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MEMORANDUM

Date:	July 5, 2013	Project #: 12470
To:	Herbie Huff Ryan Snyder Associates	
From:	Karla Kingsley, Mike Aronson, Kittelson & Associates Madeline Brozen, Tulsi Patel, UCLA	
Project:	SCAG Bike Count Data Clearinghouse: Task 5	
Subject:	Task 5: Tools for Estimating Benefits	

SUMMARY

This white paper identifies potential relationships between improved bicycle count data and travel demand modeling in the Los Angeles region. A number of tools for estimating benefits of bicycle travel, separate from regional travel demand models, are summarized. Finally, additional considerations for estimating benefits on the Los Angeles region are listed. We do not provide for development of a specific methodology, but provide resources for methodologies that could be implemented.

Improved bicycle count data in the Los Angeles region will provide certain benefits for travel demand modeling. It will be some time before the bicycle data is comprehensive enough to fully inform a travel model calibration representing all decisions related to bicycle travel. However, focused bicycle count data at a specific cordon, screenline or activity center could be used to calibrate models to represent special circumstances influencing bicycle travel (for example, at a college) or to provide model validation targets at a specific geographic location.

SCAG and Metro are currently improving the representations of bicycle travel in their regional travel demand models, and could consider building on methods tested and implemented at other agencies such as Portland Metro and San Francisco MTA.

A number of planning tools have been implemented to test various benefits of non-motorized travel, including bicycle and pedestrian travel. One of these is the Bicycle Model being developed for Los Angeles Metro, separate from but complementary to the regional travel demand model process.

Some of these tools estimate increases in bicycle demand in response to facility and land use changes, while others start with an estimate of bicycle travel and quantify expected benefits. Benefits considered include health benefits to the bicyclists themselves, safety considerations, and more global benefits related to reduced vehicle-miles of travel (VMT) and corresponding reductions in greenhouse gas (GHG) emissions.

Several prior studies have identified and quantified considerations related to VMT reduction and associated health benefits, both generally and in the Los Angeles region. Further quantification of benefits of bicycle travel can draw from the findings of these studies to derive factors specific to the Los Angeles region.

INTRODUCTION

The SCAG Bike Count Data Clearinghouse study is primarily focused on data collection and development of an accessible database of bicycle volumes data. An additional task, Task 5, is intended to identify tools for estimating benefits of bicycle travel. The following issues were considered:

- Identify an existing tool that can be documented and/or modified, or develop such a tool, to determine reductions in vehicle-miles of travel (VMT) and greenhouse gases (GHG) from bicycle use.
- Evaluate reductions of VMT and GHG from bicycling trips as well as trips where bicycling is connected to transit.
- For the bike/transit trips, identify if bike/transit trips would replace auto-access transit trips or auto-only trips.
- Identify economic costs and benefits associated with reducing single-occupant vehicle trips and VMT/GHG.
- Identify ways to interface bicycle data with the SCAG Travel Demand Model.

Development or modification of tools was not possible within the limited scope and resources for this task. Therefore, this memorandum focuses on identification of issues and available tools that may be considered for further adaptation. The following sections describe potential uses of bicycle data for travel demand modeling, potential modifications to travel demand modeling in the SCAG region, and various planning tools that have been developed to identify benefits of bicycle travel.

USE OF BICYCLE DATA FOR TRAVEL MODELING

As bicycle data collection and availability increases, that data may be used to augment travel modeling capabilities in several ways, including:

1. Potential uses of data for model calibration and validation
2. Potential uses of data for model applications

Bicycle Data for Model Calibration and Validation

Bicycle volume counts at selected locations in a region may have limited applicability for calibration and validation of travel models. However, bicycle counts with comprehensive coverage of most significant routes crossing a cordon or screenline could provide useful information for travel model enhancement.

Travel Model Calibration

Calibration of travel demand models involves estimation and adjustment of coefficients used to calculate travel demand and route choice.

Mode Choice Models

Calibration of a mode choice model requires detailed data on selected travel modes and how they correlate with socioeconomic characteristics and activities related to trip purposes. These data cannot be derived from counts, and generally require some type of interview survey such as a household activity survey. A bicycle count database has limited applicability to this type of model calibration. However, mode choice models sometimes require additional parameters for special trip types such as student trips at a university. Comprehensive data on bicycle travel relative to other modes (auto, walking, transit) at significant points around or within a university campus (or any other focused area with differing levels of bicycle travel) would provide additional calibration targets for mode choice parameters related to those unique land uses.

Bicycle Route Choice

Another potential use for bicycle counts would be calibration of a bicycle route assignment model. Most travel demand models do not assign bicycle travel to the road network, although that is an enhancement that is being considered for implementation in some travel models. Traditional vehicle traffic assignment models are based on travel time and congestion levels, and do not generally consider issues of importance to bicyclists such as safety or grades. A bicycle assignment model would require additional parameters to represent route choice of importance to bicyclists. Bicycle counts on competing routes with different characteristics (traffic levels, grades, amount of separation between bicycles and autos) would be essential to calibrate models of these route choices.

Travel Model Validation

Validation of travel models generally involves using inputs representing existing land use and transportation network conditions, and comparing the model estimates of existing travel with observed conditions. In a typical model validation, the model's estimates of traffic volumes at specific locations would be compared to traffic counts, and the model's estimates of transit ridership on specific transit services or routes would be compared to ridership counts.

If a travel model implemented an assignment of bicycle travel to the road network, it may be possible to use a bicycle count database for validation of the bicycle assignment. However, this could only be done in locations where there is good coverage of bicycle counts on most significant routes crossing a cordon or screenline. With auto travel, a majority of traffic gravitates towards higher-speed higher-volume facilities such as freeways and major arterials, so a representative model validation can often be conducted with just traffic counts on these major roads. With bicycle travel, there is not necessarily a concentration of bicycle volumes on major roads, so it may be necessary to have better count coverage on local streets as well as major roads. It may be possible to focus bicycle count efforts on certain cordons or screenlines so that model estimates of bicycle travel can be compared to counts for selected subregions.

POTENTIAL TRAVEL DEMAND MODEL MODIFICATIONS

This section summarizes the existing representations of bicycle and pedestrian travel within travel demand models, looks at case studies from other regions that have expanded their bicycle modeling capabilities, and provides potential modeling considerations for SCAG and Metro.

Existing Modeling of Bicycle and Pedestrian Travel

SCAG Modeling

The current SCAG travel demand model, as used for the 2012 Regional Transportation Plan, is a trip-based model.[1] The mode choice component considers travel times and costs for a wide variety of modes, including drive alone, shared ride, eight types of transit service (five bus, three rail), and non-motorized (walk and bike). The maximum distance assumed for walk trips is three miles and the maximum distance for bike trips is 12 miles. The mode choice calibration targets, derived from household travel surveys and other sources, include values for separate bike and walk trips. However, the calibration was performed for combined non-motorized bike and walk trips. The model produces estimates of total non-motorized trips for each origin-destination combination. These non-motorized trips are not currently assigned to the network to estimate volumes.

SCAG is currently implementing a series of travel model improvements to transition from a trip-based model to an activity-based model.[2] With the activity-based model, trips are estimated for individual persons rather than trips based on aggregate demographics in each transportation analysis zone (TAZ). The activity-based model will allow SCAG to base travel estimates on much more detailed

[1] "SCAG Regional Travel Demand Model and 2008 Model Validation," June, 2012.

[2] Telephone conversation with Hsi Hwa Hu, SCAG, February 20, 2013.

demographics. This could in turn assist with better estimates of bicycle usage, as bicycle use can be correlated with the more detailed demographic characteristics.

For representation of bicycle networks, SCAG is still considering various options for improving the representation of policies such as bicycle lanes.

SCAG is also interested in a GIS-based scenario planning model to supplement the analysis available from the travel demand model. A scenario planning model could be used to test land use or transportation changes at a more general level without the detailed coding required for the travel demand model.

Los Angeles Metro Modeling

The travel demand modeling at Los Angeles Metro generates estimates of combined non-motorized (bike and walk) trips between each origin-destination pair, similar to the SCAG modeling. As at SCAG, Metro does not assign non-motorized trips to the model network to estimate volumes at specific locations.

Metro is continuing to work on improvements to their travel demand modeling.[3] These include consideration of more detailed TAZ systems, and representation of congestion pricing scenarios. They are looking into ways to represent bicycle and walking networks, including methods to incorporate slopes based on available GIS data.

In addition to travel demand model enhancements, Metro has worked on developing tools for bicycle modeling outside of the travel demand model environment. The tools provide estimates of project benefits without full travel demand modeling. Benefits are estimated based on reasonable average values, and can include reductions in congestion, VMT and GHG. One such planning tool is described in a later section.

Bicycle Modeling at Other Agencies

More and more agencies are taking strides to better represent bicycle travel in their travel demand models. This section briefly summarizes efforts in San Francisco and in the Portland Metro region.

San Francisco

The San Francisco County Transportation Authority (SFCTA) uses a tour-based model of each person's daily trips. San Francisco replaced the traditional four-step model with this tour-based model in order to be able to more effectively evaluate the effects of transportation policies, better understand multi-modal trip-making characteristics, and account for trip-chaining and time-of-day choices.

[3] Telephone conversation with Robert Farley, Metro, February 19, 2013.

The SFCTA recently developed a bicycle route choice model that has been integrated into their travel demand model, using citizen-generated data collected from smartphone users. The SFCTA developed a GPS-enabled smartphone app, CycleTracks, that citizens could use to record their bicycle trips within San Francisco, simply by turning on the app as they rode. The app generated approximately 5,000 bicycle trips that provided data about route choice, revealing a preference for bike lanes and gentle slopes. The data revealed no effect on route choice from traffic volumes, traffic speed, number of lanes, crime rates, or nightfall, and these attributes were not included in the model. The SFCTA thus integrated attributes of trip length, turns per mile, proportion of the route traveling the wrong way on one-way streets, proportion of the route on bike paths, bike lanes, and designated bike routes, slope, cyclist gender, and trip purpose (whether it was a commute), into a logit choice model that provides the bike route choice component of the travel demand model. Table 1 shows each attribute and the coefficients.

