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An Evaluation of "High Occupancy Toll" and "Fast And Intertwined Regular" Networks

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Abstract: This paper evaluates two innovative road pricing strategies designed to manage congested freeway networks in metropolitan areas. The alternatives evaluated are: (1) a High-Occupancy Toll (HOT) network; and (2) a Fast and Intertwined Regular (FAIR) network. The alternatives both include adding a lane in each direction on congested freeway segments, but use road pricing to ensure free flow of traffic, and provide new high-quality express bus service at high frequencies with low fares. The Base Case involves adding a lane in each direction without significant demand management.

The results of the analysis suggest that both strategies would provide incremental social benefits exceeding incremental costs above the costs of lane addition in the Base Case. A FAIR network would provide significantly more incremental benefits and would also generate more new revenues, which would be adequate to pay for all incremental costs above costs for lane addition in the Base Case. A HOT network would produce revenues that would be sufficient to cover the incremental costs above the Base Case if tolls are charged during congested periods as well as off-peak. A FAIR network will provide guaranteed premium service freeway lanes for a larger number of motorists than with HOT networks, and for a much more affordable price. Also, equity concerns will be addressed through toll and transit fare reimbursements to low-income commuters, and the most advanced systems for arterial network management and operations will be put in place and maintained system wide.

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1.0 INTRODUCTION

Chen and Varaiya, in their article entitled "The Freeway Congestion Paradox," (1) have demonstrated that, once freeway vehicle density (measured in vehicles per mile) exceeds a certain critical number, both vehicle speed and vehicle flow (measured in vehicles per hour) drop precipitously. They have demonstrated the phenomenon with actual data from a section of westbound I-10 in Los Angeles. Until 5:10 am, a flow of 2,100 vehicles per lane per hour is maintained, at a speed of 58 mph. As density increases after 5:10 am, speed steadily drops, until at 7:00 am speed is a stop-and-go 15 mph, and flow decreases to 1,300 vehicles per lane per hour.

Even though demand starts to decrease after 8:00 am, the I-10 freeway does not recover its full efficiency until 11:30 am, because queued vehicles from previous hours keep vehicle density high. At these high densities, the freeway is kept in "breakdown" flow condition throughout the morning hours. Flow randomly fluctuates between 1,300 vehicles per lane per hour and 2,000 vehicles per lane per hour. Speeds randomly fluctuate between 15 mph and 30 mph. This results in a tremendous waste of motorists' time and vehicle fuel. Also, stop-and-go traffic generates excess pollutant emissions.

Road pricing (2) ensures that freeway efficiency is maintained on priced lanes. Essentially, a "price" in the form of a variable toll dissuades motorists from using a freeway lane or lanes approaching critical density. Drivers of low-occupancy vehicles who arrive when demand is high and wish to use the priced lanes pay for the improved service electronically. The toll rates vary to ensure that demand and supply are kept in balance.

2.0 STUDY ALTERNATIVES

Road pricing, transit and high-occupancy vehicle (HOV) strategies affect the demand side of vehicular travel. As discussed above, variable tolls can additionally ensure that the use of freeway capacity remains "efficient," i.e., that there is no loss of vehicle throughput due an excess of demand over the critical level at which freeway traffic flow breaks down. Road pricing strategies may be packaged with transit and HOV incentives to maximize their ability to address congestion problems. For this study, two packages of region-wide strategies are evaluated. The two alternatives and the Base Case all include adding a lane in each direction on congested freeway segments. The alternatives both attempt to ensure free flow of traffic on at least one lane, and provide fast, frequent and inexpensive express bus service on the free-flowing lane(s). The Base Case adds a general-purpose lane in each direction with no new express bus service or carpooling incentives. The alternatives are described below.

A HOT network. As proposed by Poole and Orski (3), this would be a network of premium priced lanes. A single barrier-separated High Occupancy Toll (HOT) lane would be added in each direction of freeways, with "direct connector" ramps at interchanges to avoid the need for HOT lane motorists to merge into and out of general-purpose traffic in order to use the lane. The lane(s) would provide free service for buses and vanpools, but would require full payment of the toll by smaller carpools and single-occupant vehicles. The toll would be set high enough to ensure that the lane remains free-flowing at all times. New high quality express bus service called "Bus Rapid Transit" would be provided on the HOT lanes.

A FAIR network. The Fast and Intertwined Regular (FAIR) Network concept (4) comprises: (1) conversion of the existing freeway network *during peak periods* into a premium-service free-flowing freeway network that provides new fast, frequent and inexpensive bus service; free premium service for carpools; and premium service for single-occupant vehicles paying a toll which varies to manage demand and keep the entire freeway congestion-free; (2) an intertwined network of designated free arterial routes which are improved using toll revenues (including management and operations improvements) to mitigate possible diversions of traffic from the freeway; and (3) toll and transit fare credits or refunds for low income commuters to address equity impacts and reduce the incentive for them to divert to an alternative free route.

A companion paper (4) evaluates the costs and benefits if a FAIR network were implemented *without* the lane additions assumed for this study. Listed below are several critical differences between HOT networks FAIR networks:

- A HOT network would generally have a single lane (and occasionally two lanes) in each direction, while a FAIR network utilizes all lanes on freeways.
- Because HOT networks require a separate lane, they would need additional right-of-way and pavement for buffer separation between the HOT lanes and general-purpose lanes. FAIR networks do not require additional right-of-way for lane separation, since none is required.
- A single HOT lane has reduced capacity due to physical separation of the lane. This is because a slower moving vehicle in the lane causes a gap to build up in front of it, reducing vehicle throughput. Thus, total vehicle capacity of the freeway is less than if the lane were not separated from other lanes on the freeway. With a FAIR network, the freeway lanes are not separated into sections; consequently, capacity of the freeway is not lost due to lane separation.
- A HOT network would require new direct connector ramps between the HOT lanes and other highway facilities, in order to avoid the need for HOT traffic to merge into and out of general-purpose lanes. The ramps would require new structures to "fly over" the general-purpose lanes. A FAIR network does not need new direct connector ramps, since all lanes are free-flowing.

- New exit and entry ramps to new bus stations and park-and-ride facilities will be needed for both types of networks, in order to facilitate direct access to free-flowing lanes for transit vehicles and for carpools. For FAIR networks, at-grade ramps would suffice. HOT networks would need flyover ramps to provide connections without the need for vehicles to merge through the general-purpose lanes.
- Due to the need for special direct connector ramps, the number of access and egress points from a HOT network may be limited. This reduces the ability of some motorists to access the network, or creates the need for them to drive out of their way in order to use the network. FAIR networks make access available from all existing interchanges.
- Since a HOT network must generate revenue from a single lane, only vanpools and buses are provided free service to ensure that adequate revenues are generated. There are no specific incentives for sharing a ride in a smaller carpool, and no new disincentives for solo driving. A FAIR network generates revenue from multiple lanes, so that it is not necessary to charge smaller carpools in order to generate adequate revenue. This provides an added incentive for carpooling, while providing a disincentive for solo driving.
- HOT network toll rates need to be higher than for FAIR networks. With HOT networks, there is limited premium service capacity (usually a single lane), and price must rise to a high level during peak periods to ensure that demand does not swamp this limited available capacity. Since FAIR networks have multiple lanes, much more capacity is available, and lower toll rates are sufficient to ensure that demand does not rise above available capacity. This may make use of FAIR networks more affordable to a larger population of motorists.
- With a HOT network, congestion remains on the general-purpose freeway lanes. Of course, congestion will be less than with an HOV network with the same configuration because HOT lanes can fully utilize available capacity by adjusting the toll, while HOV lanes only have the crude tool of vehicle occupancy to manage lane utilization. With a FAIR network, all freeway lanes are congestion-free. Also, advanced arterial network management and operations strategies are instituted to maximize the efficiency of the arterial network, and toll credits and transit fare credits are provided to low-income motorists to ensure that they are not induced to divert from tolled segments of freeways to free arterials.
- A HOT network does not directly address income-related equity issues. With a FAIR network, equity is addressed directly using reimbursements for tolls and transit fares for low-income commuters, with the rate of reimbursement inversely proportional to the income of the commuter's household, based on self-identification with verification. For example, the lowest income deciles would get a higher rate of reimbursement than mid-range income deciles.

3.0 THE SPRUCE MODEL

For this study, a "tabletop exercise" (as it is called in the U.K.) was conducted to estimate the impacts of the two alternatives and get a general sense of their strengths and weaknesses. A tabletop exercise combines many reasonable assumptions with a simple model to quickly produce a possible outcome. A relatively simple sketch-planning model was developed to compare the alternatives in terms of their benefits and revenue generation capabilities. The model is called "Sketch Planning for Road Use Charge Evaluation" or SPRUCE. It produces estimates of changes in a commuter's choice of travel mode and resulting changes in vehicle demand, travel delay, fuel costs and toll revenues. These estimates are then used to calculate monetized traveler benefits, external cost changes, and total social benefits.

