



Modeling the effects of congestion pricing policy on regional highway networks

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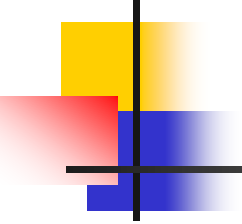
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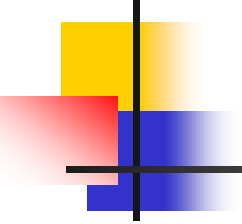
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1. Introduction

- The efficiencies of peak-load pricing on urban roads and highways have been widely cited and discussed.
- Theoretical contributions by urban economists (Vickrey, Kain, Quigley, Arnott and others) have deepened our understanding of the problems and the possibilities.

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- There have also been speculations of how peak-load pricing might be implemented in the U.S. and other countries.
 - Some authors have discussed what the land use implications might be and what kinds of effects the peak-load pricing policy may have. But this is highly speculative.
 - Applications are proceeding in various places abroad and being seriously discussed in the U.S. Do we have models to help planners as they consider implementation?

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- Tolls achieve efficiency by inducing adjustments that include a choice of time of departure. The dynamic traffic assignment (DTA) literature addresses this deficit (Ran and Boyce 1996), but these models are too complex to have penetrated planning practice.
 - Further, modeling a detailed representation of dynamic route choice remains computationally burdensome, and it would be difficult to combine DTA approaches into more detailed models of the urban economy.



2. Methodology

- The actual effects of pricing on selected thoroughfares in a complex transportation-land use system are not well understood.
- For instance, How can we model the traffic and development pressure effects of implementing peak-load pricing on selected routes in a major metropolitan area? What are the network and development pressure effects of selected pricing choices ?
- This research addresses these questions for the case of the Los Angeles metropolitan area.
- A modified version of the Southern California Planning Model (SCPM) has been applied.

