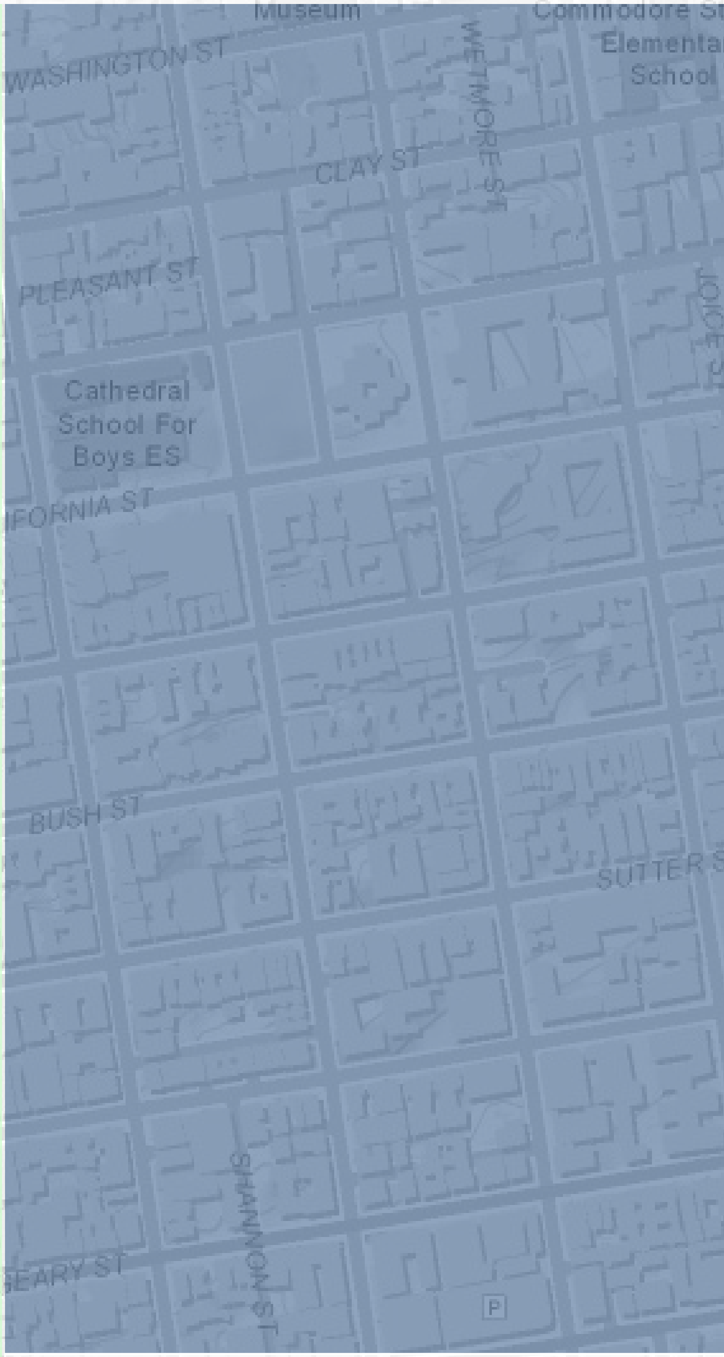
Health Effects of Road Pricing In San Francisco, California



San Francisco Department of Public Health
Program on Health, Equity and Sustainability

Technical Report: September 2011

Health Effects of Road Pricing in San Francisco, California: Findings from a Health Impact Assessment

San Francisco Department of Public Health
Program on Health, Equity and Sustainability

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Acknowledgements:

Project Lead:

San Francisco Department of Public Health

Project Director and Co-Principal Investigator: Rajiv Bhatia
Project Manager and Co-Principal Investigator: Megan Wier
Project Research Staff: Jennifer McLaughlin, Devan Morris, Cyndy Comerford Scully, Michael Harris, Julian Bedoya, Stephanie Cowles, Tom Rivard

In Coordination with:

The San Francisco County Transportation Authority: Mobility, Access and Pricing Study Team

Tilly Chang, Zabe Bent, Elizabeth Sall, Jesse Koehler, Liz Brisson, Michael Schwartz

Project Consultants:

Fehr & Peers Transportation Consultants

Meghan Mitman

San Francisco Injury Center

Rochelle Dicker, Dahianna Lopez, Dharma Sunjaya

UC Berkeley - School of Public Health

Edmund Seto

Walk San Francisco

Elizabeth Stampe

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The views expressed herein do not necessarily reflect the official policies of the City and County of San Francisco; nor does mention of the San Francisco Department of Public Health imply its endorsement.

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Executive Summary

Substantial evidence informs us that investments and choices in the transportation sector have profound effects on human health including on the level of physical activity, on morbidity and mortality from chronic diseases like asthma and heart disease, and on unintentional injuries and fatalities. Furthermore, the health consequences of transportation system infrastructure and operations are associated with significant economic costs associated with health care and productivity. According to the recent World Health Organization policy brief "Health in the Green Economy," infrastructure investments that shift transportation mode to walking, cycling and public transport provide health benefits that are more holistic and of a greater magnitude than improvements in vehicle technologies.[1] These investments can also advance social and health equity for vulnerable groups, such as children, the elderly, women, and lower-income households. Integrating measures of health performance in transportation planning and design processes and health impact assessments are two approaches to leverage the activities and expenditures in the transportation sector to support population health.

This report documents the process and findings of a Health Impact Assessment (HIA) conducted by the San Francisco Department of Public Health on one future road pricing scenario being studied by the San Francisco County Transportation Authority (SFCTA). The scenario would charge $3 during AM/PM rush hours to travel into or out of the northeast quadrant of San Francisco which includes a concentration of San Francisco's currently congested downtown streets. The scenario performed best (i.e., greatest benefits with fewest impacts) among dozens of scenarios studied, weighing SFCTA study criteria such as change in traffic and transit congestion, environmental benefits, and economic benefits. To date, no planning study for a specific road pricing proposal in the United States has included a comprehensive assessment of health impacts.

The HIA team developed a causal diagram to illustrate the potential ways in which road pricing can have an impact on health. Based on the pathway diagram, evidence of causal effects, available data, standard methods for impact analysis and concerns expressed by local and regional stakeholders, the HIA characterizes effects related to road pricing changes in the following health determinants: active transportation via walking and cycling; vehicle air pollutants; road traffic noise; vehicle-pedestrian injury; vehicle-cyclist injury; associated economic value; and equity implications. The HIA utilizes data on transportation and land use factors, socio-demographic characteristics, and health outcomes and behaviors from a variety of sources, including key inputs from the SFCTA's travel model. The analysis describes baseline conditions and characterizes the likelihood, severity, magnitude and distribution of selected health effects. Where sufficient high-quality information and methods existed, the analysis quantifies the magnitude of health effects. The following table summarizes the key quantitative findings from the HIA, which analyzed impacts under three scenarios: 2005 (existing conditions), 2015 BAU (business as usual – no road pricing), and 2015 RP (with road pricing).

Road Pricing Health Impact Assessment Findings Summary: San Francisco, California

Health Impacts (Annual Estimates)	2005	2015 BAU	2015 RP	Change: 2005 → 2015 BAU	Change: 2005 → 2015 RP	Change: 2015 BAU → 2015 RP	*Overall Confidence in Assessment*
Adverse Impacts							
Air Pollution, Mortality Attributable to Traffic-related PM 2.5 (N, Ages 30 and up)							***High - Moderate***
Citywide	65	66	63	1	-2	-3	
Congestion Pricing Zone	24	26	23	2	-1	-3	
Noise, High Annoyance (N, Ages 25 and up)							***High***
Citywide	92,500	100,400	100,300	7,900	7,800	-100	
Congestion Pricing Zone	36,800	40,600	40,500	3,800	3,700	-100	
Noise, Myocardial Infarction Associated with Traffic Noise (N, Ages 30 and up)							***Moderate***
Citywide	31	34	34	3	3	0	
Congestion Pricing Zone	18	20	20	2	2	0	
Vehicle-Pedestrian Injury Collisions (N, Total)							***High - Moderate***
Citywide	810	860	815	50	5	-45	
Congestion Pricing Zone	360	395	360	35	0	-35	
Vehicle-Cyclist Injury Collisions (N, Total)							***Moderate - Low***
Citywide	270	295	290	25	20	-5	
Congestion Pricing Zone	135	155	150	20	15	-5	
Beneficial Impacts							
Cycling for Active Transportation, Lives Saved (N, Ages 25-64)							***Moderate***
Citywide	23	25	26	2	3	1	
Congestion Pricing Zone	8	9	9	1	1	0	
Walking for Active Transportation, Lives Saved (N, Ages 25-64)							***Moderate***
Citywide	130	138	141	8	11	3	
Congestion Pricing Zone	69	76	77	7	8	1	

The 2005 findings summarize several of the current estimated health burdens and benefits of transportation system operation in San Francisco. Specifically:

- Transportation system operations are responsible for substantial health burdens in San Francisco including impacts on life-expectancy, heart disease, and injuries.
- The adverse health consequences of transportation disproportionately burden residents within the congestion pricing zone under study.
- Active transport in the city is responsible for substantial health benefits.

The differences between 2005 and 2015 Business as Usual (BAU) reflect the estimated changes to health effects attributable to the transportation system with current city plans for growth and without new policies or funding to manage transportation as the population increases, which include:

- worsening of traffic-related health impacts, exacerbated in the congestion pricing zone:
    - increases in air pollution-related health impacts, including premature mortality;
    - increases in traffic noise-related health impacts, including community annoyance and heart attacks;
    - increases in vehicle-pedestrian and vehicle-cyclist injury collisions, particularly in the congestion pricing area; and
- health benefits from increases in residents' active transportation and associated lives saved, concentrated in the congestion pricing zone.

The modest differences between 2015 BAU and 2015 RP reflect the estimated health impacts of the Northeast Cordon Road Pricing Scenario, specifically:

- modest health benefits from the moderation of increases in air pollution-related mortality to below 2005 conditions;
- modest health benefits from the moderation of annoyance related to noise in the congestion pricing zone relative to 2015 BAU;

- significant health benefits from increases in active transportation and lives saved from cycling and walking in excess of benefits estimated under 2015 BAU and 2005 conditions ;
- significant health benefits from the moderation of increases in vehicle-pedestrian injury collisions under 2015 BAU to 2005 conditions, particularly in the congestion pricing zone, as well as more modest moderation of increases in vehicle-cycling injury collisions estimated under 2015 BAU.

The table provides a qualitative summary of our confidence in the health impacts estimates considering uncertainties in the assumptions in the data used characterize health effects; the basis of these confidence assessments are detailed in the report.

The analysis describes the likelihood, severity and distribution of the selected health effects, and provides an estimate of the magnitude of these health effects attributable to transportation and the intervention of road pricing. Analysis of the distribution of health effects is critical for the assessment of social and environmental justice. This HIA used traffic density as a proxy for multiple adverse health effects associated with transportation system operation, finding no inequitable effects to low-income, elderly, or young populations defined spatially.

The HIA further estimates the economic value of the traffic-attributable health effects (adverse and beneficial) under the three scenarios. Total aggregate annual value of *adverse* health effects are substantial in all scenarios and lowest in 2015 RP (2015 RP: $1.120 billion; 2015 BAU: $1.173 billion 2005: 2005: $1.124 billion). Injuries to pedestrians and cyclists resulting from collisions with motor vehicles are the greatest contributor to adverse transportation-attributable economic costs under all scenarios – accounting for just over half of the estimated economic costs, with premature mortality attributable to air pollution accounting for an estimated 45% and approximately 2% associated with heart attacks attributable to traffic-related noise. Economic value of health *benefits* associated with active transportation are substantial – estimated to be somewhat greater than the estimated adverse transportation-related health costs in all scenarios and greatest under 2015 RP, with an estimated $1.337 billion in 2015 RP, $1.305 billion in 2015 BAU, and $1.225 billion in 2005. As this HIA quantifies only a limited number of health effects, the economic valuation estimates do not represent a full accounting of the costs and benefits of transport system operation under the three scenarios.

Overall, we conclude that transportation system operation in San Francisco has highly significant health burdens and benefits today. Health burdens are expected to increase owing to increasing motor vehicles on local roadways in the future and increasing population densities in already congested areas. Road pricing, if implemented, could moderate but not entirely eliminate the changes associated with a future under “business as usual” that includes increasing populations and traffic and no new policies or funding to manage the transportation system.

Recommendations to enhance the potential health benefits of road pricing to support reductions in transportation-associated health costs and increases in active transportation include: [a]

- increasing congestion pricing fees in circumstances likely to result in reduced health risks, for example, on “spare the air” days or applying specifically to more polluting vehicles;
- investing in walking and biking safety improvements in locations where injuries are greatest, for example with traffic calming along arterials in and near the road-pricing zone;
- using quieter, low-emission hybrid buses in areas where noise and air pollution are worse;
- investing in walking and biking infrastructure to encourage trips by foot and by bike into and out of the road-pricing zone;

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[a] Notably, a number of these recommendations are under consideration by the SFCTA as programmatic improvements or mitigations to enhance travel options or mitigate/minimize traffic and related environmental impacts as part of a road pricing comprehensive program and investment package, and were not included in the travel model outputs that informed this HIA.

- monitoring road-pricing implementation to address any unanticipated traffic increases and health impacts;
- encouraging active transportation and discouraging driving through more policies such as demand-based parking fees, “unbundling” parking in new development, and transportation demand management programs.

I. Background

A. Health Impacts of Transportation Systems

Several comprehensive reviews summarize the empirical evidence linking transportation to health effects.[2] Based on these reviews, the nexus between transportation and health can broadly be organized under four domains – access to human needs, neighborhood livability, safety, and environmental quality:

1. Access to human needs: providing (or inhibiting) access to means of livelihood (e.g., jobs), essential goods (e.g., food, fuel and water), and essential services (e.g. health care and education);
2. Neighborhood livability: facilitating movement, physical activity and social engagement and limiting crime and social disorder in one's immediate neighborhood surroundings;
3. Safety: preventing injuries and fatalities in the transport system;
4. Environmental quality: preventing emissions of environmental pollution (noise, air, water) related to system operation and associated health impacts.

Here we provide a synopsis of the health effects of transportation systems under each of these four domains. We further elaborate on the evidence linking transportation to specific health effects analyzed in this HIA in the Impacts Analysis section of this report (Section V).

Access to Human Needs: Transportation systems facilitate access to human needs, providing (or inhibiting) access to means of livelihood (e.g. jobs) essential goods (e.g., food, fuel and water), and essential services (e.g. health care and education). Transportation surveys confirm that lower income households, who are less likely to own or have access to automobiles, take fewer travel trips than middle and higher income households.[3] Disparities in transportation resources for the poor contribute to differential access to jobs, schools, shopping, and recreation – which varies by geographic area and factors including public transit access, service, and cost, and proximity to jobs, goods and services.

Neighborhood Livability: The quality and design of the built environment further affect neighborhood livability, facilitating movement, physical activity, and social engagement and potentially limiting crime and social disorder in one's immediate neighborhood surroundings. Neighborhoods that include pedestrian spaces or that have lower levels of street traffic where one can walk comfortably and safely benefit health by enabling physical activity, leisure, and social interaction.[4]

Safety: The surface transportation system produces a substantial share of unintentional injuries and fatalities, particularly among more vulnerable users such as non-motorized users. In the U.S., pedestrians and cyclists experience a disproportionately higher risk of traffic fatality compared to vehicle occupants on both a per-trip and per-mile basis.[5] High volume roadways, which are associated with both higher traffic flow and higher vehicle speeds, are primary determinants of injury frequency.[6]

Environmental Quality: Transport systems are a significant source of environmental pollutants such as increased noise or emissions to water and the air. Residents living near busy roadways experience a unique combination of environmental hazards. Grade separated highways and other high volume roadways concentrate the flow of vehicles and are accompanied by increases in vehicle pollution emissions such as particulates, nitrogen oxides, carbon monoxide, and benzene.[7] Epidemiological research supports consistent statistical associations among traffic proximity and several adverse respiratory health outcomes, including impairment of lung function and asthma incidence and symptoms in children; these associations remain significant after adjustment for economic position.[8]

Road traffic is the dominant source of community noise in urban areas; proximity to roadway facilities along with vehicle type, speed and road conditions predict urban ambient noise levels.[9] Chronic exposure to road traffic noise is associated with several adverse health outcomes, including interference with thoughts and feelings, deficits in cognitive functioning, lowered school performance, sleep disturbance, and ischemic heart disease.[10] Contaminants from the development and operation of roadways, including metals and hydrocarbons, may flow into waterways and aquifers along with water. Runoff from roadways can overwhelm the capacity of creeks or manmade storm water drainage systems and disproportionately affect residents adjacent to roadways or those downstream from natural and manmade drainage systems.

Disparate Adverse Impacts: Studies conducted in California show that ethnic minority and lower income households are disproportionately represented among populations living in close proximity to busy roadways.[11] This disproportionate proximity to busy roadways translates directly to disproportionate hazards and related health outcomes. In some places, increased pedestrian collision frequencies in low-income neighborhoods can be explained in part by differences in traffic volume and other factors in the transportation environment.[12]

B. Road Pricing: Definition and United States Policy Context

Road pricing charges a fee for the use of a road facility. The fee is set based on user demand as a function based on time of day, location, type of vehicle, number of occupants, or other factors. Road pricing is also referred to as congestion pricing, value pricing, variable pricing, peak-period pricing, or market-based pricing. Road pricing that varies with time or demand is distinct from tolling—typically a per-use (flat) fee on motorists for a given highway facility—which has a sole purpose of generating revenue for construction and maintenance of a facility. Road pricing is used to account for and manage vehicle demand on the roadways and to generate revenue – while simultaneously also achieving other goals such as reduced congestion, reduced environmental impacts (e.g., greenhouse gas emissions), or addressing other external costs occasioned by road users. Examples of road pricing include HOT (High Occupancy Toll) Lanes, variable or extended parking metering, variable bridge tolls, and congestion pricing. There are growing examples of such road and parking pricing policies nationally, and debate over whether or not these types of policies should be implemented and how revenue should subsequently be invested is ongoing.[13] The revenue from road pricing can be reinvested in the transportation system through capacity expansion, road maintenance and improvements, repayment for long-term debt, public transit service, or bicycle and pedestrian projects.[14]

In the United States, funds for building and maintaining transportation systems are limited and need to be used effectively and efficiently; public investments in the transportation system can be leveraged to achieve other social objectives. Transportation planners and policymakers have an opportunity to prevent adverse health externalities of planning and policy decisions (reducing injuries and pollutants) and to align investments to support strategies that promote public health (increasing accessibility and physical activity). However, such multi-objective decision making requires comprehensive analyses of health impacts of transportation proposals. These analyses have thus far been largely absent from a growing number of policy debates and transportation impacts analyses in the United States, despite potential health benefits from decreased air pollutants, traffic-related noise levels, and traffic collisions, and increases in active transportation. Investing road pricing revenues in transit, bike, or pedestrian improvements could also improve accessibility to basic needs for low-income households without automobiles. These types of improvements are standard practice in countries where area congestion pricing is implemented.[15]

Road pricing policy approaches might also have adverse health impacts. For example, increased traffic speeds associated with reduced congestion may increase the severity of traffic injuries and pedestrians may perceive a less safe environment for walking. Because of the multiple and potentially cumulative health impacts of traffic and transportation planning decisions, it is vital to assess the health impacts of transportation policy decisions. A growing number of health impact assessments in the U.S. are focused on transportation-related planning and policy decisions.[16]

Road pricing that applies to individual road facilities (HOT Lanes) has been implemented throughout the U.S. in California, Minnesota, Colorado, Texas, and elsewhere.[17] Although area-based road pricing has not been implemented in the United States, in 2007-2008, area-wide congestion pricing was considered but not implemented in New York City. The New York City Council passed the measure and polls showed that New York City residents backed the proposal, which provided that revenue would be invested in expanded transit service. However, the New York State Assembly did not act on the proposal and the Legislature did not adopt authorizing legislation in time to meet an April 2008 federal funding deadline.[18] A paper analyzing this experience and implications for road pricing in the U.S is available online.[19] There have been recent reports that congestion pricing will be reconsidered in New York City.[20]

Area-based road pricing is implemented elsewhere in the world, including in London's central business district, Stockholm, and Singapore. Evaluation findings of area-based congestion pricing schemes in these settings provide evidence of potential benefits of decreased driving associated with decreased vehicle emissions, reductions in traffic-related noise levels, reductions in traffic collisions including those involving pedestrians, and increases in active transportation including walking and biking.[21]

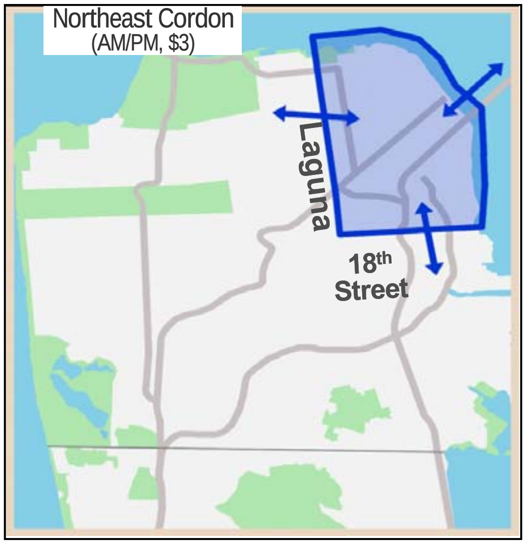
C. Road Pricing Proposals and Studies in San Francisco, California

The San Francisco County Transportation Authority (SFCTA) began a feasibility study of congestion pricing in San Francisco in 2007, funded by a $1 million grant from the Federal Highway Administration. Under all congestion pricing scenarios, motorists could choose to pay a fee to drive in specific, congested areas or corridors during peak periods, drive at different times of day, or choose other modes of travel such as transit or biking. Revenues generated would in turn fund transportation improvements, such as more frequent transit service, roadway improvements, bicycle facilities and pedestrian amenities. In December 2010 the Transportation Authority Board unanimously approved a feasibility study[22] which concluded that congestion pricing could be an effective way to manage San Francisco's transportation system and simultaneously support the city's future growth plans. The Transportation Authority Board also voted to pursue additional evaluation of the concept through environmental clearance.

In the analysis, the best performing scenarios were a Northeast Cordon (AM/PM) that would charge motorists $3 during AM/PM peak periods, and a PM-only charge of $6 for outbound traffic in the same area.[23] These scenarios were among dozens of scenarios that were examined, each with a different mix of metrics related to transportation system, environmental, economic, and equity impacts. The study assumed substantial up-front transit improvements including regional transit access improvements, e.g., BART and Caltrain, and more frequent regional and local (Muni) express buses. The study also assumed all net revenues generated would be dedicated to multi-modal improvements for motorists, pedestrians, cyclists and transit riders to the cordon area.

The focus on the north eastern part of the city emerges from the density of congestion today (average speeds on over half of streets in downtown San Francisco areas operate below 10mph for motor vehicles and 8mph for transit vehicles). However, several streets in the area are also high flow, higher speed streets with mean speeds above the speed limit. The cordon scenarios are also informed by areas where planned growth is likely to exacerbate existing congestion or create new availability of transit; flexibility/feasibility to improve transit services and other modes of travel to/from/within the area; and the availability of net revenues generated to produce sufficient funding to cover cost of improved services. The feasibility study found that a Northeast Cordon (AM/PM) Scenario that charged a $3 fee during AM/PM peak periods to drive into or out of the northeast quadrant of San Francisco bounded by Laguna, 18th, Guerrero streets and the waterfront (see map in Figure 1) performed best (i.e., greatest benefits with fewest impacts based on SFCTA criteria) among dozens of scenarios, weighing established study criteria such as change in traffic and transit congestion, environmental benefits, and economic benefits. In all, the Northeast Cordon scenario would most effectively manage demand in the city's most congested areas, deliver substantial net revenues, and present manageable impacts. The next phase of analysis will refine the system design and further evaluate benefits and impacts along the edge of the cordon, and refine the investment package.

Figure 1. The San Francisco County Transportation Authority's Mobility, Access and Pricing Study (MAPS) Boundaries for the "Northeast Cordon" Congestion Pricing Study Scenario: San Francisco, California



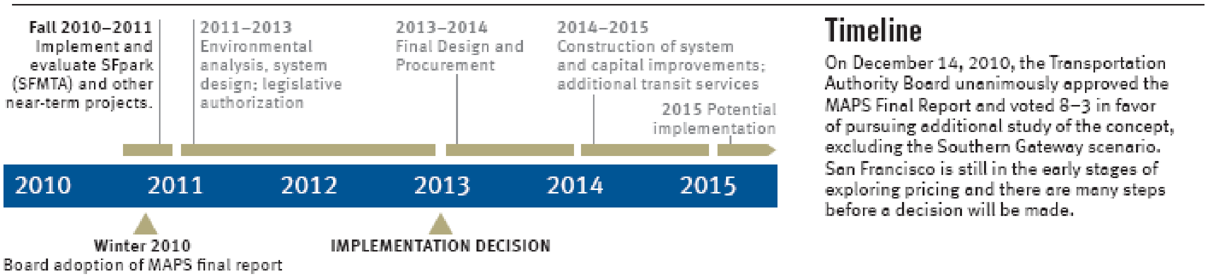
Compared to "business as usual" conditions in 2015, the Northeast Cordon (AM/PM) scenario resulted in:

- 12% fewer peak period auto trips
- 21% reduction in vehicle hours of delay (VHD) in the Northeast Cordon
- 16% reduction in Northeast Cordon Greenhouse Gas Emissions (5% citywide)
- $60-80M annual net revenue for transportation services and amenities
- 20-25% transit speed improvement

The complete feasibility study is accessible online.[24] Additional background information regarding MAPS is in Attachment A, the December 2010 MAPS Fact Sheet, and more detailed information is also available on the project website: www.sfmobility.com.

The feasibility study also evaluated a representative set of discounts or exemptions, along with a representative set of physical investments and mitigations and programmatic improvements to ensure comparable or improved access to the cordon area. Examples of program discounts, exemptions and caps include: discounts for key groups including disabled persons, low-income travelers, residents and immediate abutters of zone; exemptions for transit vehicles, taxis, and emergency vehicles; and a maximum daily cap of $6 to help mitigate impacts on delivery-oriented businesses, families w/school-age children, and potentially other populations (which would be further mitigated by programmatic enhancements to be outlined further in next phase of the MAPS evaluation). Programmatic improvements and mitigations, such as traffic calming, streetscape and landscape improvements, school ridesharing, and other similar programs, may further help to enhance travel options or minimize traffic; related potential environmental impacts would be part of the comprehensive program and investment package, ***but were not included in the model analysis***. **These discounts and program enhancements will be further evaluated and refined in the next phase of study.** The study timeline is detailed in the following Figure 2. A decision on whether or not to implement congestion pricing is at least 2-3 years away, and will be informed by the environmental studies. [25]

Figure 2. San Francisco County Transportation Authority Mobility Access and Pricing Study Timeline



On December 14, 2010, the Transportation Authority Board unanimously approved the MAPS Final Report and voted 8–3 in favor of pursuing additional study of the concept, excluding the Southern Gateway scenario. San Francisco is still in the early stages of exploring pricing and there are many steps before a decision will be made.

D. *Health Impact Assessment*

Health impact assessment (HIA) is a structured decision-support practice to characterize the anticipated health effects, both adverse and beneficial, of societal decisions including projects, plans, programs, and policies undertaken by government or the private sector. HIA makes recommendations for health-attentive policy and project design and may lead to more health-responsive decisions.[26] HIA follows a series of procedural steps outlined in Table 1. The 2010 *Minimum Elements and Practice Standards for HIA* published by the North American HIA Practice Standards Working Group describes criteria for quality practice that are employed in this application.[27]

Table 1. Stages of Health Impact Assessment

Screening	**Determine need for and value of a HIA in the decision-making process.**
Scoping	**Determine which health impacts to evaluate, methods for analysis, and workplan to complete the assessment.**
Assessment	**Conduct a baseline conditions analysis and a qualified judgment of magnitude and likelihood of potential health impacts.**
Recommendations	**Make recommendations to manage the health impacts identified, including alternatives to the decision, modifications to the proposed policy, program, or project, or mitigation measures.**
Reporting	**Complete a report of HIA findings and recommendations and communicate results to stakeholders and decision makers.**
Monitoring	**Track effects of HIA and decision outcomes as well as the effect of the decision on health impacts and/or determinants of concern.**

II. Screening and Primary Objectives

To date, no planning study for a specific road pricing proposal in the United States has included a comprehensive assessment of health impacts. The feasibility study conducted by the SFCTA (described in Section I) contributes substantially to local and national public discussion on congestion pricing and the dialogue regarding future direction of transportation policies and investments.[28] However, the feasibility study of congestion pricing did not include a comprehensive assessment of potential health impacts. Working with SFCTA staff as well as the Mayor's Office and consulting several national transportation interest groups, SFDPH staff thus considered the value of an independent HIA to the decision-making process.

SFDPH staff determined the following factors supported the conduct of an HIA:

- The congestion pricing study area affects a large share of San Francisco's land area, residents, and employees;
- Evidence suggested that the proposal would have several potential health effects;
- Several local and regional stakeholders have raised questions and concerns regarding the health and equity impacts of road pricing on air pollution and traffic hazards to pedestrians and cyclists;
- The health effects of road pricing may be important in the evaluation of policy trade-offs;
- There is little available research on the health effects of road pricing;
- Existing data and methods allowed substantive analysis of health impacts of concern;
- The SFCTA, the lead agency analyzing the policy, provided modeling data in support of the HIA;
- There was sufficient time to conduct an HIA to inform policy design and revenue investment choices; and
- The HIA could provide a model for HIA on other transportation policies or infrastructure investments at the local, regional, state or national levels.

Based on the above factors, staff articulated the following objectives for the HIA on road pricing, consistent with the stages of HIA.

HIA Phase	Study Objectives
Scoping	**1)** Enumerate the scope of priority health issues and concerns related to congestion pricing in San Francisco, California in consultation with local stakeholders and identify best available methods to analyze these impacts;
Assessment	**2)** Analyze and document baseline health factors and related conditions in the targeted area;
	3) Make evidence-based judgments of the magnitude, direction, and certainty of potential health impacts of the proposed congestion pricing policy, quantitatively and qualitatively, including potential inequitable impacts;
	4) Recommend policy modifications, decision alternatives, or other mitigations to address potential adverse health impacts;
Reporting	**5)** Report findings and recommendations to *local and regional stakeholders* in a written report which includes a succinct, accessible summary of the findings;

6) Report findings, recommendations and lessons learned to *regional, state and national public health, planning, and policy audiences* so that the HIA conceptual approach and findings may inform similar policy proposals throughout the country.

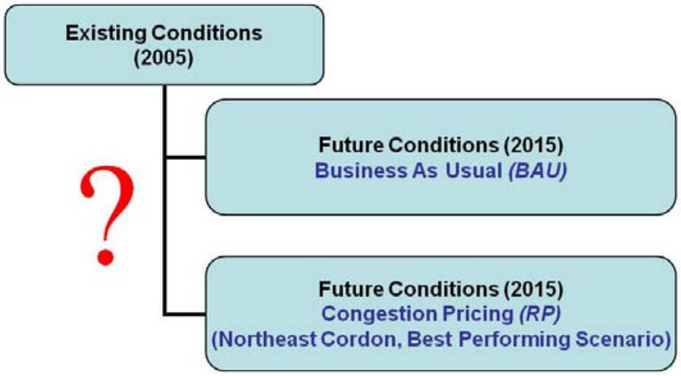
III. Scoping

In the Scoping stage SFDPH staff established geographic and temporal boundaries for the analysis, prioritized the health impacts for analysis, identified the data, methods and tools for impacts analysis, identified roles for experts and key informants, and developed a plan and timeline for external review and dissemination of findings and recommendations.

A. Decision Alternatives, Temporal and Geographic Boundaries

The HIA compared road pricing under the Northeast Cordon scenario (2015 RP) against a business as usual (no road pricing) alternative (2015 BAU) in the year 2015. The HIA compared the estimated health effects under each alternative to each other and to baseline conditions without pricing in 2005; these years of analysis are the same as those used by the SFCTA in their analyses. These scenarios are summarized in Figure 3. The geographic boundaries of the HIA are those of the City and County of San Francisco.

Figure 3. Scenarios and Time Periods for HIA Analyses



Please Note: **Throughout this report, we refer to 2015 future conditions with the following abbreviations:**

2015 BAU = 2015 under "*Business as Usual*": 2015 BAU is a future consistent with San Francisco policies and investments in which future residential and employment growth is concentrated in the eastern and southern areas of the city. These neighborhoods include the most transit accessible areas (e.g., via Muni and BART) – and also contain the most congested streets. This growth includes large increases in residents as well as increases in employees (summarized in Section IV of this report), and differs from previous growth in San Francisco in that this new housing and residents are accompanied by a growing trend in "out commuting" from San Francisco to more suburban job centers (e.g., Silicon Valley). This scenario does not include road pricing or other new policies or funding strategies to manage the transportation system as populations increase.

2015 RP = 2015 with *Road Pricing* under the Northeast Cordon Congestion Pricing Scenario: 2015 RP is a future in San Francisco with the residential and employment growth described under 2015 BAU, and additionally includes road pricing charging motorists $3 during weekday AM/PM peak periods under the Northeast Cordon Congestion Pricing Scenario detailed in the previous section. This scenario includes up-front transit service enhancements.[29] As described earlier in this report, the SFCTA had specified the Northeast Cordon Congestion Pricing Scenario as a "best performing" policy for future study.

B. Potential Pathways from Congestion Pricing to Health Impacts

The HIA team developed a causal diagram (Figure 4) to illustrate the potential ways in which road pricing can impact health. The pathways in the tan box on the right of the figure are the focus of the HIA. Empirical evidence relating transportation and health and preliminary analysis of road pricing effects on transportation behaviors conducted by the SFCTA (the direct impacts) informed the selection of environment effects and related health effects.

