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Clearing Existing Freeway Bottlenecks with Fast and Intertwined Regular Networks: Costs, Benefits and Revenues

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Patrick DeCorla-Souza, AICP
Team Leader
FEDERAL HIGHWAY ADMINISTRATION
Office of Transportation Policy Studies, HPTS
400 Seventh St. SW, Room 3324
Washington, DC 20590
Tel: (202)-366-4076
Fax: (202)-366-7696
e-mail: patrick.decorla-souza@fhwa.dot.gov

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Clearing Existing Freeway Bottlenecks with Fast and Intertwined Regular Networks: Costs, Benefits and Revenues

Patrick DeCorla-Souza, AICP

Abstract: This paper presents and evaluates an innovative and relatively low-cost road pricing strategy called "FAIR Networks" to eliminate existing congestion at freeway bottleneck locations in metropolitan areas. The concept 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 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. The evaluation is performed using sketch-planning procedures. The results suggest that a FAIR network may provide significant net social benefits and also generate sufficient new revenues to pay for arterial network and freeway network management and operations (including toll collection) as well as the new express bus service and ancillary park-and-ride facilities. Surpluses may also be available to address new transportation capacity needs in growing areas. Surpluses may be higher in areas that are more severely congested, providing needed revenue for major capacity enhancements.

Clearing Existing Freeway Bottlenecks with FAIR Networks: Cost, Benefit, Revenue and Equity Impacts

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1.0 INTRODUCTION

1.1 Purpose of the Study

There is emerging consensus that freeway bottlenecks are the prime source of recurring congestion in metropolitan areas. Freeway bottlenecks include mainline capacity shortfalls, interchange bottlenecks, and weave and merge friction at freeway entrance and exit ramps (1). The U.S. Department of Transportation (US DOT), in its Safe, Accountable, Flexible and Efficient Transportation Equity Act of 2003 (SAFETEA) proposal (2), has given special recognition to the importance of addressing bottleneck congestion. A new $1 billion a year "Performance and Maintenance Program" is proposed under SAFETEA to target improvements at such locations.

This paper presents an innovative and relatively low-cost strategy to eliminate existing congestion at freeway bottleneck locations in metropolitan areas. It is called the "Fast and Intertwined Regular (FAIR)" network concept, and 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 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 FAIR Network does not require new lanes to be constructed on the freeway mainline. It generally makes use of existing physical freeway rights-of-way and infrastructure. Some new investment will be needed for management and operations of the freeway and arterial networks, for new parking facilities, as well as for direct access ramps to and from these facilities for those choosing to park and ride in a carpool or in an express bus. An entire metropolitan FAIR network may be put in place in a relatively short period of time, without the need for time-consuming and lengthy environmental review processes generally associated with freeway widening projects. A FAIR network may also be self-financing and generate new revenue to help pay for expansion of the transportation network to address capacity needs at severely congested bottleneck locations and to accommodate growth in population, jobs and travel. In this paper, simple sketch-planning procedures, using credible assumptions, are used to estimate the cost, benefit, revenue and equity impacts from establishing a FAIR network in a major metropolitan area.

1.2 The Freeway Congestion Paradox

Chen and Varaiya, in their article entitled "The Freeway Congestion Paradox," (3) 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. At this point, according to Chen and Varaiya, the freeway's efficiency is down to 13 percent, from almost 100 percent at 5:10 am. Chen and Varaiya's measure of freeway efficiency accounts for both loss of throughput as well as loss of travel speed. It is defined as actual service throughput divided by maximum service throughput, and is calculated as follows:

Efficiency = (Flow X Speed) / (Max. flow X Max. speed)

Thus, efficiency prior to 5:10 am is estimated as (2,100 X 60) / (2,100 X 60) = 100 percent, and efficiency at 7:00 am is estimated as (1,300 X 15) / (2,100 X 60) = 13 percent.

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.

Varaiya has evaluated ramp metering as a way to maintain a high level of freeway efficiency. Ramp metering keeps excess vehicles from entering the freeway when critical vehicle densities are being approached. In an analysis of the Los Angeles freeway system (4), Varaiya estimated that a system wide ramp metering strategy could reduce annual congestion delay from 75 million vehicle hours to 25 million vehicle hours. The entire 25 million vehicle hours of delay would be incurred at entrance ramps, with mainline freeway flow being maintained at full efficiency (i.e., no delays). The analysis assumed that the same number of vehicles would be served on the freeway system as in the Base Case, i.e., no motorist would choose alternate routes to avoid ramp delays and thus exacerbate existing arterial congestion. Also, it did not account for possible delays to motorists on arterial streets resulting from queuing back-ups at freeway entrance ramps.

