THE PUBLIC COST OF URBAN TRANSPORTATION ALTERNATIVES. II

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How much more or less urban congestion reducing capacity can we expect on the average for a billion dollars spent on one mode, say light rail, as compared to another, say freeway?

That's a critically important question. It has meaningful and very significant answers. Yet many transportation planners seem to have little or no understanding of the wealth of existing data bearing on it.

This paper attempts to bring such data, from the primary sources, "out of the closet" and make it available in convenient, mode-comparative form.

CONTENTS

CONGESTION

In almost every major U.S. city today, severe and growing traffic congestion exacts a significant toll on efficiency of commerce and quality of life. For the Los Angeles Metropolitan Area the cost of congestion in 2003 has been estimated at $1870 per year for every peak-hour traveler. Nationally, counting time and fuel wasted, urban congestion costs about $9 billion per year, [9].

The root cause of congestion is simple to identify and state, namely:

a severe shortfall of transportation system capacity relative to demand.

In principle, there is a rich choice of alternatives to satisfy that capacity shortfall: more roads, freeways, bus, rail, monorail, maglev, etc. Why don't we just build that needed capacity? The simple answer: *cost.* Cost is the principal constraint.

Seemingly, there is never enough public (i.e. government) money to buy all the capacity we need. In this dilemma — need for capacity vs shortage of funding — rational decision making demands getting the most congestion reduction benefit per available public dollar, that is, cost effectiveness. There is widespread acknowledgement of the primary importance of cost effectiveness in transportation goals; almost every planning study report places cost effectiveness high on its list of goals. Yet, in practice, cost effectiveness analysis often seems too arcane and remote to be fully understood and confidently accepted by planners and decision makers. Too often cost effectiveness considerations are put off to the *last* phase of a transportation improvement study, at which point the alternatives are limited to the scope of the candidates chosen at the *outset* of the study, on the basis of prior intuition, i.e., prejudices, too often with little or no thought or understanding of the basic facts of cost effectiveness. In the end, faced with a bewildering plethora of alternatives, and incompletely understood technical cost effectiveness analysis, rational decision making is too often trumped by the simpler but ineffectual dogma of

"multimodalism",
"balance",
"providing a choice" or
"an alternative to roads",

ignoring *vast* differences in cost effectiveness of alternative modes.

COST/PERFORMANCE DATA SOURCES

One of the potentially simplest, most readily understandable, and often most accurate, but largely overlooked tools for cost effectiveness planning is the vast historical database of actual historical *achieved* cost and performance of transportation mode alternatives. The aim of this paper is to compile and present that existing cost and performance data in such a form as to provide the best possible guidance as to the cost effectiveness that may be expected of different modal alternatives, including roads, freeways, bus and rail systems, based on actual performance data from the most broadly representative and authoritative source references.

There are about 500 regional metropolitan transportation agencies in the US. All of these agencies depend in large part on federal funding, for which they are required to report annually to the two major DOT Departments, the Federal Transit Administration (FTA) and Federal Highway Administration (FHWA). These prescribed form reports cover all relevant aspects of cost and performance for every mode supported by the agency. As part of their oversight, FTA and FHWA compile these data and disseminate extensive annual cost and performance reports. These reports, listed in references [1, 2, 3, 4] are readily available and mostly on-line. While these reports themselves scrupulously avoid inter-modal cost effectiveness comparisons (professional courtesy ?), they provide all the necessary data for independent analysts to do so. These are the fundamental data sources for the analyses to follow here.

CONGESTION

Regional Congestion is logically measured in terms of regional total or average congestion travel-time delay, commonly expressed in minutes-per-mile. While there are other quantifiable costs of congestion such as accidents, insurance, fuel consumption and emissions, travel-time is usually the strongly dominant cost element. Furthermore, the other elements generally follow in close proportion to travel-time. Travel-time affords a good surrogate for the entire panoply of congestion ill-effects.

Since 1982, the Texas Transportation Institute has compiled an annual inventory of Urban Congestion, estimating the regional average speed or travel-time delay and cost for the 90 or so major US urban regions (cities) [9]. The TTI analysis is based on the quasi-annual extensive inventory of reported urban roadway physical characteristics and traffic count estimates (Annual Average Daily Traffic) every mile or so of the 400 million or so miles of road and highway in the HPMS database[3]. TTI has to make a number of assumptions to infer regional average speed and delay from this data and the TTI methodology itself has not been well documented in the detail necessary to support independent verification. For this it has been subject to — in my view — deserved criticism. Nevertheless, for two decades, TTI mobility reports have stood as the only, and by default best, internally consistent long-term quantitative accounting of U.S. Urban congestion for comparing year-to-year and city-to-city trends.