Table 1: SFCTA Bike Route Choice Model Attributes

Attribute	Coef.	SE	t-stat	p-val
Length (miles)	-1.05	0.09	-11.80	0.00
Turns per mile	-0.21	0.02	-12.15	0.00
Proportion wrong way	-13.30	0.67	-19.87	0.00
Proportion bike paths	1.89	0.31	6.17	0.00
Proportion bike lanes	2.15	0.12	17.69	0.00
Cycling frequency (< several per week)	1.85	0.04	44.94	0.00
Proportion bike routes	0.35	0.11	3.14	0.00
Average up-slope	-0.50	0.08	-6.35	0.00
Female	-0.96	0.22	-4.34	0.00
Commute	-0.90	0.11	-8.21	0.00
Log (path size)	1.07	0.04	26.38	0.00

This particular enhancement is for route choice only, and does not directly provide estimates of changes in bicycle travel demand due to changes in bicycle infrastructure or other policies.

Portland Metro

Metro, the Portland metropolitan region's Metropolitan Planning Organization, maintains the regional travel demand model, and has recently taken strides to integrate a bicycle route choice model into its four-step travel demand model. In 2007, Portland State University and OTREC led a data collection effort in which 126 participants were outfitted with GPS devices that recorded their bicycle trips, resulting in 1,449 usable observations.

From these data, researchers developed a logit choice model that revealed a preference for bicycle facilities, especially separated paths. The model considered the presence of bike lanes, paths, and boulevards, bike facilities on bridges (separated and not separated), trip distance, number of left turns, unsignalized crossings (with three ranges for traffic volumes), the proportion of the trip on roadways without bike lanes (with three ranges for traffic volumes), number of stop signs, turns, elevation gain, commute or non-commute trip type, and gender.

Metro has worked to integrate the findings from the PSU/OTREC research into the regional model both for mode choice and for route choice (once bicycle is chosen as the mode.) Table 2 shows the attributes and coefficients that go into the network utility expression for the bicycle route choice model.

Table 2: Portland Metro's Network Utility Expression Attributes

Attribute	Coef.
Links	
Bridge with no bike facility	-1.81
Bridge with no separated bike facility	-1.30
Proportion on bike boulevard	1.03
Proportion on bike path	1.57
Proportion with 2-4% upslope	-2.85
Proportion with 4-6% upslope	-7.11
Proportion with 6%+ upslope	-13.0
Proportion on AADT 10,000-20,000	
Commute	-2.82
Non-commute	-1.05
Proportion on AADT 20,000-30,000	
Commute	-7.88
Non-commute	-4.51
Proportion on AADT 30,000+	
Commute	-18.89
Non-commute	-10.30
Distance (ln)	
Commute	-8.98
Non-commute	-5.22
Turns	
Left turns unsignalized on AADT 10,000-20,000 per mile	-.782
Left turns unsignalized on AADT 20,000+ per mile	-1.87
Left or through at signal per mile	-.186
Stop signs per mile	-.0483
Left or right turns per mile	-.371
Right unsignalized crossing AADT 10,000+ per mile	-.338
Left or Through Unsignalized AADT 5,000-10,000 per mile	-.363
Left or Through Unsignalized AADT 10,000-20,000 per mile	-.516
Left or Through Unsignalized AADT 20,000+ per mile	-2.51

Potential Modeling Considerations for SCAG/Metro

Improvements to representation of bicycle and walk travel in travel models for the Southern California region would require commitment to several major data tasks.

An initial step would be to separate the modeling of bicycle and walk trips, rather than using a combined non-motorized mode. Enhancement of the mode choice estimates could then involve one or more updates to network attributes. Separate links could be coded for connections that are only accessible to bicycle and/or pedestrian travel. Additional detail could be added for bicycle facilities on streets, indicating whether bicycles are able to use a separate bike path (Class I), a bike lane (Class II) or a designated route shared with auto traffic (Class III). Another category of network detail would be information on slopes, which can be derived from GIS topographic information but would have to be mapped onto individual network links. All of these network enhancements would enhance the ability of the travel model to assess benefits of bicycle and pedestrian facilities for both the mode choice and trip assignment steps.

The agencies could also determine if it is desirable to implement a bicycle trip assignment process. Due to the large scale of the SCAG and Metro travel demand models, they do not inherently contain all of the local streets that are used for bicycle travel, so a bicycle trip assignment process may only be useful for general flows between areas. If a bicycle trip assignment step is implemented, some of the logic could be adapted from the processes tested in San Francisco and Portland.

PLANNING TOOLS FOR BENEFIT EVALUATION

Regions and jurisdictions may be able to use bicycle ridership data to refine and augment their travel demand models, as explained above. In addition to forecasting trip-making characteristics at the regional level of a travel demand model, there are other sketch planning tools that can help jurisdictions evaluate impacts of installing bicycle infrastructure, health impacts of increased physical activity, and potential emissions reductions due to mode shifts.

This section explores recently available methods, with a focus on those that have based their methods on a review of the previous efforts documented in the literature. It is structured to emphasize methods that are tool-based. For these tools, it outlines the user data inputs, the model outputs, the basic methodology and assumptions of the model, applications of the tool, and in some cases, results of studies that have used the methodology. The tools/models reviewed include:

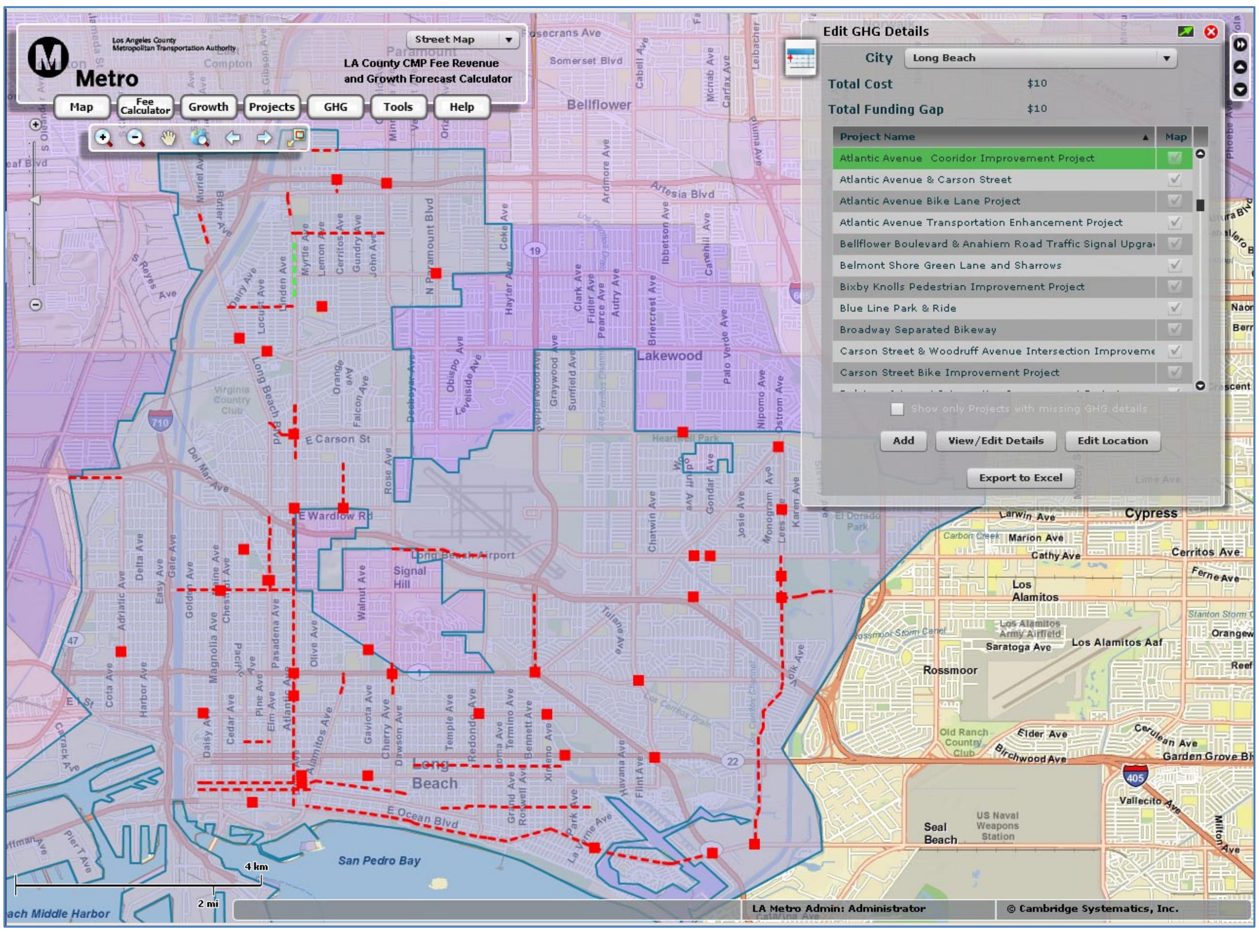
- Metro Bicycle Investment Scenario Analysis Model
- Integrated Transportation and Health Impact Modeling Tool (ITHIM)
- Health Economic Assessment Tool (HEAT)
- NCHRP 552 Bike Cost Tool
- Quantifying the Cost of Physical Inactivity
- California Air Resources Board method for calculating emissions reductions
- Rojas-Rueda, et al method for quantifying benefits from a bikeshare system

These tools are reviewed because they attempt to measure the impacts of increased bicycle activity or improved bicycle infrastructure. Other closely-related tools that are not reviewed in this section include tools that model impacts of different land use patterns, such as Urban Footprint, Envision Tomorrow, the Sustainability Planning Tool and I-PLACE3S.

Metro Bicycle Investment Scenario Analysis Model

Developed for the Los Angeles County Metropolitan Transportation Authority by Cambridge Systematics, this tool forecasts the estimated change in bicycle travel resulting from one or more bicycle investment projects (Figure 1). Users input bikeway project locations on a map and assign basic attribute information, then run an analysis that draws from socio-demographic, land use, and facility information in the project's proximity to estimate potential new bicycle trips by purpose (work, non-work utilitarian and recreational). A scenario analysis component allows the user to estimate benefits resulting from packages of bikeways, bike parking and/or bike sharing projects across four performance categories: mobility, environment, economic, and public health.

