios makes a key assumption that the age-sex ratios, R, at baseline do not change over time or in response to increases in mode share for active travel in scenarios.

Standard Deviation of Per Capita Mean Daily Active Travel Time

Travel times for active transport in most urbanized populations have a log normal distribution (Chapter 1. Figure 1.3). ITHIM USA approximates this distribution in quintiles. The shape of the log normal distribution can be estimated from an inverse transform of the arithmetic mean and its standard deviation. (Note: this item is not the standard error of a survey mean, but the standard deviation of active travel time data in the population).

Both the mean and standard deviation can be estimated from travel and health surveys. While it is possible to estimate the standard deviation from travel surveys, which typically only sample a one-day diary, ITHIM USA takes advantage of the NHANES Adult survey,[9] which includes questions on walking and cycling for transport over 7 days. This longer time period of measuring travel time is consistent with epidemiologic studies that associate health outcomes per week of physical activity. Standard deviations based on a 7-day anchor period tend to be larger than those based on 1 day anchor periods. Because NHANES does not explicitly break down active travel into walking and cycling components, this item uses NHTS2017 data (age-sex specific bike:walk time ratios) to estimate the walking and bicycling contribution to the overall active transport.

The calculation for the 2015 baseline of active travel was implemented in the batch program ' CVnonTravelMETS2020-01-13.R ', which takes into account the complex survey design of NHANES and sample weights. In addition to the standard deviation, the coefficient of variation (standard deviation divided by the mean) was also calculated for baseline active travel.

To predict the standard deviation for scenario active travel time, ITHIM USA takes into account the empirical observation that as active travel mode share increases, the variability in travel times decreases. ITHIM USA uses data from European populations (Woodcock, 2011 unpublished) to model the relationship between increasing per capita active travel time and decreasing population variability, CV.

$$CV_1 = -0.0015429 \times (AT_1 - AT_0) + CV_0$$

where 0 indicates baseline and 1 indicates scenario, and *AT* is the per capita mean active travel time (walking + bicycling).

Distribution of Population by Age and Gender

The age and sex distribution of the U.S. populations is expressed as a proportion of the total population based on data from the US Census population projections, 2014 – 2050. [15]

$$\text{Proportion}_{\text{i,j}} = \frac{n_{i,j}}{N_{\text{i,j}}},$$

where n is the number of individuals in the ith age and jth sex category and N is the total number of individuals in the population. The R batch file (USPopAgeSex2015-2050.R) was used generate annual average projections ('age_sex_region_county2010-2050.csv') from 2015 to 2050 in 5-calendar year intervals (2015-2019, 2020-2024, 2025-2029, 2030-2034, 2035-2039,2040-2044, 2045-2049, 2050-2054).

Age-Sex-Disease Specific Burden of Disease

The burden of disease due to specific causes has been estimated for the United States by the Institute for Health Metrics and Evaluation.[17] Age-sex-cause specific deaths, years of life lost, years living with disability and disability adjusted life years were downloaded from IHME's Global Burden of Disease website and reformatted into ITHIM age-sex and cause categories using the R batch program (USGBD2015format2020-01-26.R). Diagnostic categories were based on the International Classification of Diseases, 10th Revision (Table A.3).

Table A.3 Global Burden of Disease Cause Categories and Corresponding ICD-10 Codes

Title in Global Burden of Disease Database	ICD-10*
Colon and rectum cancers	C18-C21, D01.0-D01.3, D37.3-D37.5
Breast Cancer	C50, D0.5-D05.9, D48.6
Cardiovascular Disease	
Hypertensive heart disease	I11
Ischemic heart disease	I20-I25
Cerebrovascular disease	I60-I63 I65-I67, I69.0, I69.1, I69.2, I69.3
Alzheimer and other dementias	F00-F03, G30-G31
Diabetes mellitus	E10-E13 (except E10.2, E11.2, E12.2, E13.2)
Depression (major depressive disorders)	F32-F33
Road Injuries	V01-V04, V06, V09, V10-V19, V20-V29, Y85.0, V30-V79, V87.2-V87.3, V80, V82
Cardio-respiratory: a. Lower respiratory infections, upper respiratory infections b. Same as cardiovascular above + inflammatory heart diseases c. Chronic obstructive pulmonary disease, Asthma, Other respiratory diseases	 J09-J11, J13, J14, J12.1, J12 (except J12.1), J15-J22, J85, P23, J00-J06 I11, I20-I25, I60-I63 I65-I67, I69.0, I69.1, I69.2, I69.3, I40, I42 J40-J44, J45-45, J47, J30-J39, J66-J70(except J69), J82, J92, J93.0, J93.1, J95, J98 (except J98.1, J98.2, J98.3, J98.9)
Lung cancer (Trachea, bronchus and lung)	C33-C34 , D02.1-D02.2, D38.1
Acute Respiratory Infections (children < 5 years) Lower respiratory infections, upper respiratory infections	J09-J11, J13, J14, J12.1, J12 (except J12.1), J15-J22, J85, P23, J00-J06