Within the last 5 years, some major metropolitan areas have begun to operate extensive loop sensor networks that measure actual traffic flow and speed directly, for all major expressways and freeways, typically every 5 seconds and every half mile or so ,for every lane. In California this data is compiled in real-time and disseminated through the "PEMS" [10] system. Currently there are only about 20 such networks in full operation in U.S. major urban areas, and all have persistent technical problems. These problems are being addressed and the technology is rapidly improving. It is anticipated that in the near future these data will provide better absolute speed or delay data than can be inferred, as TTI does now, from the HPMS data.

In the meantime, the TTI data has been made more accessible and its message more transparent by the development of a regional volume/capacity index, VCI*[1], and associated Congestion Delay model which closely replicates the TTI congestion data, but

[1] The asterisk (*) will denote "regional"

with a much simpler input data set consisting of the five widely tabulated and available fundamental regional volume and capacity measures [5].

VOLUME*, CAPACITY* AND CONGESTION

One significant lesson that can be inferred from both the HPMS and Loop sensor data is that regional delay can be estimated with useful accuracy as a function of the *Regional Volume* to *Regional Capacity* ratio, V*/C*. This relation is quantified in [Ref 5].

What exactly do we mean by regional volume and capacity? The basic concept is simple. Say that for all his transportation needs Alan's travel averages 20 miles per day. Bill averages 15 miles per day. Between the two they generate a transportation "demand" volume of 35 "person-miles per day" (ps-mi/day)[2]. Summed over every one traveling in Metropolitan Los Angeles, for example, that adds up to a regional demand volume, V*, of some **444** million person-miles/day [3,4]. But the L.A., regional capacity, C* that is, by definition, the volume* its entire transportation system *could* handle *at reasonable, (U.S. Median) congestion delay*, is only about **280** million ps-mi/day (2003). That represents a demand/capacity, V*/C* overload factor of 1.6 times, (relative to US median). That overload is directly responsible for the nation's worst regional congestion, averaging travel-time delay of 0.7 minutes per mile, and total regional lost time of 623 million person hours per year, at an estimated cost to Los Angeles travelers and businesses of $10.9 Billion per year [9].

At this point we must carefully distinguish our use of the terms *regional* volume, V* and *regional* capacity, C* having units of {*person-miles/day*}, and referring to an entire regional system or subsystem, from common transportation usage of volume,V and capacity C, having units of {*persons/day*}, and referring to a single mile-point along a route. The two are fundamentally different and one cannot simply be converted to the other. [3] We shall use the asterisk (*) to denote pertaining to system or subsystem rather than point or scfreenline.

In principle, our V*/C* congestion problem could be solved either by *increasing C** by adding sufficient amounts of roads or transit, or by *reducing demand, V**. For the first half century of the automobile age, road builders understood that as automobile travel demand grew, we had to build road Capacity* in proportion to demand and they did so. Congestion was the exception rather than the rule

But in the early '70s as Eisenhower's National Interstate Highway System neared completion, urban planners started thinking that reducing the demand* might afford a cheaper and better way of keeping up with growth than expanding capacity*. This notion spawned any number of "Transportation Demand Management" ("TDM") fads, guided by seductive mantras such as "*We've got to get people out of their cars*" and "*We Can't Just Build Our Way Out*", and massive diversion of effort from capacity building to Transportation Demand Management.

[2] In a hydraulic analogy, volume is like the gallons-per-hour of water flowing in a pipe, capacity is proportional to the cross sectional area of the pipe.
[3] Precisely, V* and C* are the integral with respect to distance of V and C over the system or sub-system.

Most kindly put, the TDM concept has been a disaster. In spite of the strenuous efforts of transportation planners, and billions of dollars in coercions, fines, and inducements (subsidies) for alternatives, the privately owned automobile and roads continue to represent a larger and larger fraction of total travel. The automobile share has grown from 64% in 1960 to 73% in 1990 to 98% in 2003. The fraction of workers carpooling to work has declined from 19.7% in 1980 to 13.4% in 1990. U.S. public mass transport as a fraction of total person transport (ps-mi/yr), has declined from 12.6% in 1960 to 5.3% in 1990 [9] to 1.2%[4] in 2003. Transportation Demand Management inducements simply cannot come anywhere near accommodating the growth in population and transportation demand. And, as we find in [5], we CAN build our way out. The cost we are now paying for congestion delay could more than pay for getting rid of the delay.

