January, 2010

Evaluating Regional Pricing Strategies in San Francisco: Application of the SFCTA Activity-Based Regional Pricing Model

Elizabeth A. Sall, *San Francisco County Transportation Authority*
Elizabeth Bent, *San Francisco County Transportation Authority*
Billy Charlton, *San Francisco County Transportation Authority*
Jesse Koehler, *San Francisco County Transportation Authority*
Gregory D. Erhardt, *Parsons Brinckerhoff*

EVALUATING REGIONAL PRICING STRATEGIES IN SAN FRANCISCO – APPLICATION OF THE SFCTA ACTIVITY-BASED REGIONAL PRICING MODEL

Elizabeth Sall*
Senior Transportation Planner
San Francisco County Transportation Authority
100 Van Ness Ave 26th Floor San Francisco, CA USA 94102
Telephone: 415 522-4810
Elizabeth.sall@sfcta.org

Elizabeth Bent
Principal Transportation Planner
San Francisco County Transportation Authority
100 Van Ness Ave 26th Floor San Francisco, CA USA 94102
Telephone: 415 522-4819
Elizabeth.bent@sfcta.org

Billy Charlton
Deputy Director for Technology Services
San Francisco County Transportation Authority
100 Van Ness Ave 26th Floor San Francisco, CA USA 94102
Telephone: 415 522-4816
Billy.charlton@sfcta.org

Jesse Koehler
Transportation Planner
San Francisco County Transportation Authority
100 Van Ness Ave 26th Floor San Francisco, CA USA 94102
Telephone: 415 522-4808
Jesse.koehler@sfcta.org

Greg Erhardt
Senior Transportation Modeler
Parsons Brinkerhoff
303 Second Street Suite 700 North San Francisco, CA USA 94107
Telephone: 415 307-6974
erhardt@pbworld.com

Submission Date – July 31, 2009

6,579 words + 3 figures (250 x 3) + 1 table (250 x 1)= 7,579 words

Paper submitted for consideration for Presentation and Publication
Original Submission date: July 31, 2009

*Corresponding author

ABSTRACT

This paper evaluates the performance of the San Francisco County Transportation Authority's recently-enhanced Nine-County Regional Pricing Model (RPM-9), which is being used to study congestion pricing alternatives in San Francisco as a part of the Mobility, Access, and Pricing Study. This study sought to evaluate comprehensive pricing and mobility-enhancing packages to improve access and offer more sustainable travel choices to and within San Francisco. The Study tested various pricing scenarios including cordon, area, and gateway designs; various toll levels; and a range of shoulder pricing/time of day profiles. Pricing scenarios were coupled with strategies for improving accessibility for all modes of travel to, from, and within San Francisco including, but not limited to, local and regional transit investments. RPM-9's structure as a tour-based microsimulation model allowed several enhancements for this study that would not have been possible in a trip-based framework. These include the use of value-of-time distributions, rather than averages across groups; the feedback of mode and destination choice logsums to make auto ownership and tour generation sensitive to price; the explicit tracking of travelers who have paid area tolls; and enhanced peak spreading models. The disaggregate nature of RPM-9 facilitated summaries of key measures of effectiveness at various levels and types of aggregation including income level, residential location, and work location. These flexible summaries were critical to evaluating alternatives and answering questions about who was paying versus who was benefiting.

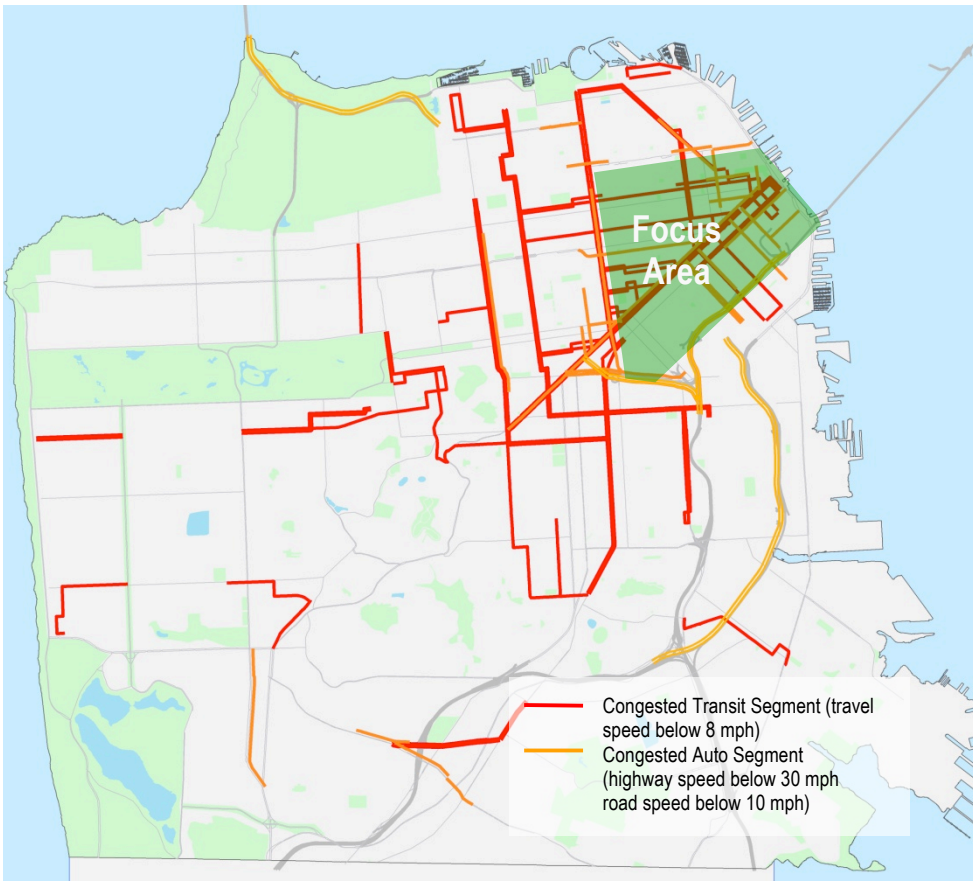
EVALUATING REGIONAL PRICING STRATEGIES IN SAN FRANCISCO – APPLICATION OF THE SFCTA ACTIVITY-BASED REGIONAL PRICING MODEL