Varaiya's analysis (4) shows that, while ramp metering accomplishes much, at least a third of freeway delay remains, even if additional delays to arterial motorists are ignored. The FAIR networks concept described in this paper, on the other hand, accomplishes the objective of freeway efficiency *without* ramp delays, i.e., all freeway delay is eliminated. Essentially, a "price" in the form of a variable toll dissuades motorists from queuing up to use a freeway approaching critical density and induces them to shift to other modes, times or routes. Solo-drivers who arrive when demand is high pay for the improved service electronically. A ramp metering strategy, on the other hand, would have motorists "pay" for freeway access with ramp delay time. Time wasted at ramp meters cannot be re-used – it is gone forever, an utter waste of a scarce resource. With pricing there is no waste of either time or money, because toll revenue can be "re-used" to provide other benefits, or returned to taxpayers in the form of tax cuts.

2.0 THE FAIR NETWORKS CONCEPT

2.1 Basic Premise of FAIR Networks

FAIR networks operate *in peak periods only.* The freeway network operates as if it were a system reserved for free premium service to carpool vehicles and transit, somewhat like the existing peak period operation of I-66 inside the Beltway in Washington, DC. However, in addition (unlike I-66), solo drivers are permitted to use the system with payment of a variable toll. Solo drivers who wish to use the freeway when demand is high may choose to pay for the improved service, or shift to other travel modes (i.e., transit or carpool), to other times of the day, or to other (free) arterial routes. Low-income commuters are the ones most likely to divert to arterial routes to avoid paying the toll. This is because, although their value of time is likely to be higher relative to their wage rates, it is likely to be lower than the toll more often than it is for higher-income commuters. To reduce the inducement for traffic diversion, as well as to address concerns about equity towards these commuters, they are offered toll or transit fare credits (or refunds) to help them pay for additional out-of-pocket costs they may incur for peak period tolls or transit fares. *Note that FAIR networks do not require any change in freeway operating policy outside the peak periods.* Free service is provided to all vehicles outside the peak periods, just as it is currently.

Relatively few vehicles need be eliminated from the traffic stream to have a substantial impact on congestion. For example, Wachs (5) observes that traffic in Boston is surprisingly free flowing on a Jewish holiday; the same phenomenon occurs in California when only California state employees are off work due to a state holiday. This suggests that we need to induce only a few motorists to change their peak period travel behavior to substantially reduce congestion. To keep motorists from returning to the highways after congestion is relieved (in order to take advantage of the improved travel times), we need a variable pricing mechanism to keep demand from rising due to the lower travel time "price."

With FAIR networks, an inducement to shift from solo driving is provided in the form of "carrots" such as inexpensive transit, a free ride in someone else's car, or transit fare credits to low-income commuters. To maximize the potential for change in travel behavior, complementary strategies may also be used, such as parking cash out, incentives for businesses to locate at high-density employment sites, and incentives for transit oriented development in residential areas. Inducement to shift from solo driving is also provided in the form of a "stick", i.e., a toll charged to middle and high-income solo drivers for use of freeway facilities approaching critical density. The FAIR network concept relies on a balance of both positive and negative inducements to get motorists off the freeway during those very few hours when vehicle densities on the freeway are approaching the critical number.

2.2 Operation of a FAIR Network

Operation of a FAIR network may best be explained using the example of I-10 in Los Angeles discussed above. With a FAIR network in place, westbound motorists after 5:10 am would see a variable message sign that may say:

"TOLL AHEAD – 10 CENTS/MI, HOV 2+ FREE
RIDESHARE LINE, TRANSIT AT NEXT EXIT"

HOV2+ is the short-hand term commonly used to refer to carpools with two or more persons. A solo driver would understand from the sign that he or she has several options:

(1) *Stay on the freeway and pay the designated toll* at highway speed using a previously acquired transponder. There would be no need to stop or even slow down – open road tolling would be employed. Even vehicles without a compatible transponder would not need to stop. License plate recognition technology would be used to identify the vehicle owner, and he or she would be sent a bill in the mail. An administrative charge would be added to the bill to cover expenses. This system is currently employed on the Highway 407 toll road in Toronto, Canada (6).

(2) *Park and use express transit service, or get a free ride in a carpool* by joining a slug line at the next exit. Special park-and-ride lots with direct access to the freeway would include express bus stations so that solo drivers could park and take the bus, or join an informal carpool as a "slug." A slug is an informal carpooler who waits to be picked up at a designated location by a solo driver who wishes to avail of free use of HOV lanes by giving a free ride to the required number of passengers. This form of carpooling, called "casual carpooling" or "dynamic ridesharing," is practiced in the Washington, DC, San Francisco and Houston metropolitan areas.

(3) *Drive on the freeway for free after by picking up a passenger from the slug line*. Of course, most regular commuters would choose to form a conventional carpool, so that stopping to pick up a passenger (or waiting to be picked up by a solo driver) would be necessary only on those days that a conventional carpool was missing a passenger for any reason (e.g., vacation).

