Development and Application of an Integrated Health Impacts Assessment Tool for the Sacramento Region

October 2017

A Research Report from the National Center for Sustainable Transportation

Alex Karner, The University of Texas at Austin
Dana Rowangould, Sustainable Systems Research, LLC
Yizheng Wu, University of California, Davis
Ofurhe Igbinedion, University of California, Davis
Jonathan London, University of California, Davis

National Center for Sustainable Transportation

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Alex Karner, Graduate Program in Community & Regional Planning, The University of Texas at Austin

Dana Rowangould, Principal, Sustainable Systems Research, LLC

Yizheng Wu, Civil and Environmental Engineering, University of California, Davis

Ofurhe Igbinedion, Geography Graduate Group, University of California, Davis

Jonathan London, Department of Human and Community Development, University of California, Davis

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EXECUTIVE SUMMARY

Plans crafted by metropolitan planning organizations (MPOs) lay out how billions of dollars in transportation investments will be made over a 20 to 30-year time horizon. Federal transportation authorizations require MPOs to identify and track key indicators of system performance (e.g. collision rates, emissions, congestion) to ensure that they are stewarding public funds wisely to meet specific goals related to safety, environmental performance, and congestion mitigation, among other areas. Concerns related to preventing discriminatory impacts of planning activities, motivated by Title VI of the 1964 Civil Rights Act, also compel agencies to assess the impacts of plans on different demographic groups.

At the same time, there is a growing desire among transportation planning agencies to develop transportation and land use plans that shift travel behavior away from driving and towards more active travel modes. Research has shown that living in areas where walking and bicycling are convenient leads to greater use of those modes, which can lead to improved health outcomes due to increases in physical activity. But increasing non-motorized travel can also increase active travelers' risk of traffic injury and exposure to air pollution. Analytical tools that assess the tradeoffs between transportation plan alternatives are needed to inform public debate and ensure that gains in some health outcomes are not being undermined by losses elsewhere. Additionally, questions remain about who will benefit from plans that promote increases in active travel.

The aim of this project is to investigate the distribution of public health impacts resulting from a regional transportation plan in the six-county Sacramento Area Council of Governments (SACOG) region. This report summarizes findings related to our three key goals:

1. **Comparison of different approaches to assessing the public health impacts of transportation plans.** Multiple datasets, tools, and methods exist for conducting such assessments. We synthesize known information about them and highlight their similarities and differences. We focus on comparing ITHIM and the California Public Health Assessment Model (C-PHAM) which is integrated into UrbanFootprint. Both have been applied in several areas of California.

2. **Employ a refined version of the Integrated Transportation Health Impacts Model (ITHIM) to quantify health impacts resulting from the 2016 SACOG Metropolitan Transportation Plan/Sustainable Communities Strategy.** We adapt ITHIM to produce estimated changes in death and disease burden by race, ethnicity, and income categories. Results are presented as totals (to indicate the magnitude of impacts) as well as standardized by age and population (to facilitate comparisons of risks faced by

different geographic areas and populations.) We also present results for each of SACOG's component counties.

3. **Report on the development of a user-friendly web interface for summarizing ITHIM results**. In response to the requests of various health and sustainability stakeholders in the SACOG Region, we created a web version of our tool that can be used to visualize existing model results. This web interface allows a user to tailor the results shown by geographic area, scenario, demographic group, outcome, and units. Future iterations of the tool will be able to simulate user-defined scenarios.

Our results demonstrate the utility of analyzing and representing the public health impacts of transportation plans in a user-friendly way for planners, policy makers, and advocates. The methodology used in this project can serve as a model for those working on active transportation, public health, and regional equity in other locations across the US.

Introduction

An important product of the regional transportation planning process is a long-range plan and a short-term spending program. Plans crafted by metropolitan planning organizations (MPOs) lay out how billions of dollars in transportation investments will be made over the subsequent 20 to 30 years. They identify the challenges that a region faces and describe how the plan will help to alleviate those challenges via transportation infrastructure investments and policy strategies. Historically, a single preferred plan was identified through a process of regional consensus-seeking and put forward to the residents of a region before being adopted by an MPO's board. That practice began to change in California, first in Sacramento, and then elsewhere, as agencies and the public increasingly sought to understand how alternative transportation and land use scenarios would affect the performance of the entire transportation system (1, 2). This work was prompted by state policies such as SB 375, California's Sustainable Communities and Climate Protection Act of 2008.

The idea of performance assessment has since become embodied in federal transportation policy (3). Moving Ahead for Progress in the 21st Century (MAP-21) Act and its follow-up transportation authorization, the Fixing America's Surface Transportation (FAST) Act both require MPOs to conduct performance-based transportation planning. In other words, they must identify and track key indicators of system performance (e.g. collision rates, emissions, congestion) to ensure that they are stewarding public funds wisely to meet specific goals related to safety, environmental performance, and congestion mitigation, among other areas.

