MODELING HEALTH EQUITY IN ACTIVE TRANSPORTATION PLANNING

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ABSTRACT

Understanding the public health impacts of transportation plans can provide stakeholders with valuable information that can aid in the selection of alternative transportation futures. Active transportation (i.e. walking, bicycling, and some public transit trips) can improve public health through increased physical activity. The Integrated Transport and Health Impacts Model (ITHIM) has been applied around the world to understand changes in public health that will result from the adoption of plans that support active travel. However, the model does not provide disaggregate information required to evaluate the social equity implications of such changes. Health benefits are typically reported as a single value (i.e. total reductions in deaths) at the county or regional level. In this work, we draw from several data sources to report demographically explicit (i.e. race/ethnicity and income) results from an ITHIM implementation that we developed for the Sacramento region in California. This disaggregation is helpful because travel behavior and health outcomes are affected by race/ethnicity and its correlates (e.g. residential location) and planning agencies are required to ensure that their policies and projects are not discriminatory. The results demonstrate that the fundamental insights of ITHIM can be applied to different racial and ethnic groups, providing decision makers with the information needed to target interventions to achieve outcomes for disadvantaged populations. They also pave the way for further spatial disaggregation.

INTRODUCTION

Contemporary transportation systems are unsustainable (*1, 2*). Policies and planning efforts aimed at achieving sustainability can take a number of forms. Technological solutions for sustainable transportation seek to minimize the per-mile impacts of driving by using less carbon-intensive fuels or vehicles (*3*). More ambitious comprehensive solutions focus on creating places conducive to walking, cycling, and public transit. These strategies can reduce greenhouse gas emissions and exposure to harmful pollutants, improve human health by increasing physical activity, and reduce social exclusion by increasing access to amenities by low-income people. But creating such places can also lead to increased local air pollution exposure and change the risk of vehicle, pedestrian, and bike collisions (*4-6*). Evaluating tradeoffs between these competing objectives is an ongoing challenge.

Understanding these comprehensive impacts is of particular importance in California, where statewide, regional, and local agencies and jurisdictions are working implement the Sustainable Communities and Climate Protection Act of 2008 (commonly known as SB 375). SB 375 requires the state's metropolitan planning organizations (MPOs) to adopt a Sustainable Communities Strategy (SCS) as a new component of long range regional transportation plans (RTPs). An SCS must describe and evaluate a combined transportation, land use, and housing plan that meets a per capita greenhouse gas emissions reduction target. MPOs have generally evaluated the performance of multiple different possible SCS scenarios prior to adopting a preferred plan.

The impacts of a particular project or plan on health and well-being are complex and situation-specific, making it difficult to apply general research to project and plan evaluation in practice. The Integrated Transport and Health Impact Model (ITHIM)--has been developed to address this gap and assess the public health impacts of alternative transportation and land use scenarios arising from expected changes in air quality, accident rates, and physical activity (*7*). When the ITHIM is calibrated to a particular geographic area it provides a powerful tool that can be used to inform transportation decision making and project prioritization. ITHIM has been applied worldwide and generally demonstrates that the public health benefits of transportation plans that increase active travel are net positive; improvements in health from increased physical activity and air quality far outweigh decreases resulting from increased traffic injury rates (*8*).

Prior iterations of ITHIM have presented results describing changes in health outcomes at the regional level, disaggregated by age-sex categories. Such results do not shed light on whether expected improvements/declines in health are equitably distributed across relevant population groups. The distribution of the benefits and burdens of transportation investments is required by federal law and executive agency guidance issued in the wake of Title VI of the 1964 Civil Rights Act (*9*). Planning agencies that receive federal funds must ensure that people of color and low-income people are not denied the timely receipt of beneficial results from public investments. The health co-benefits of active transportation plans could certainly be construed as one such benefit whose distribution must be assessed.

The purpose of this work is to develop and apply an implementation of the physical activity module of ITHIM that facilitates health equity analyses of transportation plans. We synthesize data across a wide range of sources and use "data fusion" techniques to impute missing demographic information as needed. We calibrate the model using data for the Sacramento Area Council of Governments (SACOG) region in northern California. The model is tested upon simulated travel behavior data underlying SACOG's 2016 Metropolitan Transportation Plan/Sustainable Communities Strategy (MTP/SCS). In order to make the results comparable across differently sized geographic units and demographic groups, results are normalized to generate age-standardized per capita changes in the number of deaths per year to be expected from plan implementation. The results demonstrate that the non-Hispanic Black populations are expected to experience greater health improvements from the implementation of SACOG's 2016 MTP. Whether these changes result from active travel undertaken by coercion or by choice must be investigated further to determine whether the changes represent true benefits for that population.

METHODS AND DATA

The fundamental methodological approach employed by ITHIM is known as comparative risk assessment (CRA). CRA can be used to quantify the extent to which disease burden changes when exposure to specific risk factor changes (*10*). It is an extension of the population attributable risk formula, as described in Maizlish et al. (*8*).

Data for the Sacramento ITHIM implementation were compiled from a number of sources describing physical activity and health. An overall schematic of the model structure and required inputs is shown in Figure 1. The data, their sources, and manipulation are described further below.

Health data

Health data required for ITHIM include the overall disease burden for the US and all-cause mortality rates for the Sacramento region. All-cause mortality was taken from the California Department of Public Health (CDPH) vital statistics dataset from 2008-2010. These years were chosen because the base year in SACOG's latest activity-based model, SACSIM15, is 2012 and the CDPH data after 2010 do not include the same set of demographic variables that are included through 2010. An average annual all-cause mortality rate was constructed for each age-sex-race/ethnicity and age-sex-income category, separately for each county. Upon further investigation, mortality rates for the Black population were close to or equal to zero in a number of cases across the region due to the small Black population in many counties. For this reason, we calculated a single region wide estimate of the annual all-cause mortality rate for the Black population for use in later calculations.