The structure of SPRUCE is depicted in Figure 1. Details on the model assumptions and calculations are provided in the following sections. Each of the six model steps is described briefly below.

Step 1. Based on input of total daily *freeway* traffic in the Base Case, estimates are produced by hour of the day for vehicle travel demand, vehicle throughput and delays on a typical 10-mile freeway segment. The estimates account for the phenomenon of traffic flow breakdown at high densities discussed in the Introduction. Using inputs of daily *arterial* traffic in the Base Case, vehicle travel demand and delays on parallel arterials are also estimated by hour of the day, to get total delay in the entire freeway corridor.

Step 2. A pivot point mode choice model is used to estimate peak period commuter mode shifts for each alternative, based on inputs of expected changes in travel time and out-of-pocket costs (i.e., fares and tolls) by travel mode for a typical trip using the corridor. Separate mode choice estimates are produced for freeway travelers and for travelers on the parallel arterials. The mode choice changes are then used to estimate the number of carpool vehicles and the number of express buses needed to serve transit demand.

Step 3. Estimates of vehicle travel demand, vehicle throughput and delays are produced for each alternative, for each hour. The percentage reduction in vehicle demand from Step 2 is used to estimate vehicular demand by hour on the freeway and parallel arterials. For HOT networks, it is assumed that variable pricing will ensure that the entire capacity of the HOT lane would be fully utilized, and that there will be no delays to these vehicles. The model therefore only calculates delays on the *regular* freeway lanes, based on the balance of freeway vehicle demand. The model calculates delays on arterials based on the change in vehicle demand due to shifts to alternative modes estimated in Step 2. For FAIR networks, there is no delay on the freeway. The model calculates the number of vehicles that would be diverted to arterials and calculates the change in arterial delay based on this diversion and the capacity enhancement resulting from arterial network management and operations strategies that are an integral part of the FAIR network concept.

Step 4. The model estimates toll revenues for HOT and FAIR networks, based on estimates of toll rates that will need to be charged to maintain free flow of traffic, and usage estimates for the priced lanes. For the HOT network alternative, the single separated lane has less capacity than if it were part of a multi-lane cross-section because gaps build up in front of slower moving vehicles. Average flow of *toll-paying* vehicles is estimated at 1,600 vehicles per hour, with express buses and vanpools accounting for additional non-paying traffic. For the FAIR network alternative, solo driver vehicle estimates (less diverted vehicles) from the mode choice step are used to estimate the number of toll-paying vehicles.

Step 5. The model calculates traveler benefits, comprised of consumer surplus benefits for *new carpool and transit trips*, and for those *solo drivers and previous carpoolers* who continue to use the freeway network. Tolls paid by them (from Step 4) are subtracted to get net benefits. Changes in vehicle miles of travel (VMT), calculated from traffic estimates produced in Steps 1 and 3, are used to estimate savings in external costs based an average external cost per VMT from national data. To get total social benefits, external cost savings are aggregated with estimates of traveler benefits, with toll revenues added back in (as transportation agency "benefits"), and fuel taxes saved by travelers subtracted out.

Step 6. To evaluate impacts on arterial motorists, estimates of change in delay per vehicle are calculated for a typical trip.

4.0 MODEL APPLICATION: TRAVEL AND REVENUE IMPACTS

The SPRUCE model was applied to evaluate the relative merits of the two alternative road-pricing strategies relative to the Base Case. The model was used to estimate impacts for two typical congested 10-mile freeway segments (i.e., radial and cross-town), and the results were extrapolated to the whole metropolitan network. It was assumed that the two typical freeway segments would be widened from eight free lanes to 10 free lanes in the Base Case. Average daily traffic (ADT) volume after widening was projected at 220,000 in the Base Case. For comparison, typical traffic volumes on the severely congested eight-lane western segment of the Washington Beltway in Northern Virginia ranged from 178,000 to 240,000 in 1998 (5).

4.1 Travel Impacts in the Base Case

4.1.1 Freeway Impacts

Table 1 presents travel demand and delay impacts by hour of the day in the Base Case for the AM heavy traffic direction for a 10-mile segment of a typical cross-town freeway. Freeway traffic demand by hour (col. 3) is estimated using data from NCHRP Report 187 (6). The report provides data on share of ADT (col. 1) and directional splits (col. 2) by hour for suburban cross-town and radial freeways. While these data are admittedly old and peaking of demand is less pronounced today, it is difficult to get good "demand" data from traffic counts today because counts reflect the freeway *supply* inefficiency (i.e., reduced throughput) during traffic flow breakdown conditions as demonstrated by Chen and Varaiya.

In the Base Case, capacity flow (col. 5) up to critical vehicle density is estimated at 10,500 vehicles per hour per direction for the five lanes, based on 2,100 vehicles per lane.

After traffic flow breakdown occurs (i.e., when demand exceeds critical density), actual flow is estimated at 8,250 vehicles per hour for the five lanes. This is based on a traffic flow rate of 1,650 vehicles per hour, the average of the range of 1,300 to 2,000 vehicles per hour within which actual flow fluctuates, as observed on I-10 in Los Angeles (1).

SPRUCE assumes speeds (col. 8) for free flow conditions prior to breakdown at 60 mph. After breakdown occurs, average speed is estimated at 30 mph. This is at the high end of the range of 15 mph to 30 mph within which actual speed fluctuates, as observed on I-10 in Los Angeles (1). The high end was chosen to ensure that benefits from restoring free flow are estimated conservatively. Speeds are converted to vehicle travel time per mile (col. 9) in order to calculate vehicle delay (col. 10) relative to free flow travel times. *Note that this delay does not include delay to queued vehicles.*

Delay for excess demand (i.e., "queued" vehicles that are not able to make it through the bottleneck within that hour) is calculated as the number of queued vehicles in each hour (col. 4) times one hour. Total vehicle delay (col. 11) is the aggregate of delay for vehicles that get through plus delay for queued vehicles, for a 10-mile segment. Vehicle occupancy (col. 12) is used to convert vehicle hours of delay to person hours of delay. For AM peak and PM peak commuting hours (6 am to 9 am and 4 pm to 7 pm), vehicle-occupancy is estimated at 1.1, based on data for work trips from the 1995 Nationwide Personal Transportation Survey (7). At other times, the all-purpose vehicle occupancy of 1.5 is used.

4.1.2 Arterial Impacts

As shown in Table 2, SPRUCE also estimates travel impacts on parallel arterials in the freeway corridor using hour-by-hour demand distribution estimates from NCHRP Report 187 (see cols. 1, 2 and 3). Arterial capacity (col. 5) is estimated at 3,200 vehicles per hour based on total capacity in the AM heavy direction on two arterials, for a total of four lanes. Total ADT on the two arterials is estimated at 30 percent of freeway ADT, based on the ratio of arterial capacity to freeway critical density (i.e., 3,200 / 10,500).

The flow breakdown phenomenon that occurs on freeways does not occur on arterials. Flow (col. 5) remains constant as demand increases. Excess demand (col. 6) queues up at intersections (see col. 4), incurring excess intersection delays. Estimates of average speeds (col. 8) include only "normal" delay at intersections excluding excess delay to vehicles that exceed hourly capacity. Speeds are based on the hourly Volume/Capacity (V/C) ratio and are calculated using the Bureau of Public Roads (BPR) speed estimation equation (8). Vehicle delay for traffic demand up to capacity limits (col. 10) is estimated with reference to a free flow speed of 25 mph.

Delay to "excess" vehicles above capacity limits (measured in hours) is estimated as the number of vehicles above capacity that is "queued up" during that hour (col. 4) times one hour. Total vehicle delay in each hour (col. 11) combines arterial traffic flow delay for vehicles up to capacity limits and delay due to excess queued vehicles for the 10-mile corridor. To calculate average delay per vehicle during any hour, this total delay must be divided by the total number of vehicles actually getting through, i.e. hourly throughput in col. 7.

4.2 Mode Shifts with Alternatives

SPRUCE estimates mode shifts based on a pivot-point logit mode choice model. Table 3 presents model inputs and estimates of mode shifts for freeway and arterial travelers in the heaviest AM peak hour, for the typical cross-town corridor. The logit model coefficients used in the analysis were calibrated for the Washington, DC metropolitan area (9). Toll cost and in-vehicle travel time changes (see first two sections in Table 3) over the 10-mile segment for solo-driver, carpool and transit modes were determined iteratively, based on toll rate and travel delay outputs from running SPRUCE. Cost inputs are in deflated cents for the year of model calibration. It is assumed that arterial travelers would be able to avail of the same travel time and cost incentives for transit and HOV use offered to freeway travelers.