One topic that is increasingly gaining attention is the public health impacts of transportation planning and programming activities (4–8). In the US, these impacts first became apparent with early air pollution crises during the 1950s in Los Angeles. Since that time, the automobile's contribution to air pollution, and the importance of air quality issues generally in the US, has been declining in importance due to improvements in automotive and fuel technology (e.g., 9). Risks of death and injury from collisions are another area that have historically been important but have been declining in importance over time as safety technology, seatbelt laws, and driver behavior undergo substantial changes (10). Automobile dependence looms large in both types of impacts, but our reliance on the car also influences the level of physical activity that we experience. Research has shown that living in areas where walking and bicycling are convenient leads to greater use of those modes (11). But increasing non-motorized travel can also increase injury risk and exposure to air pollution (12). Analytical tools that assess the tradeoffs between alternatives are needed to inform public debate and ensure that gains in some health outcomes are not being undermined by losses elsewhere.

The need for such tools is also motivated by an increasing desire among transportation planning agencies to develop transportation and land use plans that shift travel behavior away from driving and towards more active modes (13). Questions remain about who truly benefits from such shifts. On the one hand the types of dense urban areas well-served by public transit and with access to cycling and pedestrian amenities have historically been occupied by lowincome people and people of color. On the other hand, as these areas are revitalized these populations may not benefit from the substantial and ongoing investments targeting their neighborhoods without policies aimed at mitigating their displacement. Broader concerns related to preventing discriminatory impacts results from the products of planning activities, motivated by Title VI of the 1964 Civil Rights Act (14), also compel agencies to assess the impacts of plans on different demographic groups.

The aim of this work is to investigate the distribution of public health impacts resulting from a regional transportation plan in the six-county Sacramento Area Council of Governments (SACOG) region. This report summarizes findings related to our three key goals:

1. **Comparison of different approaches to assessing the public health impacts of transportation plans.** Multiple datasets, tools, and methods exist for conducting such assessments. One goal of this work is to synthesize known information about them and highlight their similarities and differences.
2. **Employ a refined version of the Integrated Transportation Health Impacts Model (ITHIM) to quantify health impacts resulting from the 2016 SACOG Metropolitan Transportation Plan/Sustainable Communities Strategy.** We adapt ITHIM to produce results disaggregated by race, ethnicity, and income categories. We also present results for each of SACOG's component counties.
3. **Report on the development of a user-friendly web interface for summarizing ITHIM results.** In response to the requests of various health and sustainability stakeholders in the SACOG Region, we created a web version of our tool that can be used to visualize existing model results. Future iterations of the tool will be able to simulate user-defined scenarios.

Our results demonstrate the utility of summarizing the public health impacts of transportation plans and can serve as a model for those working in other locations across the US.

Comparison of tools for assessing transportation and health impacts

Interest in quantifying the health impacts of changes in active transportation has been steadily increasing, but there is no consensus on the most appropriate methods to carry out this task. In a literature review focused on methodological considerations in assessing the health impacts of active transportation, Doorley et al. (15) identified 19 studies that examined the effects of changes in walking and/or bicycling behavior on public health outcomes. Studies were motivated by different concerns, from quantifying the health impacts of bike share system implementation to assessing the benefits of aggressive changes in travel behavior outcomes. The studies also differed in terms of the exposures and outcomes considered. Some assessed only changes in physical activity, while others included exposure to air pollution (both ambient and in-vehicle) and traffic injury risk. Both all-cause and disease-specific morbidity and mortality were considered as outcomes across the studies. Changes in relative risk (RR) or dose-response functions (DRFs) were applied to convert changes in transportation policy or travel behavior to health outcomes. Much of the work reviewed by Doorley et al. (15) is not presented in a way through which the methods and results can be applied to policy and planning situations by policy makers, advocates, or members of the public.

Because the focus of the current project is to apply and enhance ITHIM as easy-to-use tool for health impact assessment, we have included our own assessment of other existing tools here. Table 1 summarizes multiple characteristics of five different health impact assessment models appearing in the literature and practice that can be used to examine the health impacts resulting from transportation and land use plans. Each of the tools listed in the table represents the relationship between urban form, transportation, and health somewhat differently, and evaluates different health pathways. A similar, but less complete table focused only on physical activity, appears in Urban Design 4 Health and AECOM (16, Appendix A pp. 14-16). One key distinction in Table 1 is the use of comparative risk assessment (CRA) methods developed from epidemiological principles (e.g., 17) in some tools while others use a "direct" estimation approach by developing a regression model that links built environment and demographic characteristics to health outcomes (e.g., 16, Appendix A).

