

HOT Highways: Costs, Benefits and Revenues

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Abstract: *This paper discusses a broad congestion pricing approach that could potentially be implemented in the near-term. The approach involves converting existing freeways (all lanes) into premium-service free-flowing highways that provide fast, frequent and inexpensive express bus service, while charging all private vehicles a variable toll -- except for authorized buses and certified ridesharing vehicles. The toll would vary by level of demand and would be set high enough to guarantee that excessive demand will not cause a breakdown of traffic flow. The paper estimates that implementing the concept in the Los Angeles metropolitan area could reduce peak period congestion delay by an average of 27 hours per traveler annually, and save each traveler an average of 67 gallons of fuel. New toll revenues would be more than adequate to pay for all highway, transit and park-and-ride costs, and would generate significant surpluses that could provide as much as \$120 in tax refunds annually to each driver.*

1.0 INTRODUCTION

When traffic flow collapses under high traffic densities, highway capacity is lost. If only a fraction (even as small as 5-10%) of vehicles are removed from a congested highway at critical times during the rush hours, traffic would flow much more efficiently², allowing many more cars to move through the same physical space than would be possible under congested flow. By preventing congestion from taking hold, congestion pricing can recover this daily waste of public investment that occurs on congested highways when traffic flow breaks down. Most economists agree that congestion pricing represents the single most viable and sustainable approach to reducing traffic congestion.

This paper introduces a congestion pricing concept termed “Super HOT highways.” The concept is one (but not the only) approach that may be used to deal with multiple economic, social, technological, administrative and political considerations on a comprehensive basis. The approach illustrates ways to achieve high levels of transportation system performance and economic efficiency within a broad framework of public acceptance and political reality.

2.0 THE SUPER HOT TRANSPORTATION CONCEPT

Once freeway traffic exceeds a certain threshold level (measured in terms of flow of vehicles per lane per hour, or in terms of density of vehicles per mile), both vehicle speed and vehicle throughput drop precipitously. Data show that maximum vehicle throughput occurs at speeds of

¹ Disclaimer: The views expressed are those of the author and not necessarily those of the U.S. Department of Transportation or the Federal Highway Administration. This paper was prepared for presentation at the Transportation Research Board’s Freeway and Tolling Operations Conference in May 2007 in Houston, TX.

² For example, traffic flows freely in Washington DC in August, when total peak period traffic is reduced by less than 10%.

about 45 mph to 55 mph (Chen and Varaiya 2002). When severe congestion sets in, the number of vehicles that get through per hour can drop by as much as 50%, while speeds drop to “crawl” speeds of 15 to 20 mph (Chen and Varaiya 2002). At high vehicle densities, traffic bogs down due to traffic demand exceeding supply of road space. Traffic flow is kept in this condition of “collapse” for several hours after the rush of commuters has stopped. This causes further delay for motorists who arrive later in the day.

With peak-period highway pricing, a variable toll dissuades some motorists from using limited access highways (generally freeways) at critical locations where traffic demand is high, and where surges in demand may push the highway over the threshold at which traffic flow collapses. Pricing prevents a breakdown of traffic flow in the first instance, and thus maintains a high level of vehicle speed and throughput throughout the rush hours. Collapse of traffic flow from overcrowding is avoided. Not only are *more* motorists able to get to their destinations during each hour -- they also get there *faster*. Each priced lane in the median of State Route 91 in Orange County, California (on which traffic flow is managed using variable tolls) carries twice as many vehicles per lane as the adjacent toll-free lanes during the hour with heaviest traffic (US Department of Transportation 2005). Management of traffic flow through pricing has allowed twice as many vehicles to be served per lane at three to four times the speed on the free lanes.