The US disease burden in each age-sex category was extracted from the publicly available Global Burden of Disease (GBD) database (*11*). Consistent with earlier ITHIM implementations, we used disability-adjusted life years (DALYs) as a measure of disease burden. DALY estimates are only available at the US level and consider 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. They are calculated by summing years living with a disability and years of life lost due to premature death. The US disease burden is taken from GBD 2010 for consistency with the time period of the CDPH vital statistics data.

DALY estimates for the Sacramento region are calculated by scaling US DALYs by the ratio of deaths in each county to deaths in the US as a whole in each age-sex-race and age-sex income category. The ratio of deaths is obtained by dividing the all-cause mortality for each county by the county population. This scaling process is also applied across each age-gender-race/ethnicity and age-gender-income group.

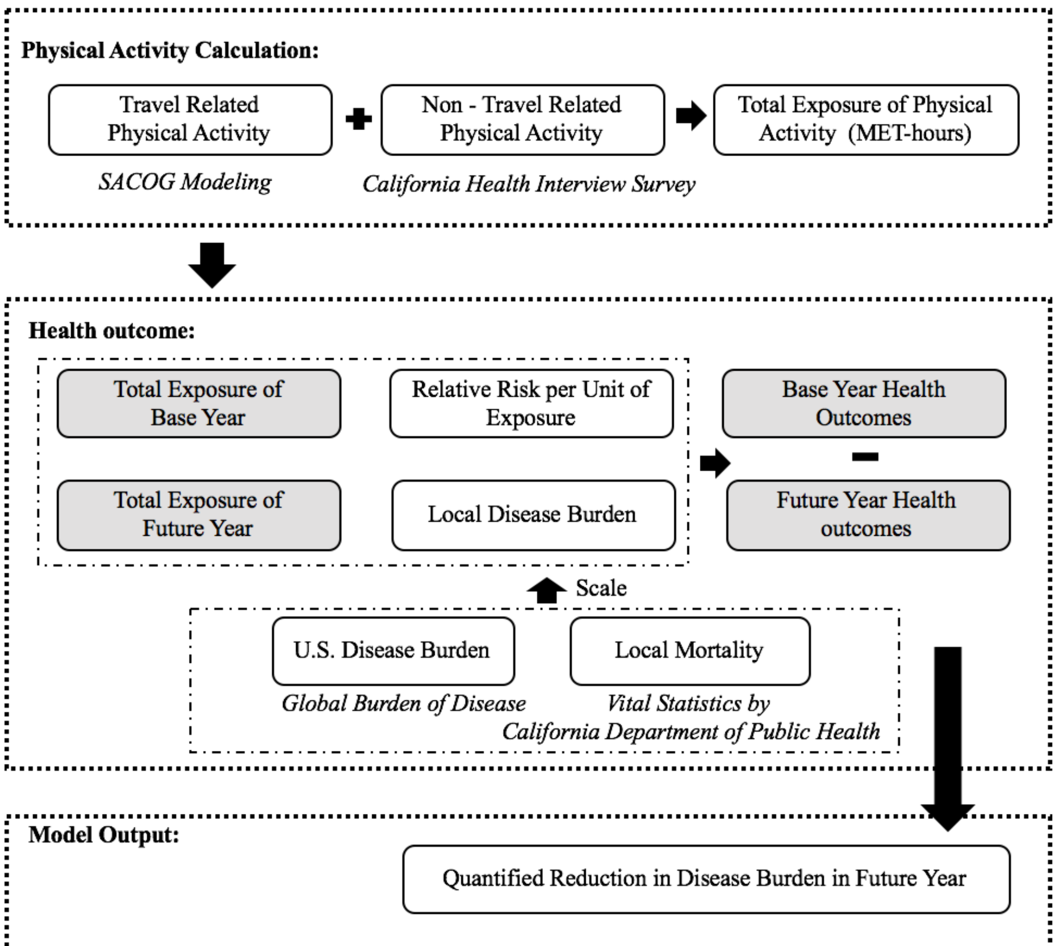


FIGURE 1. CRA schematic. Data sources shown in italics.

Physical activity data

Physical activity was quantified using SACSIM (travel-related physical activity) and the 2005 California Health Interview Survey (CHIS; occupation- and exercise-related physical activity) (*12*).

SACOG used SACSIM15 to provide transportation forecasts for the latest 2016 MTP/SCS and continues to use it for various policy analyses (*13*). SACSIM15 was calibrated and tested for a base year of 2012 and was used to forecast travel behavior in 2020 and 2036 under the 2016 plan. We used SACOG's SACSIM15 MTP/SCS outputs to estimate the average active transport (walking and cycling) time (minutes per day) and average distance (miles per day) for each demographic group for each of the three analysis years.

Non-transport physical activity data were obtained from the 2005 CHIS, which was the most recent survey year that included occupation type (used to estimate occupational activity) and exercise habits. In ITHIM, physical activity is quantified as the metabolic equivalent of task (MET), which is then used to convert time spent in active travel to energy expenditure and thus changes in health outcomes. One MET is defined as the amount of energy expended while at rest and is expressed in the unit $\frac{kcal}{kg*h}$ (*14*). Engaging in physical activity results in increased MET values. Calculated MET values are multiplied by the time spent in the activity to arrive at a figure for MET-hours per week, or total energy expenditure. MET-hours per week are also calculated for occupational and exercise physical activity (non-travel METs) using the relationships developed by Maizlish et al (*8*). The relationships between physical activity and health impacts that are included in ITHIM are drawn from systematic reviews. Here, the relative risk (*RR*) – MET-hour gradient was represented by a square root function with the relative risk of all-cause mortality for 1 MET-hour equal to 0.89 according to Woodcock et al. (*7*).