Figure 1: Example Screen from Metro Sketch Planning Tool



Tool User Inputs

- Project location (drawn on a map)
- Project type (bikeway, transit bike parking, worksite bike amenities, or bike sharing)
- Project cost
- Project-specific details, such as the type of bicycle facility (separated path, lane, cycle-track, or bike boulevard) or type of workplace amenities (secure parking, showers)

Tool Outputs

The tool produces measures across four performance categories as follows, comparing future scenarios with and without the projects constructed:

Mobility:

- New bicycle trips by purpose (work, non-work utilitarian, recreational)
- New bicycle miles traveled by purpose
- Estimated impact on vehicle hours of delay

Economic:

- Household vehicle operating cost savings

Environment:

- Reduction in greenhouse gas emissions
- Value of reduction in criteria pollutant emissions

Public Health:

- Value of health benefits due to increased physical activity.

Methodology

The model consists of (1) a logistic regression model that forecasts new utilitarian bike trips resulting from bikeway facility expansion; and (2) a two-step binary logit and linear regression model that forecasts new recreational bike trips resulting from bikeway facility expansion. Models were developed based on 2011 Los Angeles County American Community Survey (ACS) data and 2009 Los Angeles and Orange County National Household Travel Survey (NHTS) data, which revealed relationships between land use, socio-demographic data, existing facilities, and propensity to bicycle.

Benefits are estimated based on forecasts of new bike trips generated by the utilitarian and recreation trip estimation models. The model also includes sketch estimation of travel changes due to bike parking facilities, worksite bike amenities (lockers, showers), and bike sharing programs based on national research.

Applications

Agencies can use this tool to approximate local demand for bike facilities and to forecast a range of co-benefits to help prioritize a diverse range of bicycle investments. At the current time, the model is set up for sensitivity at the census tract level, but Metro is considering moving to the census block level to allow for more fine-grained analysis.

Integrated Transport and Health Impact Modeling Tool (ITHIM)

Several recent studies have employed the Integrated Transport and Health Impact Modeling Tool (ITHIM) to estimate health impacts due to increased active transportation. ITHIM was developed at the Centre for Diet and Activity Research, a research center at the University of Cambridge in the United Kingdom. It has been used to model health impacts in England,[4] California's Bay Area,[5] and Oregon.[6]

Tool User Inputs

The ITHIM tool currently is in a spreadsheet format. Figure 1 shows the user-input screens from the Bay Area-specific model.

- Age-sex population distribution in the study area.
- Age-sex specific rates of deaths and disability-adjusted life-years for a comprehensive set of causes within the study area (data from the Global Burden of Disease database).
- Road traffic severe injuries and deaths from the study area, with details about crash parties.
- Travel distances, travel times, and speeds by mode (sources for this type of data include travel surveys, regional travel demand models, census data, studies on average bicycling or walking speeds).
- Non-transportation physical activity time.
- Particulate matter concentration for the study area.

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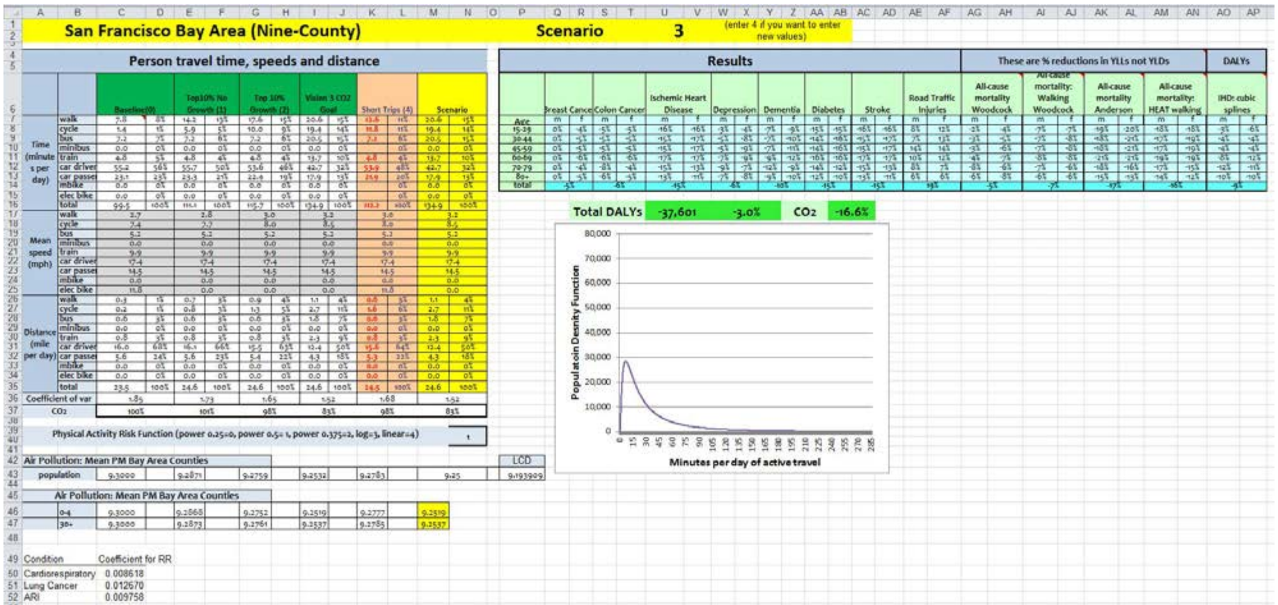
[4] Woodcock, Givoni, and Morgan. 2013. *Health Impact Modelling of Active Travel Visions for England and Wales Using an Integrated Transport and Health Impact Modeling Tool (ITHIM).* PLoS ONE.

[5] Maizlich, Woodcock, Co, Ostro, Fanai, and Fairley. 2013. *Health Cobenefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the San Francisco Bay Area.* American Journal of Public Health, Vol 103, No. 4.

[6] Oregon Health Agency and Metro. Forthcoming.

Figure 2: Example Input Pages for the ITHIM Model



Tool Outputs

- Disability-adjusted life years (DALYs) gained or lost due to three factors:
    - Levels of physical activity
    - Traffic-crash related injuries and deaths
    - Particulate matter exposure

Methodology

ITHIM uses comparative risk assessment (CRA) to estimate health impact, breaking down impacts based on three changing factors that come along with increased active transportation: changes in physical activity, risk of traffic injury, and air pollution. ITHIM does not assume a uniform intensity of activity, but instead measures activity in Metabolic Equivalents (METs). It assigns a level of intensity in METs based on observed walking speeds across different age groups and assumes an intensity of 6.8 METs (bicycling 10-11.9 mph, a slow, light effort) for all bicycling activity. In addition to incorporating age into the calculation of METs, ITHIM applies benefits to the population based on the age/sex distribution. The final outputs of the model are estimates of health benefits in disability-adjusted life years (DALYs); ITHIM stops short of converting the health benefits to economic terms.

Applications

In existing studies, ITHIM has been used to evaluate the health impacts of future scenarios for metro regions that include specified levels of active and other forms of transportation. As such, and in its current form, it is a useful complement to a travel demand model that forecasts mode shifts and changes in travel distance.

ITHIM currently is a spreadsheet tool requiring fairly extensive manual inputs, but it is undergoing iterations and is expected to be available as an online tool later in 2013. To date, it has been used at the regional level, but developers are exploring ways to apply the model at a community level as well.

Results: *Examples of Existing Studies*

In *Health Co-Benefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the Bay Area*[7], the authors used the ITHIM model to evaluate future scenarios in the Bay Area, including a business-as-usual scenario, three variants of increased active transportation mode split, and one that considers low-carbon driving (assuming advances in and adoption of low-emissions technology).

The data that authors used as inputs to the ITHIM model include:

- Age-sex specific mortality rate ratios of Bay Area and U.S. for particular diseases.
- Road traffic injuries from the Statewide Integrated Traffic Records System.
- For travel distances, travel times, and speeds for each of the various scenarios, authors used data from a number of sources, including the Bay Area Travel Survey, the Statewide and MTC travel models, the Census and American Community Survey, the California Health Interview Survey, and literature on the average speeds of walking and bicycling.
- Non-transportation physical activity time, from the California Health Interview Survey.
- Carbon emissions from the MTC model.
- Particulate matter concentration from the Bay Area Air Quality Management District air shed model and the Emissions Factors (EMFAC) model from the California Air Resources Board.

The study found a reduction in disease burden across all diseases for the active transportation scenarios, ranging from 2-15%, with the highest reduction in premature deaths due to decreased risk of cardiovascular disease. The reduction in disease burden due to increased physical activity accounted for a large majority benefits (>99%); less than 1% of health benefits came from reduced air pollution. This study found that forecasted injuries and deaths from traffic collisions *increased* with higher levels of active transportation in the Bay Area.

In *Health Impact Modelling of Active Travel Visions for England and Wales Using an Integrated Transport and Health Impact Modeling Tool,*[8] the authors used the ITHIM model to determine the health benefits of three hypothetical future scenarios that include increased levels of walking and cycling, in addition to a baseline scenario.

The data that authors used as inputs to the ITHIM model include:

- Levels of walking and cycling from "best practices" European cities, in order to inform the levels of active transportation in future scenarios.
- UK National Travel Surveys, the London Travel Demand Surveys, and the Netherlands Travel Survey were used to estimate the time walking and cycling by age and sex, total active travel time, and METs.
- The Health Survey of England to estimate non-travel related physical activity.
- Road traffic injuries from the UK Police data from Stats19 database.
- Particulate matter concentration rates from the Department for Environment, Food, and Rural Affairs.
- Great Britain Transport Statistics.

This study quantified the benefits from the increased mode split of active transportation for the three scenarios. It found an increase in DALYs in the three scenarios (all of which increased active transportation) of between 3800 and 8700 per million population. Of these, 85-90% of the DALYs were attributable to reduced disease burdens due to increased physical activity. About 2-3% of the health benefits were attributed to reduced air pollution, and 8-13% were due to decreased traffic injury risk.