Currently, our freeway systems use congestion delay as a way to ration scarce road space during rush hours. Delay imposes huge social costs on the traveling public and on the economy, and is an extremely wasteful way to allocate scarce road space. If freeway road space were instead rationed using variable tolls, the revenue generated would simply be a transfer of resources from motorists to the highway operator, and would not be a waste. The revenue could be used to generate further benefits for commuters, or to reduce taxes. Unlike taxes, the toll revenue would be obtained from travelers willing to pay in order to get a direct benefit in return -- the reduced waste of their time. By reliably preventing traffic flow breakdown and thereby ensuring a predictable trip travel time, freeway pricing would also reduce the “buffer” time that commuters must otherwise plan into their schedules. It would reduce fuel consumption and emissions, and reduce diversion of traffic to alternate routes where they may cause further congestion.

It might appear counter-intuitive that imposing a new toll on a currently free road can actually reduce traffic on parallel facilities. Figure 1 and Table 1 attempt to demonstrate how this may happen. Figure 1 shows the magnitude of the waste of time and vehicle capacity that occurs when traffic flow breaks down on the four eastbound lanes of I-66 outside the Capital Beltway in Northern Virginia, inbound towards Washington DC. Traffic flows freely up to 7 am. In the one hour period between 6 and 7 am, 8,000 vehicles are carried at an average speed of 55 mph. Traffic flow breaks down between 7 and 8 am, with speeds dropping to 30 mph and vehicle throughput dropping to 7,000 vehicles. From 8 to 9 am, throughput drops further to 6,000 vehicles, and average speed drops further to 25 mph. The reduced flow of 6,000 vehicles per hour continues between 9 am and 10 am, with speed increasing slightly to 30 mph.

FIGURE 1. TRAFFIC VOLUMES AND SPEEDS ON I-66 EASTBOUND IN NORTHERN VIRGINIA (FOUR LANES, MORNING PEAK PERIOD)