Data fusion using "hot deck" imputation

In order to conduct the equity analysis, we require physical activity and health data for each race/ethnicity group and household income group. However, in some data sets, race/ethnicity or income data are missing, e.g. in SACSIM15, there is no race/ethnicity variable in the synthetic population. Therefore, we applied hot deck imputation, a type of data fusion method, to impute missing variables as needed.

Fundamentally, hot deck imputation seeks to match records drawn from two or more data sources based on common variables that they share. Its goal is to incorporate variables from the donor dataset into the recipient dataset (*15*). In our case, we used the American Community Survey Public Use Microdata Sample (ACS PUMS) data as the donor and SACSIM15 as the recipient data. These two data sets share four matching variables: age, gender, income and county of residence. The missing variable in SACSIM15 is race/ethnicity. We use hot deck imputation to impute race/ethnicity into the SACSIM15 synthetic population. Similarly, we applied the hot deck method to impute the household income quartile into the CDPH mortality data (recipient) also using the ACS PUMS records with five matching variables: age, gender, race/ethnicity, education level and county of residence. We used the R package "StatMatch" and the function "NND.hotdeck" to implement the hot deck method (*15*).

Study area

Six counties comprise the SACOG rergion: El Dorado (ELD), Placer (PLA), Sacramento (SAC), Sutter (SUT), Yolo (YOL), and Yuba (YUB). SACOG has been advancing the frontiers of transportation modeling and performance assessment for some time (*16*) and several regional stakeholders have expressed an interest in modeling the health impacts of transportation policies and plans in order to inform their design. Additionally, a previously developed version of ITHIM includes the Sacramento region (*17*), providing a starting place for the enhanced ITHIM functionality developed here.

SACOG has used their activity-based model, SACSIM15, to estimate changes in travel behavior for the present (2012) as well as for future years (2020 and 2036) under their 2016 MTP/SCS. The plan must meet the requirements of the Sustainable Communities and Climate Protection Act of 2008 (commonly known as SB375) requiring per-capita reductions in future GHG emissions resulting from changes in travel behavior (*18*).

Health outcomes and changes in travel behavior are modeled separately for age-gender-race/ethnicity and age-gender income categories. Income was divided into regional 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). County-level demographics are shown in Table 1.

TABLE 1. Sacramento Region Demographics (Total Population: 2.27 million).

Population – grouped by race/ethnicity					
	Total	White	Black	Hispanic	Other
ELD	151,639	79.6%	0.3%	11.7%	8.4%
PLA	346,984	76.1%	0.8%	12.6%	10.5%
SAC	1,402,302	47.9%	9.3%	21.6%	21.2%
SUT	93,877	53.6%	1.9%	27.4%	17.1%
YOL	197,101	49.1%	2.4%	31.5%	17.0%
YUB	73,552	52.8%	1.8%	28.1%	17.3%

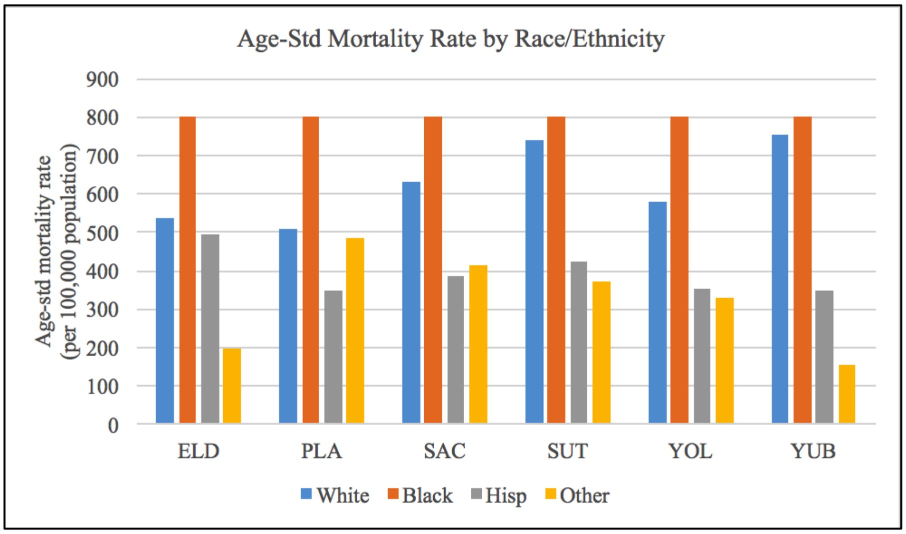
Population – grouped by household income ($ per year)					
		Quant 1	Quant 2	Quant 3	Quant 4
	Total	<32,000	32,000-62,090	62,090-105,000	>105,000
ELD	151,639	15.1%	20.4%	27.1%	37.8%
PLA	346,984	16.4%	19.7%	26.5%	37.5%
SAC	1,402,302	26.9%	26.3%	25.0%	21.7%
SUT	93,877	28.0%	31.8%	23.5%	17.4%
YOL	197,101	29.9%	23.3%	21.6%	25.2%
YUB	73,552	31.5%	32.3%	24.0%	12.3%

Source: 2012 American Community Survey 1-year estimates. White, Black, and Other categories include non-Hispanic residents of each race while the Hispanic category captures Hispanic residents of all races.