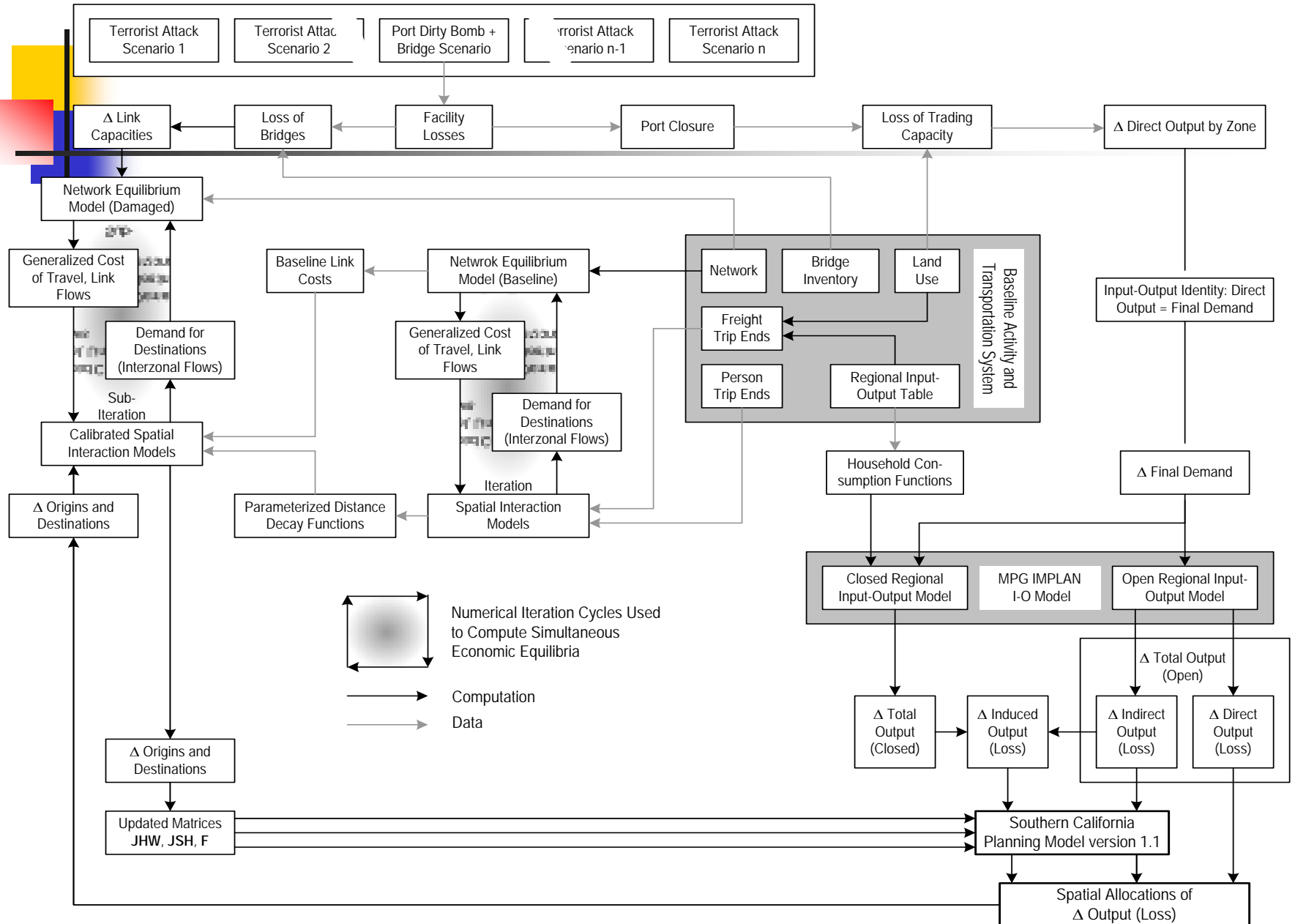


Objectives

We report on an elaboration of the Southern California Planning Model (SCPM)

Our interest is to use SCPM to model the impacts of peak-load pricing on the major thoroughfares of a major metropolitan area

Figure 1. SCPM Data flows and model calculations



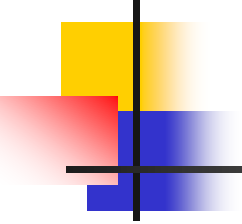
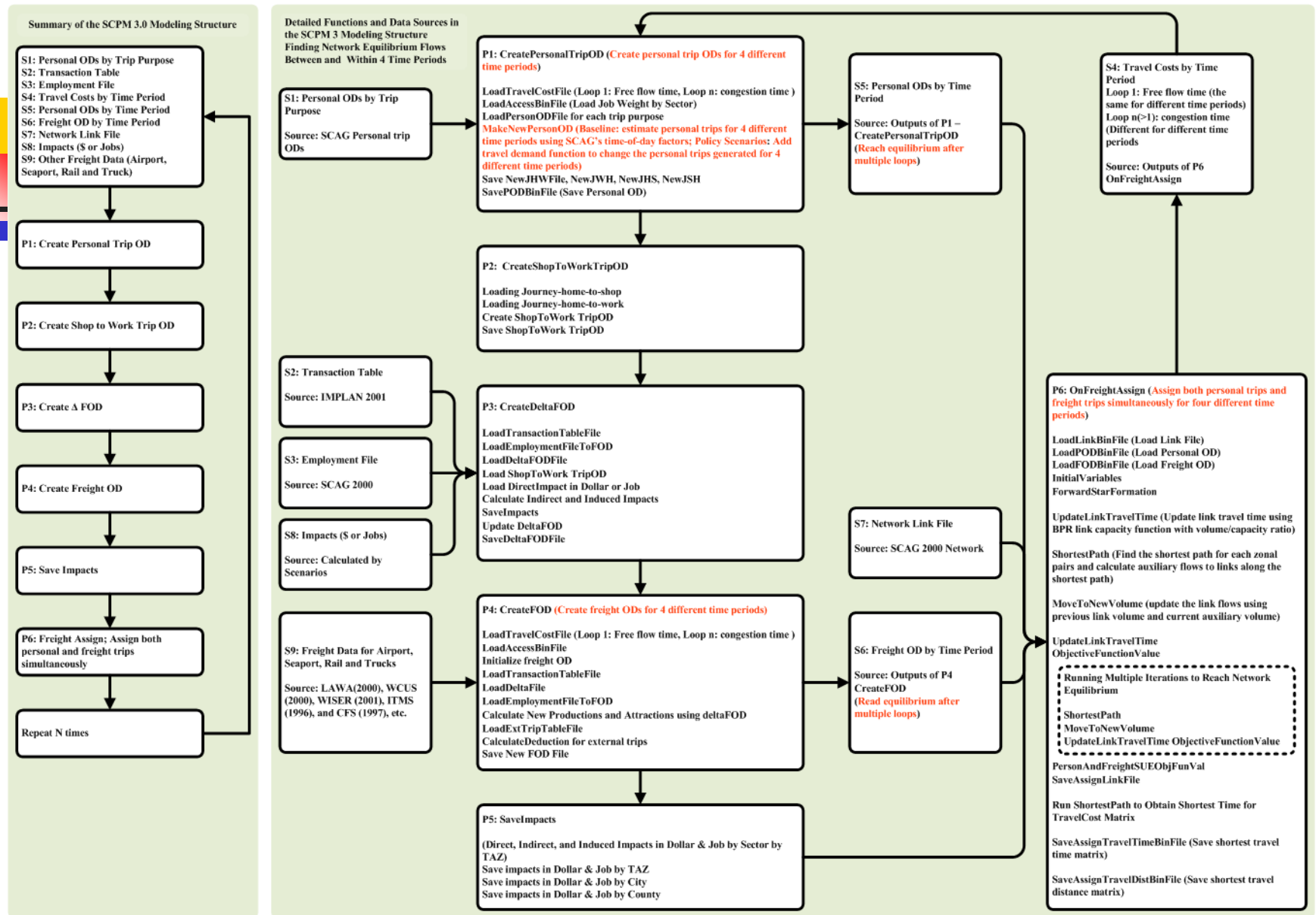
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- The innovation in this research has been to introduce time-of-day choice.
 - Cash tolls would be factored into the generalized travel cost function that drivers are thought to respond to. The fixed demand assumption for each period is dropped.
 - In this application, freight travel is affected by toll to change route but not the time of day to travel.