In this study, we concentrate on the Capacity* side of the V*/C* relation and measure the transportation benefit of a regional capacity* addition, whether road or transit, as the number of <u>person-miles per day</u> it supports or can be expected to support, in *actual* (not theoretical optimal) operational conditions. The choice to express congestion reducing capacity in person miles per-*day* rather than *per-peak-hour* is explained in [5]. In high congestion regions, like Los Angeles, as regional demand volume grows to or exceeds capacity, further increases in demand appear as a *broadening* of the congestion peak duration; the effect of modest capacity additions is evident in *day-rou*nd congestion impact, while almost invisible in terms of saturated peak-hour volume. To measure congestion in terms of peak-hour volume would imply that three hours of congestion was n worse than one hour. A person hour of wasted time in traffic has roughly the same cost to society whether it occurs during peak or off-peak hours. For these reasons, peak hour congestion does not reflect the true cost of regional congestion.

DEFINING "COST"

The purpose of this analysis is to provide transportation planners with better data to support their choice of modes to get maximum transportation capacity* (and consequent minimum congestion) within the constraint of limited available resources, funding and Right-Of-Way.

Accordingly our concern is for the *net* (i.e. after subtracting user fees), public (not counting private), total (capital plus operating), costs to the total (federal *plus* state *plus* local) government. In this context, *net cost* means the same thing as *subsidy.*

The derivation of these results is contained in Appendix 1.

RESULTS

All the major results of this analysis are derived and summarized in Table 1 following. It is intended to be a useful reference summary of the major points of inter-modal comparison. So it is worth taking some time to become familiar with the row and column definitions, as we shall do here.

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[4] 2004 U.S.: Transit: 46.5 Billion ps-mi/yr [1], and roads: 3,927 Billion ps-mi/yr [3]. ,

Table 1 compiles total US per-unit gross and net public cost and right-of-way per requirement per unit transport (person-miles per day) for all major transportation system alternatives.

By column:

C: All US Bus,
D: All US Heavy rail (like Los Angeles Red line Subway),
E: All US Commuter Rail like Southern Calif. Metrolink, (CR),
F: All US Light Rail (LR)
G: All US Transit as a whole
H: Orange County CenterLine Light Rail (projected, as of 2003)
I: Orange County Bus,
J: All US Highways, Roads and Streets incl. rural
K: All US Freeways & Expressways
L: Orange County Freeways, and
M: The ratio of US Transit (col. G) to All US Roads, (col. J).

The goal here is to support the issue of relative government cost affordability and optimal allocation of public funds among various modal alternatives. Accordingly our focus is on *government*, or *public* costs. Private costs such as the cost of an automobile or fuel [8] are irrelevant to this issue of government affordability except, insofar as they may relate to user fees.

All costs and performance quantities in this table are summed over all levels of government: city, county, state and federal and are for the fiscal year ending in 2003, the latest for which transit costs are available. Costs are expressed in 2003 dollars per person-mile. Shaded cells denote data from original sources. Others are derived therefrom.

Part 1, the upper rows 8 through 31 are the **referenced source data and derived details**.

P**art 2,** the **Bottom Lines**, rows 33 through 40, are the most significant conclusions. We will discuss these in inverse order, relegating the Part 1 source data and derivation details to the later appendices.

BOTTOM LINES Significant Findings

By Row:

33. Transport Gross cost per Person-mile

Gross costs are before accounting for user fees. Calculated as {Row 8} [Gross Cost /yr] / {Row 11}[ps-mi/yr]. Costs for the various modes vary over a range of almost 100:1; from $0.04 per person-mile for Orange County Freeways to $3.35/mile, Orange County CenterLine light rail (CenterLine *projected* cost). Notice that Orange County freeways are more efficient in this respect than national average freeways; that's because they are operating at a correspondingly higher volume loading — and congestion.

34. User fee / ps-mi (payments to the gov't.) ***and, 35. User Private Cost /ps-mi***. (payments to other private parties, e.g. base cost of automobile, supplies, parts, and accessories). [AAA Ref. 12] and ***36. User Total cost/ps-mi*** . Notice that the combined total user cost (row 35) for highway modes is two or three times that for transit users, in spite of which 98% travelers choose roads and private automobiles.

37. Transport Net Cost. /ps-mi. Calculated as Net Cost/yr {Row 10} / Person-mi/yr {Row 11}. Net cost is the cost *after subtracting user fee payments.* In other words it is the government *subsidy*, paid from general funds which would otherwise have been available for other purposes.

Transit User fees. i.e. fares, pay about 24% of transit costs {cell G24 } the other 76% is subsidy.