(4) *Exit the freeway and take an alternate toll-free arterial route.* In travel corridors with good transit service or carpool facilities and incentives (e.g., parking cash out), the number of commuters making this choice can be kept to the minimum. Additionally, low-income commuters are discouraged from using this alternative to save money by providing them with toll and transit fare credits or refunds. Investments in advanced arterial signal systems will permit accommodation of any possible traffic diversions without exacerbating arterial congestion.

A motorist with a passenger (i.e., in a two-person carpool) would simply continue to drive on the freeway. Special HOV access lanes would be provided near freeway entrance ramps, in association with park-and-ride facilities. Carpools going through these lanes would have their vehicle transponder ID numbers recorded, so that zero charges would apply to them at all toll-charging points on the freeway. The transponder readers and video surveillance cameras on the freeway would be hung from existing overpasses or overhead sign gantries wherever possible to avoid the need for expensive new gantries. Video technology, supplemented by police enforcement if necessary, would be used at HOV access ramps to ensure against use of HOV access lanes by solo drivers. The toll rates would vary dynamically, as on the I-15 express lanes in San Diego (7). The toll rates would be no higher than the rate necessary to create the right balance between demand for freeway use and critical vehicle density, in order to avoid traffic flow breakdowns.

2.3 Differences Between HOT Network and FAIR Network Concepts

The "HOT Network" concept is a road pricing strategy put forward by the Reason Foundation (8). It would convert and expand existing stretches of HOV lanes into seamless networks of High-Occupancy Toll (HOT) lanes in major metropolitan areas, and provide high quality transit service on the premium service lanes. There are several critical differences between the HOT network concept and the FAIR network concept:

- 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.

2.4 Travel Demand on a FAIR Network

Travel demand impacts and toll rates for a typical regional FAIR network have been estimated by the author based on a freeway network in a major metropolitan area such as Washington, DC. The freeway network in the Washington, DC metropolitan area consists of approximately 1,800 lane miles (9). This equates to about 300 route miles, assuming an average of 6 lanes (i.e., 3 per direction) on the network. It is estimated that only two-thirds of these lane miles, i.e., 1,200 lane miles suffer from congestion levels that will require tolling (9, 10).

Existing "Base Case" vehicle demand in the peak periods on these 1,200 lane miles, excluding any existing transit buses, is assumed to be 2,000 vehicles per hour (vph) per lane mile. This is the upper end of the range of vehicle throughput under traffic flow breakdown conditions identified by Chen and Varaiya (3). This equates to an average daily traffic volume (ADT) of about 220,000 vehicles for an 8-lane facility, calculated as follows:

- Peak period volume = 2,000 vph X 8 lanes X 6 peak hours = 96,000 vehicles
- Share of daily volume in peak periods = 44 percent, based on data in NCHRP Report 187 (11)
- Total daily traffic = 96,000 / 0.44 = 218,180

For comparison, typical traffic volumes on the severely congested 8-lane western segment of the Washington Beltway in Northern Virginia ranged from 178,000 to 240,000 in 1998 (12).

For the 6 peak hours per day during which the FAIR network policy would be in effect, total Base Case vehicle demand is estimated at 12,000 (i.e. 2,000 X 6) vehicle miles per lane mile. For the total of 1,200 congested lane miles, total freeway system vehicle demand per day in the Base Case is thus estimated to be 14.4 million (i.e., 12,000 X 1,200) vehicle miles of travel (VMT).

With a FAIR network, it is assumed that a variable toll will be charged that will be sufficiently high to keep peak period vehicle demand, excluding buses, at an average of 1,800 vehicles per lane per hour, to ensure that traffic flow breakdowns will not occur. This amounts to a 10 percent reduction in vehicular travel demand per lane per hour relative to the Base Case. For the 1,200 lane miles that are congested in the Base Case, this means that peak period demand will be reduced from 14.4 million VMT to 12.96 million VMT.

Trips on congested freeway segments also use uncongested segments of the freeway system. Assuming that a third of travel on a freeway trip occurs in free flowing conditions, this means that total freeway VMT per day would be 21.6 million VMT in the Base Case, and 19.44 million VMT with a FAIR network, i.e., a reduction of 2.16 million VMT per day or 10 percent.

Assuming that the freeway portion of a vehicle trip averages 8 miles, total freeway vehicle trips will be 2.7 million (i.e., 21.6 million / 8) in the Base Case and 2.43 million (i.e., 19.44 million / 8) with a FAIR network. On average, vehicle trips are estimated to be a total of 12 miles in length, including distance to access the freeway at the trip origin and to get to the destination from the freeway at the other end. Of the 8.0 miles involving freeway use, two-thirds or 5.4 miles are estimated to be driven on congested segments.

