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STAFF STUDY

URBAN RAIL IN AMERICA:
A REVIEW OF PROCEDURES AND RECOMMENDATIONS FROM THE REGIONAL PLAN ASSOCIATION STUDY

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EXECUTIVE SUMMARY

A series of detailed studies conducted over the last twenty years has investigated the suitability of rail mass transit service for large U.S. cities. Until recently, their authors almost universally found that the extremely high commuting volumes (20-30,000 passengers per hour during peak periods) necessary for rail transit to become the most cost-effective means of providing radial transportation service were rarely reached in the nation's urban areas. Yet a more recent study conducted by the Regional Plan Association, entitled Urban Rail in America: An Exploration of Criteria for Fixed-Guideway Transit, concluded that conventional rapid transit lines could offer sufficient cost savings compared to carrying commuters by automobiles and buses to justify their construction in at least seven U.S. cities, while modern "light Rail" lines could provide transportation service at net cost savings in at least a dozen others.

These include new heavy rail lines totaling at least 50 miles, built partly or entirely in underground tunnels, in four cities now without rail service: Los Angeles, Seattle, Honolulu, and Houston. Completing those lines meeting the authors criterion for above-ground construction in three cities with rapid transit systems now under construction -- Washington, D.C., Baltimore, and Miami -- would add another 55 miles to this total. Some 85-90 additional miles of heavy rail line additions, extensions, or replacements in the seven U.S. cities with existing rapid transit systems (New York, Chicago, Philadelphia, Boston, Cleveland, Newark, and San Francisco) are also likely to be justified by the criteria developed in the report, according to its authors.

They also recommend constructing new light rail lines totaling 90 miles or more, again partly in tunnels, in another twelve U.S. cities: Detroit, Dallas, St. Louis, Minneapolis-St. Paul, Indianapolis, Buffalo, San Diego, Portland, Louisville, Cincinnati, Denver, and Milwaukee. Three of these -- Buffalo, San Diego, and Portland -- have since begun constructing light rail lines, with the San Diego line completed in 1981 and the Buffalo system now nearing completion. Finally, they recommend serious consideration of various light rail line additions and extensions, mostly in cities having older streetcar systems, that would amount to nearly another 140 miles of new light rail transit line construction.

Typical recent construction costs suggest that completing the recommended rapid transit lines would require about $12 billion (expressed in 1983 dollars), while constructing the recommended light rail mileage would add more than $2 billion to this figure. If the additional mileages recommended for further consideration were ultimately built, total construction expenditures would probably rise to the $25-30 billion range. In contrast, total federal assistance for new mass transit construction now amounts to slightly over $400 million annually, so that building even the minimal recommended lines would require a substantial increase in the current level of public financial commitment to urban rail construction.

This study reviews the findings reported by the Regional Plan Association regarding the suitablitiy of new rail transit investments in U.S. urban areas. It does so by using operational data from recently completed rail lines to develop detailed empirical (rather than theoretical) estimates of the potential operating cost reductions, travel time savings, and land use benefits from constructing new rail transit lines. It also adds estimates of potential savings in vehicle capital and right-of-way costs that may arise when travelers carried by a new rail line rather are diverted from buses or automobiles. Finally, it compares those savings to new estimates of the costs of constructing rail transit facilities on various types of rights-of-way, which are derived from the recent U.S. and Canadian experience in building new rail lines.

Its major conclusions are that corridor travel demands are sufficient to justify constructing and operating heavy rail transit service only in a few U.S. cities already served by it, and that the number of U.S. urban travel corridors where light rail transit service appears to be an economically sensible transportation alternative is also extremely limited. Specifically, the revised estimates of rail line operating benefits and construction costs developed in this review indicate that realistic ridership forecasts cannot justify constructing any new heavy rail lines in U.S. cities, and that most of those currently under construction cannot be justified on economic grounds.

This review also indicates that the number of corridors in even the largest and most densely developed U.S. cities where constructing light rail lines can be justified by realistic estimates of their likely costs and attendant benefits also appears to be extremely limited. Most important, this group almost certainly excludes every U.S. city that is now either building or actively planning a light rail line. All of these findings are based on estimates of rail operating benefits in line-haul service only, and would be strengthened by carefully considering the costs of providing the feeder bus services and other access facilities necessary to develop acceptable ridership levels, given the residential and employment densities characteristic of most U.S. cities that are not already served by rail transit.

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THE RAIL TRANSIT CONTROVERSY

Early Analysis of Rail Transit: The Meyer-Kain-Wohl Study

A series of detailed studies conducted over the past twenty years by consulting organizations and academic researchers has investigated the suitability of rail mass transit service in large urban areas. In the earliest and most widely cited of these studies, Meyer, Kain, and Wohl studied the comparative capital and operating costs for transporting commuters from suburban residences to CBD work locations via automobiles driven on expressways, transit buses operating on expressways or dedicated facilities, and conventional heavy rail transit running on exclusive rights-of-way.[1] These authors found that conventional rail rapid transit (often called "heavy rail" transit) was the least costly means of urban transportation only when aggregate travel volumes in well-defined corridors reached levels that were very rarely found in U.S. cities.

Specifically, they concluded that heavy rail transit was the least costly mode for carrying passengers on the line-haul phase of commuting trips only at peak hour flows exceeding about 12-18,000 persons (depending on the density of urban development, which affects the costs of acquiring land on which to locate rights-of-way for the various modes). Further, they found that this figure rose to much higher levels after accounting for the additional costs of collecting rail passengers at the residential end of the commute trip and distributing them to their downtown destinations. These results owed largely to the substantial fixed capital costs for constructing rail systems (even when placed on surface or elevated alignments rather than in more costly underground tunnels), which declined to average per-passenger levels below those for autos and buses operating on expressways only when they were distributed over very large hourly passenger volumes.

Later Comparative Cost Studies

Several subsequent analyses of the potential applicability of rail transit retained the basic approach developed by Meyer, Kain, and Wohl of comparing the costs of transporting passengers by different modes at various peak hour commuting volumes. A 1973 study conducted by the Institute for Defense Analyses expanded the definition of relevant costs to include the value of time spent by travelers both waiting and riding aboard vehicles.[2] This study also introduced a further refinement by comparing "optimum" service levels for various transit modes, determined as the frequency of vehicle departures necessary to minimize the sum of capital costs, vehicle operating expenses, and the value of travelers' time for each of the modes considered. Despite these modifications, its authors again concluded that extremely high commuting volumes (above about 20,000 peak hour passengers in line-haul service and 30,000 peak riders in door-to-door service) were necessary for rail transit to offer the lowest value for this more inclusive definition of costs.

[illegible]

Keeler and his colleagues subsequently refined these results by adding the "external" costs imposed by auto commuting, including those for time lost when motorists delay one another in congested traffic, and for the damages to property and health caused by their contributions to air pollution.[3] Nevertheless, they found that when compared to autos and buses operating on expressways for typical suburban-to-downtown commuting trips, conventional rail transit became the cost-minimizing mode for carrying commuters only at volumes well over 30,000 per peak hour. Thus their results were again closely comparable to those obtained in previous studies, despite their more inclusive definition of costs and other refinements. Straszheim expanded Keeler's earlier estimates of these external costs of auto travel and added costs for the disruption and dislocation imposed during construction of transportation facilities, but still concluded that similarly high travel volumes were required to reduce average per-passenger costs of rail transit service below those of private auto travel and express bus service.[4]

URBAN RAIL IN AMERICA

In contrast to the nearly unanimous conclusions offered by this succession of reports, a more recent study conducted by the Regional Plan Association concluded that heavy rail lines partly or entirely in tunnels offered potential cost savings, in comparison to transporting commuters by automobiles and buses, that were sufficient to justify their construction in seven additional U.S. cities (three of which were by then in the process of constructing them). This report, *Urban Rail in America: An Exploration of Criteria for Fixed-Guideway Transit*, authored by Boris Pushkarev and Jeffrey Zupan, also concluded that modern "light rail" lines operating largely on surface rights-of-way, a mode that had not been specifically investigated in any of the preceding studies, could provide transportation service at net cost savings over autos and buses in at least a dozen -- and perhaps as many as twenty -- other U.S. urban areas. These findings have apparently been influential: since the report's 1980 publicaton, five U.S. cities have constructed entirely new rail transit lines, while three have completed significant additions to their existing rail systems. At the same time, another six urban areas have begun building extensive new light rail lines or additions to existing ones, and several others have started actively planning substantial new rail transit investments.

The RPA Authors' Approach

The Regional Plan Association (RPA) study evaluated the suitability of rail transit using an approach that differed slightly from these earlier "comparative cost" studies. Instead of comparing the full costs of transporting commuters using various modes, its authors estimated the potential savings in vehicle operating costs (including operator and other labor, maintenance inputs, and energy use), travelers' time, and land utilization (for transit rights-of-way and automobile parking) that could be realized by transporting commuters via heavy and light rail transit rather than by private automobiles or conventional bus service. This study also attempted a limited assessment of the potential benefits from transporting non-commuting trips by rail transit, by estimating how much they might add to rail transit ridership and thus to the resulting savings in resources used to supply transportation services.

These potential operating cost, travel time, and other savings from carrying peak hour travelers by light or heavy rail instead of their current modes were calculated for various travel volumes. Average savings per passenger diverted to rail transit show some tendency to rise with increasing travel volumes, as basic labor and propulsion energy requirements for operating rail transit vehicles are averaged over progressively larger passenger volumes, while bus and auto travel do not exhibit significant operating economies of this same nature. In contrast, the capital costs for providng rail service decline sharply with increasing travel volumes, since they represent fixed costs that are spread or averaged among increasing numbers of travelers.

There is thus some travel volume above which the sum of operaing cost, travel time, and other savings from transporting commuters by rail transit are sufficient to justify the initial capital expenditure necessary to construct a rail line of a given type (light or heavy rail), alignment (in an underground tunnel, on elevated structures, or at the surface), and length, and to acquire the necessary vehicle fleet. These volume thresholds can then be compared to actual or potential corridor travel volumes in order to determine where the construction of rail lines of various types would be economically justified. The authors of the study examined 16 U.S. cities for travel corridors sufficiently dense to support rail rapid transit service, as well as another 13 possible locations for light rail transit lines.

Interestingly, the potential savings in capital costs for vehicles and peak roadway capacity when commuters are carried by rail transit rather than autos and buses, which would be expected to be among the most significant benefits of constructing and operating rail transit, were discussed but not explicitly included in the authors' benefits calculations. This probably reflected their recognition that the scale of existing street and highway facilities, as well as perhaps an urban area's automobile and bus fleets, might not be significantly reduced in response to the construction of a new rail line. Omitting these potentially substantial savings should have served to make the analysis less likely to identify realistically achievable demand levels that would warrant building rail transit lines. On the other hand, because rail transit operates most efficiently in the line haul phase of travel, focusing on line haul service alone should have made rail systems more likely to demonstrate potential operating savings sufficient to offset their construction costs.

General Findings from the RPA Study

As Table 1 indicates, the travel volumes identified in the Regional Plan Association study as warranting construction of rail lines are

Table 1

Results of Various Urban Transportation Cost Studies

Authors	Rail System Description	Travel Volume[a] "Threshold"
Meyer, Kain, Wohl	Rapid Transit:	
	open cut	12,000
	tunnel	18,000
Boyd, Asher, Wetzler	Rapid Transit: typical new lines (about 70% surface, 30% tunnel)	> 30,000
Keeler, Small, and Associates	Rapid Transit: 75% surface, 25% tunnel	18,000-20,000
Pushkarev and Zupan	Rapid Transit:	
	100% tunnel	7,400
	33% tunnel, 67% surface	6,100
	100% surface	3,800
	Light Rail Transit:	
	20% tunnel, 80% surface	3,400
	100% surface	1,900

[a] One way peak-hour passenger volume above which rail transit becomes the cost-minimizing mode for line-haul travel.

Sources: see footnotes 1-5 to text for full references.

considerably below those reported by earlier researchers. Its authors report that rail service levels that would normally be called for where one direction peak hour commuting flows as low as 7,400 riders (allowing for normal variation throughout the day in rideship patterns and service schedules) can be sufficient to warrant constructing heavy rail lines entirely in underground tunnels. They also estimate that daily ridership levels averaging above 24,000 passengers per mile of line, which are likely to produce one-way peak hour passenger volumes of about 6,100 riders, could justify building a rapid rail line with up to one-third of its length in a tunnel, and the remainder at grade level. Finally, the authors argue that a heavy rail line built entirely on the surface (the least costly alignment) could be justified by cost savings where peak passenger volumes as low as 3,800 riders (corresponding to about 15,000 average daily riders per mile of line built) are attained.[5]

The Regional Plan Association study also offers the first careful estimates of travel volumes necessary to support construction of light rail transit lines. It reports that average weekday travel volumes as low as 7,200 passengers per line-mile, corresponding to only about 1,900 one way peak hour riders, could produce operating, travel time, and related savings sufficient to justify building surface light rail lines with extensive grade separation from street traffic. If daily passenger volumes as high as 12,800 -- corresponding to peak hourly travel flows of about 3,400 persons -- could be achieved, its authors argue, constructing as much as 20% of the length of such light rail lines in tunnels (primarily in the downtown areas they served) could be justified on the basis of the combined operating, travel time, and land cost savings it would produce.

Specific Construction Recommendations

Comparing these estimated thresholds to their estimates of corridor travel volumes in various U.S. cities, the authors identify a surprising number in which building at least a single radial transit line would appear to justified by cost savings alone. These include new heavy rail lines totaling at least 50 miles, built partly or entirely in underground tunnels, in four cities now without rail service: Los Angeles, Seattle, Honolulu, and Houston.[6] Completing those lines meeting the threshold criterion for above-ground construction in three cities with rapid transit systems now under construction -- Washington, D.C., Baltimore, and Miami -- would add another 55 miles to this total. Some 85-90 additional miles of heavy rail line additions, extensions, or replacements (again partly underground) in the seven U.S. cities with existing rail rapid transit systems (New York, Chicago, Philadelphia, Boston, Cleveland, Newark, and San Francisco) are also justified by the criteria developed in the report, according to its authors.[7]

They also recommend constructing new light rail lines totaling 90 miles or more, again partly in tunnels, in another twelve U.S. cities: Detroit, Dallas, St. Louis, Minneapolis-St.Paul, Indianapolis, Buffalo, San Diego, Portland, Louisville, Cincinnati, Denver, and Milwaukee.[8] Three of these -- Buffalo, San Diego, and Portland -- have since begun constructing light rail lines, with the San Diego line completed in 1981 and the Buffalo system now nearing completion. Finally, they recommend serious consideration of various light rail line additions and extensions, mostly in cities having older streetcar systems, that would amount to nearly another 140 miles of new light rail transit line construction.[8]

One surprising aspect of these recommendations is their apparent contradiction of the implications of all of the previous studies of the economic rationale for constructing new rail transit facilities in U.S. cities. In fact, the travel volume thresholds necessary to economically justify heavy rail transit that were developed by earlier researchers would not have warranted a single new rail rapid transit line in the U.S., since those few corridors where the thresholds were met (several in New York and a few others in Chicago and Philadelphia) were already served by heavy rail subway lines. Yet this more recent analysis strongly endorses completing most of the planned segments of three of the four new rail rapid transit systems now under construction (the conspicuous exception is the Atlanta system), while encouraging construction of new lines or extension of systems now operating in another seven. In addition, in the first such evaluation of intermediate-capacity rail alternatives, it finds that another ten urban areas with travel volumes falling short of those necessary to support rapid transit lines could still readily support single light rail lines or more elaborate systems.

