An Analysis of Ridership Forecasts for the Los Angeles Metro Red Line:

Alternative Strategies and Future Transit Improvements

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Abstract

Ridership carried by the completed Red Line will stabilize well below the levels forecast prior to the start of construction, and those currently forecast by the Los Angeles County Metropolitan Transportation Authority. This will occur because the line cannot accommodate the peak-period volumes implied by these forecasts, given the travel patterns typical of U.S. cities and the crowding levels which consumers are likely to tolerate.

The Red Line is likely to achieve the highest traffic density (passenger-miles per route-mile) of any postwar U.S. heavy-rail line. It may increase the total travel (passenger-miles) carried by the LACMTA system by more than ten percent.

The likely ridership ceiling for Red Line, once extended to Hollywood, is in the range of 100,000 -- 150,000 per weekday, assuming an adequate peak-period service level. Upon completion to North Hollywood, the likely ridership ceiling is in the range of 120,000 -- 170,000 per weekday, depending on the distribution of ridership throughout the day and consumer tolerance for peak-period crowding.

In order to accommodate 200,000 -- 250,000 passengers per weekday, as currently forecast [at June 1997], LACMTA would have to invest in upgraded terminal facilities, improved signals, and possibly, automatic train operation. The current forecasts imply peak-hour volumes exceeding 32,000 pass/hr, far higher than observed in any U.S. city except New York. Even if such demand does exist, serving it might not be cost-effective -- just as freeway widening to accommodate all peak-period demand is not cost-effective.

Evaluation of Red Line results would have to consider that 1.) travel-time savings attract more passengers and longer trips to transit, and 2.) improvements leading to significant increases in average travel distance may also lead to large operating-cost increases. The Red Line will generate an LACMTA system-wide travel (passenger-mile) increase of 6-17 percent -- or more, depending on how much Red Line travel is "new" -- all concentrated in one corridor. In order to accomplish this with buses, LACMTA would have to operate 11-16 million more vehicle-miles annually, a 14-21 percent increase over the 1996 systemwide total -- while managing to provide similar travel-time reductions. Such alternative service would cost $40-70 million more per year to operate than the Red Line. (All cost comparisons herein are based on 1996 system performance, and are expressed in 1996 dollars.)

An expanded Red Line, reaching Warner Center in the San Fernando Valley, Whittier/Atlantic in East Los Angeles, Beverly Hills, Century City, UCLA and Santa Monica would increase

LACMTA system travel (passenger-miles) by roughly 50 percent. Annual operating cost would be $100-200 million less than bus services achieving the same results.

The most needed mass transit improvement in Los Angeles is travel-time reduction. This stems from the large size of the region and the scattering of employment opportunities miles away from inner-city residents, who are effectively cordoned off from jobs which lie beyond the range of tolerable bus commuting. The large potential market for longer transit trips has been demonstrated since 1990 by the light-rail Blue Line, which attracts a peak-period average travel distance greater than ten miles.

The Red Line will be quite competitive with the 1983-1985 fare subsidies in terms of additional travel and boardings. Operating cost for the completed Red Line should fall in the range of $0.25-0.35 per passenger-mile, compared to $0.80 per passenger-mile generated by the fare subsidies. Results in terms of boardings also favor the Red Line: $3.00 per boarding compared to $4.00 per boarding (in today's dollars) attracted by the 1983-1985 subsidies.

A ten-percent increase in LACMTA annual bus-miles would generate about 70,000 additional weekday boardings, at an annual cost of $60 million. The implied cost per boarding, $2.50, is lower than that for the completed Red Line, but the cost per passenger-mile would be more than twice the Red Line figure. Successive service increases would not generate increased ridership in proportion (without other improvements), and would erode the cost-effectiveness of LACMTA's bus system.

Targeted fare subsidies and bus service expansion should be implemented, but general fare subsidies or large-scale increases in vehicle mileage are not low-cost "shortcuts" to better transit service.

The tradeoffs among busways, light rail and heavy rail include capital cost, operating cost and ridership ceilings. Busways are strongly competitive with light rail; they may be implemented in unconnected stages, as in Ottawa, and so would have a strong advantage even if capital costs were equivalent. However, busway operating costs are often underestimated. The lower peak vehicle occupancies carried by U.S. busway, transitway and HOV services imply that a busway option would have to provide 40 percent higher peak service levels than a rail alternative in the same corridor. The reasonable maximum for light rail in U.S. cities, implying four-car trains every three minutes during peak periods, is about 8,000 pass/hr, implying about 60,000 pass/weekday. Higher volumes require full grade separation, which essentially means heavy rail. Busways are not a realistic option in corridors where peak volumes exceed this level.

Ridership estimates for U.S. cities, based on performance of systems overseas, are likely to be inflated. The fact that individual heavy-rail lines carry more than one million passengers per day overseas does not imply that the same facility, duplicated in the U.S., would provide similar results. Similar examples may be given for busways and light rail.

The busway and light-rail options for the Eastside and San Fernando Valley corridors are feasible alternatives to heavy rail, and could offer similar travel times. Net capacity, however, would be considerably less. Busway operating costs would be highest of the three modes.

Light rail is probably not feasible in the Westside (Exposition) corridor without a separate entrance into downtown Los Angeles. Peak-period traffic potential and experience in other U.S. cities suggest that the current 7th St/Metro Center Blue Line terminal could not accommodate traffic from both lines.

There is no technical reason why future heavy-rail or light rail lines need include any "subway" alignment. Light rail may be built on surface streets, as the Blue Line demonstrates. Both heavy rail and light rail may be built on viaduct, alongside freight railroads and in retained cuts. However, where heavy-rail capacity is needed, and where alternative alignments are not available, construction of elevated structures along major streets may impose unacceptable environmental impacts. It is difficult to imagine a non-subway alternative to the currently-funded Red Line, except perhaps over Cahuenga Pass. In addition, failure to connect the Long Beach and Pasadena Blue Lines will eventually impose a serious peak-period capacity constraint in downtown Los Angeles, overloading the Red Line between Union Station and 7th St/Metro Center.

Los Angeles residents and community leaders should carefully consider various strategies for public transportation improvements. Capital-cost savings may be quickly absorbed by operating-cost increases. For example, $200 million would purchase 600 buses, which would cost $200 million per year to operate. Total cost for 600 buses and four years of operation: $1 billion. Maximum plausible weekday ridership increase: 200,000 -- 250,000. Service quality improvements, such as reduced travel times: none.

Dedication / *Para Dedicar*:

To Maria del P. V., a gracious young woman with a gift for mathematics, forced to drop out of high school by lack of reasonable alternatives to autos for travel between home, work and school, many miles apart.

Dedicar por Maria del P. V., una mujer joven graciosa con la habilidad para las matemáticas, obligado para caer de escuela secundaria por la carencia de alternativas razonables a los automóviles para el recorrido entre el hogar, el trabajo y la escuela, muchas millas separadas.

1) Introduction

The Los Angeles Metro Red Line is a heavy rapid transit line, with all but service tracks underground, opened in two stages in 1993-1996. Additional segments, scheduled to open in 1999 and 2000, will bring the (revenue) line length to 15 miles between Union Station and North Hollywood, with a one-mile branch to Wilshire/Western. Work on planned extensions has been suspended owing to the Los Angeles County Metropolitan Transportation Authority's financial situation. Also, in November 1998, voters in Los Angeles County approved a ban on the use of local sales-tax revenues for additional "subway" construction.

The original (1983) Draft Environmental Impact Statement for the Red Line project (then called "Metro Rail") forecast an average weekday ridership of 376,375 (by 2000). The route was later revised, in response to a 1985 methane gas eruption and fire along the planned route, and a Congressional ban on tunneling though this area. The ridership forecast was adjusted downward to 298,000 per weekday (as a consequence of longer travel times). The "current" forecast is 200,000 per weekday once extended to Hollywood, and 250,000 per weekday (by 2020) for the completed line.

It should have been clear from the beginning that ridership on the completed (16-mile) Red Line could not approach 377,000 per weekday, nor even 200,000 per weekday. The underlying limits were not considered (or, perhaps, not understood) when these forecasts were prepared.

The factors in question have little to do with "demand," since transit ridership is a measure of service consumption, not travel demand. This consumption stems from the interaction of travel demand and service supply factors. The fact that consumption ("ridership") may be influenced by service quantity has been demonstrated most recently in Portland (below), where recent light-rail service increases generated a large ridership increase.

A federally-funded study[1] of several rail projects opened during the 1980s failed to note that these lines, as built, were not capable of carrying the peak-period traffic implied by the forecasts. Given the temporal distribution of travel typical of U.S. cities, these forecasts implied peak-period loads of 300-500 passengers per vehicle. This problem stemmed from inadequate reconciliation of demand and supply factors. Since the required service levels were not provided, the forecasts in question were not tested.

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[1] Pickrell, Donald H. 1989. *Urban Rail Transit Projects: Forecast versus Actual Ridership and Costs*. Prepared for Office of Grants Management, Urban Mass Transportation Administration, U.S. Department of Transportation.

The 1983 DEIS forecast implied peak-period ridership far higher than the line, as built, might reasonably serve, given the consumption patterns typical of U.S. rail systems. The Red Line does not have sufficient capacity to accommodate the peak-period travel volumes implied by the forecasts. Actual ridership will, therefore, fall below the levels forecast.

(Similar oversights are suggested by the 1998 DEIS for Seattle's "Central Link" light-rail project. The operating plan [current at June 1997] does not provide sufficient service for the implied peak-period travel volumes.)

Another, related problem stems from changes in the average distance traveled by each passenger. The underlying limit to transit "capacity" is a function of passenger-miles, not passenger-trips. However, travel-demand modeling as typically practiced in the U.S. does not take trip length (travel distance, or ride length) into consideration. Underestimation of average travel distance (ATD) may lead to wildly inflated ridership forecasts, as was (and, evidently, remains) the case for the Red Line.

The literature regarding transit planning and travel-demand forecasting contains little information on average travel distance by transit, and virtually none regarding ATD changes resulting from service changes[2]. Travel distance, it would seem, is assumed to remain constant.

Transit passenger travel distance, however is not "constant." Linked-trip[3] data, when available (e.g. for Atlanta and Houston), illustrate that average transit trip lengths have increased since the 1970s. The principal factor driving this trend is suburbanization of population and employment, and expansion of transit services from "core" cities to serve this new development. However, an important contributing factor is the greater passenger speed provided by new rail lines, busways and HOV facilities.

In Atlanta, average passenger speed (weighted by the share of boardings carried by bus and rail modes) increased from 13.4 to 22.4 mph between 1979 and 1996. During the same period, the average distance per linked trip (or revenue passenger) increased from 5.7 to 9.8

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[2] Rosenbloom, for example, gives no information about transit travel distance. (Rosenbloom, Sandra. 1998. Transit Markets of the Future - The Challenge of Change. (Transit Cooperative Research Program Report No 28). Washington, DC: Transportation Research Board, National Research Council.)

[3] A linked trip is a complete trip from one point to another, possibly using more than one vehicle. Each linked trip is made up of one or more unlinked trips. These are trips or rides aboard a single vehicle between two points.

miles. Land-use and demographic changes are certainly responsible for some of this increase, but increased travel distance also reflects the time savings made possible by rail development.

Table 1:

Selected Statistics for U.S. Rail Transit Systems Opened After 1968 (1996 data)

	Route-Miles	Average Passenger Speed (mph)	Average Weekday Ridership	Weekday Equivalents (Annual Passengers / Average Weekday Passengers)
LIGHT RAIL				
Baltimore	21.8	27.1	21,000	301
Buffalo	6.2	18.3	25,000	283
Denver	5.3	14.6	14,000	303
Los Angeles	21.6	24.5	37,000	328
Pittsburgh	19.1	15.7	25,000	294
Portland	15.1	19.7	30,000	337
Sacramento	18.1	20.3	26,000	299
St. Louis	17.0	25.5	37,000	346
San Diego	22.6	26.0	48,000	350
San Jose	19.5	20.2	20,000	309
RED LINE *	16	32	376,375	(300)**
HEAVY RAIL				
Atlanta	46.1	32.2	234,000	309
Baltimore	14.7	29.4	42,000	279
Los Angeles****	3.0	20.0	25,000	312
Miami	21.1	30.7	48,000	300
Phila-Lindenwold	15.8	34.7	38,000	277
S.F.-BART	75.8	38.3	263,000	293
Washington, DC	89.1	31.0	676,000	287

* 1983 Draft Environmental Impact Statement parameters. ** Assumed. **** Operational Red Line segment, Union Station - Wilshire/Alvarado.Average passenger speed estimated from public timetables.