3.0 ESTIMATED COSTS FOR A REGIONAL FAIR NETWORK

3.1. Costs to Transportation Agency for Toll Collection

All costs presented in this paper are in 2003 dollars. It is assumed that the typical freeway network will employ open road tolling, with toll charging points located at approximately 3 mile intervals along the 1,200 lane miles of congested freeway segments, resulting in the need for 400 lane charging points (i.e., 1,200 lane miles/3).

Estimates for toll collection and operation costs are based on cost data for open road tolling provided by Wilbur Smith & Associates (WSA) (Personal e-mail communication with the author dated October 28, 2003). Capital costs per lane charging point are estimated at $46,000 for Electronic Toll Collection (ETC) costs and $23,500 for Video Enforcement System (VES) costs, or a total of $69,500 per lane charging point, resulting in total costs of $27.8 million (i.e., $69,5000 X 400) for the whole freeway network. Video tolling hardware and software, ETC equipment, system software, communications system, other equipment, and miscellaneous installation, project management and training costs are estimated at a total of $16.8 million. Mainline gantry costs are estimated at $25 million, and operations building costs at $2.5 million. Thus total capital costs are estimated at $72.1 million. Annualized at a seven percent (7%) discount rate and 20-year payback period, these costs amount to about $7 million per year.

Based on WSA data, annual operating costs will amount to $780,000 for 9 administrative staff and overhead, and $1.5 million for miscellaneous operations and maintenance expenses. At 15 cents a trip, annual transaction processing costs for 2.4 million vehicle trips per day (see section 2.4) for 250 weekdays per year (excluding holidays) are estimated at $90 million. Thus, total operations and maintenance costs, including administrative and miscellaneous expenses, are estimated at $92.28 million per year. Including annualized capital costs of $7 million, and annual costs for administering toll and transit fare reimbursements or credits for low-income commuters estimated at $700,000 per year, total costs for toll collection and operations will amount to about $100 million per year.

3. 2 Costs to Transit Authority for Express Bus Service

With a FAIR network, it is assumed that new express bus service would be introduced by the existing transit authority during peak periods, from 6 am to 9 am and from 4 pm to 7 pm, i.e., about six hours a day. It is estimated that this service would operate on 300 miles of freeway, i.e., about 600 route miles, at an average frequency of one bus every three minutes, i.e., 20 buses an hour throughout the peak periods. It is assumed that each bus would travel an additional 20 percent of route miles off the freeway network to pick up and drop off passengers. Thus, total revenue miles of service each day would be 720 route miles X 20 buses per hour X 6 hours, or 86,400 route miles. Assuming an average bus speed (including intermediate stops for pick ups and drop offs) of 20 mph, total revenue hours per day would be 4,320. Based on cost data for Seattle, WA (13), operating costs for a typical large metropolitan area may be estimated at $90 per revenue hour. Based on the higher labor costs for split shifts and use of part-time labor for peak period service (14), costs for a typical FAIR network are estimated to be from 1 to 10 percent higher than for conventional operations, or a maximum of about $100 per revenue hour. Operating costs would thus be $432,000 per day or about $108 million per year assuming weekday operations only, i.e., 250 days per year excluding holidays.

At an average bus speed of 20 mph, each bus would serve 60 revenue miles during each three-hour peak period. Thus, to operate 43,200 revenue miles in each peak period would require 720 buses (i.e., 43,200/60). At a cost of about $300,000 per bus (based on data on the web site of the American Public Transit Association, see http://www.apta.com/research/stats/bus/buscost.cfm), capital costs for buses would be $216 million, or an annualized cost of about $30 million assuming a seven percent (7%) discount rate and 10-year bus life. Total annualized costs for capital and operation of new express service are thus estimated at about $138 million.

At 43,200 revenue miles per peak period, a total of 86,400 revenue miles would be served each day, or 21.6 million each year. Assuming that about one-third of the 270,000 reduction in vehicle demand is a consequence of mode shifts from solo driving to transit, with the remaining two-thirds resulting from shifts to carpools, about 90,000 transit person trips would be served. At an average passenger trip distance of 10 miles, 900,000 passenger miles would be served. (The shorter average transit trip distance relative to auto trips, estimated to be 12 miles, accounts for the additional driving distance for park-and-ride transit trips.) Thus, on average, 10.4 passengers would be served per bus mile, i.e., 900,000 passenger miles / 86,400 revenue miles per day.

Revenues from transit passengers, assuming a fare of $1.00 per trip, would thus amount to $90,000 per day, or $22.5 million per year for 250 days of service. Net annual transit agency costs per year would thus be $115.5 million (i.e., $138 million – $22.5 million).

3.3 Costs to Transportation Agency for Park-and-Ride Facilities and HOV Identification

As estimated above, the toll charge will reduce freeway vehicle trip demand by 10 percent, from 2.7 million vehicle trips to 2.43 million vehicle trips per day, a reduction of about 270,000 vehicle trips. This amounts to a reduction of 135,000 return trips. In other words, as many as 135,000 additional vehicles will be parked all day, either at home, at a park-and-ride facility, or at some location other than at the work site. To estimate need for new park-and-ride spaces, it is assumed that half of these vehicles (i.e., 67,500 vehicles) will need a parking space at new park-and-ride facilities.