Figure 2. Revised SCPM Model Structure



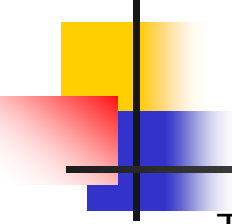


User Equilibrium with Variable Demand

We developed a user equilibrium with variable demand model (UE-VD) for time of the day choice, which has an objective function formulated as follows,

$$\begin{aligned}
 \text{Min} \quad & \sum_a \int_0^{x_a} t_a(x) dx - \sum_{o,d} \int_0^{T_{o,d}} D_{o,d}^{-1}(x) dx \\
 \text{Subject to} \quad & x_a = \sum_o \sum_d \sum_p \delta_{a,p}^{od} h_p^{od} \quad \forall a \\
 & \sum_p h_p^{od} = T_{od} \quad \forall o,d \\
 & h_p^{od} \geq 0 \quad \forall p,o,d \\
 & T_{od} \geq 0 \quad \forall o,d \\
 & T_{od} \leq \overline{T_{od}} \quad \forall o,d
 \end{aligned}$$

Where, x_a is the total flow on link a ; $t_a(x)$ is the cost-flow function to calculate average travel cost on link a ; $\delta_{a,p}^{od}$ is link-path incidence variable; h_p^{od} is flow on path p connecting OD pair o and d ; T_{od} is peak-hour trip between origin node o and destination node d ; $\overline{T_{od}}$ is the total trip between origin node o and destination node d ; p is a network path; o and d are two end nodes on the network; $D_{o,d}^{-1}(x)$ is the inverse of the demand function for O-D pair (o,d) .



The peak-hour trips are calculated using a demand function in the logit formula as follows,

$$T_{o,d} = \bar{T}_{o,d} \frac{1}{1 + e^{\theta(t_{o,d} - t'_{o,d})}}$$

The inverse demand function would be,

$$D_{o,d}^{-1}(\bullet) = t_{o,d}(T_{o,d}) = \frac{1}{\theta} \ln\left(\frac{\bar{T}_{o,d}}{T_{o,d}} - 1\right) + t'_{o,d}$$

To solve the variable demand problem with an efficient fixed-demand formulation, an excess demand function is derived as follows,

$$W_{o,d}(T'_{o,d}) = \frac{1}{\theta} \ln\left(\frac{T'_{o,d}}{T_{o,d} - T'_{o,d}}\right) + t'_{o,d}$$