Table 1 (continued):

Selected Statistics for U.S. Rail Transit Systems Opened After 1968 (1996 data)

	TRAFFIC DENSITY		Annual Vehicle-miles per Route-mile	Pass-mi Per Veh-mi	AVERAGE TRAVEL DISTANCE	
	Average Weekday Passengers Per Rt-mi	Average Wkdy Pass-mi Per Rt-mi			---Rail	---Bus
LIGHT RAIL						
Baltimore	960	6,300	102,000	18.4	6.5	3.0
Buffalo	4,030	8,900	144,000	22.0	2.2	3.2
Denver	2,550	7,100	100,000	22.0	2.8	4.3
Los Angeles	1,710	14,400	130,000	36.3	8.4	3.7
Pittsburgh	1,310	7,100	86,000	23.8	5.4	4.1
Portland	1,990	9,500	102,000	31.2	4.8	3.7
Sacramento	1,440	7,000	102,000	20.8	4.9	4.0
St. Louis	2,180	13,300	150,000	31.4	6.1	3.8
San Diego	2,120	14,000	188,000	26.5	6.6	4.1
San Jose	1,030	4,700	98,000	15.2	4.6	3.9
RED LINE*	23,500	89,400	620,000	40	3.8	***3.8
HEAVY RAIL						
Atlanta	5,080	30,500	490,000	19.4	6.0	3.1
Baltimore	2,860	11,700	288,000	11.3	4.1	3.0
Los Angeles****	8,300	12,500	266,000	14.2	1.5	3.7
Miami	2,270	17,700	278,000	19.2	7.8	4.0
Phila-Lindenwold	2,400	21,200	272,000	23.1	8.8	5.9
S.F.-BART	3,470	41,300	606,000	20.4	11.9	3.9
Washington, DC	7,590	41,000	464,000	25.1	5.4	3.2

NOTES FOR TABLE 1:

* 1983 Draft Environmental Impact Statement parameters. **Assumed. *** Wilshire Corridor bus services (1980). ****Operational Red Line segment, Union Station - Wilshire/Alvarado.

Dallas light rail omitted from this tabulation as it did not operate for the full year (1996).

Baltimore Metro (heavy rail) did not operate on Sundays.

BART "bus" average travel distance is that for AC Transit.

Source: National Transit Database statistics for 1996; Los Angeles light rail (Blue Line) statistics are for 1995. Average passenger speed estimated from public timetables.

Various parameters for U.S. rail systems opened after 1968 are presented in Table 1 (above). As may be seen, the ATD carried by rail lines is longer than carried by bus services in each city (although the magnitude of the difference varies considerably). Heavy-rail lines offer significantly faster service than light-rail facilities, and tend to attract longer (unlinked) trips.

Longer transit trips as the result of reduced travel time have substantial implications for transit planning, as will be outlined below. This is true in particular for Los Angeles, and especially so for its transit-dependent population.

Peak-period capacity imposes a limit on transit ridership in a straightforward manner. In the U.S., roughly 50 percent of weekday transit ridership occurs during the five to six busiest hours. There are well-defined limits to the number of vehicles per hour which may be operated safely, or efficiently, along a single lane or track. Although less well-defined, the number of people who will choose to occupy an enclosed space such as a transit vehicle also imposes an upper limit on "capacity." A transit facility unable to accommodate peak-period demand is unlikely to "make up" for "lost" ridership during other hours.

The fact that "capacity" is a function of passenger-miles instead of passenger-trips may be demonstrated as follows: Assume a five-mile line with four intermediate stops, each spaced one mile apart, and consider only one direction of travel. Establish a maximum service level of 100 vehicles per hour, and an enforced limit of 100 passengers per vehicle. If all passengers alight at each stop, and are replaced by 100 "new" passengers, the result is 100 x 100 = 10,000 passenger-trips per hour between each pair of stations. Result: 50,000 passenger-miles and 50,000 passenger-trips per hour (per direction). If vehicles operate full between terminals, leaving no room for boardings at intermediate stops, the hourly passenger-mile figure remains at 50,000 but the number of passenger-trips falls to 10,000. If the operator wishes to carry additional trips, either the service level or the vehicle-occupancy level must increase to accommodate additional passenger-miles of travel (PMT).

Service improvements which reduce travel time tend to attract more -- and longer -- trips, requiring additional service. However, "ridership" in terms of passenger-trips will stabilize once peak service levels reach the practical maximum, and peak vehicle occupancy reaches the limit of consumer tolerance. That, in brief, is the problem facing Los Angeles.

Two straightforward "reasonableness tests" of a transit ridership forecast may be conducted given sufficient details. These are the "passenger-mile test" and the "peak vehicle occupancy test," as outlined below. The Red Line forecasts fail both tests.

2) Passenger-Mile Test

This test is based on the relationship between service supply and consumption described by the following equation:

$$\text{ridership (passengers)} = \frac{\text{service effectiveness (pass-mi / veh-mi)}}{\text{average travel distance (mi)}} * \text{service quantity (veh-mi)}$$

The annual ridership figure, based on 300 "weekday equivalents" (the ratio of annual total to average weekday ridership), was estimated at 110 million. 300 weekday equivalents is a "typical" figure for the heavy-rail lines in Table 1. Average travel distance was 3.8 miles, as derived from the 1983 DEIS, which forecast 1,419,000 weekday passenger-miles and 376,375 weekday boardings by 2000. The test was also conducted with ATD figures of six, seven and eight miles, based on figures typical of U.S. heavy-rail lines (Table 1). Annual service level, also from the 1983 DEIS, was 10,553,000 vehicle-miles (for 2000). This implies 620,000 annual vehicle-miles per route-mile, more than operated by any heavy-rail system in Table 1[4].

[4] New York-NYCTA operated 1.2 million annual veh-mi / route-mi in 1996; New York-PATH operated 910,000 annual veh-mi / route-mi.

Table 2: Passenger Mile Test for the Los Angeles Red Line DEIS Forecast

GIVEN:		
Annual Ridership: 110 million passenger-trips		
Annual Service Supply: 10.5 million vehicle-miles		
AVERAGE		SERVICE
TRAVEL	***implies***	EFFECTIVENESS
DISTANCE		(pass-mi per veh-mi)
(miles)		
3.8		**40**
6		**63**
7		**73**
8		**84**

Even the most cursory comparison with Table 1 will reveal that the service-effectiveness levels implied by the Red Line forecast are unrealistically high (the figures for the five busiest subway lines in Tôkyô range between 69 and 93 pass-mi / veh-mi).

In general, for a U.S. urban rail system, a service-effectiveness level greater than 25 suggests that peak-period crowding may approach the threshold of consumer tolerance. Only three systems in Table 1, all light-rail lines, carry more than 30 pass-mi / veh-mi. Two of these, Los Angeles (Blue Line) and Portland, had maximum service levels which were not adequate for peak traffic levels: in Portland owing to car fleet size (1996) and in Los Angeles owing to the two-car maximum train length (LACMTA plans to lengthen station platforms to permit operation of three-car trains by fall 2000).

Service effectiveness (pass-mi / veh-mi) statistics for the five prewar U.S. heavy-rail systems (1996) were:

Boston	17.5
Chicago	17.6

New York - NYCTA	22.8
New York - PATH	22.3
Philadelphia - SEPTA	25.1

Many prewar heavy-rail lines use smaller vehicles than postwar systems, leading to relatively low service-effectiveness statistics. This is true in particular of Boston, Chicago and New York-PATH.

The ATD implied by the original Red Line DEIS suggests a serious planning oversight. ATD carried by Wilshire corridor surface buses (at 1980) was 3.8 miles, same as forecast for the rail line. The forecast assumed that rail service, 2.5 - 3 times faster than surface buses, would not attract longer trips. This assumption may have seemed reasonable, or may not have been examined at all. It did, however, lead to a hugely inflated ridership forecast. Given an "actual" ATD of 8.4 miles (same as carried by the Los Angeles LRT Blue Line), and all other factors as forecast (including the unrealistic 40 pass-mi / veh-mi), "actual" ridership would fall in proportion, to 170,000 passengers per weekday. (Operating cost per passenger would, of course, also increase in proportion.) Thus, a ridership "shortfall" and a unit operating cost "overrun" would occur only because the line attracted longer trips than forecast. The implied service effectiveness levels suggest another serious planning oversight: ridership forecasting procedures evidently did not include reconciliation of boarding forecasts for each station with the likely net capacity of the planned service[5].

4) Peak Vehicle Occupancy Test

This is based on the relationship among weekday ridership, temporal distribution of travel and peak service supply described by the following equation:

Average Weekday Ridership * Peak Traffic Share = Peak Vehicle Occupancy * Peak Service Supply

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[5] This oversight is not unique. According to UMTA, no sum of boarding forecasts for each stop of the Pittsburgh LRT project appears in either the Draft or Final EIS. These were evidently prepared without reference to service-supply factors. (Pickrell, Donald H. 1989. *Urban Rail Transit Projects: Forecast versus Actual Ridership and Costs*. Prepared for Office of Grants Management, Urban Mass Transportation Administration, U.S. Department of Transportation.)

"Peak traffic share" (PTS) is the ratio of one-way traffic during the busiest hour (in the busier direction, at the maximum-load point) to two-way, all-day ridership. This is a measure of the "peaking effect" which is characteristic of urban travel. An indicator variable, PTS reflects factors including consumer choice which shape the temporal distribution of weekday travel demand. These are not fixed, unchanging characteristics of a particular city or corridor. PTS may change significantly over time, particularly with introduction of a new service into an urban travel market -- in a manner which planners may not anticipate. PTS may also be influenced by policies encouraging long-term land-use changes to stimulate off-peak and "reverse-peak" transit patronage, and short-distance travel away from the busiest sections of the line.

Table 3. Peak Vehicle Occupancy Observations

City and Corridor	Year	Peak Service Consumption, phd	Peak Service Supply, vhd	Peak Vehicle Occupancy	
				pass/veh	pass/meter of vehicle length
LIGHT RAIL					
Boston, Green Line	1994	10,000	90	111	5.1
Buffalo, LRRT	1997	1,240	25	50	2.4
Calgary, Northeast Line	1994	3,395	33	103	3.8
" " ", South Line	1994	4,950	33	150	5.5
Dallas, Red Line, City Place	1997	1,440	12	120	4.2
Edmonton, Northeast LRT	1994	3,219	36	89	3.7
Los Angeles, Blue Line	1997	2,400	20	120	4.4
Newark, City Subway	1994	1,769	30	59	4.2
Pittsburgh, LRT	1997	2,848	27	105	4.1
Portland, Eastside LRT	1996	1,585	13	122	4.6
" " " "	1998	2,476	22	112	4.2
Sacramento, LRT east	1997	1,727	16	108	4.7
" " LRT north	1997	1,600	16	100	4.3
San Diego, South Line LRT	1996	1,757	21	84	3.6
" " East Line LRT	1997	1,200	12	100	4.3
San Jose, LRT south	1997	1,327	14	95	3.5

RED LINE (1983 Draft EIS)	2000*	30,600	180	170	7.4
HEAVY RAIL					
Atlanta, East-West Line	1994	2,986	60	50	2.2
" " North-South Line	1994	5,093	58	88	3.8
Chicago, Dearborn St. Subway	1994	9,376	112	84	5.7
Cleveland, Rapid	1997	1,230	20	62	2.8
Los Angeles, Red Line **	1997	3,400	40	85	3.7
Phila - PATCO, Lindenwold	1995	5,650	90	63	3.1
S.F. - BART, Transbay Tube	1994	14,881	169	88	4.1
" " Concord - Daly City	1994	7,349	78	94	4.4
" " Fremont - Daly City	1994	4,571	50	91	4.3
" " Richmond - Daly City	1994	3,713	40	93	4.4
" " Richmond-Fremont	1994	2,004	24	84	3.9
Vancouver, Skytrain	1994	6,932	100	69	5.6
Wash., Blue / Orange Line, Rosslyn	1997	16,400	140	117	5.0
" Red Line, Dupont Circle	1997	11,500	100	115	4.9
" Orange Line, Court H'se	1997	12,200	100	122	5.2
" Yellow Line (L'Enfant Plz)	1997	4,300	39	110	4.8
" Green Line (Maryland)	1997	2,933	27	109	4.7
" Green Line (Waterfront)	1997	2,500	40	63	2.7

* 1983 DEIS forecast for 2000, 16-mile line. ** 5-mile line between Union Station and Wilshire/Western.

The "benchmark" PTS value of 13 percent for U.S. cities is supported by a wide variety of data[6]. Individual corridors may have a lower PTS, reflecting relatively high levels of off-peak and reverse-peak traffic -- or capacity constraints leading to "peak spreading." PTS values below

[6] Demery, Leroy W., Jr. 1994. “Supply-Side Analysis and Verification of Ridership Forecasts for Mass Transit Capital Projects.” *Journal of the American Planning Association* 60, 3: 355-371.

10 percent should be considered exceptional, and reflect characteristics which are not typical of radial urban corridors in U.S. cities.

"Peak vehicle occupancy" (pass/veh) is the average number of passengers carried aboard each vehicle, past the maximum-load point, during the busiest hour in the busier direction. A more precise measure of peak vehicle occupancy is passengers per unit of vehicle length[7].

Peak vehicle occupancy differs from vehicle "capacity." The latter is based on arbitrary standards of floor space per passenger rather than consumer preference. Peak vehicle occupancy, on the other hand, reflects consumer behavior -- the observed number of people aboard each vehicle. It might also be described as "net" or "utilized" capacity.