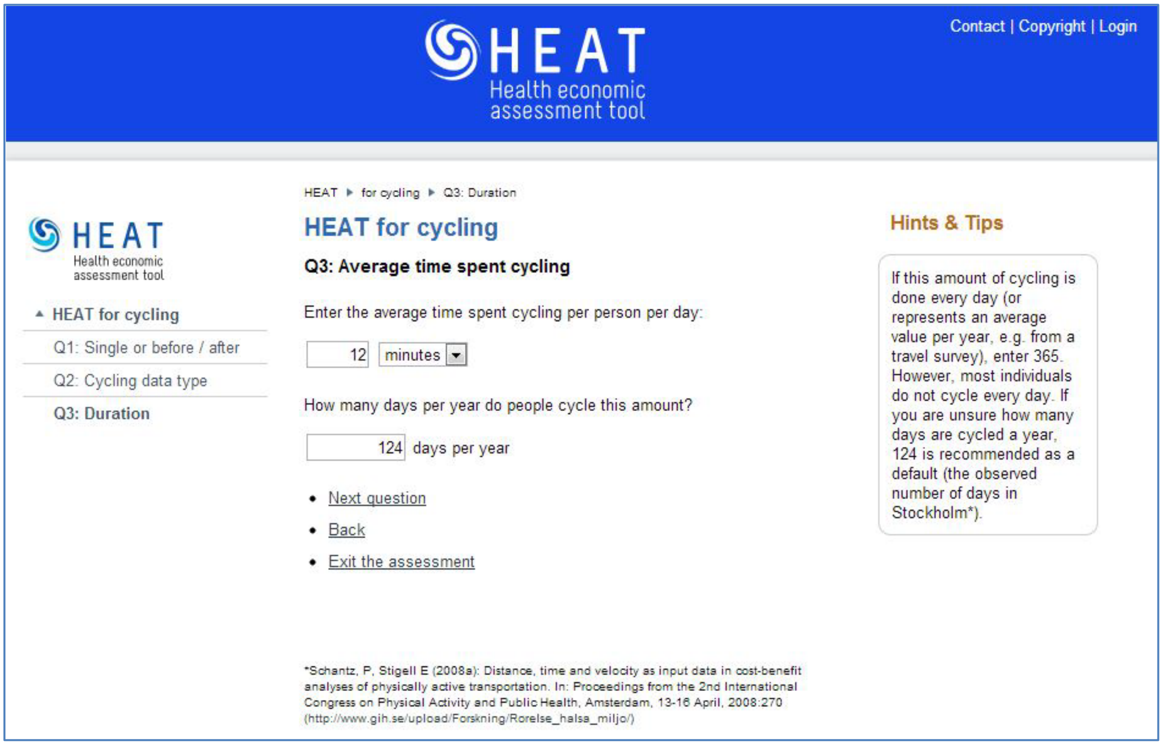
Health Economic Assessment Tool (HEAT)

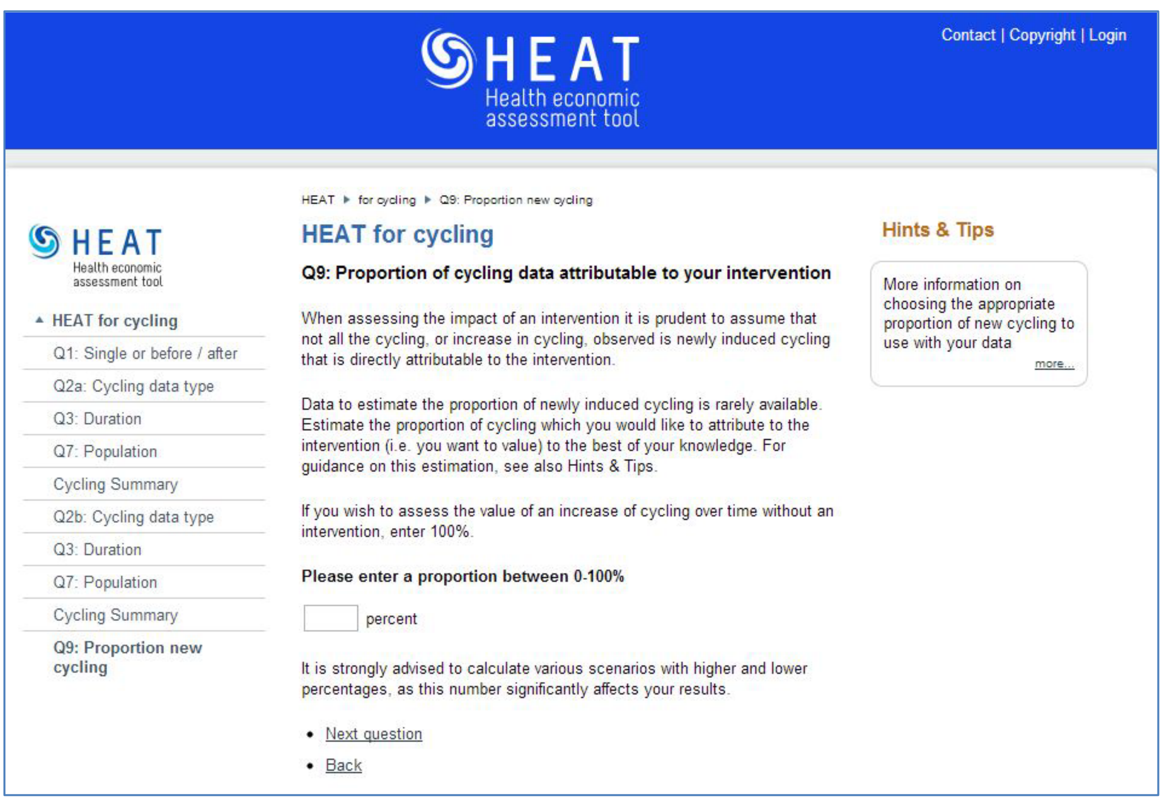
Developed by the World Health Organization, the Health Economic Assessment Tool (HEAT) for walking and cycling is the most widely used tool for quantifying benefits of walking or cycling. The tool, available online,[9] provides a user-friendly interface that estimates the health benefits resulting from walking and cycling. Figure 3 shows two example screens with user questions from the online tool.

[8] Woodcock, Givoni, and Morgan. 2013. *Health Impact Modelling of Active Travel Visions for England and Wales Using an Integrated Transport and Health Impact Modeling Tool (ITHIM).* PLoS ONE.

[9] See www.heatwalkingcycling.org

Figure 3: Example Questions from the HEAT Online Tool





Tool User Inputs

- The actual number of people in the cycling population.
- The amount of time, the distance, or the number of trips that the study population completes on a bicycle.[10]
- Time needed to reach full benefits of increased cycling.[11]
- Time period over which to calculate the benefits (default value is 10 years).
- Value of a Statistical Life (VSL) for the user country, region, or study area.
- All-cause mortality rate for the user country, region, or study area.[12]
- Discount rate. If *future* benefits are being estimated, the tool uses a discounting factor in calculating those benefits, a standard method in economic analysis.[13]
- Cost of a project or investment to increase bicycling (optional).

Tool Outputs

Figure 4 shows an example of the final output screen from the HEAT for cycling tool.

- Annual health benefits in economic terms (dollars or other currency), based on the assumed value of a statistical life (VSL).
- Total benefits over the user-specified time period.
- Discounted benefits according to the user-specified discount rate.
- Benefit cost ratio (if user enters the cost of a project or investment).

Methodology

In the process of developing the tool, the development team did an extensive literature review to assess previous methods of valuing the health benefits in economic impact analyses of transportation investments. They found 16 applicable papers that they included in a meta-analysis, finding a median benefit-cost ratio of 5:1 for active transportation investments. However, the team found a wide variation in methodologies and a general lack of transparency among the studies. They developed the HEAT methodology in collaboration with a broad international base of expert advisors from governments, research institutions, and private practices.

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[10] Ideally this data will come from a long-term data source that represents an average level of cycling.

[11] In evaluating the effect of interventions or investments, the tool considers that changes to behavior and health effects take place over a period of time, and the user is able to enter the assumed amount of time before the full benefits are realized.

[12] The tool includes all-cause mortality rates for European countries; users from other countries can input mortality rate data manually. Future refinements to HEAT may include morbidity as an additional measure to broaden the usefulness of the tool.

Figure 4: Example HEAT Tool Outputs

Financial savings as a result of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: **1,574,000 EUR**	
*Based on a **5** year build up for benefits, a **1** year build up for uptake of cycling, and an assessment period of **10** years:*	
the average annual benefit, averaged over **10** years is:	**50,000 EUR**
the total benefits accumulated over **10** years are:	**496,000 EUR**
the maximum annual benefit reached by this level of cycling, per year, is:	**67,000 EUR**
This level of benefit is realised in year **7** when both health benefits and uptake of cycling have reached the maximum levels.	
When future benefits are discounted by **5** % per year:	
the current value of the average annual benefit, averaged across 10 years is:	**36,000 EUR**
the current value of the total benefits accumulated over 10 years is:	**361,000 EUR**