The objective function can be re-formulated as follows,

$$\text{Min} \sum_a \int_0^{x_a} t_a(x) dx + \sum_{o,d} \int_0^{T'_{od}} w_{od}(v) dv$$



The solution algorithm is summarized as follows,

- Step 0: **Initialization**. Perform all-or-nothing approach to assign trips using free flow travel costs c_a for each link on the empty network. Initial feasible solutions of link flows and O-D trips in a given peak period are obtained.
- Step 1: **Update**. The travel time on link a is updated as t_a and inverse demand function value v_a is calculated.
- Step 2: **Find a feasible descent direction**. Use the updated travel time $\{t_a\}$ for an all-or-nothing assignment for the trips. It yields a set of auxiliary link flows.
- Step 3: **Find optimal parameter**. A linear approximation algorithm (LPA) such as Golden section method is applied to obtain optimal parameter satisfying the UE-VD equation
- Step 4: **Update link flows**. Link flows and O-D flows are updated.
- Step 5: **Test Convergence**. The process stops when a convergence criterion is satisfied and link flows are the optimal link flows at equilibrium condition. Otherwise, go back to Step 1 and continue the process.



3. The Choice of Policy to Test and the Analysis Results

- All the area freeway links will be tolled.
- We test two scenarios: \$0.1 per mile and \$0.3 per mile tolls,
- The \$/mile toll fee is converted to hr/mile congestion time based on the hourly wage estimated from IMPLAN 2001.
- Scenario I: \$0.1 per mile
 - > 0.0057 hr/mile or 0.3407 min/mile
- Scenario II: \$0.3 per mile
 - > 0.0170 hr/mile or 1.0220 min/mile

Table 1A. Passenger Trips and Travel Time for Baseline and Scenario, AM Peak, PM Peak, and Off Peak (Toll = \$0.3 per mile)

Time Period	Type of Road	Baseline			Scenario			% Change		
		Trips (PCEs)	Total Travel Time (PCE*Mins)	Average Travel Time (Mins)	Trips (PCEs)	Total Travel Time (PCE*Mins)*1	Average Travel Time (Mins)*1	Total Trips	Total Travel Time	Average Travel Time
AM Peak	Highway	4,926,850	28,796,972	5.84	4,530,046	13,200,017	2.91	-8.05%	-54.16%	-50.15%
	Local		40,596,044	8.24		58,084,184	12.82		43.08%	55.61%
	Total		69,393,016	14.08		71,284,201	15.74		2.73%	11.72%
PM Peak	Highway	7,724,865	34,568,832	4.48	7,325,475	15,021,011	2.05	-5.17%	-56.55%	-54.18%
	Local		51,464,912	6.66		77,855,680	10.63		51.28%	59.53%
	Total		86,033,744	11.14		92,876,691	12.68		7.95%	13.84%
Off peak	Highway	12,959,679	52,908,392	4.08	13,647,125	57,292,732	4.20	5.30%	8.29%	2.83%
	Local		79,860,288	6.16		85,469,288	6.26		7.02%	1.63%
	Total		132,768,680	10.24		142,762,020	10.46		7.53%	2.11%
	Sum	25,611,394	288,195,440	11.25	25,502,646	306,922,912	12.03	-0.42%	6.50%	6.95%

Table 1B. Passenger Trips and Travel Distance in Baseline and Scenario, AM Peak, PM Peak, and Off Peak (Toll = \$0.3 per mile)

Time Period	Type of Road	Baseline			Scenario			% Change		
		Trips (PCEs)	Total Travel Distance (PCE*Miles)	Average Travel Distance (Miles)	Trips (PCEs)	Total Travel Distance (PCE*Miles)	Average Travel Distance (Miles)	Trips	Travel Distance	Average Travel Distance
AM Peak	Highway	4,926,850	28,661,390	5.82	4,530,046	13,985,941	3.09	-8.05%	-51.20%	-46.93%
	Local		20,088,162	4.08		29,619,714	6.54		47.45%	60.36%
	Total		48,749,552	9.89		43,605,655	9.63		-10.55%	-2.72%
PM Peak	Highway	7,724,865	35,135,996	4.55	7,325,475	16,048,414	2.19	-5.17%	-54.32%	-51.83%
	Local		24,858,734	3.22		39,438,316	5.38		58.65%	67.30%
	Total		59,994,730	7.77		55,486,730	7.57		-7.51%	-2.47%
Off peak	Highway	12,959,679	56,544,620	4.36	13,647,125	61,162,608	4.48	5.30%	8.17%	2.72%
	Local		38,537,972	2.97		41,260,804	3.02		7.07%	1.67%
	Total		95,082,592	7.34		102,423,412	7.51		7.72%	2.29%
	Sum	25,611,394	203,826,874	7.96	25,502,646	201,515,797	7.90	-0.42%	-1.13%	-0.71%