Except in the four most crowded and congested U.S. and Canadian cities (Boston, Montréal, New York and Toronto), peak vehicle occupancies significantly greater than 100 pass/veh are exceptional. Recent observations are presented in Table 3 above (data for Baltimore, Philadelphia and Miami were not available).

The 100 pass/veh benchmark is somewhat less than the peak vehicle occupancies carried by recently-constructed light-rail facilities; the median (excluding the most recent observation for Portland) is 103 pass/veh. In terms of passengers per meter of vehicle length, the median, 4.2 pass/m, is just below that for HRT and corresponds to 115 passengers per 90-foot (27.4-meter) vehicle. The highest peak vehicle occupancies among the eleven systems are 5.5 pass/m in Calgary, 4.7 pass/m in Sacramento and 4.6 pass/m in Portland (at 1996).

Light-rail systems in Portland and Los Angeles are exceptional for high peak vehicle occupancy and low peak traffic share. In Portland, when the vehicle fleet was not adequate for peak-period traffic (at 1996), maximum peak ridership on the Eastside line was about 2,100 pass/hr. Weekday ridership averaged about 27,000, implying a PTS of 8 percent. This suggests 1.) displacement of passengers to "shoulder" periods due to crowding, and 2.) stronger coordination between land use and public transit than typical of U.S. cities.

In Portland, following the opening of the Westside Light Rail line in September 1998 and service increases permitted by an expanded fleet, Eastside average weekday ridership increased by 34 percent, to 37,000. The maximum peak ridership of 2,500 implied a PTS of 7 percent.

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[7] Parkinson and Fisher suggest passengers per meter of vehicle length as a uniform standard for vehicle occupancy. (Parkinson, Tom, and Ian Fisher. 1996. Rail Transit Capacity (Transit Cooperative Research Program Report No 13). Washington, DC: Transportation Research Board, National Research Council.)

The majority of the ridership growth took place outside of peak-period, peak-direction travel, and may reflect "reverse-direction" travel by Westside passengers riding "through" downtown to Eastside destinations. These results illustrate that transit service consumption -- "ridership" -- may be significantly influenced by service-supply factors.

In Los Angeles (at 1994), LRT Blue Line ridership counts implied a PTS of 6.5 percent and peak vehicle occupancy of 120 pass/veh. This suggests 1.) significant reverse-peak and off-peak traffic, and 2.) high levels of peak-period demand.

Of the heavy rail systems in Table 3, only San Francisco's BART and Washington, DC's Metrorail carried peak loads greater than 90 pass/veh. In terms of pass/meter, the highest peak vehicle occupancy among the seven heavy-rail systems are 5.7 pass/m in Chicago and 5.6 pass/m in Vancouver. The median is 4.4 pass/m, corresponding to 100 passengers per 75-foot (23-meter) vehicle.

The author asserts that, at early planning stages, use or implication of PTS values below 13 percent or peak vehicle occupancy above 4 passengers per meter of vehicle length is unwise, unless obvious factors justify forecasts based on lower PTS or higher peak vehicle occupancy. It is also unwise to assume peak service levels at or near theoretical maxima (as did the 1983 Red Line DEIS), since this provides no margin for future ridership growth.

Table 4 (below) presents the peak vehicle occupancy test results for the original Red Line forecast. The peak-period service level is based on the maximum service frequency of two minutes (30 trains/hr), as stated in the 1983 DEIS. The vehicle length of 75 feet and the maximum train length of 6 cars are also DEIS parameters.

Table 4: Peak Vehicle Occupancy Test for the 1983 Red Line DEIS Forecast

GIVEN:

Average weekday ridership: 376,375

Peak service supply: 180 vehicles per hour (75-foot / 23-meter vehicles)

Peak Traffic Share (percent)	*implies*:	Pass/Hour/Direction	Pass/Vehicle	Pass/Meter of Vehicle Length
13		48,900	272	11.8
12		45,200	251	10.9
11		41,400	230	10.0
11		41,400	230	10.0
10		37,600	209	9.1
9		33,900	188	8.2
8		30,100	167	7.3
7		26,300	146	6.3
6		22,600	126	5.5

Comparison with Table 3 will reveal that the peak vehicle occupancies implied by the Red Line ridership forecast are unrealistically high.

The peak vehicle occupancy derived from the 1983 DEIS, based on the maximum of 170 passengers per vehicle, is 7.4 pass/m. (This in turn implies a Red Line PTS slightly greater than 8 percent, significantly less than carried by most U.S. heavy-rail lines.) A peak vehicle occupancy of 6.2 pass/m exceeds any post-1990 observation in North America except for the following:

-- the heavy-rail Blue Line in Boston.

-- six of the nine subway lines in México City (data for the Guadalajara and Monterrey rail lines were not available).

-- three of the four subway lines in Montréal.

-- ten of the 20 heavy-rail lines entering the Manhattan CBD in New York City (with local and express tracks counted separately).

-- the two heavy-rail lines in Toronto.

The highest peak vehicle occupancy in the U.S., Canada or México for which published data are available is 13.4 pass/m (New York, IND Queens line, 1982). The most crowded subway line in Tôkyô, the Teito Rapid Transit Authority Chiyoda Line, had a peak vehicle occupancy of 15.9 pass/m at 1995.

Once again, test results suggest serious planning oversights during preparation of the original Red Line DEIS -- and subsequent ridership forecasts.

There are, of course, heavy-rail lines overseas which carry far more than 48,900 passengers per hour and 376,315 passengers per weekday. However, peak service parameters are very different from the Los Angeles Red Line: Tôkyô's Chiyoda Line operates 270 vehicles per hour during peak periods, roughly one ten-car train every two minutes. In addition, average travel distance (4.2 miles) and PTS (7.1 percent) are low by comparison with U.S. heavy-rail systems.

It should be noted that Red Line peak service parameters were decreased progressively as the project advanced toward construction. Planning documents from previous Wilshire Corridor studies suggested that peak-period traffic might require four tracks along part of the route. Initial Red Line planning assumed a two-track line with a maximum train length of eight cars. Train length was reduced to six cars to cut station construction cost. As noted above, the 1983 DEIS specified a service level equivalent to 620,000 annual vehicle-miles per route-mile. That specified in the 1989 Final Supplemental EIS was sharply reduced, to 390,000 annual veh-mi per route-mi. The 1986 Metro Rail Design Criteria specified vehicle performance consistent with a "designed" 90-second and a "scheduled" 150-second maximum service frequency.

D. Estimation of Maximum Likely Red Line Ridership

Readers are cautioned not to misinterpret the results above. The "passenger-mile test" and the "peak vehicle occupancy test" do not -- and cannot -- establish "demand" or "ridership potential" in the Red Line corridor. They merely demonstrate that the peak-period ridership implied by 376,375 weekday passengers, and travel patterns typical of U.S. heavy-rail systems, could not be accommodated by the Red Line as built.

Table 5 (below) presents a systematic estimation based on the "passenger-mile test." The service-effectiveness values, 20 and 25 pass-mi / veh-mi, were selected based on the "best" U.S. heavy-rail performance in Table 1. The "low" annual service level, 550,000 veh-mi per route-mi, is consistent with the 1983 DEIS operating plan, but with a maximum service frequency of five minutes (as operated on the Red Line prior to opening of the Hollywood extension). The "medium" level, 620,000 veh-mi / route-mi, is that implied by the 1983 DEIS. The "high" level, 760,000 veh-mi per route-mi, is consistent with an eight-car maximum train length (as originally planned) and a maximum service frequency of 2.5 minutes. Average travel distance was estimated at 5 miles with the extension to Hollywood, and at 6 miles following completion to North Hollywood. Readers are reminded of the inverse relationship between weekday ridership and ATD; increased ATD implies lower ridership, all else equal.

The peak vehicle occupancy test may be used to check the results in Table 5. The "low" peak service level is 72 veh/hr (12 trains/hr, 6-car trains). The "medium" level, based on the 1983 DEIS, is 180 veh/hr (30 trains/hr, 6-car trains). The "high" level is 192 veh/hr (24 trains/hr, 8-car trains).

The current five-mile Red Line has a PTS of 9.6 percent, suggesting PTS values of 9, 10 and 11 percent for the purpose of the peak vehicle occupancy test presented in Table 6 (below). Readers are again reminded of an inverse relationship, between PTS and maximum hourly traffic volume. For the purpose at hand, available data do not support assumption of a PTS less than 9 percent for a U.S. heavy-rail line.

Table 5. Estimated Likely Maximum Red Line Ridership

1.) **GIVEN:** 20 - 25 passenger-miles per vehicle-mile and:

-- a 10-mile line length (Union Station - Hollywood/Vine, and Wilshire/Vermont - Wilshire/Western); and

-- a 5-mile average travel distance (per boarding):

Annual vehicle-miles per route mile of:	*implies*	Average weekday ridership of:		
550,000		70,000	to	90,000
620,000		80,000		110,000
760,000		100,000		130,000

2.) **GIVEN:** 20 - 25 passenger-miles per vehicle-mile and:

-- a 16-mile line length (Union Station - Lankershim/Chandler; Wilshire/Vermont - Wilshire/Western); and

-- a 6-mile average travel distance (per boarding):

Annual vehicle-miles per route mile of:	*implies*	Average weekday ridership of:		
550,000		100,000	to	120,000
620,000		110,000		140,000
760,000		130,000		170,000

Table 6. Verification of Estimated Likely Maximum Red Line Ridership

Union Station - Hollywood/Vine and Wilshire/Vermont - Wilshire/Western:

AVERAGE WEEKDAY RIDERSHIP,								
70,000 - 90,000			80,000 - 110,000			100,000 - 130,000		
PEAK SERVICE SUPPLY,								
72 veh/hr ("low")			180 veh/hr ("medium")			192 veh/hr ("high")		
AND PEAK TRAFFIC SHARE (PTS)								
9	10	11	9	10	11	9	10	11
IMPLY								
5,000-8,000	7,000-9,000	8,000-10,000	7,000-10,000	8,000-11,000	9,000-12,000	9,000-12,000	10,000-13,000	11,000-14,000
PASSENGERS PER HOUR PER DIRECTION (phd), AND								
80-110	100-130	110-140	40-60	40-60	50-70	50-60	50-70	60-70
PASSENGERS PER VEHICLE								

Union Station - Lankershim/Chandler and Wilshire/Vermont - Wilshire/Western:

AVERAGE WEEKDAY RIDERSHIP,								
100,000 - 120,000			110,000 - 140,000			130,000 - 170,000		
PEAK SERVICE SUPPLY,								
72 veh/hr ("low")			180 veh/hr ("medium")			192 veh/hr ("high")		
AND PEAK TRAFFIC SHARE (PTS)								
9	10	11	9	10	11	9	10	11
IMPLY								
9,000-11,000	10,000-12,000	11,000-13,000	10,000-13,000	11,000-14,000	12,000-15,000	12,000-15,000	13,000-17,000	14,000-19,000
PASSENGERS PER HOUR PER DIRECTION (phd), AND								
130-150	140-170	150-180	60-70	60-70	70-80	60-80	70-90	70-100
PASSENGERS PER VEHICLE								

The results presented in Tables 5 and 6 may be summarized as follows. Once extended to Hollywood, given a peak service level of 90-100 veh/hr (6-car trains every 3.5 - 4 min), the Red Line weekday ridership ceiling might approach 150,000 if peak-period passengers tolerate high levels of crowding[8] [9]. If the extended line develops a traffic pattern typical of U.S. heavy-rail facilities (with a PTS of 11 percent or greater), the resulting peak capacity constraint might lower the weekday ridership ceiling to 100,000 or less, particularly if consumers are not willing to tolerate high peak period crowding. Table 6 confirms that, given a sufficiently large vehicle fleet size, this constraint could be offset with additional peak-period service.

Once extended to North Hollywood, the Red Line is likely to develop a traffic pattern with a PTS no smaller than 11 percent. The weekday ridership ceiling is therefore likely to fall in the range of 110,000 - 120,000, given a peak service level of 90-100 veh/h. Additional peak-period service (120 veh/h, requiring 6-car trains every 3 minutes), unusually high peak vehicle occupancy and low PTS might lift this to 150,000 - 170,000 per weekday.

The peak capacity constraints implied by 200,000 - 250,000 passengers per weekday might be mitigated -- given a sufficiently large vehicle fleet -- if the Red Line were retrofitted with transmission-based or "moving-block" signaling (MBS). MBS permits service frequency based on the acceleration and braking capabilities of the rolling stock, and has the potential for increasing peak-period service levels up to 30 percent[10]. An MBS-equipped heavy-rail line might operate six-car trains every 77 seconds (46 trains/hr)[11]. The resulting peak service level, 276 veh/hr, would accommodate peak traffic volumes implied by 250,000 weekday passengers, and a "worst-case" 13 percent PTS, with an acceptable level of peak-period crowding (118 pass/veh). There are, however, two caveats. First, operation of such a high service level would require substantial investment for terminal track expansion and (possibly) automatic train opera-

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8 120 passengers per 75-foot vehicle equals 5.2 pass/m.

9 Parkinson, Tom, and Ian Fisher. 1996. *Rail Transit Capacity* (Transit Cooperative Research Program Report No 13). Washington, DC: Transportation Research Board, National Research Council.