Highway users fees are all the sums that the government collects from highway users as a necessary condition of their use of highway vehicles and highways. Highway user fees pay 144% of highway costs {cell J24}. Accordingly the highways net cost is negative, less than zero, in other words not a cost at all but a profit. Highway uers fees pay all the expenses of planning, buying, building, maintaining and operating the roads plus a 44% profit to the government general funds. [Ref 7]. Arguably those excess user fee payments should be used to pay for sorely needed highway maintenance and capacity [7].

Row 38 ROW Requirement: {lane-mile, or /track mile per million ps-mi/day} Calc as (Row 13 * Row 19 / Row 16). This statistic addresses the concern often expressed that there is no more room for urban highways right of way. It shows that urban roads and highways take an order of magnitude *less* ROW space than transit modes, with the one exception of US bus operating in mixed traffic which is essentially the same as freeway (but not if operated in an exclusive guideway). This is because a bus in mixed traffic takes only a very small fraction, on average about 2% of the road space of the lane it is using, as expressed in the "ROW utilization factor" in row 19

Other than ordinary bus in mixed traffic, all transit (bus in guideway, light, heavy, and commuter rail, takes significantly more right-of-way, and in the case of light rail or guideway bus, one or two hundred times more ROW than freeways for the same capacity.

WHAT DO THE RESULTS MEAN? EDITORIALIZING.

Compared on the basis of total public cost per unit transportation benefit (C*), the most widely representative national average experience shows transit vastly more expensive than roads or freeways, on either gross or net cost basis. For every public tax dollar spent on transit generally, we could have bought from 10 to 100 or more times as much reduction of congestion, time delay, and emissions, if those same funds had been spent on roads or freeways.

Subsidized public transit's essential role is in providing mobility, and access, to jobs, stores, education, and recreation for those who for whatever reason cannot use the roads. But to promote transit for the reduction of congestion, or as a preferable alternative to roads and automobiles for the 98% of travelers that can, and demonstrably do prefer to drive, is to deny history, at an enormous cost in terms of foregone significant relief of congestion, energy consumption and air quality.

Significantly, the same is true of right-of-way effectiveness. All transit modes other than bus in mixed traffic use significantly more ROW per unit transport. Only bus operated in mixed-flow traffic is essentially equivalent to freeway in its ROW requirement.

If there is no more room for urban freeways, there's certainly no more room for transit.

TABLE 1 follows:

