APPENDIX E

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Characteristics Of Hypothetical Rail Corridors, Figures 17-46

All characteristics of corridors were chosen to encompass the range of existing data, or extend slightly beyond them.

Actual CBD employment sizes ranges from 60,000 in Sacramento to 419,000 in Chicago. (See Figure 13 in the text for details.)

CBD employment densities are defined with each employment size in combination with assumed CBD land area, with low density CBDs covering three square miles and high density CBDs covering two square miles. There are no precise definitions of CBDs, but using our definitions which were based on zip codes and employment levels (See Appendix D), we can identify several CBDs in this range of sizes. Portland, Boston, and Chicago are examples of cities with CBDs of about two square miles. Los Angeles and Washington, DC have CBDs that cover about three square miles. Philadelphia, Baltimore, San Francisco, and Buffalo are between these sizes. Some CBDs are much more spread out than these. Sacramento and Cleveland have CBDs that cover more than six square miles.

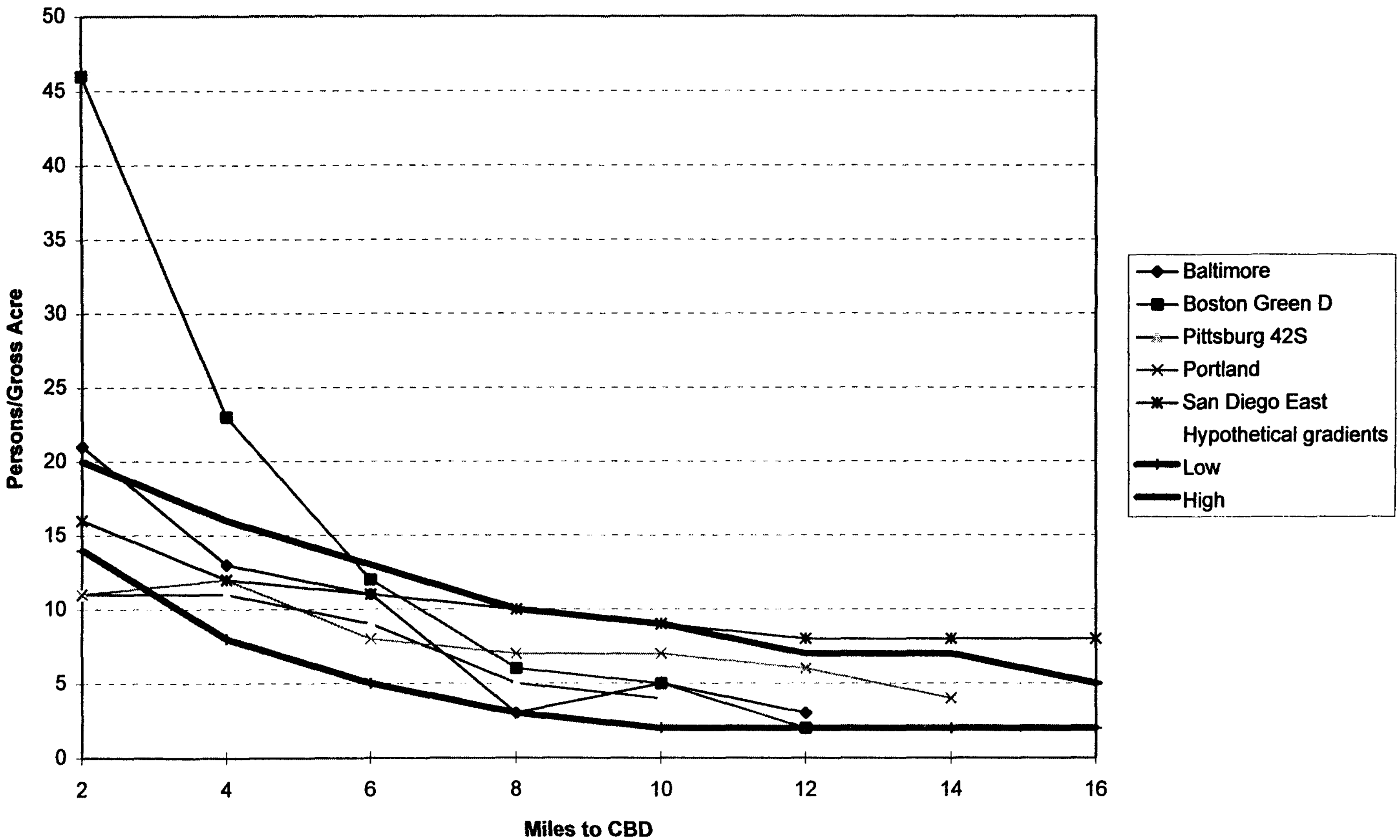
Residential density gradients were hypothesized to reflect the range of conditions in current cities with rail systems. The following figures illustrate a sample of existing light rail and commuter rail density gradients plus the upper and lower extremes of hypothetical gradients (in wider width).

Most of the light rail gradients lie between the assumed high and low extremes. Boston is an exception because residential densities are much higher near the CBD than hypothesized. It is not anticipated that cities adopting light rail today will be as dense as Boston. San Diego is also an exception being more dense than the hypothesized limits at greater distances from the CBD. San Diego illustrates the shallow gradient hypothesized for potential commuter rail in large western cities.