10 Weir, Robert S. 1992. “Moving Block Signalling Offers Cost Savings.” In *Developing Metros 199*2. Sutton, UK: Reed Business Publications.

11 There is, of course, a minimum traffic threshold below which such a system is not economic.

tion. Second, the implied peak-hour volume is 32,500 pass/hr, far higher than observed in any U.S. city outside of New York. Even if peak-period demand of this magnitude did exist, serving all of it might not be cost-effective. (The tradeoffs are similar to those faced by freeway builders.)

There is, however, no feasible way to accommodate the peak traffic volumes implied by 377,000 weekday passengers, at any likely level of vehicle occupancy, without construction of a four-track line. Even the maximum service level with MBS implies 150-177 pass/veh, or 6.5 - 7.7 pass/m.

The ridership ceiling estimates above are not "forecasts." They simply establish likely maximum ridership levels -- whatever the corridor travel demand might be. The author does not imply, nor should readers infer, that demand estimation should not be performed. Proper forecasting should consider both demand and supply factors in order to predict transit service consumption -- "ridership."

5) The Travel-Distance Dilemma

Without question, a transit service which provides significant travel time reduction will attract more passengers and longer trips. Sheer size and population density suggest that Los Angeles has a large "latent" market for longer transit trips -- particularly among transit-dependent residents.

Serving this market would involve formidable cost. Transit improvements leading to significant increases in average travel distance also create disproportionate increases in operating cost. This fact may be verified using the "passenger-mile test:" if ridership (passenger-trips) and ATD both double, then travel in terms of passenger-miles will quadruple, requiring four times as many vehicle-miles unless the operator can increase overall service effectiveness (pass-mi per veh-mi). Barring this, average cost per passenger-trip would double, and the overall operating budget would quadruple. If operating cost per vehicle-mile also increases, the transit service provider would quickly find itself in an untenable position. (Such a scenario has already occurred in at least one North American city: Ottawa.)

All-bus systems are particularly susceptible to the problem outlined above, since their incremental cost per incremental passenger-mile is higher than for a "rail-trunk / bus-feeder" network. Comparison between Atlanta and Houston illustrates this point. The Metropolitan Atlanta Rapid Transit Authority (MARTA) achieved an overall operating cost per passenger-mile of

$0.33 in 1996[12]. The Metropolitan Transit Authority of Harris County (METRO) achieved $0.46 per pass-mi in 1996. Such comparisons must be performed with care; the apparent difference of $0.13 per pass-mi narrows to $0.10 per pass-mi if general administrative costs and service effectiveness are equalized. The implied cost saving in Atlanta over an all-bus system is in the range of $60-90 million per year. Atlanta's annual passenger (linked-trip) volume was 65 million at 1996, compared to about 50 million in Houston. However, MARTA carried 68 percent more travel (passenger-miles) than Houston's METRO. The implied additional cost to METRO of serving MARTA's travel volume is more than $120 million, requiring a 70 percent increase in its 1996 operating budget.

The large potential market for longer transit trips in Los Angeles has been demonstrated since 1990, when the light-rail Blue Line opened for service. The Blue Line provides significantly lower capacity and speed than the Red Line, but the results are informative. Between 1990 and 1996, ridership carried by north-south transit routes within two miles of the rail line increased by 25 percent. At 1996, the Blue Line averaged 42,300 passengers per weekday. The reduction in corridor bus ridership over the same period accounted for just 40 percent of this figure. The Blue Line carries less than 40 percent of corridor transit ridership, but has a significant capacity constraint, imposed by the two-car maximum train length.

More significant are changes in ride length and passenger speed. ATD for all corridor transit services increased from 4.3 to 4.9 miles between 1990 and 1996. Weighted-average passenger speed for all weekday corridor boardings increased from 12.1 to 17.2 mph. The rail line provides an average passenger speed of 24.5 mph (this figure is higher over most of the line), and average travel distance exceeds eight miles. During peak hours, Blue Line ATD exceeds ten miles.

Weekday corridor passenger-miles increased from 432,000 to 620,000 between 1990 and 1996, with the Blue Line accounting for 57 percent of the latter figure. About 53 percent of Blue Line pass-mi are "new," and 47 percent "diverted" from corridor bus services. In 1995, the Blue Line carried nearly eight percent of the total passenger-miles carried by the LACMTA bus network.

The Red Line will significantly increase travel in terms of passenger-miles carried by the LACMTA system. Once completed to North Hollywood, the "minimum" ridership ceiling of

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[12] This matched the 1996 operating cost per pass-mi achieved by San Diego's transit providers as a group, including light-rail and commuter-rail services.

100,000 per weekday and "minimum likely" ATD of 6 miles imply 180 million passenger-miles annually. If half of these are "new," travel carried by LACMTA would increase by 6 percent -- all concentrated into a single corridor. More than half of Red Line pass-mi are likely to be new, as the line will introduce a great deal of "new" peak-period capacity into the corridor. 150,000 passengers per weekday, a 7-mile ATD, and 75 percent "new" pass-mi imply an overall travel increase of 17 percent -- again, all concentrated in one corridor.

An expanded Red Line system, reaching Whittier/Atlantic in East Los Angeles, Warner Center in the San Fernando Valley, UCLA and Santa Monica would have a route length of 50 miles. At early 1999, there was little prospect for construction of such a network, but potential travel impacts are substantial. Ridership would probably fall in the range of 250,000 - 350,000 per weekday, with ATD in the range of 8-10 miles. As a result, annual passenger-miles would fall in the range of 600 - 1,000 million, sufficient to increase the annual LACMTA system total by as much as 50 percent.

6) Cost Impacts of Rail Transit in Los Angeles

The cost-effectiveness of rail transit in Los Angeles cannot be assessed without estimating the cost of achieving similar results with some other mode. The analysis below is confined to operating cost.

Based on comparative costs of serving the post-1990 travel patterns in the Blue Line corridor, the rail line provided significant operating-cost savings over hypothetical non-rail alternatives. These travel patterns included a substantial number of long trips, accounting for a large quantity of passenger-miles. Serving this market segment without rail would have required extensive express bus service -- 4 to 7 times more than operated in FY 1990, the last "all-bus" year. This express service would have to serve destinations along the corridor, not just end-to-end traffic, including off-peak and weekend travel.

Analysis based on comparative cost per passenger-mile must be performed with care. This statistic may vary considerably between systems, or between lines on the same system, even given vehicles of equivalent size and performance. Cost/pass-mi is influenced by several factors, including the following:

-- Service effectiveness (pass-mi per veh-mi).

-- Labor cost (driver's hourly wage and fringe benefits).

-- General administrative and maintenance expense (per vehicle-mile).

-- Ratio of revenue vehicle-miles to revenue vehicle-hours (related to passenger speed).

-- Vertical and horizontal line profile (grades and curves).

-- Cruise speed between stops.

-- Number of stops per mile, including those required by traffic signals and road congestion.

Cost/pass-mi is quite sensitive to changes in service effectiveness: pass-mi per veh-mi. The number of stops per mile is also significant, since energy consumption is related to the number of acceleration cycles per mile. Bus operators providing a high percentage of freeway-express service have lower energy consumption per veh-mi than those with a large percentage of surface, mixed-traffic operation (roughly 30 percent lower, suggested by National Transit Database statistics). Comparisons between dissimilar systems with very different stop characteristics should be avoided. Independent contractors are able to achieve cost savings owing to lower labor and administrative expenses, but this relates to management strategy rather than mode choice.

The Blue Line provided a corridor operating-cost saving for 1996 in the range of $20-40 million, compared to the hypothetical operating cost for a non-rail alternative serving the same corridor. The implied cumulative operating cost saving (1990-1996) is roughly $100 million. If the Blue Line had been built for three-car trains, permitting additional peak-period ridership, operating-cost savings would be higher, owing to the higher ridership and pass-mi "targets" to be achieved by non-rail alternatives.

Analysis based on a "most favorable" scenario for an all-bus alternative reveals a "deficit" for the first two years of Blue Line operation -- that is, total corridor operating cost was higher with the rail line. However, this scenario revealed an unambiguous "break-even" point after two years, with the rail line providing operating-cost savings thereafter.

Operating-cost implications of the Red Line are even more substantial. Once the Red Line reaches North Hollywood, LACMTA will spend $50-90 million annually (1996$s) to accommodate the additional travel generated by the rail line (implying a 7-13 percent operating budget increase to carry up to 17 percent more travel). Operating the "expanded" Red Line network outlined above would cost $200-300 million per year (implying a 30-44 percent operating budget increase to carry up to 50 percent more travel). These figures should not surprise anyone familiar with the real world of transit operations.

In order to duplicate Red Line performance with a non-rail alternative, LACMTA would have to operate 11-16 million additional vehicle-miles annually -- 14-21 percent of total bus-miles for 1996, all in a single 16-mile corridor. The 50-mile "expanded" system would require 30-60 million additional vehicle-miles annually -- all within a 50-mile network. Quite apart from the feasibility of operating this much additional service over existing streets and freeways -- at speeds giving travel-time reductions similar to those offered by the rail system -- non-rail alternatives would cost much more to operate. A non-rail alternative to the currently-funded 16-mile Red Line, which somehow managed to achieve the same results (annual passengers and passenger-miles) would cost $40-70 million more per year (1996$s) to operate than the Red Line. The "expanded" system would provide cost savings on the order of $100-200 million over a non-rail alternative achieving similar results -- assuming this could be accomplished without a rail trunk system.

The rail cost estimates above are based on figures achieved by BART and Washington, DC. Atlanta's unit costs are more than 30 percent lower, in fact, MARTA's cost per rail vehicle-mile are more than 30 percent lower than for bus (1996). Some transit operators achieve lower unit costs than LACMTA through savings in labor and administrative expenses, but this reflects management strategy, not mode choice.

It is not clear how a non-rail alternative could be deployed in the Red Line corridor. This would require about 2,000 additional vehicle-miles per weekday for each mile of route, or 32,000 additional veh-mi per weekday between Union Station, North Hollywood, and Wilshire/Western. However, 1:1 substitution of rail veh-mi for bus veh-mi would not provide the same net capacity owing to differences in vehicle size. The additional service might be deployed along parallel arterial streets within a half-mile the corridor "spine." Peak volumes implied by Red Line weekday ridership ceilings, 12,000 -- 14,000 per hour (Table 6), would require 330-380 standard or 220-260 articulated buses per hour, based on likely peak-period vehicle occupancies. This, of course, is in addition to existing peak-period service. The additional service would also need to provide travel-time reductions similar to those provided by the Red Line.

The transportation planning literature suggests that the rail-alternative service outlined above could not be operated without dispersal of required peak capacity onto several parallel streets (and a large off-street terminal in downtown Los Angeles). Peak-period volumes up to 200 vehicles per hour on surface arterial streets have been attained with double bus lanes and stops spaced every 2-3 blocks, but service speeds range from 4 to 6 mph[13]. Articulated buses were unsuccessful in Los Angeles during the 1970s and 1980s, and were eventually phased out. They incurred three times as many accidents per vehicle-mile than standard buses, leading to high maintenance and liability costs[14].

Busway or transitway "capacity" estimates based on rated maximum vehicle occupancy are not realistic. For example, the single- and double-articulated buses used in Curitiba, Brazil, are rated for maximum loads of 160 and 270 pass/veh, respectively. However, this implies a vehicle occupancy of 9-11 pass/m during the busiest hour. This probably does not occur in Curitiba[15]; it certainly does not occur in the U.S. The highest reported vehicle occupancy for a U.S. free-way, busway or HOV service post-1990 is 3.7 pass/m (a figure well above the median of 3.0 pass/m). The highest documented peak vehicle occupancy known to the author for any U.S. bus service is 6.8 pass/m, observed in Seattle during World War II[16].

Reported peak-hour passenger volumes for the Ottawa busway system significantly overstate observable performance. Reported maxima, in the range of 9,000 - 11,000 phd, appear to be five-minute flow rates scaled up to hourly volumes. The actual peak-hour maximum volume may fall below 5,000 phd[17].

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[13] St. Jacques, Kevin, Tom, and Herbert S. Levinson. 1997. *Operational Analysis of Bus Lanes on Arterials*. (Transit Cooperative Research Program Report No 26). Washington, DC: Transportation Research Board, National Research Council.

[14] *Articulated Buses - A Planning Handbook*. 1984. Office of Service and Management Demonstration, Technical Assistance Program, Urban Mass Transportation Administration, U.S. Department of Transportation (DOT-TSC-1752).

[15] Gardner, G., P. R. Cornwell and J. A. Cracknell, *The performance of busway transit in developing cities* (Research Report 329). Crowthorne, England: Transport and Road Research Laboratory, 1991.

[16] Demoro, Harre W. 1971. *Seattle Trolley Coaches* (Interurbans Special 54). Glendale, CA.

[17] Demery, Leroy W., Jr. 1998. “Ottawa's record rider figures: are they inflated?” *Tramways & Urban Transit* 61, 723: 90.