Benefit–Cost Ratio

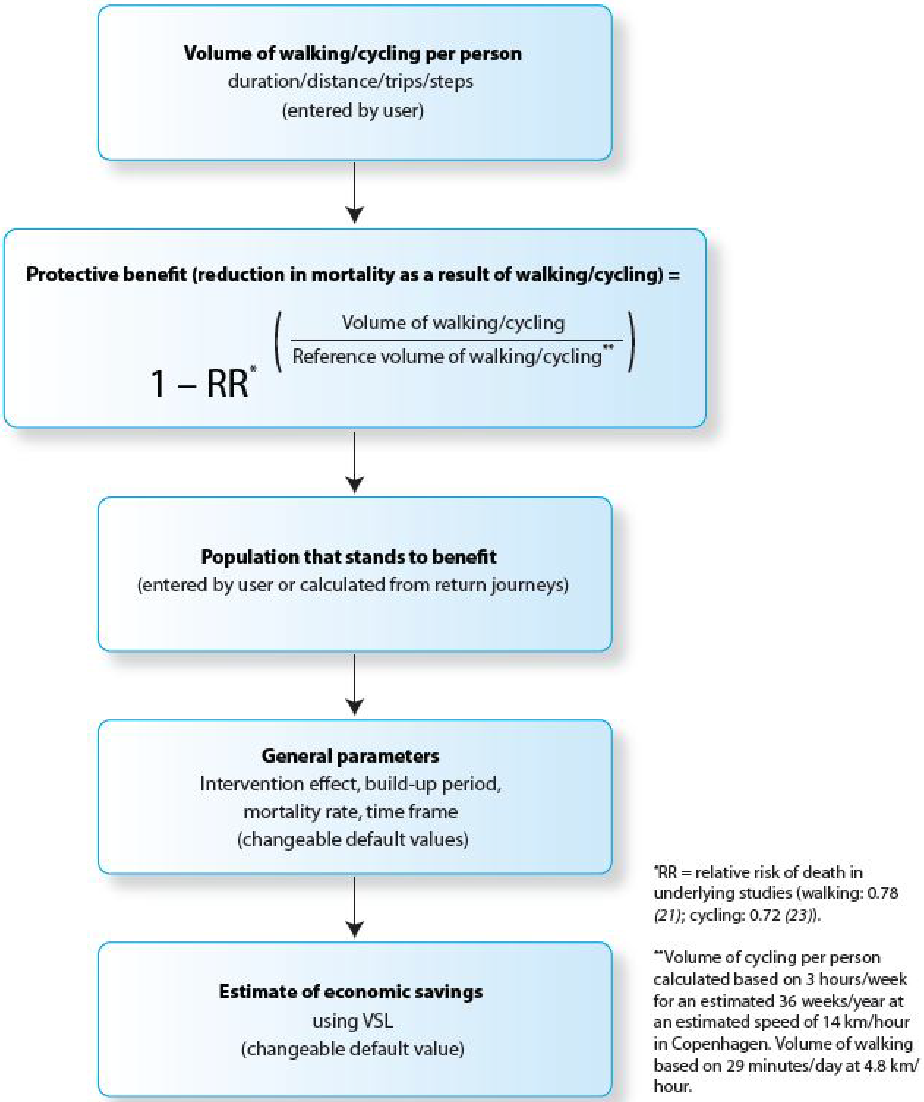
The total costs of:	**15,000 EUR**
Should produce a total saving over **10** years of:	**361,000 EUR**
assuming **5** year build up of benefits, **1** years build up of uptake, and discounting of **5** % **per year**	
The benefit to cost ratio is therefore:	**24.07:1**

Key data and assumptions that HEAT uses in calculations:

- HEAT assumes a consistent dose-response rate for the health benefits associated with increased physical activity. It does not differentiate for the level of intensity of activity, the age/gender of the participants, or for the fitness levels of the participants.
- HEAT calculates benefits for an adult population. The model assumes that 100% of the population in the user-input data is adult.
- HEAT assumes a relative risk of all-cause mortality for levels of walking and for cycling based on prior studies. It assumes a relative risk among regular cycling commuters (at a level of three hours per week, 36 weeks per year) of 0.72, compared to the non-cycling population – meaning that people cycling at this level are 28% less likely to die from all causes than the non-cycling population.
- HEAT assumes a log-linear relationship between the time spent cycling and the risk reduction, and caps the risk reduction at 50%, which is the highest observed level in the currently available studies.
- HEAT assumes that increased active transportation does not change the amount of time people spend doing non-travel related physical activity.

Figure 5 shows the function of the HEAT calculations, given the data and assumptions above.

Figure 5: HEAT Tool Process



Applications

The HEAT for cycling tool has three primary applications:

- To assess the actual or forecasted health impacts of an increase in active transportation due to infrastructure or programming investment over time (using before and after data).
- To quantify the health benefits of the existing levels of cycling or walking in a population.
- As a component of a more comprehensive health-economic assessment.

The tool does *not* estimate the levels of ridership that can be expected from an investment in infrastructure or programming.

NCHRP 552 Bike Cost Tool

NCHRP 552 *Guidelines for Analysis of Investments in Bicycle Facilities* (2005) provides guidance on estimating bike facility costs, forecasting demand for bicycling, estimating benefits associated with using bike facilities, and doing benefit-cost analyses of bicycle facilities.

The research in NCHRP 552 provided the basis for development of a sketch planning tool for estimating the costs, demand in terms of new cyclists, and economic benefits from building a new bicycle facility. The tool is available at www.bicyclinginfo.org/bikecost.

Tool User Inputs

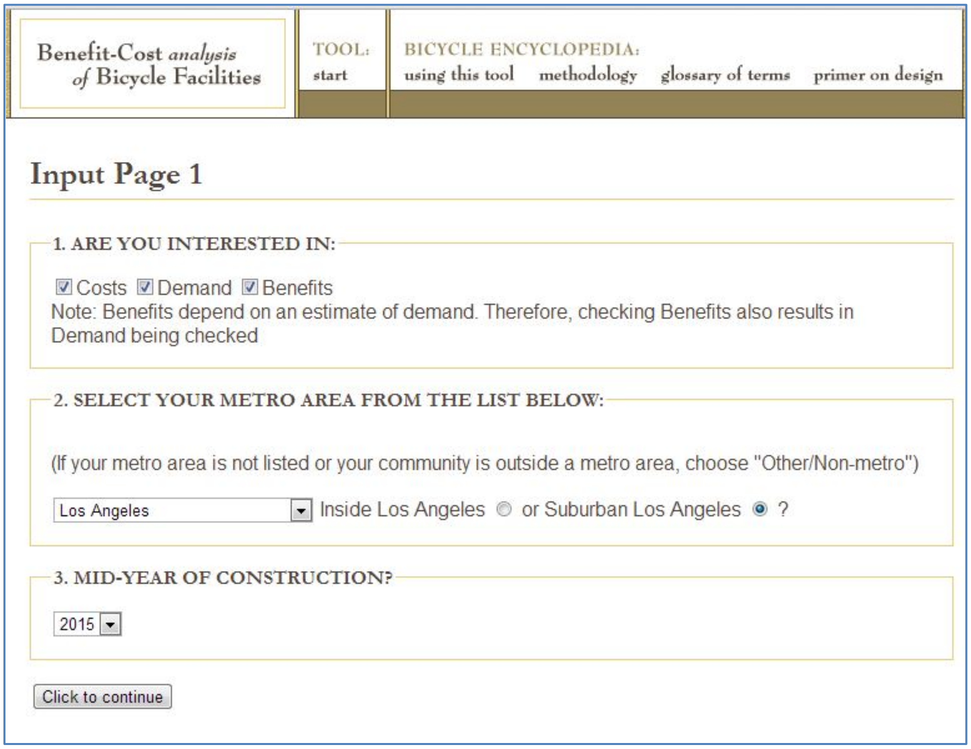
Figure 6 shows some of the example questions from the online tool. The complete list of questions includes:

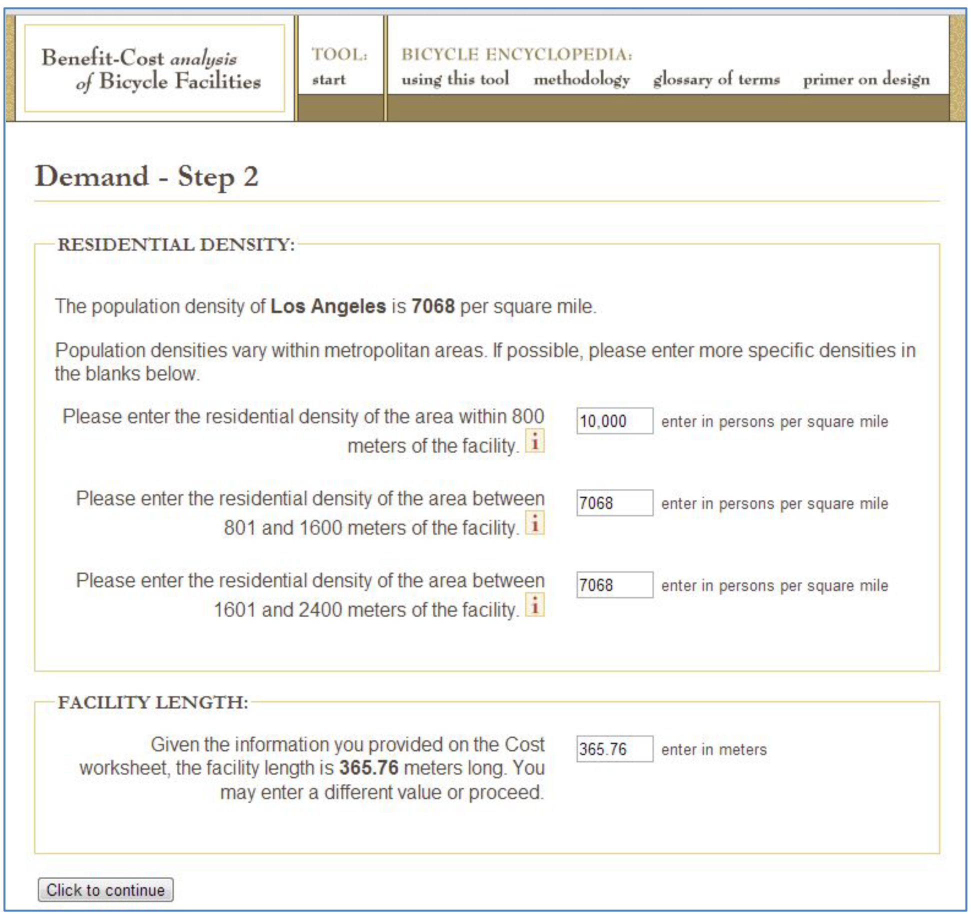
- The metropolitan region of the bicycle facility, and whether it is located in an urban or suburban part of the metro area
- Anticipated year of construction
- Facility type
    - bike lane with parking
    - bike lane without parking
    - off-street bike trail
- Facility Length
- Bicycling commute mode share in the study area[14]
- Residential density of the area surrounding the facility. The model includes the population density of the overall metropolitan region, but suggests using specific measured inputs for the residential density within 800, 1600, and 2400 meters of the facility, given a high level of variance across metro regions
- Improvement type (for estimating costs)
    - e.g. restripe v. new pavement for an on-street bike lane
    - e.g. asphalt v. concrete for a new off-street trail
- Length and width of facility area to evaluate excavation cost, curb removal, grading, and materials cost
- Standard cost of materials[15]

[14] The tool provides a commute share from the 2000 census, but allows the user to input a more recent or accurate figure, if known.