INTRODUCTION

In 2006, the United States Department of Transportation (USDOT) Value Pricing Program awarded the San Francisco County Transportation Authority (SFCTA) a grant to conduct a feasibility study for congestion pricing in San Francisco. The study, referred to as the Mobility, Access, and Pricing Study (MAPS), assesses the potential for managing travel via area-wide pricing in San Francisco's congested urban core in the northeastern part of the city. This area is expected to grow significantly over the next few decades; managing the transportation impacts of this growth is a challenge given the constrained and dense urban setting where there is limited ability to accommodate additional auto travel. The SFCTA's approach is to study roadway congestion pricing as part of comprehensive demand and system management. Congestion pricing contributes to numerous goals by managing auto travel and enhancing transit operations while providing supplemental funds to improve access via non-auto modes. This integrated approach has been successful in several cities, including Singapore, Stockholm, and London, as a way to improve quality of life while maintaining a healthy economy. To complement the comprehensive economic and policy analysis and extensive public outreach on the matter of roadway congestion pricing, the SFCTA refined its activity-based travel demand model both to test how travel choices might change in response to various congestion pricing scenarios as well as help construct and refine pricing scenarios. The output from this refined travel demand model, the Nine County Regional Pricing Model (RPM-9), informed the Study Team's movement toward a preferred scenario and the overall feasibility analysis.

At the outset of MAPS, the Study Team documented baseline congestion levels and their current and future projected impacts on San Francisco. The Texas Transportation Institute ranked the San Francisco/Oakland region as the second most congested region in the United States both in 2006 and 2007 (*1)*. On average, half of a peak period auto trip to the City's major employment centers is spent in delay. These major employment centers are comprised by the Downtown, Civic Center, and South of Market (SoMa) districts and are collectively referred to throughout this paper as the Focus Area, shown in Figure 1. Average auto speeds in the Focus Area suffer from concentrated traffic congestion and are generally below 12 mph. Surface-running transit reliability and running speed also suffer disproportionately from roadway congestion, with speeds as much as 35% lower than autos.

FIGURE 1 Location of Focus Area and Congested Streets



Over 4.6 million daily trips are made to/from/within San Francisco. Peak period transit mode share to the Focus Area is just over 40%, but given the growth that is forecast in the Focus Area by 2030 [2], failure to significantly decrease auto mode share within that timeframe would lead to a breakdown both in surface-running transit as well as auto level of service. Over half of the auto trips to the Focus Area are made by San Francisco residents, an indication that a purely regional solution such as bridge and county-line tolls would only affect a portion of drivers, and would likely be accompanied by induced driving among San Franciscans. The Focus Area will also see a large increase in housing units, with many residents of the area projected for employment centers south of the city (i.e., Silicon Valley), a commute that is largely auto-dominated.

This paper discusses the use of the RPM-9 model to assess the feasibility of congestion pricing in San Francisco and the development of a preferred pricing scenario(s) to improve mobility and access throughout San Francisco. It begins with an overview of the horizon and baseline assumptions coupled with the components of congestion pricing scenarios and mobility packages the MAPS team aimed to test. Next, it discusses the evolution of the SFCTA's current travel demand model (SF-CHAMP) into the RPM-9 model. Specifically, this section discusses the travel model improvements necessary to confidently test the types of scenarios discussed in the preceding section. Third, this paper presents the criteria used to evaluate each congestion pricing scenario along with the modeling results. The final discussion presents a summary of our conclusions and next steps.

SCENARIO DEVELOPMENT

Each pricing scenario was defined by the horizon year and its associated assumptions, the attributes that specified the "who, what, when, and where" of the congestion charge, and the toll revenue reinvestment strategy. This section describes the various attributes and situations that were tested.

Horizon Years/Baseline Assumptions

The MAPS study developed forecasts for both 2015 and 2030. 2015 depicts opening-day conditions, as it represents a reasonable potential implementation date. 2030 was used to compare the long term

benefits of congestion pricing in San Francisco. For both time horizons, the Study Team compared a priced scenario with a baseline scenario that included planned and programmed improvements.

At the county level, the land use assumptions for each year conform with the Association of Bay Area Governments' "Projections 2007" forecast (*2*). The San Francisco Planning Department further refined these forecasts at the TAZ level based on land use plans and projections for build-out dates for various pipeline projects. These assumptions project the San Francisco population to increase by roughly 4% from 2005 to 2015, and another 12% from 2015 to 2030 to a total of 923,000. Much of the increase will be focused in the city's eastern neighborhoods, where major rezoning efforts have been completed or are currently underway. Employment is expected to increase at a faster rate: 15% more jobs by 2015 and 23% more by 2030 to a total of 783,000. If realized, this lopsided growth will result in a greater jobs/housing imbalance in the city by 2030, further exacerbating observed congestion conditions.

While the MAPS Study Team analyzed both 2015 and 2030 conditions, the bulk of the analysis conducted to determine the most-promising shape and size of the tolled zone was done for 2015 scenarios. Therefore, the remainder of this paper focuses on 2015.