Two of the tools listed in Table 1 have seen widespread application in California: ITHIM and C-PHAM, which is the public health module integrated into the larger UrbanFootprint sketch planning tool. The remainder of this discussion focuses on these two tools. ITHIM relies upon CRA while C-PHAM uses a direct estimation approach. Both can estimate the health impacts of changes in physical activity and both have been calibrated for and applied to several regions in California. Each model can provide insights into the health impacts of changes to land use and transportation systems, but their capabilities and the assumptions underlying their approaches differ.

ITHIM is based upon CRA methods that have been endorsed by the World Health Organization and simulate a change in health outcomes in response to changes in a key exposure (18). General relationships between the key exposure and health outcomes are usually obtained from peer-reviewed research studies. Health outcomes can be general, like all-cause mortality, or they can be specific, like number of deaths due to heart disease. Exposures can be environmental (e.g. air pollution, noise) or related to human behavior (e.g. vegetable consumption). In some cases, increases in exposure are associated with improvements in health outcomes and in others it is the opposite. In all cases, the change in health outcomes is modeled relative to a baseline indicator of morbidity or mortality. Because of difficulties with generating morbidity and mortality estimates at sub-county geographies, shifts in travel behavior and health outcomes are often quantified at the county scale or larger. Although prior work in the CRA tradition has sometimes presented results disaggregated by age-sex categories (e.g., 6), the utility of deriving a single regional estimate of changes in health impacts is limited. Other work has simply adjusted a region-wide all-cause mortality estimate using smaller-scale estimates of changes in exposures (e.g., 19). But this approach will be inaccurate for smaller geographies to the extent that health outcomes at those scales differ from those observed at the regional level.

The direct estimation approach used by C-PHAM/UrbanFootprint, on the other hand, relies on directly linking observed health outcomes at specific spatial scales with health-related behaviors and built-environment covariates at the same scale. This approach is less common; the only direct estimation tool listed in Table 1 is C-PHAM/UrbanFootprint, reported by urban Design 4 Health (16). Details regarding the method appear in an appendix to a report sponsored by the Southern California Association of Governments (SCAG) entitled Active Transportation Health and Economic Impact Study. The report uses the direct estimation approach to quantify the health benefits of active transportation initiatives included in SCAG's 2012 and 2016 Regional Transportation Plan/Sustainable Communities Strategy. The method does not appear in the peer-reviewed literature and details regarding how spatial scale is treated are scarce. For example, the California Health Interview Survey (CHIS) data are used to model the relationship between the built environment, travel behavior, and health outcomes (e.g. body mass index and incidence of diabetes). But the relationship between this individual-level model and the larger spatial scale used by UrbanFootprint (a 150m gridcell) is not specified.

Additionally, the direct estimation approach will be limited in the same way that all regression studies are limited. No goodness-of-fit statistics are reported for the underlying models, so issues like omitted variables bias cannot be properly diagnosed. Because the tool relies upon very specific estimates of built environment variables to produce health outcomes, including intersection density and distance to parks, it will not be suitable for use with standard travel demand modeling approaches. For this reason, the approach has been embedded within UrbanFootprint, which is a scenario modeling/sketch planning tool that takes built environment measures as inputs and produces estimates of travel behavior as outputs.

In principle, either ITHIM or C-PHAM can be used to assess changes in public health in response to changes in transportation infrastructure and land use. Both tools require substantial up-front work in terms of data collection and model calibration for application in a specific study area. Both have also been applied previously in various California regions, making it possible to bypass some of the effort involved in calibration. But neither application is straightforward. While both offer their software free-of-charge, applying the tools meaningfully in a new geographic area requires acquiring or generating meaningful transportation and land use inputs which often requires interaction with the large volumes of data generated by regional travel demand models. Further, UrbanFootprint contains an integrated sketch planning framework with substantial high-resolution data requirements to establish baseline conditions. Producing a working implementation of UrbanFootprint is also likely to require hiring external consultants to calibrate, operate, and maintain the required software and webservers. On the other hand, ITHIM implementation either involves a single spreadsheet or a series of publicly available and open-source scripts used to process publicly available data sources. Implementation costs and barriers to entry are therefore likely to be higher for UrbanFootprint as compared to ITHIM.

An additional strength of CRA-based approaches is that they can provide expected changes in health outcomes from a range of disease types. CRA-based approaches can be readily modified to account for any health outcomes for which there an established relationship and baseline data. Baseline data for ITHIM calibration are typically gleaned from vital statistics data maintained by public health agencies. ITHIM can currently include mortality and disease burden attributable to physical activity (resulting from cardiovascular disease, diabetes, dementia, depression, colon cancer, breast cancer), road traffic injuries, and air pollution exposure. Conversely, the iteration of C-PHAM reported in 2015 is limited to examining the incidence of physical activity-related public health outcomes as reported from the CHIS data (including body mass index, high blood pressure, heart disease, diabetes, and self-reported health.) In C-PHAM, there is no way to extend the model to account for other diseases or health-related outcomes that are not reported in the CHIS.