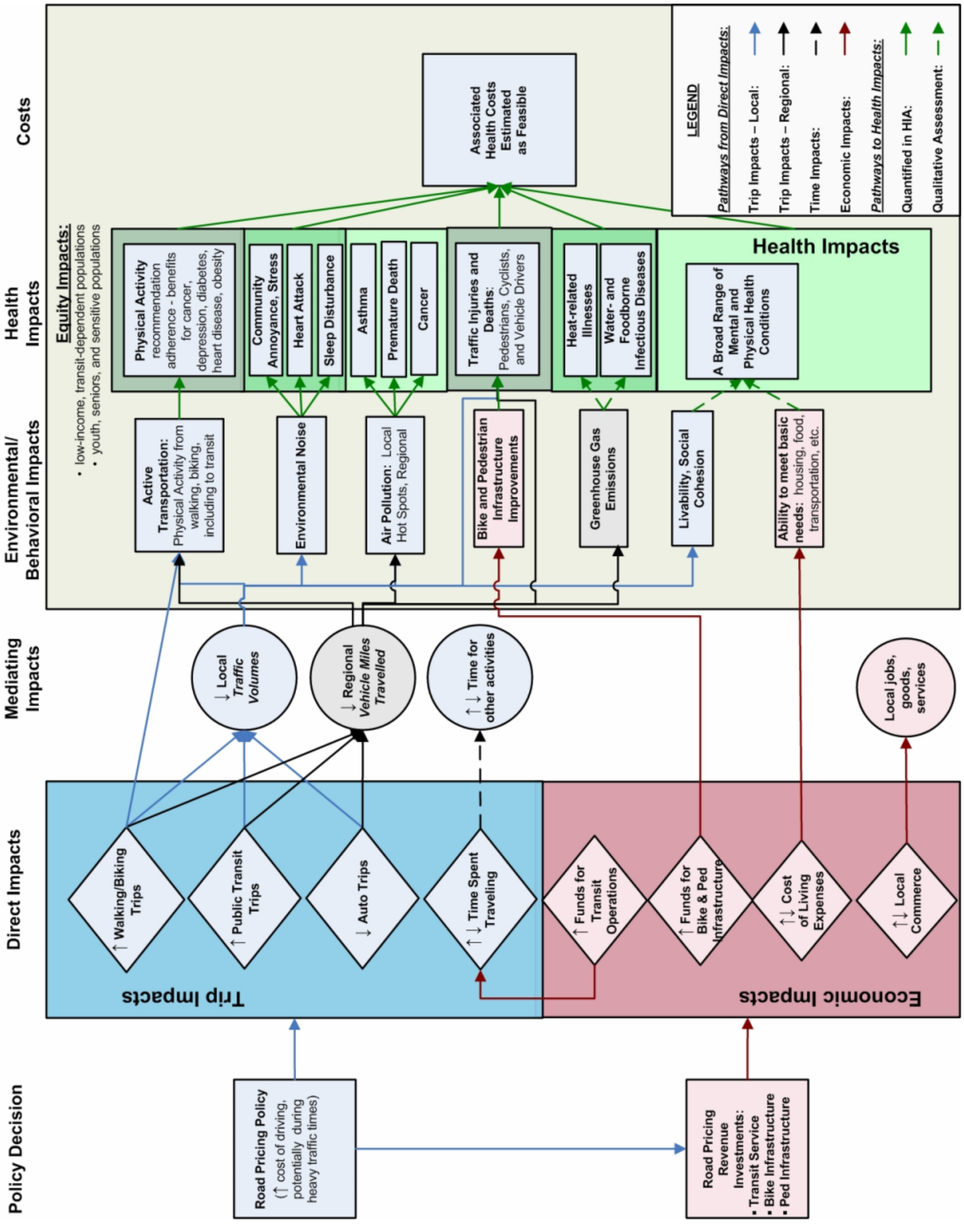
The HIA team reviewed draft versions of the causal diagram scope with local and regional stakeholders including: the SFCTA, the San Francisco Bay Area Metropolitan Transportation Commission, the San Francisco Bicycle Coalition, the Environmental Defense Fund, the Sierra Club, Walk San Francisco, Livable City, the Western SoMa Citizens Planning Task Force, the South Beach/Rincon/Mission Bay Neighborhood Association, TransForm, and Urban Habitat. The scope was also informed by SFDPH staff participation beginning in 2008 in SFCTA-led public meetings, Board hearings, webinars, and technical advisory committee meetings in which representatives from the community, local businesses, freight, sustainable transportation, local government and a number of other interests participated.

As illustrated in Figure 4, health effects result from direct effects on travel behavior and indirect effects related to other health beneficial impacts on the environment and on transportation systems. For example:

1. Increases in pricing may reduce the number of trips taken by automobile and increase the number of trips taken with active transportation modes including walking and bicycling, and also increase active transportation trips to and from public transit. Pricing could result in some people changing to alternative travel modes[30] – and therefore potentially increasing walking and biking for transportation.
2. Reductions in motor vehicle trips and miles travelled may have corresponding reductions in air pollution, greenhouse gases, traffic-related noise, and traffic collisions and their associated health impacts including lung and cardiovascular diseases, stress, asthma, and traffic-related injury and death.[31] These improvements in environmental conditions and reductions in hazards may further enable participation in active utilitarian and leisure transportation.[32]
3. Congestion pricing may provide funds for transit and transportation infrastructure, including transit service improvements and infrastructure for walkers and bicyclists, further enabling active transportation including to public transit.[33]
4. Pricing-related traffic congestion reductions may reduce delay for transit operators, improving transit service, reliability and therefore use. These improvements carry the potential to increase the use of active transportation to access transit.[34]
5. Pricing may affect travel costs, increasing transportation costs for some and reducing costs for others.

Causal diagrams for discrete pathways are included in the Impact Analysis section of this report (Section V.).

Figure 4. Pathways through which Road Pricing Policies May Impact on Health



C. Scope of Health Effects & Research Questions

Based on the above pathway diagram, evidence of causal effects, available data, standard methods for impact analysis, and concerns expressed by stakeholders, the HIA characterizes effects related to road pricing changes in the following health determinants:

- Active transportation via walking and cycling
- Air Pollutants
- Noise
- Pedestrian injury
- Cyclist injury.

For each of these determinants, we evaluated health effects for San Francisco residents under 2015 BAU compared to 2005 Existing Conditions and under a future scenario with Congestion Pricing under the North East Cordon Road Pricing scheme (2015 RP). Where sufficient data were available, we quantified how changes in these health determinants would change associated health outcomes including life-expectancy, ischemic heart disease events, and pedestrian and cyclist injuries.

Identifying decision impacts on health inequities, taking into account population vulnerabilities, is an explicit purpose of HIA. Health inequities are defined as systematic disparities in health status or in the major social determinants of health between groups with different social advantage/disadvantage (e.g., wealth, power, prestige).[35] Particular subgroups that may be particularly vulnerable to the health impacts of transportation infrastructure and operations include: youth at high risk for physical inactivity and obesity; youth, seniors, and low-income populations sensitive to air pollutants and traffic-related noise disturbances; youth at high risk of traffic related injury, and seniors at high risk of traffic related death; and low-income, transit-dependent populations, historically disproportionately burdened by the adverse health impacts of transportation planning decisions that channel motor vehicles into their communities.[36] This HIA focused on distributional impacts of alternative scenarios on populations defined by income, age, and place.

The economic value of health costs and benefits is often considered useful information to decision-makers. We also assessed the economic value of a subset of health effects quantified through this assessment.

Finally based on our analysis, we considered what transportation investments or mitigations could reduce adverse health impacts and support health benefits expected in either the 2015 BAU or 2015 RP scenarios.

A number of health-related end points were considered in our scoping process but were not analyzed in the HIA. These endpoints are listed below along with a rationale for their exclusion.

Impacts on San Francisco employees: With the exception of analysis of vehicle-pedestrian and vehicle-bicycle collision injuries, this HIA focuses on the health impacts on San Francisco residents, though there are more than half a million workers in San Francisco (over 40% of whom are not San Francisco residents),[37] approximately two-thirds of whom work in the potential congestion pricing zone. Our focus on residents was largely informed by the available health evidence and exposure-response estimates to estimate potential health impacts related to changes in air pollution, noise, and active transportation; health research regarding these effects is largely focused on resident impacts. The HIA field would benefit from additional research on how transportation policies affect employee health, in addition to the research on workers in transportation-related professions (e.g., truck drivers).

Greenhouse gas (GHG) emissions: Climate change threatens to have global and catastrophic effects on health through: increased frequency, intensity and length of heat waves, floods, droughts, windstorms and wildfire, leading to increased mortality, illness and mental health impacts; increased exposures to ground-level ozone and aeroallergens, exacerbating cardiovascular and pulmonary illness; and shifts towards warmer temperatures, leading to increased risk of food- and waterborne infectious diseases.[38] Changes in greenhouse gas emissions were estimated as a part of the SFCTA MAPS analyses and we chose not to duplicate the analysis.

Access to local jobs, goods, and services including health care, child care: Access to local resources, including employment, goods and services to meet daily needs, is fundamental to people meeting their basic needs for survival and health. Through the scoping process, communities expressed concerns regarding the potentially increasing costs of accessing these fundamental resources with the implementation of congestion pricing. The SFCTA plans to include these specific transportation issues in the next phase of study – particularly with respect to transportation of children to and from school and childcare.

Livability, social cohesion and associated mental and physical health impacts including stress: We did not include these more distal health impacts in our analysis given our already broad scope and limitations in available methods to estimate potential impacts.

Time and related stress and increased environmental exposures of being stuck in traffic or on transit: Due to limits in currently available methods and more distal health impacts we did not estimate the health impacts of changes in stress levels associated with changes in travel time. We do consider changes in time spent travelling via walking and cycling. Time spent in traffic is also associated with elevated personal exposures (e.g., to air pollution and noise), which is not taken into account in the modeling of environmental exposures.

Transportation costs and low-income drivers: The SFCTA analysis considered the broad equity implications of who would be paying the fee. While we (and SFCTA staff) acknowledge that equity is a serious concern for local and regional stakeholders, we did not focus on these larger equity issues given the SFCTA's current policy recommendations to include discounts for low-income drivers and/or transit riders, as well as additional findings that less than 5% of peak-period travelers to downtown San Francisco are drivers with annual household incomes < $50,000. Furthermore, data show many low-income travelers in the Bay Area already rely on public transit and would thus benefit from faster, more reliable transit travel times resulting from pricing fee investments. In a 2007 poll of regional travelers, the SFCTA further found that support for studying a San Francisco congestion pricing program is highest among low-income Bay Area residents.

Economic Impacts on Local Businesses: This issue was commonly raised in public forums, was addressed in the SFCTA's feasibility study, and is further described in Section 2.4 of the feasibility study report. Economic effects on businesses were not represented by commenters as health concerns.

Fee Investments: Based on available data regarding the policy, our analysis focuses on health impacts resulting from changes in travel behavior. Additional impacts are anticipated based on investments of the fee though those specifics will be determined in the next phase of the study. We therefore focused our recommendations on how investments could be leveraged to promote health.

Regional Impacts: Our HIA focuses on local impacts within the City and County of San Francisco, though congestion pricing proposals also impact on transportation behaviors and vehicle miles travelled at a regional level. Notably, the SFCTA's transportation analysis for the feasibility study was a regional analysis, and the cordon area includes local residents as well as regional workers.

D. Data Sources

Based on the framework established in Figure 4, our HIA addresses the aforementioned research questions regarding the health impacts of transportation policy decisions on residents in the City and County of San Francisco, California based on data from three scenarios: 2005 Existing Conditions, 2015 BAU, and 2015 RP. An overview of the variables used for analyses, data sources, and unit of analysis is detailed in the following table.

Table 2. Key Input Data for the Road Pricing Health Impact Assessment

Variable	Data Source	Geographic Unit of Analysis	HIA Analyses
Transportation and Land Use Conditions: 2005 , 2015 BAU, 2015 RP			
City Lots, Building Heights, Zoning Designation	SF Planning	Lot	AQ, Noise
Pedestrian Environmental Quality	PEQI Data Collection	Street Segment, Intersection	Ped Inj
Traffic Volume by Vehicle Type, Time of Day, Traffic Speed (Free Flow and Congested Conditions), Bus Volumes	SFCTA Model	Street Segment	AQ, Noise, Cyclist Inj, Ped Inj, Equity
Trips, Travel Mode by Age Category	BATS	Bay Area Region	Active Transport
Walk and Bike Trips, Travel Time	SFCTA Model	Transportation District	Active Transport, Cyclist Inj
Socio-demographic Conditions: 2005 and 2015			
Resident Age	AGS Inc. Estimates	Census Block	All
Average Household Income	ABAG Estimates	Transportation Analysis Zone	Equity
Resident Population Data	ABAG Estimates	Transportation Analysis Zone	All
Health Outcomes and Behaviors: 2005 Existing Conditions			
Mortality	CDPH (Vital Statistics)	County	AQ, Active Transport
Myocardial Infarction, Hospital Admission	CDPH (OSHPD)	County	Noise
Vehicle-Pedestrian Injury Collisions, Vehicle Cyclist Injury Collisions	SWITRS	Intersection, Census Tract, County	Ped Inj, Cyclist Inj

ABAG: Association of Bay Area Goverments
AGS, Inc.: Applied Geographic Solutions, Incorporated
AQ: Air Quality
BATS: Bay Area Travel Survey
CDPH: California Department of Public Health
Cyclist Inj: Vehicle-Cyclist Injury Collisions
Ped Inj: Vehicle-Pedestrian Injury Collisions
PEQI: Pedestrian Environmental Quality Index
OSHPD: Office of Statewide Health Planning and Development
SFCTA: San Francisco County Transportation Authority

The SFCTA's travel forecasting model – SF-CHAMP 4 - estimates changes in travel patterns in San Francisco and the broader nine-county Bay Area under different land use, population, and transportation systems conditions (see Attachment B for an overview of the model).[39] SF-CHAMP 4 model inputs include land use, transportation, and population data from the SF Planning Department, Association of Bay Area Governments, U.S. Census, Metropolitan Transportation Commission, and other sources. Model outputs include street level traffic volumes and speeds, transportation district-level trips by mode (walk/bike/transit/driving), travel duration, and district of residence of trip maker (n=12 San Francisco districts). We used these SF-CHAMP transportation model outputs for the 2005, 2015 BAU, and 2015 RP conditions, provided by SFCTA staff, *as key inputs* into the HIA analyses, where transportation parameters were necessary. An important caveat is that these inputs are also modeled outputs of the SFCTA's travel forecasting model. While the model is internationally regarded as a sophisticated travel forecasting approach which provides the best available estimates, its outputs are not precise predictions.

We also used Bay Area Travel Survey regional data on trip making and travel mode by age, as data was not available just for San Francisco, to estimate the proportion making trips and transportation mode by age.[40]

We accessed City Parcel Data (city lots), Building Data (height) and Zoning Data (Land use designation) from the SF Planning Department for more detailed spatial assignment of residential populations as described in Appendix A.

We used data collected with SFDPH's Pedestrian Environmental Quality Index (PEQI) – an observational data collection tool developed by SFDPH to assess physical environmental features that support walking in San Francisco - to assess existing conditions in and proximate to the area of focus for the congesting pricing study. The PEQI integrates 30 variables that reflect the quality of the built environment for pedestrians;[41] PEQI methods are further detailed in Appendix F.

We used the same data as the SFCTA for existing and future resident and employee populations and average household income, based on regional estimates and projections provided to the City and County of San Francisco by the Association for Bay Area Governments, the regional planning agency for the San Francisco Bay Area. We used socio-demographic data on age and sex from census-block level estimates and projections purchased by the City and County of San Francisco for existing and future conditions.[42] As noted above, an important caveat is that these are the best available future estimates and not precise predictions.

We used data on collisions resulting in injury to pedestrians and bicyclists in the City and County of San Francisco from California's Statewide Integrated Traffic Records System (SWITRS) which contains data on reported vehicle collisions on public roadways.[43] We used data on resident hospitalizations for myocardial infarction from the California Department of Public Health's Office of Statewide Health Planning and Development, and mortality data from the California Department of Public Health's Office of Vital Records.

Data caveats, uncertainties, and implications for health effects estimates are further discussed in the *Impacts Analysis* section for each specific health impact analyzed in this report; this approach to health effects characterization and uncertainty assessment is further explained in Appendix H.

E. Methods

We used the above data and ArcGIS 10, Stata 9, Microsoft Access, and Microsoft Excel software to conduct the analyses for this HIA. We include detailed summaries of the HIA methods used for each of the following key HIA outputs in the *Appendices* of this report. These methods are also summarized in their respective subsections in the Impact Analysis section of this report (Section V).

Appendix A. Methods: Population Exposure Assignment for Air Quality and Noise Impacts Estimation
Appendix B. Methods: Air Pollution Impacts on Premature Mortality
Appendix C. Methods: Noise Impacts on Community Annoyance and Myocardial Infarction
Appendix D. Methods: Active Transportation and Lives Saved from Walking and Cycling
Appendix E. Methods: Vehicle-Pedestrian Injury Collision Impacts
Appendix F. Methods and Analyses: Pedestrian Environmental Quality Index
Appendix G. Methods: Vehicle-Cyclist Injury Collision Impacts
Appendix H. Methods: Health Effects Characterization and Uncertainty Assessment

F. Health Effects Characterization and Uncertainty Assessment

Using guidance provided in *Health Impact Assessment: A Guide for Practice*, we characterized our estimated health effects based on our judgment of whether they were plausible, based on sound evidence, and logical, and also acknowledged data limitations and uncertainties.[44] Specifically, we described characteristics of the estimated health effects including likelihood, severity, magnitude, and distribution. The **likelihood** of an effect represents the degree of certainty that it will occur; **severity** of a health effect indicates its importance and intensity; **magnitude** represents how much a health outcome might change as a result of a decision course of action; and the **distribution** of effects reflects whether they are shared fairly among the affected populations. We also assessed each health effect characterization with respect to certainty in the baseline frequency of disease, assessment of exposure, and the statistical relationship between exposure and disease used to make health impacts predictions. *Appendix H* includes an excerpt from *Health Impact Assessment: A Guide for Practice* which provides a detailed summary of this approach to health effects characterization and uncertainty assessment.

IV. Baseline and Future Conditions: Populations and Traffic

In this section we describe the existing conditions in 2005 and the predicted future 2015 conditions with respect to local populations and traffic in San Francisco, California, key inputs for the HIA estimates of policy-related health impacts.

A. 2005 → 2015: Impacted Populations

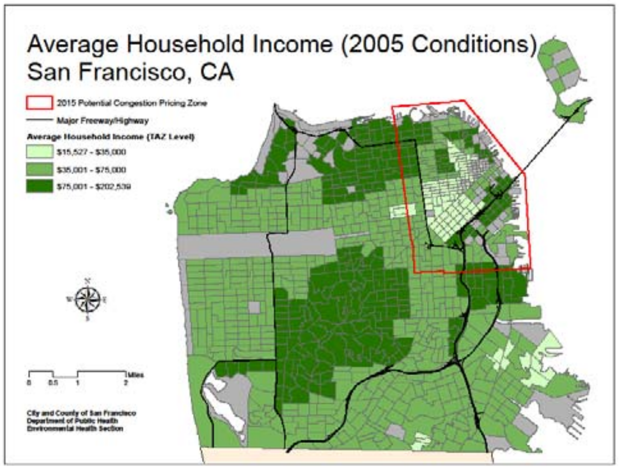


Figure 5. Average Household Income (2005, TAZ Level): San Francisco, California

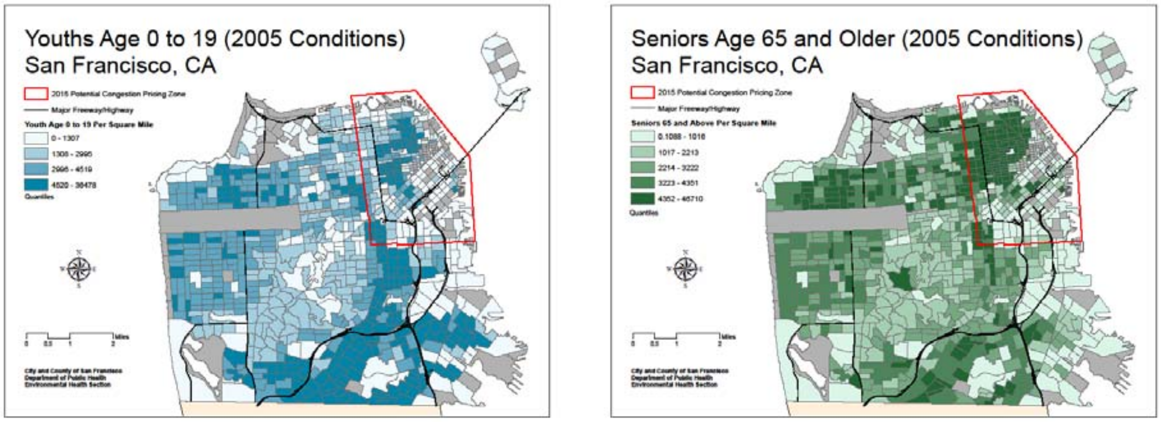
Based on our framework (Figure 4), we expect that the communities most likely to experience changes to health-relevant environmental conditions under BAU compared to a future in 2015 with congestion pricing are the residents within and proximate to the area boundaries. The congestion pricing area depicted in red in the maps in this section includes the northeast and downtown areas of San Francisco – bordered by the I-80 coming off of the Bay Bridge with off-ramps that channel commuter traffic onto local streets, 18th street to the south, and Laguna on the west. The following Table 3 compares the overall population composition in the congestion pricing area with that outside the pricing area based on a number of key population demographic indicators estimated for 2005 and 2015 conditions. This potential congestion pricing zone is comprised of a diversity of neighborhoods including San Francisco's downtown business district, Union Square, North Beach, Russian Hill, Chinatown, the Marina, Pacific Heights, Nob Hill, Downtown Civic Center, the Tenderloin, off/on ramps from the Bay Bridge, as well as South of Market, Mission Bay, and northern Potrero Hill (a map including neighborhood boundaries and neighborhood names is included in Appendix I). These neighborhoods are diverse in terms of socioeconomic status, representing some of the poorest and wealthiest communities in the city – with an evident concentration of low income communities in the congestion pricing area (Figure 5). While a lower proportion of children and youth live in the congestion pricing area (11%, 2005) compared to the area outside the zone (18%, 2005) – there are evident concentrations of children and youth in the area, particularly in and around Chinatown and the Tenderloin communities (Figure 6). A slightly higher proportion of the population in the congestion pricing area is aged 65 and older (16%, 2005) compared to populations living outside of the area (13%, 2005).

Table 3. Population Characteristics in 2005 (Existing Conditions) and 2015 (Projected): San Francisco, California

Population Characteristics	2005	2015	2005 → 2015 (*% Change*)
Residents (N)			
Citywide	796,000	824,000	**4%**
Outside Pricing Zone	624,000	641,000	**3%**
In Pricing Zone	172,000	183,000	**6%**
Employees (N)			
Citywide	553,000	637,000	**15%**
Outside Pricing Zone	188,000	208,000	**11%**
In Pricing Zone	365,000	429,000	**18%**
Average Household Income (%, TAZ level)			
Citywide			
< $35,000	14%	13%	**-1%**
$35,000 - 70,000	60%	57%	**-3%**
>$70,000	26%	30%	**4%**
Outside Pricing Zone			
< $35,000	3%	3%	**-1%**
$35,000 - 70,000	71%	67%	**-4%**
>$70,000	25%	31%	**5%**
In Pricing Zone			
< $35,000	41%	38%	**-3%**
$35,000 - 70,000	32%	34%	**3%**
>$70,000	27%	28%	**1%**
Children (% of population, age 0-4)			
Citywide	4%	4%	**0%**
Outside Pricing Zone	5%	5%	**0%**
In Pricing Zone	3%	3%	**0%**
Youth (% of population, age 5-19)			
Citywide	12%	11%	**-1%**
Outside Pricing Zone	13%	12%	**-1%**
In Pricing Zone	8%	7%	**-1%**
Seniors (% of population, age 65 and older)			
Citywide	13%	15%	**2%**
Outside Pricing Zone	13%	14%	**1%**
In Pricing Zone	16%	17%	**1%**
People of Color (% of population)			
Citywide	46%	*na*	*na*
Outside Pricing Zone	46%	*na*	*na*
In Pricing Zone	44%	*na*	*na*

The area of focus for congestion pricing draws a diversity of employees and visitors; this area includes the Financial District, City Hall and numerous local government buildings, Fisherman's Wharf, shopping and theater districts, and AT&T Park (home of the San Francisco Giants baseball team). As detailed in Table 3, approximately two-thirds of individuals employed San Francisco work in the congestion pricing target area.

Figure 6. Youth and Senior Population Densities in San Francisco, California: 2005 Conditions



As depicted in the maps in Figures 7 - 8, in 2015 there are projected increases in both residential and employee populations in San Francisco, most notably in the southeast section of the potential congestion pricing zone area (outlined in red). Specifically, we see resident population increases from 2005 to 2015 of 4% citywide, the increase in the congestion pricing area (6%) double that in areas outside the zone (3%). Employment increases in 2015 area also more concentrated in the congestion pricing study zone (Figure 8). The potential congestion pricing zone accounts for approximately 17% of the city's land area, 22% of San Francisco's residents, 66% of San Francisco employees, and approximately one-third of the city's aggregate traffic volume in the study scenarios (see next section).

Figure 7. Residential Population in 2005 and Projected Percent Change in 2015: San Francisco, California

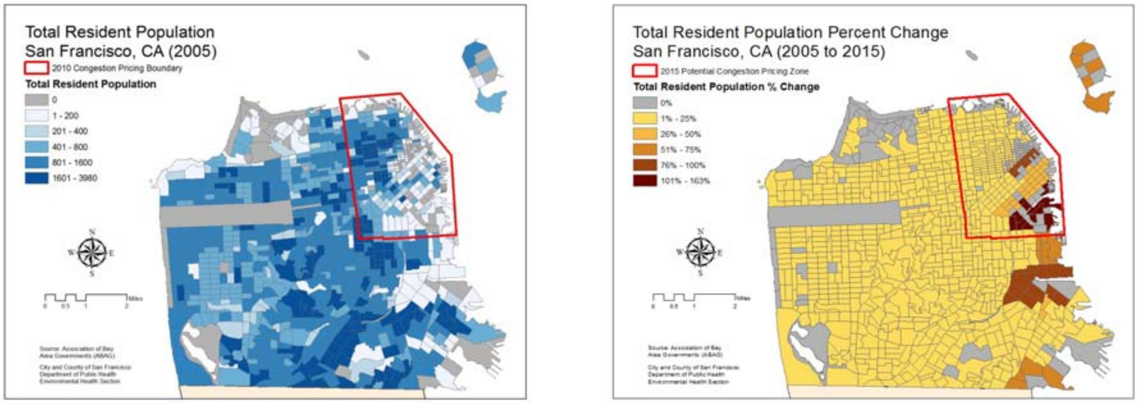
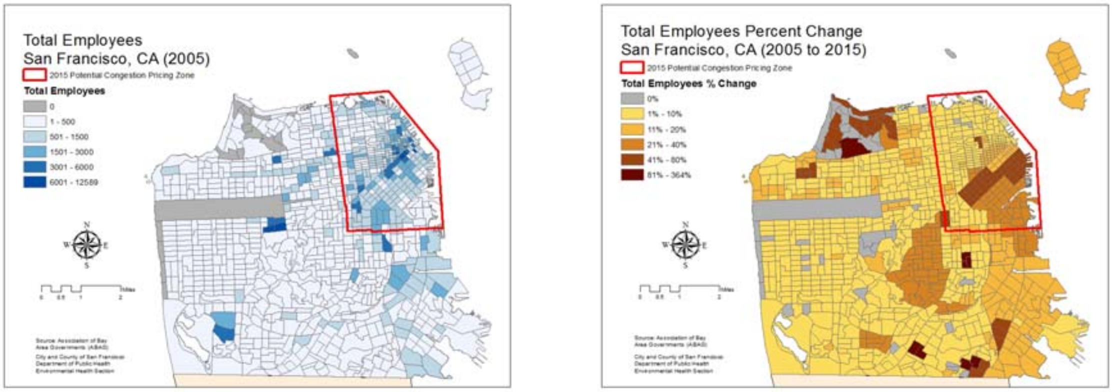


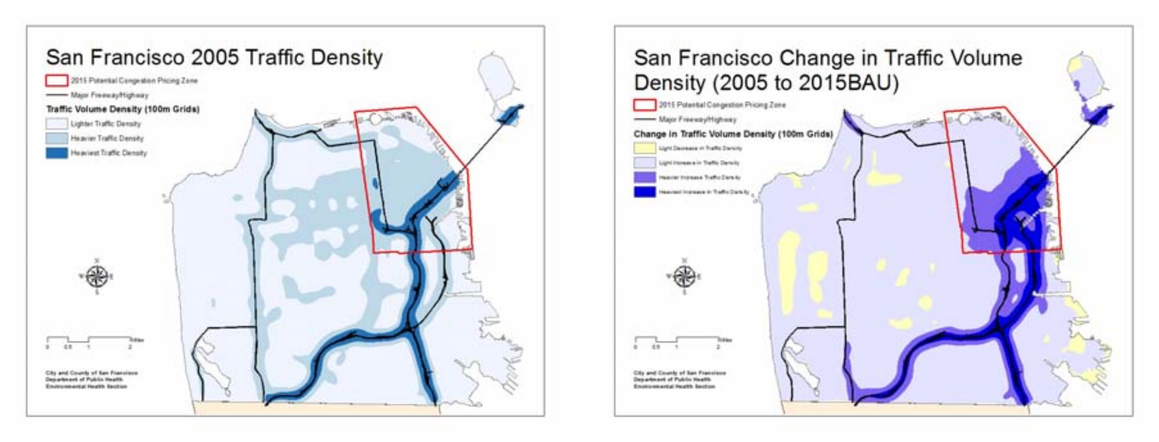
Figure 8. Employee Population in 2005 and Projected Percent Change in 2015: San Francisco, California



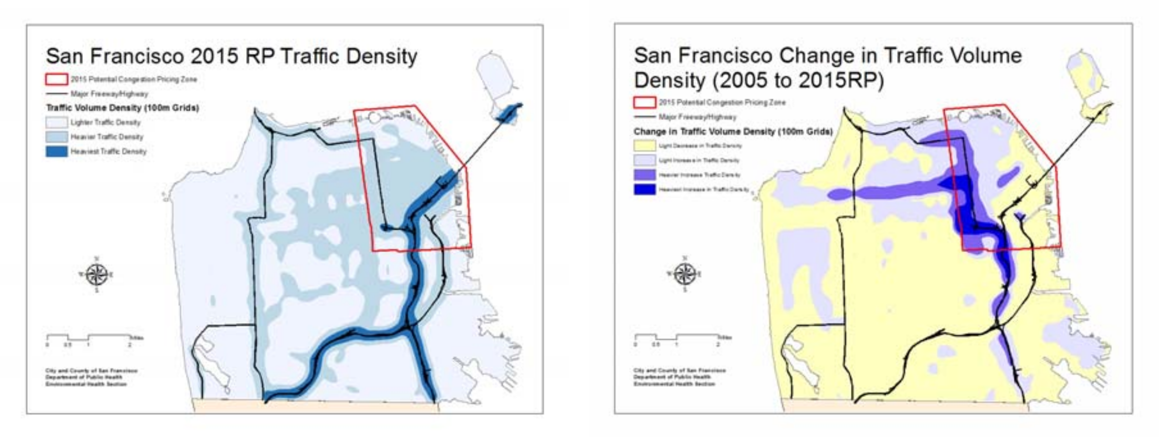
B. 2005 → 2015: Traffic Impacts

Based on the SFCTA model SF-CHAMP, there are over 4 million trips to, from, and within the city each day in 2005 conditions – approximately half of which are made by people starting trips from outside of the city. The following maps (Figure 9) depict traffic density and changes in traffic density under the three study scenarios. Map A illustrates traffic density in 2005 conditions, while Map B depicts changes in traffic density from 2005 – 2015 BAU, illustrating increases in traffic on the local streets in the already heavily trafficked congestion pricing target area as well as along San Francisco's freeways as regional traffic increases. Map C and Map E illustrate traffic density in the 2015 scenarios under business and usual versus with road pricing; Map D visualizes that spatial distribution of changes in traffic density between 2015 BAU and 2015 RP. As evident in Map D, relative to traffic density in 2015 BAU, there are traffic increases in 2015 RP on the southern edges of the road pricing boundary in the Castro area of San Francisco as well as in the Mission. There is also an increase along the northern part of Highway One which runs north and south along the western side of the City, near the Presidio and the exit off the Golden Gate Bridge.

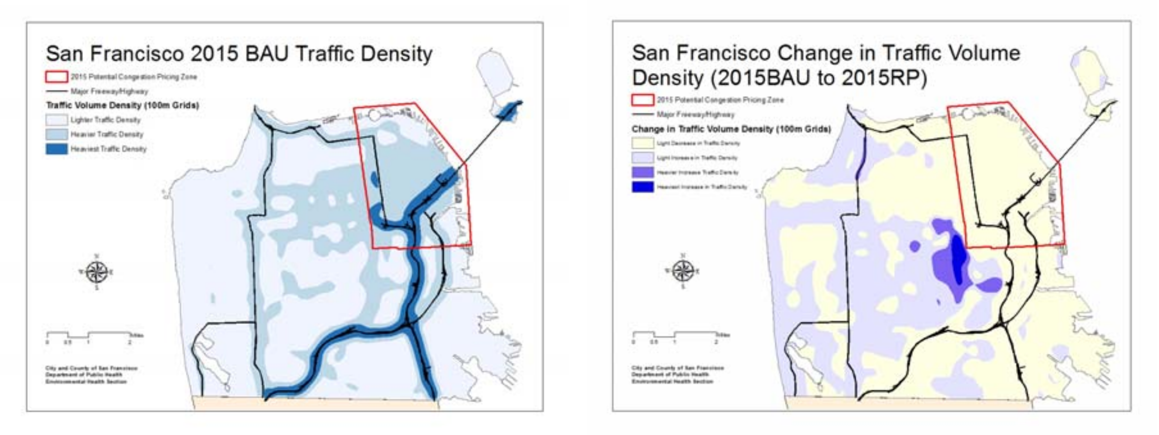
Figure 9. Traffic Volume Density in 2005, 2015 BAU, and 2015 RP: San Francisco, California



Map A. 2005 Traffic Density ***Map B. Change in Traffic Density: 2005 → 2015 BAU***



Map C. 2015 RP Traffic Density ***Map D. Change in Traffic Density: 2005 → 2015 RP***



Map E. 2015 BAU Traffic Density ***Map F. Change in Traffic Density: 2015 BAU → 2015 RP***

As detailed in the following table, from 2005 to 2015 BAU, traffic citywide is estimated to increase approximately 7% - with the increase in the congestion pricing zone (10%) double that in areas outside the zone (5%). With the introduction of road pricing in 2015, traffic is estimated to decrease citywide by 4%, with traffic reductions largely in the pricing zone (11% vs. <1% outside the pricing zone).

Table 4. Traffic Volume (Aggregated, Segment Level) in 2005, 2015 BAU, and 2015 RP Conditions Citywide, Outside and Inside the Potential Road Pricing Zone: San Francisco, CA

Traffic Volume (Aggregated)	2005	2015 BAU	2015 RP	2005 → 2015 BAU (*% Change*)	2005 → 2015 RP (*% Change*)	2015 BAU → 2015 RP (*% Change*)
Citywide	80,032,000	85,431,000	81,800,000	**7%**	**2%**	**-4%**
Outside Pricing Zone	52,675,000	55,346,000	55,108,000	**5%**	**5%**	**-0.4%**
In Pricing Zone	27,357,000	30,085,000	26,692,000	**10%**	**-2%**	**-11%**

Notably, land use and transportation policy decisions in San Francisco have directed increased residential densities along central city transportation corridors and on lands that were formerly industrial uses.[45] Several of the areas experiencing increases in residential density have high existing traffic densities, yet a low level of car ownership and higher levels of local and regional transit access (e.g., the South of Market). Other locations with planned growth are more vehicle-oriented - further from the downtown core with few local businesses and retail services (e.g., Potrero Hill and Mission Bay). As detailed in Figure 7 and Table 4, most of this new residential development – and associated increases in vehicle trips under BAU conditions - are more concentrated in the congestion pricing zone. Forecasted increases in residents and in traffic in growth areas result in increased conflicts among residential and transportation uses. Changes in transportation-attributable health effects under 2015 BAU conditions reflect these conflicts.

V. Impact Analysis

This section summarizes the results of our health impacts analysis. The subsections are organized around health determinants selected in scoping: vehicle air pollutants, traffic-related noise, active transportation, vehicle-pedestrian injury collisions, and vehicle-cyclist injury collisions. For each determinant, we provide:

- Discussion of causal effects related to exposure factors and health determinants
- Analysis of changes in proximate exposure factors and health determinants
- Quantitative analysis of one or more health outcomes
- Overall characterization of health effects
- Certainty in health effects characterization

We also include separate subsections assessing health equity with respect to traffic exposure as measured by traffic density and costs of traffic-related health impacts where monetary valuations are available.

As noted in the earlier discussion regarding the HIA data sources and methods, there are two caveats relevant for all of the analyses:

- Forecasted health effects are based on estimated changes in transportation conditions and populations (as described in *Section III*) estimated with the best available models, however actual population and transportation conditions, and thus associated health effects, may ultimately vary from these estimates. Errors in population and transportation forecasts are not likely to be different in proportion or magnitude among areas inside vs. outside the congestion pricing zone, providing more confidence regarding the estimated relative differences in health effects among the different scenarios.