[15] The tool provides materials cost estimates based on 2002 rates, but allows the user to input more recent or metro area specific cost figures.

Figure 6: Example Questions from NCHRP 255 Bike Cost Tool





Tool Outputs

Figure 7 shows an example final output screen from the NCHRP 255 model:

- Cost estimate for the construction and annual operations and maintenance of the facility.
- Low, mid, and high estimates for the demand within 1.5 miles, including residents, existing commuters, new commuters, total existing cyclists, and total new cyclists.
- Monetary benefits from the facility based on increased mobility, health, recreation, and decreased auto use (in terms of decreased congestion, decreased air pollution, and user cost savings).

Figure 7: Output from NCHRP Benefit-Cost of Bicycle Facilities Tool

Benefit-Cost *analysis* *of* Bicycle Facilities

TOOL: start

BICYCLE ENCYCLOPEDIA: using this tool methodology glossary of terms primer on design

Demand and Benefits Results

Costs

Total build year capital cost	$136,655
Annual operations and maintenance	$0

Demand

In a one and half mile (2,400 m) radius around the proposed facility:

	Low Estimate	Mid Estimate	High Estimate
Residents	57,112	57,112	57,112
Existing Commuters	228	228	228
New Commuters	70	70	70
Total Existing Cyclists	800	9,983	14,963
Total New Cyclists	313	3,113	4,632

Annual Benefits

	Low Estimate	Mid Estimate	High Estimate
Recreation	$889,737	$11,109,007	$16,650,801

Mobility - Proposed Facility Type	Per Trip	Daily	Annually
Bicycle lane with parking	$3.17	$945	$222,066

	Low Estimate	Mid Estimate	High Estimate
Health	$40,117	$398,491	$592,833
	Urban	**Suburban**	**Rural**
Decreased Auto Use	$967	$595	$74

Methodology

Cost:

In providing a cost estimate, the model can provide a sketch cost estimate drawing only on the user inputs of the facility type and size, and using default materials costs (as released, based on 2002 data). It produces a more accurate cost estimate with further user inputs regarding the local cost of materials.

Demand:

- The tool assumes that all existing bicyclists that currently use a route near the planned new facility will shift their route to use the new facility.
- Existing levels of bicycling are estimated using U.S. Census journey-to-work data for the low estimate and a function of the Census journey-to-work data for the moderate and high estimates, based on a comparison with the National Household Transportation Survey (explained in Appendix A of NCHRP 552).
- The tool assumes that new bicyclists will be induced to start riding, and that this number can be estimated based on the number of existing cyclists and the number of residents living within an 800, 1600, and 2400 meter buffer around the new facility.

Benefits:

- The method assumes a **mobility** benefit for bicycle commuters with the addition of a new bike facility. Appendix D of NCHRP 552 discusses the research that indicates people will spend extra time during their commute to travel to a route that has an off-street bicycle trail or bicycle lane. Using $12/hour as the value of time, the "mobility benefit" is calculated using a per-trip benefit of monetary savings based on time savings.
- The model calculates **health** benefits simply, using a per-capita cost savings of $128 per new bicyclist, based on a compilation of studies done in the US that estimated the annual per capita cost savings of physical activity. The studies' estimates ranged from $19 to $1175 in annual savings with an average of $128, and are listed in Appendix E.
- The model also accounts for **recreation** benefits from non-commute use of the new facility, based on studies showing a benefit of $40 (in 2004 dollars) for a day with 4 hours of recreation.
- The model calculates a **decreased auto use** benefit based on non-recreational trips on the facility. This benefit is comprised of reduced congestion, reduced air pollution, and user cost savings. The model finds a savings per mile of $0.13 in urban areas, $0.08 in suburban areas, and $0.01 in small towns or rural areas, accounting for the fact that some areas are not congested and therefore have no benefit from reduced congestion, and that benefits from reduced pollution are greater in more densely populated areas.

Applications

The NCHRP 552 Bike Cost tool can be used to assess the costs, bicyclist demand, and benefits from a new bicycle facility. It can be used to compare the costs and potential benefits of different facility investments in order to prioritize implementation in a particular region.

Quantifying the Cost of Physical Inactivity

The Department of Health Education & Promotion at East Carolina University, with support from the Centers for Disease Control and Prevention, has created an online tool[16] that estimates the economic costs of physical inactivity in a particular community or other unit of interest.

Tool User Inputs

The online tool requires inputs to respond to questions (Figure 8).

- State of study population
- Number of adults (people over 18) in the study population
- Number of working adults
- Percentage of adults 65 or older
- Median per capita salary of workforce
- The inactivity rate for the study population[17]

Tool Outputs

The model produces costs estimates that are attributed to a lack of physical activity in the study population. In theory, these are costs that would be avoided if the study population engaged in regular physical activity. Figure 9 shows an example of the tool output, including:

- Medical care costs due to physical inactivity
- Workers compensation costs
- Lost productivity costs

[16] http://www.ecu.edu/picostcalc/

[17] The default inactivity rate in the model is based on data from the Center for Disease Control for the selected state. The user can adjust this rate if they have more specific data.

Figure 8: Questions from Physical Inactivity Cost Calculator

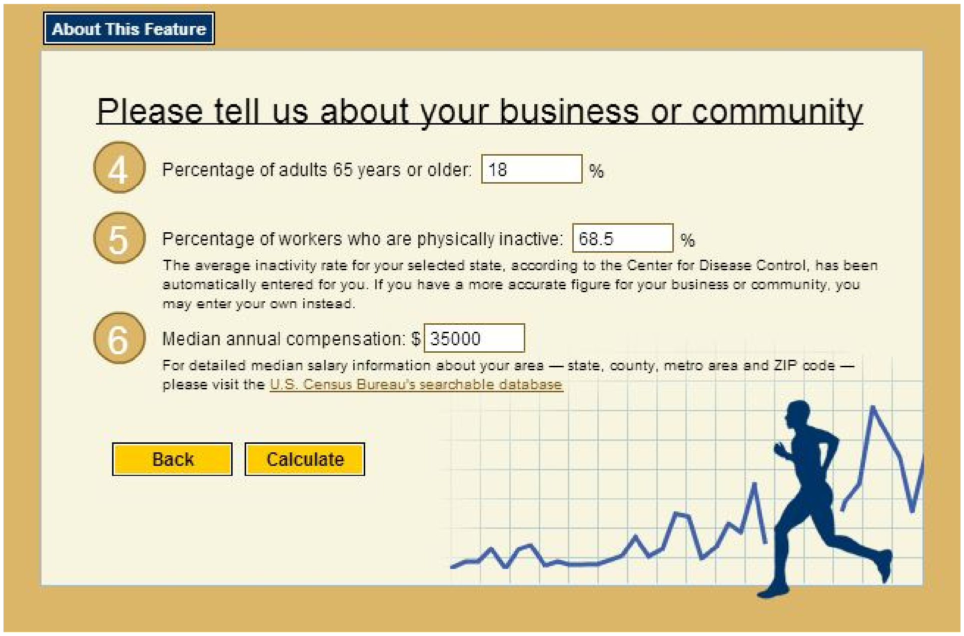


Figure 9: Example Cost Estimate Output from Physical Inactivity Calculator

Methodology

The tool defines "inactivity" as "less than 30 minutes of moderate physical activity most, if not all, days of the week." The model calculates each component of the costs separately, relying on the Surgeon General's Report on Physical Activity, the Workers' Compensation Research Institute, and the Journal of Occupational & Environmental Medicine to formulate the calculations for each component. The authors of the tool noted that the reliability of the tool varies across the three cost realms based on the level of the scientific research available, as follows:

- Medical care costs – Significant scientific evidence
- Workers Compensation Cost – Moderate scientific evidence
- Lost Productivity – Emerging scientific evidence

To calculate the medical care costs due to physical activity, the model development team identified conditions that were conclusively associated with physical activity, and then analyzed the actual medical care costs associated with treating those conditions based on data from seven states. They adjusted these costs based on the risk factor that physical inactivity contributes – i.e. a lack of physical activity contributes about 8% of all risk for cancer, based on their meta-analysis of medical research.

For workers compensation, the model uses data from the same seven states to calculate workers comp costs based on workers' salaries for strains and sprains – a type of injury that is associated with physical inactivity.

The lost productivity component is calculated using data for hours of absenteeism and "presenteeism" (attending work while sick) from actual worksite studies, and draws on median compensation data from each of the seven states' labor or commerce departments. The study team notes that they were able to draw on only two studies regarding presenteeism costs, as this is a relatively new area of study, and thus the results for lost productivity should be treated as a rough estimate only.

Applications

This tool can be used to estimate a monetary benefit that could be realized by increasing the physical activity levels of a particular population. For example:

- Employers can use the tool to evaluate the potential savings due to physical activity among employees as part of a cost-benefit analysis for implementing active transportation programs.
- Planners and policy makers can use to tool to quantify the economic benefits of a forecasted or measured increase in activity due to increasing the active transportation mode split.

California Air Resources Board Bicycling Benefits

In their May 2005 Guide, *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects,*[18] the California Air Resources Board outlines a method for estimating the vehicle trips converted to cycling and the emissions reductions from the installation of a new bike facility. With this information, they come to a measure of cost-effectiveness for the project. This methodology does **not** estimate the health effects of mode shifting to active transportation.

Tool User Inputs

Data required for estimate:

- Funding dollars
- Number of operating days per year
- Average length of bicycle trips
- Average daily traffic volume on roadway parallel to bicycle project
- City population
- Project class (bike lane or off-street path)
- Number and types of activity centers in the vicinity of the bicycle project
- Length of bicycle path or lane

[18] California Air Resources Board and Caltrans. 2005. *Methods to Find the Cost-Effectiveness of Funding Air Quality Project, for evaluating motor vehicle registration fee projects and congestion mitigation and air quality improvement (CMAQ) projects.*

Tool Outputs

The methodology produces an estimate of changes attributable to a new facility, including:

- Number of auto trips/year reduced
- Vehicle miles traveled reduced per year
- Annual emissions reductions
- The capital recovery factor
- The cost-effectiveness of funding dollars in terms of emissions reductions only.