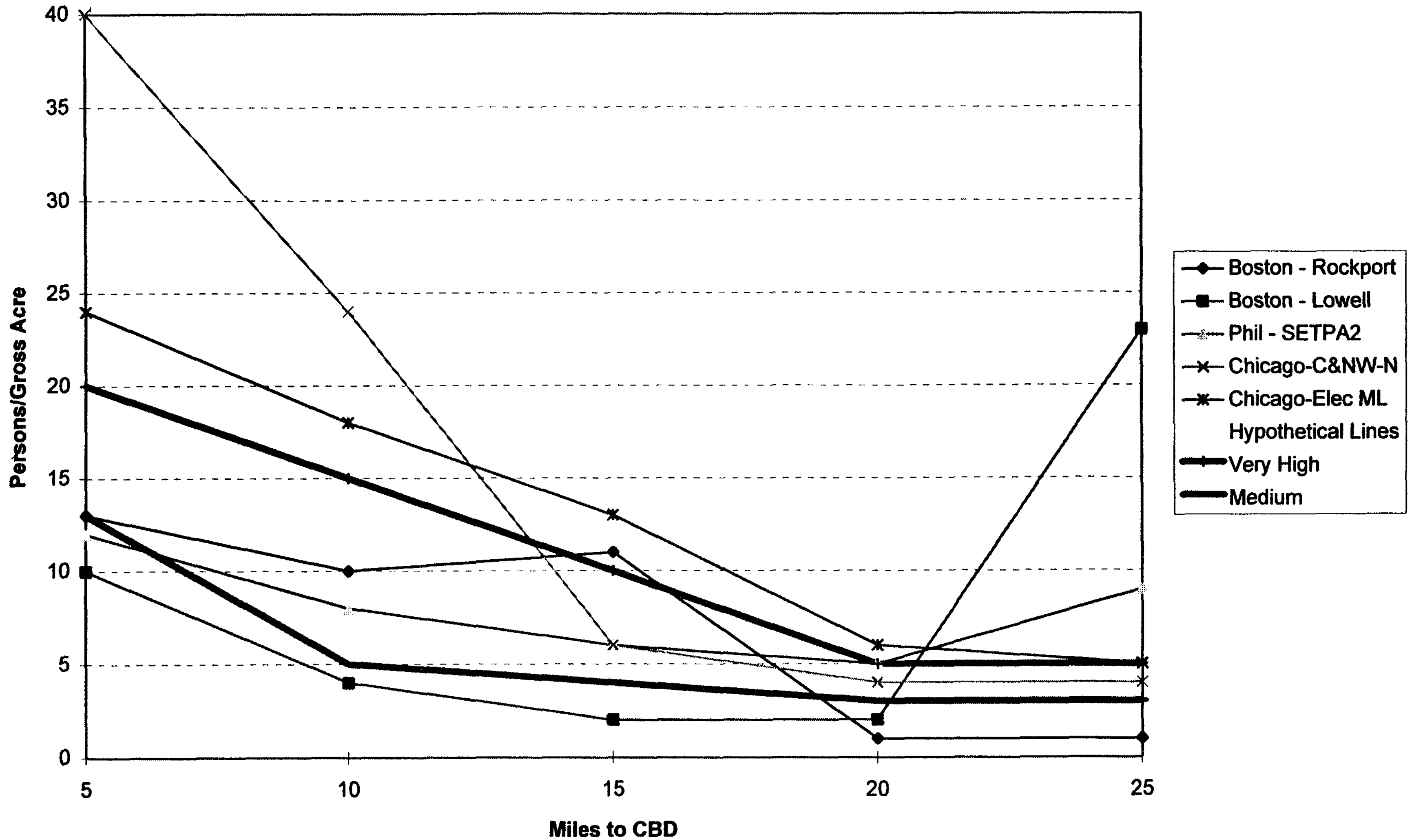
Commuter rail density gradients show more variability. Chicago commuter rail often operates in denser residential areas than the hypothesized very high gradient. However, it is not anticipated that new commuter rail cities will be as dense as Chicago. Some commuter rail systems also operate for at least part of their routes at lower densities than assumed by the medium density gradient. The Boston-Lowell line illustrates a situation not reflected in the hypothesized density gradients—a commuter rail line that terminates in a fairly dense community. In considering these gradients, it is helpful to remember that residential density gradients proved to have little impact on commuter rail ridership and that when considering commuter rail, site specific analysis will be needed.

The average access pattern is intended to reflect the percentages found in Table 5 in the text. Other access pattern assumptions are shown in the following tables.

Light Rail Density Gradients



Commuter Rail Density Gradients



Station Access Modes in Hypothetical Corridors

Light Rail

Miles	Type 1 Average		Type 2 Parking Emphasis		Type 3 Bus Emphasis	
from CBD	Park	Bus	Park	Bus	Park	Bus
1		x				x
2		x				x
3			x			x
4		x	x			x
5	x		x			x
6		x	x	x		x
7			x			x
8	x	x	x			x
9			x			x
10		x	x	x	x	x
11	x	x	x			x
12			x			x
13	x	x	x			x
14						x
15	x	x	x	x	x	x
16	x	x	x			x
17	x	x	x			x
18	x	x	x			x
19	x	x	x			x
20	x	x	x	x	x	x
21	x	x	x			x
22	x	x	x			x
23	x	x	x			x
24	x	x	x			x
25	x	x	x	x	x	x

Note: Type 1: Average is based on the typical pattern of park-and-ride and feeder bus service of light rail systems studied in this project.