4.2.1 HOT Network Mode Choice Analysis Procedures

For the HOT network, there are two options for carpoolers other than those in a vanpool: (1) stay in the regular lanes, or (2) pay the toll, assumed to be shared by an average of 2.2 persons in the carpool. The pivot-point logit model can accept either one or the other option, but not both. Therefore, the model was run twice, once with each option. The results presented in Table 3 reflect Option 1, which produced higher carpool estimates, and therefore lower vehicle demand.

Similarly, with the HOT network, solo drivers have two options – stay in the free lanes, or use the premium priced service. Again only one option, i.e., the free option, was input into the model, due to its limitations. However, this is not a major problem. Vehicular demand for the HOT lane can be assumed to be equal to capacity, since price will balance supply and demand. Solo drivers who choose HOT lanes will face a disutility (in money cost) that is equivalent to the disutility (in travel time) faced by solo drivers in the regular lanes. Therefore, overall mode share estimates for solo drivers are unaffected.

4.2.2 FAIR Network Mode Choice Analysis Procedures

For FAIR networks, there are two options for solo-drivers. They may stay on the freeway and pay the toll; or they may take an alternative free arterial route and pay an equivalent "price" in travel time. Again, the pivot point model can accept one option, but not both. However, once again, the disutilities for both options will be equivalent, because the toll on the freeway will be adjusted so that it is equivalent to the travel time "price" on the arterial. Therefore, overall estimates of mode share for solo-drivers will not be affected.

4.2.3 Mode Choice Analysis Results

Table 3 shows that transit mode share increases for both alternatives, due to the new bus service. Carpool mode shares increase significantly for the FAIR network but not for the HOT network, because the HOT network provides *free* premium service only for vanpools and not for smaller carpools. With a FAIR network, carpool mode share on the freeway is estimated to almost double from 16 percent in the Base Case to 28.5 percent, and transit mode share is estimated to increase from 2.0 percent to 7.0 percent.

As the mode choice estimates for the arterials show, some motorists from the arterials also decide to take advantage of the new transit and carpooling opportunities, thereby *reducing* vehicle demand on the arterials, excluding any traffic diverted from the freeway, by more than 5.0 percent for the FAIR network, and by 3.0 percent with a HOT network.

4.3 Travel Delays with Alternatives

4.3.1 Analysis Procedures

Procedures used to estimate travel delays in the Base Case are applied for the alternatives. Tables 4 through 6 present results for the AM heavy traffic direction for the 10-mile typical cross-town freeway corridor.

On designated HOT lanes, a speed of 60 mph is expected. So there would be no delays on those lanes, and only regular are included in the analysis of delay in Table 4.

With FAIR networks, excess hourly demand is "tolled off" the freeway as it approaches critical density. To ensure that traffic flow does not break down, a cap of 2,000 vehicles per lane per hour is set by policy. Thus a vehicle throughput of 10,000 vehicles per hour (col. 5) and speed of 60 mph (col. 8) are maintained on all lanes, and there is no delay on the freeway mainline. A 10 percent improvement in arterial capacity (col. 5 in Table 6) results from arterial management and operations improvements (10) that are an integral part of the FAIR network strategy. As Tables 3 and 5 indicate, from 7 am to 8 am there is an almost 13 percent reduction in vehicle demand for freeway use with FAIR networks. However, of the 10,758 vehicles estimated, only 10,000 can be accommodated on the freeway, leaving a balance of 758 vehicles. The model assumes that these remaining vehicles will be solo driver vehicles induced to divert to parallel arterials by the pricing scheme.

4.3.2 Analysis Results

With a HOT network, delay on the freeway is reduced because 1,600 vehicles are guaranteed free flow at all times. Also, some vehicle demand is reduced due to shifts to transit, as shown in Table 3. As Table 4 shows, there is also a reduction in delay on arterials, because the improved transit service on the freeway attracts some travelers from the arterials to use transit, as shown in Table 3.

With a FAIR network, there is a significant vehicle demand reduction on the freeway due to shifts to transit and carpools, from 100,056 vehicles in the Base Case (see Table 1) to 93,533 vehicles with the FAIR network (see Table 5). However, 758 vehicles are diverted to arterials from the freeway, so that congestion delay increases on the arterials (see Table 6), despite the increase in capacity of the arterial network as a result of advanced arterial network management and operations.

4.4 Toll Revenues Generated

4.4.1 HOT Network Toll Rates

Table 7 presents estimates of toll revenues by hour of the day for HOT and FAIR networks respectively, for the AM heavy traffic direction for the 10-mile typical cross-town freeway. The toll rates shown in Table 7 are estimated based on toll-paying motorists' average value of time. To estimate peak period HOT lane toll rates, average freeway delay per mile per vehicle in the regular lanes in the peak period (col. 10 in Table 4) is used.

To estimate the toll rate, the delay in the regular lanes is converted to a monetary value. This is done using a value of time per vehicle hour of $15.60. This value is based on the US DOT's "high value" of local travel time savings person hour (12) in 2003 dollars, accounting for a vehicle occupancy of 1.1. The high value was chosen for HOT lanes because HOT lane motorists will have a higher value of time than the average for motorists in the regular lanes *at the time they are using the lanes*. That is why they choose to use the lanes. For comparison, Small and Yan (13) estimated the value of time for State Route 91 HOT lane motorists at $13.80 per hour in 1998 dollars.

Note that the toll rate per mile calculated for the 9 to 10 am hour appears to be high. For example, State Route 91 HOT lane toll rates are only as high as 55 cents per mile in the peak hour. The model does not account for shifts to shoulder hours as toll rates in the peak hour increase. It is likely that when these shifts occur, peak hour toll rates will drop, while toll rates in shoulder hours will increase. The toll rates estimated by the model do produce reasonable overall toll revenue estimates, as demonstrated in section 6.3.

4.4.2 FAIR Network Toll Rates

For FAIR networks, many more motorists will be tolled on the multiple lanes. Price will therefore need to be lower to ensure that there is sufficient demand to efficiently use available capacity. The "low value" of time savings estimated by US DOT (i.e., $8.30 per person hour, in 2003 dollars) was used to account for this. The value did not need to be adjusted for vehicle occupancy, since only solo drivers would pay the toll and carpools would be free.

To estimate peak period FAIR network toll rates, average freeway delay per mile per vehicle in the Base Case in the peak period (col. 10 in Table 1) is converted to a monetary value using $8.30 per hour. Freeway delay in the Base Case is used to approximate the magnitude of the time delay (above the travel time on the tolled freeway) that would be faced by a solo driver if he or she decided to use an untolled alternative to avoid paying the toll on the freeway. The approximation is based on the theory that, under equilibrium conditions in the Base Case, travel time on a feasible arterial route for a specific trip will be equal to travel time on the freeway route. Since it is possible that travel time may actually increase on alternative arterial routes with FAIR networks, this will provide a low estimate of the toll needed to equate toll price with the travel time "price" on parallel arterials, and will provide a conservative estimate of revenues.

For the FAIR network, toll rates (shown in the lower part of Table 7) are based on the average delay during the entire peak period, and applied to each hour. In reality, of course, the toll rates would be determined in real time to balance supply and demand. For example, there will be a possibility for a toll rate change every six minutes if critical density is being approached, as on the express lanes on I-15 in San Diego (14). Likewise, the toll rates could drop as often as every six minutes, if actual demand is much below critical density. Also, tolls could rise on the freeway to equate to any increase in disutility of arterial travel due to increase in arterial travel time, inducing further shifts to alternate modes until a new equilibrium is reached among modes and routes.

4.4.3 Toll Revenues

For the HOT network, toll revenues in the peak period are calculated by multiplying the toll rate by 1,600 toll-paying vehicles. As Table 7 shows, the model estimates that there is little or no delay in the regular lanes outside the peak periods, and therefore estimates zero tolls during most off-peak hours, resulting in zero revenues.

On FAIR networks, based on the mode choice model results for the peak hour shown in Table 3, a total of 8,944 freeway solo drivers choose to continue to drive solo in the peak hour. Subtracting the 758 solo drivers tolled off, a total of 8,186 drivers choose to pay the toll, or about 82 percent of the capacity flow of 10,000. Toll revenues are calculated by multiplying the toll rate by the number of toll paying solo drivers, estimated as 82 percent of vehicles using the freeway in the peak periods when tolling will be in effect (6 to 9 am and 4 to 7 pm). The "net" revenues presented in Table 7 assume that 25 percent of toll revenues will be needed to provide reimbursements or credits to low-income commuters for tolls or transit fares. These reimbursements could be inversely proportional to the income of the commuter's household, based on self-identification with verification. For example, the lowest income deciles would get a higher rate of reimbursement than mid-range income deciles.