As noted above, non-rail alternatives incur higher incremental cost per incremental passenger-mile than alternatives including rail trunk lines. This is best illustrated by Ottawa's experience. The regional transit operator, OC Transpo, doubled its ridership (linked trips) between 1971 and 1982. However, ATD increased relentlessly during this period, and the average travel distance per linked trip was up by 54 percent to 1982. Travel (passenger-miles), service (vehicle-miles) and OC Transpo's inflation-adjusted operating budget all tripled between 1971 and 1982.

Meanwhile, OC Transpo began developing a busway ("transitway") network[18]. Between 1983 and 1988, Ottawa opened 7.8 miles of exclusive busways,1.4 miles of exclusive downtown bus lanes and 2.3 miles of mixed-use parkway. OC Transpo anticipated reduced costs as the result of higher operating speed permitted by the busways. Instead, it found itself squeezed between rising costs and declining ridership.

ATD increased by 15 percent between 1982 and 1987, spurred by reduced travel times permitted by busway development. Operating costs increased sharply during the same period. Inflation-adjusted cost per vehicle-mile did not change between 1975 and 1982, then rose by 20 percent to 1987. This reflected in part expanding use of articulated buses, which cost 25 percent more per veh-mi to operate than standard buses. In order to prevent further erosion of its cost-recovery ratio from 1984, OC Transpo was forced to implement higher-than-usual fare increases and, for the first time, service cuts.

The "passenger-mile test" implies that, given a service-effectiveness level which does not change, an ATD increase is correlated with increased service, decreased ridership, or some combination of the two. OC Transpo service increases averaged 2.8 million veh-mi per year between 1971 and 1975, and 1.3 million veh-mi thereafter to 1984. Service was then reduced for two consecutive years and held static for a third. Thus, a four-percent service reduction (to 1987) was concurrent with expansion of the busway network from 5.7 to 7.8 miles, and a seven percent ATD increase (to 6.2 miles). During this period, ridership (linked trips) fell by seven percent.

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[18] Ottawa's mode choice was predetermined by financial, non-technical and political factors prior to analysis of alternatives; funding constraints ruled out construction of a rail system. See: Belobaba, Peter P. 1982. “Rapid Transit Development in Medium-Sized Urban Areas: A Comparison of Planning and Decisionmaking in Two Canadian Cities.” In *Transportation Research Record 877*. Washington, DC: Transportation Research Board, National Research Council.

The consistent upward trend in ATD, although driven by factors other than passenger speed, was accelerated by travel-time savings permitted by the busways. ATD, service quantity and passenger volume all increased to 1984. Thereafter, OC Transpo stopped increasing service for financial and political reasons, ATD continued to lengthen, and passenger volume fell. These statistics are, of course, merely indicators of the underlying, more-complex causal relationships.

7) Alternative Strategies

Los Angeles would present a tough challenge for public transportation planning even without the financial and political complications of the late 1990s. Anyone familiar with the region understands why transit fails to attract a larger -- and more diverse -- ridership: long travel times. Except for freeway express lines serving suburban commuters rather than inner-city residents, L.A. bus routes average 10-15 mph. Motorists make better time even when traffic congeals, and cyclists bold enough to brave L.A. surface traffic can match or better bus travel times.

The average transit travel distance (per boarding) in Los Angeles is about four miles, has remained so since the late 1970s, and probably dates back well before then. The average travel distance per linked transit trip is longer, perhaps in the range of 6-7 miles, since many passengers transfer en route. Despite long routes and intensive use, L.A.'s current bus system serves short-distance travel.

Five to seven miles is a very short distance in Los Angeles. Many commuters (and secondary-school students) travel much farther, but not by transit whenever possible: a 15-mile trip takes a long time at 10-15 mph, and 30 miles takes an eternity. The true nature of "transit apartheid" in Southern California confines auto-less inner-city residents to within about ten miles of home. Within this invisible cordon are the jobs which most people, given a choice, would shun -- strenuous, unpleasant, and low-paid. Workers in certain industries toil long hours under sweatshop conditions for pittance wages; Hispanic women in particular suffer merciless exploitation. Employment growth, as in other U.S. metropolitan regions, is concentrated in newer suburbs, scattered miles away from the older, densely-populated communities which house L.A.'s low-income, transit-dependent residents. Inner-city residents without cars are effectively cordoned off from better jobs which lie beyond the range of tolerable bus commuting.

By contrast, the light-rail Blue Line attracts an average travel distance exceeding eight miles, and the regional commuter-rail network ("Metrolink"), opened from 1992, offers a passenger speed approaching 50 mph and attracts an average travel distance exceeding 35 miles. Rail services accounted for more than 15 percent of all transit travel (pass-mi) within the five-county metropolitan area in 1996. Without question, travel-time reductions by any mode would attract many more passengers to transit, and would best serve the needs of transit-dependent residents.

Various critics have offered several alternatives to "rail" in Los Angeles. One of these is fare subsidies, maintaining the average (LACMTA) subsidy per passenger at the FY 1985 level. This would have required an additional $100 million per year (in today's dollars) in operating subsidy between FY 1986 and FY 1991, based on the ridership actually carried. The required subsidy, and overall operating budget, would increase in proportion had this strategy attracted significantly higher ridership (a somewhat tenuous assumption, given the effects of the sharp increase in regional unemployment and depressed economic conditions of the early 1990s, and the collapse of fuel prices from FY 1986).

Previous fare subsidies, provided by the Los Angeles County Board of Supervisors in FY 1974-1975, led to a 20 percent increase in weekday boardings (a figure which elected officials viewed as disappointing). The accompanying change in ATD is not known, but may have been significant given the abolition of fare zones (a widely popular move among passengers). Ridership continued to increase through the 1970s despite fare increases, strikes, and withdrawal of the county subsidies which financed an ambitious program of route revision and service expansion. Then, fuel price increases triggered by the Iranian revolution in 1979 led to a 14 percent increase in average weekday boardings -- without any reduction in fares. ATD (per boarding) increased from 3.9 to 4.5 miles to 1982.

The FY 1983-1985 subsidies are correlated with a 19 percent increase in weekday boardings, less than experienced in 1974-1975, and a slight decrease in ATD. The boarding increase was inflated somewhat by the 1984 Olympics, held during FY 1985, for which SCRTD deployed an additional 550 buses.

If all additional boardings are attributed to fare subsidies (ignoring the influence of fuel prices), these programs generated about 140,000 additional weekday boardings in 1974-1975, and 260,000 in 1983-1985. How much of the latter increase could have been held through the subsequent fuel-price collapse and recession is not clear. What is clear is that the Red Line will be quite cost-competitive: the cost per additional passenger-mile generated by the 1983-1985 fare subsidies was about $0.80 in today's dollars; the operating cost of the completed Red Line should fall in the range of $0.25-0.35. Results in terms of boardings are similar: approximately $3.00 in operating expense per boarding for the completed Red Line, and $4.00 per additional weekday boarding for the 1983-1985 subsidy program.

"Targeted" fare subsidies for the neediest residents should be considered, but universal fare subsidies are not a low-cost alternative to the travel-time reductions and capacity increases provided by rail lines.

Another, much-touted alternative to "rail" in Los Angeles is increased bus service. Average weekday ridership carried by SCRTD/LACMTA fell by nearly 29 percent between 1985 and 1996; this was accompanied by a 23 percent decrease in vehicle-miles. A portion of these reductions resulted from transfer of routes to other operators. It seems logical that significant increases in bus service would produce a significant increase in ridership. This, of course, is true -- up to a point.

The need for better transit service in Los Angeles -- faster, less crowded, more reliable -- is obvious. Whether this might be accomplished with large increases in vehicle-miles, with no other improvements, is doubtful. LACMTA's 1996 service effectiveness (boardings per veh-mi), including the three rail lines, was higher than during the 1974-1975 and the 1979-1981 fuel shortages. It was also higher than at any time during the 1980s, except for FY 1985 (the Olympics year). On the other hand, examination of LACMTA ridership statistics for individual lines (which extend back to the mid-1970s) fails to support the widespread belief that buses are more crowded today than before. Average vehicle occupancies (all-day) have fallen significantly since the mid-1980s. These facts suggest more-efficient use of resources (and the low traffic density of lines transferred to other operators) in spite of reduced ridership.

The "passenger-mile test" illustrates that increasing service, without providing other improvements which also attract passengers, may lead to reduced productivity. Service effectiveness (pass-mi per veh-mi) will fall at the margin unless the additional vehicle-miles attract ridership in proportion to existing service. For example, a ten percent service increase will lead to lower service effectiveness unless it attracts at least ten percent greater ridership (more precisely, ten percent greater travel as measured in pass-mi). If passengers make longer trips in response to service improvements, the downward pressure on service effectiveness will ease, but previous experience in Los Angeles suggests ATD would not increase merely in response to additional vehicle-miles of service.

Successive service increases, all else equal, will produce diminishing returns once the greater attractiveness of more-frequent service is offset by declines in service effectiveness. Incremental cost per incremental boarding increases rapidly once this "point of diminishing returns" is passed. In this situation, a transit operator is likely to choose not to add additional service without making other improvements, such as investments to reduce travel times. Given a policy of unlimited service expansion on an otherwise unimproved network, ridership will cease to grow once the "saturation point" is passed. At this point, declines in service effectiveness will no longer be offset by increases in service quantity, and the incremental cost per additional passenger effectively becomes infinite[19].

In Atlanta, MARTA increased annual vehicle-miles by 47 percent between 1972 and 1978, and achieved a 35 percent increase in annual linked trips. However, service effectiveness fell by 9 percent despite a sharp decrease in (inflation-adjusted) fares. Had demand factors such as fares, fuel prices and employment remained constant, service effectiveness would have fallen farther, by as much as 25 percent. Examination of annual changes suggests that successive service increases led to successively larger decreases in service effectiveness. MARTA's pre-rail system appears to have reached the point of diminishing returns after 1974-1975, and might have reached the saturation point by 1977-1978 had not other demand factors generated additional ridership.

It is difficult to predict how LACMTA bus service effectiveness might change with successive service increases, especially given the very low (inflation-adjusted) fuel price levels at the end of the 1990s. Evaluation of historic data for the SCRTD/LACMTA system is complicated by changes in demographics, fares, fuel prices and by strikes[20]. For example, a six-percent increase in annual vehicle-miles from 1980 to 1981 was accompanied by a 12.6-percent increase in annual boardings; service effectiveness increased as well, from 14 to 17 pass-mi / veh-mi. This period also coincided with fuel-price increases triggered by the 1979 Iranian revolution, and a 23-day strike at the beginning of FY 1980. Between 1973 and 1979, a 59-percent in annual vehicle-miles was accompanied by an 84-percent increase in annual boardings; service effectiveness increased by roughly ten percent. Once again, evaluation is complicated by fare and fuel-price changes, population increases and two lengthy strikes.

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[19] Kain and Liu define "redundant service" as that which exceeds levels reasonably expected to affect system ridership. (Kain, John F., and Zhi Liu. 1995. *Secrets of Success: How Houston and San Diego Transit Providers Achieved Large Increases in Transit Ridership*; prepared for Office of Planning, Federal Transit Administration, US Department of Transportation.)

[20] Work stoppages by SCRTD drivers between 1975 and 1983 totaled more than four months.

Vehicle-mile demand elasticities for bus services ("all hours") reported by Mayworm, Lago and McEnroe[21] range from 0.63 to 0.69. This, in brief, suggests that a ten-percent increase in vehicle-miles will lead to a 6-7 percent increase in boardings. The author cautions that use of elasticities to predict the results of large system changes may produce misleading results. Based on 1996 results, a 10-percent increase in LACMTA bus-miles would generate 70,000 additional weekday boardings. The implied annual operating cost increase, $60 million, implies in turn $2.50 per additional boarding. This figure is less than the $3.00 per boarding figure for the completed Red Line. However, cost per pass-mi is twice as high as the likely figure for the completed Red Line. Atlanta's experience -- at a time of rising fuel prices and falling (inflation-adjusted) fares -- suggests that successive increments of bus service expansion, and operating-expense increase, would not generate the same proportion of increased ridership.

Successive service increases would require larger incremental cost per incremental boarding than the completed Red Line. The erosion of bus system cost-effectiveness as the result of increased vehicle-miles and declining service effectiveness is illustrated in Table 7.

Table 7. Estimated Ridership & Cost Impacts of Incremental Increases in Bus Service

Annual vehicle-miles	Average weekday boardings	Operating cost per annual boarding	Operating cost per annual pass-mi	Incremental cost per incremental boarding	Incremental cost per incremental pass-mi
Actual (1996)	1.08 million	$1.71	$0.49	---	---
1996 + 10%	1.15 million	$1.76	$0.50	$2.48	$0.71
Above + 10%	1.23 million	$1.81	$0.52	$2.55	$0.73
Above + 10%	1.31 million	$1.87	$0.53	$2.62	$0.75

Results presented in Table 7 imply that a cumulative 33-percent increase in annual bus-miles would produce a cumulative 22-percent increase in weekday boardings. These 240,000 additional weekday boardings would require a $200 million increase in LACMTA's annual bus operating budget (based on 1996 system performance). These results assume that the "best-case"

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[21] Mayworm, P., A. Lago and J. M. McEnroe. 1980. *Patronage Impacts of Changes in Transit Fares and Services*. Prepared for Urban Mass Transportation Administration, U.S. Department of Transportation (DOT-UT 90014).

elasticity reported by Mayworm et al. would be sustained as vehicle-miles increased substantially. This may not be realistic; the "point of diminishing returns" may lie within the hypothetical range of service increase in Table 7.