Type 2: Parking Emphasis increases the number of stations with parking and decreases the number with feeder bus service.

Type 3: Bus Emphasis does the opposite. The number of stations with parking decreases and the number with feeder bus increases to all stations.

APPENDIX E (continued)

Commuter Rail

Miles from CBD	Type 1 Average: Park	Type 1 Average: Bus	Type 2 More Bus, Less Park: Park	Type 2 More Bus, Less Park: Bus	Type 3 More Bus: Park	Type 3 More Bus: Bus	Type 4 Less Park: Park	Type 4 Less Park: Bus
3		x		x		x		x
6	x	x		x	x	x		x
9	x		x	x	x	x	x	
12	x	x		x	x	x		x
14	x	x	x	x	x	x	x	x
16	x			x	x	x		
18				x		x		
20	x	x	x	x	x	x	x	x
22	x	x		x	x	x		x
24				x		x		
26	x	x	x	x	x	x	x	x
28	x			x	x	x		
30	x		x	x	x	x	x	
35	x			x	x	x		
40	x	x	x	x	x	x	x	x
45	x			x	x	x		
50	x	x	x	x	x	x	x	x
55	x			x	x	x		
60	x	x	x	x	x	x	x	x
65	x			x	x	x		
70	x		x	x	x	x	x	
75	x			x	x	x		
80	x	x	x	x	x	x	x	x

Note: Type 1: Average is based on the typical pattern of park-and-ride and feeder bus service of commuter rail systems studied in this project.

Type 2: More bus, less park decreases the number of stations with parking and puts feeder bus service at all stations.

Type 3: More Bus has parking at the same stations as Type 1 but has bus service at every station.

Type 4: Less Park has feeder bus at the same stations as Type 1 but has parking at fewer stations than Type 1.

APPENDIX F

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Light Rail and Commuter Rail Cost Models

This appendix documents the data collection and model development process used to arrive at formulas for predicting light rail transit and commuter rail operating/maintenance and capital costs. Also included as attachments at the end of this appendix are a series of tables listing various cost, ridership, operating and physical characteristics for the various U.S. commuter rail and light rail transit systems investigated in developing the cost models. Light rail transit operating/maintenance and capital costs are covered first followed by similar sections for commuter rail.

Light Rail Transit Cost Models

The Federal Transit Administration (FTA) Data Tables and Transit Profiles series of reports, both based upon 1993 Section 15 Reports from the National Transit Database, served as the two primary sources of information on operations, maintenance, capital costs and other physical characteristics. Three FTA reports also provided input to the analysis process: Estimation of Operations and Maintenance Cost for Transit Systems (DOT-T-93-2, dated December 1992); Characteristics of Urban Transportation Systems (DOT-T-93-07) dated September 1992); and Light Rail Transit Capital Cost Study (dated April 5, 1991). In addition, requests for data were sent to several light rail transit properties in an attempt to supplement missing or incomplete FTA data. Together, these data sources were employed to select U.S. light rail transit systems that could be used to for developing cost models.

Light Rail Operations and Maintenance Costs

A predetermined general framework was employed for developing a series of operating and maintenance cost models based on the physical characteristics of the rail system. This approach used a two step process in which the labor requirements, in terms of the number of workers by various categories, was first estimated, and then the total operating and maintenance costs were computed based on the labor costs per worker and the relationship between non-labor costs and system annual revenue vehicle miles. The process of estimating worker requirements before arriving at dollar costs for operations and maintenance represents an enhancement of the methodology outlined in *Urban Rail in America* (Pushkarev, Zupan, and Cumella, 1980).

Of the light rail transit properties for which some information was available, 12 U.S. systems were selected as both reasonably representative of the operating and maintenance conditions that would be proscribed for a system built today and for which the necessary data was available. These 12 light rail transit systems are found in Baltimore, Boston, Buffalo, Cleveland, Los Angeles, Philadelphia, Pittsburgh, Portland, Sacramento, San Diego, San Francisco, and San Jose. The system in St. Louis was too new to obtain comparable operating and maintenance data. In addition, three Canadian systems, Calgary, Edmonton and Toronto, were initially identified for their representative operating and maintenance conditions. However, difficulty in obtaining the necessary comparable cost and physical characteristics data, combined with differences in Canadian real income levels and currency exchange rate issues, resulted in their disqualification for purposes of developing the cost models. (See Tables 1-5 in the Light Rail Attachments for specific line information.)

Table 6, "Light Rail Transit Operations & Maintenance Costs and Related Characteristics," summarizes the universe of data available and applicable for developing the light rail transit operating and maintenance cost models (see also light rail transit Tables 1-5). An important criterion in the model development was that the input data or explanatory variables selected for the models be confined to information that a sketch planner would reasonably be expected to have for a proposed system in order to maximize the usefulness and application of the models. Using the data from Table 6 (including transformations of this data), linear regression models were proposed and tested for the number of vehicle operations workers, vehicle maintenance workers, way and structures workers, and administrative/existing capital workers. The first three worker categories tended to vary with certain physical characteristics of the transit system, an expected result for labor which is largely a variable cost.