Estimated Costs of Constructing the Recommended Lines

An even more striking feature of the ambitious agenda of rail construction projects recommended by the Regional Plan Association researchers is its potentially enormous cost. If as has been the case for recently constructed heavy rail lines, about one-third of the recommended heavy rail mileage were built in tunnels, another one-sixth on modern elevated structures (as have been used in Baltimore, Miami and Atlanta), and the remainder on surface rights-of-way, typical recent construction costs suggest that completing the 190 miles of recommended[10] lines would require about $12 billion (expressed in 1983 dollars). Constructing the recommended light rail mileage -- about 10% of which would be located in tunnels -- would add more than $2 billion to this figure at typical recent costs for building U.S. and Canadian light rail lines. If the additional mileages recommended for further consideration were ultimately built, total construction expenditures would probably rise to the $25-30 billion range.

In contrast, total federal assistance for new mass transit construction now amounts to slightly over $400 million annually.[11] When local matching expenditures are added, this figure still only reaches about $500 million, so that even the minimal recommended construction program would require a substantial increase in the current level of public financial commitment to urban rail construction to complete in a reasonable period. As another indication of the magnitude of this proposed rail transit building agenda, total construction expenditures for all purposes (including roads, schools, and various public works) by states and local governments together amounted to about $40 billion during 1983.[12] Viewed still another way, the approximately $14 billion required to complete the minimal recommended agenda of rail projects would be sufficient to nearly triple the number of urban transit buses now used to provide service to the nation's metropolitan areas. Regardless of the specific comparison invoked, even the basic rail construction program recommended by the report would represent an ambitious escalation of both the national financial commitment to rail transit and the level of capital investment activity by local government.

Outline of this Review

This study reviews the findings reported by the Regional Plan Association regarding the suitablitiy of new rail transit investments in U.S. urban areas. It does so by using operational data from recently completed rail lines to develop empirical (rather than theoretical) estimates of the potential operating cost reductions, travel time savings, and other benefits from constructing new rail transit lines such as those now being planned in a number of U.S. cities. It also adds estimates of potential savings in vehicle capital and right-of-way costs that may arise when travelers are carried by a new rail line rather than by buses or in automobiles. Finally, it compares those savings to new estimates of the costs of constructing rail transit facilities on various types of rights-of-way that are derived from the recent experience in building new rail lines. Its major conclusions are that constructing and operating heavy rail transit service in the United States is economically justified only in a few corridors already served by it, and that the number of U.S. urban travel corridors where light rail transit service appears to be an economically sensible transportation alternative is also extremely limited.

POTENTIAL SAVINGS FROM RAIL TRANSIT INVESTMENTS

The Basic Model

The Regional Plan Association model evaluates the benefits from rail transit investments by first estimating the physical quantity of operating, user-supplied, and other inputs saved when rail service is substituted for bus transit and private auto travel. These estimates are developed using parametric representations of the quantity of each input required to provide comparable levels of transportation capacity using each of these three modes. Four categories of such inputs are considered: labor requirements for operating transit systems; energy inputs used to operate and service vehicles as well as to maintain lines and stations; land used for automobile parking and transit facilities; and commuters' travel time. These savings are then converted to dollar equivalents using either the market prices of the inputs or, as with travel time savings, estimates of their equivalent monetary values.

Although estimating their actual magnitudes can involve complex calculations, the reasoning underlying each of these resource savings is straightforward. Labor savings from transporting high passenger volumes by rail rather than bus transit stem from using larger vehicles that can be operated in trains, but these savings are partly offset by the approximately fixed labor requirements for right-of-way and station maintenance. (The two modes appear to have about the same vehicle maintenance and administrative labor requirements per unit of service.) Similarly, if the higher energy requirements for operating rail vehicles and the fixed energy requirements for maintaining lines and stations can be averaged over sufficiently high service levels, they can result in lower energy requirements per unit of transportation service than for bus transit and automobile travel.

Downtown land requirements can be reduced by the area that would otherwise be required to accommodate commuters' parked automobiles when they are carried by rail transit instead, and there may be additional savings if the land occupied by rights-of-way dedicated to bus and automobile travel are reduced. Commuters may also save travel time (to which they evidently attach some monetary value) if the speed at which they are carried aboard rail vehicles operating on exclusive rights-of-way exceeds those of buses and autos, which share road space with each other as well as with trucks and other vehicles. Finally, some savings in the capital resources devoted to urban transportation, including both an urban area's auto and bus vehicle fleets and the rights-of-way on which they operate, may also stem from investing in new rail transit lines.

Potential Complications in Estimating Benefits

Despite their compelling logic, each of these potential resource savings is subject to certain important qualifications. The most general of these is that achieving any of them depends on whether rail transit service is utilized as intensively by travelers as are the bus transit services and automobile transportation facilities from which the riders of a new rail system are drawn. More specifically, institutional arrangements such as contract provisions specifying minimum staffing levels may prevent potential labor savings from being fully realized. Similarly, potential energy savings from rail transit can be partly offset by losses in generating and transmitting the electric power on which it operates, and also depend critically for their realization on high occupancy of rail vehicles.

Land savings from reduced parking space can also be partly offset by land required for surface-level or elevated rail transit facilities; they can be fully realized only by locating transit lines entirely underground, by far the most costly alignment.[13] Perhaps most important, higher speeds (and thus travel time savings) for rail transit are likely to be limited to line-haul service between rail stations. Yet in the more important door-to-door travel time comparisons, any advantage of rail transit -- even with elaborate feeder bus service and closely-spaced downtown stations -- is much less obvious, if indeed it exists at all. Because of these potential complications in estimating the benefits from rail transit investments, it is instructive to review the RPA researchers' estimates of resource cost savings in light of the actual experience with recently constructed rail transit systems.

The following sections review each of the major sources of potential savings from rail transit investments -- labor, energy, land, and travelers' time. Each section also details how revised empirical estimates of the potential benefits from diverting CBD-bound urban travel from buses and automobiles to rail transit can be constructed from readily available information. The basic structure of the model developed by the RPA researchers is thus retained, but its estimates of the various parameters governing the savings achievable by rail transit are adjusted to reflect the actual operating experience of recently built U.S. and Canadian heavy and light rail transit systems. In addition, rough empirical estimates of vehicle and right-of-way cost savings made possible by reduced automobile and bus transit commuting, which were not specifically quantified in the RPA report, are constructed and added to the operating cost savings and other benefits of new rail transit investments. First, however, a more detailed description of the alternative transportation modes to which rail transit is compared, as well as of the market in which they are assumed to provide service, is provided.

The Alternatives to be Compared

The Regional Plan Association study compares the resources used in transporting passengers by rapid rail and light rail transit to those that would be consumed if they traveled instead by conventional bus transit and private automobiles. In computing the benefits from substituting rail transit for bus and auto travel, its authors assume that the rail modes can be operated very efficiently, while bus transit service is assumed to have the inefficient labor utilization and low operating speeds (8-12 miles per hour) that characterize conventional local bus service in older, very large urban areas. Similarly, automobiles are assumed to travel at about the same speeds as rail vehicles, which is probably approximately correct over the line-haul phase of urban trips, but the auto's important speed advantage in door-to-door service (stemming from its flexibility in passenger collection and distribution) is ignored.

In order to provide a more reasonable comparison of the modes, this review substantially retains the RPA assumptions about efficient rail operations (although they are revised slightly in the discussion that follows), but compares the rail modes to a form of bus transit service that is more representative of those in the large urban areas now contemplating rail investments. This consists of peak-hour radial express service, supplemented by conventional local bus service during off-peak periods. These express services are assumed to achieve speeds and labor utilization rates representative of the few large-scale express services for which operating data are available. The supplemental local service is assumed to have labor requirements and operating speeds typical of bus systems in the modern large urban areas that are now considering rail transit, rather than those of bus systems operating in the nation's oldest and most congested urban areas (most of which already have some form of rail transit system).

The RPA study further assumes extremely high seating densities and occupancy factors aboard rail transit vehicles, while using considerably lower ones for transit buses and private automobiles. For example, it envisions rapid transit vehicles capable of accommodating 142 passengers, which operate full during peak periods and achieve overall average occupancy of about 25%, while light rail vehicles accommodate 132 passengers and achieve the same occupancy factor. In practice, however, typical rapid transit vehicles accommodate only about 100-120 passengers in reasonable comfort (and even then only about half can be seated), and achieve overall occupancy factors of only 10-20% of available passenger places. Modern light rail vehicles carry somewhat fewer passengers and achieve approximately the same occupancy factors. Thus the RPA figures for passenger-carrying capacities and occupancy factors appear to overstate somewhat the performance of actual rail transit services.

This review uses somewhat more realistic but still quite favorable capacities for rail vehicles: rapid rail vehicles are assumed to accommodate 120 passengers, light rail vehicles 100, and both types of rail service are assumed to be scheduled so as to achieve occupancy factors of 100% in the peak direction during the peak hour, and 25% overall. Urban transit buses are assumed to accommodate 50 passengers at seating capacities typical of rail vehicles, and to achieve the same occupancy factors attained by rail transit service. No "optimization" of transit service frequencies such as that undertaken in previous studies (see the earlier description) is attempted, since passenger waiting times are not explicitly estimated for the various transit modes, but the peak hour schedules simulated in the analysis probably entail greater frequencies than would be dictated by an optimization procedure. Finally, instead of the 1.4 occupants assumed in the RPA study to characterize typical urban automobile trips, this review uses the actual average of 1.8 occupants for auto trips in large U.S. urban areas.

REVISED ESTIMATES OF COST SAVINGS

Potential Labor Cost Savings from Rail Transit

The Basic Concept. Table 2 reports various estimates of the unit labor input requirements for performing several functions required to produce urban transit service. These input requirements are the parameters of the labor cost savings component model developed by the RPA researchers. While the exact values of these parameters are subject to some uncertainty, the table does illustrate the nature of the potential labor savings from operating rail transit. As it indicates, labor requirements for vehicle maintenance and system administration are closely comparable among transit modes when expressed on the basis of consistent units of service. Here, the passenger place-mile is used as the basic unit of transit service, which represents the capacity to transport one passenger a distance of one mile.[14] Because rail transit allows relatively large vehicles to be operated in trains staffed by minimal crews, its operating labor requirements per unit of service fall below those of buses once the basic crew size is averaged over some threshold level of passenger service.

Table 2

Estimates of Labor Input Requirements for Urban Transportation Service

Estimates of Labor Input by Function	Heavy Rail	Light Rail	Express Bus	Local Bus
Vehicle Operations:				
RPA Estimate[a]	4.5/peak train	3.0/peak train	2.0/peak vehicle	0.61/million place-miles
New System Average[b]	8.9	6.2	1.8	0.72
Best New System Value[b]	5.5	4.7	1.2	0.63
Best Realistic Value[c]	5.0	4.0	1.2	0.65
Vehicle Maintenance: (employees/million annual place-miles)				
RPA Estimate	0.16	0.19	0.19	0.26
New System Average	0.27	0.32	0.30	0.36
Best New System Value	0.13	0.23	0.23	0.20
Best Realistic Value	0.15	0.20	0.20	0.25
ROW & Station Maintenance:				
RPA Estimate	6.7/line-mile	3.0/line-mile	0.75/line-mile	--
New System Average	7.2	4.7	--	0.10/million place-miles
Best New System Value	6.1	4.0	--	0.03
Best Realistic Value	6.0	3.5	2.0	0.07
Administration: (employees/million annual place-miles)				
RPA Estimate	0.10	0.10	0.14	0.14
New System Average Value	0.24	0.19	0.18	0.21
Best New System Value	0.18	0.19	0.14	0.15
Best Realistic Value	0.15	0.15	0.15	0.17

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[a] Source: Pushkarev and Żupan.

[b] Source: UMTA "Section 15" Reports.

[c] Author's estimate.

Yet rail systems also have more substantial fixed labor requirements for maintenance of rights-of-way and stations than do those modes that operate over streets and highways or even exclusive non-rail guideways. These labor inputs depend largely on the scale of the system rather than on the level of service it is used to provide. Thus rail transit can achieve net labor savings compared to other modes only at service volumes sufficiently high that these fixed labor requirements are offset by rail's savings in operator labor. As an illustration of this basic principle, for the values shown identified as "RPA Estimates" in Table 2, rail rapid transit service employing two-car trains has lower total labor requirements per place-mile of service than conventional bus service at service levels above a service level of about 18 million annual place-miles operated over each route-mile.[15] This corresponds to a service frequency of about 55 conventional transit buses or 13 two-car trains per hour during peak periods. These labor requirement estimates also imply that rail rapid transit could offer net labor savings compared to express bus if service levels about 40% above that threshold were provided.

Similarly, with the RPA estimates of labor utilization reported in Table 2, light rail transit service even without operating cars in trains offers potential labor savings compared to conventional and express bus transit at service volumes exceeding 4 million and 8 million yearly place-miles per mile of line, respectively. These service levels would be equivalent to about 13 and 25 hourly bus departures during peak service periods. It is important to note that these thresholds are expressed as service "intensities," or service operated per mile of line, rather than as simple volumes, because labor requirements for right-of-way and station maintenance are given per line-mile.

Revised Labor Input Estimates. The RPA researchers' estimates of labor utilization parameters that are reported in Table 2 are -- at least for the rail transit and express bus modes -- intended to represent the "best achievable" labor utilization performance, and thus the lowest readily attainable labor requirement for producing various levels of service. Table 2 also reports comparable parametric representations of the labor productivity actually achieved by modern U.S. and Canadian rail transit systems, including typical values as well as the best single value actually achieved by any recently constructed individual rail system.[16] As these supplemental data indicate, most of the parameter values used in the RPA model appear to be overly optimistic in comparison to those achieved in actual operating practice, even by systems operating modern vehicles over recently constructed rail lines.

For example, the RPA study asserts that rail operator staffs as small as 4.5 per train in peak hour service are theoretically possible, a figure that includes one-person train crews plus an additional allowance for off-train operating workers necessary to perform functions such as train dispatching, vehicle control, and yard operation. Yet in practice the lowest value actually achieved even on the extensively automated San Francisco BART system is 5.5 operators per train in peak hour service, and the average for the three newest U.S. rapid rail systems is 8.9 operators per peak train. While the RPA estimates of labor requirements for heavy rail vehicle servicing and line and station maintenance appear to be more plausible in comparison to actual experience, those for administration are well below even the best performance achieved by new U.S. rail transit systems. The labor productivity record for modern light rail systems is more sketchy, but Table 2 does indicate that the RPA estimates of its labor input requirements for train operation, line maintenance, and administration also appear to be quite optimistic in comparison to the limited actual record.

Why Actual and Theoretical Requirements May Differ. The divergence between theoretically possible and actual labor inputs for operating rail vehicles probably arises at least partly from the peaking of ridership during morning and evening rush hours, in conjunction with contract provisions that both limit the overall duration and restrict splitting of operator work shifts. For these new systems, it seems unlikely to be attributable simply to the "featherbedding" that characterizes many older rail systems, or to the maintenance of excessive night and weekend service, since they typicaly operate minimal shcedules during those hours. Their operator labor requirements seem likely to be set by factors such as social norms affecting the labor force's acceptance of inconvenient work schedules, considerations of passenger safety and convenience, and evolving patterns of urban development and travel demand that increasingly concentrate transit use on specific routes during limited hours of the day. If this is indeed the case, they should represent close to the best performance attainable in the current operating environment, even with modern rail transit technology and operating procedures.