Proportion of Colon Cancers from All Colo-Rectal Cancers

Epidemiologic studies associate physical activity with reductions in colon cancers, rather than the broader diagnostic category of colo-rectal cancers. Because IHME's GBD diagnostic groupings combines colon and rectal cancers, of which, only the former is associated with physical activity, the age-sex proportion of colon to colo-rectal cancers was calculated using U.S. mortality data for 2016 provided through CDC's WONDER query tool.[38] The sex-specific proportion of colon cancers from colo-rectal cancers is given by:

$$\text{Proportion of colon cancer deaths to all colorectal cancers}_{i,j} = \frac{\text{Colon cancer deaths}_{\text{i,j}}}{\text{Colorectal cancer deaths}_{\text{i,j}}}$$

where i = age and j = sex category.

The ' USGBD2015format2020-01-26.R ' batch file carried out the calculations, whose results were incorporated into the 'BurdenDisease.csv' data file.

Per Capita Weekly Non-travel Related Physical Activity

ITHIM USA parses total physical activity into categories for active travel and non-travel related physical activity. Ideally, the same data source would have both travel related and non-travel-related physical activity. Unfortunately, travel surveys do not typically have detail on non-travel related physical activity. The NHANES Adult survey has some overlapping information on average weekly minutes of walking and cycling for transport and average weekly minutes of non-travel related physical activity of a moderate and vigorous intensity and working status. However, the active transport times are not broken down into separate walking and cycling components. By using the age-sex specific ratios of walking time to bicycling time reported in the NHTS 2017, weekly total active travel broken down by walking and cycling can be estimated from NHANES data.

Total physical activity time pooled over moderate and vigorous leisure and work activities, and walk/bike active transport (Table A.4).

Table A.4. Suggested MET Scores from HANES Codebook

Variable	Label	Score
PAD615	Vigorous work-related activity	8
PAD630	Moderate work-related activity	4
PAD645	Walking or bicycling for transportation	4
PAD660	Vigorous leisure-time physical activity	8
PAD675	Moderate leisure-time physical activity	4

METs were converted to marginal METS (MET - 1). Following analytic guidelines suggested by NHANES for outliers, unreasonably large values of physical activity time were capped. First, the total weekly active transport time per respondent was 600 minutes (equivalent to 6 h/d × 5 d/w). Total weekly physical activity time (work-related, travel, and leisure) was capped at 2520 minutes (6 h/d × 7 d/w) and then proportionally reduced by PA source (total/2520).

The R program (CVnonTravelMETS2020-01-13.R) calculated and generated the calibration data file. Because a large proportion of survey respondents reported no travel-related physical activity, these respondents were assigned a random number for assignment to first two quintiles by age and sex. The median non-travel METS based on leisure physical activity (occupation excluded) was then calculated for each age-sex-travel physical activity quintile combination. It was assumed that there was no change in the distribution of non-travel METS between baseline and scenario.

Proportion of Vehicle Miles Traveled (VMT) by Facility Type

The calculation of road traffic injuries takes into account the facility type on which the injury occurred. Roadway types are designed to accommodate vehicle travel at a range of speeds and traffic volume, and stratification of injury rates by facility type takes into account speed and volume. ITHIM categorizes facility types as highways, arterials, and local roads. The proportion of travel by facility type is calculated for each mode (walk, bike, car, bus, truck, and motorcycle). Due to limited data, the distribution of walking is assumed to be 75% on local roads and 25% on arterials, and a negligible percent on highways. Based on studies by Dill,[39] we estimate 53% of bicycle travel on local roads, 47% on arterials, and a negligible percent on highways.
The Federal Highway Administration compiles aggregate data from states for VMT by facility type and VMT by mode for motorized modes.[23] However, breakdowns of VMT by both mode and facility type (highway, arterials, local roads) cannot be generated from these aggregate data.

Some states do provide detailed breakdowns, however, at the time of publication, only data for California (2010) were available in the appropriate format for ITHIM USA. Statewide and regional travel model data were used to provide breakdowns by facility type for motorized modes. User's may perform sensitivity analyses of road traffic injury results by varying the facility type proportions in the calibration file (Baseline_distance_by_facility_type.csv).

Bus Occupancy and Truck VMT

The ITHIM USA road traffic injury module requires both personal miles traveled (PMT) of victims and vehicle miles traveled (VMT) of striking vehicles. PMT and VMT are related through occupancy (PMT/VMT). Bus PMT was readily available in the NHTS, but bus VMT was not. Nationally published figures for bus occupancy[22] and bus PMT from NHTS were used to estimate bus VMT in 2015. Likewise, truck travel is not reported in NHTS. However, aggregate truck travel is reported by state transportation agencies and compiled by the Federal Highway Administration.[23] Per capita mean truck VMT was calculated by summing 2015 U.S. truck miles traveled (Single-Unit, 2-Axle 6-Tire or More, and Combination Trucks) and dividing the by the 2015 U.S. population.