4.5 Region Wide Impacts

Tables 1 through 7 have presented impacts for the AM heavy traffic direction for a 10-mile typical cross-town freeway. The SPRUCE model was applied to both directions of two typical orientations - radial and cross-town. Tables 8 and 9 summarize the results for the HOT and FAIR networks respectively, for both directions of typical 10-mile radial and cross-town freeway segments.

The last column of Tables 8 and 9 extrapolates estimates for the radial and cross-town segments to the full metropolitan network, based on the freeway network in Washington, DC. The freeway network in the Washington, DC metropolitan area consists of approximately 1,800 lane miles (14). It is estimated that only two-thirds of these lane miles, i.e., 1,200 lane miles suffer from the high congestion levels typified in the two 10-mile freeway segments (14, 15). Travel delays would accrue on only 1,200 congested lane miles of the network. Assuming two-thirds of the congested lane miles are radial and one-third is cross-town, 800 radial lane miles and 400 cross-town lane miles would be affected. Assuming that these existing segments are all like the typical segments evaluated above, adding a lane in each direction on these segments would increase radial lane miles to 1,000 and cross-town lane miles to 500. Thus the estimates for the 100 lane miles on the typical 10-mile radial segment (col. 3) were factored up by a factor of 10 and estimates for the cross-town segment (col. 6) were factored up by a factor of five to get total system wide impacts.

The results in Tables 8 and 9 show that vehicle demand reductions are larger for the radial orientation than for the cross-town orientation, because there are larger mode shifts to transit due to the relatively good pre-existing transit service oriented to job centers. Consequently, in radial corridors, there are larger delay reductions.

With the *HOT network*, overall delay over the network is reduced by about 50 percent relative to the Base Case. However, due to relatively low transit and HOV mode shifts with the cross-town orientation, the delay reduction for this orientation is relatively small.

The *FAIR network* reduces delay more effectively than the HOT network. About 95 percent of Base Case delay is eliminated. The FAIR network also reduces vehicular travel by a much greater extent than the HOT network, due to larger modal shifts to transit and carpools.

5.0 SOCIAL BENEFITS

5.1 Traveler Benefits

Tables 8 and 9 also summarize estimates of social benefits for the 10-mile typical freeway segments and for the whole network. Traveler benefits include benefits to commuters attracted to improved transit and carpool modes, as well as benefits to those who do not change their mode of travel and continue to drive solo, carpool or take transit as they did before. Benefits to existing transit riders will depend on the extent to which the transit agency reconfigures the existing bus routes to take advantages of free-flow travel conditions on the freeway. At this sketch planning level of analysis, it is difficult to estimate these benefits. They have therefore been ignored, providing a conservative estimate of total traveler benefits.

5.1.1 Benefits to Travelers Who Do Not Change Mode

For each alternative, the model calculates the number of vehicles used by solo drivers and existing carpoolers by subtracting from total Base Case vehicle demand the number of vehicles driven in the Base Case by new transit riders and new carpool drivers and passengers. Delay savings to solo drivers and existing carpoolers are then estimated by multiplying this number by the delay saved per vehicle, calculated from total corridor delay and vehicle demand estimates for the Base Case and alternatives (see Tables 2, 4 and 6).

Delay savings are estimated at $8.30 per person hour, the low value of time estimated by US DOT in 2003 dollars, in order to be conservative. *Fuel cost and fuel tax savings* are estimated at $3.30 and $1.20 respectively per vehicle hour of delay reduced, as follows. Fuel consumption will be reduced by 0.05 gallons per minute of delay reduced (16). Net cost of fuel (less taxes) is estimated at $1.10 per gallon. Fuel taxes are estimated at 40 cents per gallon. Fuel cost savings per vehicle hour of delay reduced is therefore estimated at $3.30, i.e., 0.05 gallons/minute X 60 minutes X $1.10; and fuel tax savings are estimated at $1.20, i.e., 0.05 gallons/minute X 60 minutes X $0.40.

Total benefits are obtained by adding delay cost savings and fuel cost savings and subtracting tolls paid, which are calculated as shown in Table 7 (see section 4.4.3). Total region wide benefits for solo drivers and previous carpoolers are estimated at about $2.5 million daily for the HOT network and about $4.7 million daily for the FAIR network, suggesting major overall cost savings for the typical trip despite the tolls paid by solo drivers amounting to $0.9 million and $1.5 million respectively.

5.1.2 Consumer Surplus Benefits for New Carpoolers and Transit Riders

Since cost per vehicle trip on the freeway will be reduced (see section 5.1.1), it is assumed that new carpoolers and transit riders are attracted to their new modes by the service improvements, and are not "forced" to take these modes because of an increase in cost for a freeway vehicle trip. Consumer surplus theory allows us to calculate the net benefits to new carpoolers and transit riders based on the change in cost per trip for carpool or transit trips.

Change in cost per trip is based on travel time cost changes. While additional reductions in cost per trip might be expected (relative to the Base Case) due to higher transit fare subsidies, convenient free park-and-ride facilities and reduced fuel consumption per carpool vehicle trip, these cost reductions are ignored in order to provide a conservative estimate of benefits. Thus, benefits are calculated as follows:

Change in cost/per trip = Delay reduced (min.) X $8.30 per hour / 60 min.
Consumer surplus = Change in cost/trip X new carpoolers & transit trips X 0.5

5.2 External Cost Savings

External costs (including air pollution, noise and crashes) are estimated at 6 cents per vehicle mile, based on the low-range nationwide estimate of these costs amounting to $153.7 billion, and nationwide vehicle miles of travel amounting to 2.7 trillion in the year 2000 (17). The low-range estimate was used to ensure conservative estimates of benefits. The reduction in VMT is estimated based on the difference in total corridor vehicle traffic volumes between the Base Case and the alternatives.

In addition to external cost reductions due to VMT reduced, air pollution costs for the remaining VMT on the freeway may be reduced, because reduced congestion delay on the freeway may reduce emissions of carbon monoxide (CO) and hydrocarbons (HC). These benefits have been ignored to ensure conservative estimates of benefits. Over the long run, employee-parking costs for employers *at the work site* will also be saved. These benefits are also ignored to ensure conservative estimates of benefits.

5.3 Total Social Benefits

Tables 8 and 9 present total social benefits for each alternative comprised of external cost savings, net traveler benefits and net toll revenues, less traveler fuel tax savings. Although tax savings are a real benefit to motorists, they are not counted as a benefit from a social perspective, because taxes are a transfer and not an actual resource cost.

5.4 Impacts on Arterial Motorists

Tables 8 and 9 present changes in person minutes of delay incurred by arterial motorists per 10-mile vehicle trip. For the HOT network, delay is either reduced or remains unchanged. For the FAIR network, morning delays average 4 to 6 person minutes per trip during the peak periods, and are as high as 14 to 17 person minutes per vehicle trip during the peak of the peak period. In reality, of course, tolls would rise on the freeway to equate to any increase in disutility on arterials due to increase in arterial travel time, inducing further shifts to alternate modes until a new equilibrium is reached among modes and routes.

However, even if congestion on arterials does increase, the impact on an individual trip will be less than indicated in Table 9. Few travelers who use arterials actually drive on them for long distances, since freeways are the first choice for such trips. Assuming that the average arterial traveler uses the arterials for a third of the entire length of the corridor, the additional delay *per vehicle trip* shown in Table 9 will be about 1.5 to 2 minutes on average, and about 5 minutes in the peak hour of the morning peak period.

5.5 Evaluation of Results

Due to its effectiveness in reducing congestion relative to the Base Case, the estimates of social benefits for HOT networks are high. Nevertheless, *for the cross-town orientation*, the HOT network segment shows *negative* traveler benefits. Tolls paid by travelers exceed their travel time and fuel cost savings benefits in aggregate. The negative benefits arise for two reasons:

1. Delay for vehicles that remain in the toll-free regular lanes in the peak period increases from 23 minutes per vehicle over the 10 mile segment in the Base Case (calculated from delay data in Table 1) to 29 minutes for the HOT network, calculated from data in Table 4. The rate of delay increases because of the reduction in total freeway capacity caused by lane separation.

2. Due to the low value of time used to estimate value of travel time savings in order to be conservative in estimating benefits, the monetary estimates of traveler and social benefits do not reflect the higher values of time of HOT lane users. The HOT network *will* provide an option for premium service that is valued very highly by those who need it when they have to be somewhere on time. Higher value trips were not differentiated in order to be consistent with US DOT guidance (12).