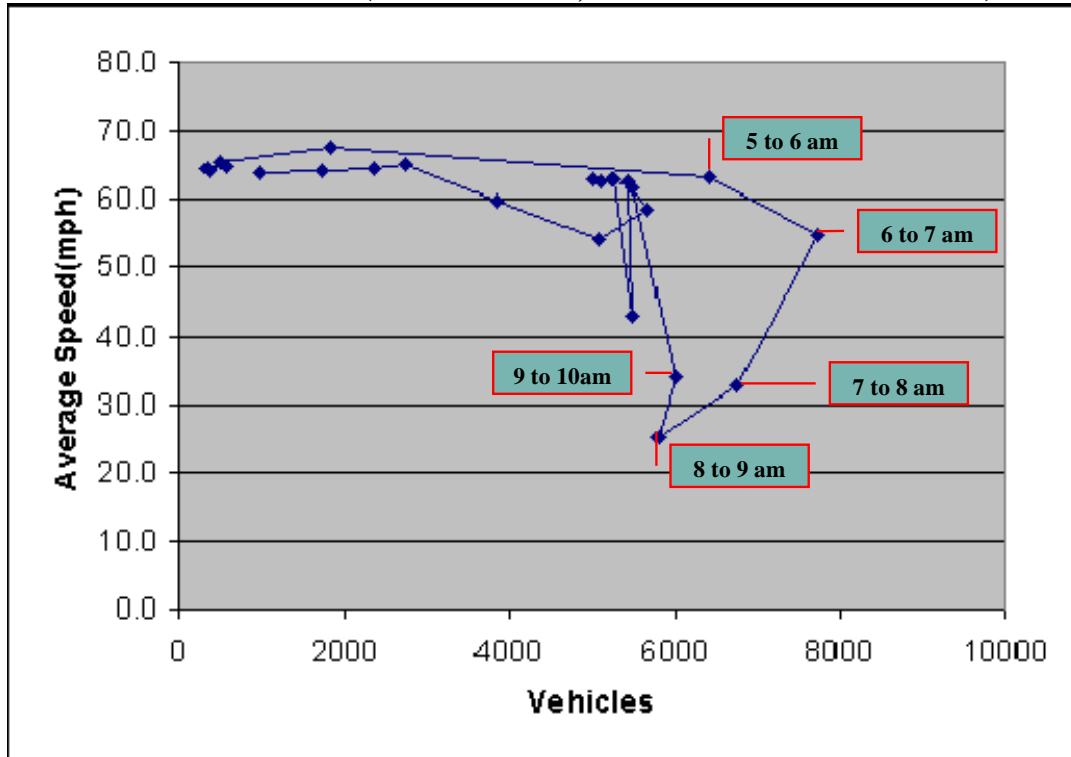


Table 1. Potential Impacts of Congestion Pricing on I-66 Eastbound

	7-8am	8-9am	9-10am	Total
<i>7-10am (no pricing)</i>				
Traffic volume	7,000	6,000	6,000	19,000
Average speed (mph)	30	25	30	
Travel time per mile (min.)	14,000	14,400	12,000	
Travel time for 10-mile trips (min.)	140,000	144,000	120,000	404,000
<i>7-10am (with pricing)</i>				
Traffic volume	8,000	8,000	3,000	19,000
Average speed (mph)	55	55	55	
Travel time per mile (min.)	8,727	8,727	3,273	
Travel time for 10-mile trips (min.)	87,273	87,273	32,727	207,273
<i>Benefits 7-10am (with pricing)</i>				
Daily travel time savings (min.)				196,727
Annual travel time savings for 10-mile trips (hours)				819,697
Value of annual time savings (at \$12 per hr.)				\$9,836,364

Table 1 provides estimates of time wasted, and the potential value of time savings on the freeway if free flow of traffic could be maintained. As much as \$10 million annually could be saved on the 10-mile eastbound freeway segment with good traffic flow management in the morning peak period. What Table 1 also shows is that, after accommodating the 19,000 existing users of the eastbound freeway who travel during the 7 am to 10 am period, there will be spare capacity of up to 5,000 vehicles available for use from 9 am to 10 am. This available capacity will draw drivers from alternative routes and from other times of the day, i.e., those who currently try to avoid congestion on the freeway. Thus, pricing the freeway to maximize throughput will reduce traffic levels on alternative routes and at other times of the day.

It takes only a small reduction in traffic demand at critical times during the peak period to restore free flow. Motorists in Washington DC experience free flowing traffic during rush hours in August, with only a small fraction of workers away on vacation and less than a 10% drop in peak period traffic volumes. Similar experiences are reported in metropolitan areas in California on State holidays, when only State employees are off work. So the key is to shift a few rush hour travelers to other modes or to other times of travel. Estimates of transit price cross-elasticity with respect to driving demand range from 0.025 to 0.056 (Glaister and Lewis 1978). Long-term elasticities tend to be much higher (Lee 2000), due to the ability of travelers to respond through changes in job or residential location in the longer-term. This suggests that a 5% reduction in driving could be achieved by a combination of reductions in transit fares and transit travel time. With free-flowing freeways, the entire freeway network could serve as a transit “fixed guideway” providing travel time advantages for express bus services.

Additional reductions could be achieved through an increase in carpooling, vanpooling, flextime and telecommuting. If freeways were free-flowing, the entire freeway network could serve as a virtual network of HOV lanes that provides toll-free service to vanpools and carpools certified by employers or the metropolitan ridesharing agency. (Certification of ridesharing vehicles avoids the need for on-highway enforcement of occupancy requirements, which can be difficult to accomplish and may disrupt the flow of traffic). HOVs would have a time advantage, providing an inducement for mode shifts to HOVs. Based on before and after data from 10 HOV lane projects implemented in the U.S., Richard H. Pratt, Consultant, Inc. et al (2000) estimate that HOV lanes result in an increase of 14% in average vehicle occupancy for autos, carpools and vanpools over *all* lanes of the freeway. This is equivalent to a 12.3% reduction in driving. Thus, a combination of travel time advantages and pricing inducements for transit and HOVs could potentially lead to a reduction in solo driving of up to 19%, i.e., 14% plus 5% due to shifts to transit.

It will also be important that area employees have flexibility to travel at less busy times, or to telecommute. Employers could be encouraged to provide such flexibility for their employees, perhaps by setting target levels for the share of flextime and telecommuting employees in order for employer-certified carpools to get toll exemptions. Other forms of incentives, such as tax incentives, may also be used.