- Health impacts of 2015 RP are estimated based on SFCTA SF-CHAMP model outputs that *do not* include programmatic improvements and mitigations that would be implemented with funding from road pricing subsequent to programmatic implementation or because of requirements for programmatic environmental mitigations. These improvements and mitigations might include traffic calming, streetscape and landscape improvements, and school ridesharing. These enhancements will be further evaluated in the next phase of the SFCTA's study.

A final note is that we refer to the area that would be included in the potential Northeast (AM/PM) Cordon Scenario boundaries as the Congestion Pricing Zone in the tables reporting the results of the analyses of 2005, 2015 BAU, and 2015 RP scenarios. Notably, the only scenario in which there is a theoretical road pricing zone and associated boundaries is the 2015 RP scenario. Under 2005 and 2015 BAU conditions, we thus use the term "Congestion Pricing Zone" (or "Road Pricing Zone," in the text) solely as a spatial reference to the area included in the potential Northeast Cordon Scenario boundaries.

A. Vehicle Air Pollutants

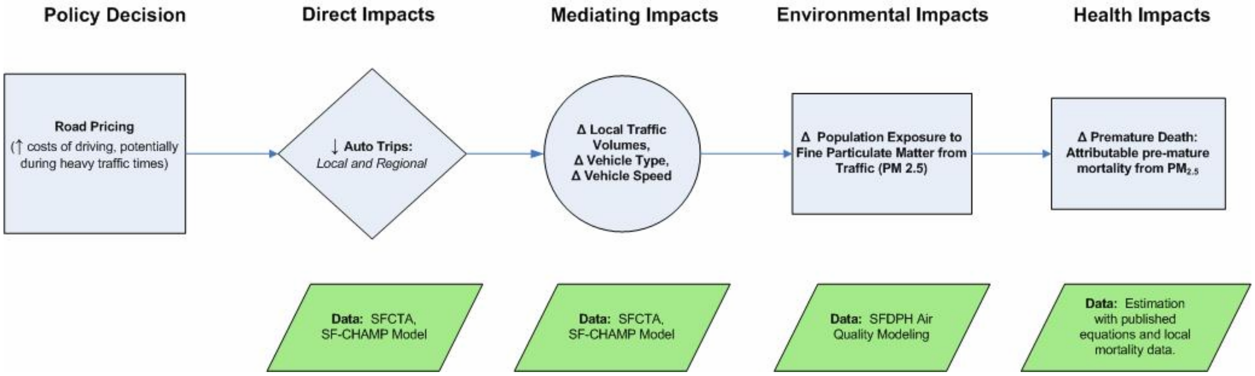
Health effects of roadway vehicle air pollutants

Engine exhaust from diesel and gasoline engines in roadway vehicles is a complex mixture of particles and gases. Air pollutants in vehicle exhaust include carbon monoxide (CO), particulate matter (PM), and nitrogen oxides (NOx), as well as other non-criteria toxic air contaminants such as benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, naphthalene, and diesel exhaust. Particulate matter, carbon monoxide, nitrogen dioxide, and ozone have well-established causal relationships with human health and are subject to nationwide ambient air quality standards, monitoring and control requirements under the Federal Clean Air Act.[46]

This report did not focus on the effects of other vehicle emissions, including ozone precursors and fine particulate matter which have important health effects over a broader spatial area. The location of roadways and other transportation facilities – and the amount of traffic associated with those facilities - determines the spatial patterns of exposure to several traffic-related air pollutant emissions from vehicle sources in urban areas. A 2007 meta-analysis based on 33 exposure studies and four pollutants - carbon dioxide, nitrogen oxides, particulates and ultra-fine particulates - found significant spatial differences exist in multiple traffic-related air pollutants relative to proximity to busy roadways.[47] Research in some locations based on measurements of fine particulate matter ($PM_{2.5}$) found that a significant share of spatial intra-urban air pollution variation in ambient levels of $PM_{2.5}$ is due to local traffic sources,[48] and that traffic density explains variation in local and regional $PM_{2.5}$ concentrations.[49] Studies on traffic proximity assess the effects of exposure to traffic-related air pollutants *collectively,* as a mixture.[50] A Health Effects Institute (HEI) Report in 2008 concluded that "Evidence was 'sufficient' to infer a causal relationship between exposure to traffic-related air pollution and exacerbation of asthma and 'suggestive' to infer a causal relationship with onset of childhood asthma, non-asthma respiratory symptoms, impaired lung function, and total and cardiovascular mortality."[51] Individual epidemiological studies associate roadway proximity or vehicle emissions to impairments of lung function; [52] asthma symptoms; [53] medical visits for asthma;[54] asthma prevalence and incidence; [55] and ischemic heart disease.[56]

Figure 10 details the pathway through which road pricing policy contributes to air pollution and related health effects. Specifically, road pricing contributes to decreases in auto trips and resulting local traffic volumes as well as changes in local traffic speeds. This in turn results in changes to vehicle pollution emissions and an associated range of health effects.

Figure 10. Health Effects of Road Pricing Policy Mediated by Air Pollution



The pathway in Figure 10 is specific for $PM_{2.5}$ and premature mortality but the framework also applies to other vehicle emissions and health effects. Pollutants with important vehicle sources are identified in Table 5. Reviews of causal evidence linking individual pollutants and health outcomes can be found in several authoritative US Environmental Protection Agency (USEPA) scientific reviews including those conducted by the **Clean Air Scientific Advisory Committee** (CASAC) on Clean Air Act criteria pollutants.[57]

Table 5. Air Pollutants with Important Motor Vehicle Sources and Associated Health Effects

	Air Pollutant	Source	Health Effects
Criteria Pollutants	**Ozone**	Tropospheric ozone is formed in the atmosphere from chemical transformation of certain air pollutants in the presence of sunlight. Ozone precursors include vehicles, other combustion processes and the evaporation of solvents, paints, and fuels	Eye irritation, airway constriction, and shortness of breath and can aggravate existing respiratory diseases such as asthma, bronchitis, and emphysema.
	Carbon Monoxide (CO)	Produced due to the incomplete combustion of fuels, particularly by motor vehicles	Reduced oxygen-carrying capacity of the blood resulting in fatigue, impaired central nervous system function, and induced angina.
	Particulate Matter ***(PM_{10} and $PM_{2.5}$)***	Diverse sources including motor vehicles (tailpipe emissions as well as brake pad and tire wear, wood burning fireplaces and stoves, industrial facilities, and ground-disturbing activities	Impaired lung function, exacerbation of acute and chronic respiratory disease, including bronchitis and asthma, emergency room visits and hospital admissions, and premature death.
	Nitrogen Dioxide (NO_2)	Combustion processes in vehicles and industrial operations	Acute and chronic respiratory disease
	Sulfur Dioxide (SO_2)	Combustion of sulfur-containing fuels such as oil, coal, and diesel	Acute and chronic respiratory
Non-criteria Pollutants	***Diesel exhaust***	Diesel engines	Probable human carcinogen (IARC Group 2A)
	Benzene	Gasoline engines	Known human carcinogen (IARC Group 1A)
	1,3 butadiene	Motor vehicle engines	Probable human carcinogen (IARC Group 2A)
	Benzo(a) pyrene	Motor vehicle engines	Probable human carcinogen (IARC Group 2A)

Analysis of Traffic-Attributable Fine Particulate Matter ($PM_{2.5}$) and Mortality

In general, reductions in air pollution sources in populated areas result in relatively proportional reductions in air pollution exposure and air pollution-attributable health effects. Traffic represents only one source of air pollution, thus the reductions in pollutant concentrations associated with a change in traffic trips and volume depends on the traffic-attributable share of the pollutant. For example, research shows that local traffic sources are responsible for roughly 20-30% of the intra-urban variation in respirable particulate matter and roughly 60-70% of the intra-urban variation of Nitrogen Dioxides in urban areas in the United States.[58]

While it is possible to estimate quantitatively the effects on multiple health outcomes for several distinct pollutants, we chose to apply estimation methods only to one pollutant-outcome relationship: premature mortality associated with chronic exposure to $PM_{2.5}$. We selected this particular outcome for the following reasons: the severity of the health outcome (pre-mature mortality); the established causal relationship between exposure to $PM_{2.5}$ and pre-mature mortality; the availability of exposure-response functions utilized in existing regulatory impacts assessment by the USEPA and the California Air Resources Board; and existing SFDPH technical capacity to model community-level traffic attributable changes in $PM_{2.5}$ concentrations. Detailed methods for the quantitative assessment are provided in Appendix B. ***The fact that we limited our analysis to one health outcome means that the quantitative estimates do not capture the full spectrum of health effect of changes in air pollution in the different scenarios.***

The following maps (Figure 11) depict traffic-attributable $PM_{2.5}$ in three scenarios: 2005, 2015 BAU, and 2015 RP. We estimated increases in the highest levels of $PM_{2.5}$ from 2005 (upper left) to 2015 BAU (upper right) in the area inside the road pricing boundary and along the freeways and highways. When comparing 2015 RP (lower right) to 2015 BAU (upper right) we see minor decreases within the cordon particularly in areas with relatively higher baseline concentrations along with minor increases in the areas just outside of the cordon boundary due to moderate increases in traffic volumes on the edges of the zone as detailed in Figure 9, Map D.

Figure 11. Traffic attributable fine particulate matter ($PM_{2.5}$) modeled in 2005, 2015 "Business As Usual" (BAU) and 2015 with Road Pricing (RP) Conditions: San Francisco, California

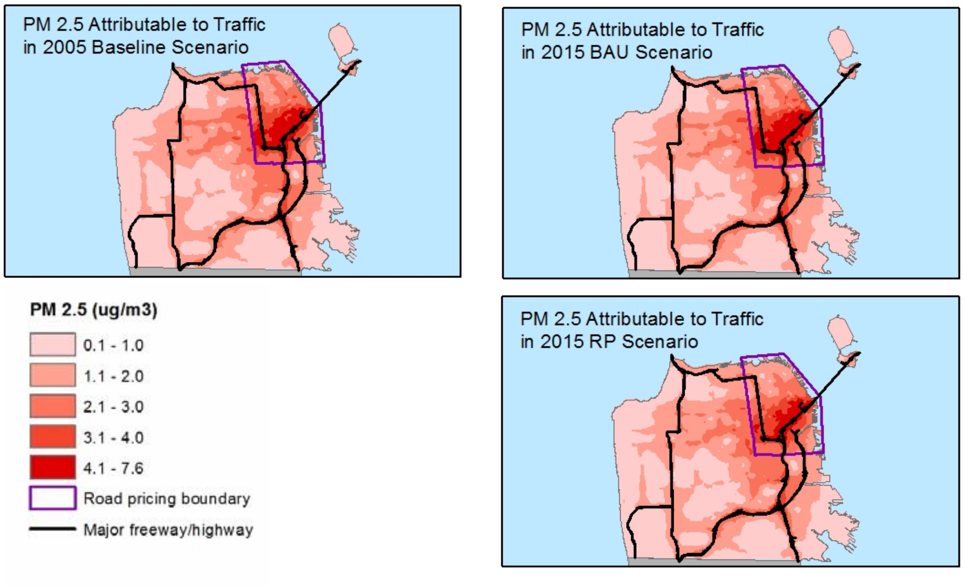


Table 6a and 6b provide a tabular summary of the differences among the scenarios documenting the proportional increase or decrease in share of the San Francisco population exposed to varying levels of traffic attributable PM$_{2.5}$. Table 6a provides estimates of this change for 2005 → 2015 BAU conditions and Table 6b provides the estimates for 2015 BAU → 2015 RP conditions.

Table 6a. Estimated Traffic Attributable Fine Particulate Matter (PM$_{2.5}$) Levels and 2015 Residential Population Exposures in 2005-2015 BAU: San Francisco, California (n=824,000)

	2015 BAU					
2005	**0.1-0.2**	**0.3-1.0**	**1.1-2.0**	**2.1-3.0**	**3.1-4.0**	**4.1-6.7**
0.1-0.2	0.2%	-	-	-	-	-
0.3-1.0	0.0%	26%	0.5%	-	-	-
1.1 -2.0	-	0.9%	36%	0.6%	-	-
2.1-3.0	-	-	1.1%	23%	0.6%	-
3.1-4.0	-	-	-	0.4%	7%	0.8%
4.1-6.7	-	-	-	-	-	4%

SUMMARY: 2015 Residents Experiencing Impacts (%)

No Change	***95%***
Reduction from 2015 BAU with 2015 RP	***2%***
Increase from 2015 BAU with 2015 RP	***3%***

Overall, under 2015 BAU relative to 2005, 95% of the population does not see a substantial change in PM$_{2.5}$ exposure. However, 2% of residents would experience decreases in exposure relative to 2005 levels, and 3% would have increases in exposure relative to 2005 levels. Importantly, residents experiencing increases in exposure tend to be those already in higher exposure areas in 2005.

Table 6b. Estimated Traffic Attributable Fine Particulate Matter (PM$_{2.5}$) Levels and 2015 Residential Population Exposures in 2015-2015 RP: San Francisco, California (n=824,000)

	2015 RP					
2015 BAU	**0.1-0.2**	**0.3-1.0**	**1.1-2.0**	**2.1-3.0**	**3.1-4.0**	**4.1-6.7**
0.1-0.2	0.2%	0.0%	-	-	-	-
0.3-1.0	0.0%	26%	0.7%	-	-	-
1.1 -2.0	-	1.0%	36%	0.7%	-	-
2.1-3.0	-	-	3%	20%	0.4%	-
3.1-4.0	-	-	-	4%	4%	-
4.1-6.7	-	-	-	-	2%	3%

SUMMARY: 2015 Residents Experiencing Impacts (%)

No Change	***88%***
Reduction from 2015 BAU with 2015 RP	***10%***
Increase from 2015 BAU with 2015 RP	***2%***

Under 2015 RP relative to 2015 BAU exposure levels, 88% of the population does not see a substantial change in PM$_{2.5}$ exposure. Ten percent of residents would have decreases in exposure relative to 2015 BAU levels, and these decreases are experienced across the range of 2015 BAU exposure levels including the highest exposure category (4.1-6.7). 2% of residents would have increases in exposure in 2015 RP relative to 2015 BAU levels.

Using the estimated changes in concentrations of PM$_{2.5}$ (methods detailed in Appendix B) and the population exposure assignment method detailed in Appendix A, we estimated the impact of pollutant concentration changes on pre-mature mortality. As detailed in the following summary, we estimate an increase in premature deaths attributable to PM$_{2.5}$ from 2005 – 2015 BAU, with an increase of one death citywide and two deaths in the cordon zone (the larger increase in deaths in the congestion pricing zone relative to citywide explained by variation in estimated net changes in $PM_{2.5}$ exposure for residents across the city largely explained by changes in vehicle volume). Under 2015 RP, we estimate a reduction of three deaths annually compared to BAU conditions – all in the area that is the focus of the congestion pricing policy.

Table 7. Mortality Attributable to Traffic-related $PM_{2.5}$ in 2005, 2015 Business As Usual, and 2015 with Road Pricing Conditions: San Francisco, California

Health Impacts (Annual Estimates)	2005	2015 BAU	2015 RP	Change: 2005 → 2015 BAU	Change: 2005 → 2015 RP	Change: 2015 BAU → 2015 RP
Air Pollution, Mortality Attributable to Traffic-related PM 2.5 (N, Ages 30 and up)						
Citywide	65	66	63	1	-2	-3
Congestion Pricing Zone	24	26	23	2	-1	-3

Health Effects Characterization: Air pollutant Health Effects

Table 8 summarizes our overall characterization of the health effects of the road pricing policy under study on premature mortality predicted by traffic-attributable $PM_{2.5}$. Based on the available evidence: there is a ***high likelihood*** that the proposed policy will reduce pre-mature mortality due to respirable particulate matter exposure health; the ***severity*** of the effect— including acute and chronic respiratory diseases and mortality—is ***high***; the ***magnitude*** of the predicted decrease in premature deaths is ***limited*** relative to 2015 BAU; and the reduction of deaths particularly in the cordon zone contributes to a ***restorative equity effect***.

Table 8. Road Pricing Policy Health Effects Characterization: Traffic Attributable $PM_{2.5}$ and Premature Mortality

Health Effects: Characteristics	Interpretation	Characterization
Overall Assessment	Based on the following health effects characterization and uncertainty factors regarding the magnitude of estimated effects, what is the overall assessment of confidence in the health effects estimate?	**High-Moderate**
Likelihood	How certain is it that the road pricing policy under study will affect traffic-related premature mortality, irrespective of the frequency, severity, or magnitude of the effect?	**Very Likely/Certain**: Consistent evidence for causality from epidemiologic studies with diverse populations, pollution mixes, and exposure range, as well as evaluation studies of congestion pricing in other countries.
Severity	How important is the effect on traffic-attributable ($PM_{2.5}$) premature deaths with regards to human function, well-being or longevity, considering the affected community's current ability to manage the health effects?	**High:** The impacts on $PM_{2.5}$ are associated with reductions in mortality.
Magnitude	How much will traffic-attributable ($PM_{2.5}$) premature deaths change as a result of the road pricing policy under study?	**Limited (High-Moderate Certainty)**[a]: Compared to 2015 BAU, 2015 with RP contributes to a decrease in 3 traffic-attributable ($PM_{2.5}$) premature deaths each year.
Distribution	Will the effects be distributed equitably across populations? Will the road pricing policy under study contribute to a reversal of baseline inequities?	**Restorative Equity Effects**: Populations in the cordon zone have been historically, disproportionately burdened with traffic-attributable air pollution in their communities. The road pricing policy under study has the potential to reduce some of this inequity and related deaths.

a See Table 9 for a summary of factors impacting on the certainty of the magnitude of the health effects characterization.

Certainty in Magnitude of Health Effects

The quantitative analysis of the magnitude of the impacts on premature mortality includes a number of assumptions and parameters with uncertainty as summarized in Table 9. These uncertainties informed the level of confidence of the health effect characterization summarized in Table 9. Two major uncertainties relate to predicting exposure and the validity of the exposure response function.

Exposure analysis depends on accuracy both in traffic changes as well as the emissions model. As stated in Section III, we used SF-CHAMP model outputs as our best available estimates of traffic in the three scenarios. The EMFAC 2007 emissions model used in this analysis accounts for vehicle types and emissions in current and future years. EMFAC 2007 does not fully account for emissions reductions likely to occur in the future, for example, with California regulations on greenhouse gas emissions from passenger vehicles authorized by California Assembly Bill 1493 (Pavley). Estimation of the impacts of these regulations has been largely focused on greenhouse gases as opposed to fine particulates. A conservative assumption made for this analysis is that the proportion of traffic comprised of trucks does not change across time or scenarios. Also, given the nature of the San Francisco bus fleet, bus volumes are not included in the traffic inputs. Given anticipated fleet conversions to alternative fuels,[59] we do not anticipate changes in on-road transit vehicles would contribute to significant changes in exposure and resultant health impacts.

The exposure-response function (ERF) is based on studies conducted in diverse contexts and is applicable to the San Francisco context. However, the studies used to develop the ERF examine the effects on health of inter-regional differences in pollutants. This analysis applies those ERFs to within-region concentration differences. Some have argued that ERFs based on inter-regional studies may under-estimate the slope of the concentration-response relationship.[60] We also assume that we can extrapolate the ERF to the exposure range found in San Francisco. The range of exposure in our analysis is within the range of the studies used to define a E-R relationship for $PM_{2.5}$. Scientific evidence has not established a threshold below which effects of $PM_{2.5}$ on mortality do not occur. The ERF does not account for differential vulnerability. Vulnerability or resilience factors to air pollution health effects may vary within study area. Our approach does not account for socio-economic factors including poverty, education, and employment that may modify the effect of $PM_{2.5}$ on mortality.

Our quantitative analysis modeled primary $PM_{2.5}$ emissions and did not include the influence of reducing NOx emissions on secondary ammonium nitrate (particle) formation. This omission is likely to underestimate the potential health benefits of road pricing.

It is important to note that bicycle commuters receive relatively high doses of air pollution compared with car commuters, given increased time in traffic, proximity to sources, and elevated minutes of ventilation – though not likely enough to counterbalance the physical activity benefits.[61] Increases in air pollution exposure associated with active transportation were not considered in the analysis of air pollution effects.

Table 9. Uncertainty Factors Regarding the Magnitude of Estimated Health Effects for Traffic-related $PM_{2.5}$ and Premature Mortality

Factors Affecting Certainty	Assessment Approach	Summary Confidence Level
Exposure Assessment	Reliable small level population estimates. Method for parcel level assignment not validated but defensible. Validated traffic volume estimates. Assuming share of truck traffic remain constant using EMFAC emissions models. Bus volumes not included; would not anticipate significant changes in impacts due to fleet conversions to alternative fuels. Emissions models (EMFAC) valid in base and future years. High uncertainty with precision of dispersion model in urban environment. Model approach has been validated based on limited measured values.	Moderate
Baseline Disease Prevalence	Mortality Rate: County-level data from vital statistics.	High
Exposure-Response Function (ERF)	Modest variation in ERF in the most reliable studies. ERF not specific to San Francisco but applicable in exposure range according to CARB expert consensus. ERF does not take into account differential vulnerability within the SF population.	Moderate

B. Road Traffic Noise

Health Effects of Road Traffic Noise

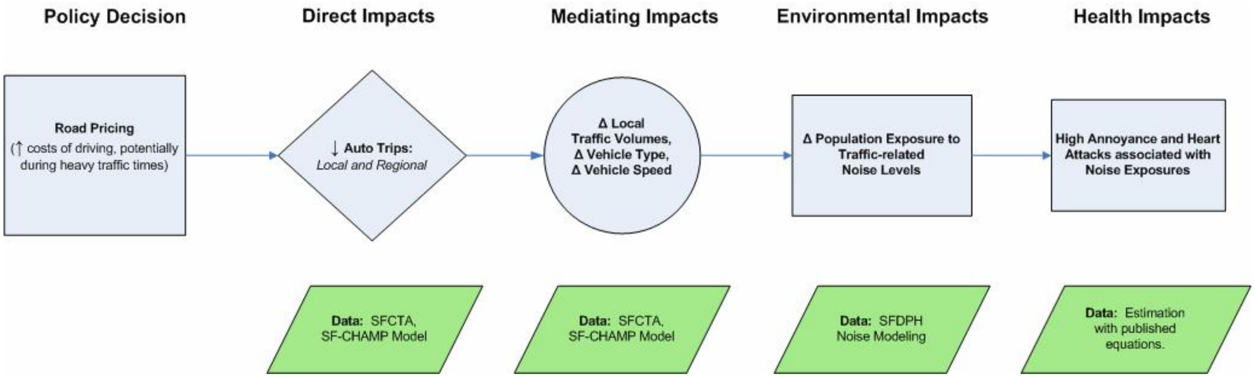
Roadway vehicles represent the primary source of urban environmental noise.[62] Exposure to noise is a function of the distance from roadways, vehicle volume, vehicle and engine type, operating speed, and roadway conditions. Health effects of environmental noise, including roadway noise, depend on the intensity of noise, on the duration of exposure, and the context of exposure. While individual sensitivity to noise may vary substantially, moderate levels of noise can limit or interfere with the ability to conduct daily tasks and activity— to have an ordinary conversation, enjoy a leisure activities, rest, sleep, concentrate or get tasks done. Noise annoyance is defined as "a feeling of resentment, displeasure, discomfort, dissatisfaction, or offense when noise interferes with someone's thoughts, feelings, or actual activities."[63]

Sufficient scientific evidence documents that chronic exposure to moderate levels of noise below levels required for mechanical damage to hearing can result in other health and physiological impacts including cognitive impairment, decreased school performance, sleep disturbance, and hypertension and ischemic heart disease.[64] Numerous well designed studies also show that children exposed to chronic transportation noise have deficits in school performance and educational outcomes.[65]

As a physiological stressor that affects the autonomic nervous system and the endocrine system, noise may harm the cardiovascular system. Substantial emerging evidence links moderate levels of traffic noise (>65 dB(A)) to hypertension and ischemic heart disease.[66] In a meta-analysis of 43 studies of noise exposure and heart disease published in 2002, road traffic noise was associated with higher risk for myocardial infarction and ischemic heart disease than in the general population, and air traffic noise was associated with consultation with a doctor about heart problems, use of cardiovascular medications, and angina pectoralis.[67] In the same meta-analysis, exposure to air traffic noise was statistically associated with hypertension with an estimated relative risks per 5 dB(A) noise increase of 1.26 (1.14-1.39). In a 2009 meta-analysis, Babisch synthesized a dose-response function between increasing noise levels above 60 dB(A) and cardiovascular risk.[68] A large study published in 2009 found a notable effect of noise on hypertension at > 64 dB(A) (OR 1.45, 95% CI 1.04 - 2.02) with age acting as an effect modifier (effects in middle aged 40-59).[69]

Figure 12 illustrates the causal pathways through which road pricing policy may impact health via changes in traffic-related noise. Similar to the pathway for air pollutant impacts, road pricing increases the cost and therefore reduces the demand for auto trips. Consequentially, pricing could decrease local traffic volumes, resulting in less traffic-related noise and diminishing its resulting health impacts. Changes in the composition of traffic based on vehicle type (e.g., increases in buses) may counterbalance reductions in noise associated with reduced traffic volumes. Increases in speed could also contribute to increased noise.

Figure 12. Pathway from Road Pricing Policy to Traffic-Related Noise Health Impacts

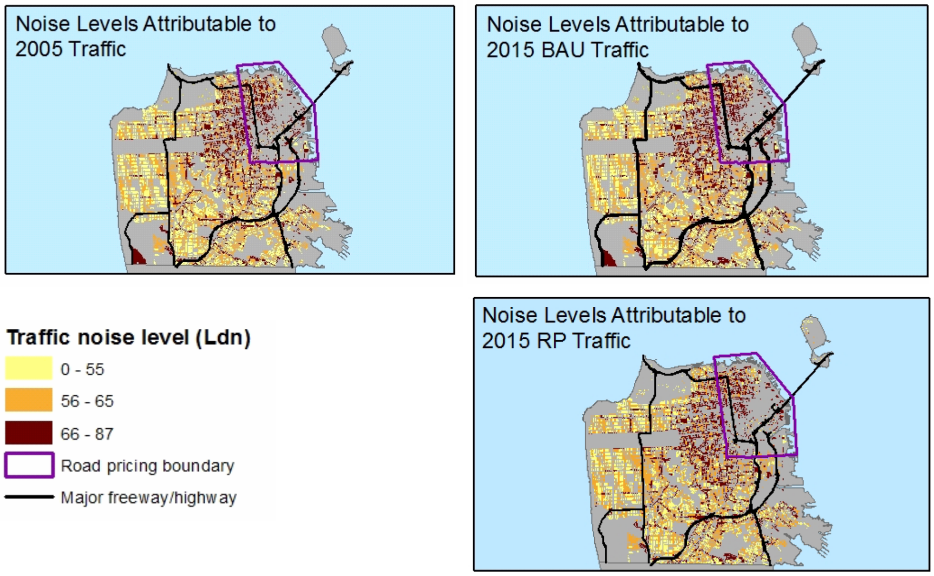


Analysis of Traffic-Attributable Noise Levels and Associated Health Impacts

As discussed above, traffic noise is causally associated with numerous effects on health, and changes in the population exposure to traffic noise would be expected to result in corresponding changes to population health. To evaluate the magnitude of the effect, we first modeled how traffic-attributable noise levels in San Francisco would change given the alternative scenarios. We then calculated the effect of the changes in noise levels on two outcomes—community annoyance and heart attacks. Analytic methods are described in Appendix C.

The maps in Figure 13 depict traffic-attributable noise levels in three scenarios: 2005**,** 2015 BAU, and 2015 RP at the residential parcel level. The highest noise levels are concentrated in and on the boundaries of the congestion pricing zone area – with noise levels elevated near freeways and highways and increasing from 2005 (upper left) to 2015 conditions both under BAU (upper right) and with road pricing (lower left). These differences in noise levels are predicted by streets with higher traffic volumes, slower congested speeds, and higher proportions of traffic comprised of trucks and/or buses proximate to residential uses.

Figure 13. Traffic attributable modeled noise levels in 2005, 2015 BAU, and 2015 RP: Residential Parcels in San Francisco, California



With regards to health, noise levels shown on the maps can be interpreted using thresholds or values for noise levels compatible with human activities and health. For example, human speech can be understood readily at background noise levels of 45 dBA, but humans require much more vocal effort to be understood when the background noise level is about 65 dBA. Table 10 provides guidance values for health-protective levels of noise in specific environments. The World Health Organization developed these guidelines based on a review of critical noise-related health effects.[70] The values in the table reflect desirable and health protective levels of noise; however, it is important to note that they have been developed without regard to context or feasibility and are not regulatory standards.

Table 10. World Health Organization Guideline Values for Community Noise in Specific Environments (1999)

Specific environment	Critical Health effect(s)	LAeq [dB(A)]	Time base [hours]	LAmax fast [dB]
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility & moderate annoyance, daytime & evening Sleep disturbance, night-time	35 30	16 8	- 45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms & preschools, indoors	Speech intelligibility, disturbance of information extraction, Message communication	35	during class	-
Pre-school bedrooms, indoor	Sleep disturbance	30	sleeping time	45
School, playground outdoors	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40
Hospital treatment rooms, indoors	Interference with rest and recovery	*(#1)*		
Industrial commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music and other Sounds through headphones/earphones	Hearing impairment (free-field value)	85 *(#4)*	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	-	-	140 *(#2)* 120 *(#2)*
Outdoors in parkland and conservations areas	Disruption of tranquility	#3		

#1: As low as possible

#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear

#3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low

#4: Under headphones, adapted to free-field values

Tables 11 a and b summarize the citywide changes in noise levels depicted at the parcel level in the above maps. Table 11a summarizes the changes from 2005 to 2015 BAU, 2% of the residential population living in areas with noise levels below 55 dBA under 2005 transportation conditions are expected to experience an increase in traffic-related noise exceeding 55 dBA (based on the day-night average sound level, Ldn) – the threshold for noise-related annoyance. An additional 5% of the population already living in areas exceeding 55 dBA in 2005 conditions could experience a substantial increase in noise levels. No groups are expected to experience a decrease in noise levels from 2005 – 2015 BAU conditions.

Table 11b summarizes the difference among noise levels between 2015 BAU to 2015 Road Pricing conditions. Under 2015 RP, 1% of the residential population living in areas with 2015 BAU noise levels below 55 dBA are expected to experience an increase in traffic-related noise to exceed 55 dBA. In addition, 6% of the population already living in areas exceeding 55 dBA in 2015 conditions experience significant increases in noise levels that shift them to a higher noise category. However, the 2015 RP scenario also appears to have a moderating effect on noise levels for some residents relative to 2015 BAU conditions – with 5% of residents experiencing a decrease of community noise levels with road pricing.

Table 11a. Estimated Traffic Attributable Noise (Ldn) Levels and 2015 Residential Population Exposures in 2005-2015 BAU: San Francisco, California (n=824,000)

	2015 BAU Noise Level in Decibels (Ldn)						
Noise Change Compared to 2005	**0-50**	**51-55**	**56-60**	**61-65**	**66-70**	**71-87**	***Total***
Stayed the same	17%	8%	14%	17%	17%	19%	***91%***
Changed but stayed quiet (≤55 ldn) in 2015 BAU	0%	1%	0%	0%	0%	0%	***1%***
Quiet (≤55 ldn) and got louder (>55 ldn) in 2015 BAU	0%	0%	2%	0%	0%	0%	***2%***
Loud (>55 ldn) and got quieter with BAU	0%	0%	0%	0%	0%	0%	***0%***
Loud (>55 ldn) and got louder in 2015 BAU	0%	0%	0%	2%	2%	1%	***5%***

Table 11b. Estimated Traffic Attributable Noise (Ldn) Levels and 2015 Residential Population Exposures in 2015 BAU-2015 RP: San Francisco, California (n=824,000)

	2015 RP Noise Level in Decibels (Ldn)						
Noise Change Compared to 2015 BAU	**0-50**	**51-55**	**56-60**	**61-65**	**66-70**	**71-87**	***Total***
Stayed the same	13%	8%	12%	16%	17%	17%	***83%***
Changed but stayed quiet (≤55 ldn) in 2015 RP	4%	2%	0%	0%	0%	0%	***6%***
Quiet (≤55 ldn) and got louder (>55 ldn) in 2015 RP	0%	0%	1%	0%	0%	0%	***1%***
Loud (>55 ldn) and got quieter with 2015 RP	0%	0%	1%	1%	1%	2%	***5%***
Loud (>55 ldn) and got louder in 2015 RP	0%	0%	2%	**2%**	**1%**	**1%**	***6%***

We used these estimated changes in population exposure to traffic-related spatial and temporal noise levels to estimate changes in expected perceptions of annoyance and ischemic heart disease events using concentration-response functions from empirical research (detailed methods in Appendix C).[71] The key findings are provided in Table 12.

Table 12. Noise-related Health Effects in 2005, 2015 Business As Usual, and 2015 with Road Pricing Conditions: San Francisco, California

Health Impacts (Annual Estimates)	2005	2015 BAU	2015 RP	Change: 2005 → 2015 BAU	Change: 2005 → 2015 RP	Change: 2015 BAU → 2015 RP
Noise, High Annoyance (N, Ages 25 and up)						
Citywide	92,500	100,400	100,300	7,900	7,800	-100
Congestion Pricing Zone	36,800	40,600	40,500	3,800	3,700	-100
Noise, Myocardial Infarction Associated with Traffic Noise (N, Ages 30 and up)						
Citywide	31	34	34	3	3	0
Congestion Pricing Zone	18	20	20	2	2	0

Citywide, for 2015 BAU relative to 2005, we estimate a 9% increase in the number of people age 25 or older who would experience perceived high annoyance (an additional 7,900 people highly annoyed); an additional three heart attacks annually attributable to traffic noise are estimated. There was no substantial difference in these effects when we looked only within the cordon zone: there would be an estimated 10% increase in number of people affected by annoyance, and two of the three heart attacks would occur in the cordon area.

Citywide, for 2015 RP relative to 2015 BAU, the analysis estimated a slight decrease in perceived high annoyance (<1%, 100 fewer people highly annoyed) and no change in myocardial infarction attributable to traffic noise. Based on the cordon zone analyses, we see the very slight decrease in perceived high annoyance was estimated in the cordon area.

Health Effects Characterization: Noise-related health effects

Table 13 summarizes our overall characterization of the health effects of the road pricing policy under study on annoyance and myocardial infarction predicted by traffic-related noise. Based on the available evidence: it is **very likely** that the proposed policy will impact traffic-related noise effects on **annoyance**, and **possible/likely** that the policy will affect noise-related myocardial infarction; ***severity*** of the effect is ***low for annoyance and high for myocardial infarction*** ; the ***magnitude*** of the predicted change is ***limited*** for both outcomes relative to 2015 BAU; and the health effects particularly in the cordon zone contribute to a ***restorative equity effect***.