TABLE 1

	A	B	C	D	E	F	G	H	I	J	K	L	M
3	**COST AND PERFORMANCE COMPARISON OF URBAN TRANSPORTATION ALTERNATVES**									© Jack Mallinckrodt 2007			
4	**Part 1. Source and Detail Data**		**M O D E S**										
5	H:\COSTS\CostComp7+.xls	**UNITS**	**US BUS**	**US HVY RAIL**	**US COMM. RAIL**	**US LT RAIL**	**ALL US TRANSIT**	**OC CntrLine (Projctd)**	**OC Bus**	**All US RDS**	**US Fwys**	**OC FWY**	**US Transit**
6	9/3/07 13:15												**US Roads**
7	Source Refs:		1	1	1	1		12	1	2,3,4,7,8	2,3,4,8	2,3,4,8	
8	Operating Expenditures	million$/yr	$ 15,240	$ 4,446	$ 3,179	$ 815	$ 23,680	$ 11	$ 150.2	$ 84,104	$ 9,403	$ 113	28.2%
9	Capital Expenditures	million$/yr	$ 3,242	$ 4,437	$ 2,479	$ 2,325	$ 12,483	$ 65	$ 7.5	$ 63,386	$ 63,536	$ 765	**19.7%**
10	Total Gross Expenditures	million$/yr	$ 18,482	$ 8,883	$ 5,658	$ 3,140	$ 36,163	$ 77	$ 157.7	$ 147,490	$ 72,939	$ 878	**24.5%**
11	User Fees	million$/yr	$ 4,270	$ 2,654	$ 1,552	$ 229	$ 8,705	$ 3.2	$ 38.7	$ 213,123	$ 105,397	$ 1,268	4.1%
12	Net Cost (Subsidy)	million$/yr	$ 14,212	$ 6,229	$ 4,106	$ 2,911	$ 27,458	$ 73	$ 119.1	$ (65,633)	$ (32,458)	$ (391)	NC
13	Person-miles/yr	million ps-mi/yr	18,921	14,354	9,715	1,576	44,567	23	268.8	3,927,265	1,041,163	19,820	**1.1%**
14	Dir Trk-Mi or Ln-mi or Rt-mi	tk-mile or ln-mi	87,835	2,237	10,011	4,986	105,069	17	334.4	2,300,000	127,072	1,529	
15	Veh-Mi/yr (Trn-mi/yr for CR and HR)	million veh-mi/yr	1,884.5	91.7	45.9	41.4	2,064	NA	$ 23.3	2,409,365	638,750	12,160	
16	DVMT	million v-mi/day	6.02	0.29	0.15	0.13	6.593	NA	0.074	6,601	1,750	33	0.1%
17	DPMT	million ps-mi/day	60.45	45.86	31.04	5.04	142	0.05	0.86	10,760	2,853	54	**1.3%**
18	DVMT/trk-mi or ln-mi	veh/day/ln	69	131	15	27	63	NA	223	2,870	13,772	21,788	2.2%
19	DPMT/trk-mi or ln-mi	ps/day/tk	688	20,501	3,101	1,010	1,355	2,647	2,569	4,678	22,448	35,515	29.0%
20	ROW Utilization Factor	#	0.019	1.00	1.00	1.00	NA	1.00	0.019	1.00	1.00	1.00	
21	Op cost/unit $/ps-mi	$/ps-mi	0.81	0.31	0.33	0.52	0.53	0.48	0.56	0.021	0.009	0.006	24.8
22	Cap Cost/Unit $/ps-mi	$/ps-mi	0.17	0.31	0.26	1.48	0.28	2.86	0.03	0.016	0.061	0.039	17.4
23	Total Gross Cos/unit, $/ps-mi	$/ps-mi	0.98	0.62	0.58	1.99	0.81	3.35	0.59	0.038	0.070	0.044	21.6
24	User Fees /unit, $/ps-mi	$/ps-mi	0.23	0.18	0.16	0.15	0.20	0.14	0.14	0.054	0.101	0.064	3.6
25	Total Net Cost, Subsidy/unit	$/ps-mi	0.75	0.43	0.42	1.85	0.62	3.21	0.44	(0.017)	(0.031)	(0.020)	
26	% Subsidy	%	77%	70%	73%	93%	76%	96%	75%	(0.04)	(0.04)	(0.04)	
27	Avg Speed , mph	mph	12.7	20.6	31.7	15.7	19.5		13.0				
28	AVO (ATO for HR and CR)	ps/veh	10.0	156.6	211.8	38.0	NA		11.2	1.63	1.63	1.63	
29	Avg Unlinked Trip Length , mi	mile	3.7	5.1	23.3	4.4	8.4	4.8	3.9	9.72			
30	ADTp	ps/day/ln	688	20501	3101	1010	1355	4,292	2,569	4,678	23,757	35,515	
31	ADTv	veh/day/ln	68.5	130.9	14.6	26.6	NA		229	2,870	14,575	21,785	
32	**Part2. Significant Results**												
33	**Transport Gross Cost /ps-mi**	$/(ps-mi)	**$ 0.98**	**$ 0.62**	**$ 0.58**	**$ 1.99**	**$ 0.81**	**$ 3.35**	**$ 0.59**	**$ 0.04**	**$ 0.07**	**$ 0.04**	**0.05**
34	**User Fee /ps-mi**	$/(ps-mi)	**$ 0.23**	**$ 0.18**	**$ 0.16**	**$ 0.15**	**$ 0.20**	**$ 0.14**	**$ 0.14**	**$ 0.05**	**$ 0.10**	**$ 0.06**	**0.28**
35	**User Private Cost/ps-mi**	$/(ps-mi)	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 0.32**	**$ 0.32**	**$ 0.32**	
36	**User Total Cost per ps-mi**	$/(ps-mi)	**$ 0.23**	**$ 0.18**	**$ 0.16**	**$ 0.15**	**$ 0.20**	**$ 0.14**	**$ 0.14**	**$ 0.37**	**$ 0.42**	**$ 0.38**	**1.92**
37	**Transport Net Cost /ps-mi**	$/(ps-mi)	**$ 0.75**	**$ 0.43**	**$ 0.42**	**$ 1.85**	**$ 0.62**	**$ 3.21**	**$ 0.44**	**$ (0.02)**	**$ (0.03)**	**$ (0.02)**	
38	**Subsidy**	%	**77%**	**70%**	**73%**	**93%**	**76%**	**96%**	**75%**	**-44.5%**	**-44.5%**	**-44.5%**	
39	**Net Cost of Capacity**	$/(ps-mi/day)	**235.1**	**135.8**	**132.3**	**578.1**	**192.8**	**1629.7**	**138.6**	**-6.1**	**-11.4**	**-7.2**	
40	**ROW Efficiency**	(ln-mi)/ (mill ps-mi/day)	**27.2**	**48.8**	**322.5**	**990.1**		**377.8**	**7.3**	**213.8**	**44.5**	**28.2**	