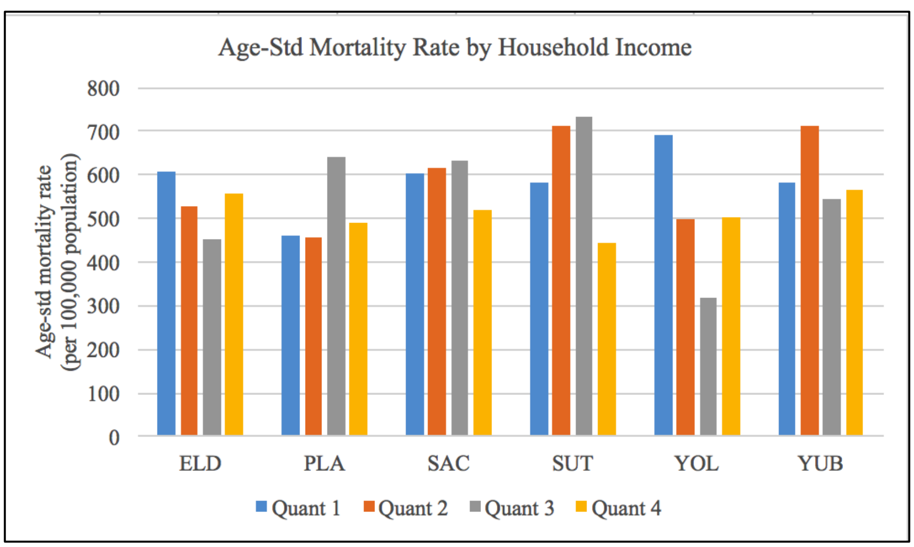
RESULTS

Baseline Mortality Rates in Sacramento Region

All-cause age-standardized death rates (standardized to the US population, per 100,000) are summarized in Figure 2. Age-standardized death rates apply the death rates of a particular population to the population distribution of a larger reference group so that rates from different locations can be compared independently of their underlying age distribution. We apply this calculation method for all race/ethnicity groups and household income groups in each county. As mentioned previously, we calculated a single region wide estimate of the all-cause mortality rate for the Black population, therefore, their age-standardized death rates are equal across all counties.



(a) Age-standardized mortality rate by race/ethnicity.



(b) Age-standardized mortality rate by race/ethnicity.

FIGURE 2. Age-standardized mortality rate in Sacramento region.

Figure 2a shows that the Black population has the highest age-standardized mortality rate of all racial/ethnic groups. Figure 2b shows that mortality rates differ across the six counties by income. For example, Quant 3 has the greatest mortality rate in Placer, Sacramento, and Sutter. But in El Dorado, Yolo, and Yuba, the mortality rates of Quant 3 are the lowest.

Estimates of Physical Activity

Tables 2-4 show estimated active travel times by county and demographic group for each modeled year, from SACSIM15 outputs for the 2016 MTP/SCS. The MTP/SCS covers the period from 2012-2036 and directs $2.8 billion in investments toward bicycle and pedestrian projects. These projects include sidewalk extensions, pedestrian bridges, intersection improvements, and bike lanes. Those efforts are aimed at encouraging more residents to walk and bike for transportation. SACSIM simulates the implementation of those policies in part by altering their highway network to reflect non-motorized friendly policies and projects.

Table 2 indicates that the overall active travel time for the entire Sacramento region increases from 2012 to 2020 and 2036, consistent with the intention of the MTP/SCS. The majority of the cycling gains occur by 2020, while the bulk of the walking gains occur after 2020.

Tables 3 and 4 show estimates of active travel time in each county and demographic group in 2010, and the percent of changes from 2012 to 2020 and 2036. Sacramento and Yolo Counties have the highest walk times, and Yolo County has the greatest cycling times. Sacramento County is the densest county in the region, and home to the City of Sacramento, the regional job center, which has a walkable downtown and several other traditional pedestrian-friendly neighborhoods. Yolo County is home to the City of Davis, a college town well known for its high rates of cycling.

Most of the walking and cycling times are greatest in the year 2036 when all MTP/SCS projects are implemented. Active travel times are relatively similar in 2012 and 2020, though in some counties (e.g. El Dorado and Placer), active travel times are lower in 2020 than in 2012 in contrast to the regional trend.

Trends in cycling time for all racial groups follow regional trend. The trend for Sacramento County is similar to Yolo with steady gains in cycle times. In the MTP/SCS, the bike route mileage in Sacramento County will increase by about 120 percent from 918 miles in 2012 to 2026 miles in 2036, which is the main reason for the increase in cycling time in Sacramento County.

Table 4 clearly indicates that Quant 1, the lowest income group, has the greatest walk time in most of the counties. Only in El Dorado County does Quant 4, the highest income group, have the greatest walk time. The cycling times of Quant 1 across all counties show the largest value as well. These results indicate that the lowest income group has the greatest overall active travel time than other three income groups.

TABLE 2. Overall Active Travel Time for the SACOG Region from SACSIM.

Mode	Year 2012	Year 2020	Year 2036
Travel time (minutes per week per capita)			
Walking	32.8	33.3	38.45
Cycling	6.1	6.8	6.95
Changes from 2012			
Walking	n/a	+1.5%	+17.2%
Cycling	n/a	+11.5%	+12.2%

TABLE 3. Active Travel Time by County, Year, and Race/Ethnicity from SACSIM.
(values in 2012 and percent changes from 2012 in 2020 and 2036)

		Walking (minutes per week per capita)				Cycling (minutes per week per capita)			
County	Year	White	Black	Hisp	Other	White	Black	Hisp	Other
ELD	12	14.3	9.5	18.7	19.4	1.6	0.5	2.9	2.6
	20	8%	-45%	-1%	-11%	-6%	0	-24%	-19%
	36	17%	24%	-4%	-1%	19%	0	-10%	-8%
PLA	12	21.7	23.5	25.7	23.0	2.1	2.4	3.3	2.3
	20	-3%	-17%	1%	-3%	5%	-33%	0	17%
	36	6%	23%	8%	13%	14%	-4%	-9%	26%
SAC	12	33.2	39.3	40.1	37.6	3.7	4.6	4.7	4.3
	20	4%	2%	1%	1%	5%	2%	4%	2%
	36	21%	17%	16%	18%	24%	20%	26%	23%
SUT	12	33.0	40.0	41.2	39.2	3.1	3.2	4.0	3.4
	20	-2%	-3%	-4%	-5%	-6%	41%	-8%	12%
	36	-3%	-17%	-1%	-3%	-3%	22%	0	9%
YOL	12	38.6	36.2	44.6	42.5	28.0	25.2	32.5	48.4
	20	7%	16%	2%	3%	14%	10%	20%	17%
	36	38%	51%	29%	29%	4%	4%	10%	5%
YUB	12	23.1	29.5	30.1	28.7	2.2	3.8	3.2	3.0
	20	4%	2%	0	-4%	5%	-63%	-3%	-10%
	36	14%	2%	13%	3%	5%	-13%	-3%	3%