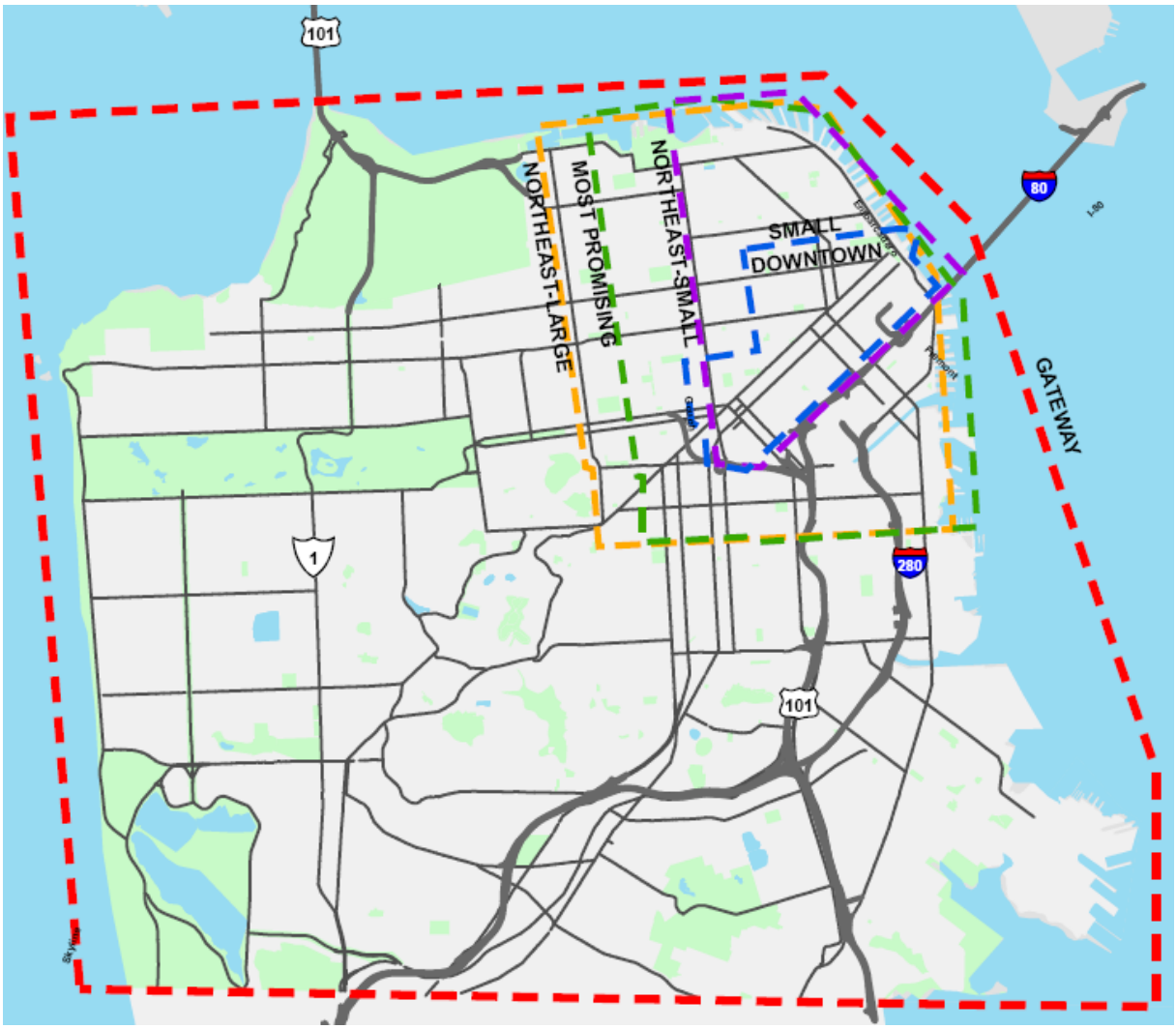
Pricing Scenario

The pricing scenario is defined by the charge type (area versus cordon), boundary of the charged area, time period for charging, price level, and toll discounts. In all cases, the charge would be assessed based on video license plate license plate recognition either along the cordon, or in the case of area tolls, throughout the charged area.

Congestion *charge types* fall under two major categories: *area* pricing, where drivers are assessed a fee for driving anywhere within a specified zone, and *cordon* pricing, in which drivers are only charged each time they cross a designated boundary.

The toll boundaries examined in this study fall under three basic categories: a *small downtown cordon* covering the central business district, a *mid-sized cordon* containing the northeastern part of the city (the *northeast cordon*), and a *gateway* charge that treats the entirety of San Francisco as a large cordon. The Study team also tested combinations of these scenarios including the *double ring*, a combined gateway and small downtown cordon. Street-by-street boundary variations were also extensively tested for the *small downtown cordon* and the *northeast cordon*. The challenge with geographic design is to maximize benefits while limiting impacts. Analysis of baseline conditions allowed the Study Team to identify the scenarios most likely to produce the benefits.

FIGURE 2 Potential Pricing Cordon Boundaries



For the purposes of the feasibility study, most of the scenarios tested variation of the toll boundaries rather than time of day and toll levels. The majority of scenarios had constant three-dollar toll during the most heavily congested weekday commuting hours: 6:00 AM to 9:00 AM and 3:30 PM to 6:30 PM, for a total of six hours a day. A few scenarios tested slight variations of this charging period: shoulder pricing (at two-dollars) during the first and last hour of the peak periods; and a higher charge during the A.M. peak period with a lower P.M. peak charge.

Each pricing scenario contained a basic package of toll discounts. RPM-9 was able to model some of these discounts explicitly; the rest were post-processed off model. The basic discount package is assumed to be: 50% discount to residents of the cordon area (with the exception of the gateway scenario); 50% discount for low-income households; fleet rates assessed for commercial vehicles and rental cars; full exemption for taxis, which are considered an extension of the city's transit system; and a one-dollar "feebate" discount for drivers who have already paid a bridge toll on that trip. By far, the biggest source of "foregone revenue" in this discount package is the one-dollar "feebate". Shared-ride vehicles are not proposed to have discounts at this time.