Road Traffic Injuries

The source of fatal injuries in the matrix of striking vehicles and victims by mode was the Fatal Analysis Reporting System (FARS),[19] and the source for serious, non-fatal injuries was the national Crash Report Sampling System.[20]

FARS is a census of fatal motor vehicle crashes that occurred within the 50 States, the District of Columbia, and Puerto Rico since 1975. To qualify as a FARS case, the crash had to involve a motor vehicle traveling on a trafficway customarily open to the public, and must have resulted in the death of a motorist or a non-motorist within 30 days of the crash. Started in 2016, CRSS is a nationally representative probability sample of all police-reported motor vehicle crashes on trafficways. FARS and CRSS have a common set of file names (ACCIDENT.csv, PERSON.csv, VEHICLES.csv), data elements and code lists which facilitates a consistent analysis of fatal and serious injuries. Collisions in which parties sustained minor injuries or only property damage were excluded from analysis in ITHIM USA.

Data were available to count the number of fatal and serious injuries by 3 different roadway types of single party and ≥2 party collisions for every pair-wise combination of modes for a striking vehicle (*i*) and victim vehicle(*j*):

$$Injuries_{ij,k,l}$$

where *ij* is a collision pair (e.g. pedestrian-car), *k* is injury severity (serious, fatal), and is roadway type (local, arterial, highway).

Two similar R programs were used to analyze FARS and CRSS data. Detailed FARS/CRSS vehicle modes were cross-walked to simpler ITHIM USA modes (BodyTypeCodes.csv). The R programs established all the parties to a collision and assigned a striking vehicle and victim vehicle based on a second (or higher) party with a larger mass (pedestrian, bicycle, motorcycle, car, bus truck). The R programs also imputed collisions for missing parties based on marginal values, and imputed missing data when crashes could not be assigned a roadway type.

ITHIM USA classified FARS roadway type (FUNC_SYS) as highways (Interstate, Principal Arterial - Other Freeways and Expressways, Principal Arterial – Other), arterials (Minor Arterial, Major Collector) and local (Minor Collector, Local). CRSS did not classify roadway types using a similarly defined data element, and a presumed correspondence was established using a roadway's posted speed limit (VSPD_LIM in 5 mph increments) and the type of CRSS-defined trafficway (VTRAFWAY) [Table A.5].

Table A.5. Crosswalk between ITHIM Roadway Type and Variables in FARS and CRSS, 2017

ITHIM Roadway	Posted Speed Limit (VSPD_LIM)	Trafficway (VTRAFWAY)
Local	≤ 30	Non-Trafficway or Driveway Access Two-Way, Not Divided One-Way Trafficway
Arterial	≥35 & ≤ 55	Two-Way, Divided, Unprotected Median Two-Way, Not Divided with a Continuous Left-Turn Lane
Arterial	≤ 60	Two-Way, Divided, Unprotected Median
Highway	≥60	Two-Way, Divided, Positive Median Barrier Entrance/Exit Ramp
Highway	≥70	Two-Way, Divided, Unprotected Median
Highway	≥50	Two-Way, Divided, Positive Median Barrier