Table 13. Road Pricing Policy Health Effects Characterization: Traffic-related Noise Health Effects

Health Effects: Characteristics	Interpretation	Characterization
Overall Assessment	Based on the following health effects characterization and uncertainty factors regarding the magnitude of estimated effects, what is the overall assessment of confidence in the health effects estimate?	**High for Annoyance; Moderate for Myocardial Infarction**
Likelihood	How certain is it that the road pricing policy under study will affect traffic-noise related annoyance and myocardial infarction, irrespective of the frequency, severity, or magnitude of the effect?	**Very Likely/Certain for Annoyance:** Consistent evidence for causality from epidemiologic studies with diverse populations, noise levels, and exposure ranges. **Possible/Likely for Myocardial Infarction (MI):** Plausible evidence for causal relationship between noise and MI prevalence with studies supporting physiological effects but limited epidemiology.
Severity	How important is the effect on traffic-noise related annoyance and myocardial infarction with regards to human function, well-being or longevity, considering the affected community's current ability to manage the health effects?	**Medium:** Acute, chronic, or permanent effects that substantially affect function, well-being, or livelihood but are largely manageable within the capacity of the community health system.
Magnitude	How much will traffic-noise related annoyance and myocardial infarction change as a result of the road pricing policy under study?	**Limited to Moderate (High Certainty for Annoyance; Moderate Certainty for MI):**[a] Compared to 2015 BAU, 2015 with RP very modestly moderates increases in annoyance in the congestion pricing area; there is not evidence of an impact on myocardial infarction.
Distribution	Will the effects be distributed equitably across populations? Will the road pricing policy under study contribute to a reversal of baseline inequities?	**Restorative Equity Effects**: Populations in the congestion pricing area have been historically, disproportionately burdened with traffic-related noise in their communities. The road pricing policy under study has the potential to reduce some of this inequity and related adverse health effects.

a See Table 14 for a summary of factors impacting on the certainty of the magnitude of the health effects characterization.

Certainty in Health Effects Characterization

As detailed in the introduction to this section, there exists a high level of causal certainty for the effects of noise on annoyance. Studies of the effect of noise on community annoyance are consistent across international contexts. A causal relationship between noise and myocardial infarction (heart attack) is less well established though research studies support the biological plausibility of this effect. Epidemiology on the subject is consistent but is limited and therefore reduced our degree of confidence in the likelihood of this effect.

We have high-moderate confidence in our exposure analysis; noise levels estimated in the baseline case conform closely to actual field measures. We conservatively estimated that truck volumes would not change in 2015 BAU vs. 2015 RP conditions. The exposure can be assigned to residential parcels and the population enumeration is reliable.

Our model used a standard bus noise level estimate and thus did not account for differences in noise levels based on bus vehicle type (e.g., electric trolley vs. diesel vs. hybrid buses). The San Francisco Municipal Transportation Agency (SFMTA) intends to replace diesel buses with quieter hybrid buses in its bus fleet. Compared to diesel buses used for San Francisco's public transit system, noise levels produced by new hybrid buses are up to 10 decibels less than current vehicles based on data provided by the SFMTA. These decreases could contribute to notable reductions in population noise exposure estimates and perceived noise for residents living within 25 meters of bus routes in both 2015 BAU and 2015 RP future scenarios. We had high confidence in the exposure-response functions for perceived noise annoyance. As detailed in Appendix C, a meta-analysis conducted for this outcome combined data from multiple international studies producing a robust exposure-response function that was applied in the exposure range of the levels reported in this HIA. The precision of the exposure response function for noise and myocardial infarction has some uncertainty because the meta-analysis on which it was based included a small number of studies.

Table 14. Uncertainty Factors Regarding the Magnitude of Estimated Health Effects of Traffic-related Noise

Factors Affecting Certainty	Assessment Approach	Summary Confidence Level
Exposure Assessment	Reliable small level population estimates. Method for parcel level assignment not validated but defensible. Model limited to traffic-related noise sources yet validated (correlated) against field noise measures. Potentially more uncertainty in future truck and bus traffic noise estimates. Uncertainty from noise emissions control technologies, including quieter hybrid bus engines.	High-Moderate
Baseline Disease Prevalence	Baseline prevalence of noise annoyance unavailable and thus estimated. Local disease prevalence data on myocardial infarction (MI) available though hospital discharge data may underestimate MI prevalence.	Moderate
Exposure-Response Function (ERF)	Community annoyance ERFs are specific to road noise sources and represents pooled analysis, multiple studies, diverse contexts, though not calibrated for San Francisco populations. MI ERF based on limited studies.	High (Community annoyance); Moderate (Myocardial infarction)

C. Active Transportation

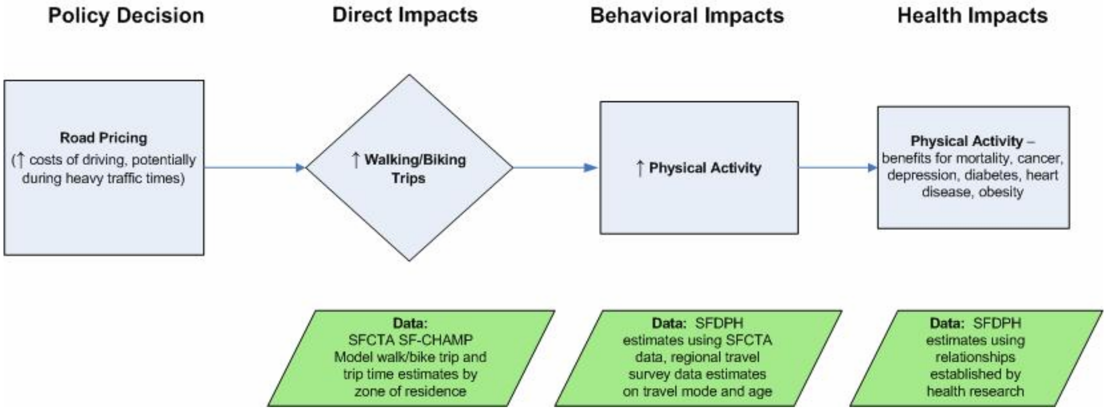
Health Effects of Physical Activity

Evidence that physical activity has multiple health benefits is unequivocal. A 2008 comprehensive review documents the particularly strong evidence for a causal relationship between activity level and enhanced cardiorespiratory and muscular fitness, cardiovascular and metabolic health biomarkers, bone health, body mass and composition in children and youth. In adults and older adults, strong evidence demonstrates that, compared to less active counterparts, more active men and women have lower rates of all-cause mortality, coronary heart disease, high blood pressure, stroke, type 2 diabetes, metabolic syndrome, colon cancer, breast cancer, and depression. For older adults, strong evidence indicates that being physically active is associated with higher levels of functional health, a lower risk of falling, and better cognitive function." This research reported reasonably consistent findings specifically for the health benefits of walking – showing a consistently lower risk of all-cause mortality for those who walk 2 or more hours per week.[72] A 2011 report issued by an international group of experts of data from Copenhagen documents similar all-cause mortality benefits from regular cycling for commuting controlling for socio-demographic and leisure time physical activity.[73] While regular physical activity can help people lead longer, healthier lives, a 2009 summary by the Robert Wood Johnson Active Living Research program revealed that fewer than 50% of children and adolescents and fewer than 10% of adults in the U.S. achieve public health recommendations of 30 to 60 minutes per day of moderate- to vigorous-intensity physical activity on 5 or more days of the week recommendations.[74]

There are multiple environmental barriers that both children and adults face to achieving recommended levels of physical activity, including: limited discretionary time; barriers to accessing parks and recreational areas; reductions in school physical education programs; and sidewalks, streets, or outdoor spaces that are not or are not perceived as safe to use. Encouraging and facilitating active transportation – walking or cycling as a form of travel for utilitarian trips – is a key strategy for increasing daily physical activity.[75] Built environmental factors that are associated with active transportation via walking and cycling include increased resident and employment density, greater diversity of land use mix (e.g., residential land use near retail land uses), shorter distances destinations, and street design factors (e.g., grid street networks, the presence of sidewalks).[76]

Based on the evidence above, Figure 14 details a pathway through which road pricing policy may affect health via active transportation. Simply stated, as the costs of auto trips increase active transportation is incentivized as a free alternative resulting in a greater number of trips made by walking or biking and therefore increasing physical activity and its associated health benefits. Additionally, road pricing generates revenue that may be invested in the transportation system to improve environments for walking and cycling and further increase trip-making.

Figure 14. Pathway from Road Pricing Policy to Physical Activity via Active Transportation



Analysis of Active Transportation and Lives Saved from Walking and Cycling

We used existing and future conditions data from the SFCTA to assess walk and bike trips and trip times for trips made by residents living in 12 geographic districts in San Francisco (the smallest reliable level of aggregation used to estimate walk and bike trips in the SFCTA's transportation analyses). We were specifically interested in estimating how changes in active transportation varied by age. We had data for existing and future conditions for area-level resident population by age, but because data was not available on trip making and travel mode by age in San Francisco, we estimated the age distribution of trips by transportation mode based on the Bay Area Travel Survey data, assuming the proportion making weekday trips and transportation mode by age were similar across the Bay Area region.

As depicted in the map in Figure 15, we collapsed the 12 districts into three districts for this analysis, defined with respect to their geographic location relative to the Northeast Cordon road pricing zone (depicted with a blue boundary on the map). The three zones are "In the Zone," turquoise, comprised of the districts mostly in the cordon zone; "On the Fringe," yellow/mustard, comprised of the districts just outside of the cordon zone; and the "Outer Districts," pink, representing those farther away from the cordon zone.

Figure 15. Activity Zones used for Active Transportation Analyses and Proportion of Residents in Each Zone by Age: San Francisco, California

	2005			2015		
Age	**In the Cordon**	**On the Fringe**	**Outer Districts**	**In the Cordon**	**On the Fringe**	**Outer Districts**
Under 5	22%	22%	57%	23%	21%	56%
5-19	19%	19%	62%	19%	18%	63%
20-44	36%	23%	41%	37%	22%	41%
45-64	31%	19%	50%	31%	19%	50%
65 and Over	35%	14%	52%	35%	14%	51%
Total	32%	20%	48%	32%	20%	48%

Table 15 summarizes the predicted changes in walking under the different study scenarios.

Table 15. Walk Trips and Walk Minutes Per Capita in 2005, Percent Change from 2005 to 2015 "Business As Usual" (BAU), and Percent Change from 2015 BAU to 2015 with Road Pricing (RP): San Francisco, California

	2005		2005 - 2015 BAU		2015 BAU - 2015 RP	
	Walk Trips Per Capita	Walk Minutes Per Capita	% Change in Walk Trips Per Capita	% Change in Walk Minutes Per Capita	% Change in Walk Trips Per Capita	% Change in Walk Minutes Per Capita
In The Zone						
Age Under 5	1.6	30	6%	7%		
Age 5-19	2.5	46	6%	7%		
Age 20-44	1.8	32	5%	7%		
Age 45-64	1.1	20	5%	6%		
Age 65 and Over	2.0	36	5%	6%		
TOTAL	***1.7***	***31***	***5%***	***7%***	***2%***	***2%***
On the Fringe						
Age Under 5	0.9	18	0%	1%		
Age 5-19	1.3	27	0%	1%		
Age 20-44	1.0	21	0%	1%		
Age 45-64	0.6	13	0%	1%		
Age 65 and Over	1.0	22	0%	0%		
TOTAL	***0.9***	***19***	***0%***	***1%***	***3%***	***3%***
Outer Districts						
Age Under 5	0.6	11	-1%	0%		
Age 5-19	0.9	17	-1%	0%		
Age 20-44	0.6	13	-1%	0%		
Age 45-64	0.4	8	-1%	0%		
Age 65 and Over	0.7	14	-1%	-1%		
TOTAL	***0.6***	***12***	***-1%***	***0%***	***2%***	***1%***

Note: percentages are listed only for the TOTAL in the 2015 BAU – 2015 RP scenario because the percentage are constant across age groups given the assumptions used to estimate the changes.

2005: In 2005 conditions, across all age groups, residents are walking more "In the Zone" – almost double that of residents "On the Fringe" and approximately three times that of residents of the Outer Districts. This is consistent with increased residential density, decreased parking availability and lower household car ownership, greater transit access and greater household proximity to goods and services "In the Zone" relative to the other districts – all factors supportive of increased walking.

2005 → 2015 BAU: Under 2015 BAU compared to 2005, there are notable increases in walk trips and time per capita only "In the Zone." This can be explained by projected increases in number of residents and existing land use and transportation characteristics supportive of walking. Walk trips may also increase due to increases in vehicle congestion and expected increases in public transit costs.

2015 BAU →2015 RP: Under 2015 with RP compared to 2015 BAU, there are modest increases in walk trips across all districts – including a 3% increase "On the Fringe." Residents with short distances trips through the road pricing boundary may switch modes from vehicles to walking when the cost of driving increases.

Table 16 summarizes the predicted changes in biking under the different study scenarios.

Table 16. Bike Trips and Bike Minutes Per Capita in 2005, Percent Change from 2005 to 2015 "Business As Usual" (BAU), and Percent Change from 2015 BAU to 2015 with Road Pricing (RP): San Francisco, California

	2005		2005 - 2015 BAU		2015 BAU - 2015 RP	
	Bike Trips Per Capita	Bike Minutes Per Capita	% Change in Bike Trips Per Capita	% Change in Bike Minutes Per Capita	% Change in Bike Trips Per Capita	% Change in Bike Minutes Per Capita
In The Zone						
Age Under 5	0.0	0.4	9%	11%		
Age 5-19	0.3	2.7	10%	12%		
Age 20-44	0.2	2.6	9%	10%		
Age 45-64	0.1	0.8	8%	10%		
Age 65 and Over	0.1	0.6	7%	9%		
TOTAL	***0.2***	***1.8***	***7%***	***9%***	***-2%***	***-1%***
On the Fringe						
Age Under 5	0.0	0.5	7%	6%		
Age 5-19	0.2	3.2	6%	6%		
Age 20-44	0.2	3.1	7%	7%		
Age 45-64	0.1	1.0	7%	7%		
Age 65 and Over	0.0	0.7	6%	6%		
TOTAL	***0.2***	***2.2***	***5%***	***5%***	***5%***	***4%***
Outer Districts						
Age Under 5	0.0	0.5	4%	6%		
Age 5-19	0.2	2.9	4%	6%		
Age 20-44	0.1	2.7	3%	6%		
Age 45-64	0.0	0.9	3%	5%		
Age 65 and Over	0.0	0.6	3%	5%		
TOTAL	***0.1***	***1.8***	***2%***	***4%***	***3%***	***3%***

Note: percentages are listed only for the TOTAL in the 2015 BAU – 2015 RP scenario because the percentages are constant across age groups given the assumptions used to estimate the changes.

2005: In 2005 we see relatively low bike trips and time travelling per capita across the zones compared to walking.

2005 → 2015 BAU: Under 2015 BAU compared to 2005 we see notable predicted increases in bike trips per capita across the zones. This is consistent with recent observed increases in biking and related investments in bicycling infrastructure. Relatively higher increases in the zone and the fringe may be explained by environments which are supportive of bike trips including bike lanes and relatively flatter terrain (for San Francisco).

2015 BAU →2015 RP: Under 2015 RP compared 2015 BAU we estimate additional increases in bike trips "On the Fringe" and in the "Outer Districts" As the cost of driving increases some residents are expected to switch modes from car to bike for trips across the cordon. Per capita bike trips slightly decrease "In the Zone" under 2015 with road pricing. This may be due, in part, to increases in transit trips replacing bike trips as road pricing revenue investments improve transit service in that area Despite this slight predicted decrease in biking "In the Zone," aggregate active transportation via biking *and* walking increases in all areas under 2015 RP compared to 2015 BAU.

Health Effects of Increases in Active Transportation

Physical activity has numerous health benefits, as summarized in the beginning of this section. Change in life expectancy is one summative outcome that captures multiple effects of physical activity on human disease and well-being.

To quantify the health benefits from increases in walking and cycling, we used the HEAT (Health Economic Assessment Tool) for Walking and Cycling developed by the World Health Organization's Regional Office for Europe (see Appendix D for further description of this tool and our approach). The HEAT tool for walking is based on a meta-analysis of international studies that found a walking exposure of 29 minutes seven days a week results in a 22% reduction in the risk of pre-mature mortality (Relative Risk = 0.78, 0.64-0.98 95% confidence interval). The HEAT relative risk estimate for all-cause mortality for cycling was estimated to be 0.72 based on a meta-analysis of three cohort studies from Copenhagen. These studies compared commuter cyclists aged 20-60 years to the general population, controlling for socioeconomic variables (age, sex, smoking etc.) as well as for leisure time physical activity.[77] As described earlier in this section, the SFCTA travel model provided data on walking and cycling trip and duration by residents at the 12-district level under all scenarios, and we further estimated the age distribution of trips by transportation mode based on the Bay Area Travel Survey data. The effect on mortality incidence was applied to locally specific mortality rates to estimate lives saved from walking and cycling.

Walking: As detailed in Table 17, we found that the modest predicted increases in walking could save an additional eight lives each year under 2015 "business as usual" compared to existing conditions, and three additional lives each year beyond BAU with 2015 RP.

Cycling: As summarized in Table 17, we found that the modest predicted increases in cycling could save an additional two lives each year under 2015 "business as usual" compared to existing conditions, and one additional life each year beyond BAU with 2015 RP.

Table 17. Lives Saved from Active Transportation in 2005, 2015 Business As Usual, and 2015 with Road Pricing Conditions: San Francisco, California

Health Impacts (Annual Estimates)	2005	2015 BAU	2015 RP	Change: 2005 → 2015 BAU	Change: 2005 → 2015 RP	Change: 2015 BAU → 2015 RP
Cycling for Active Transportation, Lives Saved (N, Ages 25-64)						
Citywide	23	25	26	2	3	1
Congestion Pricing Zone	8	9	9	1	1	0
Walking for Active Transportation, Lives Saved (N, Ages 25-64)						
Citywide	130	138	141	8	11	3
Congestion Pricing Zone	69	76	77	7	8	1

Health Effects Characterization: Lives Saved from Active Transportation Via Walking and Cycling

Table 18 summarizes our overall characterization of the health effects of the road pricing policy related to active transportation and the associated lives saved. Based on the available evidence: it is ***very likely*** that the proposed policy will increase active transportation and associated lives saved; ***severity*** of the effect— including acute and chronic respiratory diseases and mortality are ***high***; the ***magnitude*** of the predicted decrease in premature deaths is ***limited*** relative to 2015 BAU; and the reduction of deaths particularly in the cordon zone contributes to a ***restorative equity effect***.

Table 18. Road Pricing Policy Health Effects Characterization: Lives Saved from Active Transportation via Walking and Cycling

Health Effects: Characteristics	Interpretation	Characterization
Overall Assessment	Based on the following health effects characterization and uncertainty factors regarding the magnitude of estimated effects, what is the overall assessment of confidence in the health effects estimate?	**Moderate**
Likelihood	How certain is it that the road pricing policy under study will affect active transportation and associated lives saved via increases in walking and biking, irrespective of the frequency, severity, or magnitude of the effect?	**Very Likely/Certain:** Adequate evidence exists for a causal and generalizable effect based on the empirical literature, including meta-analyses and reviews conducted by a team of international experts including the World Health Organization. Evaluation studies of congestion pricing in other countries support increases in active transportation.
Severity	How important is the effect with regards to human function, well-being or longevity, considering the affected community's current ability to manage the health effects?	**High:** The impacts on active transportation are associated with reductions in mortality.
Magnitude	How much will lives saved due to increases in walking and biking change as a result of the road pricing policy under study?	**Limited (Moderate Certainty):**[a] Compared to 2015 BAU, 2015 with RP contributes to an additional 4 lives saved attributable to walking and cycling annually in San Francisco.
Distribution	Will the effects be distributed equitably across populations? Will the road pricing policy under study contribute to a reversal of baseline inequities?	**Insufficient Evidence to Evaluate:** Data not available at the refined level, in terms of area or individual characteristics, needed to evaluate the distribution of effects.

a See Table 19 for a summary of factors impacting on the certainty of the magnitude of the health effects characterization.

Certainty in Health Effects Characterization

The SFCTA's model predicted modest increases in active transportation citywide in both future scenarios but greater increases with road pricing. Congestion pricing evaluations in other countries have found similar increases in active transportation.[78]

Because trip making by age group is not estimated by the SFCTA model, we assumed that trip making and transportation mode by age in San Francisco were similar to that of the Bay Area region in order to use Bay Area Travel Survey data. The model currently does not include leisure trips, and is likely an underestimate of walking and cycling, overall. Our estimate also does not include walking trips to transit – and thus likely underestimates the overall health benefits of walking for transportation in all scenarios.

As discussed above, we estimated lives saved from changes in walking and cycling using the World Health Organization's health economic assessment tool (HEAT). HEAT provides an effect measure (exposure-response relationship) for walking and cycling specifically (versus physically active time more generally). The exposure-response relationship for walking is based on meta-analysis of international studies controlled for numerous confounders. The relative risk estimate for cycling is based on three studies in a European population, and thus there is some uncertainty about the generalizability of the estimate to a U.S. population. A meta-analysis published in 2011 of physical activity and mortality supports that the size of the protective effect for daily walking or bicycling on mortality in the HEAT tool is similar to the benefit of meeting the U.S. Surgeon Generals recommendations for adult physical activity.[79] The developers of the HEAT approach acknowledge that the focus of the HEAT tool on mortality only (and not morbidity) and adult populations - where there is currently the strongest body of evidence regarding health benefits - likely produces very conservative estimates of health benefits of active transportation in the population.[80]

The HEAT estimation approach treats exposure to walking as a dichotomous variable and predicts a health benefit (reduction in mortality) for specific population of individuals meeting a specific threshold of walking or cycling activity during a specified time period. There is good evidence for an inverse linear relationship between the amount of physical activity and mortality. In other words, every additional amount of physical activity has a proportional benefit to health. However, others have found that the benefit of increasing physical activity varies at different levels of physical activity.[81] Assuming that the inverse-linear relationship is the more accurate representation of the actual biologic processes, estimating benefits using a threshold approach could underestimate the benefits of changes in active transportation.

Table 19. Uncertainty Factors Regarding the Magnitude of Estimated Health Effects for Lives Saved from Active Transportation via Walking and Cycling

Factors Affecting Certainty	Assessment Approach	Summary Confidence Level
Exposure Assessment	Changes in walking and cycling trips and time for transportation based on model outputs from the SFCTA model at a district level, the smallest area level with reliable estimates. Used BATS (2000) data to estimate trips by age, assuming the proportion of the population travelling during the average weekday and average number of daily trips are the same within San Francisco as the rest of the Bay Area. Does not include leisure walking and cycling trips, or walking trips to transit. Likely an underestimate of walking and cycling, overall.	Moderate
Baseline Disease Prevalence	Mortality Rate: County-level data from vital statistics for people aged 25-64.	High
Exposure-Response Function (ERF)	Health Economic Assessment Tool (HEAT) for walking and cycling approach. Estimate for walking based on meta-analysis of nine studies. Estimate for cycling based on three studies and expert consensus. A threshold approach, though evidence for an inverse-linear relationship, which could result in an underestimate of overall benefits. Overall health benefits underestimated given tool focus on adults, mortality only.	Moderate

D. Vehicle-Pedestrian Injury Collisions

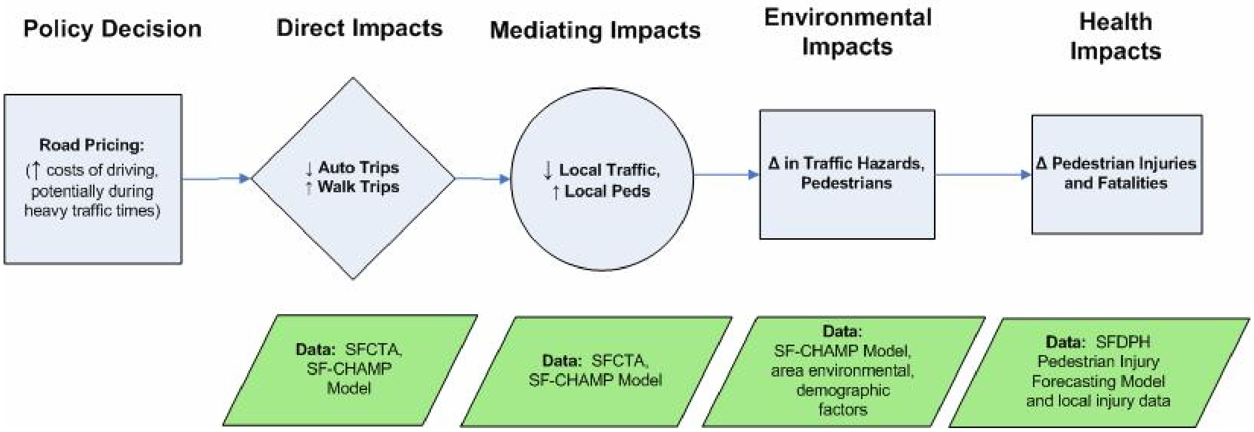
Road Pricing Effects on Pedestrian Safety

Traffic injuries and fatalities represent a significant and avoidable health burden with 33,808 deaths and 2,217,000 injuries in the United States alone in 2009. Among transportation system users pedestrians and pedal-cyclists are arguably the most vulnerable users. In the U.S., pedestrians, who are more likely to be lower-income and not own automobiles, experience a disproportionate share of traffic injuries and fatalities risks than vehicle occupants on both a per-trip and per-mile basis with 4,092 pedestrian deaths in 2009.[82]

Pedestrian and traffic volumes, vehicle speed, roadway width, intersection design and geometry, land use, pedestrian and driver behavior, and vehicle design are all factors that determine the frequency of pedestrian-vehicle collisions.[83] Vehicle and pedestrian volumes are the most important single determinants of pedestrian injury collision frequency, with non-linear but positive associations between pedestrian flows and traffic volumes with pedestrian injury collisions consistently found at the small-area level including intersections.[84] Studies also show heterogeneity in these associations, potentially due to differences in other environmental conditions including land use, transportation system, and socio-demographic factors. Roadway design and higher operating speeds are potent determinants of injury frequency as well as injury severity. Quality of pedestrian facilities are an important predictor of pedestrian injury in the research literature, based on analyses at the intersection, street segment, and small-areas levels.[85] Low-income neighborhoods are more heavily burdened with pedestrian injuries and fatalities due factors potentially including higher residential area traffic densities, greater use of active transport and public transit, and relatively poorer quality roadway facilities.[86]

The objective of road pricing policy is to reduce traffic congestion on local roadways during peak use periods, which also correspond to times of high pedestrian volumes. Reductions in traffic volume could reduce pedestrian injury. However, shifts to active transportation and public transportation (which involves active transportation) also simultaneously increase the number of pedestrians exposed to traffic hazards. Where free flow conditions do not currently exist, reductions in traffic volume may also increase traffic speed which is a risk factor for collision frequency and severity. Investments in road infrastructure funded by road pricing could address gaps in pedestrian safety engineering countermeasures and mitigate potential adverse impacts. Figure 16 details a pathway through which road pricing policy impacts changes in vehicle trips and therefore local traffic volumes, traffic hazards and ultimately vehicle-pedestrian injury collisions.

Figure 16. Pathway from Road Pricing Policy to Vehicle-Pedestrian Injury



Analysis of Vehicle-Pedestrian Injury Collisions

For this analysis, we estimated changes in pedestrian injury collision frequency (absolute) numbers in San Francisco census tracts using an area-level vehicle-pedestrian injury forecasting model developed by SFDPH.[87] The model was developed to predict changes in injury collisions attributable to changes in traffic volumes and population generally assuming no changes in roadway infrastructure (further detailed in Appendix E). Traffic volume was the single strongest predictor of pedestrian injury collisions in the model.

We applied traffic and population estimates to the model to estimate pedestrian-injury collisions under each scenario. Census tract-level traffic volume varies in all three scenarios. Model parameters that vary only between existing and future conditions are the number of residents and employees, the proportion of the population aged 65 and over, and proportion of the population living in poverty. Resident and employee populations serve as a rough proxy for pedestrian volumes. While the model considers street type, the model does not account for changes in traffic speeds or intersection level counter-measures.

Table 20 summarizes the predicted changes in vehicle-pedestrian injury collisions citywide as well as in the cordon zone.

Table 20. Annual Estimated Pedestrian Injury Collisions in 2005, 2015 Business As Usual, and 2015 with Road Pricing Conditions: San Francisco, California

Health Impacts (Annual Estimates)	2005	2015 BAU	2015 RP	Change: 2005 → 2015 BAU	Change: 2005 → 2015 RP	Change: 2015 BAU → 2015 RP
Vehicle-Pedestrian Injury Collisions (N, Total)						
Citywide	810	860	815	50	5	-45
Congestion Pricing Zone	360	395	360	35	0	-35

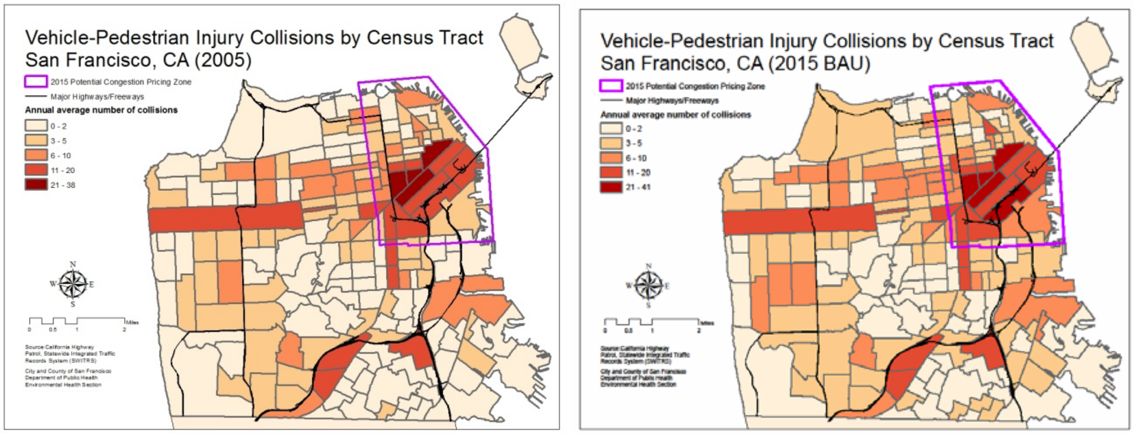
2005: Under existing (2005) conditions, we estimated 810 vehicle-pedestrian injury collisions citywide. (Note: As detailed in Appendix E, we estimated census-tract level collisions for 2005 baseline conditions based on the average of actual reported collisions for a five-year period in an effort to reduce statistical anomalies. Police-reported pedestrian-vehicle injuries and deaths in San Francisco have varied between approximately 710-910 injuries and deaths annually since 2001.) Using the population data reported in Table 3, we calculated a population rate of approximately 102/100,000 resident population – over five times the Healthy People 2010 target rate of $\leq$20/100,000 population.[88] Approximately 44% of San Francisco's vehicle-pedestrian injury collisions occur in the cordon zone that is under study, with a population rate of approximately 210/100,000 population – over two times that of the citywide population rate. The potential congestion pricing zone has the highest density of vehicle-pedestrian injuries in the city – largely explained by relatively higher concentrations of traffic, resident and employee populations.[89] Figure 17a illustrates how the pattern of injury varies widely across San Francisco census tracts.

2005 → 2015 BAU: In 2015 BAU, the model estimates that pedestrian injury collisions *increase* 6% citywide to approximately 860 annually (104/100,000 population) from 810, and *increase* in the cordon zone by 10% to approximately 395 annually (216/100,000 population) up from 360 in 2005 conditions. In this scenario, 46% of vehicle-pedestrian injury collisions occur in the cordon zone –increasing the citywide geographic disparities. These increases are largely predicted by increases in traffic, as well as by the planned population and employment growth (see Figures 7 and 8, Table 3).

2015 BAU → 2015 RP: The model estimates that pedestrian injury collisions decrease in the 2015 scenario with Road Pricing compared to 2015 BAU. This is explained by decreases in aggregate traffic volume citywide and in the cordon zone (Table 4, -4% and -11%, respectively). These decreases could result in pedestrian injury collision totals approximately at 2005 counts, with estimated collision rates below 2005 levels (citywide rate: 99/100,000 population; cordon zone rate: 197/100,000).

The following maps (Figures 17 and 18) depict the estimated census tract-level changes in the annual average absolute number of vehicle-pedestrian injury collisions in 2005, 2015 BAU and 2015 RP conditions. The maps show increases in collisions under BAU – with increases most notable in areas in the road pricing zone as well as some tracts south of the zone near the freeway. In 2015 RP, reductions in the road pricing zone relative to 2015 BAU conditions are estimated– again, explained by reductions in traffic volumes in those areas. There are a few census tracts, indicated in a salmon color, where there are modest estimated increases in vehicle-pedestrian injury collisions under 2015 RP predicted by increases in traffic volume in those tracts (as depicted in Figure 9, Map D). Note that the highest category reported in the maps for the annual average number of collisions changes under 2015 BAU conditions due to increases in total census tract collision numbers. As noted earlier, these change estimates do not account for estimated census tract changes in pedestrian volumes; implications for the results are discussed later in the section in the discussion regarding uncertainty.