Both types of tools are fundamentally limited by the representations of travel behavior that underlie them. The impacts of individual projects aimed at increasing physical activity (e.g. improvements in sidewalk quality or the implementation of a single bike lane) are not likely to be well-represented by current travel demand models, so assessing their public health impacts using either approach is not likely to yield meaningful results. Additionally, the small number of persons likely to be affected by a single project (rather than a bundle of many projects) means that any calculated health benefits are likely to be small. If accurate local data about the number of persons affected and their expected changes in behavior can be developed, then a CRA approach could be easily applied to estimate health effects, whereas direct estimation may or may not require re-calibration of the underlying regression models to achieve the same result. The Health Economic Assessment Tool (HEAT) for cycling and walking is designed to evaluate the health and economic impacts (using the value of a statistical life) of individual projects, but it too requires valid information about the travel behavior changes likely to result from project implementation. Additionally, HEAT is based upon the same methodological principles as ITHIM, so in principle, an ITHIM implementation could generate similar estimates of the health impacts of a transportation project.

A related limitation of the direct estimation approach is that the regression-estimated relationships between the built environment, travel behavior, and health can change over time. This would most likely be an issue if UrbanFootprint is used to estimate future health impacts. Applying relationships observed under current conditions to those in the future could lead to inaccurate forecasts whose direction and magnitude would be unknown. CRA incorporates information about known risk factors for specific health outcomes in a manner that is unlikely to change in the future or across the population and that is backed by substantial epidemiological evidence. In other words, an additional 30 minutes of physical activity per week is likely to have the same effect on all-cause mortality across the population in the future. But because of limitations inherent in regression modeling approaches and ongoing shifts in travel behaviors, the effect of intersection density and destination accessibility as mediated by demographics on walking behavior is likely to be much less stable over time and across different places. This means that the underlying models in C-PHAM will have to be re-estimated and calibrated over time.

In summary, both ITHIM and C-PHAM/UrbanFootprint can be used to model the public health impacts of transportation plans. Both produce similar types of outputs. In the end, the choice of which tool to use will likely be driven by particular needs in a region and whether either tool has already been applied there. ITHIM provides the capability of simultaneously considering physical activity, traffic injury, and air pollution health impacts, whereas C-PHAM/UrbanFootprint focuses on physical activity impacts.1 ITHIM can also be used to evaluate the health impacts of aspirational outcomes, for example a 5% increase in walking and biking across a region. UrbanFootprint cannot model these types of targets directly; such outcomes would have to emerge from expected changes in the urban form. UrbanFootprint would likely be more attractive where a jurisdiction is seeking a comprehensive sketch planning tool that could also simultaneously consider public health impacts.

The results generated by each tool have not been directly compared as they fundamentally generate different health outcomes. ITHIM estimates morbidity and mortality, while C-PHAM estimates incidence rates. Given their substantial methodological differences, it is not likely that they would produce results of similar magnitude. Further comparative work is needed to better understand where the two models differ and the drivers of observed differences.

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[1] Although other implementations of UrbanFootprint seem to have included air pollution and injury pathways and this functionality could be added to future iterations of C-PHAM.

Table 1. Comparison of Commonly Employed Tools for Assessing the Health Impacts of Transportation Plans

	Integrated Transport and Health Impact Model (ITHIM)	Health Economic Assessment Tool (HEAT)	California Public Health Assessment Model (C-PHAM)/UrbanFootprint public health module	Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA)	Environmental Benefits Mapping and Analysis Program Community Edition (BenMAP-CE)
Typical spatial scale	County/region	Project/plan	150 m gridcell	Census tract	User-specified
Developer/ Sponsor	Medical Research Council, others	World Health Organization	Urban Design 4 Health	Centre for Research in Environmental Epidemiology (CREAL)	US Environmental Protection Agency
Exposure pathways considered	Physical activity from walking and cycling, traffic injuries, air pollution	Physical activity from walking and cycling	Urban form variables (indirectly linked to physical activity), earlier versions included change in injury rates and air pollution	Physical activity, air pollution, noise, heat, access to green space	Air pollution (particulate matter and ozone)
User Input	Changes in travel activity by mode (aspirational, off-model literature-based estimates, or from travel demand model outputs)	Active travel estimates can be input data from various sources (e.g. travel surveys, observed counts, predictive estimates).	Changes in built environment and transportation characteristics via the UrbanFootpring sketch planning tool	Aspirational (compliance with international exposure level recommendations) for all exposure pathways	Changes in air quality (aspirational or based on modeling) Option to modify demographics, baseline health incidence, and to add health and economic relationships.
Built-in data and relationships	Health impacts of physical activity, air pollution (in some calibrations), and collision risks are based on research literature. Region-specific calibrations include baseline health, traffic injury, air quality, and travel behavior data.	Relative risk data are from published studies. Value of a statistical life.	Directly estimated from land use and transportation characteristics, demographics, California Household Travel Survey, California Health Interview Survey	Heath impacts of physical activity, air pollution, noise, heat, and access to green space based on research literature. Includes baseline data drawn from the Barcelona Health Survey (PA), land use regression (air quality), Barcelona strategic noise map, central temperature monitor, Urban Atlas (green space)	Built-in health and economic impacts of air pollution are based on research literature. Region-specific calibrations include baseline health incidence, demographics (via the pop-grid tool), and air quality monitoring data.