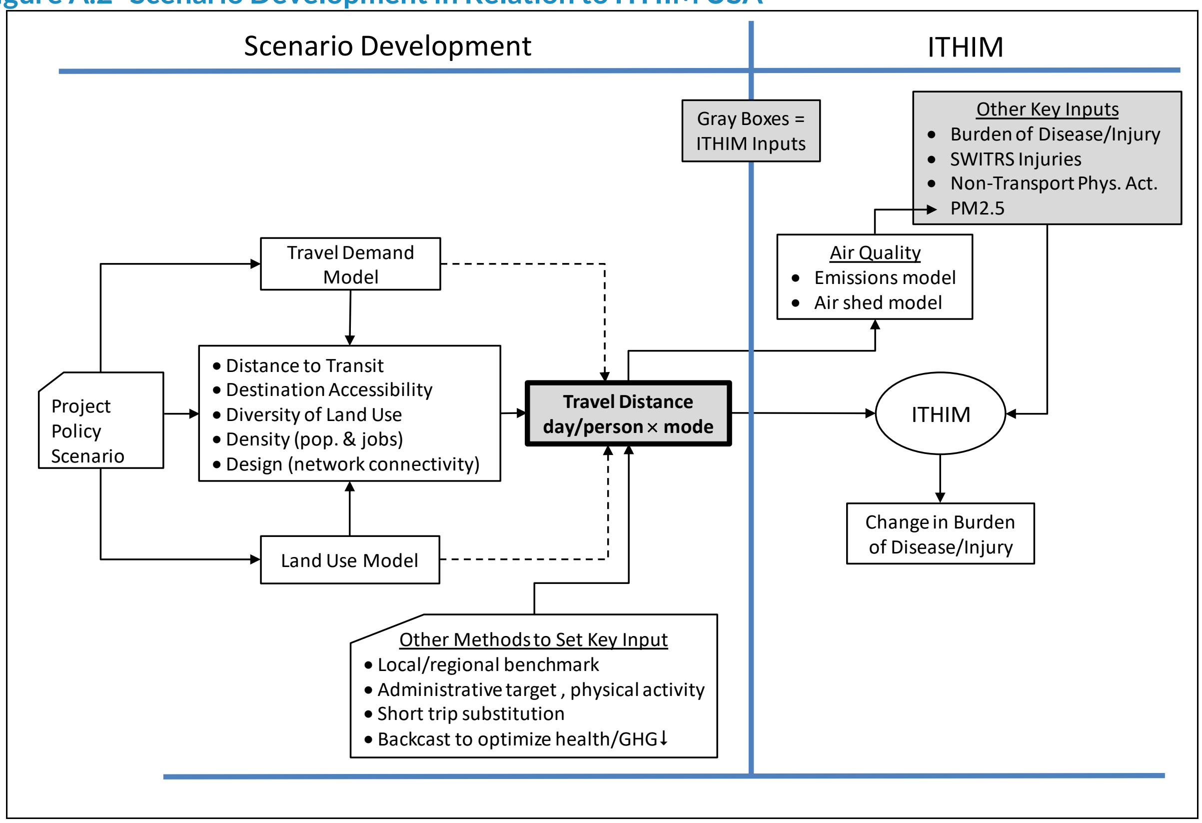
PM2.5 and Car CO_2 Emissions

The U.S. EPA MOVES model [14] used to estimate primary (PM2.5) and secondary (NOx, SO2, tire and brake wear) constituents of PM2.5. The settings included the entire United States (average) for all fuel types (gas, diesel, electric) and on-road facility types.

Scenario Data

Scenario development is outside the scope of ITHIM USA. The inputs to ITHIM are often the outputs of other models which examine how projects, policies, infrastructure investments alter travel behavior. Other ways in which scenarios may be developed are forecasting current trends or backcasting a goal, such as achieving a particular population level of physical activity.

Figure A.2 Scenario Development in Relation to ITHIM USA



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Appendix B. Integration of ITHIM with Travel Demand Models

Vehicle miles traveled by mode and facility type can be obtained from activity-based and 4-step travel demand models. These measures are available from the *trip list* and the *loaded network* of a travel model. These model outputs are described generically and then illustrated using the Metropolitan Planning Commission's (MTC) Travel Model One.

Trip List

This is a comprehensive list of all trips made in the universe of the model. A *trip* occurs any time there is movement from one location to another. A *tour* is a chain of trips which begin and end at the same location (i.e. home or work). The trip list is useful for the inputs of:

- Per capita mean daily travel distance
- Per capita mean daily travel time
- Personal travel distance by facility type,
- Vehicle distance traveled (VMT) by facility type

The trip list is generally stored as a text file (CSV) with key fields being origin/destination transportation analysis zone (TAZ), mode, person ID, purpose, time of day. Most TAZs conform to the boundaries of census tracts. The origin, destination, mode, time of day combination can be used to look up a distance and a time value associated with the trip and the person ID is used to look up age, sex, and other demographic information that might be part of an equity analysis. Once these variables are incorporated into the master trip list, the travel times and distances can be aggregated by age, sex, and mode. Before processing the trip list, it is necessary to use a "skim matrix" to provide the travel time and distance.

Skims

A *skim* is a matrix with a column and row for every TAZ in the system (Figure B.1). The cell given by the *ith* row and *jth* column depicts a travel time or distance. The matrix is stratified by time of day and mode. The MTC model has 18 modes. Because ITHIM USA modes do not correspond exactly to the MTC modes, MTC modes must be cross-walked to ITHIM categories. For example, the MTC model mode "walk-transit-walk" gives a travel time for a particular origin/destination pair; however, the time of the trip is the combined time of the walk access, the wait for transit, and the walk egress. Since "walk to transit" is included with all other walking in ITHIM, walk time and in-vehicle transit time in ABM data must be parsed into separate mode categories. This is accomplished by a computer batch file, which reads the MTC travel model modes and creates new skim files depicting the travel time in the ITHIM modes for every origin-destination combination. The code of the batch file is available upon request, but must be run with proprietary software (Cube, Citilabs, Inc.). The skims (pairwise TAZ distance and times) must be joined to the trip list.