Addressing Key Issues

A pricing strategy would need to address three key issues:

Induced Travel: The toll price will need to be high enough that the total user-borne cost to drive on a priced highway (i.e., time cost plus money cost) will not be lower than the user-borne cost to drive prior to pricing (i.e., time cost only). If the perceived user-borne cost were lower after implementing pricing, the inducement to drive could increase, endangering the free flow of traffic. To counter this effect, increased inducements would then need to be provided for other modes to compete effectively with driving (e.g., transit fare reductions).

Equity: There is a strong concern among policy-makers about the ability of low-income individuals to pay for a service that they have been getting for free. This equity concern with regard to low-income individuals may be addressed by providing toll discounts or even free service for means-tested low-income individuals who must make non-discretionary trips during rush hours.

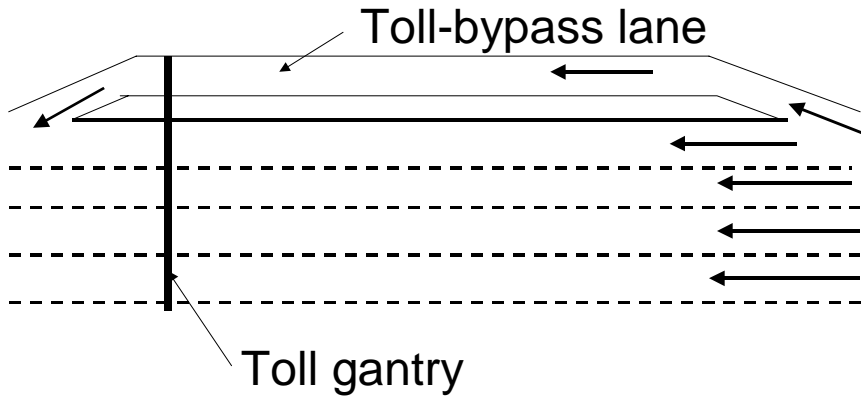
Motorist Choice: A pricing scheme may need to preserve the motorist's choice not to pay, in order to be publicly acceptable. A toll-free choice, with the same amount of motorist delays as before (or less), will be desirable, similar to the free lanes adjacent to HOT lanes. This issue of creating a toll-free choice for other motorists will be more difficult to address.

Economics Nobel Prize winner William Vickrey suggested a way to preserve the motorist's choice *not* to pay on a priced highway by creating a toll-free bypass around toll gantries placed across all existing lanes of the roadway. Motorists who choose to do so would wait in a queue in the toll-bypass lane and pay a "time" price equivalent to their previous congestion delay time (see Figure 2). This solution by itself will not work, because releasing queued vehicles after they have waited in line for the required time period would cause traffic flow to break down. It would simply delay the onset of congestion by a few minutes. But if the required reduction in driving demand during the critical period is achieved by mode shifts or shifts in time of travel, all remaining vehicles could be accommodated at free flow. Thus, to begin with the queue delay in the bypass lane might be zero. But this would not last long. As drivers notice the shortness of the queue delay, they would shift to the toll-bypass lane, until the time delay in the queue would be equivalent to the value of the (dynamically varying) toll in effect at the time. The two would be in equilibrium.

The length of the toll-bypass lane would depend on the toll rate and corresponding "time" price in effect, and the queue discharge rate. For example, if the toll were \$1.00 and the minimum value of time of freeway toll-payers were 20 cents per minute (i.e., \$12.00 per hour), the "time" price in the toll-bypass lane would be 5 minutes. If the queue discharge rate were 15 vehicles per minute, the total number of vehicles to be accommodated in the toll-bypass lane would be 75 vehicles. If the queue discharge rate were 2 vehicles per minute, there would be a total of 10 vehicles in the queue.