Table 2A. Passenger Trips and Travel Time for Baseline and Scenario, AM Peak, PM Peak, and Off Peak (Toll = \$0.1 per mile)

Time Period	Type of Road	Baseline			Scenario			% Change		
		Trips (PCEs)	Total Travel Time (PCE*Mins)	Average Travel Time (Mins)	Trips (PCEs)	Total Travel Time (PCE*Mins)*1	Average Travel Time (Mins)*1	Total Trips	Total Travel Time	Average Travel Time
AM Peak	Highway	4,926,850	28,796,972	5.84	4,983,433	25,004,728	5.02	1.15%	-13.17%	-14.15%
	Local		40,596,044	8.24		45,592,360	9.15		12.31%	11.03%
	Total		69,393,016	14.08		70,597,088	14.17		1.74%	0.58%
PM Peak	Highway	7,724,865	34,568,832	4.48	7,780,719	29,322,734	3.77	0.72%	-15.18%	-15.78%
	Local		51,464,912	6.66		58,079,104	7.46		12.85%	12.04%
	Total		86,033,744	11.14		87,401,838	11.23		1.59%	0.86%
Off peak	Highway	12,959,679	52,908,392	4.08	12,862,930	52,301,852	4.07	-0.75%	-1.15%	-0.40%
	Local		79,860,288	6.16		79,063,920	6.15		-1.00%	-0.25%
	Total		132,768,680	10.24		131,365,772	10.21		-1.06%	-0.31%
	Sum	25,611,394	288,195,440	11.25	25,627,082	289,364,698	11.29	0.06%	0.41%	0.34%

Table 2A. Passenger Trips and Travel Distance in Baseline and Scenario, AM Peak, PM Peak, and Off Peak (Toll = \$0.1 per mile)

Time Period	Type of Road	Baseline			Scenario			% Change		
		Trips (PCEs)	Total Travel Distance (PCE*Miles)	Average Travel Distance (Miles)	Trips (PCEs)	Total Travel Distance (PCE*Miles)	Average Travel Distance (Miles)	Trips	Travel Distance	Average Travel Distance
AM Peak	Highway	4,926,850	28,661,390	5.82	4,983,433	25,472,128	5.11	1.15%	-11.13%	-12.14%
	Local		20,088,162	4.08		22,923,290	4.60		14.11%	12.82%
	Total		48,749,552	9.89		48,395,418	9.71		-0.73%	-1.85%
PM Peak	Highway	7,724,865	35,135,996	4.55	7,780,719	30,444,014	3.91	0.72%	-13.35%	-13.98%
	Local		24,858,734	3.22		28,832,510	3.71		15.99%	15.15%
	Total		59,994,730	7.77		59,276,524	7.62		-1.20%	-1.91%
Off peak	Highway	12,959,679	56,544,620	4.36	12,862,930	55,893,088	4.35	-0.75%	-1.15%	-0.41%
	Local		38,537,972	2.97		38,151,296	2.97		-1.00%	-0.26%
	Total		95,082,592	7.34		94,044,384	7.31		-1.09%	-0.35%
	Sum	25,611,394	203,826,874	7.96	25,627,082	201,716,326	7.87	0.06%	-1.04%	-1.10%