The cost for construction of a surface parking lot is about $2,200 per space (15). This amounts to an annualized cost of $220 per space assuming a seven percent (7%) discount rate and 20-year life. Annualized maintenance costs are $130 per space (15). Thus total annualized costs per space are $350.

For a parking garage with 3 levels or more, construction costs are estimated at $12,300. This amounts to an annualized cost of $1,200 per space assuming a seven percent (7%) discount rate and 20-year life. Annualized maintenance costs are $250 per space (15). Thus total annualized costs per space are $1,450.

Most of the new park-and-ride spaces will be needed in exurban or suburban locations. At these locations, it is more likely that the State transportation agency will own land within existing rights-of-way near interchanges or along the freeway. It may therefore be possible to build new park-and-ride facilities on surface lots, adjacent to express bus stations. Assuming that 75 percent of new spaces at park-and-ride lots will use surface parking on existing highway rights-of-way and the rest will be in multi-storey parking garages, total system wide costs for parking for 67,500 spaces will amount to about $42.2 million per year, i.e., 65,700 X [{0.75 X $350} + {0.25 X $1,450}].

Each park-and-ride lot will also provide for HOV identification for vehicles with two or more occupants, so that the system will not bill these vehicles when their transponders are identified on the tolled freeway segments. It is estimated that ETC equipment for this purpose will be provided at HOV identification zones. Approximately 100 park-and-ride lots will be needed (i.e., each lot would accommodate about 650 vehicles on average). Therefore, about 100 HOV identification zones will be needed. Based on WSA estimates, each such zone will involve a capital cost of about $46,000, for a total of $4.6 million for 100 zones, or an annualized cost of $450,000.

Access ramps will be needed from the park-and-ride lots to the freeway. It is assumed that the number of new lane miles for ramps to and from the freeway will be approximately 0.125 mile per lot, or 12.5 lane miles for the total of 100 lots. At an estimated cost of $3 million per lane mile for construction of normal cost urban freeway lanes (16), total capital costs for ramps to and from the freeway will be about $37.5 million. This amounts to an annualized cost of $3.7 million assuming a seven percent (7%) discount rate and 20-year life.

Thus total costs for park-and-ride facilities will be:

Park-and-ride facilities	$42.2 million
HOV identification	$ 0.45 million
Access ramps	$ 3.7 million
Total	$46.35 million

3. 4 Agency Costs for Arterial Network Management and Operations Improvements

Mitretek Systems (17) reports that system capital cost for an adaptive traffic signal control system for 65 signals (expandable to 235 signals) in Arlington County, VA, amounted to $2.43 million. Mitretek also reports that the system capital cost for an advanced traffic signal control system in downtown Indianapolis (including upgrading 220 intersections and connecting them to a central computer system) amounted to $5.1 million. Based on these estimates, it is estimated that installing adaptive signal control with advanced signal systems region wide will involve a capital cost of about $75 million (i.e., 10 times the total costs for the two types of arterial system improvements), or an annualized cost of $7.5 million. Including annual operations and maintenance costs estimated at $2.5 million, management and operations of the arterial network to maximize its efficiency will involve an annual cost of $10 million.

3. 5 Total Annualized Agency Costs

Based on the above cost components for a FAIR network, total estimated annualized costs to transportation agencies for a typical FAIR network are estimated as follows:

Toll/ credit operations	$ 100.0 million
Express bus service	$ 115.5 million
Park-and-ride facilities	$ 46.4 million
Arterial network	$ 10.0 million
Total system cost	$271.9 million

4.0 ESTIMATED TOLL REVENUES FOR A REGIONAL FAIR NETWORK

4.1 Toll Rate

As discussed earlier (see section 2.4), 5.4 miles of an average freeway trip would be on congested segments that would need to be tolled.

Data from tolled express lanes on State Route 91 in Orange County, CA suggest that only about 40 percent of motorists on SR 91 are willing to pay the toll to use the express lanes in the peak hour, and the average value of time of these motorists, in 1998 dollars, is $13.80 (18). 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 from those who have lower values of time, in order to efficiently use available capacity.

Freeway delay in the Base Case is used to approximate the magnitude of the time delay 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.

The upper bound vehicle travel speed under freeway traffic flow breakdown conditions is 30 mph (3). This amounts to a delay of one minute per vehicle mile, relative to a free flow speed of 60 mph. To estimate peak period FAIR network toll rates, average freeway delay per mile per vehicle in the Base Case in the peak period is converted to a monetary value using $8.30 per hour (20). 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 the fact that a high percentage of motorists, many of whom would have relatively low values of time, could be accommodated on the available freeway capacity. One minute equates to a value of about 14 cents based on an hourly value of $8.30. Thus, the toll rate is estimated at 14 cents per mile, applied to 5.4 miles of freeway travel for an average solo driver vehicle trip, or about 75 cents per solo driver vehicle trip.