TABLE 4. Active Travel Time by County, Year, and Household Income from SACSIM
(values in 2012 and percent changes from 2012 in 2020 and 2036)

		Walking (minutes per week per capita)				Cycling (minutes per week per capita)			
County	Year	Quant1	Quant2	Quant3	Quant4	Quant1	Quant2	Quant3	Quant4
ELD	12	14.2	13.4	14.1	17.5	2.1	1.6	1.8	1.9
	20	-1%	8%	8%	3%	5%	6%	-28%	-11%
	36	8%	15%	17%	9%	5%	31%	6%	5%
PLA	12	24.7	23.1	21.0	21.8	2.7	2.4	2.1	2.1
	20	-5%	-4%	-1%	-1%	7%	4%	5%	5%
	36	2%	3%	10%	10%	7%	4%	5%	19%
SAC	12	44.0	37.0	31.2	31.1	5.4	4.3	3.3	3.1
	20	-3%	1%	6%	9%	6%	5%	6%	6%
	36	8%	18%	26%	29%	17%	28%	27%	32%
SUT	12	42.7	39.1	30.7	29.4	3.8	3.6	3.0	2.9
	20	-4%	-7%	1%	3%	0	-8%	0	0
	36	-1%	-7%	5%	15%	-5%	3%	0	7%
YOL	12	47.8	43.0	36.5	35.4	55.3	24.5	18.9	25.7
	20	2%	-1%	10%	10%	16%	19%	14%	10%
	36	21%	35%	44%	41%	0	10%	11%	12%
YUB	12	30.9	26.3	23.4	18.9	3.7	2.6	1.8	1.7
	20	0	-2%	4%	11%	-11%	-12%	28%	18%
	36	9%	7%	18%	28%	-14%	4%	28%	24%

Health Outcomes

When evaluating the range of health impacts a plan or converting health outcomes to economic outcomes, it can be informative to evaluate both DALYs and premature mortality. However for the purposes of demonstrating the demographically explicit analysis and evaluating the equity of the MTP/SCS in future years, we confine this discussion to the expected reductions in premature mortality, as DALYs exhibit similar trends.

Reduction in total deaths

For the entire Sacramento region, the total reduction in premature mortality is 9.3 and 48.3 fewer deaths in 2020 and 2036, respectively. These changes are consistent with the overall trend of active travel time shown in Table 2 and do not reflect any changes in population size or composition in 2020 or 2036. We also estimate the health outcomes by race/ethnicity and income (Figures 3 and 4, respectively).

Figure 3 shows the death reduction by race/ethnicity for 2020 and 2036 compared to the base year 2012. Negative values indicate that the total health burden increased over the 2012 burden (more deaths are expected in future years due to reductions in physical activity). For example, White residents of Sutter County show greater premature mortality in 2036 due to the decrease in walking and cycling times from 2012 to 2036 (Table 3). Most of the reductions in premature death occur in Sacramento County, which has the largest population. White residents of Yolo County also exhibit noticeable reductions, likely due to a substantial increase in walk times.