Figure B.1 Example of a skim matrix of times between origin and destination centroids of traffic analysis zones by vehicle mode

HwyPK.skm-*1 SOVTime

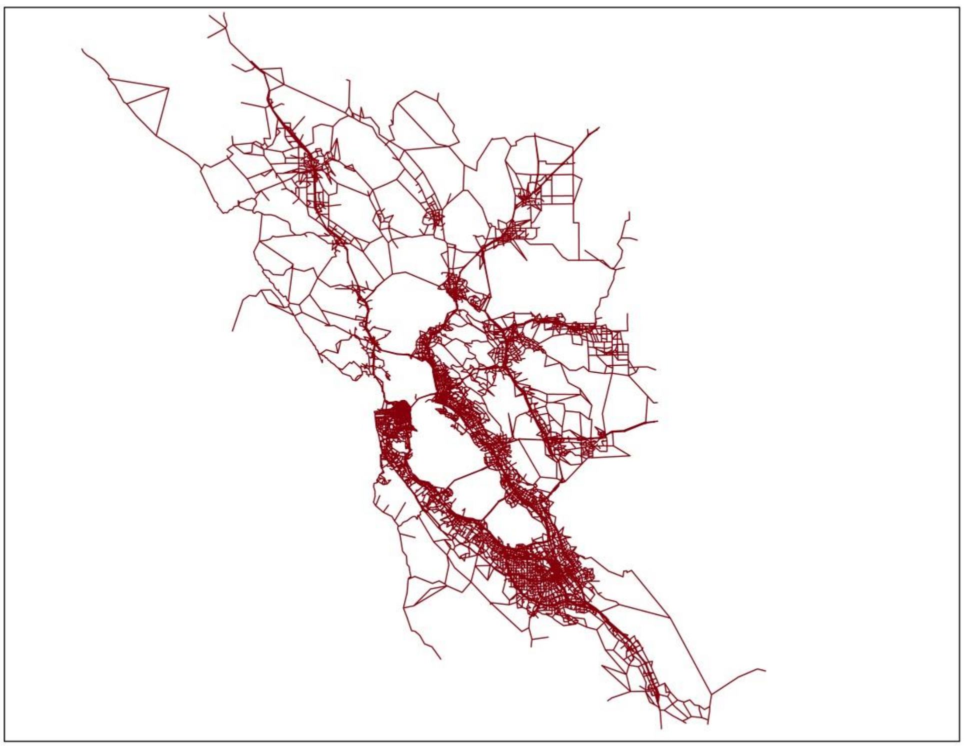
*1 SOVTime | 2 SOVDist | 3 SOVToll | 4 HOVTime | 5 HOVDist | 6 HOVToll | 7 TDTime | 8 TDDist | 9 TrkTime | 10 TrkDist

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	3.42	6.16	10.33	12.41	16.26	11.14	12.57	16.33	18.26	15.14	17.86	20.43	18.87	23.73	22.07
2	6.16	3.17	7.65	7.91	11.88	6.64	9.00	11.83	13.77	10.65	13.38	15.95	14.37	19.24	17.59
3	10.22	8.18	2.16	4.38	6.99	6.50	3.29	11.69	13.62	9.83	9.68	11.33	11.83	15.35	13.89
4	12.43	7.92	4.34	2.57	7.49	6.23	3.79	11.42	13.36	10.24	10.18	11.83	12.33	15.86	14.40
5	15.75	11.41	6.35	6.89	2.66	5.34	4.41	7.08	9.39	5.24	3.65	6.21	5.79	9.50	7.86
6	11.24	6.74	6.04	6.32	5.90	3.30	4.86	7.09	9.02	5.75	7.58	10.16	8.58	13.45	11.80
7	12.66	8.99	3.25	3.80	5.01	4.86	2.13	9.98	11.99	7.85	7.70	9.36	9.85	13.38	11.92
8	16.47	11.96	11.28	11.55	7.77	7.12	9.98	1.96	2.90	3.44	5.88	7.23	4.91	10.44	8.79
9	18.40	13.89	13.21	13.48	10.09	9.06	12.03	2.90	2.30	5.37	8.20	6.95	4.33	8.57	7.27
10	15.27	10.77	9.77	10.32	5.93	5.74	7.84	3.44	5.37	2.80	5.68	8.25	6.67	11.55	9.89
11	18.00	13.50	9.75	10.30	4.36	7.59	7.82	5.88	8.19	5.70	2.40	3.06	4.60	7.12	6.47
12	20.51	16.01	11.25	11.79	6.86	10.10	9.30	7.18	6.94	8.20	3.02	2.15	3.84	5.63	4.98
13	19.00	14.49	11.83	12.38	6.43	8.58	9.89	4.91	4.34	6.68	4.55	3.83	2.55	6.86	5.21
14	23.81	19.31	15.28	15.83	10.16	13.40	13.34	10.44	8.54	11.49	7.08	5.64	6.86	2.09	3.32
15	22.17	17.67	13.91	14.46	8.52	11.76	11.97	8.80	7.26	9.85	6.43	4.98	5.22	3.34	2.62
16	24.43	19.92	17.81	18.36	12.69	14.00	15.88	10.34	8.43	12.11	9.62	8.17	8.14	4.30	4.75
17	26.02	21.52	20.62	21.12	15.50	16.68	18.69	10.52	9.58	12.99	12.43	10.98	10.96	7.12	7.57
18	22.32	17.81	15.90	16.45	10.94	11.90	13.97	7.33	6.30	9.80	8.86	7.40	6.03	6.53	5.22
19	13.13	17.69	11.58	15.39	18.00	17.82	14.31	22.94	24.94	20.84	19.16	20.54	22.02	24.35	23.90
20	7.88	12.44	6.33	10.53	13.14	12.65	9.44	17.84	19.77	15.98	15.83	17.48	17.98	21.50	20.04
21	7.08	12.05	12.33	15.70	19.14	14.44	15.45	19.63	21.57	18.45	21.12	23.48	22.15	26.99	25.34