A similar explanation may underlie the divergence between theoretically achievable and actual labor input requirements for line maintenance and administration. But in each case its nature seems likely to be structural rather than purely institutional or political, in the sense that conditions in the urban environment in which transit service operates tend to prevent theoretically attainable labor productivity levels from actually being realized. Increasingly complex procedures for vehicle, line, and station maintenance, as well as for administrative functions such as service planning or financial management, are also likely to continue to increase actual labor requirements for producing urban transit service.

In short, these idealized minimum labor requirements are unlikely to be realized using available rail transit technology and current operating procedures, and should be modified to reflect realistic conditions in the labor markets and other components of the urban environment in which transit service must be produced and deployed. Recognizing the occasionally substantial differences between theoretically and practically attainable labor utilization levels, Table 2 also presents revised estimates of these labor input parameters. These estimates are intended to represent a compromise between the RPA estimates of minimum attainable labor utilization and the minimum actually achieved under current conditions with modern equipment and operating procedures. As such, they reflect an assumption that some improvements in rail transit labor productivity beyond those achieved by recently constructed systems are still realistically attainable, but that theoretical minimum staffing requirements are unlikely to be fully implemented. These compromise estimates of labor input requirements are used subsequently to revise the original estimates of labor cost savings produced in the RPA study.

Valuing Labor Savings. Another important question concerns the monetary rate at which labor savings achieved by rail transit should be valued. Average annual earnings for all U.S. transit workers during 1983 amounted to nearly $30,000, but the corresponding figure for the nation's largest cities -- the locations where rail transit systems are typically considered -- was considerably higher.[17] However, even the lower nationwide average figure probably overstates the true benefits from reducing transit labor use by substituting rail service for bus transit. This is because the correct benefits measure is the value to society of the labor services thereby freed, which can be approximated by the highest competitive earnings level of those workers in their most highly valued alternative occupation. Because transit workers' earnings are determined in labor markets that are largely protected from competitive forces, this alternative earnings level may be well below their current actual earnings.

Determining the likely alternative occupation of transit workers is difficult, particularly since workers in the four basic functional classes of transit labor -- vehicle operators, vehicle servicing, way and station maintenance, and administration -- have different employment alternatives. As a general approximation, it is possible to use average annual earnings for workers employed by private transportation industries that require performance of the same functions at comparable skill levels. Among such industries are intercity bus transit and local urban trucking; although niether is strictly comparable to the urban transit industry, annual earnings in each are considerably below those of typical transit workers, averaging probably no more than $25,000 in the nation's large urban areas during 1983.[18] This figure can thus be used to approximate the annual benefits for each transit worker by which labor requirements are reduced when a rail system is constructed. In comparison, the estimate of benefits per worker saved used in the RPA study is equivalent to about $32,000 per year when expressed in 1983 dollars. In the subsequent analysis, the estimates of labor savings from rail transit are evaluated at the lower figure, since in this case the underlying theory clearly dictates that it should more nearly approximate the correct value.

Savings in Energy Inputs

Rail's Potential Advantage. Urban transportation consumes various forms of energy primarily for operating vehicles, with some additional amounts used to maintain vehicles and to service rights-of-way and stations. Although each different mode's energy requirements for vehicle operation and maintenance are nearly constant per vehicle-mile regardless of how intensively vehicles are used, rail transit can still achieve significant economies on a place-mile basis because vehicle propulsion energy requirements increase less rapidly with vehicle size than does passenger carrying capacity. Energy used to service rail lines and stations increases only modestly as the intensity with which those facilities are used, so that as with labor used for the same purpose, energy consumed per place-mile of service declines as an essentially fixed input is spread over increasing service volumes. Two results of these principles are that energy consumption rates in line-haul service are considerably lower for the various transit modes than for private automobiles operating at typical current fuel economy levels, and that large transit vehicles such as rail cars can achieve the lowest energy consumption rates per place-mile if service volumes are sufficiently high.

Actual Energy Consumption Comparisons. Table 3 summarizes various estimates of energy consumption rates for common urban transportation modes: those presented in the RPA study; those estimated by the Congressional Budget Office; and estimates constructed from actual energy consumption statistics reported by individual transit operators.[19] Because the various modes typically rely on different fuel sources, these rates are converted to equivalent Btu consumption per place-mile of service for comparability, and are adjusted to reflect the varying efficiencies with which the original energy content of various fuel sources can be converted to actual vehicle propulsion energy.[20] As the table illustrates, the various estimates of vehicle propulsion energy for each mode are roughly comparable, although there remains some disagreement about energy use by modern light rail vehicles, probably reflecting the variety of vehicle designs and propulsion systems in use. The range of vehicle operation energy use estimates for local bus service is also fairly wide, with the actual average for large urban bus systems somewhat higher than either of the estimated values.

There is considerably more disagreement among the available estimates of energy requirements for transit vehicle maintenance, particularly those for local and express bus service. The estimates of actual energy consumption rates lie toward the lower end of this range, and seem likely to be the most reliable; in any case, the range of disagreement corresponds only to about 0.003 cents per place-mile at current energy prices, so that even at very high service volumes the uncertainty it introduces is probably not serious. Estimates of actual energy consumption rates for right-of-way and station maintenance are difficult to construct, and are thus unfortunately not available to help resolve the considerable disagreement between the RPA and CBO estimates. Generally, the CBO estimates are considerably higher for private automobiles, and dramatically lower for bus transit as well as for rail transit operating at typical service volumes. The subsequent analysis uses actual energy consumption rates for the different modes where they are available, and those supplied in the RPA study where actual figures cannot be obtained.

Valuing Potential Energy Savings. There remains the question of the monetary rate at which to value any potential energy savings achieved by rail transit. The RPA study evaluated energy savings at two alternative rates: one equivalent to oil prices of $46 per barrel (in 1983 dollars), still well above the $29.35 actual average price of U.S. oil imports during that year; and a higher rate equivalent to over $120 per barrel at 1983 prices, intended to reflect an estimate of the long-run social cost of obtaining future petroleum supplies.[21] Yet with the current

Table 3

Estimates of Energy Consumption by Various Urban Transportation Modes

Function and Source	Rail Rapid Transit	Light Rail Transit	Express Bus	Local Bus	Private Auto
Vehicle Operation: (Btu/place-mile)					
RPA Estimate[a]	670	370	520	670	1,890
CBO Estimate[b]	634	625	522	548	2,080
Actual Data[c]	664	425	647	758	1,720
Vehicle Maintenance: (Btu/place-mile)					
RPA Estimate	34	34	68	68	375
CBO Estimate	15	15	19	16	320
Actual Data	--	--	26	29	--
Right-of-Way and Station Maintenance:					
RPA Estimates					
tunnel	10,320 mil.	10,320 mil.	--	--	--
	annual Btu/line-mile				
surface	1,490mil.	1,490 mil.	206 Btu/ place-mi.	206 Btu/ place-mi.	206 Btu/ place-mi.
	annual Btu/line-mile				
CBO Estimates	86 Btu/ place-mi.	86 Btu/ place-mi.	15	15	400

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[a] Source: Pushkarev and Zupan.

[b] Source: U.S. Congressional Budget Office, Urban Transportation and Energy: The Potential Savings of Different Modes.

[c] Source: UMTA "Section 15" Reports.

market situation it is difficult to find long-term forecasts of world oil prices above $30 per barrel (in constant dollars), even recognizing the apparently permanent political instability in the Middle East, and some analysts argue that even the current price may be above the long-run equilibrium price that the nation can expect to pay for imports.[22] Recognizing this updated assessment, this analysis values potential energy savings at the equivalent of $30 per barrel in 1983 dollars.

Savings from Reduced Parking Demand

Potential Resource Savings. Accommodating commuters' parked automobiles in downtown areas consumes substantial amounts of land and other resources that have high opportunity costs because of their valuable alternative uses. Thus if automobile commuting can be reduced by constructing rail transit systems, the value of any resulting savings in land and other resources formerly used to supply downtown parking should be included among its benefits. However, it is important to note that any savings from making downtown land formerly occupied by parking structures available for alternative uses, which is likely to be the major source of such benefits, can be partly or even completely offset by land requirements for rail rights-of-way, stations, or other facilities. Net land savings from building rail lines can thus only be guaranteed if they are located in underground tunnels within downtown areas, which introduces considerably higher construction costs that must be weighed against the sum of land savings and various the other benefits discussed here.

Although land savings are likely to be the largest component of resource savings from reduced parking demand, savings in other capital and operating inputs may also be significant. This is particularly likely where potential reductions in downtown parking demand are at stake, since at high land prices suppliers of parking space predictably attempt to economize on land inputs. They do so by building multi-story structures or underground garages, often with on-site attendants or automated operating equipment, which amounts to substituting capital and labor inputs for land where the latter becomes costly. Thus evaluating land requirements for surface parking lots (usually 300-350 square feet per space) at downtown land prices can considerably *overstate* those benefits, yet measuring the savings from reduced downtown parking demand by the market value of actual land consumption per space (as little as 40-60 square feet in multi-story structures, and theoretically near zero in underground garages) will *understate* their true value because it omits the accompanying savings in capital, labor, and other resources.[23]

Parking Prices as a Measure of Savings. Fortunately, parking prices in downtown areas can provide a useful measure of the value of all resources used to supply parking, and thus of the monetary value of benefits from reducing parking demand. Most of the inputs used to supply parking are purchased in fairly competitive markets, so that their prices provide a good indication of their value in alternative uses, which is the desired benefits measure. In fact, market prices may even understate the total value of resources used, partly because downtown land use controls often increase the supply of parking above what would otherwise be supplied, thereby reducing its market price below the full resource cost of supplying it. Various investment tax credits and accelerated depreciation provisions of federal and state tax codes can also reduce the market price of parking below the full cost of the resources used to construct parking facilities, particularly the capital-intensive elevated and underground parking structures typical of some downtown areas. Because it is so difficult to tell how much these considerations cause market prices for parking to understate the true opportunity costs of the resources used to supply it, this analysis relies on market prices to evaluate savings from reduced parking demand.

The RPA study reports that daily parking charges are typically about $6 within the downtown areas of the nation's largest cities and about $4 (both figures adjusted to equivalent 1983 dollars) in medium size downtowns.[24] However, the downtown areas of most U.S. urban areas contemplating new rail transit investments -- even large cities such as Los Angeles, Detroit, and Dallas -- are generally not as intensively developed as cities with older rail systems, except in the immediate downtown. Over the considerably larger downtown area likely to be served by a new rail line, average parking charges are likely to be somewhat lower than these levels.[25] Thus average parking prices in the neighborhood of $5 per day are probably more appropriate for valuing savings in downtown land and other resources in large cities planning rail rapid transit lines. In contrast, a figure of about $3 per day is probably more applicable for evaluating parking-related savings in the generally smaller, less densely developed cities contemplating light rail lines.

In order to convert these savings to a basis that makes them comparable to the other benefits discussed previously, each automobile driven downtown is assumed to impose parking costs equal to one-third of the full daily charge, reflecting the fact that parking spaces are typically occupied by several vehicles over the course of the day. Likewise, each auto is assumed to be driven 8.5 miles to downtown, a figure corresponding to the national average for auto trips in large U.S. cities. Each auto is assumed to be occupied by 1.8 persons on average, again consistent with national statistics for auto trips in large urban areas.[25] Under these assumptions, potential savings from reduced parking demand amount to about 4.4 cents for each passenger-mile of automobile travel that is replaced when rail rapid transit service using underground tunnels is constructed to serve the downtown areas of very large cities. In the smaller metropolitan areas where light rail lines are more commonly planned, cost savings from reduced parking demand are likely to amount to about 3.3 cents for each place-mile of new rail transportation service that actually replaces a comparable unit of automobile travel.

Does Rail Transit offer Travel Time Savings?

Theoretical vs. Actual Operating Speeds. Probably the most controversial potential benefit from constructing rail transit is the potential saving in commuters' travel time and its attendant monetary value.

Table 4 reports estimates of the various parameters necessary to estimate the value of travel time savings, which include travel speeds by various modes and estimates of the value per unit of commuting time saved. As it indicates, there is some controversy about the specific values of several of these parameters. First, the RPA study estimates average speeds of 32 and 25 miles per hour for rapid rail and light rail transit in passenger service, yet the best values reported for revenue service by new rail transit systems are 27.5 and 23.4 mph, while average values for new rapid and light rail systems are respectively 22.5 and about 18 mph.[26] Thus it appears that its authors may be somewhat over-optimistic about the possible performance of new transit systems, even in line-haul service.

Similarly, the RPA report estimates respective speeds for express bus, local bus, and auto travel of 20, 8-12, and approximately 25 mph.[27] These appear to be somewhat below the best available estimates of their actual speeds, even for peak hour commuting travel in the nation's newer large urban areas, which range from 22-25, 12-15, and 25-35 mph.[28] The net effect of these assumptions appears to be to overestimate considerably the potential travel time savings from rail transit compared to those realized even at its best real-world performance. The estimates reported in Table 4 suggest that potential travel time savings at more realistic assumptions about operating speeds -- but ones still somewhat above even the fastest service speeds actually achieved by new rail systems -- may be only 40-50% as large as those implied by the assumptions used by the RPA researchers.

Door-to Door or Line-Haul Speed Comparisons? Further, even these more realistic estimates refer to the potential travel time advantage of rail transit in line-haul service, which is only one component of the door-to-door commuting trip. In its other components, passenger collection at the residential origin and distribution to downtown destinations, rail transit is at a distinct speed disadvantage comapred to either bus transit or automobile travel. In fact, this disadvantage may be sufficient to more than offset any advantage it enjoys in line-haul service, thus producing slower door-to-door speeds and longer travel times for equivalent commuting trips. In the subsequent analyses this complication is ignored, but it is important to recall that the resulting benefits estimates and volume thresholds for rail transit apply to only part of the commute trip, and would be substantially modified by incorporating travel time considerations for collection and distribution of rail transit passengers.

Valuing Travel Time Savings. Aside from this complication, there remains the issue of the monetary rate at which time savings should be valued. The basic premise is that travel time has some value in alternative uses, so that reducing it confers benefits by releasing more time to be dedicated to such uses. For commuting travel, the range of values of likely alternative uses is bounded by the enjoyment of leisure at one extreme and the rate of compensation for additional working time at the other. This suggests that the value of changes in commuting time should bear some relationship to individual earnings rates, but it does not provide much guidance about their exact valuation. In travel for purposes other than commuting to work, the values travelers attach to

Table 4

Estimates of Parameters Affecting Time Savings Benefits of Rail Transit

Parameter	RPA Estimate[a]	Estimated Actual Values:[b] Typical	Highest	Revised Estimate
Speeds in Passenger-Carrying Service: (miles per hour)				
Rail Rapid Transit	32	22.5	29.0	32
Light Rail Transit	27	18.0	23.4	24
Express Bus Transit	20	22.0	22.5	22
Local Bus Transit	8-12	12.4	18.4	15
Automobile	25-30	30.3c	--	25
Value of in-Vehicle Travel Time (1983 dollars/hour)	$4.80	$3.00-5.00	--	$4.00

[a] Source: Pushkarev and Zupan.

[b] Source: UMTA "Section 15" Reports.

[c] Source: U.S. Federal Highway Administration, Natiowide Personal Transportation Study, Report No. 3, "Home-to-Work Trips and Travel."

their time may be considerably lower, since activities with a lower value than earning a living are probably displaced by time spent traveling. Fortunately, in choosing among residential locations, transportation modes, and even alternate routes, travelers do reveal implicit valuations of reductions in travel time that can be estimated using commonly available data and statistical techniques.