Table 1 (continued)

Outcomes considered	All-cause mortality, disease-specific mortality, disability adjusted life years	All-cause mortality, economic benefits	Prevalence of health outcomes, body mass index, physical activity	All-cause mortality, economic benefits	Health impacts (including mortality, aggravated asthma, hospital admissions, lost school days, and many more) and their economic values
Methodological approach	Comparative risk assessment	Comparative risk assessment	Direct estimation of health outcomes via regression on urban form and transportation, demographic, and health variables	Comparative risk assessment	Comparative risk assessment
Location(s) applied	United Kingdom, United States, India, Brazil, Malaysia	United Kingdom, Spain	California	Barcelona, Spain	United States and China are built into BenMAP-CE, BenMAP has also been used in South Korea, Spain, and Japan
Representative citation(s)	(*5*, *6*, *20*)	(*21*, *22*)	(*16*, Appendix A, *23*)	(*19*)	(*24*) Listed at https://www.epa.gov/benmap/benmap-ce-applications-articles-and-presentations

Sacramento Application

Overview

The primary purpose of this work is to develop and apply a Sacramento-region implementation of ITHIM that facilitates health equity analyses of transportation plans. We synthesize data from a range of sources and impute missing race/ethnicity and income information. The ITHIM-Sacramento equity analysis tool estimates health outcomes from changes in physical activity and traffic injury in the six SACOG counties (El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba), disaggregating results by race/ethnicity and income where feasible. We demonstrate the ITHIM-Sacramento equity analysis tool by evaluating expected health outcomes due to changes in physical activity and traffic injury that are expected under SACOG's 2016 Metropolitan Transportation Plan / Sustainable Communities Strategy (MTP/SCS) scenarios and the adopted plan. Modeled results can be viewed with a user-friendly web tool.

Methods and Data

The fundamental methodological approach employed by ITHIM is known as comparative risk assessment (CRA). In the ITHIM CRA, the relationships between changes in travel behavior and expected health outcomes are obtained from scientific research studies. These general relationships are applied to region and scenario-specific population and travel data to estimate health outcomes that are expected to occur under different transportation plans. Data for the Sacramento ITHIM implementation are compiled from a number of sources describing demographics, transportation behavior, physical activity, traffic injury, and health. Below we provide an overview of the modeling methods. A more detailed discussion of methods and results can be found in the "Modeling Health Equity in Active Transportation Planning" working paper posted at https://github.com/aakarner/ITHIM-Sacramento.

Scope

To demonstrate the tool, we evaluate health outcomes of the adopted 2016 MTP/SCS for three future years (2020, 2027, 2036) and evaluate outcomes of three alternative scenarios (S1, S2, S3) in 2036. The three scenarios vary in terms of the housing and transportation provisions planned. S2 is the "preferred scenario" and is similar to the adopted 2016 MTP/SCS. S1 includes lower density housing and more emphasis on auto travel. S3 includes higher density housing and a greater emphasis on multimodal travel. All scenario and future year results are presented as a change in outcome relative to 2012, which is modeled as the baseline year.

Physical Activity

In the physical activity module, we combine baseline health data, baseline non-transport physical activity data, and baseline and scenario transport-related physical activity to estimate the health benefits of increases in walking and biking that are expected to occur under each plan scenario.

Baseline health data include the overall disease burden for the US (from the 2010 Global Burden of Disease, or GBD, database) and all-cause mortality rates for the Sacramento region (from 2008-2010 California Department of Public Health vital statistics). We use disability-adjusted life years (DALYs) as a measure of disease burden. Baseline non-transport physical activity data are from the 2005 California Health Interview Survey. Baseline and scenario-specific transport related physical activity are estimated from outputs of SACSIM15, SACOG's activity-based travel demand model. Expected changes in deaths and DALYs due to changes in transport-related physical activity are estimated based on these data and health relationships established in scientific literature.