Toll Revenue Reinvestment Package

For the purposes of the MAPS Feasibility Study, two toll-investment strategies were tested: a basic package, and a refined package. Further optimization of the revenue reinvestment will occur during subsequent system planning studies. The "basic" revenue reinvestment package included two Bus Rapid Transit (BRT) projects (along Geary Avenue and Van Ness Avenue), transit signal priority along major San Francisco bus corridors, an HOV lane entering the City from the south that transit could also use, and a ten-percent increase in peak period frequencies for regional bus lines that serve downtown San Francisco (operated by AC Transit, SamTrans, and Golden Gate Transit). The

"refined" package included many of the same improvements, but screened out regional bus lines whose demand was unresponsive to the increased service levels.

The next section discusses the enhancements made to the SFCTA's travel demand model to capture appropriate sensitivities in traveller choices to the types of scenarios discussed in this section.

TRAVEL MODEL ENHANCEMENTS

The SFCTA's travel demand model "SF-CHAMP" was one of the first activity-based travel demand models used in practice and has been continuously used and updated for a variety of projects (including New Starts forecasting), plan evaluation (San Francisco Countywide Transportation Plan), and other major investments such as the replacement of Doyle Drive (the southern access to the Golden Gate Bridge) (*3,4*). While for many studies SF-CHAMP is an appropriate and robust forecasting tool, it lacked the toll and time-of-day sensitivity and geographic breadth necessary for evaluating the congestion pricing strategies put forth by the MAPS Study Team. Therefore, a new travel demand model (based on SF-CHAMP) was developed for the purpose of this study. The improved model, named the Nine-County Regional Pricing Model (RPM-9), produced many of the metrics used to evaluate each congestion pricing scenario compared to a future baseline scenario. This section describes the development of the RPM-9 model. Erhardt et al (5) provides more detail on the model improvements.

Added Feedback Loops

The previous SF-CHAMP model did not include a feedback loop from assignment to the travel demand. Travel times were based on skims created from assigning either trip tables from the Metropolitan Transportation Commission (MTC) model, or from previous SF-CHAMP runs. This approach limited the responsiveness of the travel demand to the auto levels-of-service, which is an essential sensitivity in the context of congestion pricing. Therefore, RPM-9 uses three feedback loops between the demand and the network conditions. The link volumes from the final assignment of each feedback loop are averaged with the link volumes of the previous assignments to come up with the volumes. From these volumes, the travel times are re-calculated using the volume delay functions on each link. In addition, the trip tables themselves are averaged between each iteration. These travel times are used as input for the following feedback loop. For each iteration, convergence measures are reported and monitored, but to maintain as much consistency as possible across scenarios, a fixed number of iterations is run. This approach is consistent with experimental recommendations of Boyce et al (*6*).

Expanded Geography

The SF-CHAMP model is a hybrid model that forecasts the daily activity patterns and travel for San Francisco residents, but uses the Metropolitan Transportation Commission's (MTC) BAYCAST-90 model for non-San Francisco residents. This approach was appropriate to maintain consistency with the regional forecasts and keep the initial implementation of an advanced tool manageable. For modeling pricing policy to downtown San Francisco, however, this approach is limiting because about half of trips to the Focus Area originate outside of San Francisco. In order to treat the entire Bay Area region in a consistent manner, RPM-9 predicts the daily activity patterns and tours of every Bay Area resident in all nine counties.

In addition to the handling the obvious increase in input data requirements, the model development team implemented memory efficiencies in the skims to avoid reaching Windows operating system memory limitations, and used sampling to avoid long run times involved with microsimulating every resident of the Bay Area (an approximately eight-fold increase over just San Francisco residents). A sample rate of two was used for the first two feedback iterations while the final iteration simulated the entire population without sampling. To avoid simulation bias (*7)*, each feedback iteration is run with five different random number seeds. The resulting trip tables of each of these seeds are averaged together at the end of each feedback iteration.

Toll Choice

The original SF-CHAMP model does not have an explicit toll-choice model because there are no tolls currently within San Francisco. Rather, it adds the toll cost to the generalized cost of a particular link

in highway assignment. This implies that each vehicle in that user class has the same value-of-time. Additionally, the auto nest in the SF-CHAMP tour mode choice model only has choices for being a "driver" or a "passenger", thus ignoring that the driver of a three-person shared ride vehicle would likely only be responsible for a third of the total cost of the toll. RPM-9 was changed to include separate nests under the auto nest for *drive alone*, *shared ride 2*, and *shared ride 3-plus*. Under each of these choices is a choice of *value toll, no value toll,* or *already-paid value toll*. The value toll skim is available when the minimum generalized cost skim (based on average values-of-time) passes over the priced cordon, while the *no value toll* skim does not allow any crossing of the priced cordon. The *already-paid* value toll option is available for area-pricing situations when the toll for that time period has already been paid.

Three benefits of using the nested logit mode choice models (as opposed to highway assignment) to estimate who chooses to pay the congestion toll are (1) the logit curve itself allows for a probabilistic choice even when an average value of time is used (as opposed to modeling this purely in assignment, where for a single OD pair and user class the choice is deterministic (2) allows multiple non-cost attributes to be incorporated into the toll versus no-toll decision, and (3) the disaggregate application of the mode choice model allows the use of a distributed value of time across individuals and trip purposes.

Accessibility

Mode choice logsums represent the total quality of travel between two zones across all available modes. Since paths that are priced for congestion are included as a choice in the mode choice model, their addition (or subtraction) from the relative accessibility of each zone pair is captured. The destination choice logsums represent the total ease of travel from one origin to all possible destinations across all available modes. Depending on the transit options and how much an individual values time, congestion pricing could make some zones more accessible and other zones less accessible. Both the mode choice and destination choice logsums are measures of accessibility.

Logsums are preferable to using threshold values of accessibility such as the amount of employment that can be reached in a certain amount of time because (1) they are a continuous measure without cliff effects, (2) they are a comprehensive measure across all modes, (3) they allow different population segments to value level of service attributes in a manner that is consistent with the mode choice and destination choice models. Therefore, logsums are used in RPM-9 to represent accessibility in both the tour generation and auto ownership models.