Estimates constructed by various researchers cluster surprisingly tightly around a value of about $4.00 per hour (again in 1983 dollars), for urban commuters of typical incomes traveling under conditions offering reasonable comfort. The surprising degree of concurrence regarding this estimate suggests that it is probably an acceptable one, although it is somewhat below the figure of $4.80 (originally $3.00 per hour in 1977 dollars, adjusted to reflect wage growth since that time) proposed in the RPA study.[30] A higher value of time savings should perhaps be applied for automobile drivers shifted to rail transit service, in order to reflect the fact that they are also saved the effort of operating their automobiles, but it is extremely difficult to estimate how large such a premium might be. This would partially compensate for the previously discussed omission of a direct operator labor requirement for auto travel.

On the other hand, peak hour transit commuters probably attach a much higher value to reductions in time spent standing aboard crowded vehicles than riding under more comfortable load conditions. At least half of the passenger-carrying capacity of rail transit vehicles estimated in the RPA report consists of standing rather than seated space, while only about 30% of estimated bus capacity represents standees, and all auto passengers are of course seated.[31] One such estimate is that commuting time spent standing aboard crowded transit vehicles may be more than twice as onerous as time spent seated aboard uncrowded vehicles (the exact estimate is about $9.00 per hour at 1983 prices).[32]

Although no estimates of the additional "costliness" of time spent driving -- as compared to riding as a passenger in -- an automobile seem to be available, it seems intuitively unlikely that the total valuation of time spent driving, including travel time plus an allowance for the effort of driving, would be above this figure. Recognizing the difficulty in constructing such an estimate, the subsequent analyses use the $4.00 per hour figure to evaluate time savings that result when both former bus passengers and auto commuters are carried by a new rail transit service. The resulting estimates of the value of time savings to rail passengers in each of these categories are constructed by applying this figure to differences between the revised travel speed estimates for individual modes presented in Table 4.

Potential Capital Savings

In addition to these savings in operating inputs, resources used to supply parking, and travelers' time, constructing rail transit lines may produce some savings in the capital costs of supplying the auto and bus transportation services it replaces. These would arise partly from reductions in the number of vehicles that are owned or operated, or at least reductions in utilization of the existing fleets, with attendant savings in both depreciation of their value and interest costs for financing their ownership. These costs are assumed to be reduced in proportion to the amount of auto and bus transportation capacity replaced when their users are instead carried by a new rail line. Over the longer run, additional savings could be realized from reductions in the scale of investment in or replacement of the various rights-of-way on which automobiles and transit buses operate within urban areas.

Vehicle Fleet Reductions. Because the daily time patterns of rail and bus transit ridership are similar (although not identical -- rail transit generally experiences more peaking during weekday commuting hours), bus vehicle requirements should be reduced approximately in proportion to the number of bus riders that use a new rail system. Current capital costs for transit buses average about $3,200 per place aboard standard urban transit buses. Assuming a twelve year economic lifetime, during which vehicles operate 30,000 miles annually, and discounting at 5%, vehicle depreciation and interest costs would be equivalent to 1.7 cents per place-mile of bus service replaced by new rail transit service.[33]

For automobiles, mileage-dependent vehicle depreciation costs could also be reduced in proportion to the number of former automobile trips carried by a new rail system. With an automobile fleet consisting of the current nationwide mix of standard, compact, and sub-compact sizes, average lifetime depreciation amounts to about 7.5 cents per mile, of which approximately 70% apparently depends on mileage driven alone.[35] If automobiles are typically occupied by 1.8 persons, savings in mileage-dependent automobile depreciation would average slightly under 3 cents per passenger-mile of automobile travel replaced by new rail transit service. Some savings in interest costs for financing automobile ownership would also occur if the automobile fleet were reduced by the introduction of rail transit service.[36] These depend on opportunity costs for capital, the average value of cars in service (itself a function of new car prices, their average age, and the pattern of depreciation over car lifetimes), and their annual utilization. Using a 5% interest rate to match the discount rate used to annualize rail transit capital expenditures, the typical time profile of automobile depreciation, a $10,000 initial purchase price, and the average utilization figure of 10,000 miles per year, interest costs are about 0.8 cents per passenger-mile carried by a typical automobile over its lifetime.[37]

[illegible]

Potential Right-of-Way Savings. Right-of-way capital costs for buses operating on urban highways and arterial streets, including those for land acquisition and construction, amount to about 10.4 cents per bus-mile according to recent estimates.[34] Apportioned among 50 passenger places, this represents slightly over 0.2 cents per place-mile, which would bring total capital savings for both right-of-way and vehicles to about 1.9 cents per place-mile of bus transit service replaced by new rail transit capacity. Of course, achieving this saving depends on actually implementing bus service reductions when transit passengers are shifted to a new rail line. In practice, this has often proven difficult or controversial, since new rail systems can require elaborate feeder bus services, and eliminating bus routes nearly always reduces the quality of transit service to some riders even when those routes overlap new rail lines.

Finally, opportunity costs for right-of-way capital to accommodate the current mix of automobiles typically driven on urban highways and arterial streets are estimated to average about 6.5 and 8.7 cents per vehicle-mile, respectively.[37] At the automobile occupancy factor of 1.8 persons used here, these are equivalent to 3.6 and 4.8 cents per passenger-mile. In estimating savings in capital expenses to accomodate automobiles, rail transit service is assumed to reduce these costs by half, an estimate of the fraction of their total capacity that is dedicated to peak-period usage and could thus be eliminated if rail transit service were provided. Thus total savings -- including depreciation, interest expenses, and right-of-way cost savings -- for each passenger-mile of automobile travel that is actually replaced by new rail transit service would be slightly less than 6 cents, a potentially significant addition to the operating and user time savings estimates reported previously.

Aggregating the Benefits from Rail Transit

As the preceding discussion illustrated, the values of various forms of savings for each former bus rider carried by a new rail transit system generally differ from those for each former auto commuter. Because this is generally true for each of the categories of potential benefits discussed here -- labor savings, reductions in energy use, savings from reduced parking demand, travel time reductions, and potential capital savings -- these separate estimates must be weighted to estimate composite benefits per unit of rail transit service newly supplied or per new rider of a rail system. The appropriate weights to apply to the separate estimates of benefits per unit of rail capacity provided are the proportions in which passngers on a new rail system are assumed to be drawn from among former bus riders and auto commuters.

Sources of New Rail Ridership. Table 5 reports two estimates of these proportions used in the RPA study, as well as the actual proportions in which some recently constructed rail transit systems have actually drawn their passengers from various other travel modes.[38] As it indicates, a surprisingly small share of riders of most such systems typically represents new trips, which suggests that overlooking the potential benefits of a rail system to those making entirely new trips will not lead to a significant underestimate of its aggregate benefits. One exception is the San Francisco BART system, 27% of the riders of which reported that their trips using it had not previously been made by any mode, although this finding seems somewhat implausible.

Table 5 also indicates that as many as half of the riders of new rail transit lines can be drawn from the bus routes they replace or supplement. The range of diversion from auto travel is considerably wider, from a low of about 25% for the Atlanta rail system to a high of about 40% for the San Francisco BART system. Much of the variation in this figure is accounted for by differences in the extent to which the systems attract passengers that formerly walked, bicycled, or used taxis

Table 5

Distribution of Former Modes Used by Passengers on New U.S. Rail Transit Systems

Source of Estimate	% of Passengers Formerly Using: Bus	Automobile	Other Modes	% Making New Trips
San Francisco BART[a]	31.0%	40.2%	1.8%	27.0%
Washington, D.C. METRO[a] (Phases I-III)	54.0%	28.0%	13.0%	5.0%
Atlanta MARTA Rail[a]	57.7%	24.7%	15.7%	1.9%
RPA Estimates[b]				
"High Auto Diversion"	29%	71%	--	--
"Low Auto Diversion"	58%	42%	--	--

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[a] Source: Reported in Charles River Associates, Inc., "Cross-Cutting Analysis of Rail Rapid Transit Impact Studies in Washington, D.C., Atlanta, and San Francisco."

[b] Source: Pushkarev and Zupan.

for their trips, which is most common on the Washington, D.C. and Atlanta rapid rail systems. Unfortunately, it is difficult to estimate how the benefits from carrying these riders by rail rather than by their former modes compare to those from diverting bus passengers or auto commuters to a new rail transit service.

Further, Table 5 shows that the "low auto diversion" estimates used in the RPA study much more accuartely approximates the actual composition of the former modes of all passengers using most new rail lines. More extensive diversion from autos than these figures suggest may be achieved among peak hour commuters, upon whom the current analysis focuses, but the available evidence clearly suggests that the proportions are unlikely to approach the "high auto diversion" estimate presented in the RPA study. For these reasons, the subsequent analyses employ the lower diversion estimates (whereby 58% of new rail system riders are drawn from buses and the remaining 42% from automobiles) as weights for estimating composite benefits per unit of service supplied by a newly constructed rail system.

The Resulting Benefits Estimates

Figure 1 presents a graphic reresentation of three estimates of the benefits from constructing new rail transit lines; the upper panel of the figure (1a) displays these estimates for rail rapid transit lines, while the lower panel (1b) shows the corresponding benefits functions for modern light rail transit lines. In both cases the horizontal axis measures the intensity of transit service supplied; by using typical peaking patterns and overall load factors for rail systems, these can be converted to corresponding ridership estimates. The vertical axes measure the average monetary value of combined benefits from shifting current bus and auto commuters to rail transit, expressed in cents per place-mile of passenger carrying capacity operated by the new rail line (again with all values expressed in 1983 dollars). As discussed previously, these curves rise initially as fixed input requirements for rail operations are spread over increasing service levels, but gradually approach a constant level as these economies are exhausted.

For each type of rail line, the highest benefits curve corresponds to the more conservative benefits estimate presented in the RPA study, constructed using assumptions that are still relatively favorable to rail system operation and utilization, as indicated in the preceding discussion. The lowest curve in each half of the figure is constructed using the revised estimates of the parameters affecting new rail benefits presented in Tables 2, 3, and 4, and clarified in the preceding discussion. These lowest curves are intended to represent the most realistic estimates of combined benefits from labor cost savings, reduced energy consumption, parking demand reductions, and user time savings that should realistically be expected from investments in new rail transit lines.

The middle curve in each figure adds the capital savings estimates constructed earlier to the more realistic estimates of operating input, parking resource, and user time savings embodied in the lowest curves.

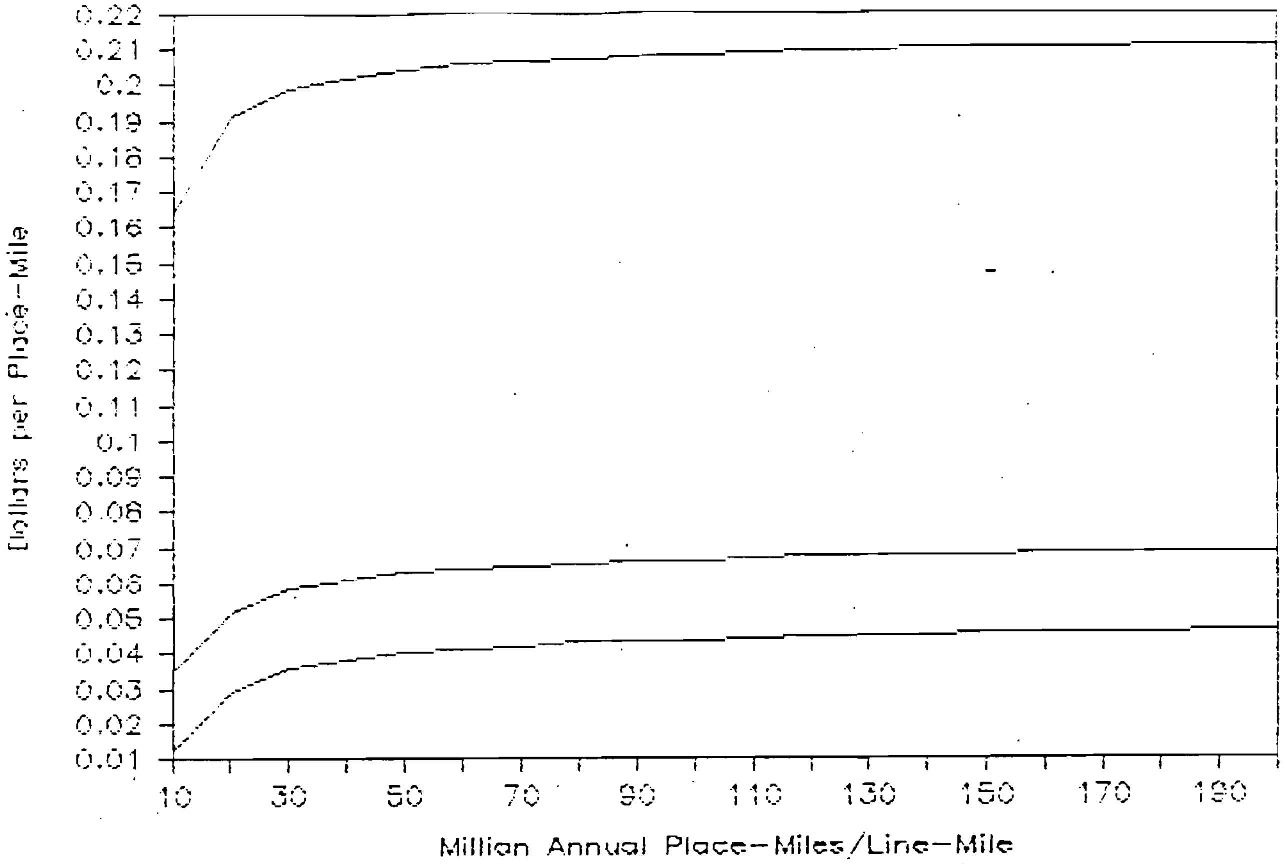


Figure 1a. Heavy Rail Benefits

(vs. Express Bus and Auto)

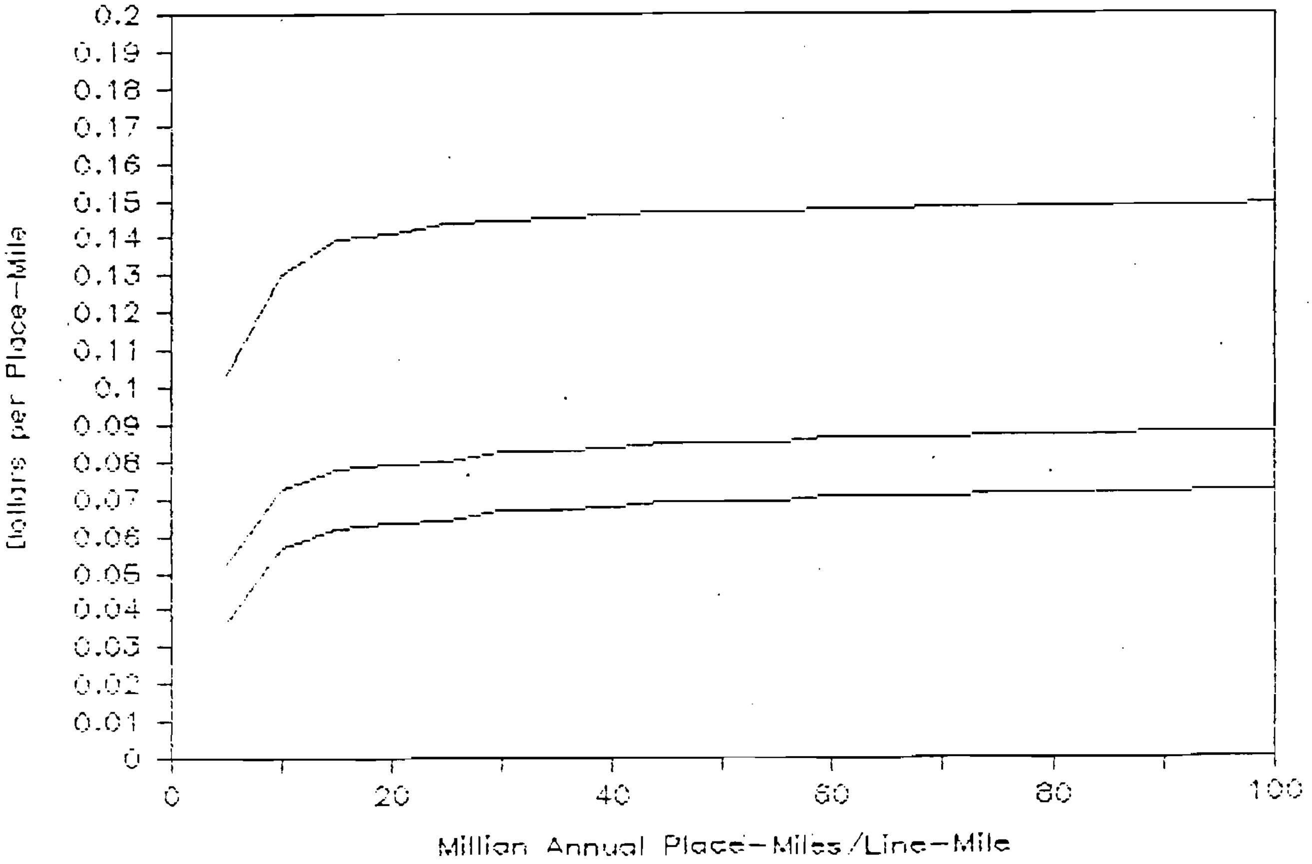


Figure 1b. Light Rail Benefits

(vs. Local Bus and Auto)

As the figures illustrate, these intermediate benefits estimates lie much closer to the lowest curves than to even the more conservative benefits curves identified in the RPA study. Since the highest benefits levels having any realistic possibility of being achieved are likely to lie in the region bounded by the more conservative RPA estimates and the lowest benefits curves shown in the figures, it is this range that is compared to the rail transit construction cost estimates developed in the next section in order to assess the suitabilty of new rail lines in the nation's urban areas.