42	SOURCES:	Shaded cells denote primary data from listed sources. Non-shaded derived therefrom.
43	Transit: [1] National Transit Database, FTA, 2003	Highway user fees allocated to road categories in proportion to total gross cost
44	Highways: [2] "Highway Statistics" FHWA 2004	For Rail components Vehicle is taken as Train
45	[3] "Highway Performance Monitoring System",FHWA, 2003	"trk" = "ln" = 13 ft width
46	Auto AVO: [4] "National Household Travel Survey", NHTS, DOT, 2001	"trk-mi"="ln-mi"=1.57 acre
47	CenterLine: [12] "5309 New Starts Report", FY2006, OCTA, 2005	

References

1. "National Transit Database and Transit Profiles" USDOT, Federal Transit Administration, for FY 1999 (Published annually). On line at <http://www.ntdprogram.com/NTD/ntdhome.nsf?OpenDatabase>

2. "Highway Statistics 1999", USDOT, Federal Highway Administration, published annually. On-line at http://www.fhwa.dot.gov/ohim/ohimstat.htm

3. "Highway Performance Monitoring System" (HPMS), FHWA, 2003. Updated every 2 to 5 years . Online at http://www.fhwa.dot.gov/policy/ohpi/hpms/

4. "National Household Travel Survey, NPTS 2001", US DOT/FHWA . On-line at <http://npts.ornl.gov/npts/1995/doc/>

5. Mallinckrodt, A. J. "A Multimodal Congestion Index", AJM Engineering, Rev 3, August, 2007. On-line at www.urbantransport.org/index1.pdf

6 "Highway Economic Requirements System", V.- IV, Technical Report", Table 7-11, FHWA-PL-00-028. December 2000 <http://www.dot.state.oh.us/gasb34/FHWAAsset_Management+GASB_34/eei%20team/hers_st/documentation/HERS%20Tech%20printready.pdf>

7. Mallinckrodt, A.J.,"Highway Subsidies", AJM Engineering, August, 2007,. on-line at <http://www.urbantransport.org/hwysub.pdf>

8. "How Much Does it Cost to Drive", AAA, on-line at <http://www.nctr.usf.edu/clearinghouse/costtodrive.html>

9. "Urban Mobility, 2004" (for year 2003 data), Texas Transportation Institute, Annual. <http://mobility.tamu.edu/>

10. "Freeway Performance Measurement System PEMS", UC Berkeley, <https://pems.eecs.berkeley.edu/>

11. "Highway Capacity Manual", Special Report 209, Transportation Research Board, National Research Council, 1985, Sect 12.

12. "5309 New Starts Report-FY2006", OCTA 2005.

APPENDIX 1. DERIVATIONS. Explanatory notes

Shaded Cells in Table 1 denote Source Data, from the indicted source reference in the column head.

Item Discussion By Row:

8. *Operating Expenditures.* These include all public expenditures for administration, research, planning, construction, operation, maintenance, law enforcement and safety.

9. *Capital Expenditures*. These include all public expenditures during the year (2003) for design, ROW acquisition, building and equipment purchases. Transportation management generally does not use nor report depreciation accounts, as would be standard practice in the private sector. There are both advantages and disadvantages of capital expenditure accounting. The principal disadvantage is the extreme year-to-year variability, which for individual agencies might often give a distorted picture, either high or low, of overall capital spending. For our purposes, however, summed over the 600 or so operating agencies represented in the national statistics, these year-to-year variances are well averaged out. In the long run, with proper accounting for the time-value of money, the two approaches must give the same annual capital costs.

10. *Total Gross Expenditures.* The sum of all US operations plus capital public expenditures for the year, 2003.

11. *User Fees (Costs).* This is the government income attributable to users of each system alternative or mode. For transit these are the fare-box receipts as tabulated in the NTDB[1]. For the Highway columns they include all tax payments to the government paid by and only by highway users as a de jure or de facto condition of their use of automobiles and highways. It does not include personal expenses of owning and running an automobile [8]. User fees is a complex, arguable, issue discussed at length and quantified in Reference [7].

12. *Total Net Expenditures.* Computed as Gross expenditures (row 9) minus user fares and fees (row 10). This is equivalent to the government "subsidy", the portion of the gross cost paid from general funds as opposed to user fees. For freeways, total highway user fees are attributed to sub-classes of highways in proportion to gross cost.