FIGURE 2. TOLL BYPASS LANE

Toll-Bypass Lane



System Operation

The “Super HOT” highway system concept proposed in this paper would involve conversion of *all* lanes on existing freeways into premium-service free-flowing freeways that provide fast, frequent and inexpensive express bus service. All vehicles, except authorized buses and certified ridesharing vehicles, would be charged a variable toll set high enough to guarantee that high demand will not cause a breakdown of traffic flow. Tolls would be charged *during congested periods only*. A peak period commuter would have several options:

- a) Pay a relatively low toll for the convenience of driving alone in free-flowing traffic on the Super HOT highway system;
- b) Join a carpool or vanpool and enjoy a fast trip on the Super HOT highway system for an even lower price by sharing the cost of the toll, or drive for free in an employer-certified or ridesharing agency-certified carpool or vanpool. Employer-certified or ridesharing-agency-certified carpool and vanpool vehicles would be identified through their transponder ID numbers and allowed free service on the Super HOT system with a passenger in the front seat. Infra-red camera technology, such as currently being used to identify carpools on the Firth of Forth bridge in Scotland, could be used to confirm the presence of a passenger and provide the free toll;
- c) Use newly expanded, faster and more convenient transit services provided by express buses that run on the Super HOT highway system; or
- d) Drive alone for free, either on the arterial street system (which would be enhanced with advanced traffic signal optimization), or on the freeway by using toll-bypass lanes constructed in advance of freeway toll gantries. The toll-bypass lanes would allow motorists to pay a “time” price in lieu of a toll, by waiting in the toll-free queue.

Licensed drivers in the area covered by the priced network, upon request, could be issued an inexpensive electronic transponder (e.g., a “sticker” tag) free of charge, along with a

transportation account. Non-residents could purchase the tags at retail outlets such as 7-Elevens, or from ATM-like machines at welcome stations located at approaches to the metropolitan area. Those not having transponders could be “video-tolled.” This means that cameras would take pictures of their license plates, and the vehicle owner would be billed for the toll plus a small administrative charge to cover the extra costs. For example, on November 1, 2006, the Florida Turnpike Enterprise, in conjunction with the Tampa Hillsborough County Expressway Authority, launched a “Pay-by-Plate” system, the first video-toll account system in the U.S. Customers who are occasional users of the Lee Roy Selmon Crosstown Expressway (between Tampa and Brandon, Florida), and do not have a transponder, can call a toll-free number to open an account. They pay a toll of \$1.25 (instead of \$1.00 for those with transponders) in order to cover costs to process the license plate images.

Ramp meters could be used on freeway entrance ramps in order to ensure that merging of incoming traffic does not break down mainline traffic flow, and to discourage short trips on the freeway on sections where there may not be a toll gantry.

In order to ensure premium service for buses and carpools when lane blockages occur as a result of an incident, overhead lane controls would be installed. The lane controls would provide priority for buses and certified HOVs during incidents. A clear lane would be designated for use only by buses and HOVs. If there is spare capacity available in the lane, it could be opened up to other vehicles for a premium toll set high enough to ensure that the traffic in the lane continues to flow freely. Vehicles in other lanes that do not get service at the guaranteed speed, due to the incident, would get an automatic refund on tolls paid.

Travel alternatives would be in place *before* congestion tolls are implemented. It is important that new vanpool and express bus systems be in operation prior to introduction of congestion tolls, with fare-free transit promotions and vanpool trial periods to encourage use. This would allow the public to get familiar with the new modal options and allow congestion tolls to be introduced with fewer concerns from the public about the viability of travel alternatives.

Travel time advantages relative to solo driving are critical for success of new transit and vanpool services. Where free-flowing HOV lanes currently do not exist on the existing congested network, an extra “*rush hour bus lane*” could be created on freeway shoulders for use by transit and authorized vanpools and paratransit vehicles during congested periods. The lanes would operate in each direction on all freeways, in conjunction with the introduction of new transit and vanpool services, and could be discontinued after all freeway lanes are restored to free-flow with pricing. A shoulder bus lane may be created by re-striping existing highway pavement. Restricting use of the shoulder lane to authorized vehicles with trained drivers would ensure that safety would not be compromised.