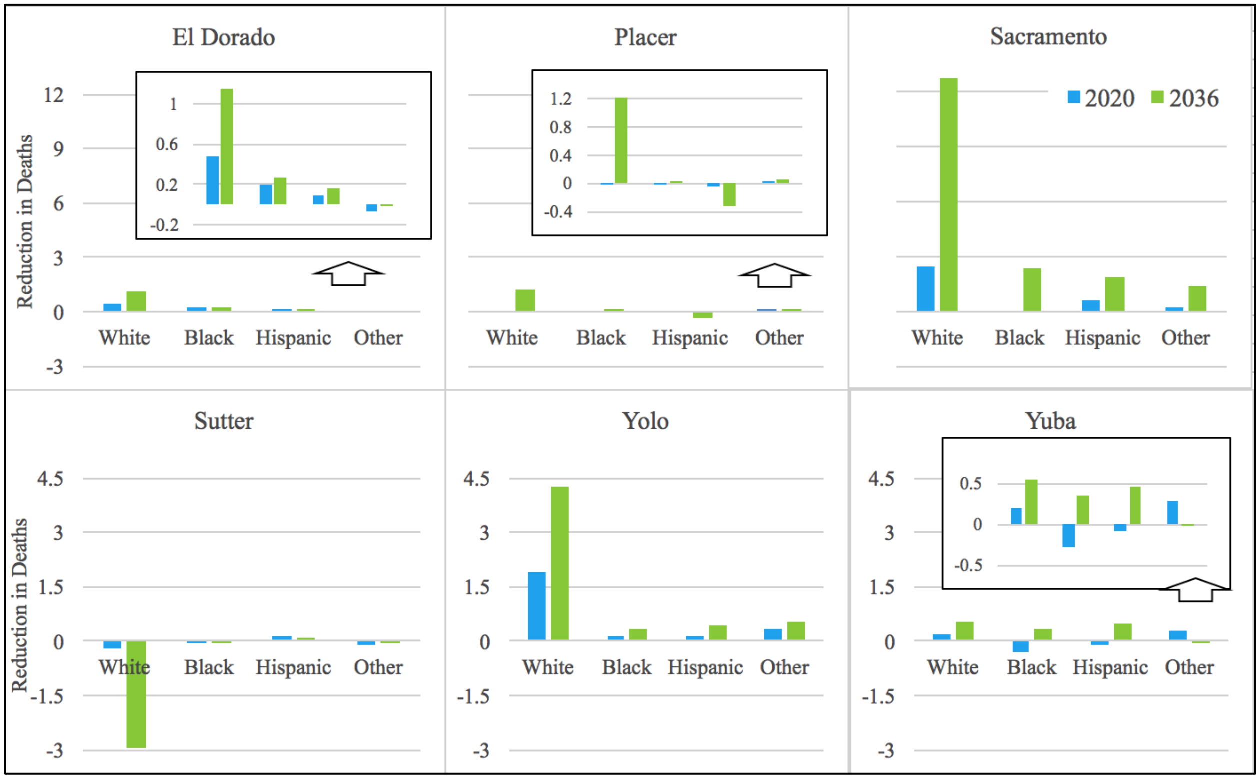


FIGURE 3. Reduction in total deaths from 2012 by race/ethnicity.

Figure 4 shows the results for each household income group. Again, impacts vary across counties and demographic groups. Sacramento County, with the largest population, shows the greatest reductions. The two lower income quantiles in Yolo County also exhibit noticeable reductions while the third quantile in Placer County shows noticeable increases in deaths.

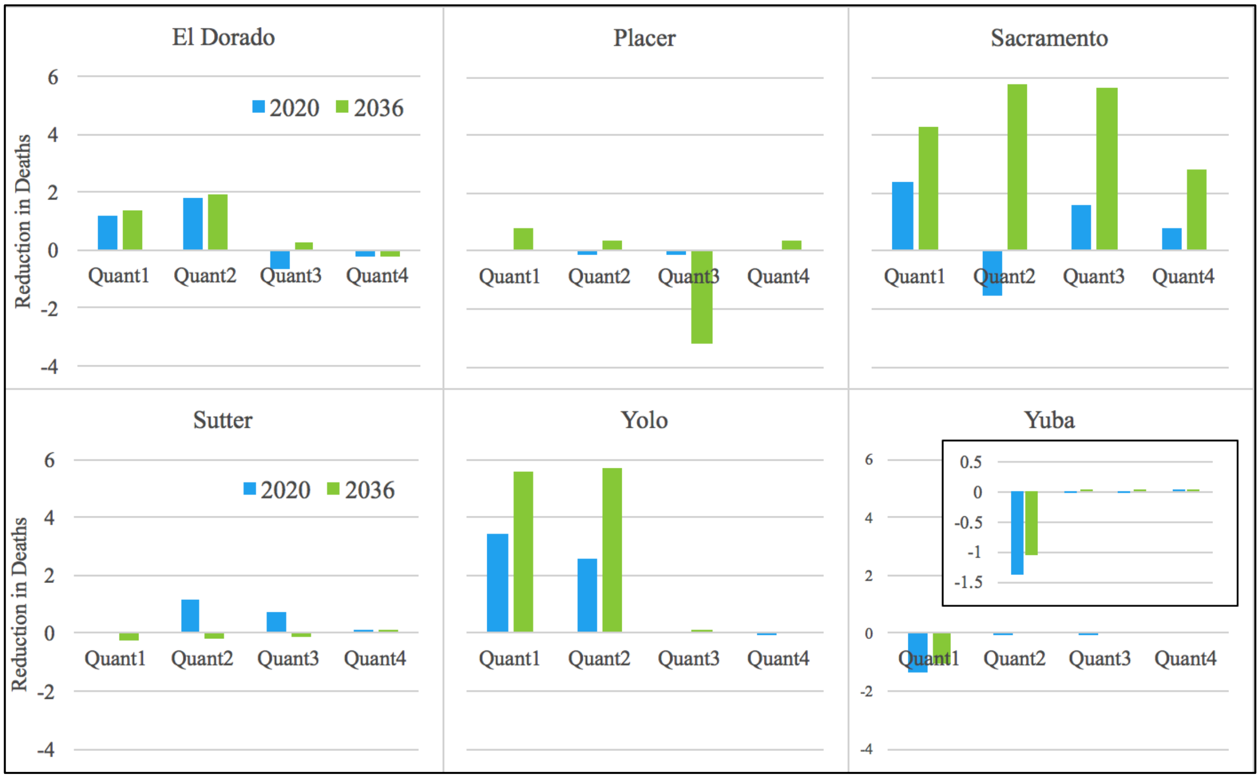


FIGURE 4. Reduction in total deaths from 2012 by income quartiles.

Age-standardized reduction in total deaths

Since each demographic group in each county has a different age/gender profile, we also examine the age-standardized health outcome (per 100,000 population). Age standardization applies the health outcomes of a particular population to the population distribution of a larger reference group so that rates from different locations can be compared independently of their underlying age distribution. We also present results per 100,000 people to allow for comparisons across areas with different total populations. We apply this calculation method for all race/ethnicity groups and household income groups in each county to facilitate a comparison of the change in risks faced by these populations (rather than a measure of their total expected impact.)

For the entire Sacramento region, the total age-standardized death reduction from 2012 is 0.4 per 100,000 people in the year 2020 and 2.2 per 100,000 people in 2036. We also estimate the age-standardized reduction in deaths per 100,000 people for each race/ethnicity and each income quartile in Figures 5 and 6, respectively.

Figure 5 shows the reduction in deaths per 100,000 people from 2012 by race/ethnicity in 2020 and 2036. In several counties, differences between demographic groups are substantial. For example, in Yolo and El Dorado Counties, non-Hispanic Black residents have a greater reduction in deaths per 100,000 people than other races/ethnicities in those Counties and for all races/ethnicities in other Counties.