    Note that for all roads and highways categories, <u>this quantity is negative</u>, meaning that total highway user fees *more* than cover total government expenditures on highways and the net amount is an *inverse* subsidy, is a government *profit* on the operation of highways. If the government were to retire completely from the roads business, no highway costs and no highway user fees, all other government budgets would have *less* to spend on other functions [7].

13. *Person-Miles/year*. This is the fundamental measure of urban transport provided by the alternative. Given as source data for Transit; derived as Vehicle miles/yr times US Average Vehicle Occupancy for all purposes 1.63 person/vehicle [4].

For all US roads this is the annual road vehicle-miles, 2.9 trillion veh-mi/yr [2], times the US national average vehicle occupancy (AVO), for all trip purposes, and time-of-day, 1.63 persons per vehicle [4].

14. *Directional Track-Miles, or Lane-Miles.* A track is considered effectively the same width as a road lane (12-13 ft) for the present purposes.

15. *Vehicle-Mile/yr* (Train mile/Year for Rail).

16. *DVMT* Daily Vehicle-Miles Traveled. Transit data is given in vehicle miles/year, and divided by (average 313 "weekdays" per year) for DVMT. Roads data is given in vehicle miles/day, multiplied by 365 for Vehicle miles/year.

17. *DPMT, Daily Person-Miles Traveled.*

18. *DVMT / Trk-mi or ln-mi.* Calc. as {row 16}/{row 14}.

19. *DPMT / trk-mi or ln-mi.* Calc as {row 17}/{row 14}.

20. *ROW utilization factor.* A bus route in mixed traffic uses only a small fraction, about 2% of capacity of the lane it uses. Calculated as 1.6 *(Bus ADT/rt)/autoADT/ln), 1.6 being the passenger car equivalent to one bus in terms of congestion [11]. For this purpose it is assumed that buses run in principal arterial street lanes.

21. *Ops Cost/unit.* The normalizing unit of transport is taken as person-mile/day. Calc. as {row 8} / {row 13}.
22. *Cap Cost/ unit.* Calc as {row 9} / {row 13}.
23. *Total Gross Cost/ unit* Calc as {row 10}/{row 13}.
24. *User fees /unit* For transit, {row 11}/{row 13}. For roads, 145% of gross cost [Ref 7]. The latter is an allocation of total user fees over all road-highway modes, in proportion to gross cost.
25. *Total net cost/ unit.* Calc as {row 12} / {row 13}.

26. *% subsidy:* Net cost{row 10}/Total Gross Expenditure {Row 8} x 100.

27. *Average Speed:* Vehicle miles / Vehicle hours, mph.

28. *Average Vehicle Occupancy:* For transit = person-miles/vehicle miles Calc {row 13}/{row 15}. For roads from Ref [4]

29. *Average Trip Length:* For transit this is given as a single link (i.e. transfer to transfer) in a commonly multi-link end-to-end trip. For roads, end-to-end trip. So not generally comparable between roads and transit.

30. *ADTp:* Average Daily Traffic, *persons*/day passing a point or screen-line. Calc as {row 13} / {row 14}.

31. *ADPv:* Average Daily Traffic, *vehicles*/day passing a point or screen-line. Calc as ADTp /AVO, {row 30}/{row 28}.

Rows 33 to 40 have been discussed above in the context of bottom line results.

Appendix 2. FREEWAY GROSS COST

The seminal Department Of Transportation references, “Transit Profiles” [1]. and “Highway Statistics” [2] provide most of the necessary data on performance and costs for every transit agency and mode, and for all US roads taken as a whole. This provides, arguably, the best, most reliable possible estimate of probable performance of a typical capacity addition of any given mode. However, the reported cost data do not differentiate between different classes of roads, in particular freeways. Therefore, Table 2 compiles a widely representative collection of freeways for which costs are known or well estimated and derives from them the necessary comparable statistic, $/ps-mi, for the freeway component of Table 1.

The compilation in Table 2 is in two parts, first: total (operating plus amortized capital) cost per day per lane-mile; second: volume per day per lane, which together with the average vehicle occupancy yield the cost per unit transportation, $/person-mile:

The first four freeway items (rows) in Table 2 are from the FHWA HERS (Highway Economic Requirements System) program [6]. These are the results of a major freeway cost data collection effort by FHWA in support of their ongoing effort to standardize and improve highway long-term economic planning. These provide a range of costs of various freeway build and widening scenarios ranging from $1.7 to $9.2 million/lane-mile. All costs quoted herein are updated from the year of reference to 2004 dollars on the basis of the US ENR Construction Costs Index.