THE COSTS OF CONSTRUCTING RAIL TRANSIT FACILITIES

Reliable estimates of the costs of constructing new rapid transit and light rail facilities also play a critical role in evaluating modern rail transit investments, since their suitability depends on how those costs compare to their potential resource savings and other benefits. As discussed previously, the fixed costs of constructing rail lines (converted to equivalent streams of recurring costs) decline on a per-unit basis as they are averaged over increasing service or ridership volumes. These average costs -- plus an allowance for the additional cost of equipping the system with vehicles -- will be exceeded by the benefits from operating the system beyond some threshold volume; levels of service or ridership above this threshold thus offer the potential for net cost savings from rail transit. Despite the importance of using reliable cost estimates, past studies of rail transit's suitability have usually relied on simple per-mile cost figures derived from limited construction experience or engineering unit cost estimates.

Thus one reason for analyzing actual construction expenditures in detail is to improve the reliability of rail capital cost estimates, in recognition of their critical role. This section attempts to do so by exploiting the added information on rail transit structure and equipment costs provided by the recent increase in rail transit construction activity in North American cities. It analyzes the costs of constructing and equipping thirty-two recent rail transit systems, individual lines, and line extensions in U.S. and Canadian urban areas, in order to develop estimates of the unit costs for constructing various functional components of transit systems such as rights-of-way, guideway, stations, and vehicles.[39]

Potential Sources of Variation in Construction Costs

An obvious question is how much of these differences in construction costs can be explained by variations in the extent, design, and capacities of the individual facilities constructed, rather than by harder to identify factors such as variation in local construction prices, geologic and topographic consideratons, or effectiveness in project management.[40] Rail transit systems consist of several basic functional components or units: the track or guideway itself; the right-of-way on which it is located (which may be in underground tunnels, at the suface, or on elevated structures); passenger stations; transit vehicles; and support facilities such as storage yards and maintenance terminals. Some of the wide variation in the costs of constructing rail transit lines clearly stems from the choice of alignment for the guideway when the system is planned. Building elevated structures is likely to be somewhat more costly than preparing at-grade roadbeds, while constructing tunnels can in turn be significantly more expensive.

Land Prices. Land acquisition expenses are also a potentially important determinant of the full costs of providing surface or elevated rights-of-way, although it is difficult to specify *a priori* how land requirements will differ between at-grade and elevated alignments in specific corridors. Land costs can of course be largely avoided by tunneling, but only with its attendant expense; in general, the cost-minimizing alignment will change in response to variation in land prices, but right-of-way costs should still rise somewhat in response to increasing land prices. In addition, differences in construction technology can apparently account for considerable differences in tunneling costs, as can local geologic conditions and details of tunnel alignments.

Station Characteristics. The locations, passenger handling capacities, and architectural characteritics of transit stations also seem likely to be among the critical determinants of their construction costs. Surface stations are able to employ the simplest passenger access facilities and platform designs, and are likely to offer the fewest complications in construction procedures. Thus they should be ess costly to construct than stations of equivalent capacity situated on elevated structures or in underground excavations. As with the guideway itself, however, land requirements for surface stations may be considerably larger and thus more costly than those for elevated or underground stations. Although underground placement of stations can again substantially reduce land acquisition requirements, excavation and construction costs can be substantial, especially where they must be designed to accommodate large passenger volumes.

Certain physical features of stations, some of which are determined by the anticipated volume of passenger traffic, also seem likely to have a pronounced effect on station construction costs. These include total station size or volume, the specific platform layout employed, and the number and capacities of passenger access and egress facilities. Some design considerations such as depth underground or architectural elaborateness can also affect station construction costs, even though they may not affect actual passenger-handling capacity or other dimensions of in-use performance. Unfortunately, most of these design parameters are site-specific as well as difficult to measure explicitly, so their specific effects on station construction expenses are difficult to isolate.

A Simple Model of Rail Construction Expenses

Although the range of potentially important determinants of rail project costs is evidently quite wide, a logical first step is to investigate the association between actual expenditures for individual rail transit construction projects and the number and types of their respective functional components. Two basic categories of these components are rights-of-way and stations, each of which can be classified according to their location in underground tunnels or excavations, at grade level, or on elevated structures. Using this classification, Tables 6 and 7 report the makeup of seventeen recent or current rail rapid transit and thirteen light rail transit construction projects. Because the spacing of stations appears to be relatively consistent among the various projects, it is also plausible to investigate the association of project costs with only the length of right-of-way of each of these three types.

Thus two basic models can be used to relate each project's total costs to its component makeup:

$$(1)\ TC = a_0 + a_1*UGMI + a_2*AGMI + a_3*ELMI$$

and

$$(2)\ TC = b_0 + b_1*UGMI + b_2*AGMI + b_3*ELMI + b_4*UGSTNS + b_5*AGSTNS + b_6*ELSTNS$$

where TC = total project expenditures (in 1983 dollars)
UGMI = miles of two-track line in underground tunnels
AGMI = miles of two-track line at-grade
ELMI = miles of two-track line on elevated structures
UGSTNS = number of stations underground
AGSTNS = number of stations at grade
ELSTNS = number of stations on elevated structures.

Interpreting the Model's Parameters. In model (1), a_1, a_2, and a_3 correspond respectively to the unit -- in this case, per mile -- construction costs of underground, surface, and elevated rapid transit line segments, inclusive of station construction costs.[41] Analogously, the coefficients b_1, b_2, and b_3 in model 2 represent the unit construction costs of these three types of line segments exclusive of the costs of constructing stations, which are represented by b_4, b_5, and b_6 for underground, surface, and elevated stations. The interpretation of the terms a_0 and b_0 is more ambiguous, but theoretically they represent expenditures for planning and constructing the minimal complement of ancillary facilities necessary to supplement the system described by the line-mile and station variables. Including these terms recognizes that some project construction costs may not be uniquely assignable to a specific structural component of the project.

One complication in their interpretation arises from the previously discussed fact that new systems will generally require the installation of such facilities, while projects that represent line additions or extensions of existing systems may not require significant expansion of their capacity. Further, if the scale of vehicle storage and maintenance facilities is closely correlated with line mileages or number of

Table 6

Rail Rapid Transit Construction Project Characteristics

		Two-Track Miles/Number of Stations:		
City	Project	In Tunnel	Surface	Elevated
Cleveland	GCRTA Initial Line	--	14.9/15	--
	GCRTA Airport Extension	0.3/0	3.8/3	--
Philadelphia	PATCO Lindenwold Line	--	14.5/13	--
	SEPTA Snyder-Pattison Line	1.2/0	--	--
San Francisco	BART System	20.0/14	27.0/7	24.0/13
Washington, D.C.	WMATA Metro			
	Phases I-IVA	22.4/28	13.3/13	1.5/1
	Phases V-VI	12.5/9	9.2/8	2.5/2
Atlanta	MARTA Rail Phase A	5.5/8	5.8/7	2.4/2
Baltimore	MTA Metro Phase I	4.5/6	--	3.2/3
Boston	MBTA Red Line			
	Southern Ext.	--	9.5/5	--
	Northwest Ext.	3.2/4	--	--
	MBTA Orange Line North Ext.	1.0/2	4.4/5	--
Miami	Metrorail N-S Line	--	1.7/0	19.3/20
New York	NYCTA 63d St. Ext.	12.0/0	--	--
	NYCTA 2d Ave. Ext.	7.2/0	--	--
Chicago	CTA Dan Ryan Line	--	9.4/9	1.1/0
	CTA Milwaukee Ext.	1.2/2	3.9/4	--
	CTA O'Hare Ext.	0.6/1	6.6/3	--

Sources: Estimated by author from individual system maps and descriptions.

Table 7

Light Rail Transit Construction Project Characteristics

City	Project	Two-Track Miles/Number of Stations: in Tunnel	Surface	Elevated
Buffalo	NFTA Initial Line	5.2/8	1.2/6	--
Calgary	CT Southeast Line	0.7/0	6.9/11	--
	CT Northeast Line	--	6.1/7	--
Edmonton	ETS Surface Line	--	3.5/4	--
	ETS Downtown Subway	0.9/4	--	--
	ETS North Extension	--	1.4/2	--
San Diego	MTDB San Ysidro Line	--	16/18[a]	--
San Francisco	MUNI/BART Tunnel and Line Extension	5.7/4[b]	13.3/7	--
Boston	MBTA Green Line Riverside Branch Reconstruction	--	12.0/0[c]	--
Newark	NJT Subway Reconstruction	4.3/4[d]	--	--
Pittsburgh	PAT Tunnel and Reconstruction	1.0/3	12.3/7	--
Portland	Tri-Met Banfield Line	--	15.1/16	--
Toronto	TTC Scarborough Line Extension	--	--	4.3/6
Vancouver	MTOC Initial Line	--	--	12.1/15

[a] Total length is 16.0 miles, of which 1.7 miles and 8 stations were newly constructed.

[b] Tunnel and stations jointly used by BART system.

[c] Minor rehabilitation of 13 stations accompanied line reconstruction.

[d] Tunnel not rebuilt, but line substantially rehabilitated.

Sources: Estimated by author from system maps and descriptions.

stations, their costs will be subsumed within the line and station unit cost estimates instead of being incorporated into the intercept terms. In this case the intercept terms will capture the effects of any remaining variables that influence overall project costs but are not explicitly included in the model, and may be mistakenly interpreted if they are regarded simply as the costs of constructing fixed facilities. Because of these potential complications in their interpretation, variants of both models that exclude their respective intercept terms were also estimated.

Empirical Estimates of Unit Costs

A variety of methods can be used to estimate the parameters of these models ($a_0,..,a_3$ and $b_0,..,b_6$). Among these are allocation of expenditure accounts to individual functional units, engineering-based estimation of resource requirements (labor, materials, etc.) for constructing individual components, and assignment of individual contract awards to particular system components. A related empirical approach used here is to statistically estimate their values using a sample of observations on project costs and their individual component makeups. One important difference when this method is employed is the implicit inclusion of a residual term in each model, which captures variation in individual project costs that is not accounted for by the variables included in the model. In contrast, cost assignment or allocation procedures typically would attempt to leave no residual expenditures unassigned.

Tables 8 and 9 report ordinary least squares estimates of the unit costs of heavy and light rail transit project components (these are derived by computing the coefficient values that minimize the sum of the squared values of these unexplained residual terms.) Because each project's total expenditures are expressed in equivalent 1983 dollars, the resulting estimates of unit costs for project components can also be interpreted in 1983 dollars. These estimates exhibit a surprising degree of consistency and precision, especially considering the variety of projects represented, which range from short connector line segments without stations to full rapid transit systems incorporating tunnel, at-grade, and elevated lines and stations. While these unit cost estimates do not by themselves provide much insight into the *causes* of variation in rail system costs, differences in line mileage, station spacing, and right-of-way alignments (at grade, underground, or elevated) among individual projects apparently do account for a substantial part of the variation in their construction expenses.

Interpreting the Results. A few specific implications of the estimates reported in Tables 8 and 9 are particularly noteworthy. First, the intercept terms are consistently only about as large as their standard errors, suggesting that there is a very low probability that the true values of a_0 and b_0 differ significantly from zero. Second, it is interesting to note that even the model including only the line length variables accounts for more than half of the wide variation in the costs of both heavy and light rail projects, despite its simple specification. This may occur partly because the range of station spacings among different projects using any specific type of alignment is fairly narrow.

Table 8

Least-Squares Regressions of Rail Rapid Transit Project Construction Costs on Project Characteristics (n=18)

Variable	Coefficient (Standard Error) in Specification:					
	1	2	3	4	5	6
Constant	34.1		74.9		78.2	
	(67.9)		(62.4)		(62.4)	
2-Track Miles in Tunnel	137.1	126.5	100.4	102.8	103.3	101.4
	(8.0)	(8.3)	(11.2)	(10.0)	(11.5)	(11.3)
2-Track Miles at Grade	27.8	30.8	17.8	22.3	16.6	23.9
	(8.1)	(6.8)	(7.5)	(12.2)	(8.1)	(9.1)
2-Track Miles on Elevated	49.3	55.3	46.5	49.3	54.5	53.1
	(8.4)	(9.3)	(17.1)	(14.6)	(8.9)	(10.5)
Stations Underground			36.0	39.5	41.5	42.9
			(11.4)	(11.2)	(11.1)	(11.3)
Stations at Grade			6.7	9.7		
			(4.6)	(5.0)		
Stations on Elevated			23.0	22.9		
			(16.1)	(16.3)		
Stations at Grade or Elevated					14.9	16.4
					(9.8)	(9.5)
Adjusted R^2 of Regression	0.75	0.80	0.59	0.64	0.68	0.70
Standard Error of Estimate[a]	199.6	211.6	135.7	154.4	141.1	174.7

---

[a] Millions of 1983 dollars, around a mean of $987.7 million.