The HOT network alternative produces about $0.9 million per day in revenue for peak period operations. This is more than half of that generated by the FAIR network, even though revenue is generated only from a single lane in each direction, while FAIR networks generate revenue from all five lanes in each direction. This is not surprising, however, because toll rates are lower for FAIR networks, and payouts are made to low-income commuters amounting to about 25 percent of revenues. HOT lanes generate more revenue *per vehicle served*. Motorists are willing to pay higher tolls for longer periods, because congestion is high on regular lanes and may continue for longer periods than in the Base Case, because overall freeway capacity is reduced due to lane separation.

6.0 BENEFIT-COST AND FINANCIAL ANALYSIS

6.1 Estimated Costs for a Regional HOT Network

Poole and Orski (3) estimate construction costs for direct connector ramps to provide HOT lane access in Washington, DC at about $1,040 million, or an annualized cost of about $100 million assuming a seven percent discount rate and a 20-year payback period. Capital costs for toll collection with lane separation using plastic pylons are estimated at $73 million, or an annualized cost of about $7 million. Annual operating costs for the 400-lane mile network (including some existing HOV lane miles) will amount to about $40 million based on operating costs of about $100,000 per lane mile per year estimated by Wilbur Smith Associates for proposed HOT lanes on State Route 1 in Santa Cruz, CA (18). Thus, incremental annualized costs above the Base Case are estimated at $147 million.

Costs for express bus service will be identical to that for a FAIR network. These costs have been estimated at $115.5 million in a companion paper (4). Costs for park-and-ride facilities have been estimated at $46.4 million (4). However, park-and-ride facility costs will be lower for HOT networks, since carpoolers will be fewer, and HOV identification will not be needed. Since transit and carpool demand is about half of that in the FAIR network alternative, only about half the number of parking spaces will be needed. Therefore, costs are estimated to be 50 percent of that estimated for the FAIR network. Thus total costs for a typical 400-lane mile HOT network are estimated as follows:

Toll collection and connector ramps	$ 147.0 million
Express bus service	$ 115.5 million
Park-and-ride facilities	$ 23.2 million
Total system cost	$285.7 million

Since a typical 10-mile freeway segment would require 20 lane miles of HOT lanes, costs for such a segment have been estimated at one-twentieth (i.e., 20 lane miles / 400 lane miles) of that for the region wide network. Results are presented in Table 10.

6.2 Estimated Costs for a Regional FAIR Network

The companion paper (4) presents cost estimates for a FAIR network without lane additions, based on a 300-mile metropolitan freeway network such as Washington, DC. The estimates for tolling are based on 1,200 existing lane miles that suffer from congestion levels that will require tolling. Since the tolled segments assumed in this study would amount to 1,500 lane miles (including 300 lane miles added by freeway expansion), costs are estimated to be 25 percent higher than for a 1,200-lane mile tolled network. Making this adjustment for tolling costs, total estimated annualized costs to transportation agencies are estimated as follows:

Arterial network operations	$ 10.0 million
Toll/ credit operations	$ 125.0 million
Express bus service	$ 115.5 million
Park-and-ride facilities	$ 46.4 million
Total system cost	$296.9 million

Since the typical 10-mile freeway segment would involve 100 lane miles, costs for such a segment have been estimated at one-fifteenth (i.e., 100 lane miles / 1,500 lane miles for the region wide network). Results are presented in Table 10. Note that the 1,500 lane miles equate to 150 route miles on 15 segments of 10 miles each, whereas the HOT network's 400 lane miles equate to 200 route miles. The higher route mileage for the HOT network accounts for the additional route mileage needed to connect the fifteen 10-mile segments of the HOT network at congested locations considered in this study.

6.3 Economic Efficiency and Financial Feasibility

Table 10 summarizes, for each freeway orientation and for the regional network, the annualized costs, toll revenues and social benefits, assuming operation of the HOT and FAIR networks only during peak periods on weekdays. Benefits are estimated by multiplying daily benefits by 250 days per year, excluding weekends and holidays. Costs to toll-payers for purchase of transponders have been subtracted from the annualized social benefits. The comparison of system wide benefits and costs suggests that a cost-benefit ratio of 3.0 may be achieved for HOT networks, while FAIR networks may achieve a benefit-cost ratio in excess of 5.0.

For the HOT network, toll revenues have also been estimated for 24-hour operation, 365 days per year, based on the assumption that off-peak and weekend revenues will amount to 25 percent of total revenues, or 33 percent of peak period revenues. This is based on data for the SR 91 HOT lanes in Orange County, CA (3). A comparison of system wide revenues to system wide costs suggests that, for HOT networks, annual *peak period* toll revenues will be adequate to pay for annualized incremental costs above the Base Case for toll collection operations, direct connector ramps and park-and-ride facilities. Revenues may also be sufficient to fund transit service, if tolls are continued in off-peak periods. For FAIR networks, the revenues will be adequate to cover all incremental costs, including the annualized costs of toll collection, new express bus service, park-and-ride facilities, and arterial network management and operations.

Note, however, that "incremental" costs exclude costs for lane additions, because this is a cost that will also be incurred in the Base Case used for comparison. However, with a FAIR network, a surplus estimated at over $80 million per year could support an $800 million bond program to fund some of the lane additions. Costs of construction for high cost urban freeway widening projects are estimated at $8 million per lane mile (19). Assuming this cost would apply region wide, 100 new lane miles could be constructed for $800 million, or about one-third of the 300 new lane miles needed for the Base Case and the FAIR network alternative.

With 24-hour tolls throughout the week, a HOT network would produce about $20 million per year in surplus revenues. This surplus could support a $200 million bond program, which could pay for construction of 25 new lane miles, i.e., about one-sixteenth of the 400 lane miles that would be needed (including the connections between the 300 lane miles needed on congested segments).

With regard to the typical 10-mile segments, the analysis results suggest that radial orientations provide higher net social benefits and benefit-cost ratios. The difference between orientations with regard to benefit-cost ratios is more significant for the HOT network. It should be noted, however, that *the benefit-cost ratios are overstated*. This is because costs are understated, since economies of scale that apply to region wide implementation will not exist for individual segments. Also, benefits and toll revenues are overstated, because the synergistic mode choice impacts from region wide application will not exist, and bottlenecks would occur at the termini of individual segments, decreasing travel delay and fuel cost savings.

Toll revenue estimates for HOT network segments appear to be reasonable. Annual toll revenues for the radial segment amount to $7.8 per lane. For comparison, on the four radially oriented HOT lanes on State Route 91 in California, which are 10 miles in length, toll revenues generated amount to about $30 million per year, or about $7.5 million per lane.

Annual toll revenues for the cross-town oriented HOT lanes are about double those for the radial segment, or about $15.2 million per lane. For comparison, a private company is proposing to build four HOT lanes over about 10 miles on the cross-town oriented Capital Beltway in Northern Virginia, and expects to finance the estimated $600 million in construction costs from toll revenues. To do so, it would need to get about $60 million per year in toll revenues, or about $15 million per lane.

More detailed and comprehensive analysis, using more detailed travel models (8) will be needed to get better estimates of travel impacts, benefits and revenues at the region wide level. However, it should be noted that four-step models (8) available to Metropolitan Planning Organizations are generally not able to simulate the freeway breakdown phenomenon that is essential to the analysis, and they will need to be improved in order to perform this type of study.

7.0 CONCLUSIONS

The analysis performed in this paper suggests that the SPRUCE model developed for this study may be a useful tool to conduct tabletop exercises to evaluate alternative combinations of transit, HOV and road pricing strategies. The results of the analysis suggest that both HOT and FAIR networks would provide incremental social benefits exceeding greatly the incremental costs above the costs for a Base Case involving addition of free lanes. FAIR networks would be a more effective and a more cost-efficient way to address metropolitan congestion than HOT networks. A FAIR network will provide guaranteed premium service for a larger number of motorists than a HOT network would, and for a more affordable price. Equity concerns will be addressed directly through toll and transit fare reimbursements to low-income commuters, and the most advanced systems for arterial network management and operations will be put in place and maintained system wide.

A FAIR network would also generate more new revenues than a HOT network. Revenues would be adequate to pay for all incremental costs above costs for lane addition in the Base Case. A HOT network would produce revenues that would be sufficient to cover all incremental costs above the Base Case if tolls are charged during congested periods as well as off-peak.