Time of Day Choice

Of particular interest to the MAPS study team is the ability of pricing to be used as an incentive to induce drivers to switch their travel out of the peak periods. The MAPS Study Team needed to test the feasibility of shoulder pricing scenarios where the tolling-level would be highest during the "peak-of-the-peak" period, and lower as the peak periods transitioned to off-peak periods. The SF-CHAMP model has five time periods including two three-hour peak periods (6:00 AM to 9:00 AM and 3:30 PM to 6:30 PM). In order to examine the shoulder-pricing scenarios, RPM-9 includes time of day models at two levels. The first is a tour time of day model that forecasts time of day choices to the five aggregate time periods as a function of tour mode choice logsums. In addition, a more disaggregate time-of-day model is capable of forecasting the peak spreading of auto vehicle trips at the half-hourly level based on highway travel times between the origin-destination pairs. This trip time of day model was estimated from stated preference survey data as described below.

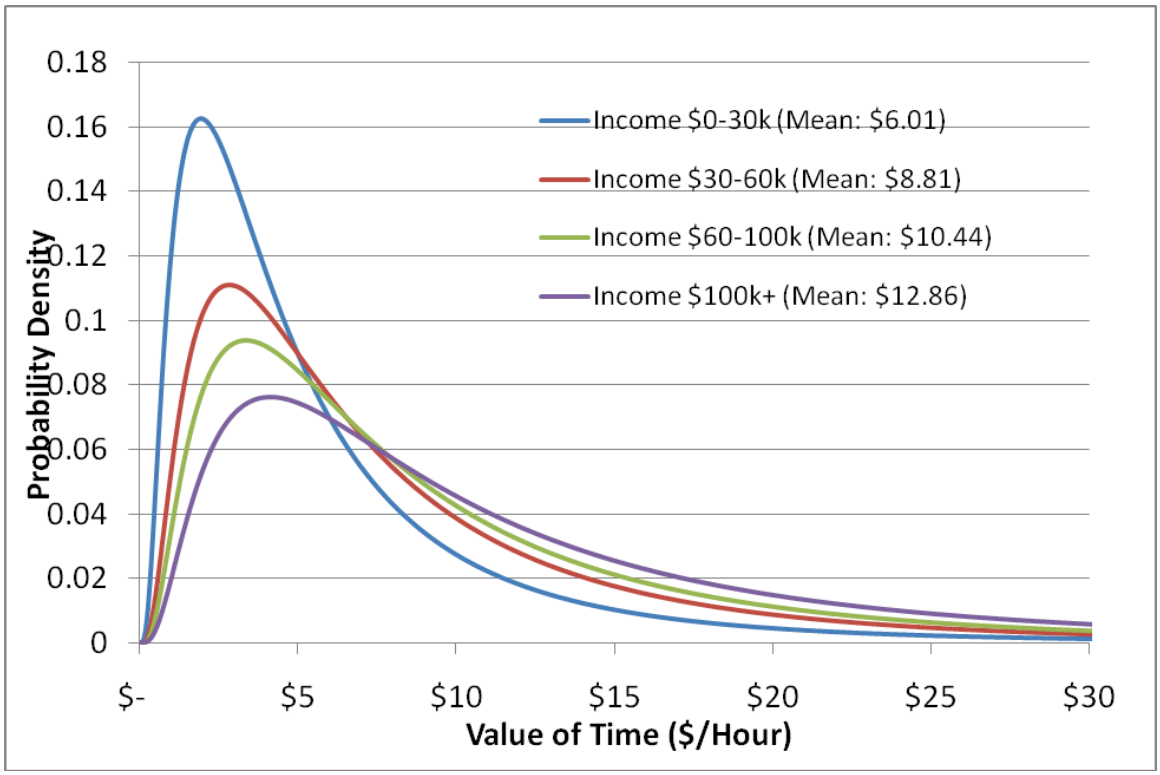
Values of Time

The values of time are drawn from a log normal distribution with a mean determined as a function of income and a sigma of 0.87. For mandatory tour purposes, the mean value of time is determined as a function of income, where the mean value of time is $3.80/hour for incomes less than $25,000 per year, $5.56/hour for incomes $25,000-$45,000 per year, $6.59/hour for incomes $45,000-$75,000 per year and $8.12/hour for incomes greater than $75,000 per year. The mean value of time for non-mandatory purposes is 2/3 that of mandatory purposes. All values in this paragraph are specified in 1989 dollars for consistency with the costs in the model. These value of time distributions are shown graphically in Figure 2. Persons less than 18 years old use a value of time equal to 2/3 of the value

used for adults in the household. A maximum value of $50/hour is used, and a minimum of $1/hour is imposed. The distributions were derived using the SP survey data and maximum likelihood estimation for mixed logit models. Accounting for value of time heterogeneity in travel models is important for pricing applications (*8*).

The mixed-logit time-of-day model was estimated based on a stated preference survey administered to 663 travelers driving to downtown San Francisco where they were asked to trade off cost, time shifts, and mode shifts. It is applied disaggregately to all auto-person trips based on each individuals' trip purpose and value of time. Mixed logit is important in this case because it allows the user to estimate a distribution on a coefficient, rather than just the mean value. In this case, a distribution was estimated on the travel time variable, asserting a lognormal form. The cost coefficients are estimated as standard, non-distributed, coefficients segmented by income.

FIGURE 3 Estimated Value of Time Distributions in 2005 Dollars



Highway and Transit Assignment

To achieve a more rigorous highway assignment solution, the RPM-9 final highway assignments all run to a relative gap of 0.005. Previously, they had been run to a maximum of 99 iterations, which meant that each highway assignment may have been terminated at different relative gap closures, making congestion levels across scenarios difficult to compare (*9*). New link cost functions for highways were estimated based on observed speed and volume data in the city's Doyle Drive corridor.