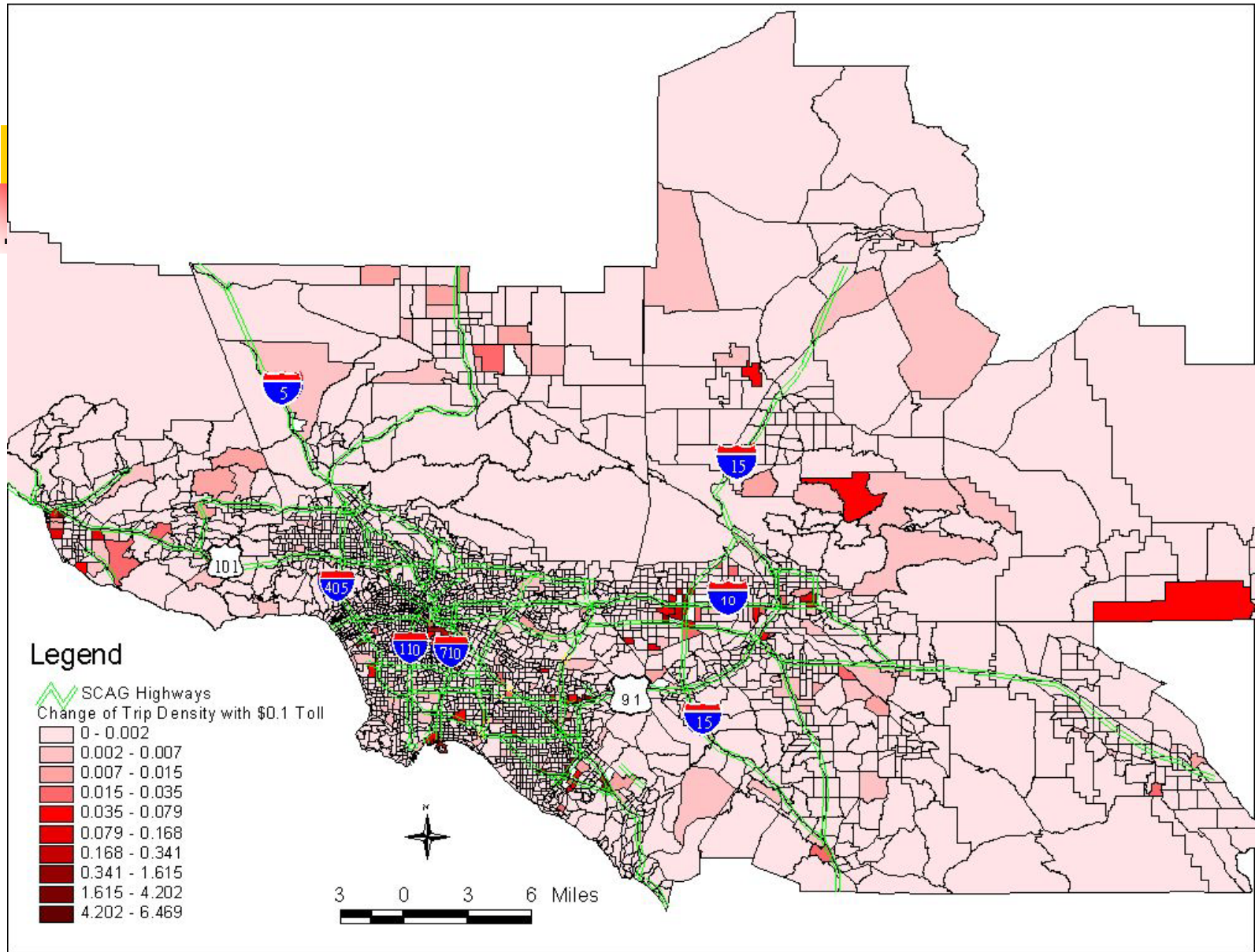
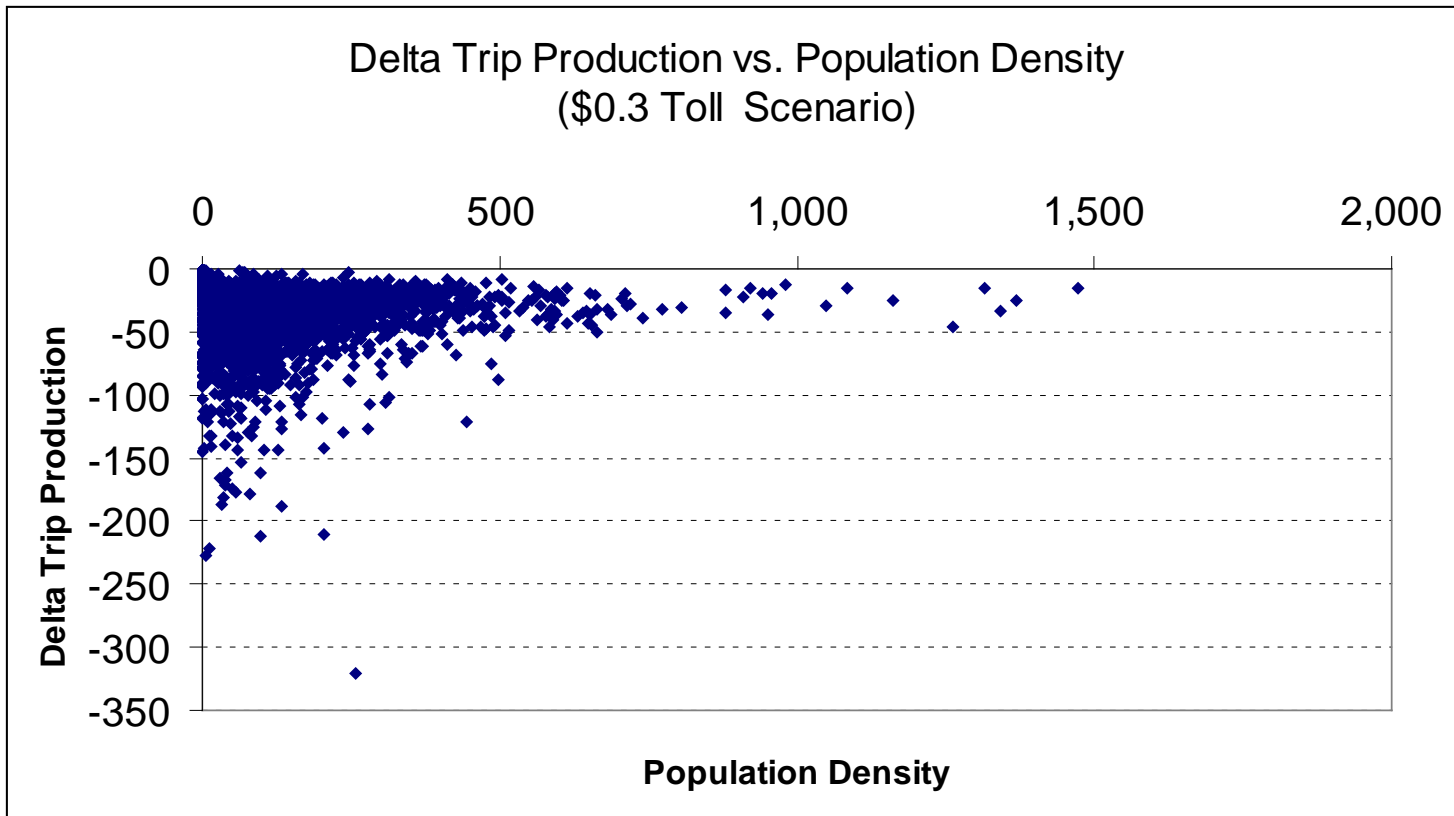
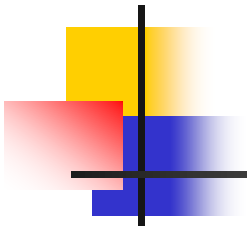