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 (20). Likewise, the toll rates could drop as often as every six minutes, if actual demand is much below critical density. Also, tolls would rise on the freeway to equate to any increase in disutility due to increase in arterial travel time, inducing further shifts to alternate modes until a new equilibrium is reached among modes and routes.

The reasonableness of the estimated toll rate can be assessed by comparing it with toll rates on existing priced lanes in California. Toll rates need to be lower than that reflected on SR 91, to ensure that demand is high enough to efficiently use available capacity. The highest toll rate on SR 91, at $5.50, translates to 55 cents per mile. The average peak period toll on the I-15 HOT lanes in San Diego, CA is 33 cents per mile and can be as high as $4 per trip (20). The estimated average toll rate for the FAIR network of 14 cents per mile (or 75 cents per trip) thus appears to be reasonable, since it is much lower than the peak hour toll rates in San Diego and Orange County.

4.2 Total Annual Toll Revenue

For revenue estimation, it is assumed that 20 percent of vehicles using the freeway in the AM and PM peaks will be exempt vehicles or carpools (i.e., about 10 percent existing carpools, and about 10 percent exempt vehicles and new carpools), and will not pay a toll. Thus 80 percent of vehicles using the freeway will be driven by solo drivers who will actually pay the toll. As estimated earlier in Section 2.4, tolled segments will serve 12.96 vehicle miles of travel (VMT). At an average toll rate of 14 cents per vehicle mile, revenues of $1.45 million per day would be generated from the 10.368 million VMT (i.e., 12.96 million X 0.80) that would be tolled. This would amount to about $362.9 million for 250 days of operation.

It is assumed that, on average, payments equal to 20 percent of the toll revenues would be credited or reimbursed to low-income commuters for tolls and/or transit fares. Thus payouts to low-income commuters would amount to $72.6 million. Therefore, net toll revenues would be about $290.3 million.

5.0 ESTIMATED SYSTEM WIDE BENEFITS WITH A FAIR NETWORK

5.1 Traveler Benefits

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 New Transit and Carpool Riders

As estimated earlier (see section 2.4), total freeway VMT would be reduced from 21.6 million VMT to 19.44 million VMT, i.e., a reduction of 2.16 million VMT per day. This amounts to a reduction of 540 million VMT per year. Costs per mile to operate an automobile average 15.3 cents per mile (21), and accident insurance costs average an additional 7 cents per mile (22). Thus the annual reduction of 540 million VMT could result in total potential cost savings of $120.4 million per year (i.e., 540 million X 22.3 cents).

Of the 270,000 vehicle trips reduced (see section 2.4), it is estimated that a reduction of 90,000 trips would be the result of solo drivers shifting to transit (see section 3.2). It is estimated that the remaining 180,000 vehicle trips will be reduced due to solo drivers forming two-person carpools. Since two solo drivers must form a carpool for every vehicle trip reduced, there will be 360,000 new carpool *person* trips. Thus the total number of new transit and carpool person trips is estimated at 450,000, or 225,000 return trips. The $120.4 million annual cost savings thus amount to about $530 per commuter per year.

However, it should be recognized that new carpoolers and transit riders trade off these cost savings against the cost, inconvenience and extra time involved in using the carpool and transit modes. Consumer surplus theory allows us to calculate the net benefits to new carpoolers and transit riders. Since cost per vehicle trip on the freeway will be reduced (see next section), it is assumed that new carpoolers and transit riders are attracted to their new modes by the service improvements, and not are not "forced" to take these modes because of an increase in cost for a freeway vehicle trip. Since a typical carpool or transit trip takes 5.4 minutes less than in the Base Case (because delay is eliminated on the two-thirds of the 8 mile freeway trip that was previously congested), consumer surplus for the 450,000 new carpool and transit trips is calculated as follows:

Change in cost/per trip= 5.4 min. X $8.30 per hour / 60 min= $0.747

Consumer surplus = \$0.747 X 450,000 X ½ = \$168,075 per day

Note that the low value of local travel time estimated by US DOT (19) was used, in order to get a conservative estimate of benefits. 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 due to reduced congestion, these cost reductions were ignored in order to provide a conservative estimate of benefits. The annual consumer surplus for 250 days is thus calculated at \$42.0 million.