With a FAIR network, a surplus estimated at over $80 million per year could support an $800 million bond program to fund about one-third of the 300 new lane miles of needed freeway expansion, assuming a construction cost of $8 million per lane mile. With 24-hour tolls throughout the week, a HOT network would produce about $20 million per year in surplus revenues, which could support a $200 million bond program to pay for construction of 25 new lane miles, i.e., about one-sixteenth of the 400 lane miles that would be needed.

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TABLE 1. BASE CASE FREEWAY TRAVEL DEMAND AND DELAY – CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

Freeway											10-mile segment total		
ADT	220,000												
	% ADT	Dir. Split	Hourly Vehicle Demand	Queued Vehicles from previous hour	Capacity Flow	Excess Hourly Demand	Actual Hourly Through put	Avg. Speed (mph)	Avg. Min/ Mile	Delay/ veh./ mile (min.)	Total Veh Delay (hrs.)	Avg. Veh. Occ.	Total Person Delay (hrs.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
6:00-7:00 am	5.50%	64.00%	7,744		10,500	0	7,744	60.0	1.00	0.00	0.0	1.1	0.0
7:00-8:00 am	10.00%	56.00%	12,320	0	8,250	4,070	8,250	30.0	2.00	1.00	1,375.0	1.1	1512.5
8:00-9:00 am	6.00%	54.00%	7,128	4,070	8,250	2,948	8,250	30.0	2.00	1.00	5,445.0	1.1	5989.5
9:00-10:00 am	4.50%	54.00%	5,346	2,948	10,500	0	8,294	60.0	1.00	0.00	2,948.0	1.5	4422.0
10:00-11:00am	4.00%	52.00%	4,576	0	10,500	0	4,576	60.0	1.00	0.00	0.0	1.5	0.0
11:00-12:00pm	4.00%	50.00%	4,400	0	10,500	0	4,400	60.0	1.00	0.00	0.0	1.5	0.0
12:00-1:00 pm	4.00%	50.00%	4,400	0	10,500	0	4,400	60.0	1.00	0.00	0.0	1.5	0.0
1:00-2:00pm	4.00%	50.00%	4,400	0	10,500	0	4,400	60.0	1.00	0.00	0.0	1.5	0.0
2:00-3:00pm	4.50%	54.00%	5,346	0	10,500	0	5,346	60.0	1.00	0.00	0.0	1.5	0.0
3:00-4:00 pm	7.50%	50.00%	8,250	0	10,500	0	8,250	60.0	1.00	0.00	0.0	1.5	0.0
4:00-5:00 pm	10.00%	46.00%	10,120	0	10,500	0	10,120	60.0	1.00	0.00	0.0	1.1	0.0
5:00-6:00 pm	9.00%	42.00%	8,316	0	10,500	0	8,316	60.0	1.00	0.00	0.0	1.1	0.0
6:00-7:00 pm	5.50%	48.00%	5,808	0	10,500	0	5,808	60.0	1.00	0.00	0.0	1.1	0.0
7:00-8:00 pm	4.50%	48.00%	4,752	0	10,500	0	4,752	60.0	1.00	0.00	0.0	1.5	0.0
8:00-9:00 pm	3.50%	50.00%	3,850	0	10,500	0	3,850	60.0	1.00	0.00	0.0	1.5	0.0
9:00-10:00 pm	3.00%	50.00%	3,300	0	10,500	0	3,300	60.0	1.00	0.00	0.0	1.5	0.0
Total			**100,056**				**100,056**				**9,768**		**11,924**

TABLE 2. BASE CASE ARTERIAL TRAVEL DEMAND AND DELAY- CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

Arterials											10-mile segment total		
ADT	66,000												
	% ADT	Dir. Split	Hourly Vehicle Demand	Queued Vehicles from previous hour	Capacity Flow	Excess Hourly Demand	Actual Hourly Through put	Avg. Speed (mph)	Avg. Min/ Mile	Delay/ veh./ mile (min.)	Total Veh Delay (hrs.)	Avg. Auto Occ.	Total Person Delay (hrs.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
6:00-7:00 am	5.50%	64.00%	2,323	0	3,200	0	2,323	24.00	2.50	0.10	38.7	1.1	42.6
7:00-8:00 am	10.00%	56.00%	3,696	0	3,200	496	3,200	21.74	2.76	0.36	192.0	1.1	211.2
8:00-9:00 am	6.00%	54.00%	2,138	496	3,200	0	2,634	23.39	2.57	0.17	568.6	1.1	625.5
9:00-10:00 am	4.50%	54.00%	1,604	0	3,200	0	1,604	24.77	2.42	0.02	6.1	1.5	9.1
10:00-11:00am	4.00%	52.00%	1,373	0	3,200	0	1,373	24.87	2.41	0.01	2.8	1.5	4.2
11:00-12:00pm	4.00%	50.00%	1,320	0	3,200	0	1,320	24.89	2.41	0.01	2.3	1.5	3.4
12:00-1:00 pm	4.00%	50.00%	1,320	0	3,200	0	1,320	24.89	2.41	0.01	2.3	1.5	3.4
1:00-2:00pm	4.00%	50.00%	1,320	0	3,200	0	1,320	24.89	2.41	0.01	2.3	1.5	3.4
2:00-3:00pm	4.50%	54.00%	1,604	0	3,200	0	1,604	24.77	2.42	0.02	6.1	1.5	9.1
3:00-4:00 pm	7.50%	50.00%	2,475	0	3,200	0	2,475	23.73	2.53	0.13	53.1	1.5	79.7
4:00-5:00 pm	10.00%	46.00%	3,036	0	3,200	0	3,036	22.29	2.69	0.29	147.6	1.1	162.4
5:00-6:00 pm	9.00%	42.00%	2,495	0	3,200	0	2,495	23.69	2.53	0.13	55.3	1.1	60.8
6:00-7:00 pm	5.50%	48.00%	1,742	0	3,200	0	1,742	24.67	2.43	0.03	9.2	1.1	10.1
7:00-8:00 pm	4.50%	48.00%	1,426	0	3,200	0	1,426	24.85	2.41	0.01	3.4	1.5	5.1
8:00-9:00 pm	3.50%	50.00%	1,155	0	3,200	0	1,155	24.94	2.41	0.01	1.2	1.5	1.8
9:00-10:00 pm	3.00%	50.00%	990	0	3,200	0	990	24.97	2.40	0.00	0.5	1.5	0.8
Total			**27,872**				**27,872**				**1,089.7**		**1,230.0**
CORRIDOR TOTAL			**127,928**						**Tot. delay**		**10,857.7**		**13,154.0**

TABLE 3. MODE SHIFTS 7 AM TO 8 AM - CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

	Base Case		**HOT Network**		**FAIR Network**	
	Freeway	**Arterial**	**Freeway**	**Arterial**	**Freeway**	**Arterial**
Change in in-vehicle times (min)						
Solo driver			0	0	-16	0
Carpool			0	0	-16	-16
Transit			-18	-18	-16	-16
Change in costs (cents)						
Solo driver			0	0	180	0
Carpool			0	0	0	0
Transit			-150	-150	-150	-150
Final (normalized) calculations of shares:						
Solo driver	81.67%	81.67%	79.09%	79.09%	64.68%	75.49%
Carpool	16.33%	16.33%	15.82%	15.82%	28.56%	19.82%
Transit	2.00%	2.00%	5.09%	5.09%	6.77%	4.69%
			100.00%	100.00%	100.00%	100.00%
Person trips:						
Solo driver	11,293	3,388	10,937	3,281	8,944	3,132
Carpool	2,259	678	2,187	656	3,949	822
Transit	277	83	704	211	936	195
Total	13,829	4,149	13,829	4,149	13,829	4,149
Vehicle trips:						
Solo driver	11,293	3,388	10,937	3,281	8,944	3,132
Carpool	1,027	308	994	298	1,795	374
Transit	6	2	14	4	19	4
Total	**12,326**	**3,698**	**11,946**	**3,584**	**10,758**	**3,509**
Percent change			**3.04%**	**3.04%**	**12.68%**	**5.05%**

TABLE 4. IMPACTS OF HOT NETWORK - CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