RPM-9's geographic expansion required a thorough review of the transit path building parameters and networks to assure both that all available paths were enumerated and the paths being chosen were reasonable. The MAPS Study Team adjusted several path-building parameters, and refined and corrected network coding across the nine-county Bay Area.

Discount Logic

As part of a comprehensive tolling scenario, the MAPS Study Team examined various discount policies. The logic for these policies had to be coded into the RPM-9 model. Two of the most important discounts are for *passthru* trips, which completely pass through San Francisco on US-101/I-80 and never touch city streets; and for a bridge toll *feebate*, which gives discounts to cars that have already paid a bridge toll. Logic to allow for area pricing as opposed to cordon pricing is also added.

Computing Power

Three major enhancements included in the RPM-9 model necessitate a significant amount of computation over and above the SF-CHAMP model: (1) the number of individuals being simulated increased from just San Francisco, to the entire Bay Area, (2) the model is run with three feedback loops, or essentially three times over, and (3) the convergence requirements of highway assignments, which require a significant amount of computing time, was changed to a relative gap of 0.005, which can result in almost 300 iterations of highway assignment to be run. The MAPS Study Team had two requirements related to run time: (1) each individual scenario needed to run in one day, allowing immediate and rapid feedback for scenario development, and (2) dozens of scenarios needed to be run each week in order to remain on schedule. In order to meet these requirements, the SFCTA purchased new multi-core machines bringing the total number of processors available for RPM-9 runs to forty. These forty processors were split up into two sets so that two model runs could be run side-by-side. The core models, written in C++, are distributed to available cores via a Python script. The skims, highway assignments, and other TP+ scripts are distributed via Cube Cluster. A Python wrapper around the TP+ scripts allows the user to specify how these scripts are distributed in order to optimize work flow without having to manually change the TP+ code for each run. In all, this distribution of computing power allowed the Study team to run over 100 scenarios, over 50 of which were kept for further analysis.

Model Calibration and Validation

The RPM-9 model is calibrated with data from the 2000 Census and the Bay Area Travel Survey. The model is validated based on observed roadway and transit counts by time-of-day, direction, and transit line for both 2000 and 2005. While the model validates well on average for the entire region, particular attention is paid to travel into and out of the downtown area. Table 1 represent a small sample some of the many validation metrics. Note that when choices had to be made, a better 2005 validation was targeted rather than 2000. 2000 was at the height of the dot-com bubble in the Bay Area and was the anomaly of the past decade.

TABLE 1 Selected Model Validation Metrics

Auto Volume Validation on Bay Bridge

Year 2000			**Inbound**			**Outbound**
Time of Day	Observed	Modeled	Difference	Observed	Modeled	Difference
Early AM	18,601	13,334	-28.3%	3,173	3,780	19.1%
AM Peak	26,865	30,399	13.2%	21,519	16,694	-22.4%
Midday	48,576	53,510	10.2%	47,064	54,729	16.3%
PM Peak	24,238	22,224	-8.3%	31,528	32,542	3.2%
Evening	22,270	26,926	20.9%	41,311	42,788	3.6%
Total	140,550	146,393	4.2%	144,595	150,533	4.1%
Year: 2005			**Inbound**			**Outbound**
Time of Day	Observed	Modeled	Difference	Observed	Modeled	Difference
Early AM	14,148	11,370	-19.6%	4,233	3,708	-12.4%
AM Peak	27,358	28,431	3.9%	20,112	16,805	-16.4%
Midday	47,348	49,320	4.2%	49,892	52,236	4.7%
PM Peak	4,292	21,504	-11.5%	29,256	30,539	4.4%
Evening	26,715	24,831	-7.1%	39,948	39,463	-1.2%
Total	139,862	135,455	-3.2%	143,441	142,751	-0.5%

BART Transbay Screenline

Year 2000			**Inbound**			**Outbound**
Time of Day	Observed	Modeled	Difference	Observed	Modeled	Difference
Early AM	2,519	3,801	51%	206	251	22%
AM Peak	35,485	37,458	6%	5,327	7,005	31%
Midday	22,708	19,984	-12%	13,690	17,149	25%
PM Peak	8,655	9,987	15%	34,355	32,791	-5%
Evening	5,465	3,873	-29%	25,256	15,560	-38%
Total	74,832	75,103	0%	78,834	72,756	-8%
Year 2005			**Inbound**			**Outbound**
Time of Day	Observed	Modeled	Difference	Observed	Modeled	Difference
AM Peak	33,031	33,473	1.3%	6,372	8,418	32%
PM Peak	9,444	10,419	10%	33,063	31,613	-4%

The next section outlines the evaluation criteria that were used to evaluate each of the tested scenarios along with evaluation results. Specifically, it focuses on evaluation criteria informed by the RPM-9 model.

EVALUATION AND RESULTS

In order to evaluate the feasibility of congestion pricing in San Francisco, the Study Team compared potential benefits, impacts, and costs of a variety of congestion pricing scenarios using several metrics. Specific areas of consideration included mobility, accessibility, equity, health, financial viability, and economic impacts. The new RPM-9 model was used to compare and assess each congestion pricing scenario with a future baseline based on the metrics detailed below.

Evaluation Criteria

Mobility

One of the primary goals of congestion pricing is to improve mobility, particularly during periods of time and areas where mobility is expected to severely degrade over the next decade. The MAPS study team used the RPM-9 model outputs to compare the following mobility-related objectives. **Vehicle hours of delay** quantified the amount of time wasted in congestion. **Peak/off-peak travel time ratios** for both auto and transit modes, between key origin and destinations allowed the team to dial in on where mobility could improve due to time-of-day shifts. **Transit load factors** identified corridors with high transit potential as well as corridors that transit overcrowding needed to be addressed through increased service or time of day changes; transit loads that were highly responsive to service increases were also identified as places where re-investment of tolling revenue would be effective. Maps of **traffic volume changes** in response to tolling were useful in identifying potential mobility impacts due to diversions around the tolled cordon.