5.1.2 Benefits to Travelers Who Do Not Change Mode

5.1.2.1 Highway Travel Time Savings for Solo Drivers and Existing Carpoolers

The upper bound vehicle travel speed under freeway traffic flow breakdown conditions is 30 mph (3). This amounts to a delay of one minute per vehicle mile, relative to a free flow speed of 60 mph. If peak period freeway vehicles each save one minute per mile on previously congested segments, total travel time saved per vehicle trip is 5.4 minutes over the 5.4 miles driven on previously congested segments. Of the 2.43 million vehicle trips using the freeway network (see section 2.4), there will be a total of 2.25 million vehicle trips made by solo drivers and existing carpools (subtracting the *new* 180,000 carpool vehicle trips calculated above.) Time saved by these 2.25 million vehicle trips per day that will continue to be made with a FAIR network will thus amount to 202,500 vehicle hours per day, i.e., 2.25 million trips X 5.4 min.

At vehicle occupancy of 1.1 during peak periods for commute vehicle trips (23), previously existing carpool vehicle trips are estimated at 270,000 per day, assuming a carpool size of 2.0. The remaining solo driver trips with FAIR networks are thus estimated at 1.98 million trips per day, i.e., by subtracting 270,000 trips from the total of 2.25 million trips for solo drivers and existing carpools. Thus total travel time cost savings for solo drivers and existing carpools are estimated as follows:

Solo driver savings	= (5.4 min./60) X \$8.30 X 1.98 m. X 250	= \$369.8 million
Carpooler savings	= (5.4 min./60) X \$8.30 X 0.27 m. X 2 X 250	= \$100.8 million
Total savings		= 470.6 million

Travelers on the freeway will also benefit from increased trip travel time reliability, but a value has not been placed on this benefit. With near-guaranteed arrival times, travelers will no longer need to maintain a large "buffer" time (e.g., leave home earlier) in order to guarantee on-time arrival. Even non-recurring congestion on the freeway could be reduced. For example, if an accident or incident were to occur on the freeway in the morning, toll rates could rise to ensure free flow under the capacity restriction, encouraging even more motorists to carpool or take transit on that day than under normal conditions. People have demonstrated their willingness to change their travel habits under special situations, e.g. snow emergencies.

Traffic diversions from the freeway to arterials are likely to be offset by reductions in vehicle traffic on arterials due to mode shifts to carpool or transit, because arterial motorists would have about the same transit and HOV incentives as those using the freeway. Additionally, Mitretek (17) reports that adaptive traffic signal control systems have produced delay reductions of 5 to 42 percent; and signal coordination along 76 corridors in California cities reduced delay by 25 percent. Signal coordination and adaptive traffic signal control systems will be implemented as part of the advanced signal systems proposed as an integral part of FAIR networks. Therefore, it is assumed that arterial traffic flow may improve, or at least not deteriorate, with FAIR networks.

5.1.2.2 Highway Vehicle Fuel Cost Savings for Solo Drivers and Existing Carpools

It is estimated that fuel consumption will be reduced by 0.05 gallons per minute of delay reduced (24). 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. Thus motorist fuel cost savings annually are estimated as follows:

Solo driver savings:		
Fuel cost savings	= (5.4 min./60) X $3.30 X 1.98 mil. X 250	= $147.0 million
Fuel tax savings	= (5.4 min./60) X $1.20 X 1.98 mil. X 250	= $53.5 million
Total savings		= 200.5 million

Existing carpool vehicle savings:		
Fuel cost savings	= (5.4 min./60) X $3.30 X 270,000 X 250	= $20.0 million
Fuel tax savings	= (5.4 min./60) X $1.20 X 270,000 X 250	= $7.3 million
Total savings		= 27.3 million

Total fuel cost savings to solo drivers and previously existing carpools thus amount to $227.8 million annually.

5.1.2.3 Transponder and Toll Costs for Freeway Vehicles

Based on 1.22 million vehicles (i.e., 2.43 million return trips) that would be tolled on average each day, it is estimated that the total number of vehicles that would be outfitted with transponders would be about 2 million. At a cost of $25 per transponder, total costs for transponders would amount to $50 million, or an annualized cost of $7 million assuming a 10-year life and 7% discount rate. Net tolls paid, as calculated earlier in section 4.2, would amount to $290.3 million per year. Thus total traveler costs for tolling would amount to $297.3 million per year.

5.1.3 Net Peak Period Traveler Benefits

Net annual traveler benefits are calculated as follows:

Benefits to carpool and transit riders	= $ 42.0 million
Benefits to solo drivers & existing carpools:	
Highway travel time savings	= $470.6 million
Fuel cost savings	= $227.8 million
Tolls and transponder costs	=(-$297.3 million)
Total benefits	= $443.1 million

Note that travel time savings benefits to solo drivers of about $370 million calculated in section 5.1.2.1 far exceed the toll and transponder costs of about $297 million. Additionally, solo drivers save about $200 million in fuel costs (see section 5.1.2.2). Therefore, total cost per solo driver trip will actually be reduced compared to the Base Case.