(One might assume a vehicle-mile demand elasticity for LACMTA bus services that is 1.) significantly higher than the figures presented by Mayworm et al., and 2.) sustainable over a large increase in vehicle-miles, but would do so in the absence of supporting evidence.)

The author does not imply, nor should the reader infer, that bus service expansion should not be carried out. However, large-scale increase in bus vehicle-miles without other upgrades could not provide a low-cost "shortcut" to the transit improvements which Los Angeles sorely needs.

8) Transit Service Reliability -- A Commentary

The lack of data regarding transit service reliability in Los Angeles forces the author to resort to personal recollections[22]. During the 1970s and 1980s, surface bus routes averaged 10-15 mph, or less, depending on location and time of day. Limited-stop routes, when available, were not substantially faster. Certain groups of vehicles had narrower aisles than others, creating an acute problem on busy routes: long delays at stops for loading and unloading. Any more than a handful of standees aboard such vehicles would lead to considerable slowing of service, creating ever-mounting delays on long lines.

Out of curiosity, the author conducted an informal survey during the early 1980s, comparing scheduled times on driver schedules ("paddles") with actual times through discreet observation over drivers' shoulders. He found that individual buses on long, busy lines typically ran 10-30 minutes behind schedule, even during midday hours, owing to cumulative delays resulting from loading, unloading, street congestion, traffic accidents and so forth. This problem was practically invisible to passengers (except on lines having branches or "turnback" service), but created problems when service was relatively infrequent.

Since L.A. bus routes suffered chronic delays, one critical aspect of transit service was very unreliable -- transfer connections. The degree of inconvenience varied depending on location

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[22] The author lived in Los Angeles between 1960 and 1988, did not own a car for most of this period, and averaged 500 - 1,000 miles per month by transit during the 1970s and 1980s.

and time of day. Missed connections, annoying when service was infrequent, were infuriating if the connecting bus was the "last" of the day. (Being stranded on the way home from the skating rink, for example, was part of growing up in L.A.) Reliability of connections between SCRTD and smaller municipal operators was often tenuous, especially late at night.

(The impact of these problems on staff morale, together with SCRTD's history of poor labor relations, certainly led to increased passenger complaints about driver discourtesy .)

The fare-subsidy years of 1983-1985 are portrayed by certain authors as a golden age for L.A. transit passengers. The author remembers differently. During this period, auto use grew rapidly, spurred by falling fuel prices and the strong regional economy. Mounting congestion on streets and freeways eroded bus service reliability at a time of record ridership growth -- which led to further erosion in service quality. SCRTD scheduled fewer than 200 additional peak-hour buses, an increase of less than ten percent. Weekday boardings, meanwhile, increased by 250,000, or 18.5 percent. Transit-dependent passengers bore the brunt of increased delays, peak-period crowding, and another, more serious problem: missed runs. Scheduled services might fail to appear even during off-peak, late-night and early-morning hours. SCRTD won recognition for special services during the 1984 Summer Olympics, for which it deployed 550 buses. Meanwhile, service reliability on "regular" routes reached an apparent low point, with many long delays and missed runs.

The extent to which sheer unreliability of service contributed to L.A.'s post-1985 ridership decline is unknown, and probably unknowable. However, the "demand elasticity" of missed connections, long delays, late-night "no shows" and so forth might best be expressed as the percentage of passengers who, given access to autos, would desert transit permanently.

9) Potential Future Transit Improvements

The transit service quality improvement most needed in Los Angeles is an overall reduction in travel times. The associated challenges may be explored using the following example. Of the busiest north-south transit corridors west of downtown Los Angeles, the Crenshaw corridor is perhaps the most likely candidate for major investment (Vermont Avenue, the busiest, is closely paralleled by the Harbor Freeway Transitway). The current bus route 210 operates between Hollywood and South Bay Galleria via Vine St., Rossmore Ave. and Crenshaw Blvd., and carries about 20,000 passengers per weekday (1996), down from about 30,000 per day at 1985.

Peak-period vehicles along the 20-mile route average about 13 mph; ATD is 3.6 mi (1996); up from 3.3 mi at 1985.

A hypothetical 50-percent reduction in travel times, implying a doubling of passenger speed (to 26 mph) would provide significant benefits. Sample estimated travel-time reductions from Martin Luther King Jr. Blvd., the approximate corridor midpoint, are presented in Table 8 (below):

Table 8. Estimated Time Savings of Crenshaw Corridor Travel Speed Increases

Origin	Destination	Distance	Current Peak-Period Travel Time	Estimated Travel Time Given 26 mph Passenger Speed	Implied Travel Time Saving
King Blvd.	Wilshire Blvd.	5 miles	22 min	12 min	10 min
King Blvd.	Hollywood Blvd.	8 miles	43 min	19 min	24 min
King Blvd.	Manchester Ave	4 miles	21 min	10 min	11 min
King Blvd.	Crenshaw / I-105	6 miles	38 min	16 min	22 min
King Blvd.	South Bay Galleria	11 miles	54 min	24 min	30 min
Hollywood Blvd.	South Bay Galleria	20 miles	93 min	44 min	49 min

Potential ridership impacts of these time savings are difficult to establish without 1.) demand analysis to establish "potential" service consumption (ridership), 2.) supply analysis to determine how this demand might be served, and 3.) cost analysis to determine what level of demand should be served. Steps 1.) and 3.) are beyond the scope of this paper. Step 2.), however, may be performed to establish likely ridership ceilings, assuming a "background" of demand large enough to produce positive ridership changes in response to service improvements.

The travel-time elasticities of demand presented by Mayworm et al.[23] range from - 0.59 to - 1.03; suggesting that a ten-percent travel-time reduction would lead to a 6-10 percent ridership increase. As noted above, use of elasticities to predict the results of large system changes may produce misleading results; ridership increases resulting from large travel-time reductions might be less than predicted owing to peak-period capacity constraints. The postulated 50 percent reduction in travel times implies a minimum weekday ridership of 30,000. The accelerated Line 210 would require a net peak-period capacity in the range of 3,000 - 4,000 pass/hr, assuming that the (unconstrained) PTS would fall in the range of 10-13 percent. This of course can be provided with buses in mixed traffic, although not at speeds corresponding to a 50-percent reduction in travel times. As noted above, surface buses along route 210 once carried 30,000 passengers per weekday without any limited-stop or express service. Analysis fails to reveal a significant case for major investment -- thus far.

Returning to the starting assumptions -- a 50-percent reduction travel times along a 20-mile corridor (serving densely-populated areas with many transit-dependent residents), not tied to any specific mode, and a "baseline" assumption of 30,000 passengers per weekday -- brings up the question of "forecast horizon." This may be explained as the ridership, anticipated to occur a certain number of years after opening, which is used to justify construction of the planned facility. Forecast horizon is a highly controversial topic in the U.S.; many critics contend that unrealistic forecasts are used to justify construction of unneeded transit projects. The other side of the coin is that failure to make reasonable provisions for future ridership growth is a serious planning error[24].

Unconstrained growth at an annual rate of three percent would bring the average weekday ridership up to 50,000 within 20 years. The same growth rate would bring average weekday ridership up to 40,000 within ten years. The above figures are offered merely as examples. Without demand analysis, the likely rate of ridership growth cannot be established with any reasonable precision. In addition, the author cautions that peak capacity constraints may slow, or stop, the forecast rate of ridership growth. The 50,000-per-weekday figure will be used to illustrate this point.

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[23] Mayworm, P., A. Lago and J. M. McEnroe. 1980. *Patronage Impacts of Changes in Transit Fares and Services*. Prepared for Urban Mass Transportation Administration, U.S. Department of Transportation (DOT-UT 90014).

[24] American cities seem prone to this error; construction of the Blue Line with a maximum two-car train length is a good example.

An average weekday ridership of 50,000 implies a net peak capacity requirement of 6,500 pass/hr, using the "benchmark" 13 percent PTS. Service at or near the "peak capacity requirement" would have to be operated for roughly six hours each weekday, during the a.m. and p.m. peak periods. Based on likely levels of peak vehicle occupancy, 6,500 veh/hr implies about 60 veh/hr with light rail, 65 veh/h with heavy rail (owing to shorter vehicle length), and 180 standard or 120 articulated buses per hour. All of the above service levels are attainable given a single pair of lanes or tracks, but only the heavy-rail option would offer significant "reserve" capacity for future ridership growth. "Light rail" implies a practical limit of four-car trains and three-minute maximum service frequency. 60 veh/h could be achieved with three-car trains every three minutes or four-car trains every four minutes, but this service level would be near the practical limit.

(Recommendation of alignments or configurations is beyond the scope of this paper. However, for the benefit of readers unfamiliar with Los Angeles, portions of Crenshaw Boulevard are wide enough for a center-median busway or light-rail line, but others are relatively narrow and carry heavy vehicular traffic. As a practical matter, provision of a 26-mph passenger speed would require major investment for segregated alignments, either elevated or underground, over the majority of the route. An elevated alignment along the northern portion of the corridor, where traffic might be heaviest, would probably attract strong local opposition.)

10) The Mode-Choice Question

Challenges related to mode choice may be explored using the light-rail Blue Line as an example. The Southern California Association of Governments (SCAG) boarding forecast for the year 2000 (prepared during the mid-1980s) is 54,700 per weekday. During its first full year of operation, the Blue Line averaged 33,000 passengers per weekday. The disparity between the "year 2000" forecast and the ridership carried during the initial years attracted much criticism[25], but average weekday ridership reached 49,600 by 1998, an annual average growth rate of seven percent over the first six years of operation.

In terms of average weekday pass-mi per route-mi, the Blue Line is the most intensively-used postwar light rail line in the U.S., although those in St. Louis and San Diego are not far behind (Table 1). The Blue Line is also one of the most crowded -- or overcrowded -- rail transit sys-

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[25] See, for example, Moore, James E., II. 1993. “Ridership and Cost on the Long Beach - Los Angeles Blue Line Train.” *Transportation Research* 27A, 2: 139-152.

tems in the U.S. or Canada during peak periods. The very high pass-mi / veh-mi statistic, 36.3 (1996) reflects long peak-period ATD and high levels of peak vehicle occupancy. It is not often remembered that the originally planned car fleet size was 30 vehicles -- woefully inadequate for the traffic which actually developed.

A heavy-rail line in the Blue Line corridor would require full grade separation, an elevated or subway alignment along Washington Blvd. and Flower St. in downtown Los Angeles, and an elevated or subway alignment into downtown Long Beach[26]. Capital cost would have been roughly twice that of the existing Blue Line, approximately $2 billion. End-to-end running times would be significantly faster, about 38 minutes vs. 53 min (peak), but the line carries little end-to-end traffic. The time saving for the large majority of passengers would be small -- about five minutes between Washington and 7th St/Metro Center stations. The estimated weekday "ridership ceiling," assuming 20-25 pass-mi / veh-mi, ATD of 8.4 mi (as the current line carries), 600,000 annual veh-mi / route-mi and a 21-mi line length, is in the range of 100,000 - 130,000 per weekday. Whether a heavy-rail line would actually generate this level of ridership, and whether serving this level of ridership would be cost-effective, are topics beyond the scope of this paper[27]. However, 100,000 passengers per day is clearly beyond the potential of the current Blue Line. Three-car trains during peak hours and a peak vehicle occupancy of 110 pass/veh imply about 55,000 passengers per weekday given current schedules; four-car trains and 110 pass/veh imply about 60,000 passengers per weekday. Four-car trains operated every three minutes might provide sufficient peak-period capacity for 60,000 - 80,000 passengers per weekday, but operation of this level of service along the street track in downtown Los Angeles and Long Beach might create significant problems.

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[26] Previous rapid transit plans proposed an alignment along the Los Angeles River, turning eastward in subway to reach Long Beach Blvd.

[27] A heavy-rail Blue Line carrying 100,000 or more passengers per weekday would probably also require 1.) construction of an additional subway route between 7th St/Metro Center and Union Station, and 2.) construction of the Pasadena Blue Line to compatible standards.

A Blue Line busway might have cost less than the existing rail facility[28]. It would presumably not include underground terminal facility in downtown L.A., but hypothetical construction standards are complicated by the issue of peak service supply. It would also cost significantly more to operate than today's rail line.

The maximum one-hour traffic volume carried by the Blue Line is roughly the same as that carried by the El Monte Busway: 2,500 per hour. However, the Blue Line carries this traffic with a maximum service level of 12 trains, or 24 vehicles, per hour. Owing to the larger size of rail vehicles and the higher peak vehicle occupancies which they typically carry, a busway would need to provide more than 70 veh/hr to match the Blue Line's peak-period performance. The "potential" Blue Line peak-period ridership is not clear, but is obviously greater than that currently carried. Three-car trains might accommodate 3,600 -- 4,000 passengers per hour, which would require 100-115 buses per hour. Three-car trains operated every three minutes, the practical limit for the current line without major investment, might accommodate 5,000 -- 7,000 pass/hr, which would require 140-200 buses per hour. Such high service levels, with resulting impacts on cross traffic, would have to be operated for six hours each weekday.