Table 9

Least-Squares Regressions of Light Rail Transit Project Construction Costs on Project Characteristics (n=14)

Variable	Coefficient (Standard Error) in Specification: 1	2	3	4	5	6
Constant	24.6		32.6		33.3	
	(39.3)		(24.7)		(33.4)	
2-Track Miles in Tunnel	87.7	89.6	48.0	50.8	34.1	38.3
	(12.2)	(11.6)	(16.1)	(16.5)	(20.3)	(19.8)
2-Track Miles at Grade	13.9	16.1	12.9	10.7	15.7	13.5
	(4.7)	(3.0)	(3.1)	(2.7)	(3.7)	(3.0)
2-Track Miles on Elevated	59.3	61.8	65.0	61.8	57.2	55.5
	(7.7)	(6.4)	(4.4)	(3.8)	(6.2)	(5.9)
Stations Underground			36.9	32.5	49.0	43.4
			(13.2)	(13.3)	(16.7)	(15.7)
Stations at Grade			8.1	7.2		
			(2.3)	(2.3)		
Stations at Grade or Elevated					6.3	5.9
					(3.1)	(2.8)
Adjusted R^2 of Regression	0.66	0.72	0.58	0.65	0.57	0.64
Standard Error of Estimate[a]	84.6	82.5	47.5	49.2	61.1	61.1

---

[a] Millions of 1983 dolllars, around a mean of $772.0 million.

On the other hand, some improvement in the explanatory power of the models is achieved by separately specifying line lengths and numbers of stations, as evidenced by the smaller standard errors in estimating total project costs with this slightly more complex version of the model (reported as specifications 3 and 4 in each of the two tables).[43] These estimation results also indicate that the per-mile costs of constructing elevated line segments are still considerably higher than those for at-grade guideways, even when the expenses for constructing stations are separated from those of building line segments alone. In turn, the costs of building transit lines in underground tunnels substantially exceed those for constructing lines on elevated structures.

The estimates of construction costs for surface and elevated rapid transit stations also differ somewhat once they are disaggregated from those for building their associated lines, with elevated stations typically about twice as expensive to build as those at grade level. The small sample of recently built elevated light rail facilities, together with the limited variation in their station spacings, makes it impossible to reliably separate the costs of constructing elevated lines and stations. For both heavy and light rail lines, underground stations appear to be four to five times more costly to build than stations at grade level.

Point Estimates of Unit Construction Costs. Table 10 summarizes the estimates of line and station construction costs obtained from the two samples of rail transit projects. As it indicates, rapid transit lines in underground tunnels including conventional station spacings (about 1.2 stations per mile) typically cost about $127-150 million per mile to construct.[44] (Again, these and all subsequent estimates are reported in 1983 dollars.) This range reflects the different estimates obtained when line and station costs are estimated jointly, or estimated separately and subsequently added. The comparable range of estimates for light rail lines in underground tunnels is $90-95 million per mile, including the 1.3 stations per mile that is typical of recently constructed examples of this type of facility.

Comparable figures for surface lines are somewhat closer -- typically $30-32 million for rapid rail lines, and $16-18 million for light rail surface lines, including costs for their representative station densities of 0.77 and 0.93 per mile. For lines on elevated structures, estimated rapid transit and light rail construction costs, including stations at typical densities of 0.70 and 1.28 per mile, are $55 and $62 million per mile. Although superficially surprising, the higher cost estimate for light than for rapid rail transit is no doubt partly explained by the fact that each line-mile of light rail typically includes nearly twice as many stations as each mile of rapid transit line. In addition, the only recent examples of elevated light rail lines actually represent an experimental, intermediate-capacity technology, so its slightly higher estimated expense is less surprising.

Thus it appears that significant savings can be achieved by cities that choose to employ light rail rather than full-scale rapid transit. These potential savings apparently stem primarily from its lower

Table 10

Estimates of Unit Construction Costs for Rail Transit Projects

Component	Typical Rapid Transit Unit Construction Cost[a] (millions of 1983 $)	Typical Light Rail Unit Construction Cost[b] (millions of 1983 $)
Two-Track Mile, in Tunnel:		
Including Stations	$ 127	$ 90
Excluding Stations	$ 103	$ 51
Two-Track Mile, at Grade:		
Including Stations	$ 31	$ 16
Excluding Stations	$ 22	$ 11
Two-Track Mile, on Elevated Structure:		
Including Stations	$ 55	$ 62
Excluding Stations	$ 39	--
Underground Stations	$ 40	$ 33
At-Grade Stations	$ 10	$ 7
Elevated Stations	$ 23	--

[a] Source: Parameter estimates for specifications 2 and 4 in Table 8, rounded to nearest million.

[b] Source: Parameter estimates for specifications 2 and 4 in Table 9, rounded to nearest million.

right-of-way and line construction costs, rather than from significant savings in constructing stations or other facilities, since per-mile costs for the two types of lines are surprisingly similar when stations are included. Much of the potentail cost savings from light rail has apparently been offset by its characteristic use of more frequent stations than is conventional with heavy rail lines, although this design difference may be partly intended to compensate for the somewhat slower operating speeds of light rail vehicles in an effort to provide door-to-door travel times that compare favorably to those offered by rail rapid transit.

Vehicle Capital Costs

The cost estimates discussed so far reflect only those for acquiring rights-of-way and constructing rail lines and related facilities, but do not include the additional expense of acquiring rail vehices. After adjusting recent purchase prices to equivalent 1983 dollars, acquisition costs for modern heavy and light rail rail vehicles cluster surprisingly tightly around a figure of about $8,700 per passenger place (assuming seating densities and standee spaces equivalent to those aboard typical transit buses).[45] Assuming a useful lifetime for rail vehicles of 40 years and discounting at 5%, the equivalent annualized figure for depreciation and interest costs is about $620 per passenger place for both heavy and light rail cars.

Peaking in daily ridership patterns and the necessity of providing spare vehicles combine to require about 19 passenger-places of vehicle capacity for supplying each million annual place-miles of rapid rail service; the corresponding requirement for light rail vehicle capacity is about 26 passenger-places of vehicle capacity per million annual place-miles of service supplied.[46] Thus the annualized vehicle capital costs per place-mile of service are equivalent to about 1.2 and 1.6 cents for heavy and light rail lines, fairly comparable to those for vehicle capacity in automobile transportation and bus transit service. Unlike those for constructing rail lines themselves, however, these costs do not vary substantially with the intensity of service provided because the number of vehicles required rises proportionally with the level of service operated.

Rail Transit Cost Curves

Figure 2 illustrates capital cost curves for building and equipping rail transit lines, based on the estimates of line and station construction and vehicle costs presented here. Each curve illustrates the variation of average total capital costs for providing rail transit with the level of service provided, assuming typical peaking characteristics in the ridership pattern to which service is tailored. Again, because of the substantial fixed costs of line construction, these average costs decline sharply with increasing service volumes even when the variable expenses for providing vehicles are included. The range of service levels for which capital costs are illustrated extends from relatively low levels upward to the theoretical capacity of each type of line with normal constraints on train length and separation.

Figure 2a. Heavy Rail Investment Costs

(Average Cost per Place-Mile)

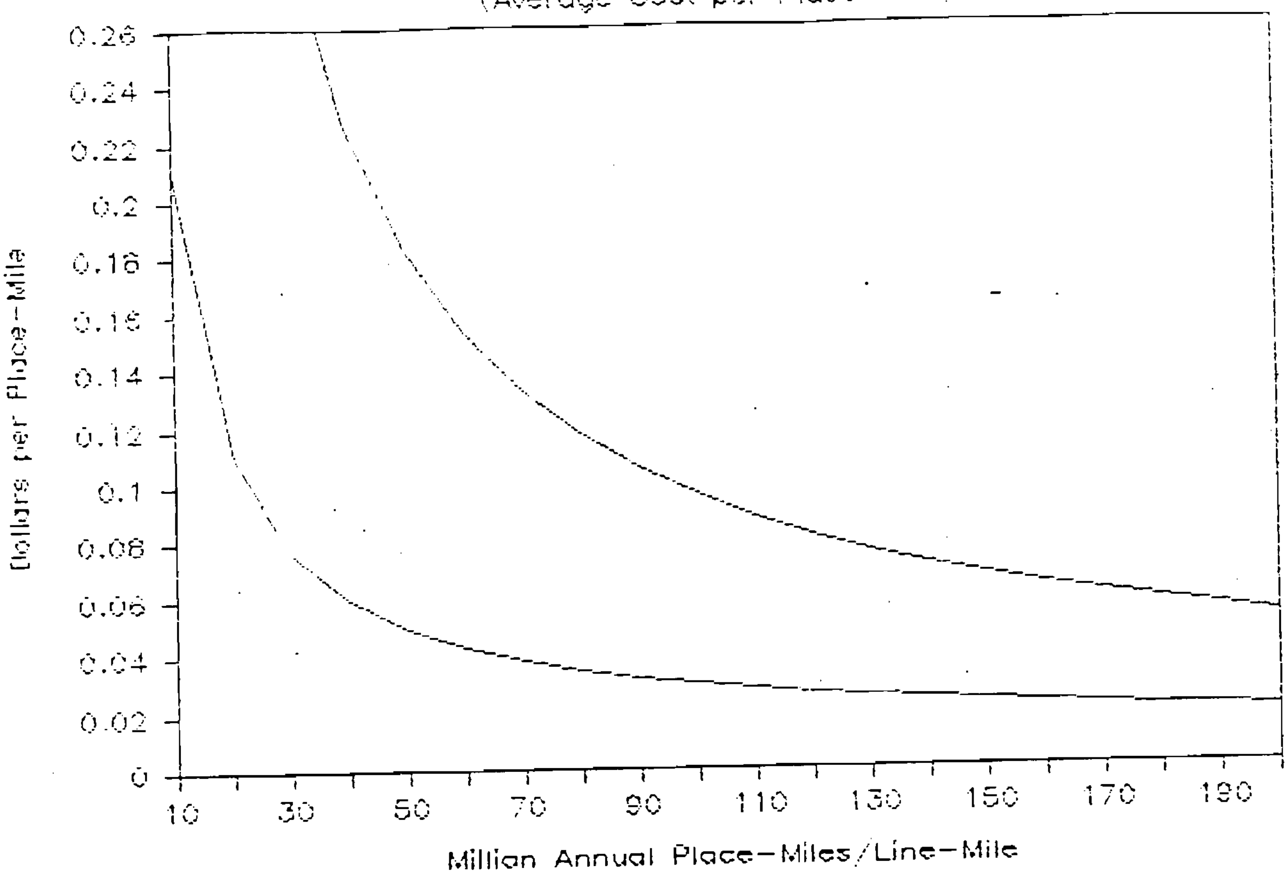


Figure 2b. Light Rail Investment Costs

(Average Cost per Place-Mile)

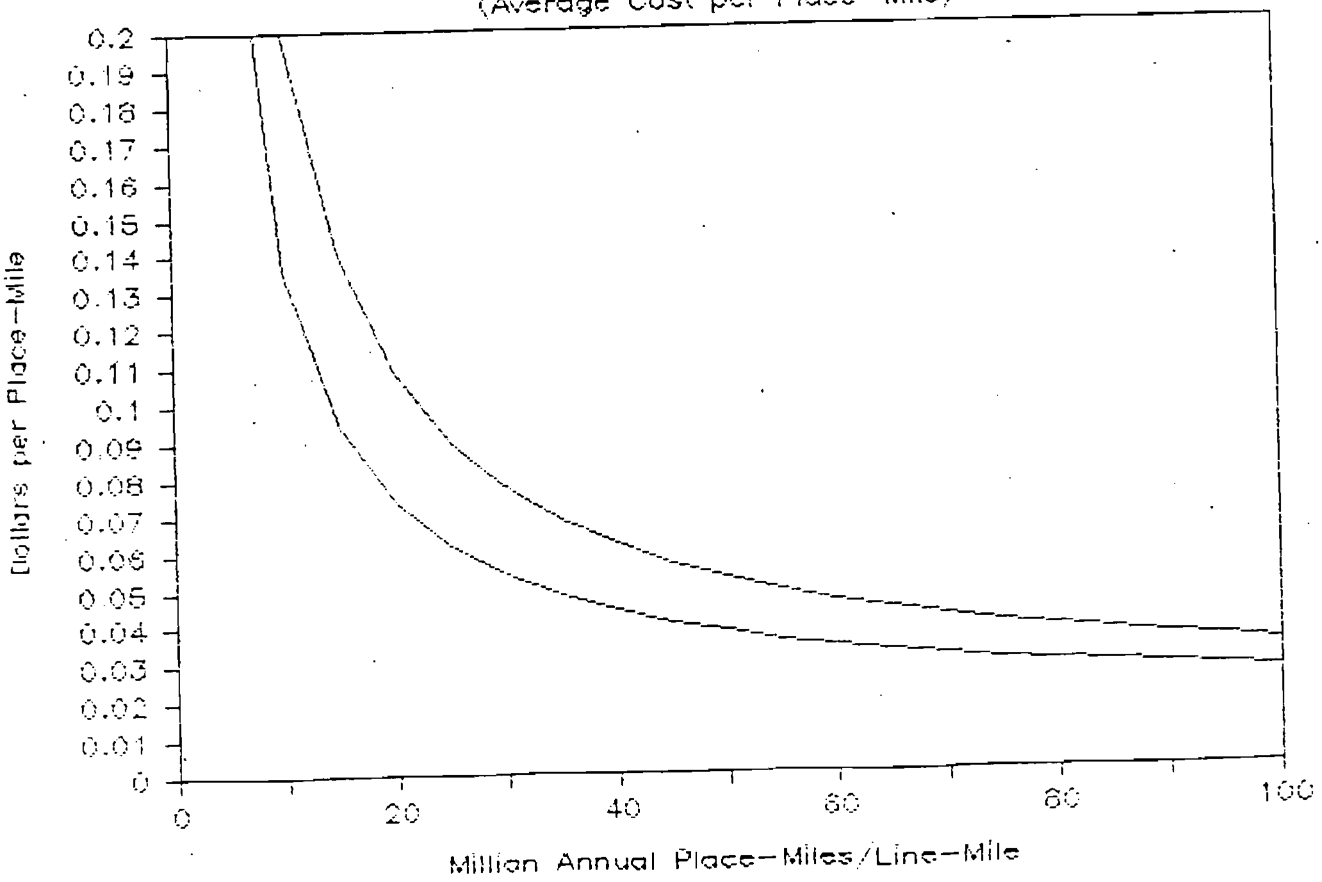


Figure 2a shows average total capital (construction plus vehicle) costs for rapid rail lines entirely at-grade and entirely in underground tunnels, computed for identical average station frequencies of 1.1 per mile of line. Corresponding cost curves for elevated lines, as well as for lines using these three alignments in various combinations, will lie between the two curves illustrated. Figure 2b shows comparable curves for light rail lines, except that the upper curve represents a line 20% underground with its remainder at grade, about the upper limit of tunneling likely to be undertaken for a light rail line. Light rail line construction costs are estimated using the slightly higher station frequencies that are typical of recently constructed lines (about 1.3 stations per mile of line). As the figures illustrate, these average cost curves at first slope sharply downward with increasing service volumes, then less steeply so as service volumes rise through moderate to high levels.

COMBINING THE BENEFIT AND COST CURVES: RAIL INVESTMENT "THRESHOLDS"

By superimposing the graphic representations of rail line benefits and capital costs developed in preceding sections, service volume thresholds above which the potential operating, land, capital, and travel time savings offered by new rail lines exceed the costs of building them can be identified. At service levels meeting or exceeding these thresholds, constructing rail lines to carry passengers that would otherwise have traveled by bus and automobile can result in net cost savings. Of course, achieving these savings depends on actually reaching passenger load factors on new rail lines that are comparable to those for the bus transit services and automobile travel from which rail passengers are drawn.