Loaded Networks

Loaded network files are a spatial representation of every travel link in the region, highways, arterials, and local roads (Figure B.2). Each trip in the trip lists is "loaded" onto the travel network creating a congested network, and trips are reassigned by a computer algorithm until there is an equilibrium (i.e. further iterations converge). The trip distribution at convergence is written out as GIS shape files which include a .dbf file whose rows for each link has attributes such as length, roadway type, automobile volume, and truck volume. With a lookup table from ABM facility type to ITHIM roadway type, an aggregation of VMT by ITHIM facility type becomes possible. VMT is generally not calculated in these attribute files but it can be obtained by multiplying the total amount of vehicle volume by the length (in miles) of each link. The loaded networks can provide slightly different VMT than the trip lists because of error at the end points and on centroid connectors. Based on advice of travel modelers at MTC, we use the trip list VMT measure for VMT and the loaded networks to calculate the *proportion* of VMT on each roadway type.

Figure B.2 MTC Travel Network



Data Processing

Data processing has been implemented at MTC using both SAS and R code. Please contact Dr. Maizlish or Lisa Zorn (lzorn@mtc.gov) if you would like to obtain a copy of the batch files. The following tables illustrate the types of data and crosswalks that must be constructed or programmed to integrate travel model output into ITHIM.

Table B.1 Data Dictionary for MTC Trip List

Name	Definition
hh_id	Unique household ID number
person_id	Unique person ID number
person_num	Person number unique to the household
tour_id	Individual tour number unique to the person
stop_id	Stop number unique to half tour
inbound	Inbound stop indicator
tour_purpose	Tour purpose, given the type of tour
orig_purpose	Purpose at the origin end of the trip
dest_purpose	Purpose at the destination end of the trip
orig_taz	Origin transportation analysis zone
orig_walk_segment	Walk to transit origin sub-zone (not located in space)
dest_taz	Destination transportation analysis zone
dest_walk_segment	Walk to transit destination sub-zone (not located in space)
depart_hour	Time of departure for the trip
trip_mode*	Travel mode for the trip
tour_mode	Primary (though not necessarily used) travel mode for the tour
tour_category	The type of tour for which this trip is a part

* Trip mode levels: Integer, 1 - Drive alone free; 2 - Drive alone pay; 3 - Shared ride 2 free; 4 - Shared ride 2 pay; 5 - Shared ride 3+ free; 6 - Shared ride 3+ pay; 7 - Walk; 8 - Bike; 9 - Walk to local bus; 10 - Walk to light rail or ferry; 11 - Walk to express bus; 12 - Walk to BART; 13 - Walk to commuter rail; 14 - Drive to local bus; 15 - Drive to light rail or ferry; 16 - Drive to express bus; 17 - Drive to BART; 18 - Drive to commuter rail (http://mtcgis.mtc.ca.gov/foswiki/Main/IndividualTrip)

Table B.2 Data Dictionary for ITHIM SKIM

Variables in Skim Output		
orig	ivtR_wTrnD	ddist_dTrnW
dest	wait_wTrnD	bike_bike
walk_walk	dtime_wTrnD	da_time
walk_wTrnW	ddist_wTrnD	da_dist
ivtB_wTrnW	walk_dTrnW	s2_time
ivtR_wTrnW	ivtB_dTrnW	s2_dist
wait_wTrnW	ivtR_dTrnW	s3_time
walk_wTrnD	wait_dTrnW	s3_dist
ivtB_wTrnD	dtime_dTrnW	

*First term is the ITHIM mode (walk=walk, ivtB=in vehicle time bus, ivtR=in vehicle time rail, wait=dwell time, dtime=drive time, ddist=drive distance, da=drive alone, s2=shared ride 2, s3=shared ride 3+.

** Second term is the mode from which it come (walk=walk, wTrnW=walk transit walk, wTrnD=walk transit drive, dTrnW=drive transit walk, bike=bike), the drive only modes have a second term describing the measure (time or dist).