Regular lanes

Freeway

	% ADT	Dir. Split	Hourly Vehicle Demand	Queued Vehicles from previous hour	Capacity Flow	Excess Hourly Demand	Actual Hourly Through put	Avg. Speed (mph)	Avg. Min/ Mile	Delay/ veh./ mile (min.)	10-mile segment Total Veh Delay (hrs.)	Avg. Auto Occ.	Total Person Delay (hrs.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
6:00-7:00 am	5.50%	64.00%	5,909	0	8,400	0	5,909	60.0	1.00	0.00	0.0	1.1	0.0
7:00-8:00 am	10.00%	56.00%	10,346	0	6,600	3,746	6,600	30.0	2.00	1.00	1,100.0	1.1	1210.0
8:00-9:00 am	6.00%	54.00%	5,311	3,746	6,600	2,457	6,600	30.0	2.00	1.00	4,845.7	1.1	5330.3
9:00-10:00 am	4.50%	54.00%	3,746	2,457	8,400	0	6,203	60.0	1.00	0.00	2,457.2	1.5	3685.8
10:00-11:00am	4.00%	52.00%	2,976	0	8,400	0	2,976	60.0	1.00	0.00	0.0	1.5	0.0
11:00-12:00pm	4.00%	50.00%	2,800	0	8,400	0	2,800	60.0	1.00	0.00	0.0	1.5	0.0
12:00-1:00 pm	4.00%	50.00%	2,800	0	8,400	0	2,800	60.0	1.00	0.00	0.0	1.5	0.0
1:00-2:00pm	4.00%	50.00%	2,800	0	8,400	0	2,800	60.0	1.00	0.00	0.0	1.5	0.0
2:00-3:00pm	4.50%	54.00%	3,746	0	8,400	0	3,746	60.0	1.00	0.00	0.0	1.5	0.0
3:00-4:00 pm	7.50%	50.00%	6,650	0	8,400	0	6,650	60.0	1.00	0.00	0.0	1.5	0.0
4:00-5:00 pm	10.00%	46.00%	8,213	0	8,400	0	8,213	60.0	1.00	0.00	0.0	1.1	0.0
5:00-6:00 pm	9.00%	42.00%	6,463	0	8,400	0	6,463	60.0	1.00	0.00	0.0	1.1	0.0
6:00-7:00 pm	5.50%	48.00%	4,032	0	8,400	0	4,032	60.0	1.00	0.00	0.0	1.1	0.0
7:00-8:00 pm	4.50%	48.00%	3,152	0	8,400	0	3,152	60.0	1.00	0.00	0.0	1.5	0.0
8:00-9:00 pm	3.50%	50.00%	2,250	0	8,400	0	2,250	60.0	1.00	0.00	0.0	1.5	0.0
9:00-10:00 pm	3.00%	50.00%	1,700	0	8,400	0	1,700	60.0	1.00	0.00	0.0	1.5	0.0
Total			**72,893**				**72,893**				**8,403**		**10,226**
Arterial													
Total			**27,403**				**27,403**				**920.2**		**1,043.6**
CORRIDOR TOTAL			**125,896**						**Tot. delay**		**9,323.1**		**11,269.7**

TABLE 5. FREEWAY IMPACTS OF FAIR NETWORK - CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

Freeway											**10-mile segment total**		
	% ADT	**Dir. Split**	**Hourly Vehicle Demand**	**Queued Vehicles from previous hour**	**Capacity Flow**	**Excess Hourly Demand**	**Actual Hourly Through put**	**Avg. Speed (mph)**	**Avg. Min/ Mile**	**Delay/ veh./ mile (min.)**	**Total Veh Delay (hrs.)**	**Occ.**	**Demand Diverted (hrs.)**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**
6:00-7:00 am	5.50%	64.00%	6,508	0	10,000	0	6,508	60.0	1.00	0.00	0.0		0
6:00-7:00 am	5.50%	64.00%	6,762	0	10,000	0	6,762	60.0	1.00	0.00	0.0		0
7:00-8:00 am	10.00%	56.00%	10,758	0	10,000	758	10,000	60.0	1.00	0.00	0.0		758
8:00-9:00 am	6.00%	54.00%	6,224	0	10,000	0	6,224	60.0	1.00	0.00	0.0		0
9:00-10:00 am	4.50%	54.00%	5,346	0	10,500	0	5,346	60.0	1.00	0.00	0.0		0
10:00-11:00am	4.00%	52.00%	4,576	0	10,500	0	4,576	60.0	1.00	0.00	0.0		0
11:00-12:00pm	4.00%	50.00%	4,400	0	10,500	0	4,400	60.0	1.00	0.00	0.0		0
12:00-1:00 pm	4.00%	50.00%	4,400	0	10,500	0	4,400	60.0	1.00	0.00	0.0		0
1:00-2:00pm	4.00%	50.00%	4,400	0	10,500	0	4,400	60.0	1.00	0.00	0.0		0
2:00-3:00pm	4.50%	54.00%	5,346	0	10,500	0	5,346	60.0	1.00	0.00	0.0		0
3:00-4:00 pm	7.50%	50.00%	8,250	0	10,500	0	8,250	60.0	1.00	0.00	0.0		0
4:00-5:00 pm	10.00%	46.00%	8,837	0	10,000	0	8,837	60.0	1.00	0.00	0.0		0
5:00-6:00 pm	9.00%	42.00%	7,261	0	10,000	0	7,261	60.0	1.00	0.00	0.0		0
6:00-7:00 pm	5.50%	48.00%	5,071	0	10,000	0	5,071	60.0	1.00	0.00	0.0		0
7:00-8:00 pm	4.50%	48.00%	4,752	0	10,500	0	4,752	60.0	1.00	0.00	0.0		0
8:00-9:00 pm	3.50%	50.00%	3,850	0	10,500	0	3,850	60.0	1.00	0.00	0.0		0
9:00-10:00 pm	3.00%	50.00%	3,300	0	10,500	0	3,300	60.0	1.00	0.00	0.0		0
Total			**93,533**				**92,775**				**0**		**758**

TABLE 6. ARTERIAL IMPACTS OF FAIR NETWORK - CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

Arterials											**10-mile segment total**		
ADT	**66,000**												
	% ADT	**Dir. Split**	**Hourly Vehicle Demand**	**Queued Vehicles from previous hour**	**Capacity Flow**	**Excess Hourly Demand**	**Actual Hourly Through put**	**Avg. Speed (mph)**	**Avg. Min/ Mile**	**Delay/ veh./ mile (min.)**	**Total Veh Delay (hrs.)**	**Avg. Auto Occ.**	**Total Person Delay (hrs.)**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	(7)	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**
6:00-7:00 am	5.50%	64.00%	2,206	0	3,520	0	2,206	24.43	2.46	0.06	20.4	1.1	22.5
7:00-8:00 am	10.00%	56.00%	3,509	758	3,520	747	3,520	21.74	2.76	0.36	968.7	1.1	1065.6
8:00-9:00 am	6.00%	54.00%	2,030	747	3,520	0	2,777	23.63	2.54	0.14	811.4	1.1	892.5
9:00-10:00 am	4.50%	54.00%	1,604	0	3,520	0	1,604	24.84	2.42	0.02	4.1	1.5	6.2
10:00-11:00am	4.00%	52.00%	1,373	0	3,520	0	1,373	24.91	2.41	0.01	1.9	1.5	2.9
11:00-12:00pm	4.00%	50.00%	1,320	0	3,520	0	1,320	24.93	2.41	0.01	1.6	1.5	2.3
12:00-1:00 pm	4.00%	50.00%	1,320	0	3,520	0	1,320	24.93	2.41	0.01	1.6	1.5	2.3
1:00-2:00pm	4.00%	50.00%	1,320	0	3,520	0	1,320	24.93	2.41	0.01	1.6	1.5	2.3
2:00-3:00pm	4.50%	54.00%	1,604	0	3,520	0	1,604	24.84	2.42	0.02	4.1	1.5	6.2
3:00-4:00 pm	7.50%	50.00%	2,475	0	3,520	0	2,475	24.12	2.49	0.09	36.3	1.5	54.4
4:00-5:00 pm	10.00%	46.00%	2,883	0	3,520	0	2,883	23.42	2.56	0.16	77.8	1.1	85.6
5:00-6:00 pm	9.00%	42.00%	2,369	0	3,520	0	2,369	24.25	2.47	0.07	29.1	1.1	32.1
6:00-7:00 pm	5.50%	48.00%	1,654	0	3,520	0	1,654	24.82	2.42	0.02	4.8	1.1	5.3
7:00-8:00 pm	4.50%	48.00%	1,426	0	3,520	0	1,426	24.90	2.41	0.01	2.3	1.5	3.5
8:00-9:00 pm	3.50%	50.00%	1,155	0	3,520	0	1,155	24.96	2.40	0.00	0.8	1.5	1.2
9:00-10:00 pm	3.00%	50.00%	990	0	3,520	0	990	24.98	2.40	0.00	0.4	1.5	0.6
Total			**27,092**				**27,850**				**1,965.8**		**2,183.8**
CORRIDOR TOTAL			**120,625**						**Tot. delay**		**1,965.8**		**2,183.8**