Traffic Injury

In the injury module, we combine baseline transport injuries and collision rates with baseline and scenario travel distances by mode to estimate the change in collision risks due to changes in walking, biking, and driving. US baseline transport injury rates are from the 2010 GBD database. Sacramento region baseline 2006 – 2016 collision rates are from the Statewide Integrated Traffic Records System (SWITRS) and the Transportation Injury Mapping System (TIMS). Baseline and scenario travel distances by mode are estimated from outputs of SACSIM15. Expected changes in deaths and DALYs due to changes in traffic collisions are estimated based on these data and relationships established in scientific literature.

Disaggregating Estimates by Race/Ethnicity and Income

In order to conduct the equity analysis, we require data for each race/ethnicity and household income group. However, in some data sets, race/ethnicity or income information is missing. Where feasible we apply hot deck imputation, a data fusion method, to impute missing variables as needed. We estimate the health outcomes due to changes in physical activity by race/ethnicity and income. Income is divided into region-specific quantiles (Quant 1 is <$32,000/yr, Quant 2 is $32,000 - $62,090/yr, Quant 3 is $62,090 - 105,000/yr, and Quant 4 is >$105,000/yr). White, Black, and Other categories include non-Hispanic residents of each race while the Hispanic category captures Hispanic residents of all races. Due to data limitations, traffic injury estimates are not estimated by income and are only estimated for two race/ethnicity categories: Non-Hispanic White and People of Color (which includes Black and Other race categories and Hispanic residents of all races).

Results and Discussion

Detailed results can be viewed at https://aakarner.shinyapps.io/06_equity_analysis. This web interface allows users to tailor the results by the geographic area, scenario, demographic group, outcome, and units shown. Below we describe these output options and discuss the results for an example output. A more detailed discussion of results can be found in the working paper posted at https://github.com/aakarner/ITHIM-Sacramento.

Health outcomes from changes in physical activity and traffic injury are estimated for the six SACOG counties (El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba). We evaluate health outcomes of the adopted 2016 MTP/SCS for three future years (2020, 2027, 2036) and for the three alternative scenarios (S1, S2, S3) in 2036. All results are presented as a change in outcome relative to 2012, which is modeled as the baseline year. Physical activity results can be disaggregated by race/ethnicity and income while traffic injury results can only be disaggregated by race/ethnicity. Health outcomes are presented as deaths and disability-adjusted life years (DALYs). DALYs are a measure of disease burden that considers both life years lost due to premature mortality and the reduction in quality of life caused by life years spent living with illness-related disability. Both total death and DALY values and death and DALY values standardized by age and population are presented. Total death and DALY values provide insight into the magnitude of the impacts to a particular geographic area or population. Standardized death and DALY values are age-standardized per capita values that account for differences in a population's size and age-gender distribution to facilitate comparisons of the risks faced by individuals in different demographic groups and geographic areas. These standardized values show the risk of death or DALYs assuming identical population and age-gender distributions.

Two examples of the tool's results are shown in **Figure 1** and Figure 2. **Figure 1** shows the estimated of reduction in total deaths due to physical activity and traffic injury changes under the 2016 MTP/SCS adopted plan. Both White and people of color residents are expected to see no change or fewer deaths in El Dorado, Placer, Sacramento, Yolo, and Yuba counties by 2036. In Sutter County deaths are estimated to increase for both race/ethnicity categories by 2036. The change in total impacts is greatest for Sacramento County, largely because of its larger population. Breaking these estimates down by physical activity versus traffic injury (not shown here) shows that physical activity underlies most of the health benefits in Sacramento County.

The estimates standardized by age and population (Figure 2) similarly demonstrate that the risk of death faced by White residents and residents of color of El Dorado, Placer, Sacramento, and Yolo counties and White residents of Placer county decreases or does not change under the adopted 2016 MTP/SCS in 2036, while risks faced by White and people of color residents of Sutter county and people of color residents of Placer county increase. Conversely, these standardized estimates show that the reduction in risk faced by Yolo county individual residents is greatest. Breaking these estimates down by physical activity vs injury (not shown) shows that physical activity plays a greater role in the decrease in health risks in Yolo county, although traffic injury is not far behind.