Accessibility

While mobility captures the ease of movement between different points, accessibility can be defined as the number of opportunities available within a certain travel time, cost, or distance threshold. Therefore an increase in mobility would also increase ones accessibility; however, accessibility also captures the importance of improving mobility to economic centers compared to a mobility improvement where there are little or no destinations. While the RPM-9 model captures measures of mobility as *logsums*, the consequence of accessibility change is reflected in **overall trip-making**, which is a more publicly tangible metric.

Equity

The MAPS study examines equity by viewing each of the other evaluation criteria through the lens of a historically disadvantaged group and comparing that with the population as a whole. Because RPM-9 simulates the daily travel of each individual living in the Bay Area, the Study Team was able to summarize the evaluation criteria based on specific attributes. Sub-populations that the Study Team specifically examined include lower-income households (below $50,000 annual household income), zero-car households, and residents within or adjacent to a priced zone.

Health

The San Francisco Department of Public Health is in the process of doing a full Health Impact Assessment of Congestion Pricing in San Francisco. For the MAPS study, they helped the Study Team evaluate a few primary health metrics. **Emissions** are calculated based on vehicle miles traveled (VMT) by speed and facility type, and the team calculates **collisions** based on vehicle miles traveled by facility type. The results of the full Health Impact Assessment are not presented within the context of this report. However, any references to reductions in VMT can be translated into reduced amounts of greenhouse gas.

Revenue Generation

One of the main questions that the MAPS study aims to answer is whether congestion pricing generates enough revenue to both offset the costs of tolling and pay for a large-enough package of transportation improvements to increase mobility and accessibility. Financial consultants developed a detailed financial model to estimate the amount of money the toll system would generate that would be available for transportation improvements and to test various financing approaches for implementation of the charging system and supporting transportation investments. RPM-9 was used to find the **number of toll transactions** (since there is a cost to processing each transaction) as well as the **amount and number of discounts**. Depending on the tolling and discount policy tested, there were several possible toll-levels that an individual vehicle could be assessed. A separate revenue model simulating many possibilities was created for the purpose of determining the financial feasibility of congestion pricing. While the RPM-9 model was used as an input to this process, the details of the revenue model are not discussed within the context of this paper. Rather, relative conclusions are made based on the number of toll transactions RPM-9 forecasts.

Economic Impact

The MAPS Study Team commissioned economic consultants to study the potential economic impact of several congestion pricing scenarios in San Francisco. As an input, the economic impact study used the travel patterns forecast by RPM-9 for each individual in the Bay Area for both future baseline and the priced scenarios. While the economic impacts of congestion pricing are an important consideration for the Study Team, they are not discussed within the context of this paper.

Results

For the sake of brevity, rather than discuss the quantitative results of each evaluation metric for each of the dozens of scenarios tested, this paper discusses the results in terms of useful findings regarding scenarios that helped the Study Team arrive at a preferred scenario.

The *Gateway* scenarios showed potentially high revenue generation due to the large number of drivers entering and exiting the city during peak hours. However, several key drawbacks led to removing it from consideration. Most importantly, the Gateway scenarios failed to significantly reduce delay in the Focus Area during peak periods (morning peak vehicle hours of delay were reduced by 4% compared to the baseline). The baseline analysis noted that roughly half of peak period motorists in the Focus Area are going to or from other places within San Francisco. While some this congestion was reduced due to tolls on *regional* trips, the Gateway scenario actually *increased* the number of drivers from *within* San Francisco to the Focus Area – thus cancelling out much of the congestion benefit of the toll. Albeit financially feasible, the Gateway scenario's failure to meet any other criteria eliminated it from consideration.

A derivative of the Gateway scenario, the *Southern Gateway* tested a peak congestion toll only along the southern border of San Francisco, leaving existing bridge tolls stay as-is at the remaining points of entry. This scenario gives even fewer benefits and less revenue than the other Gateway scenarios. Daily vehicle hours of delay are reduced by approximately 3% in the Focus Area. However, travel time ratios to the North and East Bay both increase, most likely due to latent demand that is now traveling through San Francisco on capacity freed up by fewer tolled travelers from the South.

The *Small Downtown Cordon* scenarios show potentially high benefits within the Focus Area coupled with some significant impacts immediately surrounding the cordon, and not very much revenue potential. Scenarios that tolled three dollars for all three hours of the peaks reduced vehicle delay and VMT inside the Focus Area by 30-40 percent. Focus Area accessibility was relatively flat under these scenarios, with overall peak Focus Area person trips reduced by 1-3%. Furthermore, vehicles skirting around the priced cordon inflicted significant burdens on neighborhood streets. Due to its small size, the Downtown Cordon options did not generate enough transactions to gross significant revenue and while it could potentially offset the operating, maintenance, and capital costs of congestion pricing, it would not be able to financially support the transit investments necessary to provide a comprehensive mobility solution.

The *Northeast Cordon* set of scenarios had the best combination of reasonable mobility benefits, and relatively small impacts. These scenarios utilize a somewhat larger pricing cordon (relative to the Small Downtown Cordon) to reduce diversionary effects—by including San Francisco's northeast waterfront as one of the zonal boundaries. "NE-Large," the largest of the Northeast Cordon scenarios and "NE-Small" (the smallest) provide a good context for examining the feasibility of this geographic design. Both scenarios have a negligible (<<0.1%) impact on overall accessibility in San Francisco as measured by daily person trips, and increased daily transit mode share for all of San Francisco by two percentage points to 21%. The main difference between these scenarios is where the benefits and impacts occur. If benefits were just assessed within the Focus Area, then NE-Small would perform well, reducing Focus Area VMT by 15% (compared to 8% for Big Dog) and Focus Area vehicle hours of delay by more than 20% (compared to 11%). NE-Large, on the other hand, provides benefits across a wider area, reducing VMT by 4.5% across all of San Francisco and reducing delay by almost 10%, while NE-Small only moves each of these measures by 2%. Each of these scenarios has different impacts as well. NE-Small similar to the Small Downtown Cordon, is small enough to make it easy to avoid. The problem with that is twofold: (1) the number of toll transactions approaches a level of infeasibility – NE-Small yields under 150,000 daily transactions compared to over a quarter of a million for NE-Large; and (2) the diverted traffic severely impacts the

mobility of the surrounding neighborhoods. While not as pronounced a problem as in both Gateway scenarios, there was still some evidence of induced travel by residents of the zone despite the tolled area being very transit rich. Comparing these two scenarios, it is evident that a toll boundary in the middle could provide the best tradeoff between local and regional impacts and benefits while remaining financially feasible.