TABLE 7. TOLL REVENUES FOR HOT AND FAIR NETWORKS - CROSS-TOWN CORRIDOR, AM HEAVY TRAFFIC DIRECTION

HOT Network	**Cost of Delay per mile ($)**	**Toll per mile ($)**	**1,600 Vehicles Subject to Toll**	**Tolls Collected per mi. ($)**	**Net Revenue 10 mi.**
6:00-7:00 am	0.00	0.47	1,600	$0	$0
7:00-8:00 am	0.26	0.47	1,600	$416	$4,160
8:00-9:00 am	1.15	0.47	1,600	$1,833	$18,326
9:00-10:00 am	0.62	0.62	1,600	$989	$9,887
10:00-11:00am	0.00	0.00	1,600	$0	$0
11:00-12:00pm	0.00	0.00	1,600	$0	$0
12:00-1:00 pm	0.00	0.00	1,600	$0	$0
1:00-2:00pm	0.00	0.00	1,600	$0	$0
2:00-3:00pm	0.00	0.00	1,600	$0	$0
3:00-4:00 pm	0.00	0.00	1,600	$0	$0
4:00-5:00 pm	0.00	0.00	1,600	$0	$0
5:00-6:00 pm	0.00	0.00	1,600	$0	$0
6:00-7:00 pm	0.00	0.00	1,600	$0	$0
7:00-8:00 pm	0.00	0.00	1,600	$0	$0
8:00-9:00 pm	0.00	0.00	1,600	$0	$0
9:00-10:00 pm	0.00	0.00	1,600	$0	$0
Total				**$3,237**	**$32,373**

FAIR Network	**Cost of Delay per mile ($)**	**Toll per mile ($)**	**82% Pk. Veh. Subject to Toll**	**Tolls Collected per mi. ($)**	**Credits Disbursed Per mi. ($)**	**Net Revenue 10 mi. ($)**
6:00-7:00 am	0.23	0.23	5,535	$1,266	$317	$9,495
7:00-8:00 am	0.23	0.23	8,186	$1,872	$468	$14,042
8:00-9:00 am	0.23	0.23	5,095	$1,165	$291	$8,740
Total				**$4,304**	**$1,076**	**$32,277**

TABLE 8. SUMMARY OF DAILY BENEFITS FOR HOT NETWORK– TYPICAL CORRIDORS AND FULL NETWORK

	Radial Segment - 10 miles			Cross-town segment - 10 miles			Full
	AM Peak	**PM Peak**	**Both**	**AM Peak**	**PM Peak**	**Both**	**Network**
Daily Person Hours of Delay							
Base case	28,616	21,083	49,699	13,154	25,247	38,401	688,993
HOT network	13,341	3,689	17,031	11,270	20,274	31,543	328,025
Change	15,275	17,393	32,668	1,884	4,974	6,858	360,967
Percent change	**53.4%**	**82.5%**	**65.7%**	**14.3%**	**19.7%**	**17.9%**	**52.4%**
VMT							
Base case	1,305,920	1,167,980	2,473,900	1,279,278	1,237,522	2,516,800	37,323,000
HOT network	1,219,416	1,105,521	2,324,937	1,258,964	1,207,594	2,466,558	35,582,162
Change	86,504	62,459	148,963	20,314	29,928	50,242	1,740,838
Percent change	**6.6%**	**5.3%**	**6.0%**	**1.6%**	**2.4%**	**2.0%**	**4.7%**
Benefits:							
Daily Net Toll Revenue	$35,880	$10,902	$46,782	$32,373	$59,282	$91,655	$926,100
Benefits to SOV and previous carpool trips	$93,771	$169,365	$263,136	-$13,780	-$10,575	-$24,355	$2,509,585
Consumer surplus for new carpool & transit	$11,867	$3,026	$14,893	$2,449	$6,981	$9,431	$196,087
Total traveler benefits	$105,638	$172,392	$278,029	-$11,331	-$3,593	-$14,924	$2,705,672
Fuel taxes reduced	$11,415	$15,871	$27,286	$1,637	$4,288	$5,925	$302,481
Change in external costs	$5,190	$3,748	$8,938	$1,219	$1,796	$3,015	$104,450
Total social benefits	**$135,293**	**$171,171**	**$306,464**	**$20,624**	**$53,197**	**$73,820**	**$3,433,741**
Arterial Impacts							
Change in delay average (person min/veh)	-0.52	-2.69		-0.90	-3.75		
Change in delay 7-8am (person min/veh)	0.00	-0.42		0.00	-0.46		
Change in delay 5-6pm (person min/veh)	-0.22	-0.94		-0.17	-3.40		

TABLE 9. SUMMARY OF BENEFITS AND COSTS FOR FAIR NETWORK– TYPICAL CORRIDORS AND FULL NETWORK

	Radial Segment - 10 miles			Cross-town segment - 10 miles			Full
	AM Peak	**PM Peak**	**Both**	**AM Peak**	**PM Peak**	**Both**	**Network**
Daily Person Hours of Delay							
Base case	28,616	21,083	49,699	13,154	25,247	38,401	688,993
FAIR network	1,832	187	2,019	2,184	1,044	3,228	36,329
Change	26,784	20,896	47,680	10,970	24,203	35,174	652,664
Percent change	**93.6%**	**99.1%**	**95.9%**	**83.4%**	**95.9%**	**91.6%**	**94.7%**
VMT							
Base case	1,305,920	1,167,980	2,473,900	1,279,278	1,237,522	2,516,800	37,323,000
FAIR network	1,156,293	1,046,629	2,202,921	1,206,249	1,160,070	2,366,320	33,860,813
Change	149,627	121,351	270,979	73,029	77,452	150,480	3,462,187
Percent change	11.5%	10.4%	11.0%	5.7%	6.3%	6.0%	9.3%
Benefits:							
Daily Net Toll Revenue	$42,847	$54,794	$97,641	$32,277	$80,844	$113,120	$1,542,015
Benefits to SOV and previous carpool trips	$192,334	$152,888	$345,222	$77,217	$168,235	$245,452	$4,679,478
Consumer surplus for new carpool & transit	$23,493	$27,575	$51,067	$11,269	$26,275	$37,545	$698,399
Total traveler benefits	$215,827	$180,462	$396,289	$88,486	$194,510	$282,997	$5,377,877
Fuel taxes reduced	$20,706	$18,285	$38,990	$9,640	$21,929	$31,569	$547,747
Change in external costs	$8,978	$7,281	$16,259	$4,382	$4,647	$9,029	$207,731
Total social benefits	**$246,946**	**$224,253**	**$471,199**	**$115,505**	**$258,072**	**$373,577**	**$6,579,876**
Arterial Impacts							
Peak change in delay avg (person min/veh)	4.30	-3.86		6.25	-5.65		
Change in delay 7-8am (person min/veh)	17.28	-0.35		14.20	-1.46		
Change in delay 5-6pm (person min/veh)	-0.35	-2.68		-0.65	-6.60		

TABLE 10. ANNUALIZED COSTS AND BENEFITS

	Radial Segment	Cross-town Segment	Full Network
HOT NETWORK			
Annualized Costs for HOT Network			
Toll collection and connector ramps	$7.4	$7.4	$147.0
New transit service	$5.8	$5.8	$115.5
Arterial network	$0.0	$0.0	$0.0
Parking facility costs	$1.2	$1.2	$23.2
Total cost	**$14.3**	**$14.3**	**$285.7**
Transponder costs	$0.5	$0.5	$7.0
Annualized Benefits of HOT Network	$76.6	$18.5	$858.4
B/C Ratio	**5.4**	**1.3**	**3.0**
Net annual benefit	$62.3	$4.2	$572.7
Present value of net benefits	$660.3	$44.2	$6,067.6
Annual toll revenues (peak periods)	**$11.7**	**$22.9**	**$231.5**
Annual toll revenues (peak and off-peak)	**$15.6**	**$30.5**	**$307.9**
FAIR NETWORK			
Annualized Costs for FAIR Network			
Toll collection cost	$8.3	$8.3	$125.0
New transit service	$7.7	$7.7	$115.5
Arterial network	$0.7	$0.7	$10.0
Parking facility costs	$3.1	$3.1	$46.4
Total cost	**$19.8**	**$19.8**	**$296.9**
Transponder costs	$0.5	$0.5	$7.0
Annualized Benefits of FAIR Network	$117.3	$92.9	$1,638.0
B/C Ratio	**5.9**	**4.7**	**5.5**
Net annual benefit	$97.5	$73.1	$1,341.1
Present value of net benefits	$1,033.3	$774.8	$14,207.3
Annual toll revenues	**$24.4**	**$28.3**	**$385.5**

FIGURE 1. STRUCTURE OF SPRUCE MODEL