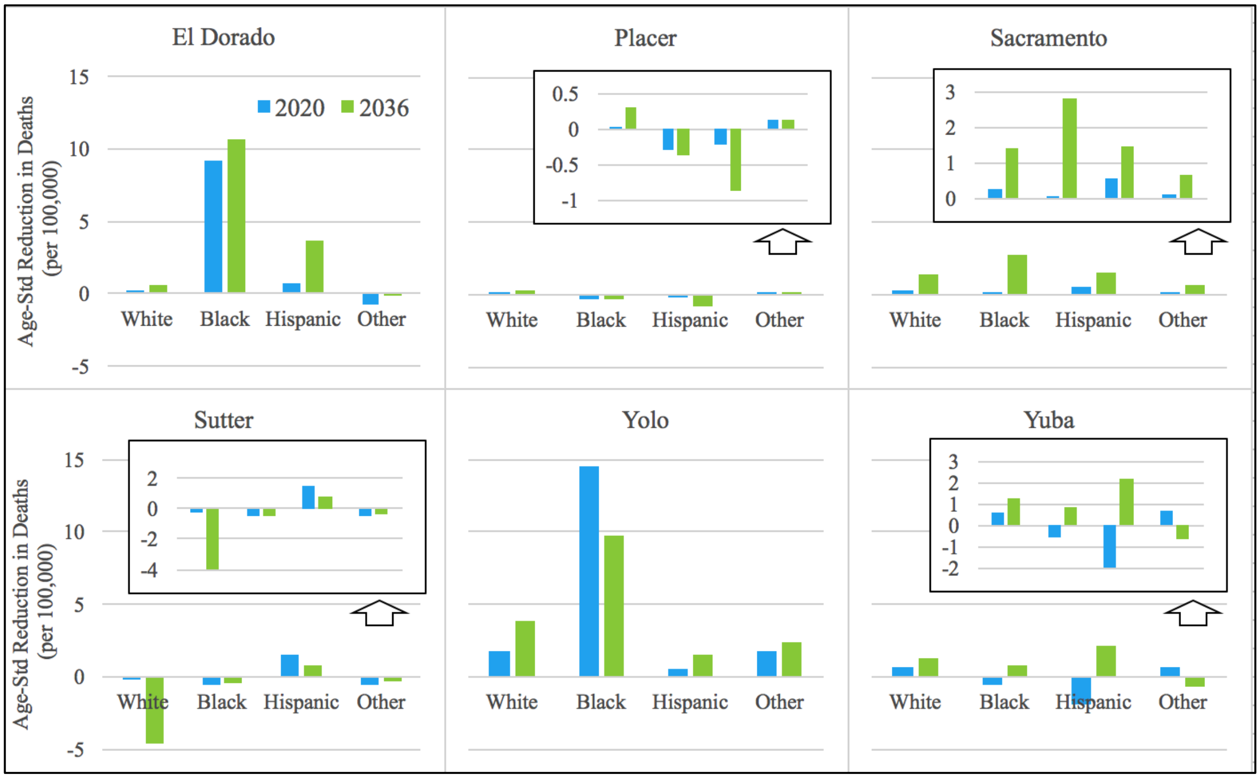


FIGURE 5. Age-standardized reduction in deaths per 100,000 people from 2012 by race/ethnicity.

When considering the effects of household income (Figure 6), we again observe substantial differences between groups and counties. For example, in El Dorado and Yolo Counties, the lower two income quantiles show greater reductions in deaths per 100,000 people than higher income quantiles. At the same time the lowest income quantile in Yuba County shows negative deaths avoided, indicating an increase in deaths.

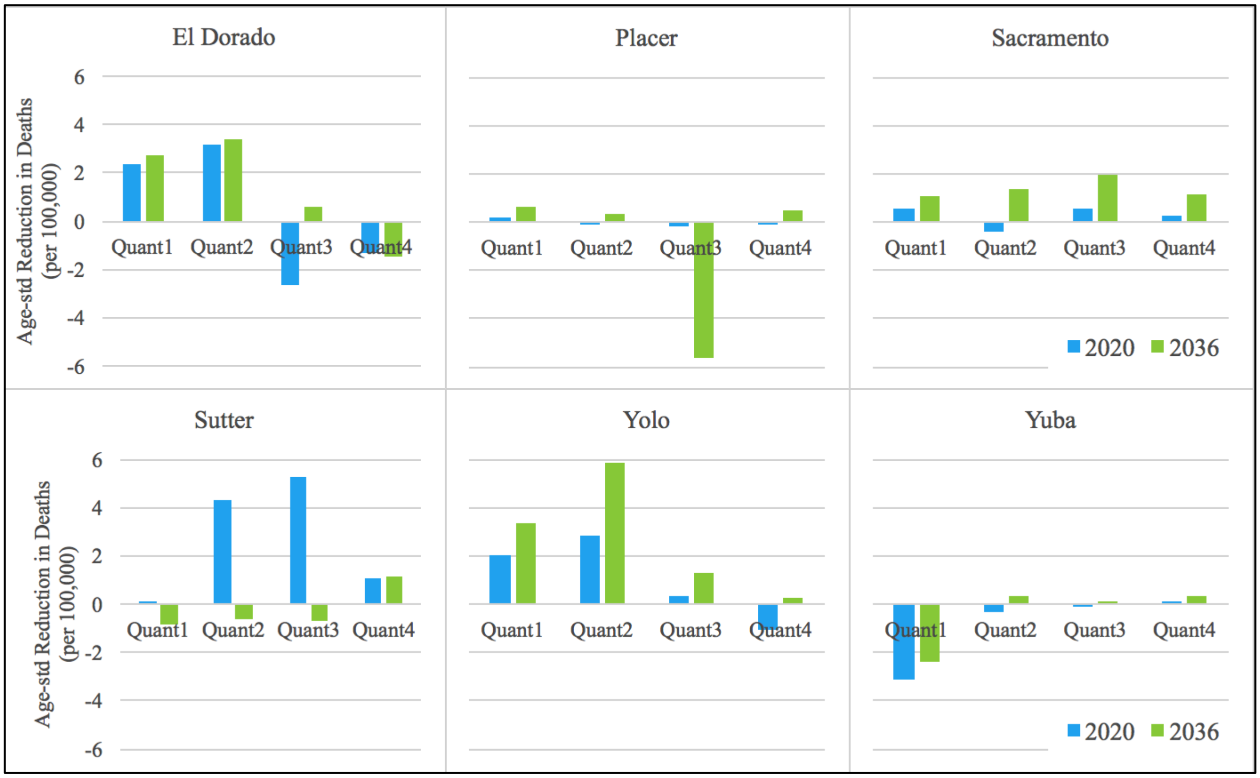


FIGURE 6. Age-standardized reduction in deaths per 100,000 people from 2012 by income quartile.