Figure 17a. Vehicle-Pedestrian Injury Collisions in 2005 and 2015 "Business As Usual" (BAU) Conditions: San Francisco, California



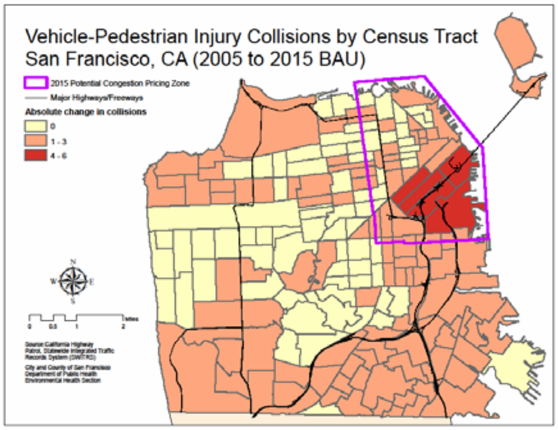
Vehicle-Pedestrian Injury Collisions by Census Tract
San Francisco, CA (2005)

Source:California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS)
City and County of San Francisco Department of Public Health Environmental Health Section

Vehicle-Pedestrian Injury Collisions by Census Tract
San Francisco, CA (2015 BAU)

Source:California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS)
City and County of San Francisco Department of Public Health Environmental Health Section

Figure 17b. Estimated Change in Vehicle-Pedestrian Injury Collisions from 2005 → 2015 "Business As Usual" (BAU) Conditions: San Francisco, California



Vehicle-Pedestrian Injury Collisions by Census Tract
San Francisco, CA (2005 to 2015 BAU)

Source:California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS)
City and County of San Francisco Department of Public Health Environmental Health Section

Figure 18a. Vehicle-Pedestrian Injury Collisions in 2015 "Business As Usual" (BAU) and 2015 with Road Pricing (RP) Conditions: San Francisco, California

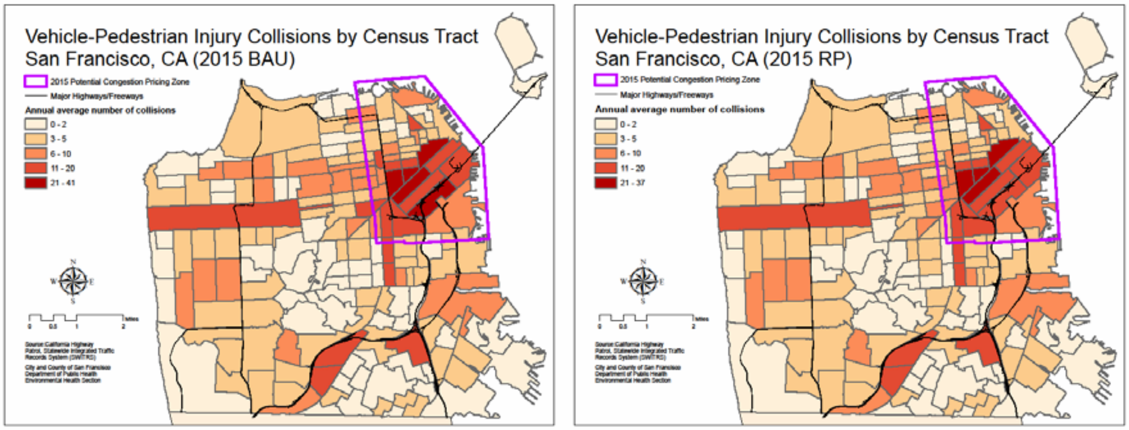
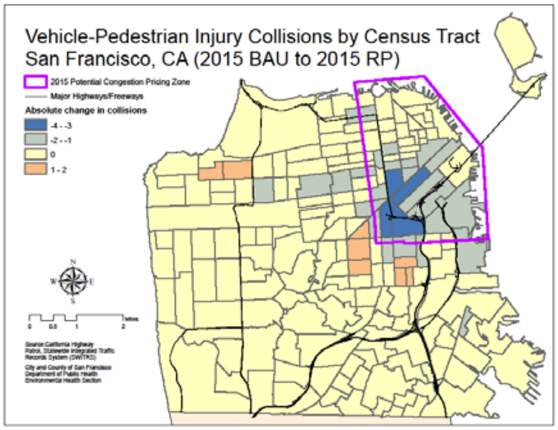
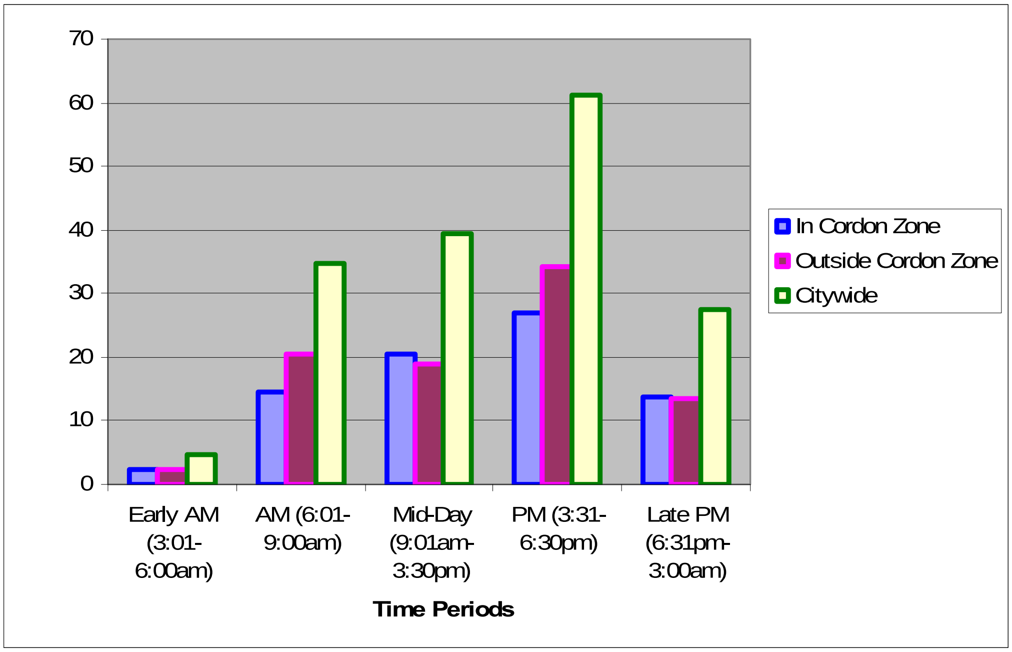


Figure 18b. Estimated Changes in Vehicle-Pedestrian Injury Collisions in 2015 "Business As Usual" (BAU) → 2015 with Road Pricing (RP) Conditions: San Francisco, California



Because the congestion pricing scenario largely reduces traffic volumes during peak commute periods, we considered the time of day of pedestrian injury collisions in San Francisco for the five-year period 2004- 2008. The blue line in Figure 19 indicates the annual average number of pedestrian injury collisions within the cordon zone under study, the pink line the area outside the cordon zone, and the green line the overall citywide pattern. There are evident peaks during the AM and PM peak periods, providing additional support regarding the plausibility of traffic reductions during the peak commute times as contributing to reductions in pedestrian injury collisions. Specifically, over half of pedestrian injury collisions during 2004-2008 occurred during the AM and PM commute periods that are the focus of the congestion pricing charge (53% of the total in the cordon zone, 61% of the total outside of the cordon zone). The temporal pattern of collisions is not accounted for in our model, and our estimates could therefore underestimate the potential impact of congestion pricing policy on pedestrian injury given the policy reduces traffic volume during peak injury periods; conversely, there could also be changes in the temporal distribution of pedestrian injury collisions as traffic shifts to non-peak times.

Figure 19. Annual Average Pedestrian Injury Collisions by Time of Day (2004-2008): San Francisco, California



Additional Targeted Pedestrian Safety Analyses: High-Injury Corridors and Pedestrian Environmental Quality

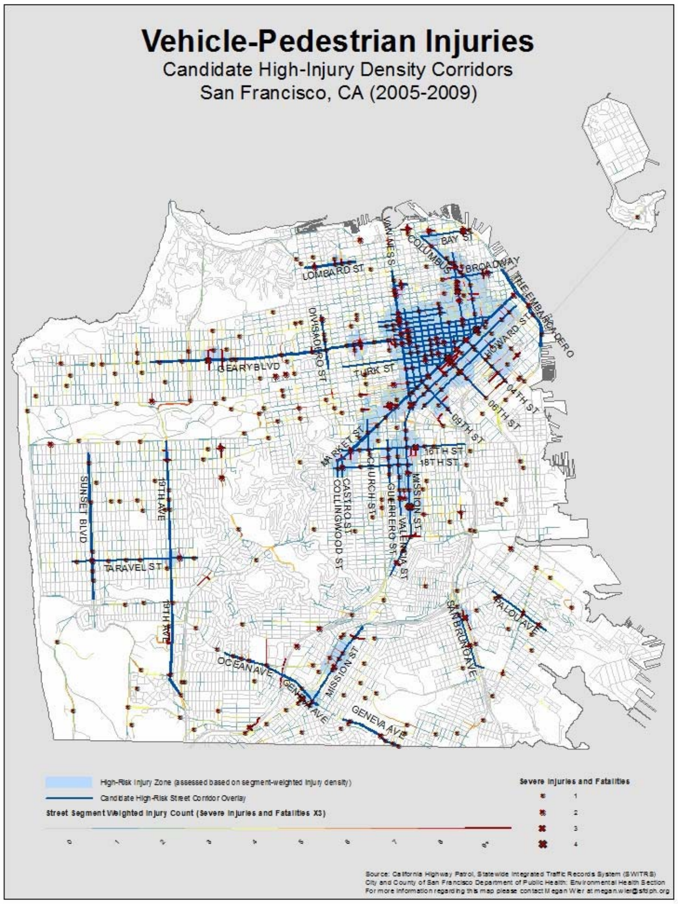
To provide additional data on existing conditions and risk factors related to pedestrian injuries and to inform our HIA recommendations regarding pedestrian safety, we further analyzed high-injury pedestrian corridors in San Francisco, as well as the pedestrian environmental quality in communities with existing high numbers or predicted increases in vehicle-pedestrian injury collisions.

High-Injury Corridors

Vehicle-pedestrian injury collisions are often concentrated along corridors and in areas with an aggregation of multiple environmental-level risk factors including higher traffic volumes and greater pedestrian activity. Analysis of police-reported vehicle-pedestrian injury collision data for 2005-2009 underscores the concentration of injuries in San Francisco.

The map in Figure 20 identifies high-injury areas and corridors defined as closely-spaced, high injury street segments, each high-injury street segment with an injury count >9. To give weight to injury severity, each severe or fatal injury was counted as three non-severe injuries. The 6.7% of city street miles identified as high-injury corridors (in blue) account for 55% of severe and fatal pedestrian injuries and 51% of total pedestrian injuries during the analysis period. The patterns echo differences in census tract level injury frequency illustrated in Figures 17 and 18.

Figure 20. High-Injury Density Corridors for Vehicle-Pedestrian Injuries (2005-2009): San Francisco, California



Source: California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS)
City and County of San Francisco Department of Public Health: Environmental Health Section
For more information regarding this map please contact Megan Wier at megan.wier@sfdph.org

Pedestrian Environmental Quality in Areas with High Existing and Future Increases in Pedestrian Injury

We also collected baseline street and intersection conditions data for this HIA with the Pedestrian Environmental Quality Index (PEQI). The PEQI is a quantitative observational instrument to describe and summarize street and intersection environmental factors known to affect people's travel behaviors and pedestrian safety. The index provides a total score for each street segment and intersection assessed, which is computed as the sum of 31 weighted intersection and street indictors. The scores are categorically ranked into five classifications ranging from "ideal quality" for pedestrians to "poor quality" for pedestrians. The SFDPH developed the PEQI for a number of purposes, including assessing existing physical conditions and demonstrating the need for improvements in the course of land use and transportation planning, community education regarding built environmental factors that either promote or discourage walking in local neighborhoods, and to fill a gap in data regarding the physical environment on our city streets in order to assess how it predicts key health determinants such as physical activity. The PEQI methodology is described in further detail in Appendix F.

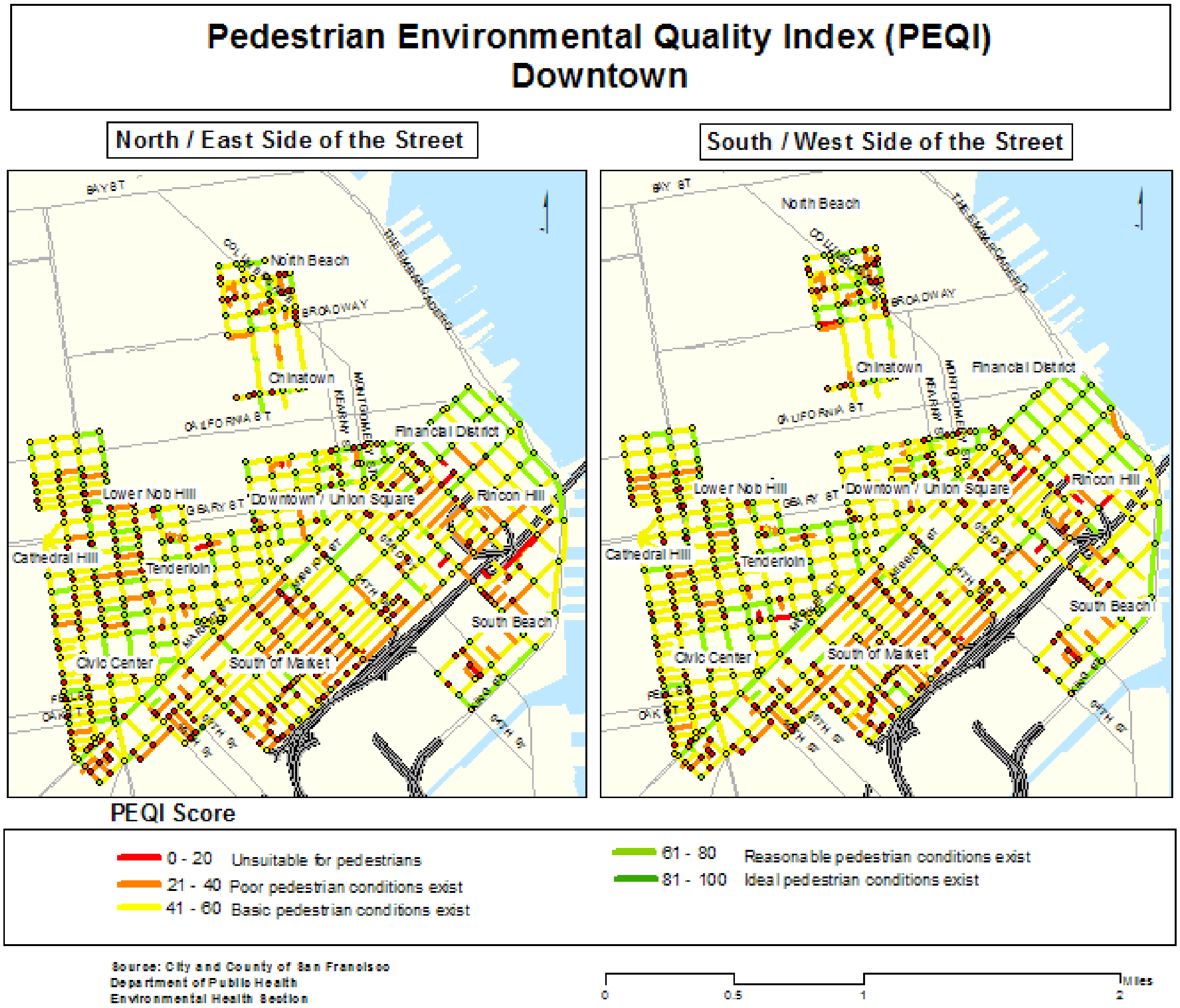
We were particularly interested in assessing intersection and street level factors in the pedestrian environment that support safe walking to inform our recommendations to improve pedestrian safety in and near the cordon zone. As noted in Table 22, the SFDPH Vehicle-Pedestrian Injury Collision Model does not account for these intersection and street specific factors. For PEQI data collection, we focused on areas with existing high number of injuries as well as areas with projected increases in injuries based on our vehicle-pedestrian injury forecasting model findings. PEQI scores reflect the degree to which environmental factors supportive of walking and pedestrian safety has been incorporated into street segment and intersection design. The PEQI scores street segments and intersections separately, on a scale from 0 -100. We are currently using the following categories for scoring, a priori, with equal intervals of 20 points for all categories:

- 100-81 = highest quality, many important pedestrian conditions present - “Ideal”
- 80- 61 = high quality, some important pedestrian conditions present - “Reasonable”
- 60- 41 = average quality, pedestrian conditions present but room for improvement -“Basic”
- 40- 21 = low quality, minimal pedestrian conditions – “Poor”
- 20 and below = poor quality, pedestrian conditions absent – “Not Suitable for Pedestrians”

We conducted detailed PEQI analyses for communities in and out of the zone to inform HIA recommendations. These analyses are included in Appendix F, along with the PEQI Methods, and inform our recommendations for prioritizing infrastructure improvements related to pedestrian safety and walking conditions in the next section of this report.

Figure 21 depicts one of the maps of the PEQI findings for the streets and intersections surveyed in the congestion pricing zone, followed by a summary of the PEQI findings for the SoMa neighborhood (labeled in the map).

Figure 21. Pedestrian Environmental Quality in the Congestion Pricing Zone



South of Market

In South of Market, 198 intersections and 646 street segments were assessed using the PEQI (see Figure 21). The average PEQI intersection score was 28, which was the lowest score in the survey for area. Over 60 percent of the intersections lack basic pedestrian amenities and engineering countermeasures and were ranked "not suitable for pedestrians" by the PEQI (*red* intersections). Many of these intersections are junctions with short streets and alleys where there are no crosswalks, signals, or signs warning pedestrians to look for cars; in some cases additional pedestrian infrastructure might be appropriate and in other places not, based on factors including existing and projected pedestrian and traffic volumes. The average PEQI street score for the streets was 47, also the lowest scoring neighborhood in this survey. Twenty-five percent of the streets were ranked "poor" (*orange* streets) or "not suitable for pedestrians" (*red* streets). Many of the street segments that ranked "poor" are near the freeway, with high traffic volumes and no traffic calming. Harrison is one street in particular that scored poorly throughout South of Market.

Health Effects Characterization: Vehicle-Pedestrian Injury Collisions

The following table summarizes our overall characterization of the health effects of the road pricing policy under study on vehicle-pedestrian injury collisions. Based on the available evidence: there is a ***high likelihood*** that the proposed policy will impact on vehicle pedestrian-injury collisions; ***severity*** of the effects are ***high*** and important with respect to the health of San Franciscans; the ***magnitude*** of the predicted decrease in vehicle-pedestrian injury collisions is ***substantial*** relative to predicted increases under 2015 BAU; and the reduction of injuries particularly in the specific census tracts in the cordon zone relative to the increases anticipated under 2015 BAU contributes to a ***restorative equity effect*** as decreases are predicted in areas historically disproportionately adversely impacted by pedestrian injury. Overall, given the assumptions and uncertainties discussed further below, we have a high-moderate degree of confidence in our characterization of these health effects.

Table 21. Road Pricing Policy Health Effects Characterization: Vehicle-Pedestrian Injury Collisions

Health Effects: Characteristics	Interpretation	Characterization
Overall Assessment	Based on the following health effects characterization and uncertainty factors regarding the magnitude of estimated effects, what is the overall assessment of confidence in the health effects estimate?	**High-Moderate**
Likelihood	How certain is it that the road pricing policy under study will affect vehicle-pedestrian injury collisions, irrespective of the frequency, severity, or magnitude of the effect?	**Very Likely/Certain:** Adequate evidence exists for a causal and generalizable effect based on the empirical literature, evaluation studies of congestion pricing in other countries.
Severity	How important is the effect on vehicle-pedestrian injury collisions with regards to human function, well-being or longevity, considering the affected community's current ability to manage the health effects of vehicle-pedestrian injury collisions?	**High:** Reduces acute and permanent effects that are potentially disabling or life-threatening. 22% of all traumatic injuries in San Francisco are caused by auto-versus-pedestrian collisions.
Magnitude	How much will vehicle-pedestrian injury collisions change as a result of the road pricing policy under study?	**Substantial (High-Moderate Certainty):**[a] Compared to 2015 BAU, 2015 with RP contributes to a decrease in vehicle-pedestrian injury collisions of 5% citywide, and of 9% in the cordon zone.
Distribution	Will the effects be distributed equitably across populations? Will the road pricing policy under study contribute to a reversal of baseline inequities?	**Restorative Equity Effects:** Populations in the cordon zone have been historically, disproportionately burdened with vehicle-pedestrian injury collisions in their communities. The road pricing policy under study has the potential to reduce some of this inequity.

a See Table 22 for a summary of factors impacting on the certainty of the magnitude of the health effects characterization.

Certainty in Health Effect Characterization

A summary of the principal uncertainties in our characterization of road pricing effects on vehicle-pedestrian injury collisions is provided in Table 22. The strengths and limitations of traffic volume and population forecasts which are key inputs into the model and other analyses in this HIA are discussed at the beginning of Section V.

We have high-moderate overall confidence in the forecasting model, which was developed using local injury data and overall explains a substantial share (>70%) of variation in injury frequencies at the level of the census-tract.[90] The model further accounts for a well-established non-linear relationship between changes in pedestrian and vehicle volumes and changes in injury frequency.[91] Furthermore, predicted decreases in pedestrian injury collisions under 2015 RP conditions are similar to the decreases seen with the introduction of congestion pricing in London.[92]

Nevertheless, there are several important uncertainties to the precision of future estimates. Importantly, the model was created based on observed counts of injuries. Observed counts of vehicle-pedestrian injuries based upon the collisions reported to and recorded by police generally underestimate the true burden of vehicle-pedestrian injuries. An analysis in San Francisco comparing data from 2000-2001 police records with hospital data from San Francisco General Hospital (SFGH, the City's Level-I Trauma Center which sees the majority of more severely injured pedestrians) found that 22% of pedestrians injured and seen at SFGH were not reported in police records.[93] Undercounts of baseline injuries based on police record data thus will translate into undercounts of predicted future injuries.

In addition, the model does not account for other pedestrian-injury risk factors that may change with road pricing. Specifically, data were not available to account for speed which is strong predictor of injury collision frequency. The area-level model also did not account intersection-level street characteristics; however, we have no reliable way of predicting how these countermeasures might change under future scenarios. Our analysis estimated changes in all pedestrian-collision injuries and not in injury severity. Speed is the most significant modifiable predictor of pedestrian injury severity.[94] The SFCTA has conducted analyses regarding estimated changes in vehicle speeds with road pricing and found up to 25% increases in speeds on the most congested streets, from an average of 10 to 12 mph. Conceivably, these increases in average travel speeds may have potential effects on injury severity.

Table 22. Uncertainty Factors Regarding the Magnitude of Estimated Health Effects for Vehicle-Pedestrian Injury Collisions

Factors Affecting Certainty	Assessment Approach	Summary Confidence Level
Exposure Assessment	SFDPH model parameters (census-tract level) include estimates of the following conditions: traffic volume; proxies for pedestrian activity (number of residents and employees, neighborhood commercial zoning, land area, population living in poverty, population aged 65 and older); proxies for traffic speeds (proportion of streets that are arterial streets without transit). Attenuated per-pedestrian risk with increasing numbers of pedestrians is incorporated into the model parameter for employees, which was fit using the natural log; the traffic volume parameter is also a natural log consistent with the empirical literature. Direct estimates of pedestrian volumes, traffic speeds, and intersection-level engineering factors are not included as city-wide data for those factors was not available.	Moderate
Baseline Disease Prevalence	Vehicle-pedestrian injury collision data from the California Highway Patrol's Statewide Integrated Traffic Records System (SWITRS). Research in San Francisco has demonstrated that SWITRS data underestimates total injury burden using hospital data as a gold standard, with lower rates of under-reporting for more severe injuries (Sciortino et al. 2005). This uncertainty results in an underestimate of the effect.	High-Moderate
Exposure-Response Function (ERF)	SFDPH model is specific to San Francisco, predicting over 70% of the variation in pedestrian injury collisions in census tracts. Model has not yet been validated over time. The model's area-level approach, indicative of small-area hot spots, is appropriate for area-level policy assessment.	High-Moderate

E. Vehicle-Cyclist Injury Collisions

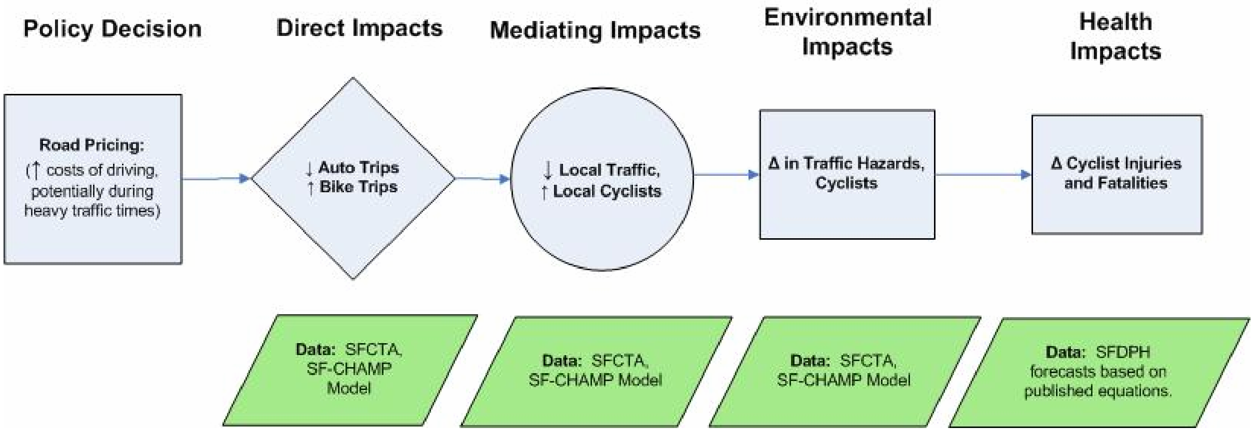
Road Pricing Effects on Cyclist Safety

As stated in the previous section, traffic injuries and fatalities represent a significant and avoidable health burden, with cyclists and pedestrians arguably the most vulnerable road users. In the U.S., cyclists experience a disproportionate share of traffic injury and fatality risks compared to vehicle occupants on a per-trip basis – with estimated per-trip fatality rates over two times that of motor vehicles (21.0 vs. 9.2 per 100 million person trips).[95] Despite higher risk of injury per trip, cycling is a relatively low-cost, physically active form of transportation that is growing in popularity in the U.S. in recent years - with an overall 64% increase in bike commuters in the U.S. from 1990-2009 and with trends particularly notable in urban areas including San Francisco, Portland, Minneapolis, Washington DC, Chicago, and New York City.[96]

The objective of road pricing is to reduce traffic congestion on local roadways during peak use periods, which also correspond to times of high utilitarian cyclist volumes. Reductions in traffic volume will tend to reduce the likelihood of vehicle-cyclist injury collisions. However, greater use of cycles may increase the number of cyclists exposed to traffic hazards. Where free flow conditions do not currently exist, reductions in traffic volume may also increase traffic speed which is a risk factor for collision frequency and severity. Investments in road infrastructure funded by road pricing could address gaps in cyclist safety engineering countermeasures, though could also increase transit service on streets frequented by cyclists.

Figure 22 details a pathway through which road pricing policy impacts changes in vehicle trips and cyclist trips, and therefore changes in traffic hazards and cyclists and ultimately vehicle-cyclist injury collisions.

Figure 22. Pathway from Road Pricing Policy to Vehicle-Cyclist Injury

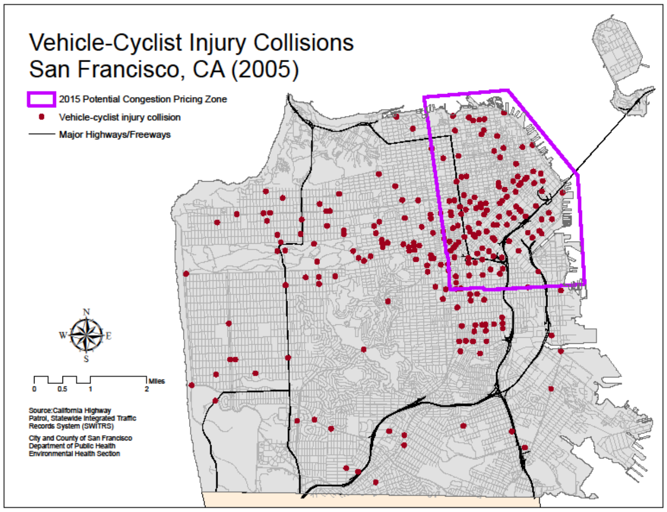


Analysis of Vehicle- Cyclist Injury Collisions

We estimated expected changes in vehicle-cyclist injury collisions using collision data from 2005 and changes in motor vehicle and cyclist trips from the SFCTA's model. We used a simple prediction model that assumes that future injuries are a non-linear function of changes in motor vehicle and cyclist trips (i.e., decreasing per-cyclist risk with increasing cyclists; increasing per-cyclist risk with increasing vehicles; decreasing per-motorist risk with increasing vehicles). This approach is based on empirical studies of vehicle-cyclist collisions and has been applied to predict hypothetical scenarios in changes in collisions associated with changes in transportation mode share.[97] Similar to the vehicle-pedestrian injury models, changes in vehicle volumes have a stronger influence on vehicle-cyclist collisions than changes in cyclists volumes. A detailed description of methods is in Appendix G.

The map in Figure 23 depicts intersection-level vehicle-cyclist injury collisions under actual 2005 conditions. The concentration of collisions in the potential congestion pricing zone is evident – with approximately 50% of vehicle-cyclist collisions occurring in the congestion pricing zone.

Figure 23. Vehicle-Cyclist Injury Collisions in 2005: San Francisco, California



Source:California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS)

City and County of San Francisco Department of Public Health Environmental Health Section

Cyclist injury and collisions – including vehicle-cyclist injury collisions – have been increasing in San Francisco in recent years. Based on data on police reported injuries from SWITRS for 2006 – 2009, there were 273 injuries to cyclists in collisions with motor vehicles reported by the police in 2006, climbing to 424 in 2009 – a 55% increase. Because of under-reporting of cyclist injuries to police, these statistics are likely to represent an undercount of the true number of vehicle-cyclist injuries in San Francisco. These increases parallel those in cycling in San Francisco. For example, the San Francisco Municipal Transportation Agency's annual citywide bicycle count found that counts of observed cyclists increased by 53% during those same years, from 5,500 in 2006 to 8,441 in 2009.[98]

The following table summarizes the predicted changes in vehicle-cyclist injury collisions citywide as well as in the cordon zone.

Table 23. Annual Estimated Vehicle-Cyclist Injury Collisions in 2005, 2015 Business As Usual, and 2015 with Road Pricing Conditions: San Francisco, California

Health Impacts (Annual Estimates)	2005	2015 BAU	2015 RP	Change: 2005 → 2015 BAU	Change: 2005 → 2015 RP	Change: 2015 BAU → 2015 RP
Vehicle-Cyclist Injury Collisions (N, Total)						
Citywide	270	295	290	25	20	-5
Congestion Pricing Zone	135	155	150	20	15	-5

2005: In 2005 conditions, the annual number of police-reported vehicle-cyclist injury collisions in San Francisco is approximately 270. Approximately half of San Francisco's vehicle-cyclist injury collisions occur in the cordon zone that is under study. The high-density of vehicle-cyclist injury in the proposed congestion pricing zone is explained largely by higher volumes of traffic and cyclists in this zone.

2005 → 2015 BAU: In 2015 BAU, based on the model, we estimate vehicle-cyclist injury collisions will increase 9% citywide to 295 total vehicle-cyclist injury collisions, with a 15% increase in the potential congestion pricing zone accounting for 80% of the citywide increase. Similar to the baseline conditions, approximately 50% of total injuries are expected to occur in the congestion pricing zone. Increases in the number of injury collisions are related to predicted increases in traffic and cycling to and from San Francisco's downtown core.

2015 BAU → 2015 RP: We estimate that vehicle-cyclist injury collisions could also increase relative to baseline conditions under a future road pricing scenario; however the increase will be smaller than in the business as usual scenario. Decreases in vehicle traffic volume citywide and in the cordon zone explain the moderation of the expected injuries.

Because the congestion pricing scenario largely reduces traffic volumes during peak commute periods, as with pedestrian injury collisions we also assessed the time of day of vehicle-cyclist injury collisions in San Francisco. We found that approximately 30% of vehicle-cyclist injury collisions occur during the AM and PM peak commute periods, supportive of our finding that changes in traffic volume during those peak commute periods could have a protective effect on vehicle-cyclist injury collisions.

Health Effects Characterization: Vehicle-Cyclist Injury Collisions

Table 24 summarizes our overall characterization of the health effects of the road pricing policy under study on vehicle-cyclist injury collisions. Based on the available evidence: there is a **high likelihood** that the proposed policy will impact on vehicle cyclist-injury collisions; severity of the effects are **high** and important with respect to the health of San Franciscans; the magnitude of the change in vehicle-cyclist injury collisions among future scenarios is substantial with 2015 RP moderating the predicted increase of injuries expected under 2015 BAU. The largest moderating effects on cyclist injuries occurs within the cordon zone contributing to a restorative equity effect as decreases are predicted in areas historically disproportionately adversely impacted by cyclist injury. Overall, given the assumptions and uncertainties discussed further below, we have a moderate-low degree of confidence in our characterization of these health effects. The estimated increase in vehicle-cyclist collisions in both future scenarios makes a case for investments in additional protective engineering countermeasures for cyclists in San Francisco. Section VI provides several recommendations for measures to improve cyclist safety.

Table 24. Road Pricing Policy Health Effects Characterization: Vehicle-Cyclist Injury Collisions

Health Effects: Characteristics	Interpretation	Characterization
Overall Assessment	Based on the following health effects characterization and uncertainty factors regarding the magnitude of estimated effects, what is the overall assessment of confidence in the health effects estimate?	**Moderate-Low**
Likelihood	How certain is it that the road pricing policy under study will affect vehicle-cyclist injury collisions, irrespective of the frequency, severity, or magnitude of the effect?	**Very Likely/Certain:** Adequate evidence exists for a causal and generalizable effect based on the empirical literature and evaluations from implementation of congestion pricing in other countries.
Severity	How important is the effect on vehicle-cyclist injury collisions with regards to human function, well-being or longevity, considering the affected community's current ability to manage the health effects of vehicle-cyclist injury collisions?	**High:** Reduces acute and permanent effects that are potentially disabling or life-threatening.
Magnitude	How much will vehicle-cyclist injury collisions change as a result of the road pricing policy under study?	**Substantial (Moderate-Low Certainty):**[a] Compared to 2015 BAU, 2015 with RP contributes to a decrease in vehicle-cyclist injury collisions of 3% citywide and in the cordon zone.
Distribution	Will the effects be distributed equitably across populations? Will the road pricing policy under study contribute to a reversal of baseline inequities?	**Restorative Equity Effects:** The cordon zone area has a historically high burden of vehicle-cyclist injury collisions. The road pricing policy under study has the potential to reduce some of this inequity.

a See Table 25 for a summary of factors impacting on the certainty of the magnitude of the health effects characterization.

Certainty in Health Effect Characterization

A summary of the principal uncertainties in our characterization of road pricing effects on vehicle-cyclist injury collisions is provided in Table 25. The strengths and limitations of traffic volume and population forecasts which are key inputs into the model and other analyses in this HIA are discussed at the beginning of Section V. Overall, we have limited to moderate confidence in the precision of estimates of future cyclist injuries predicted by the model. For several important reasons, discussed below, our modeling approach may be over or under-estimating future bicycle injury frequencies.

First, the model could be over-estimating injuries if future improvements in road infrastructure reduced hazards for bicyclists. Our estimation approach based on vehicle and cycle volumes alone does not account for bicycle infrastructure or safety countermeasures that might change in the future under 2015 BAU or road pricing conditions. Bicycle infrastructure is expected to improve citywide over the next years due to programmed improvements. However, at present, there is limited evidence on the protective effects of bicycle lanes on urban streets so the ultimate safety effects of this infrastructure cannot be predicted.[99]

Importantly, future estimates of cyclist injuries are a function of baseline frequency of injuries. Baseline counts of vehicle-cyclist injuries based upon the collisions reported to and recorded by police generally underestimate the true burden of vehicle-cyclist injuries. Undercounts of baseline injuries thus will translate into undercounts of future injuries.

There are several other reasons that our modeling approach could underestimate the future change in cyclist injuries. Most important, the SFCTA model could be underestimating the future changes in cycling. Notably, the actual observed increase in vehicle-cyclist collisions from 2006 to 2009 (55% change) is over three times the increase predicted by our model from 2005 to 2015. A likely explanation for this increase is an increase in cycling not accounted for by the model. Other explanations for this increase in reported cyclist injuries include an increase in the proportion of collisions being reported to police and changes in driver or cyclist safety behaviors.

Our predictions clearly underestimate the full burden of cyclist injuries in baseline and future scenarios as we have only accounted for and modeled changes in injuries associated with vehicle-cyclist injury collisions, excluding injuries to cyclists that do not involve an occupied motor vehicle. Causes of cyclist only injuries may include cyclists swerving to avoid a collision and hazardous roadway conditions (e.g. potholes). A recent analysis by the San Francisco Injury Center of patients seen by the San Francisco General Hospital (SFGH) for trauma sustained while cycling found that approximately 25% of those patients were injured in a “cyclist only” crash that did not involve contact with a motor vehicle. These “cyclist-only” crashes were notably under-reported in the police-reported SWITRS data historically relied upon by the City to monitor collisions over time. Specifically, 22% of SFGH patient records did not matched with a SWITRS record; of those SFGH records, 58.5% were cyclists injured in a crash with a motor vehicle and 41.5% were of cyclist-only injuries. Notably, 42% of cyclist injuries reported by SWITRS did not match with a SFGH record; of those SWITRS records, 91% were injured in a crash with a motor vehicle and 9% were cyclist-only injuries.[100]

Our estimation approach predicts total vehicle-cyclist injury collisions and does not account for any effects on collision severity. Changes in travel speeds associated with infrastructure changes or changes in vehicle volume may increase or decrease speed, thereby affecting injury severity. As summarized in the previous section, the SFCTA has conducted analyses regarding estimated changes in vehicle speeds with road pricing and found up to 25% increases in speeds on the most congested streets, from an average of 10 to 12 mph. Conceivably, these increases in average travel speeds may have potential effects on injury severity.