In some cases, two different yet reasonable explanatory variables that were highly correlated could not both be used in a single model due to the problem of multicollinearity. For example, annual revenue hours of service and annual revenue miles of service have different meanings and units (magnitudes), yet comparing across systems, these two variables are highly correlated, i.e., one is close to a linear function of the other. As a result, both variables could not be used in a model to predict the number of vehicle operations workers. In most cases of potential multicollinearity, the choice of which variable to include was obvious from *a priori* expectations and/or cost theory. In a few cases of very similar variables, the one that provided the best fit in the regression model was used.

The equations for the number of workers by labor category resulting from the regression models are provided below in Exhibit 1, along with summary equations converting labor requirements to labor and total O&M dollars. More detailed information about the regression model results can be found at the end of Light Rail Attachment.

The model for vehicle operations workers proved to be a straightforward linear relationship of the number of vehicles operating in maximum service, the annual revenue hours of service and the average vehicle speed, with an adjusted R-squared of 0.965. This means that 96.5 percent of the variation in the number of vehicle operations workers is accounted for by the three explanatory variables. The first two explanatory variables capture that more vehicles and/or more hours of service require more workers. Average vehicle speed further adds the productivity effects of the system: faster speeds yield quicker trips, which means a vehicle and its workers can start a new trip sooner, hence the inverse relationship between workers and speed, as fewer workers are required with more frequent trips. Vehicle maintenance workers was determined to be a linear function of the fleet size, annual revenue hours of service, and the number of track miles per fleet vehicle, with an adjusted R-squared of 0.926. The larger the fleet, the more hours of service provided by the fleet, and/or the higher the average number of miles traveled per vehicle all lead to higher maintenance worker requirements.

Exhibit 1: Light Rail Transit Operation and Maintenance Cost Model Equations

Number of Vehicle Operations Workers =	31.43	+	1.93	×	Number of Vehicles in Maximum Service
		+	0.280	×	Annual Revenue Hours of Service (in 1,000s)
		+	-2.81	×	Average Vehicle Speed (mph)
Number of Vehicle Maintenance Workers =	-43.24	+	0.884	×	Number of Vehicles in Fleet
		+	0.212	×	Annual Revenue Hours of Service (in 1,000s)
		+	35.61	×	Number of Track Miles per Vehicle in Fleet
Number of Way & Structure Maint. Workers*	-64.54	+	3.02	×	Number of Track Miles
		+	61.41		If Average Station Spacing is Less than ½ mile.
Number of Administrative & Capital Staff =	-31.39	+	0.826	×	Number of Track Miles
		+	0.667	×	Annual Revenue Miles (in 1,000s) per Vehicle in Fleet
Summary Formula for Light Rail Transit O&M Labor Requirements =	-107.75	+	0.492	×	Annual Revenue Hours of Service × 1,000
		+	3.85	×	Number of Track Miles
		+	35.61	×	Number of Track Miles per Vehicle in Fleet
		+	1.93	×	Number of Vehicles in Maximum Service
		+	0.884	×	Number of Vehicles in Fleet
		+	0.667	×	Annual Revenue Miles (in 1,000s) per Vehicle in Fleet
		+	-2.81	×	Average Vehicle Speed (mph)
		+	61.41		If Average Station Spacing is Less than ½ mile.
Summary Formula for Light Rail Transit O&M Labor Costs (1993 $) =	**$ 66,004**	**×**	**Total Light Rail O&M Labor Requirements**		
Where $66,004 is the Average O&M Labor Cost per Worker (1993 Dollars, Geographic Cost of Living Normalized)					
Summary Formula for Light Rail O&M Non-Labor Costs (1993 $) =	**$1,342,000**	**+**	**1,441**	**×**	**Annual Revenue Miles (in 1,000s)**
Summary Formula for Tatal Light Rail O&M (Labor & Non-Labor) Costs =	**The Sum of the Above Two Amounts**				

*-333.01 for Philadelphia per dummy variable to correct for track miles maintained but no longer in service.

Way and structures workers was a bit more difficult to model across the 12 system sample. The size of the system as measured in track miles proved to be the best explanatory variable for predicting way and structures workers, although number of crossings, average station spacing, number of stations and directional route miles were also investigated. Multicollinearity problems prevented adding any of these variables to a model based on track miles with the exception of a factor to account for close station spacing. The resulting model thus included track miles and an adjustment factor increasing the number of way and structures workers when the average station spacing was less then one-half mile, with an adjusted R-squared of 0.809. This model also included a dummy variable for the Philadelphia system to account for track miles that continue to be maintained but are no longer in revenue service.

Development of a model for predicting the number of administrative and capital workers based upon the physical characteristics of the rail system proved to be a challenging task. There is likely to be a considerable fixed cost component to the need for administrative workers that does not necessary vary directly with hours or miles of service, station spacing, or number of vehicles. In addition, ridership trends, fare collection operations, marketing and information services all likely contribute to administrative worker requirements, but represented data that was either not uniformly available for the system used to develop the models or would not be included in the information available to the sketch planner using the resulting models. In the end, variables were chosen based upon their ability to serve as proxy measures for other attributes believed to be more closely tied to administrative costs. The model for administrative and capital workers was determined to be a linear function of the number of track miles in operation to capture the magnitude of the physical system requiring administration as well as the annual number of revenue miles of service traveled per vehicle in the system's fleet, which attempts to capture how intensely the systems resources requiring administration are employed.