It is also important to recall that these thresholds apply to line-haul service only, which represents only one component of each urban trip. Yet line-haul service is the function for which rail transit is likely to enjoy its greatest comparative advantage, since the substantial capital costs of providing rail facilities can be spread over the largest passenger volumes. The previous studies that have examined separately the costs of providing passenger collection and distribution services at the origin and destination ends of the line-haul trip have concluded that these considerations substantially reduce any cost advantage (or markedly increase any disadvantage) for rail transit stemming from line-haul considerations alone.[47]

Revised Investment Threshold Estimates

With these cautions in mind, Figure 3 combines the revised benefits functions previously presented in Figure 1 with the average construction cost curves for rail transit lines that were shown in Figure 2. Again, the first panel (Figure 3a) refers to rail rapid transit service, while the lower panel (Figure 3b) represents cost and benefit functions for light rail lines. For each type of system, four different annual

Figure 3a. Heavy Rail Benefits & Costs

(vs. Express Bus and Auto)

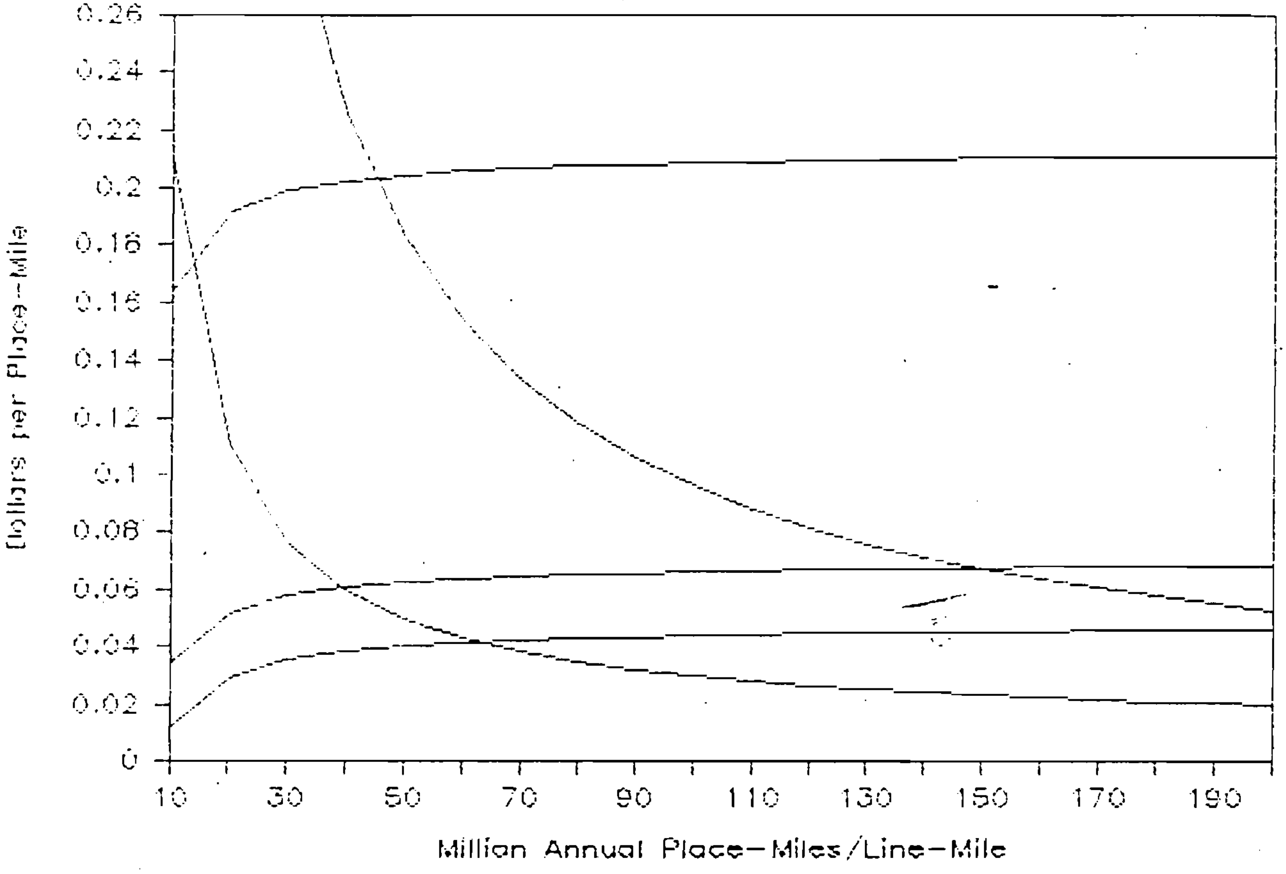
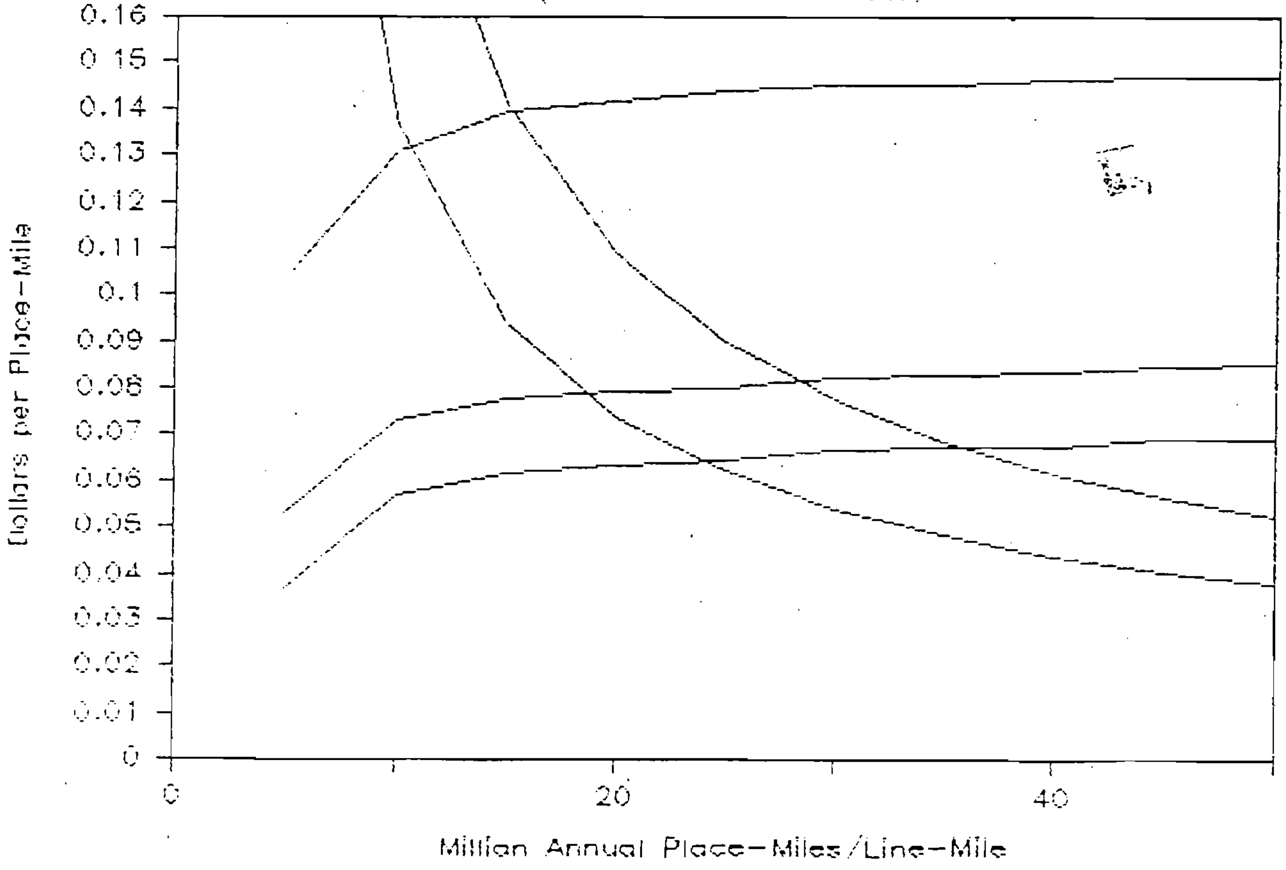


Figure 3b. Light Rail Benefits & Costs

(vs. Local Bus and Auto)



service volumes and associated peak ridership thresholds above which net cost savings could potentially result from building rail lines can be identified. These correspond to the intersections of the two revised benefits curves from Figure 1 (which differ only because the upper curve includes potential capital cost savings from reduced auto and bus travel) with each of the two construction cost curves from Figure 2. As indicated previously, these cost curves are intended to represent a high- and low-cost line alignment for each of the two rail technologies: 100% tunnel and 100% surface for heavy rail; and 25% tunnel and 100% surface for light rail lines.

For both types of rail lines, the lowest of these four thresholds represents the point at which the more optimistic benefits estimates (those including vehicle and right-of-way capital cost savings) rise to a level matching the estimates of construction costs for surface rail lines. The highest threshold in each panel represents the intersection of the higher average construction cost function (corresponding to a line partly or entirely underground) with the curve representing the revised benefits estimates excluding potential capital cost savings. Their ranges are 36-180 thousand daily passenger-miles of travel per mile of line for rail rapid transit systems, depending on the exact alignment chosen, and about 16-31 thousand daily passenger-miles of transit travel per mile of newly constructed light rail line. The following discussion compares these to the RPA estimates, and attempts to assess the plausibility of achieving them in U.S. cities.

How Different are These Revised Thresholds?

Rapid Transit. Table 11 summarizes these thresholds, and compares them to the service and ridership volumes originally identified in the RPA study as warranting the construction of rail lines with the specific alignments tested here. As it indicates, the revisions of rail line operating benefits and construction costs developed in this analysis substantially modify its conclusions about service and travel volumes necessary to justify building rail transit lines. These revisions indicate that underground rail rapid transit lines are likely to produce net cost savings in line-haul service only when an annual level of service commensurate with typical weekday peak hour travel volumes entering a downtown area well above 15,000 passengers is operated. This contrasts with the peak passenger threshold of only about 7,400 riders reported in the earlier RPA study for this type of line. With typical time patterns of daily ridership, this revised threshold estimate would correspond to about 123,000 average daily passengers on each mile of rapid transit line constructed in an underground tunnel.[48]

This result accords closely with the conclusions of earlier studies regarding the volumes at which rail rapid transit becomes the cost-minimizing mode of line-haul transportation service. Further, according to their findings it would be raised considerably if the complications in supplementing rail transit line-haul service with effective residential collection and downtown distribution services. Table 11 also reports that surface rapid transit lines are likely to produce net cost savings only above service volumes that would normally be operated where

Table 11

Estimates of Service and Ridership Volumes Necessary for Rail Investments to Produce Net Cost Savings

Line Type and Alignment	Original RPA Estimate[a]	with Revised Benefits:[b] including Capital Savings	excluding Capital Savings
Rail Rapid Transit, entirely in Tunnel:			
One-Way Peak Hour Passengers	7,400	31,600	> 42,000
Avg. Weekday Pass.-Miles/Line-Mile	28,800	123,200	> 164,000
Rail Rapid Transit, entirely on Surface:			
One-Way Peak Hour Passengers	3,800	8,500	13,100
Avg. Weekday Pass.-Miles/Line-Mile	14,800	32,900	50,900
Light Rail Transit, 20% in Tunnel:			
One-Way Peak Hour Passengers	3,400	6,100	7,600
Avg. Weekday Pass.-Miles/Line-Mile	13,100	23,800	29,600
Light Rail Transit, Entirely on Surface:			
One-Way Peak Hour Passengers	1,900	4,000	5,100
Avg. Weekday Pass.-Miles/Line-Mile	7,400	15,600	19,700

[a] Source: Pushkarev and Zupan.

[b] Source: Computations by author described in text and displayed in Figure 3.

one-way peak hour passenger volumes reach at least 8,500 riders, and perhaps as much as 50% above that level, if they are to be justified on economic grounds. This revised figure is more than double the passenger volume threshold identified for surface rail rapid transit lines by the RPA researchers; with typical daily travel patterns, it would correspond to daily ridership figures that average over 50,000 passengers per mile of line.

Prospects for Light Rail. Similar, if somewhat less drastic, revisions to the earlier report's conclusions about service and ridership levels necessary for light rail lines to produce overall cost savings follow from the revised benefit and construction cost functions produced in this review. As Table 11 indicates, the revised minimum service volume estimates for surface light rail lines to produce net savings would typically be operated where maximum passenger volumes reached 4,000 one-way peak hour riders. Peak travel volumes of this scale are usually associated with average weekday ridership levels above 15,000 per mile of line. This revised threshold contrasts with the corresponding estimate of slightly less than 2,000 peak passenger reported in the RPA study. For light rail lines built with about 20% of their mileage underground, maximum peak hour ridership levels closer to 6,000 passengers (corresponding to nearly 24,000 average daily passengers using each mile of newly built line) would have to occur in order to justify operating a level of service that would produce net cost savings over other modes of travel. Again, this revised estimate is well above the 3,400 peak rider figure corresponding to the RPA-estimated threshold for this type of line and alignment.

Estimates of Actual Travel Volumes

These service volume thresholds are hard to interpret by themselves, but the more important question is whether they would be justified by actual levels of travel activity prevailing in individual corridors of specific U.S. cities. To facilitate this comparison, Table 12 reports two sets of relevant travel volume estimates. The first includes the RPA researchers' maximum estimates of average daily ridership per mile on a hypothetical (and usually very short) rail line in the most heavily traveled corridor of various cities. These estimates incorporate assumptions about transit and auto performance that produce fairly optimistic estimates for new rail lines' mode shares of corridor travel.[49] One-way peak hour passenger volumes that would normally correspond to these average daily ridership estimates, computed using typical peaking patterns in transit ridership on existing systems, are also reported in the table.

The second set of estimates is constructed from the Journey-to-Work statistics for individual urban areas reported in the 1980 U.S. Census. It is obtained by adding the number of work trips that originate in the suburban and central city areas of each urban area and are destined for its Central Business District (CBD). This aggregate estimate of CBD-bound work travel is then converted to an estimate of inbound travel during the three-hour morning peak period, and divided by the number of travel corridors entering the CBD of each urban area, in order to arrive

Table 12

Estimates of Potential Rail System Ridership and Peak Hour Corridor Volumes

Urban Area	RPA Estimate of Maximum Daily Passenger-Miles/Line-Mile on any Route[a]	Estimated 3-Hour Peak Commute Travel Volume in Typical Radial Corridor[b]
Los Angeles	21,800	14,200
Seattle	25,900	12,000
Honolulu	23,900	9,100
Houston	15,100	14,200
Detroit	19,000	17,500
Dallas	15,700	10,800
Baltimore	21,000	12,400
Miami	13,300	3,800
St. Louis	13,700	11,500
Atlanta	13,000	11,900
Milwaukee	13,700	10,500
Minneapolis-St. Paul	11,200	11,500
Buffalo	9,100	8,700
San Diego	9,100	6,800
Portland	7,300	8,500
Denver	6,700	9,500
Columbus	6,100	11,600
Kansas City	5,900	5,200
Indianapolis	6,400	9,100
Louisville	6,500	9,000
Cincinnati	5,600	11,900
Phoenix	2,900	9,400
San Antonio	2,800	6,600
Dayton	2,600	5,800
Providence	1,900	4,600
Salt Lake City	--	8,700
Sacramento	--	5,600
Rochester	--	7,600

[a] Source: Pushkarev and Zupan, Exhibits 4.9 and 4.10.