Table 25. Magnitude of the Estimated Health Effects for Vehicle-Cyclist Injury Collisions: Uncertainty Factors

Factors Affecting Certainty	Assessment Approach	Summary Confidence Level
Exposure Assessment	A simple forecasting approach based on estimates of motor vehicle trips and cycling trips in 2005 and 2015 conditions. Intersection-level engineering factors, recreational cycling trips not considered in the analysis.	Moderate-Low
Baseline Disease Prevalence	Vehicle-cyclist injury collision data from the California Highway Patrol's Statewide Integrated Traffic Records System (SWITRS). Likely an underestimate of total injury collisions.	Moderate
Exposure-Response Function (ERF)	Model parameters informed by summary of international findings regarding the relationship between changes in motor vehicle and cyclist trips and vehicle-cyclist injury. There is consistency in the findings regarding a non-linear relationship though variance in parameter values (accounted for with sensitivity analyses). Variance in model parameters potentially due to regional differences in environmental and/or socio-demographic factors not accounted for in the model.	Moderate-Low

F. Health Inequities

Road Pricing and Health Inequities

Health inequities are defined as systematic disparities in health status or in the major social determinants of health between groups with different social advantage/disadvantage (e.g., wealth, power, prestige).[101] Transportation policies have several potential effects on determinants of health including the quality, accessibility, and cost of transportation, transportation hazards, and exposure to environmental hazards, neighborhood livability, and opportunities for physical activity. Policy effects in any of these domains may favor or be adverse to specific populations experiencing or vulnerable to health inequities.

The SFCTA preliminary studies considered potential equity impacts of the fee on low-income drivers, as detailed in the Scoping section (III.D.) of this report. These studies concluded that a congestion pricing program would "not have an undue impact on low-income individuals."[102] This assessment was based on their study recommendations that the policy include a 50% discount for low-income travelers; that approximately 5% of peak-period travelers to downtown San Francisco are drivers with annual household incomes < $50,000; and that many low-income travelers in the Bay Area already rely on public transit and would thus benefit from faster, more reliable transit travel times resulting from pricing fee investments. The SFCTA further found that support for studying a San Francisco congestion pricing program is highest among low-income Bay Area residents.

This HIA analyzed the health effects of road pricing with respect to spatial equity, assessing effects on air and noise pollution, physical activity, and transportation-related injuries city-wide and within the congestion pricing area under study, as detailed in each of the distinct impacts analyses subsections. This section contributes an additional analysis of whether these effects are equitably distributed under the road pricing scenario among populations defined by household income or by age. There are several reasons to consider the particular effects on children and youth, seniors, and low-income populations. Children and adolescents are particularly vulnerable to traffic-related health exposures due to their ongoing growth and development – with lungs still maturing and particularly susceptible to air pollution, with brain development underway and adversely impacted by traffic-related noise and disturbance to sleep and the ability to concentrate, and with cognitive functions unable to fully comprehend and respond to potentially fatal traffic hazards. Seniors are often more dependent on non-motorized transportation for their daily needs, and are more likely to die in vehicle-pedestrian injury collisions – over six times more likely based on recent analyses in San Francisco. Low income populations have been historically, disproportionately exposed to traffic-related hazards and their adverse health impacts. Additionally, these communities typically are confronted with other social and environmental stressors which cumulatively contribute to disproportionate adverse health effects, including: poor housing quality; stressful work environments; and limited economic resources to meet basic needs for housing, food, transportation, and health care.

Equity of Traffic-Related Health Hazardous Environmental Exposures for children and youth, seniors, and low-income populations

We used traffic density as a general proxy for adverse environmental exposures and hazards of traffic. The intensity of vehicle air pollution emissions, traffic noise, and safety hazards to non-motorized users are all generally proportional to the density and proximity of vehicles in an area. We created a summary measure of traffic density at the small-area transportation analysis zone (TAZ) level to assess area-level traffic exposure in 2005, 2015 BAU, and 2015 RP conditions using ArcGIS mapping tools (see methodological footnote, below).[b] Traffic density maps were presented earlier in this report (Figure 9). Table 26 summarizes the total population exposure in the three study scenarios for three traffic density categories, with categories consistent for each scenario and cut-points created based on the TAZ-level distribution of traffic density in 2005 conditions.

Table 26. The Distribution of Traffic Density in the General Population: 2005, 2015 Business As Usual, 2015 with Road Pricing

	2005	2015 BAU	2015 RP
Traffic density	*Population, N = 796,000*	*Population, N = 824,000*	*Population, N = 824,000*
At or below average traffic density	67%	65%	66%
1 - 2x average traffic density	24%	25%	26%
>2x average traffic density	9%	10%	9%

Overall, there is a moderate increase in the proportion of the population exposed to higher traffic density from 2005 to 2015 BAU conditions. For 2015 RP relative to 2005, there is a smaller population increase in traffic exposure. These findings are consistent with the analysis of air pollutant and noise impacts.

Traffic Density Distributions by Age

The following table summarizes traffic density by age in 2005, 2015 BAU, and 2015 RP conditions.

Table 27. Traffic Density by Age: 2005, 2015 Business As Usual, 2015 with Road Pricing

	2005			2015 BAU			2015 RP		
	Youth: Ages 0-19	Adults: Ages 20-64	Seniors: Ages 65+	Youth: Ages 0-19	Adults: Ages 20-64	Seniors: Ages 65+	Youth: Ages 0-19	Adults: Ages 20-64	Seniors: Ages 65+
	N= 126,000	*N= 563,000*	*N= 107,000*	*N= 127,000*	*N= 575,000*	*N= 122,000*	*N= 127,000*	*N= 575,000*	*N= 122,000*
At or below average traffic density	71%	66%	66%	70%	64%	64%	71%	65%	66%
1 - 2x average traffic density	19%	25%	25%	19%	26%	24%	20%	27%	25%
>2x average traffic density	9%	9%	9%	11%	10%	11%	9%	8%	9%

Under 2005 conditions, youth aged 0-19 have a higher proportion of their population (71%) represented in areas with less than average traffic density, relative to adults and seniors. However, youth are proportionally

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[b] We first converted street segment traffic volumes to a density metric using a 100-meter grid size and the ArcGIS kernel density method. We next converted the ArcGIS raster data to point data, and assigned the density values to their corresponding TAZ using a spatial join, aggregated the values, and finally normalized the data by the TAZ area. We used 2005 baseline traffic density conditions by TAZ to create the average traffic density, 1-2x average traffic density, and >2x average traffic density categories used in the analysis. We selected these categories based on the distribution of traffic density in San Francisco.

represented in the highest traffic density areas. Traffic density exposure for the elderly is similar to that as that of the overall adult population under 2005 conditions. Figure 6 in Section IV illustrates youth and senior population densities in San Francisco areas under 2005 conditions; as evidenced in the maps, there are higher concentrations of youth in western San Francisco where there are lower concentrations of traffic density.

The relative differences in exposure by age remain largely unchanged under both future 2015 scenarios (BAU and RP) – with a higher proportion of youth in the less than average exposure category relative to adults and seniors in all three scenarios, but similar proportions in the highest exposure category for all three age groups. In fact, the 2015 RP scenario provides a moderately protective equity effect by reducing exposure across all age groups relative to 2015 BAU.

Traffic Density Distributions by Average Area Household Income

The following table summarizes traffic density by average area household income in 2005, 2015 BAU, and 2015 RP conditions.

Table 28. Traffic Density by Income: 2005, 2015 Business As Usual, 2015 with Road Pricing

	2005			2015 BAU			2015 RP		
	Avg. HH Income: <$35,000	**Avg. HH Income: $35-70,000**	**Avg. HH Income: >$70,000**	**Avg. HH Income: <$35,000**	**Avg. HH Income: $35-70,000**	**Avg. HH Income: >$70,000**	**Avg. HH Income: <$35,000**	**Avg. HH Income: $35-70,000**	**Avg. HH Income: >$70,000**
	N= 98,000	*N= 496,000*	*N= 202,000*	*N= 88,000*	*N= 487,000*	*N= 249,000*	*N= 88,000*	*N= 487,000*	*N= 249,000*
At or below average traffic density	31%	70%	77%	25%	69%	71%	25%	70%	72%
1 - 2x average traffic density	64%	20%	15%	67%	20%	20%	68%	21%	20%
>2x average traffic density	5%	9%	9%	8%	11%	9%	7%	9%	8%

Differences in exposure to traffic density for each income group are notable under baseline conditions. Compared to the highest income households (with average household income >$70,000) fewer low-income households (<$35,000) live in areas with less than average traffic density (77% vs 31%). Although low-income households are in areas with lower levels of the highest average traffic density (5% vs. 9%), overall a higher percentage of the low-income households are in areas with average or above average traffic density compared to higher income households (69% vs. 24%).

Figure 5 (Section IV) illustrates average household income by TAZ in San Francisco under 2005 conditions. Visually comparing that map to the traffic density maps in Figure 9 reveals that area-level concentrated poverty (as measured by average household income <$35,000) is associated with higher area traffic density. This may be the result of past transportation and land use planning and policy decisions which increased traffic on the streets of lower income communities.

Future conditions under 2015 BAU estimate traffic density increases for all income categories. Among low income households, fewer are predicted to live in lower traffic areas (25% vs. 31%) and more could live in higher traffic areas (8% vs. 5%). 2015 with road pricing contributes to relatively moderate decreases in traffic density exposure citywide. There is still a decrease in the proportion of low income households experiencing lower traffic density under 2015 RP; however, the increase in the proportion of low-income households in high traffic density areas (7% vs. 5%) is smaller than under 2015 BAU conditions (8% vs. 5%).

Of note, areas where the lowest income communities experience higher concentrations of traffic are also areas with the lowest prevalence of motor vehicle ownership and, as detailed in the Active Transportation analysis – areas where more residents walk (or rely on transit) for transportation. As described in the vehicle-pedestrian injury collision and vehicle-cyclist injury collision analysis sections, these communities are currently disproportionately burdened with injuries to vulnerable road users.

Overall, under 2005 conditions low-income households are disproportionately burdened with environmental exposures related to higher traffic densities - including air pollution, noise, and pedestrian safety hazards. Based on this analysis, 2015 with road pricing is expected to mitigate some increased exposure to traffic density predicted under 2015 BAU. As discussed in the rest of this section (V.), the road pricing policy under study has a very moderate beneficial effect in reducing exposure across all populations.

G. Costs

Economic Valuation of Transportation-Attributable Health Outcomes

This section provides our analysis of the economic value of the health effects analyzed in prior sections. We assessed the economic cost or benefit of transportation-related health effects only for those health effects that were quantified and that had accepted monetary valuation methods. The approach used is generally consistent with the practices used in regulatory impact assessment and cost benefit analysis by the U.S. Environmental Protection Agency (USEPA) and other regulatory impact assessments.[103]

The economic value of health effects can include direct health care costs as well indirect costs such as lost wages for individuals, lost productivity for employers, pain and suffering for individuals, relatives, and family members. Furthermore, changes in the health of one individual can also affect the health and well-being of another, resulting in additional economic costs. There are a range of methods available to assess the economic value of health effects. Methods differ in their ability to capture the range of costs of health outcomes, including costs that do no have economic markets. For example, some of the earliest methods to value life in assessments of pre-mature mortality were based only on assessments of effects on lost economic productivity or income and gave no value to "intangibles" such as grief. In contrast, hedonic economic methods attempt to capture such intangible and non-market effects by using observations of economic behaviors (e.g. trade-offs among wages and hazardous employment, the cost of the purchase of consumer safety products) to reveal what value individuals give to protecting life. The hedonic method makes important assumptions about individual knowledge and employment choices. The contingent valuation method assumes a hypothetical market and asks individuals to state their willingness to pay for a change in the risk of mortality, typically via a survey. Although each of the above methods has limitations, the contingent valuation method appears to have become the preferred approach to value life in the context of regulatory analysis.[104]

A summary of economic values of health effects, valuation methods, and sources used to value health effects is described below and provided in Table 29.

Table 29. Economic Valuation of Health Effects: Input and Methods

Health Outcome	Economic Valuation	Valuation Year	Adjusted 2010 Year Value	Economic Valuation Method	Agency Source
Adverse Effects					
Avoidable mortality attributable to traffic-related fine particulate matter (PM 2.5)					
	$ 7,400,000	2006	$ 8,004,040	Meta-analysis of wage-differential and stated preference studies	USEPA
Annoyance due to traffic-related noise					
	N/A	*N/A*	*N/A*	Estimates for U.S. populations not available	*N/A*
Myocardial infarction cases attributable to traffic-related noise					
	$ 262,600	2000	$ 332,529	Sum of Lifetime Medical Cost, Lost Productivity, and Present value of Earnings; age 65 female and 70 male respectively; average of male and female	Harvard Center for Risk Analysis
Avoidable mortality attributable to vehicle-pedestrian and vehicle-cyclist collisions					
	$ 7,400,000	2006	$ 8,004,040	Meta-analysis of wage-differential and stated preference studies	USEPA
Avoidable non-lethal injuries by severity attributable to vehicle-pedestrian and vehicle-cyclist					
Minor	$ 14,800	2006	$ 16,008	Estimated as a fraction of the VSL based on the severity of the injury	USDOT
Moderate	$ 114,700	2006	$ 124,063		
Serious	$ 425,500	2006	$ 460,232		
Severe	$ 1,387,500	2006	$ 1,500,757		
Critical	$ 5,642,500	2006	$ 6,103,080		
Beneficial Effects					
Mortality averted due to physical activity via walking and biking for active transportation					
	$ 7,400,000	2006	$ 8,004,040	Meta-analysis of wage-differential and stated preference studies	USEPA

For all impacts on life expectancy , including traffic fatalities, pre-mature mortality from particulate matter exposure, and reduced mortality from improved physical activity, we used the USEPA default central “value of statistical life” (VSL) of $7.4 million (2006$).[105] Notably, the VSL used by the USEPA is different than the VSL values used by some other Federal agencies including the USDOT.

For ischemic heart disease events we used a valuation combining three types of costs of non-fatal myocardial infarctions: lifetime medical cost, lost productivity, and lost wages.[106] This valuation approach does not capture the value of averting the illness or other intangibles. We assumed that none of the ischemic heart disease events would be fatal.

To assess the value of non-fatal traffic injuries, we used a method following on US DOT guidelines for economic valuation[107] that scales the value of injuries as a fraction of the VSL based on how the injury affects of the quality of life. Injuries are categorized along a Maximum Abbreviated Injury Scale (MAIS), into levels ranging from MAIS 1 (minor) to MAIS 5 (critical). Table 30 provides the parameters used to multiply by the current value of preventing a fatality to obtain the value of preventing injuries of the relevant types.

Table 30. U.S. Department of Transportation Guideline Values for Lethal and Non-Lethal Injuries

MAIS Level	Severity	Fraction of VSL
MAIS 1	Minor	0.0020
MAIS 2	Moderate	0.0155
MAIS 3	Serious	0.0575
MAIS 4	Severe	0.1875
MAIS 5	Critical	0.7625
MAIS 6	Fatal	1.0000

We estimated the annual economic value of transportation-attributable health effects under each of the three transportation scenarios—2005 baseline, 2015 BAU, and 2015 RP using the outputs of the quantitative health effects analysis described in this report (see Executive Summary table). We assumed that the distribution of the severity of vehicle-pedestrian and vehicle-cyclist injury collisions would remain similar to the distribution under 2005 baseline conditions. We used injury severity assigned in SWITRS to assign the above MAIS codes as follows, using the proportion of motor vehicle-pedestrian and motor vehicle-cyclist injuries seen by San Francisco General Hospital, San Francisco's only trauma center, to inform the proportion of injuries that were critical (MAIS 5) and severe (MAIS 4). We conducted analysis for the scenario year only and thus did not discount future effects.

Table 31 provides estimates of the economic value of costs of motor vehicle use and the health benefits of non-motorized transportation. The total aggregate annual economic value of transportation-attributable adverse health effects was lowest in 2015 RP - $4 million lower than costs estimated for 2005 and $53 million less than costs estimated for 2015 BAU. Vehicle-pedestrian and vehicle-cyclist injury collisions contributed the most to the economic value of adverse health effects under all scenarios – accounting for just over half of the estimated health-associated costs. Premature mortality attributable to air pollution was the next most important contributor, accounting for approximately 45% of costs. Approximately 2% of the enumerated costs were associated with heart attacks attributable to traffic-related noise.

Table 31. Annual Economic Values of Transportation-Attributable Health Effects under 2005, 2015 BAU, and 2015 RP scenarios: San Francisco, California

Health Outcome	Economic Value of Health Outcome ($2010)	Cases / Events			Estimated Economic Value *(Millions of $)*		
		2005	2015 BAU	2015 RP	2005	2015 BAU	2015 RP
Adverse Effects Value: **Total**					***$ 1,124***	***$ 1,173***	***$ 1,120***
Avoidable mortality attributable to traffic-related fine particulate matter (PM 2.5)							
	$8,004,000	65	66	63	$ 520	$ 528	$ 504
Annoyance due to traffic-related noise							
	N/A	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Myocardial infarction cases attributable to traffic-related noise							
	$332,529	31	34	34	$ 10	$ 11	$ 11
Avoidable injuries by severity attributable to vehicle-pedestrian and vehicle-cyclist collisions							
Minor	$16,008	575	615	587	$ 9	$ 10	$ 9
Moderate	$124,062	196	210	201	$ 24	$ 26	$ 25
Serious	$460,232	196	210	201	$ 90	$ 97	$ 93
Severe	$1,500,757	56	60	57	$ 84	$ 90	$ 86
Critical	$6,103,000	37	40	38	$ 228	$ 243	$ 232
Fatal	$8,004,000	20	21	20	$ 158	$ 168	$ 160
Beneficial Effects Value: **Total**					***$ 1,225***	***$ 1,305***	***$ 1,337***
Mortality averted attributable to biking for active transportation							
	$ 8,004,000	**23**	**25**	**26**	**$ 184**	**$ 200**	**$ 208**
Mortality averted attributable to walking for active transportation							
	$ 8,004,000	**130**	**138**	**141**	**$ 1,041**	**$ 1,105**	**$ 1,129**
Green: estimates of beneficial *cost savings* from mortality averted from active transportation via walking and biking.							

Estimated beneficial cost savings from mortality averted from active transportation via walking and biking were slightly greater than the estimated adverse health costs in all scenarios, with an estimated $1.34 billion in 2015 RP, $1.31 billion in 2015 BAU, and $1.23 billion in 2005. Beneficial cost savings are greatest under the 2015 RP scenario.

Limitations

This economic valuation of transportation-related health effects has several important limitations.

- First, this economic analysis did not count all of the health and welfare outcomes attributable to transportation. We did not quantify each health effect identified, (for example, asthma related to vehicle emissions or cognitive impairment due to noise) and we did not quantify physical activity effects on chronic disease morbidity.
- Second, as discussed above, we could not identify suitable economic values for each health effect quantified. Specifically, we did not identify published U.S. values for the noise-related health effect of subjective annoyance. While valuation methods exist for noise and health outcomes based on studies in European countries, we could not find examples of economic values of noise-related health effects in the U.S. literature or examples of noise-related health costs in U.S. Cost-benefit analysis. We did not apply

the European values to the U.S. population in the interest of consistency in valuations used for our economic analysis.

- Third, as with all economic valuations of health and welfare outcomes, this analysis has several general conceptual limitations. The reasonability of placing a monetary price on health or life and assessing the value of health to future generations is a topic of ongoing debate.[108]
- Finally, the economic costs and benefits should not be construed to represent a complete cost-benefit analysis of the proposal. For example, we did not consider the include the direct costs of transportation of the value of time spent or saved as a result of the pricing program.

VI. Recommendations

Recommendations for Maximizing the Health Benefits of Road Pricing Policy

This section provides recommendations for investments and strategies to support the success of road pricing and maximize its health benefits. Identifying feasible and effective recommendations for policy or decision alternatives and mitigations is a key part of the HIA process. In general, road pricing as designed has moderate health and equity benefits relative to business as usual scenarios. As the negative health consequences of road pricing are few, the following recommendations are provided for investments and strategies that would complement road pricing as a health improvement strategy. Further, the HIA findings provide direction with respect to targeting policies and mitigations to specific locations to address potential adverse impacts and enhance health benefits.

One of the specific benefits of road pricing is that it generates revenue that may be used to maintain and improve transportation infrastructure. An objective of road pricing is to reduce the negative impacts of private motor vehicles on the transportation system, it is therefore appropriate that revenues from road pricing be used to improve the quality and safety of transportation for transit and non-motorized transportation users. Many such investments can be leveraged for improving health.

We propose the following recommendations based on reviews of the existing interdisciplinary literature and consultation with experts in transportation, economics, and environmental planning – including those who are consultants on our study team. SFDPH and other members of the research team have substantial experience in formulating recommendations for transportation and land use policy base on experience with HIA and through the development and application of the healthy development measurement tool (HDMT; www.thehdmt.org). In formulating these recommendations, it was critical to include consideration of investments with particular benefits for transit-dependent populations and neighborhoods that have been historically burdened by adverse impacts of the transportation system, because this new revenue can redress those injustices. Our recommendations are not exhaustive, and further study could likely identify additional best practices.

A number of these recommendations are already under consideration by the SFCTA as programmatic improvements or mitigations to potentially enhance travel options or mitigate/minimize traffic and related environmental impacts as part of a comprehensive program and investment package. Additionally, these improvements – and their potential impact – have not been identified at this stage of the SFCTA's study of the potential congestion pricing policy, nor were they included in the travel model outputs that informed this HIA. The SFCTA travel model does not currently have the capacity to account fully for all expected investments. Similarly, this HIA has not prospectively modeled any physical environmental changes that may result from road pricing revenue investments. These investments could have significant independent health effects that could be assessed in a separate, future analysis.

A number of these recommendations are consistent with and/or would support other ongoing, inter-agency efforts currently underway in the City and County of San Francisco. SFDPH is engaged with sister agencies in work to assess and address transportation system-related health effects, including the Citywide Pedestrian Safety Task Force and the Community Risk Reduction Plan to improve air quality. Partnerships among City agencies, including SFDPH, would be used to help finalize any package of improvements to accompany the implementation of pricing.

Air Quality

We expect that the road pricing policy may moderate air pollution increase in areas with expected growth in vehicle air pollution emissions. There are not cumulative negative air quality consequences requiring mitigation, however, augmenting the fee or extending the fee to other times may amplify these benefits - specifically:

- Consider augmenting the fee on days with poor air quality (e.g. BAAQMD spare the air days).
- Consider augmenting the fee for vehicles with relatively greater pollutant emissions per passenger-mile.

Noise

As discussed in the impact analysis section, we expect noise will modestly increase in all scenarios and this increase is likely to be greatest along transit corridors. Following are recommendations to moderate these increases:

- Consider applying the fees to motorcycles.
- Consider augmenting the fee for the noisiest vehicles, including large commercial freight trucks.
- Consider road pricing investments in quieter transit vehicle or road surface technologies.
- Consider utilizing the fee to provide subsidies for residential acoustical protection along the noisiest thoroughfares.

Active Transportation

Pricing policies will result in shifts to transit and non-motorized transport, increasing physical activity. Augmenting the fee or extending the fee to other times may amplify these benefits. Improvement strategies for pedestrian safety and cyclist safety, cited below, would likely enhance the benefits of the policy on physical activity. Specific recommendations for physical activity are:

- Consider using fees to augment cyclist – transit facilities/infrastructure to improve active transportation connections, particularly for the western part of the city with the lowest active transportation rates and the farthest distance to travel from downtown (e.g., secure bike parking near transit).[109]
- Consider using fees in support of employer-based transportation demand management programs to incentivize commuting to work via walking, biking and public transit and decrease driving.[110]
- Adding street trees, public seating, pedestrian scale lighting, and enhancing public art on the sidewalks.[111]

Pedestrian Safety

Pricing reduces road volume and consequentially one of the most important determinants of injury frequency. Pricing policies also will result in shifts to transit and non-motorized transport, increasing the number of pedestrians exposed to hazards from motorized vehicles. Reducing congestion may also increase vehicle speeds on local roadways. Policies and investments could include enforcement and engineering strategies to mitigate these effects and improve safety for non-motorized users.

Specific recommendations include:

- Consider investing road pricing revenues in traffic safety enforcement within and at the edge of the congestion pricing zone, combined with media messages targeted at reducing hazardous driving behaviors.

- Consider investing road pricing revenues to implement pedestrian safety engineering strategies along identified high-risk pedestrian corridors within and at the boundary of the congestion pricing zone – with particular attention to streets near senior centers, schools, health centers, and other key community facilities that attract vulnerable users.

- Based on the PEQI data analysis, South of Market is most in need of preventive and anticipatory environmental design for pedestrians. Specific changes in SoMa and other high-injury areas could include: [112]
    - Reducing the number of lanes or narrowing the roadway on multilane roads
    - Adding traffic calming measures along high-risk corridors and streets including: lane narrowing, signal timing, dynamic speed display signs, speed radar trailers, and street trees
    - Adding mid-block, signalized crossings on long blocks
    - Extending signalized crossing times for pedestrians
    - Adding curb-extensions and median islands
    - Installing high visibility crosswalks and advance yield lines
    - Adding pedestrian-scaled lighting
    - Reducing and restricting curb cuts for motor vehicles
    - Providing beacons or hybrid signals at key crossing locations
    - Relocating bus stops to safe crossing locations
    - Providing enhancements to traffic signals, such as leading pedestrian intervals, scramble phases, protected left turns, or prohibited right turns on red

Further target pedestrian safety engineering countermeasures and environmental improvements to roadways, particularly arterials, outside the congestion pricing zone with existing high numbers of pedestrian injuries and fatalities (see Figure 20) anticipated to experience additional traffic under 2015 BAU and/or 2015 RP conditions. Specific improvements to consider include:[113]

- Systematically installing pedestrian signals, crosswalks (high visibility crosswalks when warranted) and bulb outs at key intersections along neighborhood commercial corridors
- Installing evenly-lit pedestrian-scaled lighting that makes pedestrians visible
- Reducing and restricting curb cuts for motor vehicles
- Adding directional curb ramps to all intersections

Cyclist Safety

Pricing reduces road volumes and consequentially one of the most important determinants of injury frequency. As stated above, pricing policies also will results in shifts to transit and non-motorized transport, increasing the number of cyclists exposed to hazards from motorized vehicles. Reducing congestion may also increase vehicle speeds on local roadways. Policies and investments could include enforcement and engineering strategies to mitigate these effects and improve safety for non-motorized users. In existing conditions, cycling and cyclist injuries have been increasing. Revenue investments in resurfacing streets commonly used by cyclists help to reduce environmental hazards (e.g., uneven surfaces). Specific recommendations for cyclist safety include:[114]

- Consider investing in engineering measures that reduce injury risks to cyclists from motor vehicle collisions – particularly on busy arterials with higher cyclist volumes or designated bike routes – including the traffic calming measures cited above and bike boxes at intersections.
- Consider investing in separated bikeways via parking or other physical buffers, particularly on busy arterials, truck routes, or transit routes with higher cyclist volumes
- Consider targeted enforcement efforts to keep bike facilities clear of motor vehicles and improve motorist and cyclist behavior/compliance

Monitoring

Monitoring the implementation of the policy, should it be implemented, is an important strategy for assessing its impacts and addressing any unanticipated effects related to health and equity. Specific recommendations for monitoring include:

- Monitoring indicators of the distribution of health, geographic, and other equity-related effects, including: local traffic volumes and speeds, pedestrian and cyclist injuries, noise complaints, cut-through traffic complaints, noise and air pollutant levels, pedestrian and cyclist volumes, use of policy discounts by low-income and other identified populations, and other indicators as appropriate.

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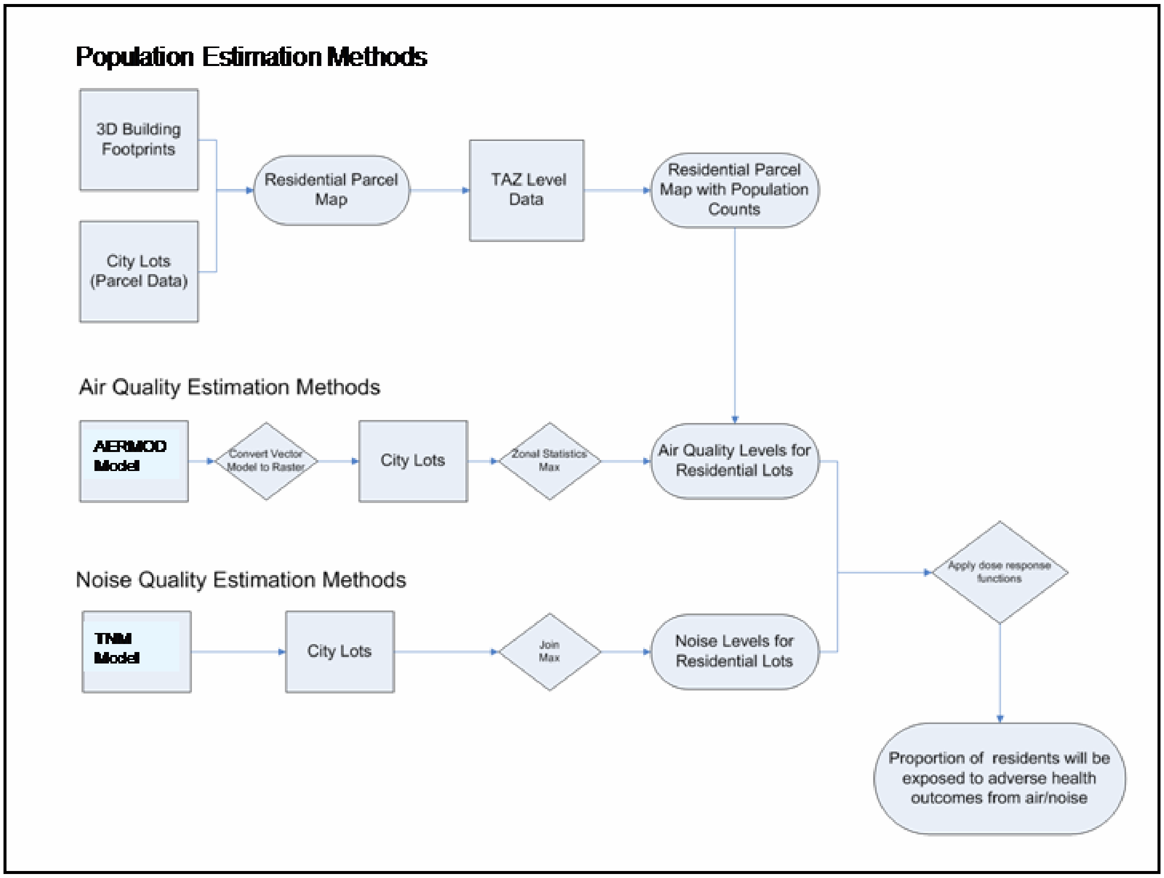
Appendix A. Methods: Population Exposure Assignment for Air Quality and Noise Impacts Estimation

Summary: The evaluation of exposure to air and noise pollution depends on the location of the source of emission as well as the location of the population. The following figure and summary provide an overview of the methods we used to estimate the residential population and residential population exposure for the air quality and noise HIA analyses.



AERMOD: U.S. Environmental Protection Agency recommended air quality modeling, further described in Appendix B.[i]

TNM: Traffic Noise Model (TNM from the Federal Highway Administration, further described in Appendix C.[ii]

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[i] Additional information available at: *www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod*.

[ii] Additional information available at: *www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_v25/*.

Appendix A. Methods: Population Exposure Assignment for Air Quality and Noise Impacts Estimation

1) Population Estimation Methods

Residential population at the Transportation Analysis Zone (TAZ) level (as detailed in Table 2 of the report) was assigned to each residential land parcel in San Francisco based on an estimate of total relative building floor area (area of parcel x average height of buildings) using the following formula:

Population of residential land parcel (A) = (B*C)/D

Where:

A = Population of residential land parcel
B = TAZ residential population
C = Building Floor Area estimate of residential land parcel
D = Total Building Floor of all residential land parcels in the specified TAZ

Residential land parcels were defined as parcels with a specified land use of residential or mixed land use (residential/commercial). For residential parcels, the entire parcel building floor area was used to calculate residential density. For mixed land use, we assume residential housing started on the second floor of the building. Land use information was obtained from the San Francisco Planning Department, based on data from the San Francisco Assessors Office and Department of Building Inspections. Additionally, residential building footprints were provided for the Presidio by Presidio GIS, Fort Mason by the Golden Gate National Recreation Area, and Treasure Island/Yerba Buena by Treasure Island Development Authority.

For data not available on a TAZ level, proportions for race and age categories were derived from 2008 population and 2014 estimates (as specified in Table 2 of the report) and applied to the TAZ level data.

2) Air Quality and Noise Exposure Estimation

As detailed in the Figure above, in a parallel process we estimated exposure levels to traffic-related air pollution (fine particulate matter, PM 2.5) and traffic-related noise levels (as detailed in Appendix B and C) under the three study scenarios (2005, 2015 BAU, 2015 RP) and assigned the maximum exposure level to the population in the corresponding residential parcel. This use of maximum exposure tends to overestimate health impacts, which is consistent with providing a health-protective margin of safety in impacts estimation. Additionally, the HIA describes relative estimated changes in health impacts across the three scenarios – estimates in each of the scenarios based on the same assumptions. Appendices B and C provide more information regarding the specific methods used to estimate health impacts.

Appendix B. Methods: Traffic-Attributable Fine Particulate Matter ($PM_{2.5}$) Exposure and Premature Mortality

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Summary: We estimated traffic-attributable ambient fine particulate matter ($PM_{2.5}$) concentrations for the City and County of San Francisco for each of the three study scenarios assigning exposure to the population at the level of the residential parcel. We then estimated excess traffic-attributable PM 2.5 mortality for each scenario utilizing residential populations and exposure data, exposure-response functions derived from well-designed epidemiologic studies, and current mortality incidence data for the City and County of San Francisco.

1. Estimation of Traffic-Attributable Ambient PM2.5

We estimated traffic-attributable $PM_{2.5}$ concentrations for the three study scenarios (2005, 2015 BAU, 2015 RP) using the AERMOD air pollution dispersion model.[a] Model inputs included traffic volume data, speed, vehicle emissions, and meteorology. Traffic volume (annual average hourly) and speed data at the street segment level were estimated using the San Francisco County Transportation Authority's SF-CHAMP model (See Table 2 of the final report). We used the California Air Resources Board EMFAC 2007[b] model to estimate $PM_{2.5}$ emissions in grams/mile. One year of hourly meteorological data (2008) was obtained from the Bay Area Air Quality Management District. The dispersion model estimated ambient concentrations city wide.

2. Health Impact Predictive Function

A typical health impact predictive function has four components: 1) an effect estimate or exposure-response function from an epidemiological or toxicological study; 2) an estimate for an exposure or exposure change; 3) a baseline incidence rate for the health effect; and 4) an estimate of the size of the population affected by exposure. Based on the population exposure estimated in each study scenario, we calculated excess traffic-attributable $PM_{2.5}$ mortality for each exposure category using the following equation.

$$\textbf{Attributable Deaths} = (e^{(-\beta * \delta \text{ PM2.5})} - 1) * I_O * P_{exp}$$

Where:

$e^{(-\beta * \delta \text{ PM2.5})}$ = an estimate of the relative risk of the incidence of mortality in a population exposed to a particular increment of $PM_{2.5}$ above background levels

β = coefficient of $PM_{2.5}$ parameter in regression model

δ $PM_{2.5}$ = traffic attributable ambient concentration of $PM_{2.5}$

I_O = crude mortality incidence rate

P_{exp} is the size of the population (> 30 years old) experiencing a change in exposure

3. Population Exposure to Traffic-Attributable Ambient $PM_{2.5}$

We assigned the modeled $PM_{2.5}$ exposure to each parcel using the maximum modeled ambient exposure concentration at the parcel. We created discrete exposure categories for the range of traffic attributable $PM_{2.5}$ concentration citywide. We estimated residential population data at the parcel level (estimated as detailed in Appendix A) to estimate the population exposed at each exposure category.

Appendix B. Methods: Traffic-Attributable Fine Particulate Matter (PM$_{2.5}$) Exposure and Premature Mortality

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4. Baseline Disease and Mortality Incidence

We utilized all-cause mortality incidence data provided for the City and County of San Francisco by the California Department of Public Health.