The 1990 Orange County 20 year plan included 248 lane-miles of freeway addition, estimated at that time as averaging $7.3 million/ln-mi. Ten years later, in year 2000, 374 lane-miles had been built at an average cost of $7.7 million/ln-mi.

Also at about 1990 the Automobile Club of Southern California put forth a wide ranging plan of recommended freeways to be widened or built, at an average cost of $11.0 million per ln-mi (updated to 2002 $).

Representative of the most expensive freeway, the Boston Central Artery provides 161 lane-miles at a total cost of $90.7 million/ln-mi. This included an exceptionally wide range of extra expenses including tunneling, bridges, and community redevelopment.

All these costs include right-of-way which is usually the larger part of the total cost. Together these costs cover an immense range of from $1.65 to $95 million per lane-mile. Of course averages can never replace actual estimates or experience in individual cases, but for broad policy and planning purposes it is essential to have a nominal cost expectation and we take that to be $10 million/lane mile, close to the geometric mean of the extremes, somewhat more than the worst case DOT HERS scenario, and conservatively covering most recent current multi-freeway programs.

On the basis of 30-year life and 3% *real* interest (corresponding to the use of *constant* 2002 dollars), the corresponding total annualized cost including operations and maintenance (O&M) is $574,000 per lane-mile per year, or $1572 per lane-mile per day.

Transportation volume per lane-mile, varies significantly from city to city, closely related to regional congestion level (see [5] and particularly the discussion at Figure 2 there. The data for this is compiled and documented annually in [2], Table HM-72 for all major cities. Table 1 here shows it varying from 12,772 veh/day/ln for Birmingham, AL (first quartile, less than average congestion), to 14,086 for San Antonio (median, average congestion), to 23,293 veh/day/ln-mi for Los Angeles, (worst case in US). We will use the U.S. median value, 14,086 person-miles/day/lane-mile as most representative.

Average vehicle occupancy (AVO) is taken from the National Personal Transportation Survey (NPTS) [4]. While AVO varies somewhat with place, time-of-day, and trip purpose (to work, school, shopping, etc.) it is well characterized by the US average for all times and purposes, 1.63 persons/vehicle [4].

Combining all these factors gives the bottom line, gross cost, $0.071 (seven cents) per person-mile, 2003$ carried forward to Table 2.

This is a median cost estimate, and as shown, is subject to a wide range of variability in individual cases as shown in its component ranges above.

Table 2. Freeway Cost / person-mile

All costs expressed in year 2002 dollars

Urban Freeway Costs, $/lane-mile	**$million/ln-mi**	
HERS		
Reconstruct and Add High-Cost Lanes	9.2	"HERS Technical Report", FHWA, Dec 2000, Table 7-11
Reconstruct and Add Normal-Cost Lanes	3.9	"
Major Widening at High Cost	9.2	"
Minor Widening	1.7	"
Orange County 20 yr plan, 1990, 248 ln-mi	7.3	OC 20 Year Plan, 1990
Orange County actual, last 10 yrs., 374 ln-mi	7.7	OC Register, 11Feb, 1999
Auto Club Yr 2000 plan	11.0	"Year 2000 Plan", Auto Club of Southern Calif.
Boston Central Artery (Big Dig), 161 ln-mi	90.7	Central Artery Web Site. Believed to be max US.
Median Consensus	10.0	million $/ln-mi, 2000 dollars

Annualization Factor, 30 yr, 3% real interest	0.050	
Annualized Fwy Cap Cost	$ 500,000	yr 2000 $/yr/ln-mi
Annual O&M	$ 74,000	yr 2000 $/yr/ln-mi, Caltrans
Total Annualized Cost	$ 574,000	yr 2000 $/yr/ln-mi
Total Daily Cost (365 day/yr)	$ 1,572.6	yr 2000 $/day/ln-mi

Volume, veh/day / lane-mile		
Volume / ln-mi		
Los Angeles (Max)	23,293	veh/day/ln = veh-mi/day/ln-mi
Sacramento (3rd Quartile)	16,916	
San Antonio (Median)	14,086	
Brimingham (1st Quartile)	12,772	

Overall Cost/Benefit, median $/person-mile		
Gross Cost / veh-mi	$ 0.112	yr2002 $/veh-mi
Gross Cost / ps-mi (AVO =1.59)	0.07	NTPS 95, all US, all purposes

* All costs expressed in 2002$, translated from terms of orignal reference based on the ENR Construction index.