The results standardized by age and population shown in Figure 2 are an indication of the changes in the risk of death faced by the average resident of each community whereas the total results shown in **Figure 1** reflect the changes in impact to each community as a whole (which depends on the average risk to each resident and the total population and its distribution by age and gender). For example, suppose that community A's residents are all in their twenties and community B's residents are all in their sixties and both communities have the same baseline travel behavior and then experience identical changes in travel behavior. The change in total deaths (corresponding to community-level impacts) will be greater in community B while the change in standardized deaths (corresponding to individual-level risks) will be the same in both communities. Similarly, if community C has a population of 10 and community D has a population of 100,000 (and they have the same baseline and change in travel behavior) then the change in total deaths will be greater in community D while the change in deaths standardized by age and population will be the same in both communities. In other words, the community-level impacts will be greater in community D although the change in individual-level risks will be the same in both communities. Thus, standardized estimates facilitate comparisons of the change in risk across communities holding their population size and age-gender distributions constant.

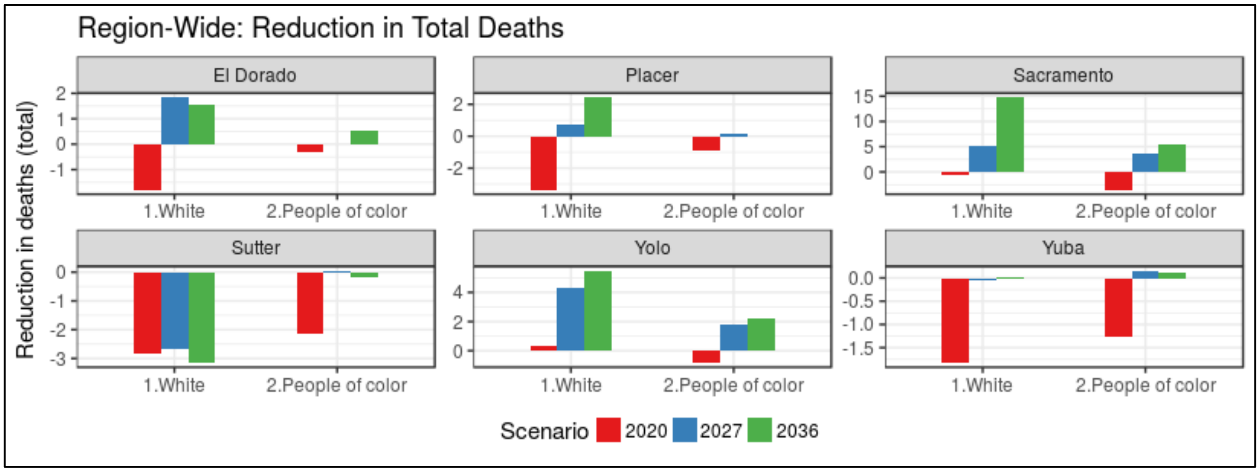

Figure 1. Example ITHIM-Sacramento equity analysis web tool output. This example shows the region-wide reduction in total deaths due to changes in physical activity and traffic injury in future years under the 2016 MTP/SCS adopted plan, disaggregated by county and race/ethnicity relative to base year 2012. This example was generated using the web-tool's "Advanced Plots" tab with County = All, Scenario = 2016 MTP/SCS Adopted Plan in Future Years, Demographic = Race/Ethnicity, Outcome = Both Physical Activity and Injury, and Units = Deaths - total.