[b] Source: Estimated by author from statistics reported in U.S. Bureau of the Census, "Journey to Work: Metropolitan Commuting Flows," 1980. See text for description of estimation method.

at an estimate of the average number of peak-period work trips in a typical radial travel corridor within each urban area. The resulting figure represents an estimate of daily commuting travel in the corridor by all modes, some fraction of which would use a newly-built rail line serving the corridor. In addition, such a line would be likely to carry some CBD-bound trips made for purposes other than commuting to work, as well as some trips passing entirely through the CBD en route to other destinations, depending on the exact alignment chosen for the line.

Overall Implications of the Revised Estimates

The combined implication of these revised estimates of the passenger volumes at which rail lines can produce cost savings and the estimates of prospective travel volumes is indeed striking. Under even the most optimistic of these revised rail benefits estimates, and even with the lower construction costs attainable by placing them on surface rights-of-way except in the most densely developed areas they traverse, no new heavy rail lines appear to be economically justified in U.S. cities, including some cities currently building such facilities and others now actively planning their construction. This finding is based on an economic evaluation of rail transit for line-haul service alone, and would be considerably strengthened by incorporating the pronounced cost disadvantage in providing residential feeder and downtown distribution services to support heavy rail transit lines. It accords surprisingly closely with the implications of the series of previous economic evaluations of the costs of providing urban transportation service reviewed earlier, but contrasts sharply with the findings reported in the study by the Regional Plan Association.

A similar conclusion emerges from the revisions of light rail construction cost and benefits estimates developed here. The number of urban travel corridors in even the largest and most densely developed U.S. cities not yet served by rail transit where constructing light rail lines can be justified by realistic estimates of their likely costs and attendant benefits also appears to be extremely limited. Further, this limited number excludes nearly every U.S. city now either building or actively planning to construct a light rail line. Again, this finding is based on an economic evaluation of light rail transit in line-haul service only, and would almost certainly be strengthened by a careful consideration of the costs of providing the feeder bus services necessary to ensure acceptable light rail ridership levels at the residential densities characteristic of the suburban areas of most U.S. cities. It also stands in distinct contrast to the recommendations presented by the recent Regional Plan Association report.

Both of these conclusions appear to be relatively insensitive to reasonable variations in the assumptions underlying the benefit and cost estimates from which they stem. More streamlined rail transit labor staffing requirements, substantially higher petroleum prices and lower automotive fuel economy, higher values of travel time, or more generous estimates of the savings in parking resources, highway construction costs, and bus and auto fleets do not substantially affect these qualitative findings. The conclusions are somewhat more sensitive to changes in the costs of constructing rail lines, but the approach used to estimate those costs is probably considerably more reliable than those used hertofore; in fact, construction costs in any specific instance are about as likely to be higher than those estimated here as they are to be lower.

Finally, a host of caveats has been identified throughout this review, representing areas of empirical uncertainty, unresolved conceptual issues, or omitted but potentially important considerations. The most important of these are introduced by the cost considerations in providing bus feeder services necessary to support rail transit; questions about the allocation of capital costs between peak and other users; the uncertain prospects for achieving utilization of rail transit facilities comparable to that in auto transportation or even bus transit service; and the uncertainty of actually achieving substantial reductions in highway capacity and the automobile and bus vehicle fleets. The critical aspect of each of these reservations is that the uncertainty it introduces is likely to make the economic case for constructing new rail transit lines even weaker and more limited than it appears to be on the basis of the revised benefit and construction cost estimates developed in this review.

NOTES

1. John R. Meyer, John F. Kain, and Martin Wohl, The Urban Transportation Problem, Cambridge, Massachusetts: Harvard University Press, 1965, Chapters 8-11.

2. J. Hayden Boyd, Norman J. Asher, and Elliot S. Wetzler, "Nontechnological Innovation in Urban Transit: A Comparison of Some Alternatives," Journal of Urban Economics, Vol. 5 No. 1, January 1978, pp. 1-20.

3. Theodore E. Keeler, Kenneth A. Small, and Associates, The Full Costs of Urban Transport, Part III: Automobile Costs and Final Intermodal Cost Comparisons, Monograph No. 21, Institute of Urban and Regional Development, University of California, Berkeley, July 1975, pp. pp 127-132.

4. Mahlon R. Straszheim, "Assessing the Social Costs of Urban Transportation Technologies," in Mahlon R. Straszheim and Peter A. Mieszkowski, eds., Current Issues in Urban Economics, Baltimore, Maryland: The Johns Hopkins University Press, 1979, pp. 196-232.

5. Boris Pushkarev and Jeffrey Zupan, Urban Rail in America: An Exploration of Criteria for Fixed Guideway Transit, report by the Regional Plan Association, Inc., to U.S. Urban Mass Transportation Administration, number UMTA-NY-06-0061-80-1, November 1980, pp. 164-165; also published as Urban Rail in America by Indiana University Press, Bloomington, Indiana, 1982.

6. Pushkarev and Zupan, pp. 251-256.

7. Pushkarev and Zupan, pp. 272-276.

8. Pushkarev and Zupan, pp. 258-262.

9. Pushkarev and Zupan, p. 277.

10. Based on cost estimates for line and station constructed by the author and reported subsequently in this paper.

11. Pushkarev and Zupan, pp. 249-256.

12. Data Resources, Inc., Review of the U.S. Economy, April 1984, pp. 1.86-1.88.

13. For estimates of land requirements for urban transportation rights-of-way, see Meyer, Kain, and Wohl, pp. 119-211, and Pushkarev and Zupan, pp. 145-152.

14. To insure a fair comparison among the costs of transporting passengers by various modes, it is important that their units of capacity be of comparable quality. Yet in the analysis reviewed here, all automobile place-miles are by definition seated, while bus capacity estimates include approximately 25% standees, and rail vehicle capacity estimates include 45-55% standees. Thus its estimates of cost savings arising when travelers are carried aboard rail vehicles rather than buses and

14. (continued) autos do not represent costs for transportation service of equivalent (average) quality, and rail systems are more likely to show cost savings than would a comparison of the full costs of providing genuinely equivalent service using the three modes.

15. See Pushkarev and Zupan, Exhibit 2.11, p. 113. This threshold is computed by solving for the service volume that produces average total labor requirements per place-mile of service equal to those for local bus operations. Assuming that one-way major direction peak hour passengers are about 12% of all daily place-miles of service provided, that there are 280 weekday equivalents duribg each year, and that rail vehicles accommodating 142 passengers are operated in 4-car trains at an average speed (including allowances for layovers, deadheading, etc.) of 25 miles per hour, this volume appears to be somewhat below the 18 million annual place-miles per line-mile figure.

16. The new rail rapid transit systems considered in this analysis are the PATCO-Lindenwold Line, the San Francisco Bay Area Rapid Transit (BART) System, the Washington, D.C. Metrorail System, and the Atlanta MARTA Rail System. Light rail lines considered are those in Calgary, Edmonton, and San Diego. Information on the two Canadian light rail lines was obtained from operating statistics compiled by those cities' Transportation Departments, and for U.S. systems from U.S. Urban Mass Transportation Administration, National Urban Mass Transportation Statistics, various years.

17. Computed from statistics reported in Robert Cervero, Monitoring Financial and Operating Trends Among U.S. Transit Properties, report prepared for U.S. Department of Transportation, Transportation Systems Center, May 1984, and American Public Transit Association, Transit Fact Book, 1982.

18. Estimated from average weekly earnings statistics for intercity and suburban transit and urban trucking workers reported in U.S. Bureau of Labor Statistics, Supplement to Employment and Earnings, July 1984. Even the $25,000 per figure appears too high in comparison to the BLS figures, which imply annual compensation levels averaging about $15,900 and $21,200 for the two industries, but these include some workers in smaller urban areas where wage rates are likely to be lower.

19. These estimates are derived from the following sources: Pushkarev and Zupan, pp. 118-145; U.S. Urban Mass Transportation Administration, National Urban Mass Transportation Statistics, April 1984, Table 3.13.1; and U.S. Congressional Budget Office, Urban Transportation and Energy: The Potential Savings of Different Modes, Washington, D.C., Government Printing Office, 1977, pp. 30-35.

20. Pushkarev and Zupan, p. 120.

21. Data Resources, Inc., Review of the U.S. Economy, April 1984, pp. 1.116-1.118 and p. 11.34.

22. Data Resources, Inc., U.S. Long Term Review, Spring 1984, pp. 1.24, 1.45-1.46, and 1.53.

23. Estimated from data reported in Robert A. Weant, Parking Garage Planning and Operation, Westport, Connecticut, Eno Foundation for Transportation, Inc., 1978, Chapter 3.

24. Pushkarev and Zupan, p. 160.

25. Reported in U.S. Federal Highway Administration, Nationwide Personal Transportaton Study, Report No. 3: "Purposes of Vehicle Trips and Travel," 1980, Table 6, p. 16.

26. Estimated from statistics reported in U.S. Urban Mass Transportation Administration, National Urban Mass Transportation Statistics, April 1984, and information supplied by the City of Edmonton, Transportation Management Department.

27. Pushkarev and Zupan, pp. 87-118.

28. Bus transit operating speeds were estimated from U.S. Urban Mass Transportation Administration, National Urban Mass Transportaton Statistics, April 1984. Auto travel speeds are door-to-door average speeds estimated from time and distance data reported in U.S. Federal Highway Administration, Nationwide Personal Transportation Study, Report No. 4: "Home-to-Work Trips and Travel," 1980, but they include all work travel within urban areas, which overstates average speeds for peak hour travel in CDB-bound corridors.

29. Some information on actual door-to-door travel speeds for various urban transportaton modes in large cities is provided by data collected by the Census Bureau; it suggests average overall speeds of 30.3, 12.3, and 17.4 miles per hour for automobile, bus, and rail transit travel to work in major urban areas. See U.S. Bureau of the Census, Current Population Reports, Series P-23, "The Journey to Work in the United States," 1976, 1977, and 1978.

30. Pushkarev and Zupan, pp. 160-162.

31. Pushkarev and Zupan, Appendix A-5, pp. 314-316.

32. Reported in Douglass B. Lee, "Value of Travel Time," appendix to Evaluation of Major Transportation Investments, staff study, Transportation Systems Center, U.S. Department of Transportation, June 1984.

33. Estimated from contract price data reported in Michael Rossetti, "Bus Transit Procurements," internal memorandum, Transportation Systems Center, U.S. Department of Transportation, and bus utilization data reported in U.S. Urban Mass Transportation Administration, National Urban Mass Transportation Statistics, April 1984.

34. Reported in Guide to Highway Cost Allocation Study Methods, Volume II: Technical Appendix, U.S. Federal Highway Administration and Transportation Systems Center, April 1984.

35. Depreciation figures are from U.S. Federal Highway Administration, Cost of Owning and Operating Automobiles and Vans, 1984, Table 1; these

35 (continued). are apportioned between age and mileage using estimates derived from Kenneth A. Small, "Automobile Interest and Depreciation Costs," unpublished paper, Institute for Urban and Regional Development, University of California, Berkeley, September 1973.

36. Interest costs must be added to depreciation figures in order to make them equivalent to capital costs for rail transit, since the latter are annualized from initial construction and acquisition costs using capital recovery factors that embody both depreciation and amortization of capital investments.

37. Estimates of the time pattern of depreciation are derived from year-by-year depreciation estimates reported in Tables 2-6 of U.S. Federal Highway Administration, *Cost of Owning and Operating Automobiles and Vans*, 1984.

38. Statistics on travel modes formerly utilized by riders of new rail systems are summarized in Charles River Associates, *Cross-Cutting Analysis of Rail Transit Impact Studies in Washington, D.C., Atlanta, and San Francisco*, prepared for Transportation Systems Center, U.S. Department of Transportation, August 1983.

39. Where they were available, annual construction outlays were converted to 1983 dollars using changes from the year in which they were incurred to 1983 in construction cost indices for individual U.S. urban areas reported in *Engineering News Record*, various issues. Where annual outlays were not available, total project expenditures were adjusted by the change in the appropriate construction cost index between the middle year of the project and its 1983 average value. Because no construction cost index is reported for the Washington, D.C. area, expenditures for constructing that city's METRO system were adjusted to 1983 dollars using the change in the index for the Baltimore metropolitan area reported in the same source. All of the cost estimates for heavy rail systems are for completed projects, while those for two of the light rail systems included in the sample (those in Portland and Vancouver) are the most recent available for those systems, which are now under construction.

40. Most U.S. rail rapid transit systems employ 56.5 inch wide rails, although a few such as the San Francisco BART system and Philadelhia's Lindenwold High Speed line operate over slightly wider-guage (62.5 inch) rails. The two basic guideways used by most urban rail transit systems -- full "metro" or heavy rail and the narrower streetcar or light rail track -- are closely comparable among specific installations, despite some limited variation in the actual gauge of track utilized. For the relatively simple rail transit networks recently built in North America, other elements of the guideway such as electrification, switching, and train control facilities are also fairly standardized. Rapid transit vehicle dimensions vary from 8.3 feet in width by 46 feet in length (the dimensions of the oldest vehicles in use on Philadelphia's SEPTA rapid transit lines) to 10.5 by 75 feet (on the San Francisco BART system), while modern light rail vehicle dimensions vary from 8.9 by 59.3 feet to 9.25 by 88.2 feet.

41. Average station spacings for underground, surface, and elevated alignments are 0.86, 1.34, and 1.42 miles for the 17 heavy rail projects included in this analysis, and 0.77, 1.08, and 0.78 miles for the 15 light rail projects studied. The figure for heavy rail lines in tunnels excludes the 8-mile transbay tube of the San Francisco BART system.

42. This can be seen by examining the figures reported in Tables 6 and 7 above.

43. Note that adjusted R^2 declines despite this improvement in precision, in response to the reduction in the already very limited number of degrees of freedom imposed by the more complex specification.

44. Station *densities* are the reciprocals of the station *spacing* figures reported in *note 41 above*.

45. Computed from contract prices reported in Michael Rossetti, "Rail Transit Vehicle Procurements," internal memorandum, Transportation Systems Center, U.S. Department of Transportation, and figures reported in *Mass Transit*, various issues. The range of figures for rapid transit vehicles is $7,080 (for the original San Francisco BART "A" cars) to $7,850 (for the recently delivered Baltimore MTA vehicles), while that for light rail vehicles is $7,270 (for the San Francisco MUNI and Boston MBTA light rail vehicles) to $7,660 (for light rail cars purchased by the San Diego Metropolitan Transit Commission). Passenger-carrying capacities of rail vehicles are estimated by allowing 0.5 square meters per passenger, a density at which only about 50% of passengers will actually be seated.

46. Computed by assuming that each year has 280 weekday equivalents, overall rail system load factors average 23%, one-way peak hour ridership is 12% of average weekday ridership, and that heavy and light rail vehicles operate at average speeds of 25 and 18 miles per hour, including allowances for time in non-revenue service.

47. For example, Meyer, Kain, and Wohl found that in line haul service, rail rapid transit service had total costs below those of automobiles in medium-density cities at peak hourly travel volumes of about 10-12,000, but these rose to about 20,000 per hour when costs for passenger collection and distribution were added; see Figures 34, 52, and 53.

48. This measure refers to one passenger riding for a full mile of line; thus one passenger-mile per line-mile is generally *not* equivalent to one passenger boarding or passenger trip, because passenger trips are typically shorter than the full length of the rail line. If, for example, passenger trips average half the length of the line, average daily passenger-miles per mile of line will equal one-half of daily ridership or boardings.

49. Pushkarev and Zupan, Exhibits 4.9 and 4.10, pp. 280-283.

50. U.S. Bureau of the Census, *1980 Census of Population*, Subject Report PC80-2-6C, "The Journey to Work: Metropolitan Commuting Flows," Table 3.