The current Blue Line generates far fewer traffic movements (at grade crossings and intersections) than a busway. Even at the hypothetical maximum service level, the light-rail line would create just 40 traffic movements per hour (20 trains per hour in each direction). A busway would create a minimum of 140 traffic movements per hour to carry today's traffic, and up to 400 per hour to accommodate future ridership growth. These figures imply that a Blue Line busway might require 1.) more-extensive grade separation than the current rail line, and 2.) carefully-designed preferential-lane treatment in downtown Los Angeles and Long Beach.

Current Blue Line travel patterns and comparative LACMTA costs suggest that a Blue Line busway would cost roughly $25 million more per year (1996$s) to operate than the rail line. This saving would increase given a longer maximum train length (and increased peak-period traffic); no similar "economy of scale" may be accomplished with a busway since buses cannot be op-

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[28] A federally-funded study found that Pittsburgh's East Busway cost "no less than a rail line requiring similar cut and fill work." (Pultz, Susan, and David Koffman. 1987. *The Martin Luther King, Jr., East Busway in Pittsburgh, PA*. Washington, DC: Office of Technical Assistance, Urban Mass Transit Administration, U.S. Department of Transportation.)

erated in trains, driven by a single person[29]. The hypothetical cost saving approaches $35 million per year given 60,000 passengers per weekday, the "likely maximum" or "ceiling" ridership for the Blue Line in its light-rail configuration.

The various alternatives now under consideration for Eastside, Westside and San Fernando Valley transit projects include heavy-rail, light-rail and busway alternatives. Busways and light rail are strongly competitive, capable of providing similar net capacity and travel-time reductions given similar alignments (a light-rail alternative with a downtown subway will, of course, have an advantage over a busway using surface preferential lanes). Busways may be built in stages, starting with several unconnected segments which are gradually expanded and linked as traffic justifies and finances permit[30]. This would provide a strong advantage even if capital costs were equivalent.

On the other hand, capital-cost savings estimated for busways may prove difficult to achieve. The type of problems encountered when building the Blue Line along an existing rail alignment were not related to the mode choice[31]. The capital-cost "savings" over "light rail" touted by Ottawa[32] (and, in particular, its former general manager) are quoted verbatim from the alternatives analyses conducted before the busways were built, and are not based on subsequent performance evaluation.

Equally important is a tendency to underestimate busway operating costs relative to rail alternatives. The median peak vehicle occupancy for U.S. busway, transitway and HOV services is 2.9 passengers per meter. The rail median, 4.1 pass/m, is 40 percent higher, in fact, the rail

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29 A three-car Blue Line light rail train has the same likely net capacity as nine standard or six articulated buses.

30 Many European cities have used a similar strategy to create modern light rail systems out of existing streetcar systems, but this is no longer an option for Los Angeles.

31 See: McSpedon, Edward. 1989. “Building Light Rail Transit in Existing Corridors -- Panacea or Nightmare?” In: *Light Rail Transit: New Systems At Affordable Prices*. Washington, DC: Transportation Research Board, National Research Council.

32 See, for example, “OC Transpo and its Transitway Network.” *Bus Ride*, October 1986.

median is higher than the bus maximum. This difference, a reflection of consumer choice[33], implies that a busway alternative would have to operate 40 percent more peak-period service than a rail alternative in order to carry the same ridership. (This also implies higher capital costs, for facilities built for higher service levels.)

Busway alternatives are not realistic in corridors where anticipated traffic exceeds the reasonable maximum for light rail (this, in the U.S., is about 8,000 pass/hr or 60,000 pass/weekday). Some transport authorities contend that an advanced bus network would perform as well or better than any system including a rail component, in almost any urban environment. It is not well remembered that this idea was once thoroughly scrutinized -- in Singapore. Planners concluded by the mid-1970s that a heavy-rail trunk system would become necessary as traffic outgrew the capacity of an all-bus network. This drew criticism from the World Bank and opposition from government finance officials on grounds of cost.

A team of Harvard University economists prepared a report[34] supporting an all-bus alternative, arguing that heavy-rail costs would substantially exceed benefits in Singapore. However, the findings of the Harvard team did not stand up to subsequent review, which found that 1.) substantial increases in bus operating costs were not considered, 2.) the proposed all-bus system had major problems, such as unrealistic assumptions regarding operating speed, the necessary fleet size, and failure to consider the need for large downtown bus terminals, and 3.) the plan did not address how to handle large numbers of passengers at downtown terminals. The Singapore government decided in favor of heavy rail[35].

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33 Tennyson states that when service conditions (travel time, fare, service frequency, population and population density) are equal, rail transit will attract 34-43 percent more riders than bus transit. (Tennyson, E. L. 1989. "Impact on Transit Patronage of Cessation or Inauguration of Rail Service." In: *Transportation Research Record 1221*. Washington, DC: Transportation Research Board, National Research Council.)

34 See: *Singapore's Transport and Urban Development Options: Final Report of the MRT Review Team*. 1980. Singapore: MRT Review Team.

35 Additional references:

Awanohara, Susumu. "Singapore Plans for a New Era." *Far Eastern Economic Review*, February 15, 1980.
Awanohara, Susumu. "Ready, Get Set, Don't Go." *Far Eastern Economic Review*, August 22, 1980.
Awanohara, Susumu. "MRT -- More Reflective Thought." *Far Eastern Economic Review*, August 22, 1981.
Seah, Chee Meow. 1981. *The MRT Debate in Singapore: To Do or Not To Do?* Southeast Asian Affairs. Institute of Southeast Asian Studies.

The ridership-ceiling estimates presented in this paper have been criticized as "too low." Individual heavy-rail lines overseas carry up to a million people per weekday, leading some to expect the same in U.S. cities. This perspective fails to consider critical differences in travel patterns. Tôkyô's heavy-rail Ginza Line, for example, is nearly nine miles long and carries more than one million people each day. Such performance would not be duplicated even if this line were faithfully reproduced in any U.S. city. The average travel distance is just 2.3 miles, peak vehicle occupancy is 11.1 pass/meter, and the PTS is a very low 3.0 percent[36]. In other words, the maximum peak traffic volume of 32,000 pass/hr is just three percent of the all-day total ridership. No such thing occurs on any rail-transit line in the U.S. or Canada.

Light rail has been described as "a high-capacity transit system capable of carrying upwards of 25,000 passengers per hour each way."[37] Busway "theoretical maximum" capacity in Los Angeles has been estimated at more than 190,000 pass/hr[38]. Both figures, from the standpoint of what might be achieved in U.S. cities, are pure fantasy. Boston's light-rail Green Line has a downtown subway[39] and carries 10,000 pass/hr; traffic carried by San Francisco's Muni Metro subway may approach this figure. Otherwise, no other U.S. light-rail system exceeds 3,000 pass/hr. As stated above, the practical limit for "light rail," given four-car trains and a three-minute maximum service frequency, is about 8,000 pass/hr. Higher volumes require full grade separation, which effectively means heavy rail. The busway "capacity" figure is the greater fantasy; it is based on the "crush load" of 270 pass/veh for "double-articulated" buses as operated in Curitiba, Brazil. This, as noted above, does not occur even in Curitiba. The postulated peak service level, 720 vehicles per hour, would be impossible to operate without 1.) a large

[36] The absolute minimum, given a 20-hour service day, is 2.5 percent, which would require that passenger volumes be perfectly balanced by direction, throughout the day.

[37] *Citizen's Guide to Central Link Light Rail*. 1998. Seattle: Central Puget Sound Regional Transit Authority.

[38] Rubin, Thomas A., and James E. Moore II. 1997. *Better Transportation Alternatives for Los Angeles*. Policy Study No. 232, Reason Public Policy Institute.

[39] Peak-period service level was 90 veh/hr and peak vehicle occupancy was 111 pass/veh at 1994.

off-street terminal connected directly to the busway[40], or 2.) multiple sets of preferential lanes through downtown[41].

11) Conclusions and Discussion

It should be clear that transit ridership forecasts which do not include proper consideration of service characteristics -- and likely consumer behavior with respect to peak-period crowding -- will mislead and eventually disappoint. The completed Red Line's performance, no matter how remarkable, will be judged against an unattainable target (376,375 weekday passengers) for a long time to come.

Although the current ridership forecasts for the completed Red Line are still unrealistically high (without substantial investment to increase peak-period capacity), those produced for the planned Eastside, Westside (Exposition Corridor) and San Fernando Valley transit projects appear reasonable. Some of the forecasts may be too low, which would lead to construction of facilities inadequate for peak-hour traffic, and constraining future ridership growth.

11.1) The Eastside Corridor

A surface light-rail line or bus transitway to Boyle Heights and East Los Angeles, along East First St., Indiana St. and Whittier Blvd. is feasible and could provide travel-time reductions not significantly different from a heavy-rail line. This fact is demonstrated daily by the Blue Line surface operation along Washington Blvd. Light rail or a bus transitway, given traffic-signal preemption and an average distance between stops of about one mile, could certainly achieve the same speed as the Blue Line does along Washington Blvd.: 20.4 mph. Travel time between Union Station and 1st/Lorena would be about ten minutes, compared to about eight minutes by heavy rail. Union Station to Whittier/Atlantic would require about 19 minutes, compared to 15 minutes by heavy rail. Light-rail or busway times would, of course, be lengthened consid-

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[40] The Lincoln Tunnel between New York City and New Jersey carries nearly 800 buses per hour in a special reserved lane, but this is connected directly to the huge Port Authority Bus Terminal.

[41] 720 veh/hr would require four separate one-way couplets with double bus lanes.

erably without traffic signal pre-emption, or with stations spaced more closely than along Washington Boulevard.

Peak capacity requirements, based on the forecast of 11,400 -- 11,500 passengers per weekday (and a 13 percent PTS), would be relatively modest: about 1,500 passengers per hour, requiring 15 light-rail vehicles per hour (two-car trains every 7.5 minutes), or, for the busway alternative, 40 standard buses or 27 articulated buses per hour. As noted above, the bus alternative would have to provide roughly 40 percent more peak-period service than rail alternatives, based on observed peak vehicle occupancies from various U.S. cities (including Los Angeles).

Annual operating cost, based on the above ridership forecast and an average travel distance of 2.5 -- 3.5 miles, would be in the range of $4-6 million for the bus transitway alternative, or $3-4 million for the light-rail option (1996$s).

The Eastside ridership forecast fails to make a strong case for heavy rail, but other factors must be considered. The ridership ceiling of a surface light rail line or bus transitway is not much greater than the forecast ridership. Operating restrictions which are typical of "new" light-rail lines with street track[42] establish the practical maximum service frequency in the range of 3-5 minutes. The distance between intersections along the planned line, and the typical requirement that no cross street be blocked by a stopped train, impose rigid constraints on maximum train length. If restricted to two-car trains every five minutes during peak periods, the light-rail alternative would have a practical net capacity in the range of about 2,400 pass/hr, unless passengers tolerate very high levels of crowding, as on the Blue Line. This implies a practical net capacity of about 18,000 passengers per weekday, assuming a 13 percent PTS.

In order to carry 2,400 pass/hr, the bus transitway alternative would have to operate 65 standard buses or 44 articulated buses per hour. A busway option might operate as many as 100 vehicles per hour without undue difficulty, providing a practical net capacity of 5,500 pass/hr with articulated vehicles. This implies a ridership ceiling somewhat greater than 40,000 per weekday. Light rail could match this performance with approximately 55 veh/hr, implying three-car trains every three minutes during peak periods.

[42] e.g. no more than one train per traffic-signal (green) cycle, and minimum separation between trains of one city block at all times.

An "Eastside Blue Line" or bus transitway might develop a traffic pattern similar to the existing Blue Line, with a very low PTS, and a similar ridership level. Assuming that this would occur, without extensive analysis of travel demand and the potential interaction of demand and supply factors, would be most unwise. Such analysis, if it demonstrated the potential for a traffic pattern similar to the Long Beach Blue Line on the Eastside, would actually strengthen the case for a heavy-rail alternative.

The case for an Eastside heavy-rail project begins with the question of how to accommodate the peak-period passengers transferring to connecting services at Union Station. Passenger convenience, although important, is not the primary issue. The current facilities at Union Station (Patsaouras Transit Plaza) could certainly accommodate an additional 40 buses and 1,500 passengers during the busiest hour. An additional 65 buses and 2,400 passengers during the busiest hour should not create problems, but practical limitations on terminal capacity might constrain the achievable peak-period volume well below the 5,500 pass/hr figure stated above. A light-rail option might require significant modifications to the Patsaouras Transit Plaza facility or creation of a separate terminal.