Using the four models described above, the total worker requirements for a proposed light rail transit system can be calculated. This labor requirement can then be multiplied by an average labor cost per worker to arrive at total labor costs. Based upon the 12 system sample, the average labor cost per worker, inclusive of benefits and adjusted for geographic cost of living differences, was calculated at $66,004 in 1993 dollars. Intracity cost of living adjustments were made using the American Chamber of Commerce Researchers Association (ACCRA) Cost of Living Index. The application of the cost of living adjustment to the existing sample systems provided a better calibration "fit" when using the model values for workers to estimate the actual dollar labor costs for the 12 sample systems.

Once non-labor costs are added, annual operating and maintenance costs can be fully estimated. To account for the non-labor costs, which are largely energy expenditures, the relationship between non-labor costs and annual revenue vehicle miles of service was examined. A linear regression model indicated that 63 percent of the variation in non-labor costs was explained by annual revenue vehicle miles and a constant term representing a fixed cost component.

Light Rail Transit Capital Costs

Of the 12 U.S. systems used to develop the operating and maintenance cost models, four systems are too dated for their capital costs to be useful in estimating costs for new systems. As a result, construction and related development costs for the eight most recently constructed light rail transit lines in the United States were used for purposes of developing a capital cost model. These eight light rail transit system lines are listed below.

- Baltimore Central Line
- Los Angeles Blue Line
- Pittsburgh South Hills Line
- Portland Banfield Line
- Sacramento Starter Line
- St. Louis Initial Line
- San Diego South Line
- San Jose Guadeloupe Line

This sample represents the more recent development trends in light rail systems and in composite are representative of the new systems that may be considered in cities planning or evaluating the potential for light rail transit. The unit cost and the application cost model resulting from this analysis should provide a test for the reasonableness of conceptual planning-level capital cost estimates and a tool for the preparation of such comparative estimates.

The estimation of capital costs in project planning is usually based on the definition of alignment conditions such as the horizontal and vertical profile, capital asset requirements and the unit cost measures of each asset category. The unique features of the study systems and their impact on capital unit cost can be mitigated by analysis and the development of composite unit cost. The development of the study database concentrated on actual unit capital cost that should be helpful in preparing capital cost estimates for cities considering light rail transit.

Actual construction cost for the eight cities comprising the construction data base were broken down by project category and reflected in 1993 dollars. The categories utilized include:

- Guideway (line and structures)
- Stations (and parking)
- Right-of-Way
- Traction Power
- Train Control, Signals and Communication
- Utilities, Betterments and Mitigation
- Vehicles and Spare Parts
- Fare Collection
- Yard and Shops
- Agency Cost

The analysis of the data from the respective systems was used to arrange the capital cost into these ten categories as consistently as possible and to identify any anomalies that tended to distort the component cost. The sources of data and reference materials included materials from the 1993 National Transit Database, materials supplied by the agencies, materials from an FTA report entitled Light Rail Transit Capital Cost Study (UMTA-MD-08-7001, April 5, 1991) and materials contained in Parsons Brinckerhoff's capital cost files.

Light Rail Transit Table 7 (in the Light Rail Attachment) provides a summary of light rail capital cost and percentage of "as built" cost by category for the eight study cities. The table also reflects the average cost and percentage of total represented by the respective category for the eight cities. In addition to the total cost per component, a unit cost for stations and vehicles was calculated for each system. The cost of fare collection is also expressed on a per station basis and the yard and shop cost are presented as a function of the transit vehicles. A total cost per route mile for each system is reflected at the bottom of the table. The average cost of the systems per route mile is $22.6 million 1993 dollars.

Table 8 presents the capital cost summary of light rail unit cost for the eight study cities. In addition to the unit cost by component, the table presents the percentage of vertical profile for each study city by at-grade, elevated and subway. The resulting average of 86 percent at-grade, 11 percent elevated and three percent cut/subway is used in establishing the representative mix unit measure for guideway and stations in Table 9, Light Rail Transit Conceptual Cost Estimates by System Component, when the vertical profile is not known and only a rough estimate of route length (or miles) is known. The unit cost in Table 9 reflect the adjusted cost necessary to remove system anomalies from the individual system component cost. As an example, the Pittsburgh right-of-way cost include the purchase of the Panhandle Bridge and an existing railroad tunnel under a portion of the CBD. As a result, adjustments were necessary to the right-of-way cost and guideway cost to prevent distorting the unit cost. And finally Table 9 Supplement provides a series of increasingly complex formulas for calculating the capital cost of a proposed light rail system for conceptual mode comparison purposes. A general definition of capital cost components follows this introductory section.

GUIDEWAY COMPONENTS

This component of capital cost includes the track and structural requirements and generally includes: grading, drainage, sub-ballast, ballast, cross ties, fasteners, rail, special trackwork, track structures and supports, traction power pole supports and other miscellaneous items generally included as part of the guideway along the right-of-way. If the number of track miles of each of the three vertical profile types are known (at-grade, elevated or subway), the unit cost provided can be used to estimate the guideway cost. If only the total length of the guideway is known, the unit cost for the representative mix of vertical profiles can be used to estimate the guideway cost or a new composite more representative of the vertical profile anticipated can be created. In this case, the representative mix reflects a weighted average unit price of the eight systems utilized to develop this unit cost: 86 percent at-grade, 11 percent elevated and four percent cut or subway. This category of project cost, exclusive of engineering and design, usually represents from 22 to 30 percent of the total projects capital cost.