Methodology

The Guide uses adjustment factors based on the length and class of the bike facility and the ADT of the parallel roadway, and the method applies these factors to the calculations. The factors are different for university towns with a population of less than 250,000, based on research showing higher levels of cycling in these towns (FHWA National Bicycle and Walking Study, 1992). The Guide also gives factors for activity centers credits and emissions. Finally, it provides formulas to calculate the auto trips reduction, VMT reductions, the emissions reductions, and the cost-effectiveness, shown here. Figure 10 shows the tables with adjustment factors used in this method.

Formulas	Units
Annual Auto Trip Reduced = (Days) * (ADT) * (Adjustment factor on ADT for auto trips replaced by bike trips from the bike facility + Credit for Activity Centers near the project)	trips/year
Annual Auto VMT Reduced = (Auto Trips) * (Length)	miles/year
Annual Emission Reductions (ROG, NOx, and PM10) = [(Annual Auto Trips Reduced)*(Auto Trip End Factor) + (Annual Auto VMT Reduced)*(Auto VMT Factor)]/454	lbs/year
Capital Recovery Factor (CRF) = $\frac{(1+i)^n (i)}{(1+i)^n - 1}$ where: *i* = discount rate (Assume 3 percent) n = project life	
Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)	dollars/lb

Figure 10: Factors from California Air Resources Board Methodology

ADJUSTMENT FACTORS				
BIKE FACILITY CLASS	AVERAGE DAILY TRAFFIC (ADT)	LENGTH OF BIKE PROJECT (one direction)	ADJUSTMENT FACTORS FOR CITIES WITH POP. ≥ 250,000 and non-university towns < 250,000	ADJUSTMENT FACTORS FOR UNIVERSITY TOWNS WITH POP. < 250,000
Class 1 (bike path) & Class 2 (bike lane)	ADT ≤ 12,000 vehicles per day	≤ 1 mile	.0019	.0104
		>1 & ≤ 2 miles	.0029	.0155
		> 2 miles	.0038	.0207
Class 1 (bike path) & Class 2 (bike lane)	12,000< ADT ≤24,000 vehicles per day	≤ 1 mile	.0014	.0073
		>1 & ≤ 2 miles	.0020	.0109
		> 2 miles	.0027	.0145
Class 2 bike lane	24,000< ADT ≤30,000 vehicles per day Maximum is 30,000	≤ 1 mile	.0010	.0052
		>1 & ≤ 2 miles	.0014	.0078
		> 2 miles	.0019	.0104

ACTIVITY CENTERS CREDITS		
Types of Activity Centers: Bank, church, hospital or HMO, light rail station (park & ride), office park, post office, public library, shopping area or grocery store, university or junior college.		
Count your activity centers. If there are…	**Credit (C) Within 1/2 mile**	**Credit (C) Within 1/4 mile**
Three (3)	.0005	.001
More than 3 but less than 7	.001	.002
7 or more	.0015	.003

Emission Factor Inputs for Auto Travel

	Default	Units	Default	Units
	Auto Trip End Factor		**Auto VMT Factor**	
ROG Factor	1.020	grams/trip	0.266	grams/mile
NOx Factor	0.458	"	0.319	"
PM10 Factor	0.016	"	0.219	"

Applications

This methodology is primarily used to help local agencies in California estimate the emissions reductions associated with a particular investment in bicycle infrastructure, and the cost/benefit ratio of that investment in terms of emissions reductions. This tool is used to help jurisdictions apply for CMAQ funding for various projects.

Rojas-Rueda Bicycle Benefit Evaluation

Another study by Rojas Rueda et al used a methodology similar to the HEAT and ITHIM models. In *The Health Risks and Benefits of Cycling in Urban Environments Compared with Car Use: Health Impact Assessment Study,*[19] the authors estimated the number of deaths avoided due to the introduction of the "Bicing" bicycle sharing system in Barcelona, Spain. They analyzed the health impacts due to increased physical activity, air pollution (exposure), and road traffic incidents. This paper does not include the development of a tool that can be used by others, but it is included here because it demonstrates the evaluation of a particular intervention.

Tool Inputs

- Trip duration for bicycle trips on Bicing and for cars
- Distance travelled per trip for both modes
- Average speed for both modes
- Fatal traffic incident rates
- Number of trips per day
- Percentage of vehicles that use diesel v. petrol
- Efficiency and carbon emissions of diesel v. petrol vehicles
- Expected mortality rates for 16-64 age group
- Total population of Barcelona
- Population using Bicing each day
- Population changing from car to bicycle

Tool Outputs

Following are the model outputs in this study. This section also shows the specific results from this study, which determined the following outputs attributable to the introduction of the Bicing Bike Sharing system in Barcelona.

- Change in the number of deaths per year due to road traffic injury: + 0.03 deaths/year
- Change in the number of deaths per year due to air pollution: + 0.13 deaths/year
- Change in the number of deaths per year due to physical activity: - 12.46 deaths/year
- Carbon dioxide emissions saved: 9,062,344 kg/year

Methodology

The study used data from travel surveys for Barcelona and from data provided by the Bicing management company to determine values for trip distance, frequency, and speed. The authors of the study assumed that 90% of trips on Bicing were trips that had previously been made in a car. In

[19] Rojas-Rueda, de Nazelle, Tainio, and Nieuwenhuijsen. 2011. *British Medical Journal;* 343:d4521

the calculation for traffic mortality, the authors looked at all-cause mortality data for bikes and cars and then calculated the relative risks of traveling via each mode per mile. For physical activity, the authors used the same methodology as used in the HEAT tool – using relative risk of all-cause mortality for people traveling by bicycling using Bicing instead of by car.

With regards to air pollution, the authors took a different approach than the other models. They used previous research to identify the inhalation rates and PM exposure for cycling and driving in Barcelona. Using these rates, along with trip duration by mode, they estimated yearly inhaled doses of 2.5 PM and applied relative risk functions to the two groups in order to find the number of expected change in mortality rates due to switching from car travel to Bicing.

Finally, they estimated the carbon dioxide emissions reductions based on the characteristics of the Barcelona vehicle fleet and factors from the Catalan Office of Climate Change.

Application

This study shows the application of methods very similar to those used in the HEAT and ITHIM tools. It evaluated the impacts of a specific intervention – the introduction of Bicing, the bicycle-sharing system in Barcelona, Spain.

The authors found that, among the Bicing population of 181,982 bicycle-sharers, 12.46 annual deaths were avoided due to physical activity; they found an expected increase of 0.03 deaths from road traffic incidents and 0.13 deaths from air pollution.

NCHRP 08-78: Estimating Bicycling and Walking for Planning and Project Development

Travel demand models are widely used and relied upon in transportation planning; therefore, there is a need to improve representation of bicycling and walking in the models. However, in addition to incorporating bicycling and walking into travel demand models (which draw on trip tables and network utility), various regions have also explored other options for forecasting bicycling and walking trips as they relate to built environment factors, the four “Ds” of density, diversity, design, and destinations. The forthcoming NCHRP 08-78 report, “Estimating Bicycling and Walking for Planning and Project Development,” will report these methods that have been used, ranging from sketch planning tools to GIS-based spatial models. NCHRP 08-78 will also include guidance for choosing analytic methods to estimate and/or forecast bicycle and pedestrian travel and then apply them to specific planning needs related to bicycle and pedestrian travel.

CONSIDERATIONS FOR BENEFIT ESTIMATION IN THE LOS ANGELES REGION

Analysts have calculated estimates and projections of total and per capita VMT for the Los Angeles County and greater metropolitan area. However, there is limited knowledge of the connection between these VMT measurements and their related GHG emissions. This knowledge gap may exist because VMT, alone, does not provide an accurate measurement of travel-related GHG emissions. A vehicle's GHG emissions vary depending on several factors outside of VMT, including fuel efficiency, driving behavior, average speed and variance (traffic congestion), and vehicle type[20,21]. The following sections outline VMT estimations for the Los Angeles area, the region's vehicle-attributed GHG emissions, and VMT estimations of specific traveler groups and the associated GHG emissions.

Per Capita VMT in the LA Area

According to a study by the Brookings Institute, the Los Angeles-Long Beach-Santa Ana metropolitan region in 2005 had a per capita VMT of about 7,672 miles[22]. According to the Caltrans Highway Performance Monitoring System, as reported by the Los Angeles County Metropolitan Transportation Authority ("Metro"), LA County's annual per capita VMT was 8,243 miles in 1997, and was reduced to 7,869 in 2010. This is the equivalent of about a one mile reduction in daily VMT per person over the three years[23].

Regional Vehicle-Related GHG Emissions

The Center for Neighborhood Technology mapped vehicle related GHG emissions by city in the Los Angeles region and vehicle GHG emissions per household across the region. The LEM (location efficiency model) was used for creating the mapped data. The model predicts VMT using a combination of data collected from smog check odometer records, household income and size, vehicle ownership, transit service, pedestrian friendliness (measured by block size), residential density.

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[20] Barth, M., & Boriboonsomsin, K. (2009). Traffic Congestion and Greenhouse Gases. Access , 2-9.

[21] Matute, J. Measuring Vehicle Greenhouse Gas Emissions for SB 375 Implementation . Los Angeles: The Lewis Center.

[22] Metropolitan Policy Program. (2008). MetroPolicy: Shaping a New Federal Partnership for a Metropolitan Nation. Washington D.C.: Brookings Institute.

[23] Los Angeles County Metropolitan Transportation Authority. (2012). 2012 Metro Sustainability Report. Los Angeles: Metro.

Figure 1 shows aggregated annual CO_2 emissions from vehicles per square mile of each city. This map shows emissions to be greater in the more densely populated areas. Much of the city of Los Angeles is shown to have about 7,450 tons of CO_2 emission per square mile, with some areas approaching up to 81,100 tons of emissions.

Figure 2 shows a more detailed distribution of CO2 emissions, by indicating estimated annual CO2 emissions per household. Figures 1 and 2 are using the same data but by changing the denominator, figure 2 displays emissions per household to be lower in densely populated areas than in the more suburban cities surrounding Los Angeles. Households at the center of the city are predicted to have about 2.5 tons of vehicle-related CO2 emissions per year, while a large part of the city has annual vehicle-related CO2 emissions of 9 tons[24].