5.2 External Cost Savings

The change in external costs per mile (including air pollution, noise and crashes) due to reduced traffic is estimated at 6 cents per vehicle mile. This cost per vehicle mile was calculated 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 (25). The low-range estimate was used to ensure a conservative estimate of benefits. Based on the annual increase of 21.6 million in bus VMT (see section 3.2) and the annual reduction of 540 million VMT for other vehicles (see section 5.1.1), external cost savings are estimated at $31.1 million (i.e., 518.4 million VMT X $0.06).

In addition to external cost reductions due to VMT reduced, air pollution costs for the remaining VMT on the freeway will be reduced, because a FAIR network reduces congestion delay on the freeway and emissions of carbon monoxide (CO) and hydrocarbons (HC) may thereby be reduced. 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 Annual Benefits

To get total social benefits, external cost savings are aggregated with estimates of toll revenues to agencies and traveler benefits calculated previously. However, fuel taxes saved by travelers must be subtracted from traveler benefits. 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. Total annual social benefits are thus estimated as follows:

External cost savings	= $ 31.1 million
Net traveler benefits	= $443.1 million
Net toll revenues	= $290.3 million
Fuel taxes saved	=(-$60.7 million)
Total	= $703.8 million

6.0 EVALUATION

It should be noted that a conservative assumption (i.e., 30 mph) was used with regard to travel speeds on the freeway under breakdown flow in the Base Case. This amounts to a delay of just one minute per mile, or 5.4 minutes over a 5.4-mile congested segment on the freeway. While this may reflect conditions in less congested metropolitan areas, it is certainly not reflective of more congested metropolitan areas such as Washington, DC (9). Chen and Varaiya's data for I-10 in Los Angeles suggest that speeds can drop to 15 mph, which translates to a delay of three minutes per mile, or 16.2 minutes for a 5.4-mile congested segment. Freeways in severely congested metropolitan areas are more likely to average 20 mph (which translates to a delay of 2 minutes per mile) over their congested segments. Effects of FAIR networks with a "High" scenario for existing congestion have therefore been evaluated for this study, assuming an average congested speed of 20 mph in the Base Case, or a 10.8-minute delay on a 5.4-mile congested segment on the freeway. Note that with more severe congestion, toll rates will also need to be higher in order to achieve an equivalent demand reduction, since willingness-to-pay will be higher when more time is saved.

In Table 1, the "Low" scenario summarizes the annualized system wide costs, net toll revenues and benefits estimated in the previous sections, with travel speed on congested segments assumed to be 30 mph. The "High" scenario reflects a more severely congested metropolitan area where travel speed on congested segments is assumed to be 20 mph. The comparison of system wide benefits and costs suggests that a cost-benefit ratio in excess of 2.0 will be achieved even in less congested metropolitan areas, while more severely congested metropolitan areas may see benefit-cost ratios as high as 5.0.

TABLE 1. SUMMARY OF COSTS, BENEFITS AND REVENUES (Million dollars annually)

	Low	High
Annualized costs	$271.9	$271.9
Annual social benefits	$703.8	$1,383.5
Net annual benefits	$431.6	$1,111.3
Annual revenues after credits	$290.3	$580.6
Benefit-cost ratio	2.6	5.1
Excess of revenues over costs	$18.4	$ 308.7

A comparison of system wide revenues to system wide costs suggests that annual toll revenues will exceed annualized costs in moderately congested areas by about $18 million, and will exceed annualized costs by as much as $309 million in severely congested areas. A $309 million annual surplus could support a $3 billion bond program and allow construction of as many as 375 new lane miles at $8 million per lane mile (16). The more severe the congestion, the larger the revenues available for addressing congestion problems. Of course, costs for constructing new transportation capacity also tend to be highest in large urban areas with the most severe congestion.

8.0 CONCLUSIONS

This paper has presented and evaluated a relatively low-cost, cost-effective and equitable strategy called "FAIR networks" to eliminate existing congestion at freeway bottleneck locations in metropolitan areas. FAIR networks will provide a *package* of benefits to the public that will increase their transportation choices, including:

- New fast, frequent and inexpensive bus service, such as "Bus Rapid Transit".
- A new HOV 2+ system providing guaranteed premium service across the whole network, not just on a few freeway segments.
- Guaranteed premium service freeway lanes for a larger number of motorists than with HOT networks, and for a much more affordable price, since supply (i.e., number of available lanes) would be much greater.

The results of the sketch-planning analysis presented in the paper suggest that a FAIR network may provide significant net social benefits and also generate sufficient new revenues to pay for arterial network and freeway network management and operations (including toll collection) as well as the new express bus service and ancillary park-and-ride facilities. Surpluses may also be available to address new transportation capacity needs in growing areas. Surpluses may be higher in areas that are more severely congested, providing needed revenue for major capacity enhancements.

Equity concerns may be addressed through toll and transit fare reimbursements to low-income commuters. Arterial travelers will be minimally affected, because some revenues from tolls will be used to ensure that the most advanced systems for arterial network management and operations are put in place and adequately maintained system wide.

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