STATIONS (AND PARKING)

This component of capital cost includes: platforms, canopies, signage and graphics, lighting, heating, ventilation and air conditioning (where applicable), landscaping, bus drop-off and parking, amenities, access requirements and related cost impacts such as platform length, escalators/elevators, pedestrian access, disability access mode and weather coverage. These unit costs are based on 400'-0" platforms accommodating a four-car train. While serviceable, the station cost represent simple and functional stations in keeping with the light rail concept. In general, the cost are slightly conservative and represent side platform stations.

If the vertical profile of each station has been identified, the respective unit cost can be used to calculate the station capital cost. If the vertical profile is unknown, the unit cost for a representative mix based on the eight systems analyzed can be used in a manner similar to that explained under guideway above. Exclusive of engineering and design, stations represent approximately five to seven percent of the system cost.

The parking cost includes adequate surface parking spaces to accommodate approximately 25 percent of the average daily ridership at the stations out of the CBD core. With an average station spacing of 0.8 miles and an average route length of 22 miles, the parking is concentrated at the stations outside of a five mile radius from the CBD. A 500-car parking lot cost approximately $1,500,000 1993 dollars.

YARD AND SHOPS

The yard and shops component includes the necessary facilities, service vehicles, and tools and equipment to maintain, store, dispatch and operate and maintain the vehicle fleet and maintain the systems ways and structures. The major shop functions include heavy repair, running repair, motor, truck, wheel turning, catenary machine, air conditioning, electronics, communications, car wash/car cleaning, and maintenance of way. The facility also includes the operators facility, ready room and dispatch, central control, a revenue collection center, and the train storage yard.

The unit cost, exclusive of engineering and design, is expressed as a cost per vehicle. This unit cost is applicable for a fleet of 30 to 50 vehicles. As the fleet size increases, the unit cost should decrease. For a fleet of 30 vehicles, a capital cost of $14.1 million results. On average the yard and shop cost represents three to eight percent of the light rail system cost.

RIGHT-OF-WAY

This capital cost category covers all property acquisition and property acquisition related cost such as appraisals, relocation, etc. The unit cost for right-of-way is expressed in terms of cost per track mile and is based on a composite average for the eight systems analyzed. The composite unit cost per route mile was normalized to eliminate the purchase of extraordinary items such as river crossing, tunnels, etc. If the number of acres and a cost per core and urban acre are unknown, the unit cost provides a reasonable proxy for right-of-way cost. Allowances for any known extraordinary cost should be added to the right-of-way estimate.

TRACTION POWER

This component includes: the traction power substations, the catenary poles, brackets, wire, hardware and other miscellaneous items necessary to the conversion and distribution of traction power. The unit cost represents an adjusted average of the eight systems analyzed. Exclusive of design and engineering, this cost generally comprises four to five percent of the projects capital cost.

TRAIN CONTROL, SIGNALS AND COMMUNICATIONS

This component includes: the train control, block signal and communications elements of the systemwide components. The unit cost represents an adjusted average of the eight systems analyzed. Exclusive of engineering and design, these costs generally represent four to five percent of the total project capital cost.

UTILITIES, BETTERMENTS AND MITIGATION MEASURES

Development of a light rail system involves utility relocation and the mitigation of construction and community impacts that are not directly related to the provision of rail service. This component includes a unit cost per track mile to accommodate utility and railroad relocation and betterments, the environmental mitigation measures typically resulting from the EIS process and the roadway, intersection, landscaping, lighting and other amenities resulting from the community involvement and permitting processes. On average this component represents eight to ten percent of the project capital cost. If specific extraordinary cost have been identified for a project, they should be added to the estimate allowance for this category.

VEHICLES AND SPARE PARTS

This component includes the vehicle fleet and the initial order of spare parts. The cost is based on a unit cost for an 80- to 90-foot articulated light rail vehicle with an average seated capacity for 64 people and standing capacity for an additional 64 persons; a loading of about 130 persons. The unit cost is exclusive of engineering and design by the owner or owners representatives. A premium of approximately $200,000 per vehicle should be added for low floor vehicles.

FARE COLLECTION

This component consists of the fare vending, validation, and change machines representing the hardware supporting the "proof of payment" fare collection system. The estimate is based on an average of two sets of equipment per stations. The revenue collection and maintenance equipment is included with the yard and shop estimate. In general, exclusive of engineering and design, this category represents less than one percent of the projects capital cost.

AGENCY COST

This component includes the cost of the owner's staff, owner's representatives, and the general and administrative expenses of the owner. Included are the cost of administration, project management, all studies, engineering and design, construction and procurement management, design support, testing and start-up, insurance, financing fees and other miscellaneous expenses. The unit cost per track mile for this category represents an adjusted composite average for the eight systems analyzed. This cost can also be calculated as a percentage of the nine capital components described above. This category typically represents 25 to 30 percent of the total project capital cost.

Commuter Rail Cost Models

As with the light rail transit systems, the primary data sources included the Federal Transit Administration (FTA) Data Tables and Transit Profiles series of reports, both based upon 1993 Section 15 Reports from the National Transit Database. In addition, requests for data were sent to several commuter rail properties in an attempt to supplement missing or incomplete FTA data. Together, these data sources were employed to select U.S. commuter rail systems that could be used for developing cost models.