VMT Calculations and GHG Emissions for Specific Travelers

In 2011, Metro surveyed bicyclists at 19 of the Los Angeles' Metro rail stations. Data on trip origin and destination were collected and this sample data was extrapolated to annual trips. This study found approximately 322,000 automobile trips was replaced by bike-rail travel, resulting in a VMT reduction of 3.96 million miles annually and CO2 equivalents reduction of 2,152 tons. The GHG emissions were calculated using the Caltrans Emissions Factors model[25].

Another Metro report aimed to understand the cost effectiveness of their service delivery efforts in reducing VMT and GHG emissions[26]. These calculations were produced based on 2009 studies of existing transportation infrastructure and projections on future additions. Looking at employers participating in the Employee Commute Reduction Programs that Metro offers, they estimated that a VMT reduction just above 40.1 million miles is achieved annually, resulting in a GHG reduction of 17,107 metric tons of CO2 equivalent (MtCO2e). This is a conservative estimate of motor vehicle commute trips that Metro replaces because it only includes the larger employers that participate in their programs.

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[24] Center for Neighborhood Technology. (2003). Combating Global Warming Through Sustainable Surface Transportation Policy. Chicago: Transportation Research Board; National Research Council; Transit Cooperative Research Program.

[25] Los Angeles County Metropolitan Transportation Authority. (2011). Bicycle-Rail Trip Analysis & Greenhouse Gas Emissions Reduction Focused Study. Los Angeles.

[26] Los Angeles County Metropolitan Transportation Authority. (2010). Greenhouse Gas Emissions Cost Effectiveness Study. Los Angeles.

Figure 11: Los Angeles Area CO_2 per Square Mile

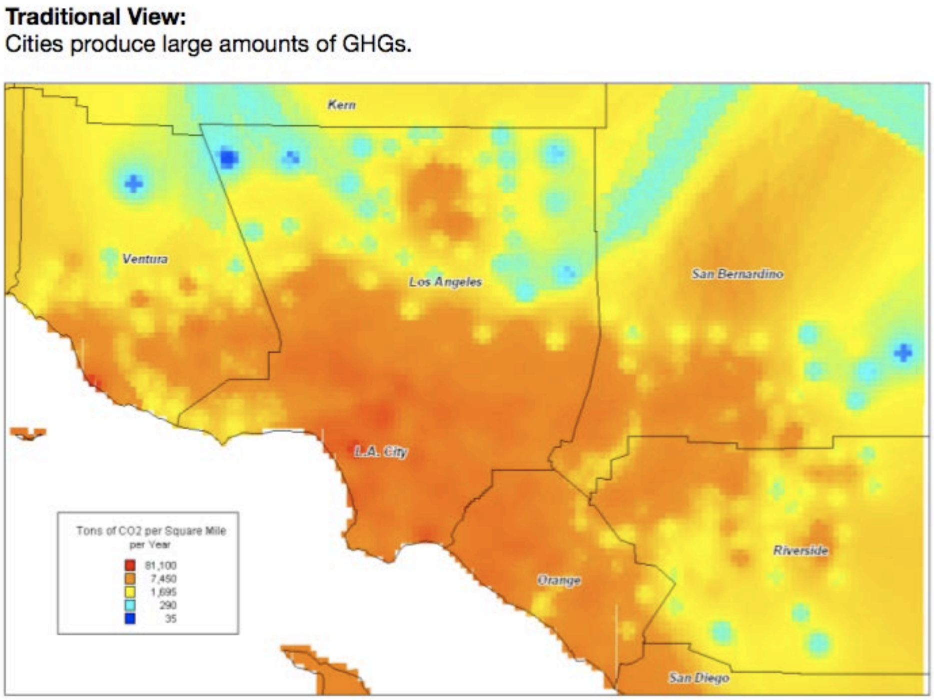
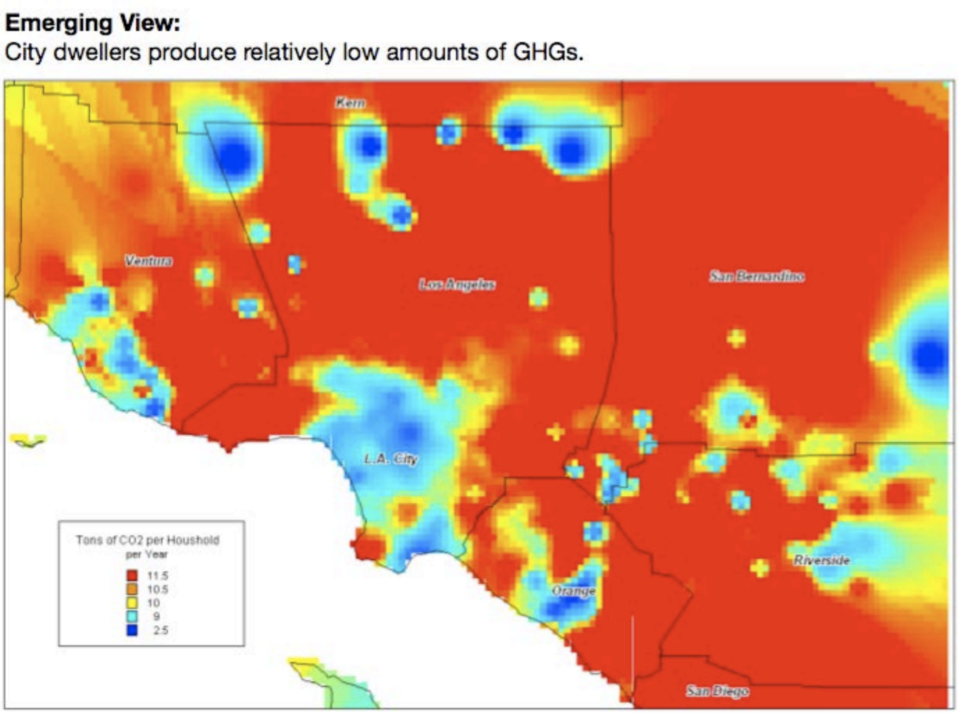


Figure 12: Los Angeles Area CO_2 per Household



Metro also estimated the VMT and GHG reductions resulting from the College Transit Passes that are available to students at 13 campuses. Using separate survey results to estimate how many trips would have been made by car if the pass was not made available, Metro calculated benefits to include about 177.3 million mile reduction in VMT annually and GHG reduction of 75,516 MtCO2e.

Emissions and Public Health in the Los Angeles Region

Greenhouse gas (GHG) emissions pose a significant threat to public health[27]. These GHG emissions come from a variety of sources, including transportation. Not all vehicle emissions are considered GHG emissions. Table 3 lists selected vehicle emissions and their effects on public health. The contribution of GHG emissions to climate change can also lead to indirect public health effects, but the table describes direct effects.

Table 3: Health Effects of Vehicle Emissions

Pollutant Group	Sources	Scale	Known Health Effects
Ozone	Photochemical reactions from NOx and VOCs	Regional	Eye and throat irritation; reduced exercise capacity; exacerbation of respiratory disease
Fine particulate matter (PM 10 and PM2.5)	Diesel engines and other sources	Local and regional	Upper respiratory tract irritation and infection; exacerbation of and increase mortality from cardio respiratory diseases
Carbon Monoxide (CO)	Engine	Very local	Headache, nausea, dizziness, breathlessness, fatigue, visual disturbance, confusion, angina, coma, health, low birthweight
Nitrogen Oxides	Engine	Local and regional	Eye irritation, upper respiratory tract infection, exacerbation of asthma, irritation of bronchi
Air toxics	Fuel production and engines	Very local	Eye irritation, lung cancer, asthma, cancer

According to the U.S Environmental Protection Agency, carbon dioxide, methane, nitrous oxide, and fluorinated gases are the main GHGs[28], some of which are emitted by vehicles. Vehicle emissions,

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[27] Maizlish, N., Woodcock, J., Co, S., Ostro, B., Fanai, A., & Fairley, D. (2013). Health Cobenefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the San Francisco Bay Area. American Journal of Public Health , 703-709.

[28] Overview of Greenhouse Gases. (2011). Retrieved June 18, 2013, from Environmental Protection Agency: http://www.epa.gov/climatechange/ghgemissions/gases.html.

including GHGs, are most commonly studied as a whole and consequent emissions have been found to contribute to poor lung development and premature deaths. Direct health implications of GHG emissions specific to the Los Angeles region are not well studied.

Poor Lung Development in Children

An eight year USC study found children between the ages of 10 and 18 years old who live within 500 meters of a freeway experience adverse effects on their lung development.[29] This group was compared with the children who lived 1,500 meters or more from a freeway. The study stated that the effect of the local traffic exposure was independent of the regional air quality. Children across the 12 selected Southern California communities demonstrated reduced growth in lungs and lung function, and higher rates of respiratory disease like asthma. The researchers report that since lung development is almost complete by the age of 18, it is more likely that those with strained lung development will have suboptimal lung function through their adult life. These results are supported by Perez, et al.[30]

Traffic Congestion's Contribution to Premature Deaths

The Harvard School of Public Health found, in their 2010 study, reported estimates of premature deaths that traffic congestion would contribute to if mobility and infrastructure remained unchanged.[31] They estimated for the Los Angeles-Long Beach-Santa Ana metropolitan area that in 2000, 722 premature deaths could be attributed to traffic congestion. The number of premature deaths was declining over time, with 547 in 2005, 426 in 2010, and predicted to be about 360 in 2015.

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[29] Guaderman, W., Vora, H., McConnell, R., Berhane, K., Gilliland, F., Thomas, D., et al. (2007). Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. The Lanclet , 571-577.

[30] Perez, L., Lurmann, F., Wilson, J., Pastor, M., Brandt, S., Kunzli, N., et al. (2012). Near-roadway pollution and childhood asthma: implications for developing "win-win" compact urban development and clean vehicle strategies. Environ Health Perspect , 1619-26.

[31] Levy, J. I., Buonocore, J. J., & von Stackelberg, K. (2010). The Public Health Costs of Traffic Congestion: A Health Risk Assessment. Harvard Univeristy, School of Public Health. Boston: Harvard Center for Risk Analysis.