Figure 4. The Change of Trip Production Densities, \$0.1 Toll Scenario



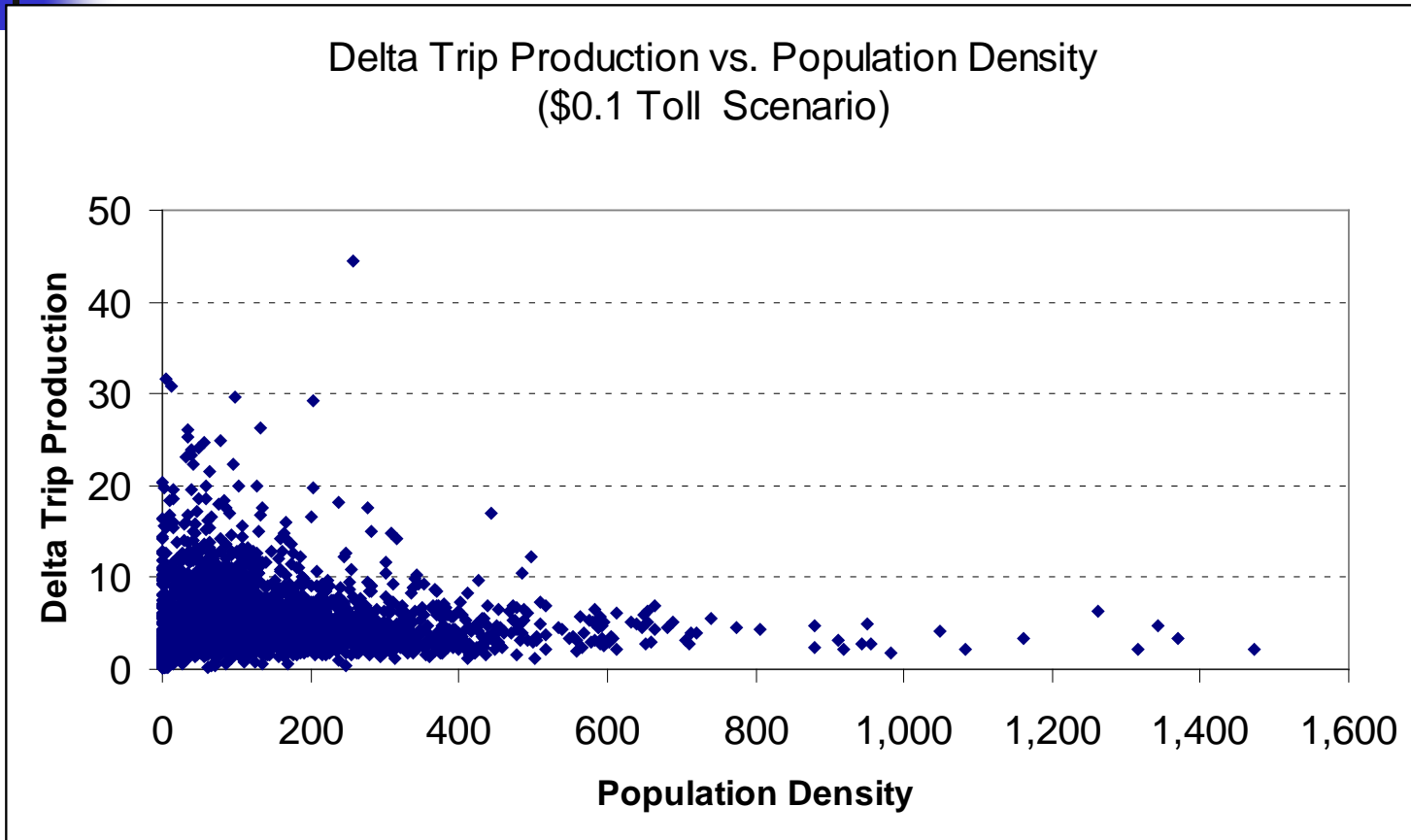
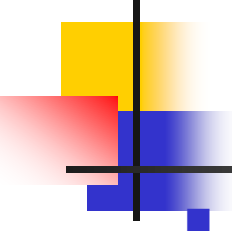


Figure 6. Delta Passenger Trip Production vs. Population density, the \$0.1 Toll Scenario



4. Findings and Conclusions

- In this study, We focus on changes for the total trip (average and total trip times) as well as changes for the freeway and surface street components in different cash toll scenarios.
- We find that, depending on the scenario, the extent to which drivers used tolled vs. untolled segments, varied substantially.
- Assuming that there are 250 days of the year in which congestion tolling occurs, the lower toll (\$0.10/mile) transfers substantially more revenue to the tolling authority than would the higher toll (\$0.30/mile), \$1,420 million vs. \$550 million.
- The higher toll moves trip volumes from the peaks to the off-peak periods, but the trip volume effects for the lower toll are very minor.



Both tolls cause improvements in average and total freeway travel times, but at the cost of increased travel times on non-tolled surface streets. For the lower toll, this adds up to only minor changes in overall travel times. For the higher toll, aggregate travel times increase as riders try to avoid the toll.

- The trade-off facing policy makers is complex: internalized externalities vs. improved peak-hour levels-of-service vs. greater revenues collected. Notably, improved levels of service on tolled freeways comes at the expense of greatly increased use of surface roads.
- We also found that there is no association between TAZ population density and changes in trips produced.