Another issue is future ridership growth. An annual growth rate of seven percent, as experienced on the Blue Line, would bring Eastside ridership to 25,000 per weekday within 11 years. Peak-period volumes would exceed 3,000 pass/hr, unless constrained by ceilings imposed by terminal capacity, practical limitations on peak-period service frequency, or consumer tolerance for peak-period crowding. Eastside project ridership would reach nearly 45,000 per weekday after 20 years of unconstrained growth at seven percent annually, implying peak-period passenger volumes of nearly 6,000 per hour. These figures are near the practical maximum for bus or light-rail alternatives. Given an average weekday ridership of 25,000, annual operating costs for the bus alternative would exceed that for rail by $4-5 million annually, or by $7-9 million annually given 45,000 passengers per weekday (assuming an ATD of 2.5 -- 3.5 miles).

The Boyle Heights -- East Los Angeles area has a population exceeding 200,000 (1990 census) in an area of 13 square miles. The population density at 1990 was 16,300 per square mile, among the region's highest. The Eastside's high percentage of low-income households without access to autos suggests a large market for improved transit services offering travel-time reductions. An Eastside Red Line extension would provide one-seat service to employment opportunities well beyond the "cordon" imposed by long travel times aboard surface buses. Hollywood, for example, would be less than 30 minutes from 1st/Lorena, and North Hollywood would be less than 40 minutes away. By comparison, peak-period bus services require 40 minutes for the seven-mile trip between Atlantic Blvd. and downtown Los Angeles.

The choice among bus transitway, light rail and heavy rail for the Eastside also involves regional planning issues. An Eastside Red Line might eventually be extended from 1st/Lorena to Whittier/Atlantic, then southwest along railroad or freeway alignments toward an eventual terminal in Norwalk, shared with bus services, Metrolink, Amtrak and a possible future Orange County rail system. It would become a major transportation link in southwestern Los Angeles County, offering a very attractive alternative to auto commuting -- and much-improved access to employment locations for transit-dependent residents.

The issues outlined above, related to the Eastside mode choice, are similar to those involved with other corridors. However, each corridor currently under study has its own unique characteristics which introduce additional issues.

11.2) The San Fernando Valley Corridor

A busway or light-rail line between North Hollywood and Warner Center would have no difficulty matching the passenger speed achieved by Blue Line trains over the reserved-track portion of the line -- 33.5 mph. This, of course, assumes grade-crossing protection, grade separation at the busiest cross streets and spacing between stations (1.4 miles) similar to the Blue Line between Washington and Willow stations. Such a line could provide significant travel-time reductions: North Hollywood to Van Nuys would require less than ten minutes; North Hollywood to Warner Center would require about 25 minutes.

The current estimated capital cost for the busway alternative may be unrealistically low; the well-documented problems involved in constructing a new transit facility along an existing railroad alignment are not confined to light rail[43].

Operating-cost differences between rail and bus modes would be significant, given the likelihood that a rapid-transit facility in the southern San Fernando Valley would attract a large amount of travel (passenger-miles). The light-rail alternative, although forecast to attract 45 percent higher ridership (23,400 per weekday vs. 16,100 per weekday), would cost $2 million (1996$s) per year less to operate ($14 million vs. $16 million per year, assuming a 6-mile ATD).

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[43] Readers are again advised to see: McSpedon, Edward. 1989. "Building Light Rail Transit in Existing Corridors -- Panacea or Nightmare?" In: *Light Rail Transit: New Systems At Affordable Prices*. Washington, DC: Transportation Research Board, National Research Council.

The operating-cost issue may be better explored by placing both modes on an equal footing. Assuming that either alternative would attract 25,000 passengers per weekday, the annual operating-cost advantage of the light-rail option grows to $9 million (again assuming a 6-mile ATD). Unconstrained ridership growth at an annual rate of seven percent would bring average weekday ridership to Blue Line levels (50,000 per weekday) after ten years. At this point, a busway would cost $18 million more per year to operate than a rail alternative; cumulative savings over ten years would total nearly $150 million (1996$s).

The case for a heavy-rail extension from Lankershim/Chandler toward Warner Center might be based on eventual need for net capacity greater than 50,000 -- 60,000 passengers per weekday, or 6,000 -- 8,000 pass/hr. Based on observed peak vehicle occupancies in Los Angeles and other U.S. cities, light rail might reasonably accommodate 8,000 pass/hr with four-car trains every three minutes; doing so with buses would require 220 standard or 145 articulated buses per hour. Whether this traffic potential exists is a subject for detailed demand analysis; the author notes that the San Fernando Valley south of Roscoe Blvd. housed more than 675,000 people at the 1990 census. Another issue for the San Fernando Valley corridor, regardless of mode choice, is the potential for eventual northward extension from Warner Center to Chatsworth, providing an interchange with regional bus services, Metrolink and Amtrak.

11.3) The Westside Corridor

The Exposition Corridor, between downtown Los Angeles and Santa Monica along an abandoned railroad right-of-way, presents a tough challenge for transportation planning. As with the Valley corridor, a busway or light-rail line would have no difficulty achieving passenger speeds similar to the Blue Line -- again assuming similar spacing between stations, grade-crossing protection and grade separation where cross traffic requires. Downtown Los Angeles to Exposition/La Brea would require less than 20 minutes; downtown L.A. to Santa Monica would require less than 40 minutes. This line would certainly attract heavy traffic regardless of mode. It could also be completed long before a Red Line extension to West Los Angeles and Santa Monica.

A light-rail alternative sharing the Blue Line terminal at 7th St/Metro Center appears impractical, given the current peak service frequency of five minutes between Blue Line trains. Westside traffic would soon grow to require a similar peak service frequency. Even if a combined peak frequency of 2.5 min was technically possible from 7th St/Metro Center to Flower St. and Washington Blvd., schedule reliability would suffer owing to the operational difficulties of "meshing" two long, busy lines. Westside traffic would also increase the peak-period pressure on the Red Line interchange at 7th St/Metro Center, and the need for a Blue Line connector between 7th St/Metro Center and the Pasadena Blue Line at Union Station.

Barring extensive reconstruction of the 7th St/Metro Center light-rail terminal, a Westside light rail line would probably require a separate entrance into downtown Los Angeles. Resolution of this particular issue would require a detailed engineering study, considering the experience of other U.S. light-rail systems[44]. Either the light-rail or busway alternatives might be developed concurrently with an Eastside project, and operated jointly, linked by preferential lanes through downtown.

The operating-cost issue would be significant, given the relatively high ridership and long ATD that a Westside line would attract. The light-rail forecast, 36,600 passengers per weekday, is nearly ten percent higher than the busway forecast, 33,400 per weekday. If both modes are placed on an equal footing (using the rail forecast), annual rail operating cost would fall in the range of $20-25 million (1996$s), while annual busway operating cost would fall in the range of $35-40 million (assuming an ATD in the range of 6-7 miles). Ridership would reach current Blue Line levels within five years, given unconstrained growth at an annual rate of seven percent. The cumulative operating-cost savings provided by the rail alternative during this period would fall in the range of $80-90 million. Continued ridership growth significantly beyond Blue Line levels might require peak-period capacity in the heavy-rail range.

11.4) The Alignment Debate: Subway, Surface or Elevated

As demonstrated by various cities in the U.S. and overseas, there is no particular reason why any future heavy-rail or light-rail line in Los Angeles need include any more "subway" tracks -- from a purely technical standpoint. Light rail lines may be built on surface streets, as the Blue Line demonstrates. Heavy-rail lines have been built on elevated structure over surface streets,

[44] In San Francisco, the stub-end downtown Muni Metro terminal at Embarcadero station imposed a serious capacity constraint for many years until construction of new tail tracks.

even in densely-populated areas or the business centers of very large cities[45]. Light-rail and heavy-rail lines may be built on elevated viaduct, alongside freight railroads or on abandoned railroad rights-of-way, or in retained cuts. Heavy-rail lines need not be fully grade-separated, as demonstrated in Japan.

In locations where heavy-rail capacity is needed and alternative alignments are not available, construction of heavy-rail lines over major streets may impose unacceptable environmental impacts. A non-subway alternative to the currently-funded Red Line is difficult to imagine[46], as are non-subway alternatives in the corridors which most clearly need heavy-rail capacity. It is also difficult to imagine a non-subway alternative to the Blue Line connector between 7th St/Metro Center and Union Station. Failure to link the Long Beach and Pasadena Blue Line segments will eventually impose a serious peak-period capacity constraint in downtown Los Angeles, overloading the Red Line.

Eventual westward extension of the Red Line from Wilshire/Western might also overload the existing facility. As outlined above, a Red Line "ridership ceiling" of 120,000 -- 170,000 passengers per weekday is associated with a peak-period service frequency of 3 to 3.5 minutes -- between downtown Los Angeles and North Hollywood. This would leave rather little room for additional trains serving the westward (Wilshire) line. An extension to Wilshire/Fairfax is forecast to carry 21,600 passengers per weekday, unimpressive considering the relatively small travel-time saving over the current Wilshire Limited bus services and the Red Line connection at Wilshire/Western. Traffic potential given additional extensions is considerable in light of the travel-time savings: 15 minutes to UCLA, and 30 minutes to Santa Monica. Assuming ridership

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[45] New York has many miles of elevated heavy-rail lines although no longer in Manhattan and downtown Brooklyn. Chicago's downtown "L" is still very much a part of its urban landscape. Elevated heavy-rail lines in Philadelphia and Boston always used downtown subways; the Philadelphia elevateds remain but those in Boston have been replaced by new heavy-rail lines without elevated structures. More-recent examples of heavy-rail lines with elevated structure near, but not in, the business centers of major cities include Miami's Metrorail, San Francisco's BART, and Vancouver, BC's Skytrain.

[46] Except perhaps over Cahuenga Pass between Hollywood and North Hollywood, as once planned.

of 75,000 per day on an extended Red Line[47], the peak-hour traffic volume might fall in the range of 7,000 - 10,000 per hour. This would require 10-14 six-car trains per hour, implying a peak service frequency between 4 and 6 minutes. These trains would have to share tracks with North Hollywood trains -- operating every 3 to 3.5 minutes -- between Wilshire/Vermont and Union Station, a combined service of 27-34 trains per hour (every 1.75 to two minutes). Maintaining this level of service with good schedule reliability would prove a daunting task without an advanced-technology signal system -- or additional tracks between Vermont Ave and downtown Los Angeles.

According to an old saying, there are no easy answers, only intelligent choices. According to another old saying, sometimes referred to as "Murphy's Second Law," it is inevitable that change will proceed gradually. There are no low-cost, low-effort, short-term solutions to the public transportation problems of Los Angeles. Local residents and community leaders will need to carefully consider various strategies, since capital-cost savings may be quickly absorbed by increased operating cost.

As an example, an investment of $200 million, the construction cost of 1-2 miles of heavy-rail subway, would buy about 600 buses. LACMTA could use these to increase annual bus-miles by more than 30 percent. Doing so, however, would attract no more than 200,000 -- 250,000 additional weekday boardings -- at an annual cost of $200 million in additional operating expense. The 600 buses and four years' worth of operations would cost $1 billion. To match the performance of the Red Line, as outlined above, about 45-70 percent of the additional vehicle-miles would have to be deployed in the Red Line corridor. Doing so would cost roughly $90-140 million per year, $40-70 million per year more than likely Red Line operating costs. The difference represents funds which could be used to support additional bus service elsewhere in the region, 5-10 million annual vehicle-miles by 100-200 additional buses.

Significantly increased transit ridership will require significantly higher expenditures for operations, and significant capital investments. In other words, increased ridership will occur only in response to more and better transit service. Strategies based on minimizing capital expenditures, or diversion of all possible resources to bus purchase and operation, will fail. An unim-

[47] This figure is conservative. The current Red Line averaged 25,000 passengers per weekday in 1996; Wilshire Boulevard bus services carried 38,000 passengers per weekday at the end of 1996. Services on parallel streets within one-half mile of Wilshire Blvd., including Third St., Sixth St. and Olympic Blvd. carried an additional 60,000 passengers per weekday in 1996. These figures do not include services operated by Santa Monica Municipal Bus Lines in the western part of the corridor.

proved surface bus system cannot meet the needs of Los Angeles, no matter how much service is operated. Southern California includes some of the most densely-populated urban land in the U.S. The 50-square-mile rectangle including downtown Los Angeles, Hollywood and Wilshire Corridor, almost exactly the size of San Francisco, is only a small part of the urbanized area. However, if incorporated as a separate city, this area would have the second-highest population density of any U.S. metropolitan center.

On the other hand, busway, light rail and heavy rail lines cannot be built throughout the region all at once, even if available funding were greatly increased. Many busy corridors will be served with surface buses for years to come. A comprehensive regional public transportation plan would have to include short-term, medium-term and long-range elements, including innovative strategies to reduce travel times by surface bus and improve the reliability of transfer connections. The needs of transit-dependent residents must be considered, but public transit systems which fail to attract broader ridership will lose political support, stagnate and decay.

This paper, focusing on technical issues, has highlighted only one aspect of the transportation choices facing the Los Angeles region. Many other factors, financial, economic, social and political, will have to be considered as part of the planning process. The potential for success has been demonstrated by the El Monte Transitway, and more recently by the Blue Line and the Metrolink commuter-rail network. The completed Red Line will certainly provide additional evidence that, through incremental development of transit facilities providing significant reductions in travel time and other service-quality increases, Southern California can develop a viable and popular alternative to the automobile.