The best middle ground scenario that the Study Team arrived at is bounded by Laguna, Guerrero, and 18th Streets. This "Revised Northeast Cordon" is financially feasible, has the most benefits and the least impacts. Toll transactions for this scenario hovered just under a quarter million, similar to NE-Large. However, the Preferred Scenario has a smaller perimeter than NE-Large which translates to smaller capital and maintenance costs. AM, PM, and Daily transit mode share rose by 4 percentage points in the Focus Area, and 2 percentage points across the board for San Francisco. Daily VMT drops by 5 percent in San Francisco and 10 percent in the Focus Area, and Daily hours of vehicle delay decrease by 11 percent for San Francisco and 15 percent for the Focus Area. Under the preferred scenario, the weighted average AM peak auto travel time to the Focus Area is also expected to be reduced by 7 percent overall, 22 percent from the East Bay, and 10 percent from parts of San Francisco outside the Focus Area. While there are some negative spillover effects projected for some areas adjacent to the priced zone, the problem is not nearly as pronounced as with the smaller cordons and would be mitigated in detailed program design. In particular, the naturally hilly geography at the western corner of the Preferred Cordon makes diverting along the edges of the tolled area undesirable.

The issue of equity is often raised at the same time that roadway pricing is, and rightfully so. A roadway charge on its own could affect low-income travelers disproportionately, though in San Francisco's case, the proportion of low-income drivers in the peak is relatively low (approximately 5%). The potential regressivity of congestion pricing is addressed within the context of MAPS by providing everybody more travel options – including an auto trip with less time wasted in delay as well as a more reliable, quick, and frequent trip via transit. The overall effect on mobility can be described by the total number of trips made. Because RPM-9 is a disaggregate model, microsimulating and saving the daily travel patterns of every individual, the Study Team was able to separate out low-income households and evaluate their mobility compared to the overall mobility of the population. For the Preferred Cordon, the Study Team found that while daily trips to the Focus Area were reduced by 38%, trips made by low-income households only decreased by 1.5%. Therefore, the Preferred Cordon has a positive effect on the mobility of low-income households relative to the general population.

CONCLUSIONS

To date, the major finding from this study is that a congestion pricing program would be feasible for San Francisco, contributing to local, regional and statewide goals for congestion management, sustainable economic growth, and reduced climate change impacts. The RPM-9 model provided the MAPS Study Team with valuable and timely advice to support the MAPS Feasibility Study. The rapid feedback (possible through a sub-24-hour model run time) enabled the study team to test a multitude of scenarios and conditions in order to quickly arrive at a preferred alternative that met the key goals of increasing mobility while being financially feasible. The rapid feedback also allowed the Study Team to allay public and agency concerns by producing specialized model runs to address their questions. The microsimulation nature of RPM-9 allowed an in-depth, yet flexible analysis of key populations, and the state-of-the-art methodologies embedded in RPM-9 gave the Study Team confidence in their overall conclusions.

ACKNOWLEDGEMENTS

The authors would like to thank José Luis Moscovich, the Executive Director of the San Francisco County Transportation Authority as well as the rest of the RPM-9 Development Team including Joe Castiglione, Joel Freedman, and Mark Bradley.

REFERENCES

1. Texas Transportation Institute. 2009. 2009 Annual Urban Mobility Report. http://mobility.tamu.edu/ums/
2. Association of Bay Area Governments. ABAG Projections 2007. http://www.abag.ca.gov/planning/currentfcst/proj07.html
3. Davidson, W., R. Donnelly, P. Vovsha, J. Freedman, S. Ruegg, J. Hicks, J. Castiglione and R. Picado. 2007. Synthesis of first practices and operational research approaches in activity-based travel demand modeling. Transportation Research Vol. 41A, No. 5: 464-488.
4. Freedman, J., J. Castiglione, and B. Charlton. 2006. Analysis of New Starts Project by Using Tour-Based Model of San Francisco, California. Transportation Research Record 1981.
5. Erhardt, G.D., B. Charlton, J. Freedman, J. Castiglione, and M. Bradley. 2008. Enhancement and Application of an Activity-Based Travel Model for Congestion Pricing. Paper presented at TRB Innovations in Travel Modeling conference, June 23-25, in Portland, OR.
6. Boyce, D., C.R. O'Neill, and W. Scherr. 2007. New Computational Results on Solving the Sequential Procedure with Feedback. Paper presented at TRB Planning Applications Conference, May, Daytona FL.
7. Castiglione, J., J. Feedman, and M. Bradley. 2008. Systematic Investigation of Variability due to Random Simulation Error in an Activity-Based Microsimulation Forecasting Model. Transportation Research Record 1831.
8. Lawton, Keith. 2008. Keynote Address: So Much to Do – So Little Done? So Much To Do – So Little Time? Presented at TRB Innovations in Travel Modeling Conference, June 23-25, in Portland, OR.

   http://www.trb-forecasting.org/ITM08/Plenary/Lawton.pdf
9. Boyce D., B. Ralevic-Dekic, H. Bar-Gera. 2004. Convergence of Traffic Assignments: how Much is Enough? ASCE Journal of Transportation Engineering 130: 49-55.