5. Exposure Response Function

The relationship between long term community-level PM$_{2.5}$ exposures over multiple years and community-level annual mortality rates has been examined in several well-designed, peer-reviewed prospective cohort studies. These studies, conducted in the U.S. general population, report consistent statistically significant associations between PM$_{2.5}$ and premature mortality. Three seminal studies based on two large general population cohorts (American Cancer Society and Harvard Six Cities) are summarized in the table below. The study by Jerrett et al (2005) re-analyzed the American Cancer Society cohort using a different approach to exposure assignment and a subset of a cohort in Los Angeles, California.

Key Cohort Studies of Long Term Exposure to PM$_{2.5}$ **and Mortality**

Cohort/ Publication	**Population**	**RR per 10 ug/m3** PM$_{2.5}$ **(95% Confidence Interval)**
American Cancer Society **Pope (2002)**[c]	USA, 51 cities Adults, Age > 30 years	1.06 (1.02-1.11)
Harvard Six Cities **Laden (2006)**[d]	USA, Multiple Cities General Population	1.16 (1.07, 1.26)
American Cancer Society **Jerrett (2005)**[e]	USA, Los Angeles Large Cohort *(valid for comparison with large samples of U.S. Population)*	1.17 (1.05 -1.30)

In developing exposure response functions for regulatory health impact assessment, the U.S. Environmental Protection Agency relies on the American Cancer Society (ACS) cohort[f] and the Harvard Six Cities cohort,[g] because of their geographic scope and their extensive reexamination.[h] Lower risk estimates from the ACS cohort may be due to higher population socio-economic status or exposure misclassification from retrospective exposure assessments.[i] In the re-analysis by Jerrett et al. (2005) of an ACS subpopulation in Los Angeles, more spatially refined intra-regional exposure data may have reduced such exposure misclassification, potentially explaining a higher central relative risk estimate of 1.17 in the same population.

Brunelle-Yeung et al conclude that a RR=1.01 per 1μg/m^3 PM$_{2.5}$ (1% increase in mortality per 1μg/m3 of long-term PM$_{2.5}$) represents a central estimate of the exposure response function based upon the epidemiologic literature.[j] This exposure response function also represents the average of the individual estimates provided by 12 experts.[k] We utilized this exposure response function (RR=1.01 per 1μg/m^3 PM$_{2.5}$) in our health impact prediction equation.

Appendix B. Methods: Traffic-Attributable Fine Particulate Matter ($PM_{2.5}$) Exposure and Premature Mortality

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Appendix C. Methods: Road Traffic Noise and Noise-related Annoyance and Myocardial Infarction

Summary: We estimated sound levels for the City and County of San Francisco for the three scenarios and assigned modeled ambient sound levels to residential parcels. We then estimated population exposure levels to ambient sound based on the estimated number of residents of each parcel. We estimated changes in noise-related annoyance (defined below) using a well-established exposure-response function based on data pooled from international studies. We estimated noise-attributable cases of myocardial infarction using an exposure response function derived from a meta-analysis of studies along with baseline myocardial infarction incidence rates for San Francisco, California.

1. Estimation of Ambient Sound Levels

We estimated 24-hour (L_{dn}) and daytime (L_{day}) ambient sound levels for the three study scenarios using the FHWA's traffic noise model.[a,b] Model inputs included traffic volumes by time of day, vehicle type (car, truck), and traffic speeds (described in Table 2). Traffic also includes existing and future estimates of bus volumes. We assigned proportion of trucks that were heavy versus medium trucks based on neighborhood-level estimates on arterial versus non-arterial streets using aerial photography.[c]

2. Estimation of Population Exposure

We used the residential population data at the parcel level (estimated as detailed in Appendix A) and assigned the modeled noise level exposure to each parcel using the maximum modeled noise exposure level within 25 meters of the parcel.

3. Health Impact Prediction Functions

a) Noise Annoyance

Noise annoyance is defined as "a feeling of resentment, displeasure, discomfort, dissatisfaction, or offense when noise interferes with someone's thoughts, feelings, or actual activities."[d] Miedema (2001) pooled 45 international studies relating 24 hour noise levels and self-rated noise annoyance and used these pooled data to develop exposure response functions for annoyance from road, railroad, and aviation noise.[e] The polynomial equation below estimates the proportion of the population reporting high levels of noise annoyance based on the 24-hour sound level (L_{dn}) for road traffic noise. This function applies to a range of exposure from 42 dBA to 75 dBA.

$$\%HA = 9.994\times10^{-4}\left(L_{dn}-42\right)^3 - 1.523\times10^{-2}\left(L_{dn}-42\right)^2 + 0.538\left(L_{dn}-42\right)$$

Using this function, we estimated the proportion of residents expected to be highly annoyed for 1dB sound level increments from 42dBA to 75dBA. We then multiplied these proportions by the number of people in each exposure category. The population exposed to noise levels above 75 dBA was assigned to the 75 dBA exposure category.

b) Myocardial Infarction

Babich (2008) pooled data from four well-designed studies on noise and the incidence of myocardial infarction (MI) to derive an exposure-response curve for MI incidence and daytime residential noise.[f] A polynomial function was fit to the pooled data for noise levels between 55- 80 dBA:

$$\mathbf{OR = 1.629657 - 0.000613*(L_{day})^2 + 0.000007357*(L_{day})^3}$$

Appendix C. Methods: Road Traffic Noise and Noise-related Annoyance and Myocardial Infarction

We used this exposure-response function to estimate the OR_i for MI incidence for 1 dBA sound level increments from 55 dBA to 80 dBA. We then estimated the relative risk of MI incidence for each increment (RR_i) using the following standard formula:

$$\mathbf{RR= OR/[1 + P_{MI} *(OR -1)]}$$

Where $\mathbf{P_{MI}}$ **=** 0.00182 (the baseline incidence of MI)

We obtained baseline prevalence of myocardial infarction from a California Department of Public Health analysis of hospitalization discharge data reported to the Office of Statewide Health Planning and Development (OSHPD).[g] Data are collected from every licensed acute care hospital in California, excluding federal hospitals. We then estimated the fraction of MI cases attributable to noise exposure under each scenario using the standard formula for calculating attributable fractions for multiple category exposure.[h,i]

$$\mathbf{AFq = (\mathit{R}q - \mathit{1}) / \mathit{R}q}$$

Where $Rq= \sum_i (q_i\ RR_i)$ *and* q_i is the proportion of the population exposed at each exposure level.

Finally, to estimate the annual number of traffic noise-attributable MI cases, we multiplied the attributable fraction for each scenario by the product of the estimated population older than 30 years and the baseline MI incidence rate.

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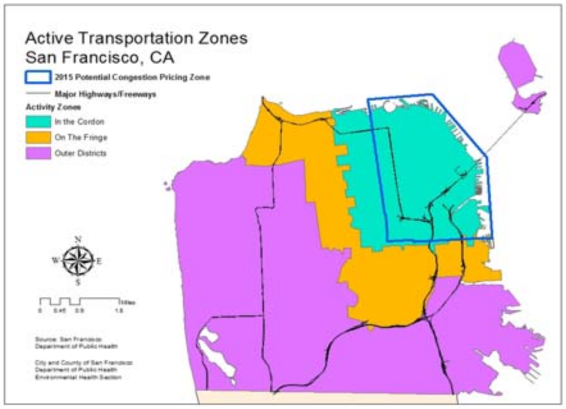
Appendix D. Methods: Active Transportation and Lives Saved from Walking and Cycling

Walk and Bike Trips and Times by Age: We used existing and future conditions data from the SFCTA model to assess walk and bike trips and trip times made by residents living in 12 geographic districts in San Francisco (the smallest reliable level of aggregation used to estimate walk and bike trips in the SFCTA's transportation analyses). We used data for existing and future conditions for area-level resident population and age as detailed in Table 2 of the final report. As depicted in the map below, we collapsed the 12 districts into three districts, defined with by their geographic location relative to the road pricing zone under study (depicted with a blue boundary on the map). The three zones are "In the Zone," turquoise, comprised of the districts mostly in the cordon zone; "On the Fringe," yellow/mustard, comprised of the districts just outside of the cordon zone; and the "Outer Districts," pink, representing those farther away from the cordon zone.



Data were available on trip making and travel mode by district of residence but not by age in San Francisco, so we estimated trip making and transportation mode by age based on the Bay Area Travel Survey data (2000), assuming the proportion making trips and transportation mode by age were similar across the Bay Area region.[a]

Lives Saved Due to Changes in Cycling and Walking: We used the WHO/Europe Health Economic Assessment Tool (HEAT) to estimate the number of lives saved to walking and cycling under the three study scenarios, which is readily available online. [b]

We used the trip and trip time estimates by age described above for residents in the three districts along with the annual death rate for San Francisco residents aged 25-64 (267/100,000 residents) as inputs into the tool, which estimates annual lives saved from walking or cycling based on relative risk estimates applied to a population achieving a specified amount of annual physical activity from walking or cycling. For walking, the HEAT tool estimate is based on an epidemiologic meta-analysis which found a relative risk estimate of 0.78 (95% confidence interval: 0.64-0.98) for a walking exposure of 29 minutes seven days a week. For cycling, the HEAT tool is based on the relative risk data from three combined Copenhagen cohort studies which found a relative risk of all-cause mortality of 0.72 among regular commuter cyclists aged

20-60 years relative to the general population after controlling for socioeconomic variables (age, sex, smoking etc.) as well as for leisure time physical activity.

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Appendix E. Methods: Vehicle-Pedestrian Injury Collision Impacts

Summary: We estimated census-tract level changes in vehicle-pedestrian injury collisions using a multivariate, linear, area-level regression model to predict the natural log of vehicle-pedestrian injury collisions in San Francisco census tracts.

1. 2005 Conditions: Vehicle-Pedestrian Injury Collisions at the Census-Tract Level

We estimated census-tract level collisions for 2005 baseline conditions based on the average of actual reported collisions for a five-year period (2001-2005) in an effort to reduce statistical anomalies including regression to the mean. We used collision data from the Statewide Integrated Traffic Records System (SWITRS) which contains data on reported vehicle collisions on public roadways and is maintained by the California Highway Patrol. SWITRS vehicle-pedestrian injury collision data were imported into ArcGIS (version 9.2; ESRI Inc., Redlands, California, USA) and geocoded to the intersection of the reported primary and secondary streets (exact street address is not collected). We used a spatial join to assign vehicle-pedestrian injury collisions to one of the 176 census tracts in San Francisco. We excluded non-injury collisions which are reported as “Property Damage Only”. We included collisions resulting in pedestrian injuries and/or fatalities, hereafter referred to as “vehicle-pedestrian injury collisions”.

2. 2015 Conditions (Business As Usual (BAU), Road Pricing (RP)): Estimating Changes in Vehicle-Pedestrian Injury Collisions at the Census-Tract Level

The San Francisco Department of Public Health developed a census-tract level model of pedestrian injury collision frequency as a function of aggregate traffic volume (log-transformed), street, land use and population characteristics. The model predicts over 70% of the variation in vehicle-pedestrian injury collision in San Francisco census tracts and is published in the peer-reviewed scientific journal *Accident Analysis & Prevention*. [a]

We used this multivariate, linear, area-level (census tract) regression model developed in San Francisco to estimate future changes in vehicle-pedestrian injury collisions. The model predicts census tract level vehicle-pedestrian injury collision counts (log-transformed) using the following equation, where b_0 is a constant and $\sum b_i X_i$ are significant area-level model predictors including traffic volume (log-transformed), proportion arterial streets (without surface transit), proportion of zoning that is neighborhood commercial or residential neighborhood commercial, number of employees (log-transformed), number of residents, land area, proportion of the population living below poverty, and proportion of the population aged 65 and older.

$$\ln(\textit{Ped Injury Collisions}) = b_0 + \sum b_i X_i$$

Notably, several significant model predictors are potential proxies for pedestrian exposure: employee and residential populations, the proportion of land area zoned neighborhood commercial or residential-neighborhood commercial (a pedestrian attractor), and the proportion of people living in poverty (who are often more dependent on walking for transportation).

Appendix E. Methods: Vehicle-Pedestrian Injury Collision Impacts

We used the model to estimate 2005, 2015 BAU, and 2015 RP conditions, changing model parameters based on estimated changes for those years in census-tract level traffic volume, number of residents and employees, proportion of the population aged over 65 and proportion low income. Data for model covariates were obtained from the San Francisco County Transportation Authority and census-based estimates and planning projections from the City and County of San Francisco and are further detailed in Table 2 of the final report. We used the model predictions to calculate percent change in collisions from 2005 – 2015 BAU, 2005 – 2015 RP, and 2015 BAU – 2015 RP, and applied those percentages to the above 2005 conditions data to estimate absolute changes in vehicle-pedestrian injury collisions at the census tract level.

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Appendix F. Methods and Analyses: Pedestrian Environmental Quality Index (PEQI)

Summary: In response to community concerns regarding a lack of data on the pedestrian environment, the San Francisco Department of Public Health's Program on Health, Equity and Sustainability developed the Pedestrian Environmental Quality Index (PEQI) to assess the quality of the physical pedestrian environment and inform pedestrian planning needs. The PEQI draws on published research and work from numerous cities to assess the physical environment, focusing on factors that impact whether people walk and the safety of the pedestrian environment in a neighborhood. The goal of the PEQI analysis is to examine walkability factors, to evaluate the existing quality of the pedestrian environment and to identify potential improvements during land use and transportation planning.

Methods

The PEQI is an observational survey which quantifies street and intersection factors empirically known to affect people's travel behaviors, and is organized into five categories: traffic, street design, land use, intersections, and safety. Within these categories are 30 indicators that reflect the quality of the built environment for pedestrians and comprise the survey used for data collection. SFDPH aggregates these indicators to create a weighted summary index, which can be reported as an overall index or deconstructed by pedestrian environmental category (see the following Table) or even by each indicator. Additional information regarding the PEQI, including a detailed methods report, and a data collection manual, the data collection form, and customize database, can be accessed online.[i]

Table. PEQI Indicators by Pedestrian Environmental Category

Intersection Safety	Traffic	Street Design	Perceived Safety	Land Use
▪ Crosswalks ▪ Ladder crosswalk ▪ Countdown signal ▪ Signal at intersection ▪ Crossing speed ▪ Crosswalk scramble ▪ No turn on red ▪ Traffic calming features ▪ Additional signs for pedestrians	▪ Number of vehicle lanes ▪ Two-way traffic ▪ Vehicle speed ▪ Traffic volume ▪ Traffic calming features	▪ Width of sidewalk ▪ Sidewalk impediments ▪ Large sidewalk obstructions ▪ Presence of curb ▪ Driveway cuts ▪ Trees ▪ Planters/gardens ▪ Public seating ▪ Presence of a buffer	▪ Illegal graffiti ▪ Litter ▪ Lighting ▪ Construction sites ▪ Abandoned buildings	▪ Public art/historic sites ▪ Restaurant and retail use

The PEQI data are primarily collected with an observational survey[ii] based upon the visual assessment of street segments and intersections by a trained observer. A survey form is completed for each individual intersection and street segment (i.e., the segment of a street between two intersections). One indicator

– traffic volume – is not collected on the survey. For this variable SFDPH uses existing street segment traffic counts from the SFCTA's SFCHAMP model.

After data are collected for all desired streets and intersections, the PEQI data are entered into a database so that indicator responses can be converted into numeric values and then scored. Once data entry is complete, a series of programs applies weights to each indicator response, and calculates the PEQI summary scores for Street Segments and Intersections.

Indicator scores for each indicator category were created based on a survey of national experts, including city and transportation planners and consultants, and pedestrian advocates, regarding their importance to pedestrian environmental quality. To create the overall *Street Segment*, *Intersection and other Domain* PEQI scores (see Table, above), SFDPH aggregates the Indicator Response Category Weighted Scores and standardizes those PEQI summary scores so that the maximum score is "100" by multiplying that summed total by the corresponding Domain or Street Segment (Overall) weight.

PEQI scores reflect the degree to which environmental factors supportive of walking and pedestrian safety have been incorporated into street segment and intersection design. The PEQI scores street segments and intersections separately, on a scale from 0 -100. SFDPH is currently using the following categories for scoring, *a priori*, with equal intervals of 20 points for all categories:

100-81 = highest quality, many important pedestrian conditions present - "Ideal"

80- 61 = high quality, some important pedestrian conditions present - "Reasonable"

60- 41 = average quality, pedestrian conditions present but room for improvement -"Basic"

40- 21 = low quality, minimal pedestrian conditions – "Poor"

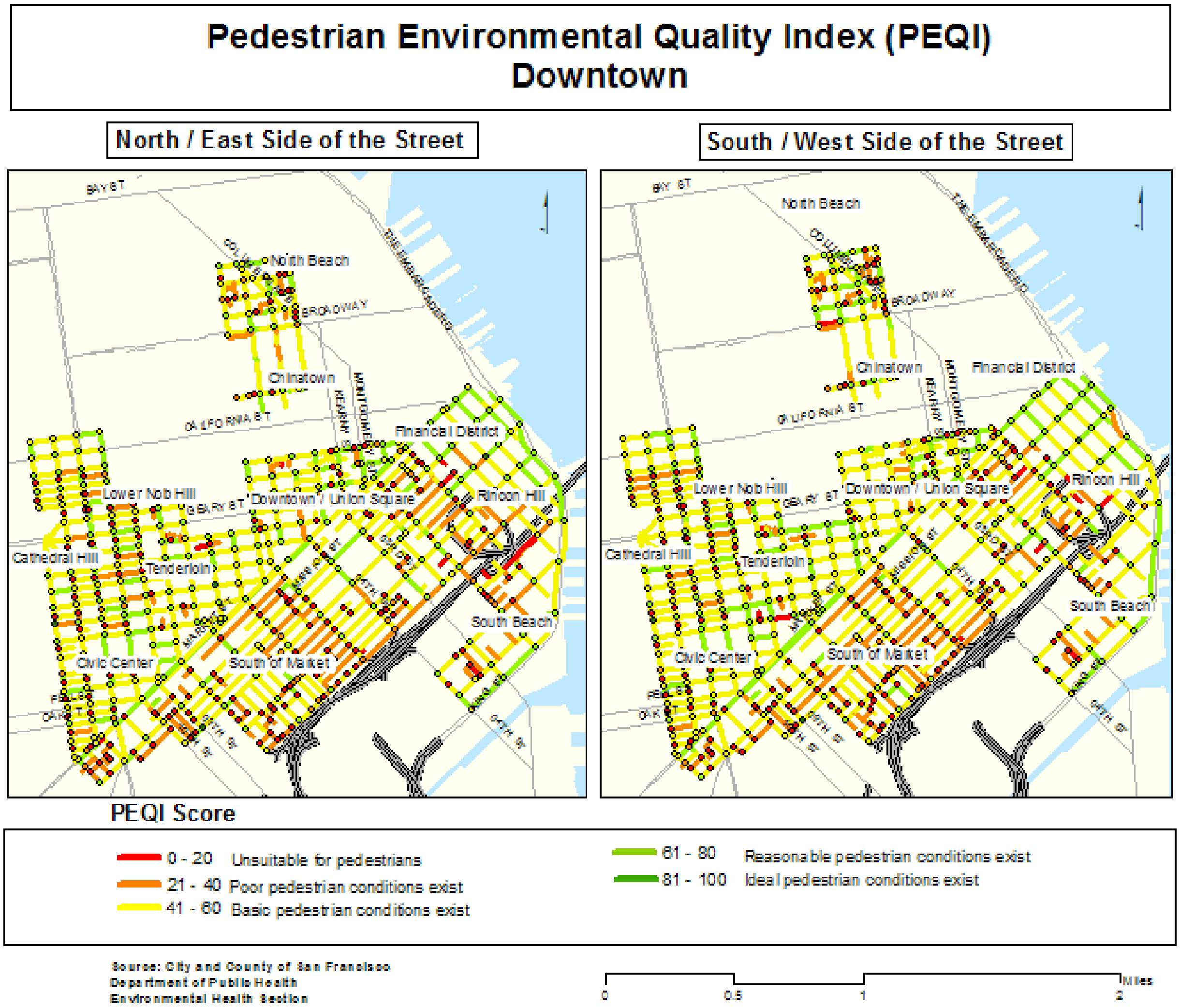
20 and below = poor quality, pedestrian conditions absent – "Not Suitable for Pedestrians"

Detailed information regarding the indicator scores and this overall scoring approach is provided in the online report referenced above. A reliability study of the PEQI is currently underway.

The next section includes a detailed summary of the PEQI analyses and findings for the Road Pricing HIA.

Analysis: Inside the Congestion Pricing Zone

Figure A. Pedestrian Environmental Quality in the Congestion Pricing Zone



Source: City and County of San Francisco
Department of Public Health
Environmental Health Section

South of Market

In South of Market 198 intersections and 646 street segments were assessed using the PEQI (see Figure A). The average PEQI intersection score was 28, which was the lowest score in the survey for area. Over 60 percent of the intersections lack basic pedestrian amenities and engineering countermeasures and were ranked “not suitable for pedestrians” by the PEQI (*red* intersections). Many of these intersections are junctions with short streets and alleys where there are no crosswalks, signals, or signs warning pedestrians to look for cars; in some cases additional pedestrian infrastructure might be appropriate and in other places not, based on factors including existing and projected pedestrian and traffic volumes. The average PEQI street score for the streets was 47, also the lowest scoring neighborhood in this survey. Twenty-five percent of the streets were ranked “poor” (*orange* streets) or “not suitable for pedestrians” (*red* streets). Many of the street segments that ranked “poor” are near the freeway, with high traffic volumes and no traffic calming. Harrison is one street in particular that scored poorly throughout South of Market.

Tenderloin

In Tenderloin 65 intersections and 216 street segments were assessed using the PEQI (see Figure A). The average PEQI intersection score was 49. The majority of the intersection had “reasonable” pedestrian conditions (*light green)* or “basic” (*yellow*, scores in the mid-range). There were three intersections on O’Farrell Street which ranked “not suitable for pedestrians” (*red* intersections). These intersections were uncontrolled intersections, without crosswalk, traffic calming, pedestrian countermeasures and all missing curb ramps. The average PEQI street score for the streets was 52, with the majority of streets having “basic” conditions (*yellow* streets). There was one segment of Macallister Street which was ranked “not suitable for pedestrians” (*red* street) due to missing sidewalks and no pedestrian amenities.

Civic Center

In Civic Center 58 intersections and 206 street segments were assessed using the PEQI (see Figure A). The average PEQI score for the intersections was 42, with approximately one third of the intersections lacking basic pedestrian amenities and engineering countermeasures and were ranked “not suitable for pedestrians” by the PEQI (*red* intersections). The majority of these intersections were uncontrolled intersections, without crosswalk, pedestrian counter measures and missing curb ramps. The neighborhood streets have mostly “basic” (*yellow* streets) pedestrian environmental conditions with an average score of 53. The streets that ranked poorly (*orange* streets) were all short streets and alleys.

Lower Nob Hill/Cathedral Hill/Lower Pacific Heights

In the Lower Nob Hill Area 65 intersections and 214 street segments were assessed using the PEQI (See Figure A). The average PEQI score for the intersections was 39, with half of the intersections ranked “not suitable for pedestrians” (*red* intersections) or “poor” (*orange* intersections) by the PEQI. These intersections were all uncontrolled intersections without crosswalks, curb ramps and very little traffic calming or pedestrian countermeasures. The streets have mostly “basic” pedestrian environmental conditions (*yellow*, scores in the mid-range) with an average score of 54. There were 12 streets that ranked “poor” (*orange* streets), this included Austin Street and several other alleys and short streets.

Downtown/Union Square

In the Downtown/Union Square area 60 intersections and 208 street segments were assessed using the PEQI (See Figure A). The average PEQI score for the intersections was 38, with half the intersections ranked “not suitable for pedestrians” (*red* intersections) or “poor” (*orange* intersections) by the PEQI. Many of these intersections are on Bush Street or around Union Square. The streets have mostly “basic” (*yellow* streets) and “reasonable” (*light green* streets) pedestrian environmental conditions with an average score of 55. There are two segments on Bush Street and several shorter streets that ranked “poor” (*orange* street).

Financial District

In the Financial District 60 intersections and 150 street segments were assessed using the PEQI (see Figure A). The average PEQI score for the intersections was 43, with most intersections having "basic conditions" (*yellow*, scores in the mid-range). The intersections that ranked "not suitable for pedestrians" (*red* intersections) were mostly between 1st Street and New Montgomery Street and several intersections on Bush Street, the majority of which were uncontrolled intersections. The average PEQI score for the streets was 56, with approximately 75 percent of the streets having either "basic" (*yellow* streets) or "reasonable" pedestrian conditions (*light green* streets). There were several street segments around the Transbay Terminal that scored poorly, but can be partly contributed to the construction.

Rincon Hill

In Rincon Hill 26 intersections and 92 street segments were assessed using the PEQI (see Figure A). The average PEQI score for the intersections was 45, approximately a third of the intersections which ranked "not suitable for pedestrians" (*red* intersections) or "poor" (*orange* intersections) by the PEQI were all centered on alleys and freeway on and off ramps. The PEQI score for the streets was 47. While the majority of the streets had "basic" (*yellow* streets) and "reasonable" (light green streets) pedestrian quality, there were seven streets that did not have sidewalks and five streets that had sidewalks less than five feet wide. The majority of streets ranked "poor" (*orange* streets) or "not suitable for pedestrians" (*red* streets) were in close proximity to freeway on and off ramps.

South Beach

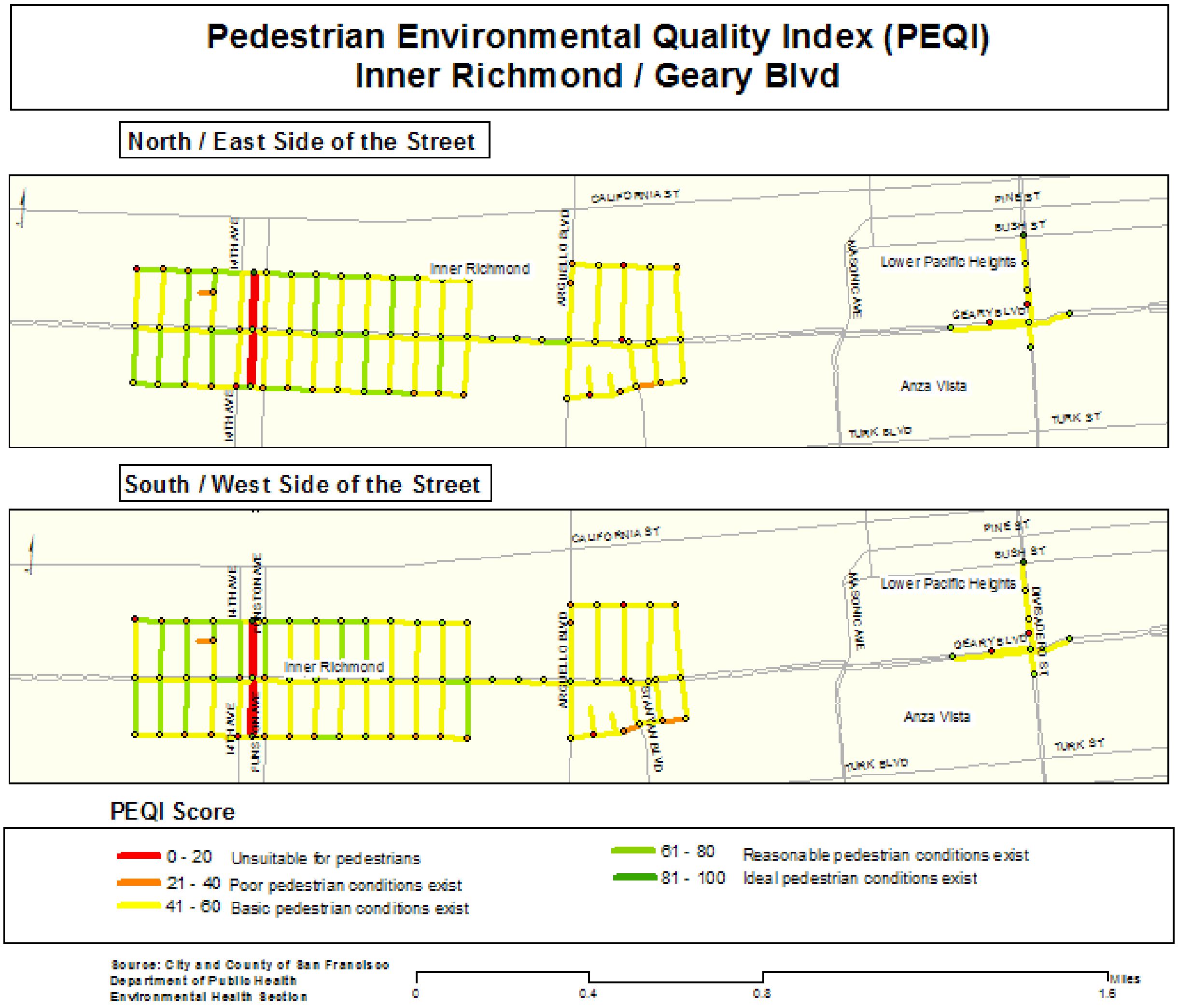
In South Beach 25 intersections and 96 street segments were assessed using the PEQI (see Figure A). The average PEQI score for the intersections was 35, approximately half of the intersections ranked "not suitable for pedestrians" (*red* intersections). These intersections tended to be uncontrolled intersections connected to alleys. The PEQI score for the streets was 51; the majority of the streets that ranked "poor" (*orange* streets) in this neighborhood were alleys. There were also several street segments on Brannan Streets that scored "poor" (*orange*); all of these street segments had major sidewalk impediments.

North Beach/Chinatown

In North Beach/Chinatown 57 intersections and 200 street segments were assessed using the PEQI (see Figure A). The average PEQI score for the intersections was 33. As illustrated in the maps, almost half of the intersections lack basic pedestrian amenities and engineering countermeasures and were ranked "not suitable for pedestrians" by the PEQI (*red* intersections). Many of these intersections are junctions with short streets and alleys, but there were also low scoring intersections on major roads, such as Powell Street, Stockton Street and Grant Avenue. The PEQI score for the streets was 53. The neighborhood streets have mostly "basic" (*yellow*, scores in the mid-range) pedestrian environmental conditions. A few have poor pedestrian conditions (*orange)*, such as Broadway Street between Mason Street and Powell Street, one segment of Powell Street and some of the alleys.

Analysis: Outside the Congestion Pricing Zone

Figure B. Pedestrian Environmental Quality along Geary Boulevard

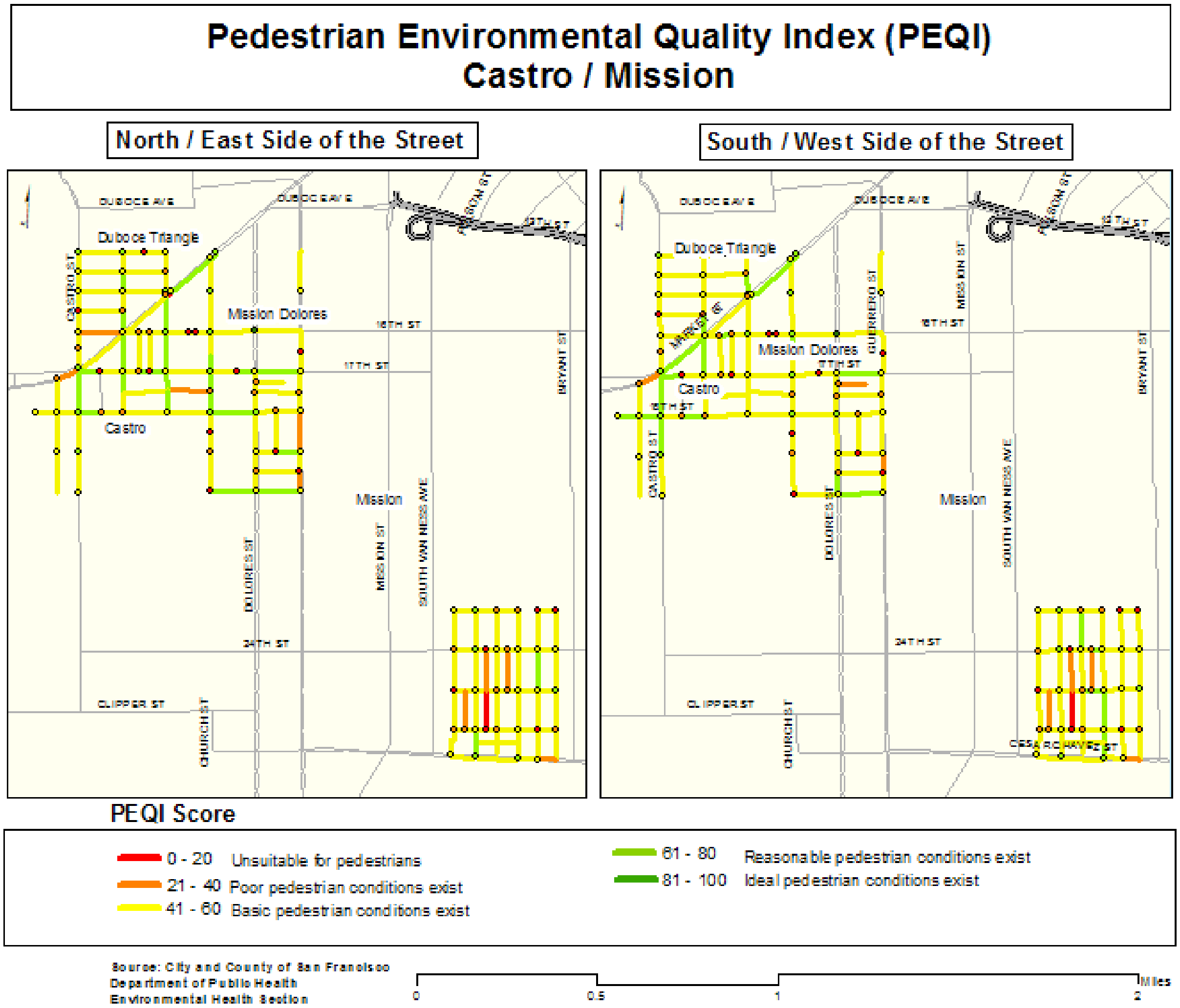


Source: City and County of San Francisco Department of Public Health Environmental Health Section

Inner Richmond

In the Inner Richmond 78 intersections and 230 street segments were assessed using the PEQI (See Figure B). Over half the intersections were ranked to have “reasonable” pedestrian conditions (light green) or “basic” (*yellow*, scores in the mid-range) pedestrian quality. Nine intersections were ranked “not suitable for pedestrians” (*red* intersections). Many of these intersections were uncontrolled intersection and lacked basic pedestrian amenities and engineering countermeasures .The neighborhood streets have mostly “basic” (*yellow* streets) pedestrian environmental conditions with an average score of 55. One street, Park Presidio Boulevard ranked “not suitable for pedestrians” (*red* street). This street lacked sidewalks, was a multi-lane road and had high traffic volumes.

Figure C. Pedestrian Environmental Quality in the Castro and the Mission



Mission Dolores/Castro/Duboce Triangle

In the Mission Dolores/Castro/Duboce Triangle area 71 intersections and 210 street segments were assessed using the PEQI (See Figure C). The average PEQI score for the intersections was 40, although over half of the intersections have “not suitable for pedestrians” (*red* intersections) or “poor” (*orange* streets) environmental quality. Many of these intersections were uncontrolled intersections without crosswalks. The PEQI score for the streets was 55. The neighborhood streets have mostly “basic” (*yellow*, scores in the mid-range) and “reasonable” pedestrian conditions (*light green*). A few have poor pedestrian conditions (*orange)*, such as Guerrero Street between 18th Street and 20th Street and some of the alleys.