DISCUSSION

This study draws from several data sources to estimate the future health effects of physical activity in different race/ethnicity and household income populations in the six counties in the Sacramento region. As expected, we find that the direction of the change in health burden is inversely related to the change in physical activity: increases in physical activity correspond to improved health outcomes and vice versa. The magnitude of health outcomes (premature mortality and DALYs) is driven by the magnitude of changes in physical activity and the magnitude of baseline health burdens.

When examining the disaggregated results by race/ethnicity and income, we observe that expected changes in health burdens vary widely across demographic groups and counties. We present total reductions in deaths as well as age-standardized deaths per 100,000 people in order to compare the expected impacts and risks, respectively, for each demographic group. For example, White residents of Sacramento County show the greatest reductions in total deaths, while Black residents of El Dorado and Yolo County show the greatest reductions in age-standardized deaths per 100,000. The first observation is weighted heavily by the population size and age distribution of the population (e.g. the population of White Sacramento County residents is substantial), while the second observation is not influenced by population size or age distribution and provides an indication of the change in comparative risks faced by different populations (e.g. on average, each Black resident of El Dorado and Yolo County will experience a greater reduction in death risk).

Note that in some counties, the active transport time increases while health outcomes worsen. For example, in Placer County, the third income quartile's walking time increases from 21 to 23 min/week from 2012 to 2036, and the cycling time increases from 2.1 to 2.2 min/week. However, their health burden increases in future years, with an increase in mortality and DALYs in 2036. This is caused by the aggregation of the results shown here. In the ITHIM, we estimate the physical activity and health burden in each age and sex category separately, and then aggregate them to output the final results for the entire population and for an age-standardized population. Although the overall active transport time is increasing, in an age/gender subcategory it may decrease. If a subcategory that exhibits a decrease in active travel has a high baseline health burden it will affect the estimated health outcome more than age/gender subgroups with a lower baseline health burden, resulting in results that appear counterintuitive when examining active travel and health in the aggregate.

Overall, the substantial variation between counties and demographic groups demonstrates the utility of demographically explicit equity analysis, which can be used to ensure that different populations and communities equitably share the costs and benefits of transportation investments. This type of health equity evaluation can inform decision-making and aid in project prioritization. However, it is critical to understand what drives observed differences rather than simply comparing outcomes across groups. For example, are substantial reductions in deaths for a low income quantile driven by better bike and pedestrian infrastructure, or greater distances to transit stops? The former implies an overall improvement in accessibility and transportation options, while the latter implies a decrease in accessibility which may compromise health in other ways, e.g. via reduced access to health care and economic opportunities. A closer examination of the plan itself and the modeled travel behavior could provide insight into the underlying causes of observed differences.

Strengths and Limitations

This study used the hot deck method to impute missing demographic variables to support a demographically resolved analysis. This results in stronger estimates of outcomes for the populations examined. At the same time, this method glosses over any complexities in behavior or baseline health burdens that the underlying data and matching variables fail to capture, e.g. to the extent that travel behavior varies by race/ethnicity independently of the match variables used to impute the missing demographics in the SACSIM data (age, gender, income, county) this analysis would fail to capture that nuance. Furthermore, the functions in the ITHIM are applied uniformly across demographic groups; this analysis does not capture any variation in the relationship between physical activity and health that may be tied to race/ethnicity or income. Similarly, variation in input data that may occur at the sub-county level is not addressed here. Additionally, in some cases the available data for a subpopulation are sparse and therefore noisy, so some spatial aggregation of data was necessary, e.g. for Black residents in the study area. The use of the R computing language facilitated the greater complexity of the estimates and outputs in this study.

Note that this analysis accounts for the benefits of increased physical activity without accounting for the risks due to exposure to air pollution or the risk of injury due to collisions. Previous studies indicate that in general the benefits of increased physical activity outweigh the risks posed by the additional exposure to air pollution that active travel presents (*19, 20*).

CONCLUSIONS

In this study, we demonstrated use of the Integrated Transport Health Impact Model (ITHIM) to evaluate the equity of health outcomes resulting from regional transportation plan implementation. We find that changes in travel behavior and health outcomes vary widely by race/ethnicity, income, and county. HIA models generally do not disaggregate results to allow for social equity analysis. When crafting a transportation and land use policy and plan it is critical to evaluate the distribution of outcomes in order to ensure that the benefits and burdens are distributed fairly.

Overall active travel times increase across the region under the transportation plan. Accordingly, health burdens are expected to decrease. These findings do not hold for all demographic groups or in all counties, however, as some groups exhibit an increase in expected deaths. However, it is critical to understand what drives observed differences rather than simply comparing outcomes across groups, as some changes which increase active travel may be a benefit (e.g. improved bike/pedestrian infrastructure) or a burden (e.g. greater distance to transit stops). A closer examination of the plan itself and the modeled travel behavior could provide insight into the underlying causes of observed differences which would aid in the interpretation of the distribution of benefits and burdens. Future research can improve upon these results by evaluating spatial variation in outcomes and seeking input data with greater demographic resolution.

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