3.0 ADVANTAGES OF A SUPER HOT TRANSPORTATION SYSTEM

An entire metropolitan Super HOT network may be put in place in a relatively short period of time. Time-consuming and lengthy environmental review processes generally associated with freeway widening projects will not delay implementation. Some new investment will be needed for the initial shoulder bus lanes, for toll-bypass lanes, for management and operation of the

freeway and arterial networks, for new express bus and vanpool services, and for new park-and-ride facilities. However, these will not require the extent of environmental review normally necessary for road widening projects.

The Super HOT concept has several advantages over the managed lane approach. Since all lanes would be priced, there would be no need for additional rights-of-way and pavement for barrier or buffer separation between priced lanes and toll-free general-purpose lanes. Neither would expensive connector ramps be needed for efficient movement of priced vehicles through busy freeway interchanges. All lanes would be available for use by all vehicles. This would maximize motorists' freedom to switch lanes and consequently maximize highway capacity. A slower moving vehicle in a separated single lane causes a gap to build up in front of it, reducing vehicle throughput. Additionally, vehicle throughput *per lane* is lower when fewer adjacent lanes are available for use by all traffic, since drivers of faster vehicles find it more difficult to switch lanes and overtake slower vehicles in order to occupy large gaps between vehicles.

Super HOT highways would allow direct access to premium service lanes from *all* existing freeway entrance ramps. They would avoid the need for traffic to merge into and out of priced lanes from adjacent general-purpose lanes. Such weaving movements are inconvenient for buses and for motorists, and reduce safety and highway capacity on the free lanes.

With Super HOT highways, much more premium service capacity would be available on multiple lanes. Therefore, relatively lower toll rates would be sufficient to ensure that traffic demand does not rise above available capacity. This would make use of the highway more affordable to a larger population of middle and lower-income motorists. And those who cannot afford the toll nor shift their mode or time of travel would be no worse off than before, since they could choose a toll-bypass lane and pay a "time" price no higher than their previous delay time, to get free-flowing service on the freeway in return.

Finally, with a Super HOT system, *all* lanes are congestion-free.

4.0 ADDRESSING TRAFFIC DIVERSION CONCERNS

It is true that when toll rates are raised on existing tollways, some drivers divert to toll-free arterials or surface streets to avoid paying the higher tolls. However, unlike conventional tollways, priced highways provide many more travel options. A Super HOT system would have several differences relative to tollways. These differences would reduce the potential for traffic diversion to parallel toll-free facilities.

First, variable tolls would provide options to motorists to reduce or eliminate their costs for new tolls by shifting their time of travel. In the case of tollways with flat tolls all day, drivers cannot escape tolls or avail themselves of a lower toll rate simply by traveling at a different time.

Second, introduction of variable tolls during congested periods would be accompanied by high-quality transit services and expanded availability of enhanced carpool and vanpool options on free-flowing "virtual" HOV networks, so that some solo drivers would shift to using transit, vanpools or carpools, rather than diverting to parallel toll-free roadways.

Third, those who are not willing to pay the toll would have an option to wait in a toll-bypass lane and get a high-speed, predictable trip time for free. Wait times on the toll-bypass lanes can be expected to be lower than delays on alternative routes. Thus, there would be no incentive to divert from the freeway.

Fourth, when pricing is introduced on previously congested highways, some motorists who were previously deterred by freeway congestion and had diverted to parallel arterials may shift back to the free flowing priced highways, which would accommodate higher rush hour traffic volumes in a shorter period of time, as explained previously with the I-66 example. Note, however, that despite this shift from arterials, as long as parallel arterials remain toll-free, new motorists (for example, those who shift from other less convenient times of travel) can be expected take the place of any traffic that shifts from the arterials to the priced highways. Thus, while total hourly vehicle and person trip throughput in the corridor may increase, severity of arterial congestion cannot be expected to improve significantly during key congested periods. However, the *duration* of congestion (i.e., the length of the congested period) can be expected to be shortened. For example, the availability of spare capacity on I-66 from 9 am to 10 am will draw traffic from parallel arterials, reducing congestion on the arterials during that hour.