Mission

In The Mission 35 intersections and 124 street segments were assessed using the PEQI. The average PEQI score for the intersections was 39. Over half of the intersections have “not suitable for pedestrians" (*red* intersections) or "poor" (*orange* intersections) environmental quality. These intersections are spread through the Mission on 23rd Street through 26th Street. The PEQI score for the streets was 52, with most of the streets having "basic" (*yellow*, scores in the mid-range) pedestrian environmental conditions. The streets that ranked poor (*orange* streets) were mostly alley streets with missing sidewalks.

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Appendix G. Methods: Vehicle-Cyclist Injury Collision Impacts

Summary: We estimated city-wide changes in vehicle-cyclist injury collisions using an accident prediction equation derived from studies of vehicle-cyclist collisions and published in the peer-reviewed journal *Accident Analysis & Prevention* (Elvik 2009). The equation requires only two parameters – existing and future motor vehicle trips, and existing and future bicycle trips.

1. 2005 Conditions: Vehicle-Cyclist Injury Collisions, Citywide and in the Cordon Zone

We estimated vehicle-cyclist injury collisions for 2005 baseline conditions citywide using actual reported collisions in collision data from the Statewide Integrated Traffic Records System (SWITRS) which contains data on reported vehicle collisions on public roadways (CHP, 2008). SWITRS vehicle-cyclist injury collision data were imported into ArcGIS (version 9.2; ESRI Inc., Redlands, California, USA) and geocoded to the intersection of the reported primary and secondary streets (exact street address is not collected). We excluded non-injury collisions which are reported as "Property Damage Only". We included collisions resulting in cyclist injuries and/or fatalities, hereafter referred to as "vehicle-cyclist injury collisions".

2. 2015 Conditions (Business As Usual (BAU), Road Pricing (RP)): Estimating Changes in Vehicle-Cyclist Injury Collisions, Citywide and in the Cordon Zone

We estimated future vehicle-cyclist injury collisions using an accident prediction model equation derived from studies of vehicle-cyclist collisions and published in the peer-reviewed journal *Accident Analysis & Prevention*.[a] Model inputs are the number of motor vehicles and the number of cyclists in the different study scenarios, as detailed in the following equation:

$$\text{\% Change in Vehicle-Cyclist Collisions} = \frac{(MV_{t2})^{0.7}(CYC_{t2})^{0.5}}{(MV_{t1})^{0.7}(CYC_{t1})^{0.5}}$$

Where:

MV = Number of motor vehicle trips
CYC = Number of Cyclist trips
t1 = Time period 1
t2 = Time period 2

We used this equation to estimate percent change in collisions from 2005 – 2015 BAU and from 2015 BAU – 2015 RP, based on projected changes in motor vehicle and cyclist trips using data outputs from the San Francisco County Transportation Authority's model. We then applied those percentages to the above 2005 conditions data to estimate absolute changes in vehicle-cyclist injury collisions citywide and in the cordon zone.

We also conducted sensitivity analyses of the model estimates consistent with Elvik (2009), varying the exponents as follows: MV = 0.8, CYC = 0.4; MV = 0.6, CYC = 0.7, and obtained very similar estimates in the same direction of change.

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Appendix H. Methods: Health Effects Characterization and Uncertainty Assessment

Summary: Following is an excerpt from *Health Impact Assessment: A Guide for Practice*[a] describing the approach used to characterize estimated health effects and uncertainties for this HIA.

Characterizing expected effects on health

After the assessment team has gathered information and evidence and conducted analysis using data, they will next need to synthesize their findings into a characterization of the expected health effects. There is no gold standard for health effects characterizations in HIA and these characterizations are not testable or falsifiable. The validity of characterizations rest on whether the assessment team's judgments are plausible, based on sound evidence, applies logical reasoning, and acknowledges data limitations and uncertainties. (Veerman 2007; Petticrew 2007)

Four important and commonly described characteristics of health effects include likelihood, severity, magnitude, and distribution. The **likelihood** of an effect represents the degree of certainty that it will occur; likelihood is high when there is an established cause and effect relationship. The **severity** of a health effect indicates its importance and intensity; for example, a disabling or life-threatening injury is more severe than a self-limited infection. The **magnitude** represents how much a health outcome might change as a result of a decision course of action. A magnitude may include the expected change in the population frequency of symptoms, disease, illness, injury, disability, or reduced life-expectancy and is typically estimated function of several factors including (1) the size of the population, (2) the baseline frequency of disease, injury, illness, or mortality in the population, (3) the size of the change in the health risk or resilience factor, and (4) the size or strength of association between an affected health risk factor and health outcomes (e.g. the relative risk). The **distribution** of effects reflects whether they are shared fairly among the affected populations. Each health effect characterization has a related assessment of the uncertainty or limitations. (See step on uncertainty below)

In practice, these characteristics can be subject to varied interpretation both among members of the assessment team and among stakeholders and decision-makers. Consequentially, discussion and debate on the meaning and sufficiency of the characteristics and the evidence required to make a particular characterization should be considered a necessary and useful part of a transparent HIA process.

Effect characterization in HIA may benefit from a common typology or nomenclature. The scheme described in the table below provides one typology that can be used or adapted for diverse types of HIA. In any such scheme, each health effect analyzed in HIA needs to be separately characterized. The HIA should also explain where one or more health effect characteristics cannot be provided.

Health effect characteristics and their interpretation

Likelihood	How certain is it that the decision will effect health determinants or outcomes irrespective of the frequency, severity, or magnitude
Unlikely/ Implausible	Logically implausible effect; substantial evidence against mechanism of effect
Possible	Logically plausible effect with limited or uncertain supporting evidence
Likely	Logically plausible effect with substantial and consistent supporting evidence and substantial uncertainties
Very Likely / Certain	Adequate evidence for a causal and generalizable effect
Insufficient Evidence / Not Evaluated	–

Appendix H. Methods: Health Effects Characterization and Uncertainty Assessment

Severity	**How important is the effect with regards to human function, well being, or longevity, considering the affected community's current ability to manage the health effects**
Low	Acute, short term effects with limited and reversible effects on function, well-being, or livelihood that are tolerable or entirely manageable within the capacity of the community health system.
Medium	Acute, chronic, or permanent effects that substantially affect function, well-being, or livelihood but are largely manageable within the capacity of the community health system; **OR** Acute, short-term effects on function, well-being, or livelihood that are not manageable within the capacity of the community health system
High	Acute, chronic, or permanent effects that are potentially disabling or life-threatening, regardless of community health system manageability; **OR** Effects that impair the development of children or harm future generations.
Insufficient Evidence / Not Evaluated	–
Magnitude	**How much will health outcomes change as a result of the decision (i.e., what is the expected change in the population frequency of the symptoms, disease, illness, injury, disability, or mortality).**
Limited	A change of less than 1/10th of one percent in the population frequency of a health endpoint
Moderate	A change of between 1/10th to one percent in the population frequency of a health endpoint
Substantial	A change of greater than one percent in the population frequency of a health endpoint
Insufficient Evidence / Not Evaluated	–
Distribution	**Will the effects, whether adverse or beneficial, be distributed equitably across populations. Will the decision reverse or undo baseline or historical inequities.**
Disproportionate harms	The decision will result in disproportionate adverse effects to populations defined by demographics, culture, or geography
Disproportionate benefits	The decision will result in disproportionate beneficial effects to populations defined by demographics, culture, or geography
Restorative equity effects	The decision will reverse or undo existing or historical inequitable health-relevant conditions or health disparities
Insufficient Evidence / Not Evaluated	–

All health effect characterization should be supported with specific evidence.

Appendix H. Methods: Health Effects Characterization and Uncertainty Assessment

Describing Sources of Uncertainty

HIA should always assess how gaps in evidence or assumptions may affect the confidence in the characterization of health effects. Each fact used in supporting an inference is a potential source of uncertainty. For example, uncertainties in the baseline frequency of disease, the distribution of exposure, or the relationship between exposure and disease all generate uncertainty in health effect estimates derived from these parameters. Common simplifying assumptions, for example, populations affected by a decision are similar to study populations, may also be important sources of uncertainty.

A straightforward approach to characterizing the level confidence is to identify each parameter that contributes to the effect characterization and then to describe qualitatively the uncertainty in that parameter, explaining how it may vary (be over- or under-estimated) and describing the influence of such variation on the health effect conclusions. Table 6, below, illustrates the conclusions of such an uncertainty analysis using the hypothetical example of an HIA conducted on automated speed enforcement cameras discussed above.

> *In many ways, the task of prediction in HIA is analogous to the task of diagnosis and prognosis in clinical medical practice where a practitioner applies training and experience, a patient's history, and diagnostic tests. Prognosis in medicine assumes uncertainty and the possibility of error, the need for monitoring, and*

When making quantitative estimates, sensitivity analysis (SA) can help examine the relative importance of uncertain data inputs on predicted outcomes. While SA can employ various techniques, a general approach is estimating effects while varying parameters that are considered to be uncertain.

Uncertainty in Health Effect Characterization of Automated Speed Enforcement

Health Effect Characteristic	Factors affecting certainty	Confidence Level
Likelihood	▪ Established physical explanation of effects ▪ Consistent findings of empirical studies in diverse urban contexts ▪ Effects in prospective interventions	High
Severity	None	High
Magnitude	Exposure Assessment ▪ Distribution based on measured speed on a sample of 25, 30, and 35 mph city streets ▪ Speeds aggregated into five mph increments ▪ Measures may under-represent high speed and volume streets ▪ Distribution of measured speed may underestimate or overestimate distribution of impact speed Baseline Disease Prevalence ▪ Pedestrian injury collisions are often under-reported Exposure Response Functions ▪ Speed-collision ERF not specific to pedestrian injury collisions ▪ Speed-collision ERF not validated in study location ▪ Speed-severity ERF not validated in study location	Moderate
Distribution	Not assessed	N/A

REFERENCES

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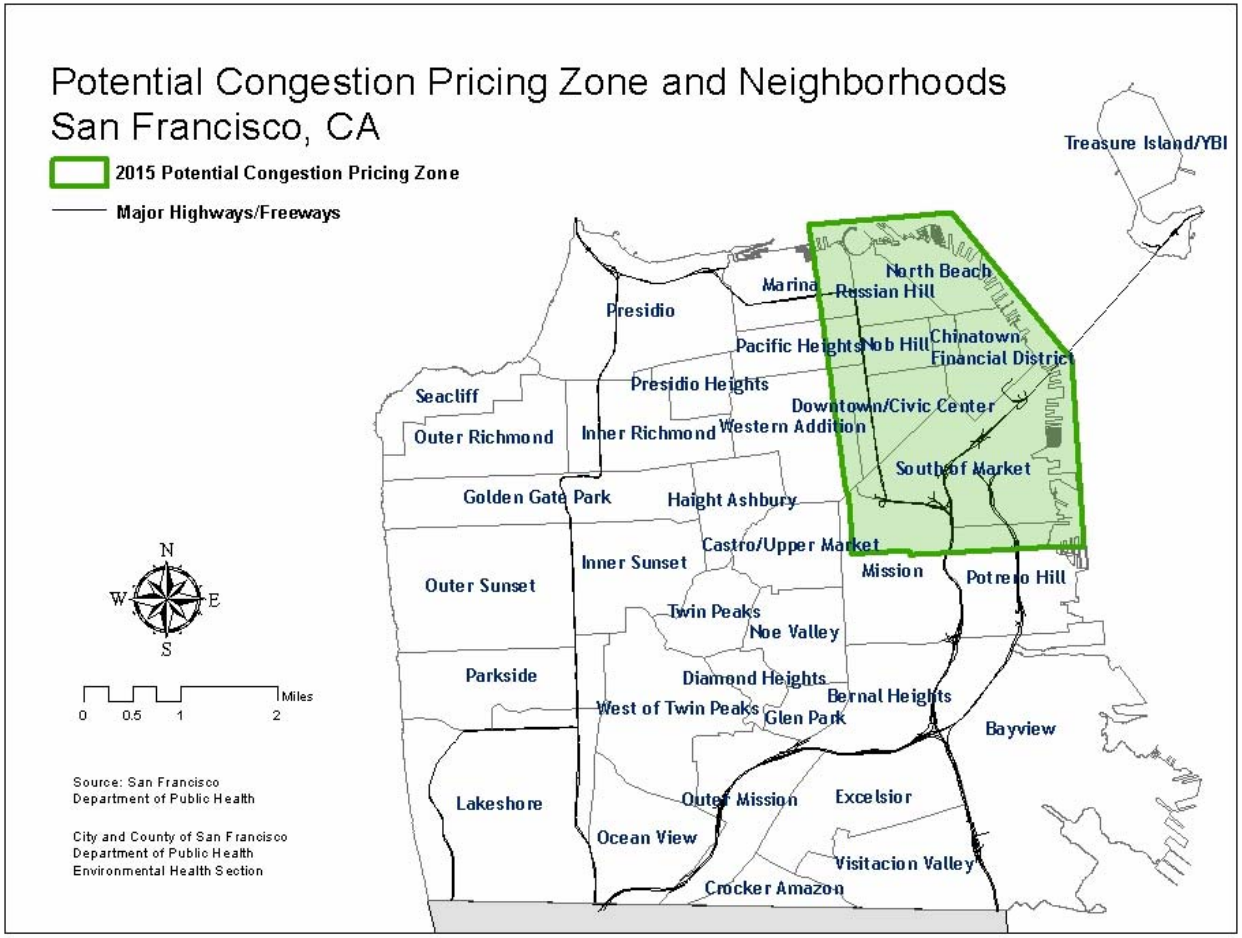
[a] Bhatia R. 2011. Health Impact Assessment: A Guide for Practice.

Appendix I. San Francisco Planning Neighborhood Boundaries and Names



Neighborhood boundaries defined by the San Francisco Planning Department.

Attachment A

SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY

Fact Sheet

LAST UPDATED
December 2010

Mobility, Access, and Pricing Study

Congestion pricing involves charging drivers a user fee to drive in specific, congested areas, and using the revenue generated to fund transportation improvements, such as better transit service, road improvements, and bicycle and pedestrian projects. The Mobility, Access, and Pricing Study (MAPS) examines the feasibility of a congestion pricing program in San Francisco, finding that it could be a highly effective way to manage our transportation system more efficiently and support the city's future growth plans.

A solution for San Francisco's congestion problem

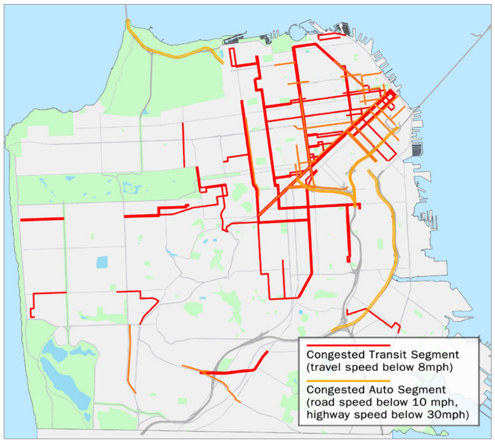
Peak-period traffic congestion in the city's core areas negatively impacts our transportation system. During rush hour, congestion makes travel by both automobile and transit slow, with average auto speeds at 10 mph and average transit speeds at 8 mph in much of the downtown areas (see map, right). Congestion is already a problem today, and the city has ambitious growth plans for the future. Unless bold measures are taken, our streets will be unable to accommodate this growth without traffic coming to a standstill. A mobility and pricing program would send a signal to drivers to consider alternatives to driving in the peak and generate significant new revenue that would greatly improve transit service and the road network in San Francisco. Benefits from a potential congestion pricing program would include:

- 12% fewer peak period vehicle trips
- 21% reduction in vehicle hours of delay
- 5% reduction in greenhouse gases citywide
- $60–80 million in annual net revenue for mobility improvements
- 20–25% transit speed improvement
- 12% reduction in pedestrian incidents

Given the high level of innovation associated with a congestion pricing program, a measured way to move forward is through a pilot project. A pilot would operate for 6–12 months and allow for real-time evaluation before the city considers anything permanent. Even then, several steps would be required before an implementation decision could be made.

Revenues generated by congestion pricing would fund transportation improvements, such as better transit service, road improvements, and bicycle and pedestrian projects.

Average travel speeds, PM peak hour



SOURCE: SFMTA APC data, 2007, and SFCTA LOS Monitoring, 2009.

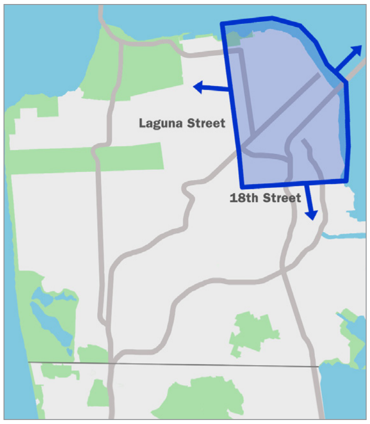
Contact Us!

- www.sfmobility.com
- www.facebook.com/sfmobility
- www.twitter.com/sanfranciscota
- sfmobility@sfcta.org
- 415.522.4819
- San Francisco County Transportation Authority
  100 Van Ness Avenue, 26th Floor
  San Francisco, CA 94102
  Attn: MAPS study

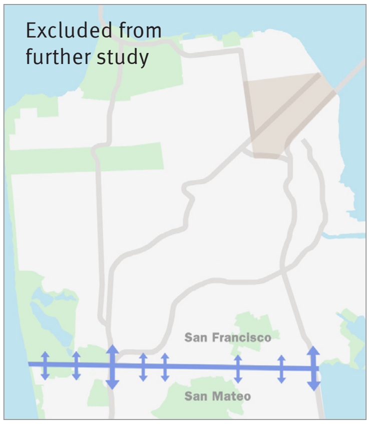
Effective Scenarios

MAPS has identified three high-performing scenarios, each of which would be accompanied by substantial up-front transit improvements in corridors impacted by the fee. A future phase of the study will exclude additional analysis of the Southern Gateway scenario but will include designing an additional scenario that could achieve comparable benefits through a combination of downtown parking management policies and a modified cordon.

1. The AM/PM Northeast Cordon would collect $3/crossing from cars entering or leaving the zone in both AM and PM peak hours (capped at $6/day).



2. The PM-Outbound Northeast Cordon would collect $6/day from cars leaving the zone in the outbound direction during PM peak hours.



3. The Southern Gateway would collect $3/crossing from cars crossing the San Francisco-San Mateo county line in both directions in both AM and PM peak hours (capped at $6/day). It would also include increased parking rates downtown.

Congestion pricing and equity

For several reasons, we are confident that a congestion pricing program will not have an undue impact on low-income individuals:

- The Study recommends a 50% discount for low-income travelers;
- Only approximately 5% of peak-period travelers to downtown San Francisco are drivers with annual household incomes lower than $50,000;
- Support for studying a San Francisco congestion pricing program is highest among low-income Bay Area residents;
- Many of low-income travelers in the Bay Area are already on transit; congestion pricing will get transit moving faster, bringing all travelers faster, more reliable travel times.

Congestion pricing and the economy

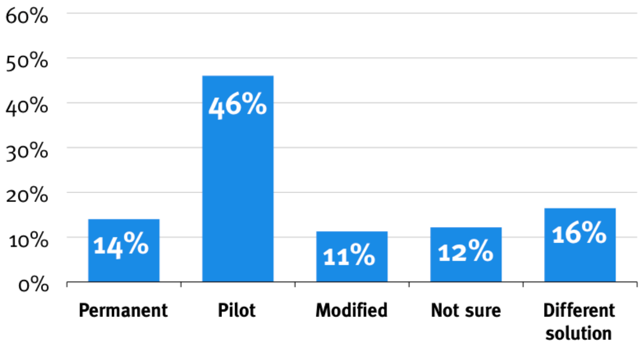
The Study analyzed economic impacts of a program, finding that the program would have a neutral to positive impact for the following reasons:

- Congestion pricing would alleviate the severe economic costs caused by congestion in San Francisco today. More than half of the travel time for the average Bay Area auto trip can be attributed to congestion delay, translating to a cost of almost $7 per trip in travel time lost due to congestion, or over $2 billion for individuals and businesses in 2005. This is time and money that can be better used by Bay Area residents.
- More foot traffic is expected downtown, which could lead to more retail activity within the congestion pricing zone, as was the case when London and Stockholm implemented congestion pricing programs.

What does the public think?

We have conducted four rounds of outreach over the course of the Study, reaching over 1,000 Bay Area residents through workshops, webinars, polls, focus groups, and other means.

Feedback from the most recent round of public meetings suggests support for continued evaluation of congestion pricing.



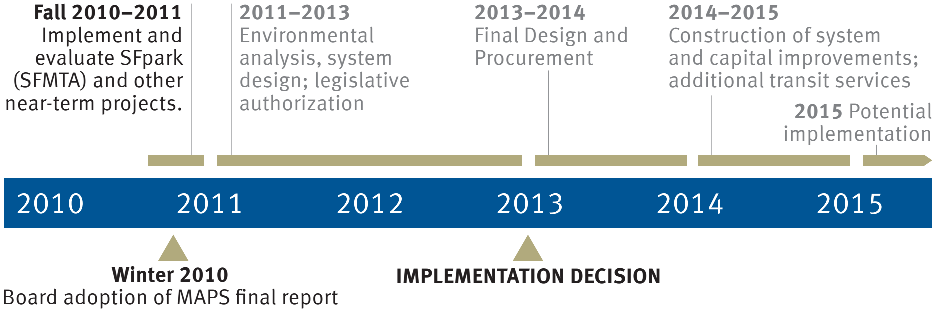
Permanent: I support implementing a permanent program.

Pilot: I prefer a pilot program approach.

Modified: I could support congestion pricing with modifications.

Not sure: I'm not sure yet/undecided/need more information.

Different solution: I prefer another solution.



Fall 2010–2011 Implement and evaluate SFpark (SFMTA) and other near-term projects.

2011–2013 Environmental analysis, system design; legislative authorization

2013–2014 Final Design and Procurement

2014–2015 Construction of system and capital improvements; additional transit services

2015 Potential implementation

Winter 2010 Board adoption of MAPS final report

IMPLEMENTATION DECISION

Timeline

On December 14, 2010, the Transportation Authority Board unanimously approved the MAPS Final Report and voted 8–3 in favor of pursuing additional study of the concept, excluding the Southern Gateway scenario. San Francisco is still in the early stages of exploring pricing and there are many steps before a decision will be made.

Attachment B

Usage Example: Trip Diversions from Van Ness Avenue, with Bus Rapid Transit (BRT) Project

Van Ness Diversions, 2010 Base to 2010 Project		
Change in Volume at California St.	1700	100%
Traffic diverted onto:		
Parallel streets in corridor	800	47%
Transit or suppressed trips	73	4%
Parallel streets outside corridor	**827**	**49%**
Of traffic on streets outside corridor:		
About 1/2 are way beyond corridor (19th Ave, Kezar, etc.)		24%
About 1/2 are evenly distributed across grid network		25%

Trips Diverted from Van Ness Avenue, with BRT Project (PM)

	Regional Trips	Local Trips	Total
Divertible	1,823 (19%)	3,168 (33%)	4,991 (52%)
Not Divertible	1,352 (14%)	3,239 (34%)	4,591 (48%)
Total	3,175 (33%)	6.407 (67%)	9,582 (100%)

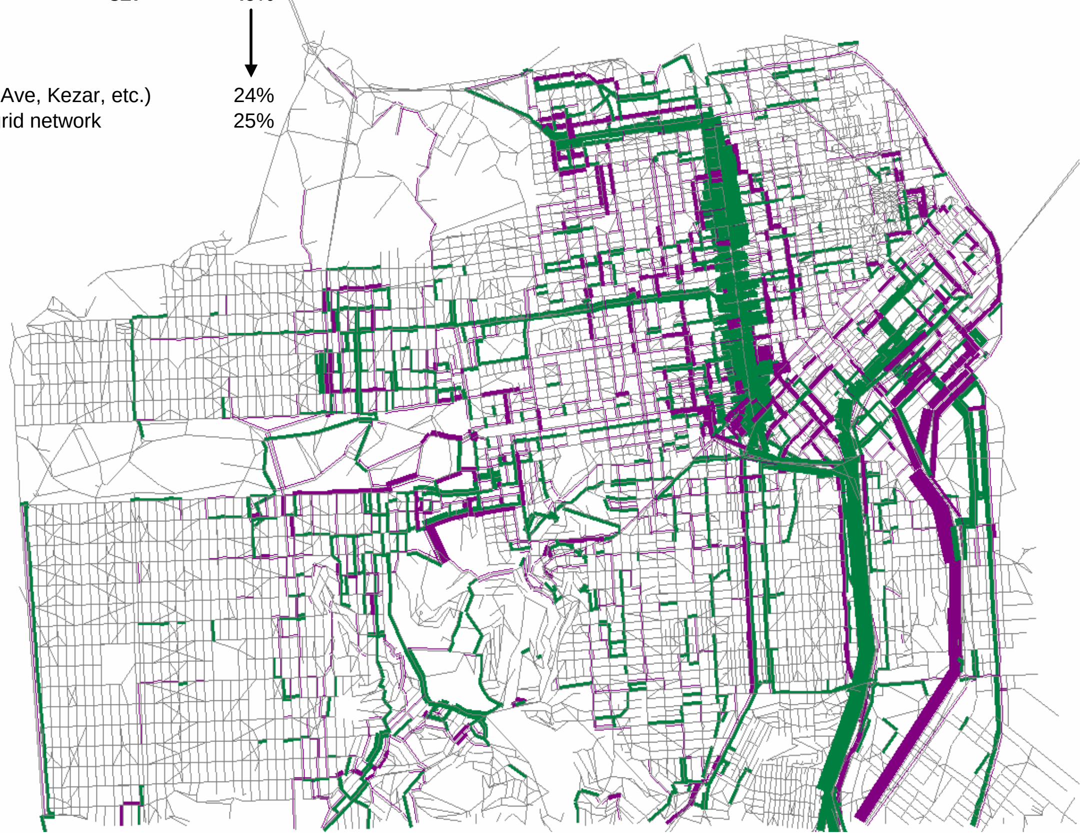
Green shows streets with less traffic.

Purple shows streets with more traffic.

The removal of one lane of through traffic from Van Ness is a 1/3 reduction in capacity on that roadway. The remaining two lanes are only slightly more congested – 71% of volume remains.

Due to the dense grid system and availability of wide parallel streets, the other streets within the corridor absorb almost 50% of the diverted traffic.

Other city streets absorb the remainder.



Trips Diverted from Van Ness Avenue, with BRT Project

Usage Example: Golden Gate Bridge Destinations

Doyle Drive Users (PM)

Less than 5% of vehicles on Doyle Drive (the access road connecting the Golden Gate Bridge to the Marina District in San Francisco) are traveling to or from the East Bay or South Bay.

The remainder are using Doyle to travel either across town or over the Golden Gate Bridge. Less than 25% come from Van Ness Avenue. Almost 30% use Franklin Street.

Thus about half of the traffic on Doyle westbound comes from Van Ness Corridor. At Lombard, 60% of northbound traffic on Van Ness is destined for Doyle Drive. At Grove, only 14% is destined for Doyle.

The San Francisco Model... in Fifteen Minutes

Winter 2011

How can models help us test policy questions? System efficiency... pricing strategies... demographic impacts... equity...

Models are just one tool in the planner's kit that lets us compare alternatives, estimate impacts, assess ridership and benefit, and determine winners and losers.

No one tool can do everything – and no tool anywhere can replace good planning judgment. But, an effective model, used properly, is a sharp tool for decisionmaking.

Trip Based Models: Your Father's Travel Forecasting Approach

Generation
What kinds of trips? How many?

▶

Distribution
From where to where?

▶

Mode Choice
What mode? Transit, Auto, Carpool Nonmotorized?

▶

Assignment
What specific route?

Criticisms: No relationship between trips (in space, time, or mode!); nonmotorized modes usually missing; biased due to "zonal" aggregation

Tour Based Models:

Tour based models predict activities, locations, and times.

A tour is an entire chain of trips, from a primary origin to all destinations, and then back to the primary origin.

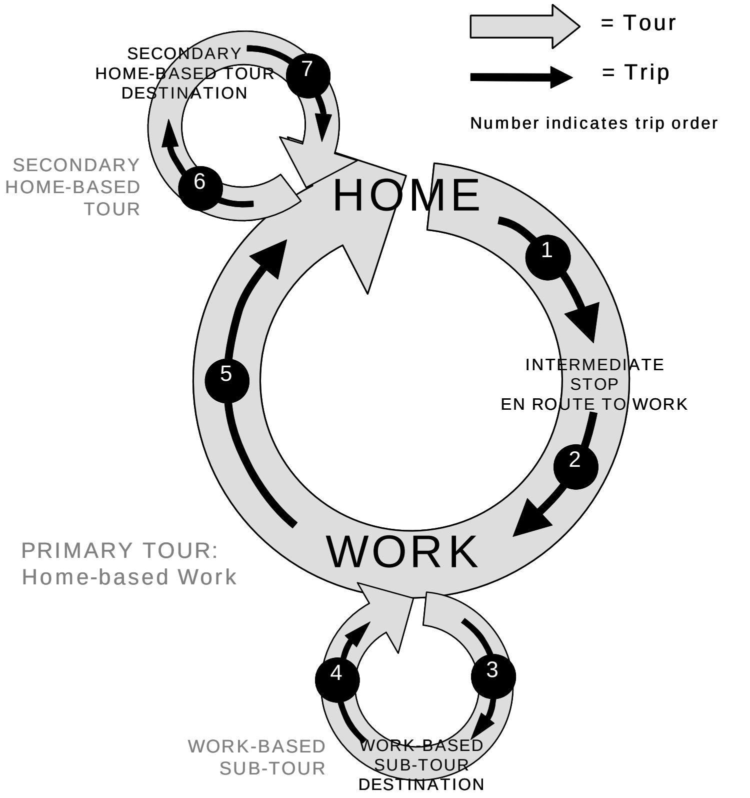
Using chains means trips now have <u>relationships:</u>

(1) Primary Destination versus intermediate stops

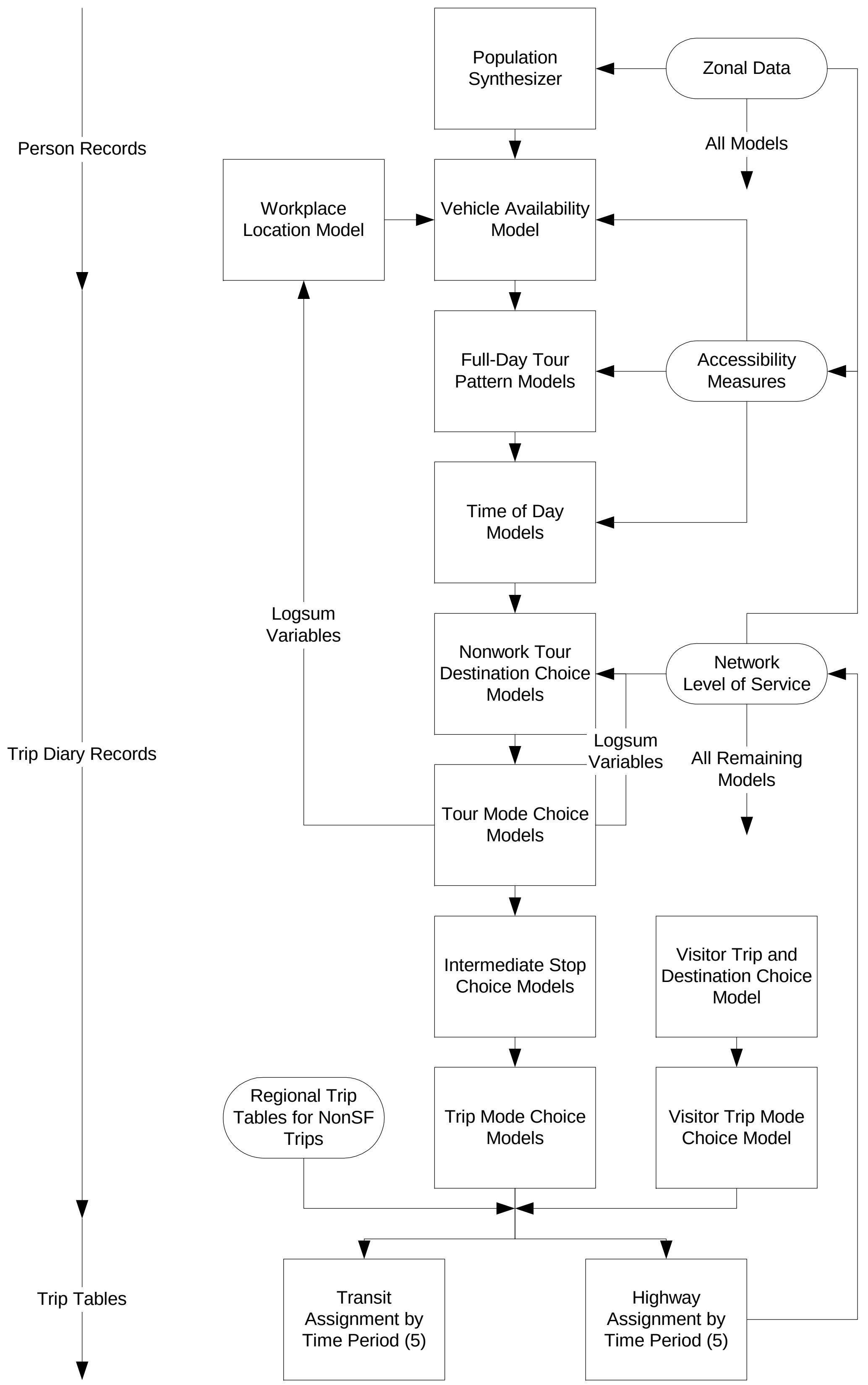
(2) Consequences of mode availability:
e.g. trip mode depends on the full tour mode:
Leaving the car at home? Then no driving
for any trip on that tour.

(3) Based on activity diaries for the household
... travel is implicit.

(4) More able to test key policy questions
no non-home-based trips
e.g. system efficiency, pricing strategies,
demographic impacts.



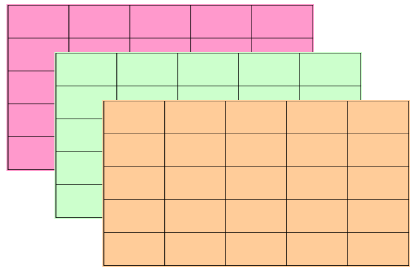
SF-CHAMP Model Process Diagram



Microsimulation of Individual Behavior

Trip Based Models:

While trip-based models aggregate travel into "zones" and then predict fractional probabilities for each zone and market segment, the San Francisco tour-based model simulates travel choices for every person in every household in the city.



Each market segment is a new set of trip tables.

Rows and columns represent the "zones" that encompass the city.

Tour Based Models:

The SF Model uses microsimulation of a "synthetic" population to do this. The dataset is "just like" the real people in San Francisco – based on recent U.S. Census data.

Household	Person	Income	Jobs	Gender	Age
1	1	3	1	0	24
1	2	3	1	0	23
1	3	4	0	1	3
2	1	2	2	0	32
2	2	3	1	1	34
3	1	3	1	1	56
3	2	1	2	1	49
3	3	2	0	0	15
3	4	3	0	1	18

Each market segment is a new column.

Every "synthetic" person in every household is present in the datafile and is modeled individually.

Model Development

Complete:

Value of time heterogeneity added for pricing sensitivity
Expanded geographic bounds from San Francisco to whole Bay Area
Updated accessibility variables

In development:

Bike Route Choice (mode choice sensitive to bike facilities, etc.)
Land use growth allocation model
Dynamic Traffic Assignment – Accounting for queues, bottlenecks, signal timing
Travel Demand Management (TDM) Policies (i.e. fare subsidies)
Discrete representation of Parking

Soon:

Refresh underlying data with Census/Survey data