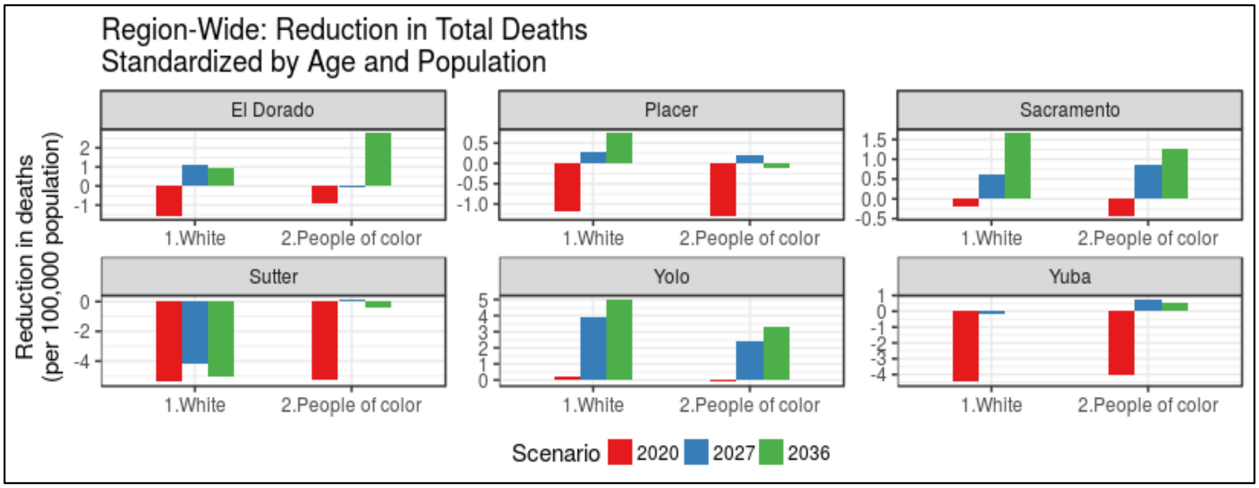

Figure 2. Example ITHIM-Sacramento equity analysis web tool output. This example shows the region-wide reduction in deaths standardized by age and population due to changes in physical activity and traffic injury in future years under the adopted 2016 MTP/SCS, disaggregated by county and race/ethnicity relative to the base year 2012. This example was generated using the web-tool's "Advanced Plot" tab with County = All, Scenario = 2016 MTP/SCS Adopted Plan in Future Years, Demographic = Race/Ethnicity, Outcome = Both Physical Activity and Injury, and Units = Deaths – standardized by age and population.

Applications

By helping to visualize the health impacts of different planning scenarios, the ITHIM-Sacramento equity analysis tool can be used by policy makers, planners, and community advocates to develop a shared information base to inform crucial decisions about the region's future. With limited resources, such regional planning often entails trade-offs between different values (e.g., expansion of suburban development vs. densification of urban cores or investments in bicycle and pedestrian infrastructure vs roadway construction). In many cases, the public health impacts of these decisions are either not addressed or addressed too generally to guide decision-making. Furthermore, health disparities and environmental justice impacts are often given limited attention. The ITHIM-Sacramento equity analysis tool can elevate the quality of the civic dialogue about how to build healthy communities and regions and the specific strategies needed to achieve this. It is recommended that leaders in the policy, planning, advocacy, business and philanthropic sectors familiarize themselves with the ITHIM methodology and explore how it can support their work. Ideally, this will occur in collaborative forums hosted by regional entities such as SACOG, the Sacramento Air Quality Management District, or area universities such as UC Davis.

Limitations

The ITHIM-Sacramento equity analysis tool imputes missing demographic variables to support a demographically resolved analysis. This results in stronger estimates of outcomes for the populations examined but at the same time glosses over any complexities in behavior or baseline health burdens that the underlying data and matching variables fail to capture. Additionally, in some cases the available data for a subpopulation are sparse and therefore noisy, so some spatial aggregation of data was necessary. A sensitivity analysis would shed light on the extent to which these decisions affect modeled outcomes but is beyond the scope of this effort.

Web Interface

Detailed model results can be viewed at https://aakarner.shinyapps.io/06_equity_analysis. The website includes an "**About and FAQ**" tab that describes the project effort and instructions for using the website. A "**Simple Aggregated Plots**" tab shows estimated health impacts due to physical activity and injury effects for the entire population of the Sacramento region (including all six SACOG counties). These results can be tailored by scenario and units shown. An "**Advanced Plots"** tab shows estimated health impacts for several subpopulations in the region (disaggregated by race/ethnicity, income, county) and also allows the user to view health impacts by physical activity, injury, or both. These results can be tailored by the geographic area, scenario, demographic group, outcome, and units shown. Webinar materials describing the project and web tool can be found at https://github.com/aakarner/ITHIM-Sacramento.

Source Code and Model Documentation

All source code and model documentation (including the latest working paper documenting the methods and results and webinar materials) are available at https://github.com/aakarner/ITHIM-Sacramento. This source code can be used to replicate this approach in other regions or to update the built-in values for the Sacramento region. The next phase of this work (underway in 2017-2018) will include the capability to 1) enter user-defined scenario data (based on outputs from the regional travel demand model or modifications to the scenarios shown here) and 2) evaluate health outcomes at smaller (sub-county) geographic areas.

Conclusions

The ITHIM-Sacramento equity analysis tool combines the region's health, injury, and physical activity information with research-based relationships about the health outcomes of changes in travel behavior to estimate the health effects of future regional transportation planning scenarios. We demonstrate the ITHIM-Sacramento equity analysis tool by evaluating expected health outcomes that are expected under SACOG's 2016 Metropolitan Transportation Plan / Sustainable Communities Strategy (MTP/SCS) scenarios and the adopted plan. The estimated health impacts for several subpopulations in the region (broken out by race/ethnicity, income, county) are presented in a user-friendly web interface that allows a user to specify the geographic area, scenario, demographic group, outcome, and units shown. Changes in death and disease burden (represented as DALYs) can be shown as totals to understand the overall magnitude of the effects. They can also be shown as age and population standardized values to facilitate comparisons across populations and geographic areas.

The ITHIM-Sacramento tool can be used to support health equity analysis of the modeled scenarios. Phase II of this work (currently underway) will allow users to analyze new scenario information via the web tool in order to evaluate the health and equity implications of changes in transportation outcomes. It will also allow for estimates of health outcomes in smaller (sub-county) geographic areas.

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