Finally, if toll revenues are used to pay for optimizing traffic signal controls on parallel arterials (in cases where they may not currently be optimized), this could help to further improve traffic flow on them.

5.0 BENEFITS AND REVENUES

A sketch-planning tool was developed by the author to assist in the estimation of the potential impacts of pricing all lanes of a limited access highway facility or network, in particular the costs, benefits and revenues. The tool is called Tool for Rush-hour User Charge Evaluation, i.e., TRUCE and is available on FHWA's Office of Operations web site.

The potential of the Super HOT concept was assessed using TRUCE for the Los Angeles metropolitan area which has one of the most heavily congested freeway networks in the U.S. Input data for TRUCE for 2003 were obtained from the Texas Transportation Institute's (TTI) Urban Mobility Study (Texas Transportation Institute 2005). Inputs included:

- The peak-period "travel time index" (Texas Transportation Institute 2005), which, along with a free flow freeway speed of 60 mph, was used to calculate average network speeds.
- Total daily freeway vehicle miles of travel (VMT), which was used to calculate peak period VMT, based on 8 rush hours and the share of travel in the AM and PM peak periods from the 2001 National Household Travel Survey (US Department of Transportation 2004).
- Number of freeway lane miles, which was used to calculate the average hourly traffic volume per lane over the 8-hour period, for both directions.

Based on the above inputs, TRUCE was used to estimate the impacts of the Super HOT concept. Detailed discussion of the analytical procedures is provided in DeCorla-Souza (2007). The estimated costs for the Multimodal package included:

- Highway capital and operating costs for open road tolling, traffic management and toll bypass lanes.
- Costs for new express bus services and park-and-ride lots.

Estimated benefits included:

- Highway motorist travel time and fuel cost savings, and the value of travel time reliability.
- Transit travel time and bus operating cost savings.

Table 2 summarizes estimates of toll revenues, benefits and costs of the multi-modal pricing package. Based on a UK study (Department for Transport 2004), highway benefits based only on travel time and fuel savings may be increased by 20% to account for benefits of trip time reliability. The benefit/cost ratio would be 4.8. Because of the conservative assumptions used to estimate benefits in the analysis, these estimates are conservative. The results of the financial analysis suggest that the multi-modal pricing package would be financially self-sufficient. Annual toll revenue surpluses would be over \$1 billion. These surpluses could allow tax refunds of over \$80 per person or \$120 per licensed driver.

Table 2. Estimates of Super HOT System Costs, Benefits and Revenues for Los Angeles

<u>Los Angeles</u>	
<u>Annualized benefits (million \$)</u>	
Highway time and fuel savings	\$3,835.44
Value of reliable trip times	\$767.09
Transit benefits	\$184.36
Multimodal benefits	\$4,786.90
<u>Annualized costs (million \$)</u>	
Highway costs	\$324.58
Transit costs	\$668.78
Multimodal costs	\$993.36
Net social benefits	\$3,793.53
Multimodal benefit/cost ratio	4.8
<u>Annual toll revenues vs. costs</u>	
Toll revenues (million \$)	\$2,036.20
Multimodal costs (million \$)	\$993.36
Surplus (million \$)	\$1,042.83
Surplus per person	\$83.43
Surplus per driver	\$120.91
<u>Annual delay reduced (hours)</u>	
Total delay reduced	178,564,260
Delay reduced per traveler	27
<u>Annual fuel saved (gallons)</u>	
Total fuel saved	449,981,935
Fuel saved per traveler	67

6.0 CONCLUDING THOUGHTS

A “Super HOT” transportation network in a large metropolitan area or a portion of a major metropolitan area could provide social benefits that far exceed multimodal investment and operating costs. An illustrative analysis for Los Angeles suggests that revenues from tolls would be sufficient to pay for all costs, including new express bus services and park-and-ride services that would complement the pricing scheme. The multi-modal pricing package would be financially self-sufficient, with annual toll revenue surpluses. A limited short-term “trial” demonstrating the concept on a congested tollway in a major metropolitan area may help show if the concept will work, and lead to public acceptance of larger-scale system-wide implementation.

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