Although similar in objective, the development of cost models for commuter rail poses a more difficult task than for light rail transit. Commuter rail systems vary much more widely in their physical characteristics, operations, development and capital costs, and right-of-way. Likewise, there are few standards components in proposing and costing a new commuter rail line or system. This variation makes it difficult to use a relatively small sample of relevant existing systems to develop operating/maintenance and capital cost models for use by planners in predicting the costs of new systems. The methodology employed in developing commuter rail operating/maintenance and capital cost models is described below.

Commuter Rail Operations and Maintenance Costs

The initial approach for predicting commuter rail O&M costs employed the available data for 16 U.S. commuter rail systems in a relatively simple model which estimated dollar costs directly from certain system characteristics. This preliminary approach was taken because much of the desirable operating and physical characteristics data required for a more detailed modeling process, including worker counts by labor category, were not available for all systems. However, it was decided that the two step approach used in the light rail models, where labor requirements in four worker categories are computed first and then converted to O&M dollar costs, was preferable from the standpoint of the model's intended objective and use. Complete data for only 11 systems were available for this latter approach. Worker category relationships for the Boston MBTA system were an order of magnitude too small, indicating the presence of contracted operations and maintenance workers, necessitating the omission of this data, further limiting the data sample to ten observations.

The ten U.S. commuter rail properties used in developing the O&M cost models include rail lines in Baltimore, Boston, Fort Lauderdale/Miami, Hartford, New Jersey, Philadelphia, San Francisco, Washington D.C, four in Chicago, two in Los Angeles and two in New York (see the Commuter Rail Table 6 in the Commuter Rail Attachment for more specific line information).

Table 6, "Commuter Rail Operations & Maintenance Costs and Related Characteristics" summarizes the universe of data available and applicable for developing the commuter rail operating and maintenance cost models. As in the light rail case, an important criterion in the model development was that the input data or explanatory variables selected for the models be confined to information that a sketch planner would reasonably be expected to have for a proposed system in order to maximize the usefulness and application of the models. Using the data from Table 6 (including transformations of this data), linear regression models were proposed and tested for the number of vehicle operations workers, vehicle maintenance workers, way and structures workers, and administrative/existing capital workers.

Exhibit 2. Commuter Rail Operation and Maintenance Cost Model Equations

Number of Vehicle Operations Workers =	30.542	+	1.351	×	Annual Revenue Hours of Service (in 1,000s)
Number of Vehicle Maintenance Workers =			1.265	×	Number of Vehicles in Fleet
Number of Way & Structure Maint. Workers =	(-1.109	+	0.020	×	Number of Track Miles
			0.302	×	Annual Revenue Miles (in 1,000s) per Track Mile)^2
Number of Administrative & Capital Staff =			0.250	×	Total of Non-Adimistrative Workers Above
Summary Formula for Total Commuter Rail O&M Labor Requirements =	1.25 × {		30.542		
		+	1.351	×	Annual Revenue Hours of Service (in 1,000s)
		+	1.265	×	Number of Vehicles in Fleet
		+ (	-1.109		
		+	0.020	×	Number of Track Miles
		+	0.302	×	Annual Revenue Miles (in 1,000s) per Track Mile)^2
Summary Formula for Total Commuter Rail O&M Labor Costs =	**$60,000**	**×**	**Total Light Rail O&M Labor Requirements**		
Where $60,000 is the Average O&M Labor Cost per Worker (1993 Dollars)					
Summary Formula for Total Commuter Rail O&M (Labor & Non-Labor) Costs =	**$84,507**	**×**	**Total Light Rail O&M Labor Requirements**		
Where $84,507 = $60,000/0.71 is the Average Total O&M Cost per Worker					

In some cases, two different yet reasonable explanatory variable that were highly correlated could not both be used in a single model due to the problem of multicollinearity. This problem is particularly prevalent in such a small sample. Where multicollinearity problems arose, the choice of which variable to include was made from *a priori* expectations and/or cost theory. In a few cases of very similar variables, the one that provided the best fit in the regression model was used. Even where multicollinearity was not a problem, the degrees of freedom available with a ten observation sample prevented the development of model with more than one or two explanatory variables.

The equations for the number of workers by labor category resulting from the regression models are provided in Exhibit 2. More detailed information about the regression model results can be found at the end of the Commuter Rail Attachments.

The model for vehicle operations workers proved to be a straightforward linear relationship of the annual revenue hours of service, with an adjusted R-squared of 0.959. This explanatory variable captures the expected positive relationship between vehicle operation workers and total hours of service operation provided. Vehicle maintenance workers was determined to be a linear function of the fleet size, with an adjusted R-squared of 0.973. The equation was forced through the origin to avoid a negative intercept, and an outlier observation (New York Metro North) was dropped. As expected, the larger the fleet, the more maintenance workers required to maintain it.

For the number of workers engaged in maintenance of way and structures, two explanatory variables proved significant in model development — the number of track miles and the annual vehicle-miles per track mile. The logic for this is as follows; the more miles of track and the greater the intensity of use of the track, the more workers required to maintain it. However, larger systems did not necessary require exact proportional increases in way and structures maintenance workers. To correct for this observation and arrive at a reasonably good model fit, the square-root of the number of workers was used in the regression model, with an adjusted R-squared of 0.821.