Table B.3 Data Dictionary for Volume in Loaded Network by Vehicle Type

Variables used in Loaded Networks					
A (origin node)	VOLEA_SMT	VOLAM_HVT	VOLMD_TOT	VOLEV_DA	VOL24HR_S2
B (dest node)	VOLEA_HVT	VOLAM_TOT	VOLPM_DA	VOLEV_S2	VOL24HR_S3
DISTANCE (length of link)	VOLEA_TOT	VOLMD_DA	VOLPM_S2	VOLEV_S3	VOL24HR_SM
FT (facility type)	VOLAM_DA	VOLMD_S2	VOLPM_S3	VOLEV_SM	VOL24HR_HV
VOLEA_DA	VOLAM_S2	VOLMD_S3	VOLPM_SM	VOLEV_HV	VOL24HR_DAT
VOLEA_S2	VOLAM_S3	VOLMD_SM	VOLPM_HV	VOLEV_DAT	VOL24HR_S2T
VOLEA_S3	VOLAM_SM	VOLMD_HV	VOLPM_DAT	VOLEV_S2T	VOL24HR_S3T
VOLEA_SM	VOLAM_HV	VOLMD_DAT	VOLPM_S2T	VOLEV_S3T	VOL24HR_SMT
VOLEA_HV	VOLAM_DAT	VOLMD_S2T	VOLPM_S3T	VOLEV_SMT	VOL24HR_HVT
VOLEA_DAT	VOLAM_S2T	VOLMD_S3T	VOLPM_SMT	VOLEV_HVT	VOL24HR_TOT
VOLEA_S2T	VOLAM_S3T	VOLMD_SMT	VOLPM_HVT	VOLEV_TOT	VMT24HR
VOLEA_S3T	VOLAM_SMT	VOLMD_HVT	VOLPM_TOT	VOL24HR_DA	VHT24HR

* VOLXX refers to the volume for the time period (EA=3-6AM, AM=6-10AM, MD=10-3PM, PM=3-7PM, EV=7-3AM)

**Modes (DA=drive alone, S2=shared ride 2, S3=shared ride 3, SM=small/medium truck, HV=heavy truck, DAT=drive access transit)

Table B.4 MTC to ITHIM Facility Type Lookup

MTC Facility Type	ITHIM Facility Type
Freeway-to-freeway connector	Highway
Freeway	Highway
Expressway	Highway
Collector	Arterial
Freeway ramp	Highway
Dummy link	Local
Major arterial	Arterial
Special facility	None observed

Table B.5 Examples of Selected Modes in MTC ABM and ITHIM

MTC Mode Name	ITHIM Mode
Drive alone free	Car
Drive alone pay	Car
Shared ride 2 free	Car
Shared ride 2 pay	Car
Shared ride 3+ free	Car
Shared ride 3+ pay	Car
Walk	Walk
Bike	Bike
Walk to local bus	Walk
Walk to light rail of ferry	Walk
Walk to express bus	Walk
Walk to BART	Walk
Walk to commuter rail	Walk
Drive to local bus	Car
Drive to light rail of ferry	Car
Drive to express bus	Car
Drive to BART	Car
Drive to commuter rail	Car

Appendix C: Scenario Walking and Cycling Associated with Increases in Baseline Transit

Background

Multiplying baseline levels of active travel is an intuitive way of formulating goals that appeals governmental agencies and other users. Since the earliest spreadsheet versions of California ITHIM, a “What If” scenario based on multiples of baseline active travel has been one of the built-in scenarios. Baseline multiples are expressed as per capita mean daily modal distances, which, for walking and cycling, are translated into physical activity time based on average speeds of 3 and 12 mph for walking and cycling, respectively. The options in the baseline multiples scenario have evolved in response to user requests to account for the interplay of several modes (walking, cycling, cars, and transit) and the level of substitution of car miles by active transport and transit.

The earliest versions of baseline multiples considered only walking, cycling and car travel, and forced a 1:1 or 100% replacement of car miles by increases in walking and cycling. This constrained scenario travel distances over all modes to be the same as the baseline. This was a simplifying assumption so health impacts for each health pathway (physical activity, PM2.5, road traffic injuries) could be more easily attributed to walk, bike and car modes. Because transit is inextricably linked to active travel, the next improvements allowed users to specify changes in transit (bus and rail). However, to maintain distance equivalency in baseline and scenario, transit-associated walking and cycling were not automatically added to the overall total for active transport. Transit increases were offset by decreases in car VMT, thus reducing health impacts of car travel on road traffic injuries and PM2.5. An additional methodological refinement was to allow users to specify the percentage of replacement of car VMT by walking, biking, and transit (100% or 1:1 substitution is the default).

The purpose of this Use Case is to illustrate how to leverage ITHIM calibration data to explicitly add transit-associated walking and cycling to total walking and cycling multiples. For jurisdictions with long-term planning that emphasizes relatively large increases in transit as a strategy for meeting carbon reduction goals, ITHIM USA can be used to assess the magnitude and direction of health impacts for a transit-priority strategy.

Methods

Data Source

The source of data for walking and cycling associated with transit is the National Household Travel Survey, 2017. The trip file (trippub.csv) enumerates each trip, n, by mode for each sample person. The trip file was subsetted for rail and bus trips (n) and the walk and bike trips (n – 1 or n+1) that preceded and followed. The duration of all bus and rail trips was summed as was bike and walk trips. The ratio of the sum of walking time to the sum of bus/rail travel time expresses the per minute change in walking to or from transit per minute duration of transit trips.

$$Ratio_{walk:transit} = \frac{\sum walk\ minutes}{\sum transit\ minutes}$$

$$Ratio_{bike:transit} = \frac{\sum bike\ minutes}{\sum transit\ minutes}$$

Scenario Walking and Cycling as a Function of Scenario Multiple of Transit

To calculate the scenario per capita mean weekly minutes of walking, S_{walk}, as a function of multiples of transit, we add the transit-associated walking time to the baseline, B, walking time. The transit associated walking time is the product of the transit multiple, walk-transit ratio, and the baseline transit time:

$$S_{walk\ min/person/wk} = B_{walk\ min/person/wk} + (\text{Transit multiple}-1) \times Ratio_{walk:transit} \times B_{transit\ min/person/wk}$$

For cycling, we get a corresponding equation:

$$S_{bike\ min/person/wk} = B_{bike\ min/person/wk} + (\text{Transit multiple}-1) \times Ratio_{bike:transit} \times B_{transit\ min/person/wk}$$

The accompanying spreadsheet (MultiplesBaselineTransitUse-Case2020-02-24.xlsx) provides the formula for California and major regions taking into account region-specific walking and cycling transit ratios. Users can input specific transit multiples and generate transit-associated walking and cycling expressed as multiples of baseline walking and cycling.

Results

Table 1 illustrates the calculation for a baseline transit multiple of 1.5 (50% increase over baseline). If transit were increased by 50%, cycling to and from transit would increase by 15.8% and walking to and from transit would increase by 19.7% over baseline levels of walking and cycling. To input the transit-associated walking and cycling, input the baseline multiples for cycling (1.158445) and walking (1.196667) in their respective dialogue boxes:

Table 2 provides pre-calculated baseline multiples of walking and cycling for increments of transit multiples. Expressed and percent increases the increments include 1, 5, 10, 25, 100 to 900% increases in transit. Because the relationship is linear, one can predict any multiple by multiplying the 1% change by the desired increase. For example, to predict walking for a 13% increase in the California transit multiple, one can apply the following formula:

$$Walk\ Multiple = 1 + [13 \times\ (1.003933334 - 1)] =\ 1.051133$$

Increases in walking and cycling – independent of transit – can also be added in the baseline multiples interface of ITHIM USA. A doubling of walking on top of the transit-associated walking due to a 50% increase in transit, would be a total multiple of 2.196667.

Discussion

There are assumptions and limitations to this method of associating walking and cycling with transit. This is a time- and distance-based rather than trip-based approach. This method assumes modes switch from cars to walking, cycling, and transit. In practice, mode switching might occur between walking, cycling, transit. This would alter levels of physical activity, risks for road traffic injuries, and PM2.5 and their associated changes in the burden of disease.

This method assumes a linear relationship between transit-associated walking and cycling and transit time over all levels of transit time. This assumption is probably more realistic for local transit, and less so for long (intercity) transit trips for which active travel would level off. Travel-associated walking and cycling is limited by the sane factors that constrain travel in general, including total time budget available for transport. In this method, bus and rail travel times were pooled together, but may vary with regard to their association with walking and cycling.

References

US Department of Transportation. 2017 National Household Travel Survey. Version 1.1. Washington DC: US Department of Transportation; 2017. https://nhts.ornl.gov/

Table C1. Walking and Cycling Associated with a 50% increase in Transit, United States, 2017

Mode	Baseline min/p/w*	Multiple of Transit	AT min/ Transit Min Ratio	Scenario min/p/w	Multiple of Baseline
Bike	2.7		0.017100257	2.72	1.158
Walk	42.9		0.336168248	43.08	1.197
Transit	50.2	1.5			

* Per capita weekly mean minutes
Source: National Household Travel Survey, 2017

Table C2. Active Transport Baseline Multiples as a Function of Multiples of Transit Baseline, United States 2015

Transit	Percent	United States	
Multiples	Increase	Bike	Walk
1.01	1	1.003	1.004
1.05	5	1.016	1.020
1.10	10	1.032	1.039
1.25	25	1.079	1.098
1.50	50	1.158	1.197
2.00	200	1.317	1.393
3.00	300	1.634	1.787
4.00	400	1.951	2.180
5.00	500	2.268	2.573
10.00	1000	3.852	4.540