None of the available data series proved to serve as reasonable explanatory variables for predicting the number of administrative and capital workers. In light of this finding, it was hypothesized that the administrative and capital worker requirement varied directly with the total number of operation and maintenance workers represented in the other three categories. As a result, the number of administrative workers was posed as a direct linear function of the total non-administrative workers in a regression model forced through the origin, where one administrative and capital worker is required for every four non-administrative workers. This hypothesized relationship was very consistent across the ten sample systems.

Using the four models described above, the total worker requirements for a proposed commuter rail line can be calculated. The resulting labor requirement can then be multiplied by an average labor cost per worker to arrive at total labor costs, or an average total O&M cost per worker to yield total operating and maintenance costs. Based upon the ten system sample, the average labor cost per worker, inclusive of benefits was calculated at $60,000 in 1993 dollars. With non-labor costs added in, the average total O&M cost per worker reaches $84,507. The limited sample size and wide variation in the commuter rail system characteristics did not warrant the more involved approach for arriving at non-labor costs used in the light rail transit case.

Commuter Rail Capital Costs

Unlike the all new construction and development cost associated with a planned light rail system, new commuter rail systems are generally developed largely on existing railroad rights-of-way and may share the facilities with other passenger or freight service based on a trackage agreement, operate exclusively on a facility purchased from a railroad and upgraded, or some combination of the two. The identification of a select set of projects for analysis and the subsequent development of unit cost is therefore less valid for commuter rail than it was for light rail as a result of the variables of track ownership introduced. The variables are compounded by the fact that much of the upgrade work resulting from a trackage agreement may be done by railroad work forces and disparate costs associated with railroad labor agreements result.

The analysis of the capital costs for the typical light rail transit system centered around a determination of the set of infrastructure physical characteristics. For the commuter rail capital costs, the focus is on upgrading the facilities of an existing railroad by a new system operator or for a new use. It is assumed that rough quantities for the horizontal and vertical alignment could be obtained from the railroad or an abbreviated field survey. If the quantities are unavailable, a typical unit cost for each project component was developed from the composite physical characteristic of a prototypical system 40 miles long with an average station spacing of 2.8 miles. The sources of data for the analysis included materials from the 1993 National Transit Data Base, materials from the agencies, an FTA report entitled "Characteristics of Urban Transportation Systems (DOT-T-93-07)" dated September 1992, and the records and files of Parsons Brinckerhoff.

The estimation of capital costs in project planning is usually based on the definition of alignment conditions such as horizontal and vertical profile, capital asset requirements and the unit cost measures of each asset category. The development of the study concentrated on unit capital cost that should be helpful in preparing capital cost estimates in other regions considering commuter rail transit.

Table 7, "Commuter Rail Conceptual Capital Cost Estimates by System Component" provides a range of tools for estimating capital cost. Use of the tools is dependent on the quantitative data available at the component and subcomponent level. The capital cost frame work is broken into eight components, supplemented by subcomponents, as follows:

- Trackwork
- Stations and Parking
- Centralized Train Control (CTC), Signals and Crossing Protection
- Site Improvements
- Maintenance and Storage Facility
- Right-of-Way
- Rolling Stock
- Agency Cost

A composite figure of $5.8 million 1993 dollars per route mile results for the development of a prototypical system. This unit cost can be used to estimate capital cost when only a rough route length is known. A more detailed capital cost estimate can be developed by applying the component or subcomponent unit cost to the quantities associated with a planned system. Following is a brief description of the system components:

TRACKWORK IMPROVEMENTS

The subcomponent listing is fairly self-explanatory.

STATIONS AND PARKING

This component of capital cost includes platforms, canopies, signage and graphics, fare collections, lighting, landscaping, bus drop-off and parking, access requirements and related cost impacts such as platform length, escalators/elevators, pedestrian access, disability access mode and weather coverage. These unit costs are based on 800'-0" platforms.

The parking cost includes adequate surface parking spaces to accommodate 80 percent of the average daily ridership at the stations outside of the CBD core. With an average station spacing of 2.8 miles and an average route length of 40 miles, the parking is concentrated at the stations outside a five mile radius from the CBD.

CTC, SIGNALS AND CROSSING PROTECTION

The subcomponent listing is self-explanatory.

SITE IMPROVEMENTS

The subcomponent listing is fairly self-explanatory.

MAINTENANCE AND STORAGE FACILITY

The maintenance and storage facility component includes the necessary facilities, service vehicles, and tools and equipment to maintain, store, dispatch and operate the commuter rail trains. The major shops include heavy repair, truck, wheel turning, machine, air conditioning, electronics, communications, locomotive brake testing, blow down and car wash/car clearing, and maintenance of way. The facility also includes the operators facility, ready room and dispatch, central control, and a revenue collection center and train storage yard.

RIGHT-OF-WAY

This capital cost category covers all property acquisition and property acquisition related cost such as appraisals and relocations. The unit cost for right-of-way is expressed in terms of cost per track mile and is based on a composite average from other systems. The cost excludes the cost of acquisition of the right-of-way from the railroad. This cost needs to be added to the total for right-of-way.

ROLLING STOCK

The subcomponent listing is self-explanatory.

AGENCY COST

This component includes the cost of the owners staff, owners representatives, and the general and administrative expenses of the owners. Included are the costs of administration, project management, all studies, engineering and design, construction and procurement management, design support, testing and start-up, insurance, financing fees, and other miscellaneous expenses.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation