

HOW MUCH DOES A TRANSIT TRIP COST?

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by

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ABSTRACT

How much does a transit trip cost? How does the subsidy a transit trip vary from trip-to-trip, passenger-to-passenger, and system-to-system? How does the subsidy of public transit patrons vary among various classes of transit users? These are important matters of public policy that have received surprisingly little attention in the research literature in recent years.

The cost of producing public transit service is not uniform, but varies by trip type (such as local or express), trip length, time of travel, and direction of travel, among other factors. Yet the models employed by public transit operators to estimate costs typically do not account for this variation. The exclusion of cost variability in most transit cost allocation models has long been noted in the literature, particularly with respect to time-of-day variations in costs.

This analysis addresses many of the limitations of cost allocation models typically used in practice by developing a set of models that account for marginal variations in vehicle passenger capacity, capital costs, and time-of-day costs using FY 1994 capital and operating data for the Los Angeles MTA. This analysis is unique in that it combines a number of previously and separately proposed improvements to cost allocation models. In comparison to the model currently used by the MTA, we find that the models developed for this analysis estimate: higher peak costs and off-peak costs, significant cost variation by mode, and lower costs for incremental additions in service. The focus of this study is on the limitations of the rudimentary cost allocation models employed by most transit operators, and not on the MTA *per se*. This analysis finds that an array of factors addressed separately in the literature can be simultaneously and

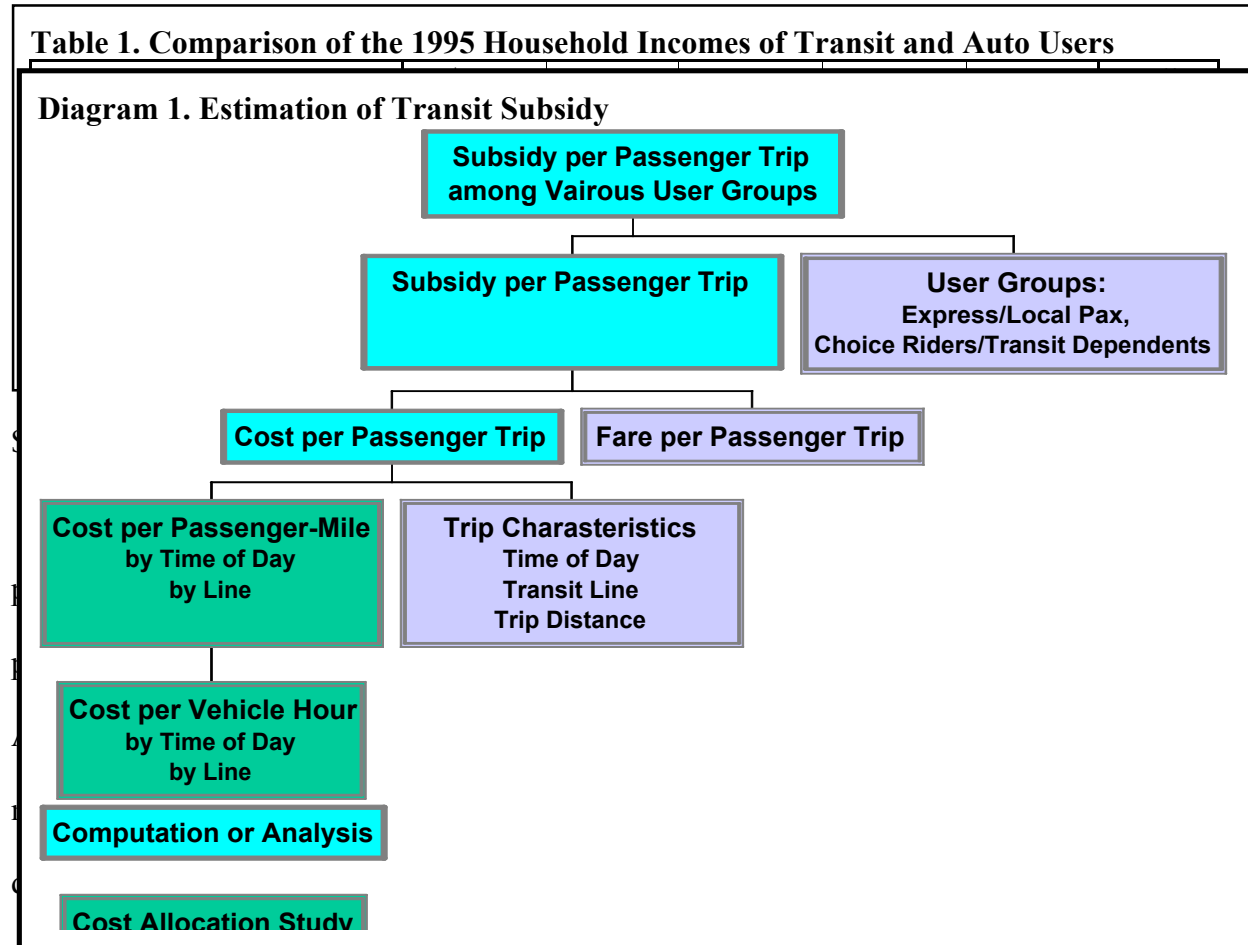
practically incorporated into a usable cost allocation model to provide transit systems with far better information on the highly variable costs of producing service.

THE DEMOGRAPHICS OF TRANSIT SUBSIDIES

At the dawn of the last century, public transit was a centerpiece of urban life. Streetcars in particular were the backbone of nearly every urban transportation system in the U.S., shuttling workers and shoppers between burgeoning central business districts and sprawling streetcar suburbs. In 1902, U.S. street railways were operating over 60,000 vehicles on nearly 17,000 miles of track (Jones, 1985). Transit ridership data from this era are fragmentary, but in 1927 Americans averaged 145 annual transit rides per capita.¹ A hundred years later public transit systems still carry large numbers of urban travelers in absolute terms, but *role* of public transit in U.S. cities has changed dramatically. While there were over 8.1 billion U.S. public transit trips in 1998, annual per capita ridership had declined to 30.² This decline in transit usage, of course, has been more than compensated by an explosion in private vehicle travel; in 1995, passenger-miles of travel in private vehicles outpaced public transit by a ratio of greater than 70 to 1 (Bureau of Transportation Statistics, 1997).

Despite a significant efforts by planners and others to improve public transit in an effort to increase ridership and reduce the congestion and air pollution associated with widespread automobile use, the demographics of public transit nationwide have continued to shift from so-called “choice” riders to those — who because of age, income, or disability — depend on public transit. Table 1 shows that, in 1995, the patrons of public transit were far more likely than automobile users to reside in low-income households; over half of transit passengers and over

two-thirds of all bus and light rail riders resided in households with 1995 incomes below



subsidies among the users of public transit. This paper reports on the progress of our research

examining these questions.

The cost of carrying a passenger on public transit that is not covered by the fare paid or related income, is the subsidy of that passenger. But while this is straightforward, even obvious, conceptually, actually calculating the subsidy of an individual trip is by no means a simple proposition. Diagram 1 summarizes the steps involved in estimating the subsidies of various classes of transit users, and shows that two kinds of information are required. First, one must

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carefully allocate the costs of transit services to some measure of service provided (shown in green in the figure). And, second, one must connect these costs to detailed information on the consumption of transit services by individual riders (shown in lavender). From these two sets of information, calculations can then be made regarding the cost and subsidy of individual trips. Finally, these calculations can then be aggregated in various ways to compare the subsidies of various classes of users, such as commuter rail versus bus passenger, low income versus high-income riders, or African-American versus white riders (shown in aqua).

This paper reports primarily on our work — using the Los Angeles Metropolitan Transportation Authority as a case study — to fully and accurately estimate the costs of service provision. It concludes with some discussion of our research-in-progress on the demographics of transit trip making in Los Angeles, and speculates on the findings and implications of the work completed to date.

MEASURING TRANSIT COSTS

Many transportation managers in the private sector might be surprised to learn that their public sector counterparts often have very limited information on the costs of providing public transit service. Airlines and private shipping companies often develop highly sophisticated models to estimate how the cost of carrying passengers or freight varies by season, day-of-the-week, time-of-day, direction, and mode. By contrast, public transit managers often have only rudimentary information linking budgetary inputs to service outputs. One might argue that, as publically subsidized services, transit systems need not be as concerned with such fine-grained cost-estimation detail as profit-driven private businesses. But the broad social policy objectives of public transit do not obviate the need for good cost information to guide managers, transit

policy boards, and funding agencies. For example, most policy boards adopt fare structures without a clear understanding of how the cost of service varies from passenger to passenger or trip to trip. Similarly, in making decisions on adding or deleting peak period or off-peak service, transit managers and boards may often have limited or incomplete information regarding the cost or savings from such changes.

Quite obviously, trips on public transit are not uniform; among other factors, they vary by trip type, trip length, time of travel, and direction of travel. Likewise, the services deployed by transit operators to serve these trips -- paratransit vans, buses, rail operating as demand response, local, or express service -- varies significantly. The cost of operating these modes and services obviously varies, sometimes dramatically. Yet the techniques employed by most public transit operators to estimate these costs do not account for this variability, nor are they structured to distinguish the estimation of overall costs from those at the margin.

A number of scholars over the years have raised concerns over the limitations of transit cost estimation techniques used in practice. These techniques use a variety of methods to relate the production of transit service to costs. The most common approach uses models that allocate budgetary line items to various measures of service output, and most moderately-sized and large transit systems use cost allocation models of one form or another (Carter et al., 1984). Such models can, for example, aid managing in tracking cost-efficiency over time or in estimating the costs or savings of changes in service (Levinson and Conrad, 1979). In a more limited fashion, the models are used by policy makers and funding agencies to inform choices over the deployment of services and allocation of funding (Peskin, 1982). A number of researchers over the years have suggested modifications to improve the models to account for the variability of

transit costs, particularly with respect to time-of-day differences in costs, yet transit operators have generally been slow to adopt such improvements into practice (Cohen et al., 1988).

Our research has sought to address this gap between research on transit cost allocation models and their application in practice, by developing a set of related models that account for marginal variations in capital costs, vehicle capacity, and time-of-day costs using capital and operating data from the Los Angeles Metropolitan Transportation Authority (MTA). This analysis is unique in that it combines a number of previously and separately suggested modifications to cost allocation models.

We compare the results of the models developed for this analysis with the current MTA model, which is typical of those used by U.S. transit operators. In this comparison, we separately estimate the total systemwide costs of bus and rail. We then compare the estimated variations in costs among individual bus lines. Finally, we compare the estimated costs of incremental additions of bus service on a sample of five lines. These comparisons clearly reveal substantial deviations in estimated modal and time-of-day costs between the models developed for this analysis and the standard MTA model. This analysis also shows that models developed here to account for variations in capital costs, vehicle passenger capacity, and time-of-day costs can be practically implemented using data normally available to transit operators to produce a more fine grained analysis to better inform decision making.

COST ALLOCATION MODELS

Transit cost allocation models are based on the concept that the cost of supplying service is a function of the service produced, measured in terms of vehicle-hours or seat-miles of service. Transit costs include both operating costs and capital costs, though most cost allocation

models only include operating costs. These costs can be differentiated into variable, semi-fixed, and fixed costs (Levinson and Conrad, 1979; Arthur Anderson & Co., 1974; Taylor, 1975; Kemp et al., 1981):

X **variable costs** - costs directly linked with vehicle operations such as driver wages and fringe benefits, and non-driver variable costs such as fuel and vehicle maintenance;

X **semi-fixed costs** - costs not directly linked to service changes but influenced by the level or pattern of service such as rolling stock, revenue collection, and marketing;

X **fixed costs** - costs insensitive to marginal changes in service levels such as shop building maintenance, administrative costs, buildings and equipment, and other long-term fixed costs.

Vehicle hours and vehicle miles are two of the most common outputs used to measure unit costs. Most models use some combination of vehicle hours of operation and vehicle miles to account for costs such as labor, fuel, tires, and maintenance costs. For example, labor costs such as driver wages and fringe benefits, which constitute a large portion of operating costs, are typically assigned to vehicle hours. Costs of fuel, maintenance, and repairs are usually assigned to vehicle miles of operation. In addition, the peak number of vehicles in service may be included in the model to account for overhead items such as administrative expenses, plant maintenance, and storage costs that generally do not vary either by vehicle hours or vehicle miles but are assumed to be more closely related to fleet size (Cervero, 1982). Additional variables

such as the number of revenue passengers or peak-period vehicle “pull-outs” (vehicles leaving the yard to begin revenue service) can also be added to the model (Cervero, 1982; Talley, 1988).

Combining the classification of direct operation, direct overhead, and indirect overhead costs with the variables typically used in cost allocation models produces a total of nine potential combinations as shown in Figure 1. Some combinations, such as peak vehicles/variable costs, will not typically have any expense items assigned to them, while others such as vehicle hours/fixed overhead costs may or may not depending on the particular costs estimated by the model.

Figure 1. Relationships between Cost Inputs and Service Outputs			
	Variable Costs	Semi-fixed Costs	Fixed Costs
Vehicle hours	Strong	Strong	Moderate
Vehicle miles	Strong	Moderate	Weak
Peak vehicles	Weak	Strong	Strong
Source: Adapted from Taylor (1975)			

To calibrate a model, system-wide expenses are estimated and assigned to one or more of the specified outputs that are considered most closely related to those costs. After each individual expense item is assigned, a coefficient representing the unit cost rate for each variable unit of service output is determined by summing the expenses in each category and dividing by the respective level of service output. To determine the cost of a service change, these cost rates are simply multiplied by the expected net change in each respective output quantity and then summed. The method is easy to understand and can be calibrated and applied using data

normally collected by transit operators. The basic function can be expressed as follows (Lem et al., 1994):

$$C = \sum_{i=1}^n U_i * X_i \quad \text{equation (1)}$$

C	:estimated costs
i	:a particular measurable service characteristic which represents the scale of operations
n	:number of service characteristics included in the model
U_i	:unit cost of characteristic i
X_i	:quantity or value of characteristic i in the analysis

There are two forms these models commonly take. *Partially* allocated models generally include only variable costs and some semi-fixed costs, and are used to estimate the costs of marginal or incremental service changes (Carter et al. 1984; Li, 1997). *Fully* allocated models include variable and most or all fixed costs (though in practice they commonly exclude capital costs), and are mainly used to compare performance between modes or systems. The sum of the individual route costs produced by a *fully* allocated model thus equals the total system cost (Cherwony et al., 1981). The test of a good model — either *partially* allocated or *fully* allocated — is that it accurately links changes in service to changes in cost.

Unfortunately, the cost allocation models used in practice are often a hybrid of partially and fully allocated models. By including some semi-fixed and fixed costs such models tend to overestimate the costs or savings associated with small changes in service (Kemp et al., 1981; Talley, 1988; Stopher et al., 1987; New York City Transit Authority, 1988). On the other hand, by excluding most capital costs (land, vehicles, buildings, etc.) they significantly underestimate the full cost of transit service (since, in the long-run, all expense items can be considered variable and are appropriately included in the model). A robust cost allocation model thus segregates

expenses into variable, semi-fixed, and fixed costs, and considers only those costs that in fact vary with service outputs over the scope and scale of the analysis. Cherwony (1981) has termed this dynamic approach to cost allocation modeling *fixed-variable analysis*.

Exclusion of Capital Costs from Fixed Cost Calculations

The cost allocation models used in practice typically do not account for the cost of capital (vehicles, equipment, etc.). A few previous studies have noted this omission and have included capital costs to compare productivity between different bus systems (Cervero, 1980) or between different modes (Li, 1997). One explanation for the exclusion of capital expenses in most cost allocation models is that transit operations in the U.S. are usually funded primarily through farebox revenues and local subsidies, while capital costs are more often funded by state and, especially, federal subsidies which are more likely to be considered “off-budget” by transit operators. From the perspective of the taxpayer, of course, such distinctions are not especially meaningful. Given the current policy emphasis on multimodal transit service, including capital costs is especially important, because the combination of capital and operating costs can vary substantially across alternative modes. In addition, the omission of capital costs can also be a problem in comparing the costs of publically operated and privately contracted transit services (Chomitz et al., 1985).

Modal Variations in Passenger Capacity

In comparing system performance between different modes, operators do not normally consider differences in vehicle passenger capacity among various transit modes (Li, 1997). In other words, a vehicle hour of transit service is not directly comparable between

paratransit, bus, and rail. Failure to account for vehicle capacity can bias modal comparisons against higher vehicle capacity modes like rail.

The Problem of Peaking

As early as the 1920s, the growth of automobile ownership and usage began to erode the use of transit for off-peak travel. Today, the automobile dominates metropolitan travel and transit plays a subordinate role in all but the centers of the oldest, largest American cities. In particular, transit agencies have lost most weekend, evening, and counter-direction traffic resulting in an increasing temporal and directional concentration of transit demand (Jones, 1985; Wachs, 1989). Studies have clearly shown that it costs significantly more per unit of output to provide service in the peak periods than in the off-peak (Kemp et al., 1981; Cervero, 1982; Cherwony and Mundle, 1978; Charles River Associates Incorporated, 1989; Parody et al., 1990). In practice, however, transit policy board members rarely consider the costs of peaking on transit service.

Public transit is a highly labor-intensive industry. Costs related to labor represent the largest proportion of operating costs. The cost of labor, though, can vary significantly throughout the day. Labor contracts often limit or prohibit part-time labor and limit split- and spread-time shifts resulting in underutilization of the workforce and thereby lowering labor efficiency (Jones, 1985; Wachs, 1989; Pickrell, 1986). Although many of these excess wage expenditures occur during off-peak periods, a reasonable argument can be made for attributing them to the peak since they would not be incurred but for peak service levels (Cervero, 1980).

Moreover, during peak periods many vehicles carry passengers predominately or exclusively in one direction resulting in less efficient utilization of equipment. High peak hour

service demands increase fleet costs associated with purchasing and maintaining additional vehicles needed only for peak service (Pickrell, 1986; Tomazinis and Takyi, 1989). In addition, peak period-only service runs proportionally increase the costs of “deadheading” vehicles to and from storage yards. Since fixed costs are generally scaled to peak level service, average unit cost models that are temporally insensitive may not capture actual cost differences where different routes have similar peak vehicle requirements but different off-peak requirements (Savage, 1988).

A survey of thirty transit agencies conducted by Cohen *et al.* (Cohen et al., 1988) found that none used cost allocation models that distinguished between the cost of providing service by time of day or day of week. The survey also revealed that transit officials recognize deficiencies in their cost allocation procedures but that operators continue to use simple cost estimation methods even though more sophisticated techniques are available.

Other Limitations

Regardless of the number of added refinements, however, there are limitations inherent to all cost allocation models. For example, there is little agreement in the literature on which output measures best reflect changes in cost (Li, 1997; Stopher et al., 1987; Biemiller and Munro, 1981). Some cost items may be related to more than one measure (Kemp et al., 1981). The various output measures used, such as vehicle hours and vehicle miles, are not independent but in fact highly correlated (Kemp et al., 1981; Talley, 1988). Finally, since these models are usually based on systemwide costs, they do not fully account for cost variations on individual routes (Cervero, 1982).

DEVELOPMENT OF COMPREHENSIVE COST ALLOCATION MODEL

This study uses data collected by the Los Angeles Metropolitan Transportation Authority (MTA) for the 1994 fiscal year. Contrary to the popular perception of Los Angeles as the most automobile dominated metropolitan area in the U.S., the MTA is the fourth largest public transit system and second largest bus operator in the country in terms of unlinked passenger trips, operating 131 bus and three rail lines serving 391 million passengers annually. While the Los Angeles MTA cost allocation model has been modified and improved over the years, it is typical of most such models used in practice in that it does not account for variations by in capital costs, vehicle passenger capacity, or time of day. The MTA model relates operating costs to vehicle hours, vehicle miles, peak vehicles, and the number of passenger boardings as shown below (Lem et al., 1994).

$$OC_j = (U_{VH} * VH_j + U_{VM} * VM_j + U_{PV} * PV_j + U_{TP} * TP_j) * (1 + F) \quad \text{equation (2)}$$

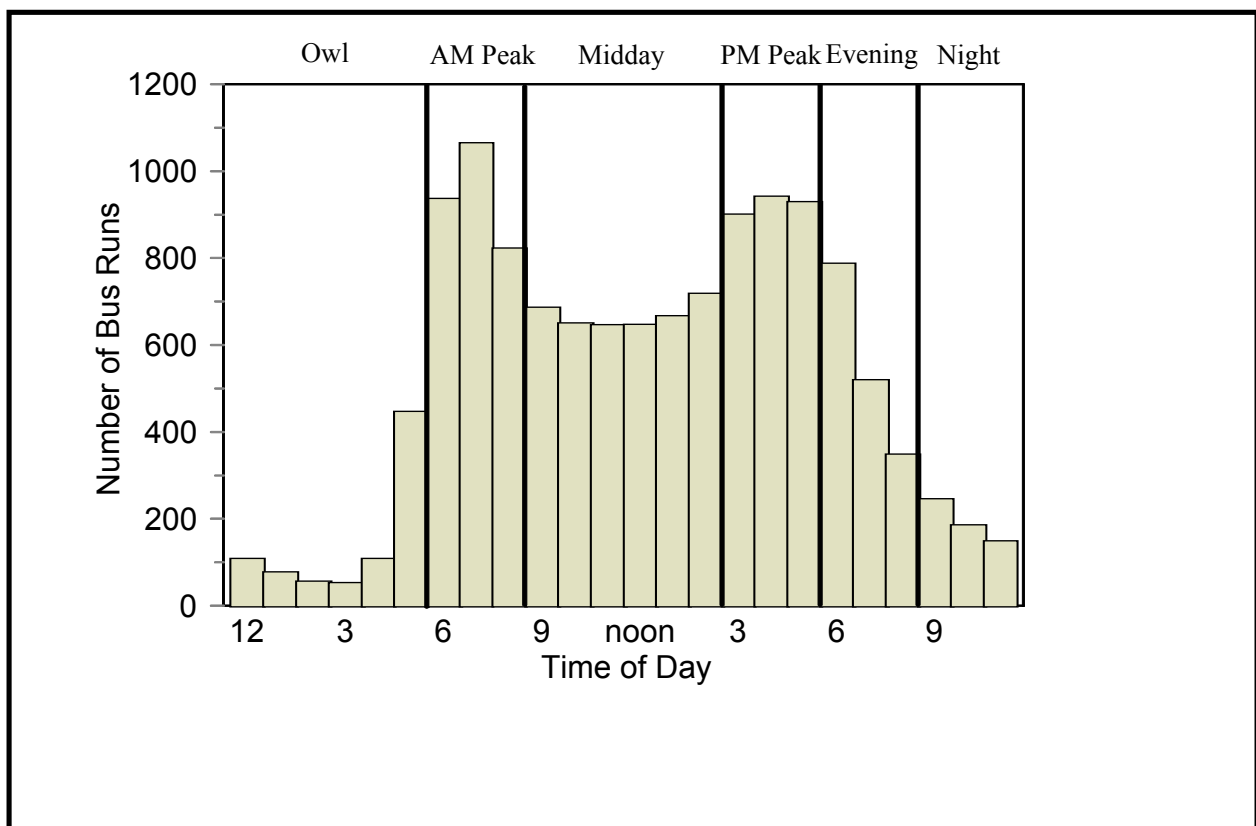
<i>OC</i>	:estimated operating costs
<i>j</i>	:unit of analysis in question — system, line, etc.
<i>U</i>	:unit cost per service output
<i>VH</i>	:scheduled vehicle hours
<i>VM</i>	:scheduled vehicle miles
<i>PV</i>	:PM peak vehicles
<i>TP</i>	:total passengers
<i>F</i>	:fixed overhead cost factor

This model allocates costs for labor to scheduled vehicle hours; fuel, maintenance, and repair equipment to scheduled vehicle miles; fixed non-maintenance labor and administration costs to peak vehicles; and overhead costs, such as customer service and ticket sales, to passenger boardings. The model also includes a constant multiplier to allocate indirect expenditures such as data collection, planning, and management to each line based on their share of overall operating costs. The formula is calibrated for each fiscal year based on total annual operating costs.

Accounting for the Variability of Service and Costs

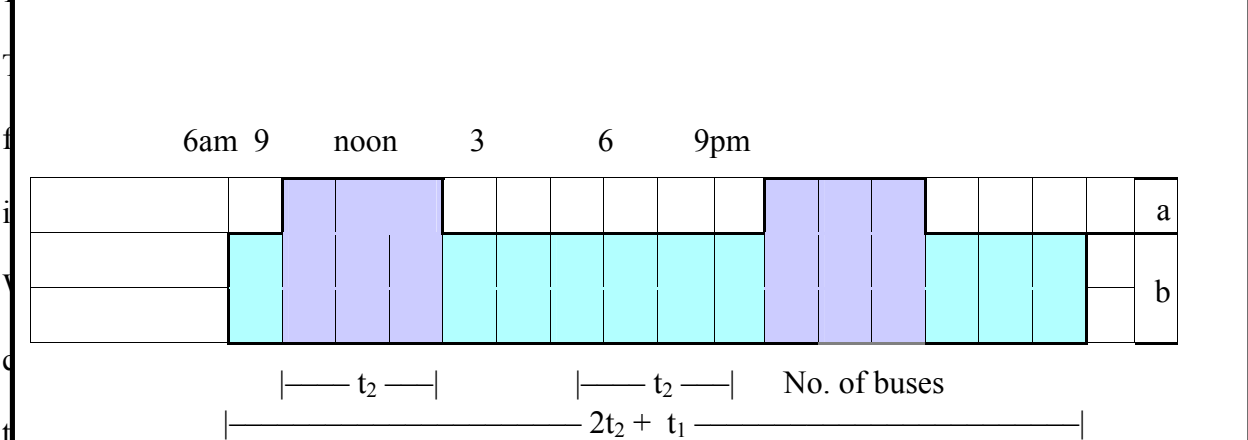
Several studies have proposed modifications to account for the effects of peaking.

These temporal variation models typically provide separate cost estimates for two periods, the peak period and the off-peak or base period. Most suggested approaches to allocating variable costs apply different unit cost factors to the peak and off-peak periods. Studies of semi-fixed operating and capital cost allocation generally allocate a higher percentage (or all) of these costs to the peaks. In this study, we combine both operating and capital costs and disaggregate service into multiple time periods to better reflect the changes in transit demand and service throughout



the day.

Figure 1. Time of Day Variation in Service Levels: Los Angeles MTA



Base operations require a total of “b” buses to be in revenue service throughout the service day ($2t_2+t_1$). During the AM Peak (7-9am) and the PM Peak periods (4-6pm) an additional “a” buses are needed to meet the extra demand. The vehicle hour-related costs of the Peak (C_P) and Base (C_B) service are given by:

$$C_P = 2t_2(a + b) * U \quad \text{equation (3)}$$

$$C_B = t_1b * U \quad \text{equation (4)}$$

U :unit cost of service output

The ratio of peak costs to base costs (S) is given by:

$$S = \frac{C_P}{C_B} = \frac{2t_2(a + b)}{t_1b} \quad \text{equation (5)}$$

Source: Adapted from Cervero (1980).

Figure 2. Average Cost Approach to Allocating Costs by Service Levels.

Adjustment of Operating Costs Associated with Vehicle Hours

A review of the literature suggests that the unit costs of service should be adjusted to reflect variations in labor productivity and vehicle usage throughout the day. Three methods have been proposed by others to allocate variable costs by time of day. The *Statistical Approach* regresses operating cost data from different run types at different times of day to estimate peak and off-peak costs (McClenahan et al., 1978). A second, *Resource-Based Approach*, modifies output quantity estimates by time of day and day of week based on changes in the number of pay hours and vehicles required by various service runs (Cherwony et al., 1981). A third, *Cost Adjustment Approach*, and the one applied here, calculates separate coefficients for costs associated with different service outputs for each time period. In allocating costs to the different time periods, we distinguish between costs that vary by service level at different times of day and those costs that are generally invariant with respect to time.

Accounting for Labor Utilization

To account for time-of-day differences in labor utilization, we multiply the vehicle hours factor by a labor utilization factor derived for each period representing the relative share of the ratio of pay hours to scheduled vehicle hours. The basic form of the model is given by Yu

(1986):

$$LUF_i = \left(\frac{PH_i}{VH_i} \right) \frac{\sum_j VH_j}{\sum_j PH_j} \quad \text{equation}$$

(6)

LUF_i : Labor Utilization Factor for period i

PH_i :pay hours for period i
 VH_i :vehicle hours for period i

Cherwony and Mundle (1978, 1980) developed a *Peak-Base Model* based on this approach to compute separate vehicle hour unit cost estimates for the peak and base periods. Vehicle hour coefficients are adjusted to account for the relatively higher proportion of pay hours during peak operations based on the relative productivity of labor (n), which is a ratio of pay hours to vehicle hours in the peak and off-peak, and the service index (s), which compares vehicle hours by time of day (Equations (7) and (8) can be derived directly from equation (6)):

$$U_{PVH} = LUF_P * U_{VH} = \frac{n(1+s)}{(1+ns)} * U_{VH} \quad \text{equation (7)}$$

$$U_{BVH} = LUF_B * U_{VH} = \frac{(1+s)}{(1+ns)} * U_{VH} \quad \text{equation (8)}$$

where $0 < LUF_B < 1 < LUF_P$

U_{PVH} :vehicle hour unit cost estimate for the peak
 U_{BVH} :vehicle hour unit cost estimate for the base
 n :relative labor productivity ($= (PH_P / VH_P) / (PH_B / VH_B)$)
 s :vehicle hour coefficient ($= (VH_P / VH_B)$)
 $PH_{P \text{ or } B}$:pay hours for peak or base period
 $VH_{P \text{ or } B}$:vehicle hours for peak or base period

Studies by Kemp (Kemp et al., 1981), Cervero (1980, 1982), Charles River Associates (1989), and Parody *et al.* (1990) used this method to modify vehicle hour unit costs between the base and peak periods. Charles River Associates and Parody *et al.* used a constant value, 1.20, as an estimate of relative labor productivity for bus systems based on a survey of prior studies (the sample values ranged from 1.09 to 1.337). Cervero also apportioned operating expenses between peak and off-peak time periods based on a sample of individual bus lines for the precursor agency of the Los Angeles MTA. Pay hours were assigned to the base or the peak

using “attribution rules” developed with agency staff based upon a determination whether the pay hours were “caused” by demands in the peak or in the base or both. These time period adjustments resulted in a 30.2 percent difference in relative labor productivity (n) and a 28.3 percent difference in vehicle hour coefficients (s) between the peak and base period for the system (there were 39.3 % more pay hours than vehicle hours in the peak and 7 % more in the base) (Cervero, 1980). Since labor costs account for more than half of total operating costs, these differences in vehicle hour unit costs are not trivial. Given variations in available operating data from system to system, a number of other methods to account for time-of-day differences in labor utilization have been proposed over the years (Cohen et al., 1988; Levinson, 1978; Reilly, 1977).

Using a method similar to the *Peak-Base Model* discussed above, we adjusted the vehicle hour coefficients in the MTA model to reflect the variation in peak and off-peak labor costs. Data were not available on the ratio of pay hours to vehicle hours by time of day for the study period, so we used Cervero’s (1980) average labor productivity factor and data on the peak to base ratio of vehicle hours for each bus line (s) to calculate *peak* and *off-peak* (*base plus shoulder*) unit costs for each line using equations (6) and (7). For the *off-peak* we used the sum of vehicle hours in the Midday, Evening, Night, and Owl periods, and for the *peak* period we used vehicle hours in the AM and PM Peak periods.

Accounting for Vehicle Utilization

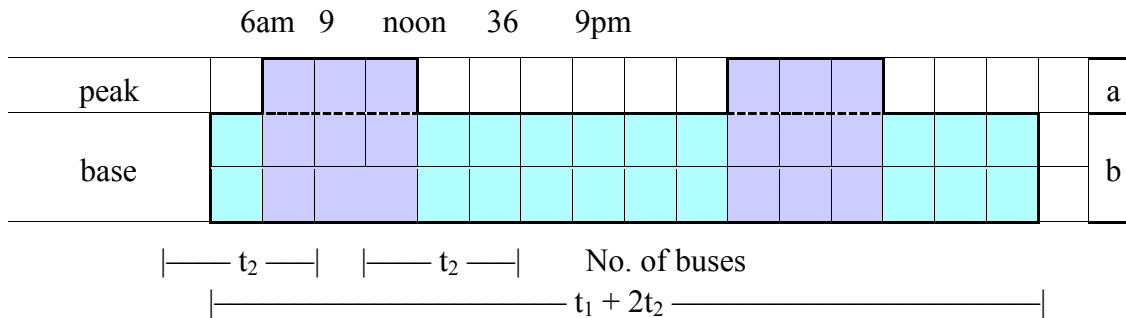
Nearly all transit vehicles “deadhead” to and from storage facilities or maintenance yards at the start and conclusion of revenue service. For vehicles operated in peak period only service, the ratio of out-of-service vehicles miles to in-service vehicle miles is greater than for vehicles in

revenue service for longer periods. In other words, vehicle utilization is in general lower during peak periods than during off-peak periods. To account for this time-of-day variation in vehicle utilization, we allocated costs on the basis of total (or “scheduled”) vehicle miles, but used in-service vehicle miles and hours to develop our unit cost measures. Doing so, in effect, applied a vehicle utilization factor comparable to the labor utilization factor described above.

Including Fixed and Semi-Fixed Costs

For fixed costs that do not vary by unit of service output, a different method is needed to allocate costs to each time period. Charles River Associates (1989) and Parody *et al.* (1990) reviewed studies that examined capital cost allocation to the peak and off-peak periods, classifying the prior studies into two groups: (1) those where all capital costs were assigned to the peak on the assumption that these resources would not be needed but for the peak period demand (Taylor, 1975; Cherwony and Mundle, 1978; Reilly, 1977; Meyer et al., 1965; Mohring, 1972), and (2) those where capital costs were apportioned by the relative usage between the peak and the off-peak on the assumption that operators would supply some level of service even without peak service (Cervero, 1982; Cervero, 1980; Charles River Associates, 1989; Levinson, 1978; Boyd et al., 1973; Savage, 1989; Lee, 1986; Kerin, 1989). Acknowledging this split in the literature, Charles River Associates (1986) used a peak to off-peak factor of 85 percent for subway and commuter rail capital expenses and 80 percent for bus capital expenses. Similarly, Cervero (1980) used a ratio of 85/15 between the peak and base respectively, to attribute some of the depreciation of buses to off-peak usage, and allocated non-capital overhead costs as described in Figure 4.

Service layer



The cost assigned to the base period (C_1) is given by the formula:

$$C_1 = (t_1 + 2t_2)b * U_B \quad \text{equation (9)}$$

U_B, U_P :unit cost of service output in the base and peak periods

The costs of the additional peak service (C_2) is then given by the formula:

$$C_2 = 2t_2 a * U_P \quad \text{equation (10)}$$

The costs incurred during the Peak period ($2t_2$) is given by the full cost of the extra peak service plus the share of the base service that is pro-rated to the Peak period:

$$C_P = \frac{2t_2}{2t_2 + t_1} C_1 + C_2 \quad \text{equation (11)}$$

Source: Adapted from Levinson (1978) and Cervero (1980)

Figure 3. Marginal Cost Approach to Allocating Costs by Service Levels

In a more refined application of the principles shown in Figure 4, the Bradford Bus Study allocated overhead costs, including vehicle facility costs, non-maintenance and administrative labor costs, and other overhead costs, according to the number of vehicles in service for the whole system during each time period. This method assumes that all buses in service during the period with the smallest number of in-service vehicles will be utilized in any other periods that have higher vehicle requirements. Based on the number of incremental vehicles and vehicle operating hours, the fixed costs to provide service over the whole system can be calculated for each period. These costs can then be further disaggregated to individual lines (within each time period) by the relative number of buses for each line (Savage, 1989).

In this study, we used the Bradford Bus Study method to allocate fixed operating, vehicle capital, and non-vehicle capital costs to individual lines by time period. For the allocation of vehicle capital costs, Figure 5 shows a representation of the number of buses in service during each service period during a typical weekday, and the apportionment of the total vehicle capital costs for the whole system to each time period for each service “layer.” The total number of buses required for each period is indicated in the column at the left. Owl service (12 midnight-6am) requires 58 buses, Night service (9pm-midnight) an additional 207 buses, Evening service (6-9pm) another 638 buses, and so on. Buses in the first service “layer” (I) are assumed here to run for 24 hours a day. Thus, if a line has Owl service, those buses are assumed to be available for use the rest of the day, and therefore the capital costs of those vehicles are spread over all time periods. The share of capital costs needed to provide one hour of service for the whole system in this layer can be obtained by dividing the daily capital cost of a bus (\$94.14) times the number of required buses, 58, divided by 24 hours. Capital costs were annualized using

generally accepted accounting principles; space limitations do not permit a full description of these calculations, though the details are available from the authors. Similarly, buses added for use in the *shoulder* period are also available for service during the *peak* and their capital costs are spread over the *shoulder* and *peak* periods. Buses assigned exclusively to the highest peak period (AM Peak) run for only 3 hours. The capital cost for one hour of service exclusively during the AM Peak period equals the daily capital cost of one bus times the number of buses in the top service layer (VI), 6, divided by 3 hours of service. These hourly figures were multiplied the number of hours in each service period to obtain the values shown in Figure 5. Costs for each service period are the sum of the figures in each of the columns. Similar assignments were made for the operating overhead costs assigned to peak vehicles (to account for the fact that some of these costs properly should be attributed to weekend service, we adjusted the weekday totals by a factor representing the relative shares of weekday and weekend service for each period). These values were then distributed to each individual line in proportion to the number of required vehicles on each line during that time period.

In contrast to the semi-fixed character of vehicle capital and operating overhead costs, however, non-vehicle capital costs are likely unrelated to the peakedness of transit service. Assigning such costs using the Bradford method would thus inappropriately increase costs assigned to the peak period. We chose, therefore, to simply allocate non-vehicle capital costs to each time period based on the proportion of total in-service vehicle hours in each time period.

Service layer / # Buses	3am	6	9	noon	3pm	6	9
	\$565						
	\$31,207				\$31,207		
	\$3,954		\$7,908		\$3,954		
	\$12,012		\$24,024		\$12,012	\$12,012	
	\$3,248		\$6,496		\$3,248	\$3,248	\$3,248
\$1,365	\$682		\$1,365		\$682	\$682	\$682
	Owl	AM Peak		Midday	PM Peak	Evening	Night
Total Cost/Day	\$1,365		\$51,668	\$39,792	\$51,103	\$15,942	\$3,930

Figure 4. Marginal Cost Approach to Allocating Vehicle Capital Costs: Los Angeles MTA

Allocation of LRT Operating and Vehicle Capital Costs

Operating and capital costs of the MTA’s light rail service were allocated in a similar fashion to that for bus service as described above. Due to data limitations, however, costs were allocated to each period using a three variable cost allocation model (vehicle hours, vehicle miles, and peak vehicles) instead of the four variable model used for buses. In addition, data limitations also prevented the application of a labor utilization factor to peak-period LRT costs.

Resulting Models

Using the modifications described in the preceding sections, we developed three variants of comprehensive cost allocation model – a *Fully-Allocated Model*, and two *Partially-Allocated Models*, as defined below:

1. *Fully-Allocated Model*

$$\begin{aligned} FAC_{ij} &= OC_{ij} + CC_{ij} \\ &= (LUF_{ij} * U_{VH} * VH_{ij} + U_{VM} * VM_{ij} + PVC_{ij} + U_{TP} * TP_{ij}) * (1 + F) \\ &\quad + VCC_{ij} + OCC * (IVH_{ij} / IVH_{day,system}) \end{aligned} \quad \text{equation (12)}$$

($LUF_{ij} = 1, F = U_{TP} = 0$ for LRT)

2. *Partially-Allocated Model I*

$$\begin{aligned} PAC_{ij} &= OC_{ij} + VCC_{ij} \\ &= (LUF_{ij} * U_{VH} * VH_{ij} + U_{VM} * VM_{ij} + PVC_{ij} + U_{TP} * TP_{ij}) * (1 + F) \\ &\quad + VCC_{ij} \end{aligned} \quad \text{equation (13)}$$

3. *Partially-Allocated Model II*

$$\begin{aligned} PAC_{ij} &= OC_{ij} + VCC_{ij} \\ &= (LUF_{ij} * U_{VH} * VH_{ij} + U_{VM} * VM_{ij}) + VCC_{ij} \end{aligned} \quad \text{equation (14)}$$

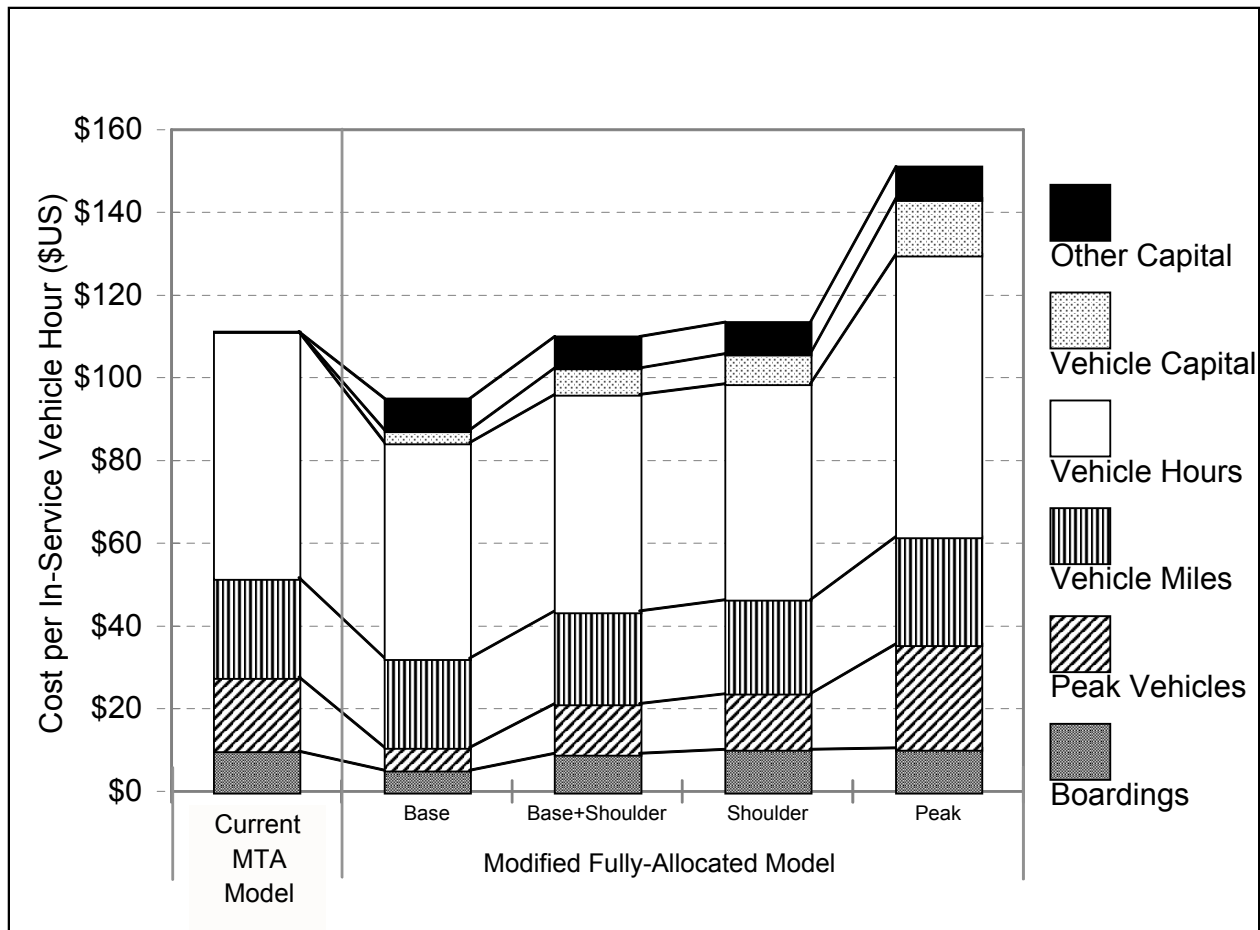
FAC :costs estimated by the fully-allocated model
PAC :costs estimated by the partially-allocated model
i :time of day (base, shoulder, and peak) or daily
j :unit of analysis in question — system, line, etc.
CC :estimated capital costs — vehicles, buildings, equipment, land, etc.
PVC :peak vehicle cost estimated by the modified model
VCC :vehicle capital costs
OCC :other capital costs
IVH :in-service vehicle hours
OC :estimated operating costs
U :unit cost per service output
VH :scheduled vehicle hours
VM :scheduled vehicle miles
PV :PM peak vehicles
TP :total passengers
F :fixed overhead cost factor

Findings

After developing a new cost allocation model to account for variations in capital costs, vehicle passenger capacity, and time-of-day costs, we then used operating data compiled by the Los Angeles MTA to compare these three variations of this new model with the model currently used by the MTA. The *Fully-Allocated Model* was used to examine systemwide costs and to compare costs between the bus and light rail (LRT) modes. The *Partially-Allocated Models I* and *II* were used to compare costs between bus lines within the MTA system and to estimate the cost of small service increases on five sample lines. The results of these comparisons reveal significant time-of-day variations in costs and even greater differences in costs between modes, neither of which is captured in the model currently used by the MTA, nor by similar cost allocation models used by most other public transit systems.

Comparison of the *Fully-Allocated Model* with a Typical Cost Allocation Model

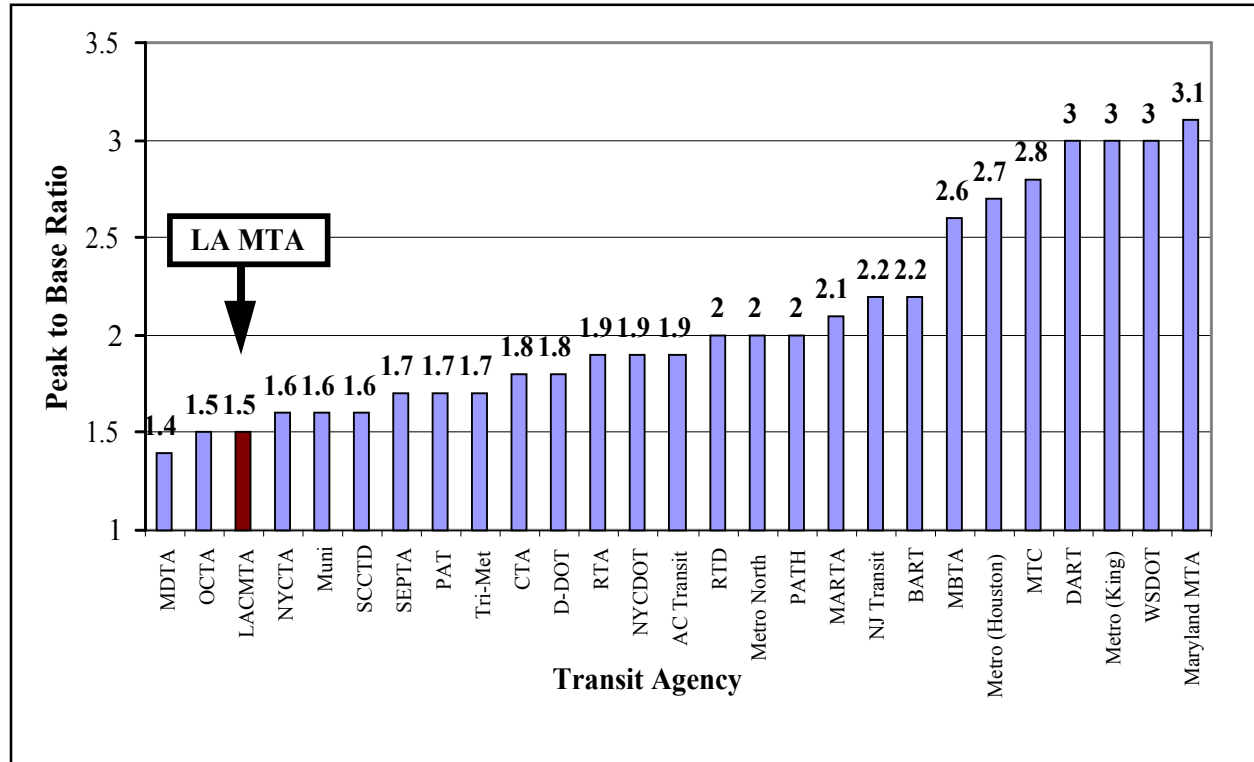
The time-of-day cost variations estimated in this analysis are similar to those found by others, in that the peak periods account for over half of all costs (Cervero, 1980; Parody et al., 1990; Levinson, 1978). Figure 6 below shows that the *Fully-Allocated Model* developed for this analysis estimates the total cost of operating peak period bus service in 1994 at \$151.01 per in-service vehicle hour, which is 35.9 percent higher than the per hour cost of \$111.10 estimated by the MTA model. This figure also shows that the *Fully-Allocated Model* estimates base period costs to be \$94.96 per in-service vehicle hour, or 14.5 percent below the MTA model estimate. It is important to note that these base period costs are estimated to be lower than those of the MTA model despite the inclusion of annualized vehicle and non-vehicle capital costs.



5. Comparison of Estimated Systemwide Costs Between the MTA Model and the *Fully-Allocated Model*

Overall, the systemwide bus costs estimated by the *Fully-Allocated Model* vary by \$56.05 per in-service vehicle hour, or 59.0 percent between the base and peak periods. This substantial difference in peak and base period costs is all the more remarkable given that the Los Angeles MTA has the third lowest peak-to-base vehicle ratio of any major U.S. transit operator (Figure 7). The relatively large peak-to-base cost differential estimated for a transit operator with a very low peak-to-base vehicle ratio suggests that the inclusion of time-of-day cost estimates in the

cost allocation models used by other U.S. transit systems would produce time-of-day cost differentials even greater than those observed here.



6. Peak/Base Ratios of the Twenty-Seven Largest Transit Operators

We then compared the fully allocated systemwide bus costs described above with similar cost data for the one MTA LRT line in operation at the time these data were collected. This comparison, summarized in Figure 8 below, shows that, considering the (1) annualized vehicle and non-vehicle capital costs, (2) higher seating capacity of LRT *vis-a-vis* bus, and (3) time-of-day cost differentials, the cost per seat-hour of service is substantially higher on the LRT, due mostly, though not entirely, to the much higher annualized non-vehicle capital costs. Buses

operate on streets and highways paid largely others: property owners (via property taxes) and private vehicle operators (via motor fuels taxes). For the LRT line, by contrast, the cost of right-of-way, track, catenary, and stations were paid by the transit operator. These costs, when annualized using generally accepted accounting principles, comprise 49.1 percent of fully allocated costs per seat hour of LRT service. Other LRT unit costs are higher than bus costs as well, due to higher per-seat vehicle capital costs and to higher per-seat expenditures by the MTA on LRT operations, such as for security.

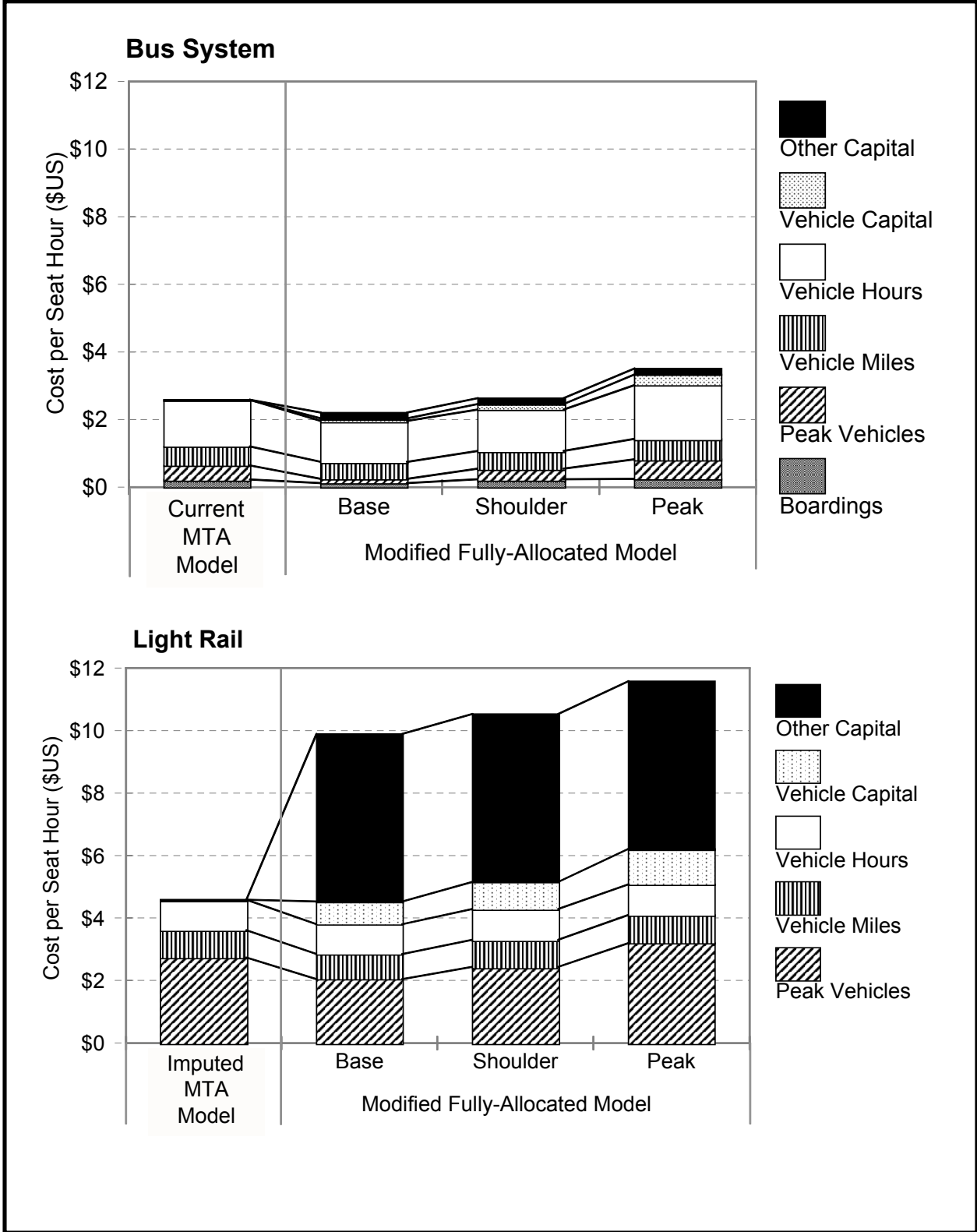


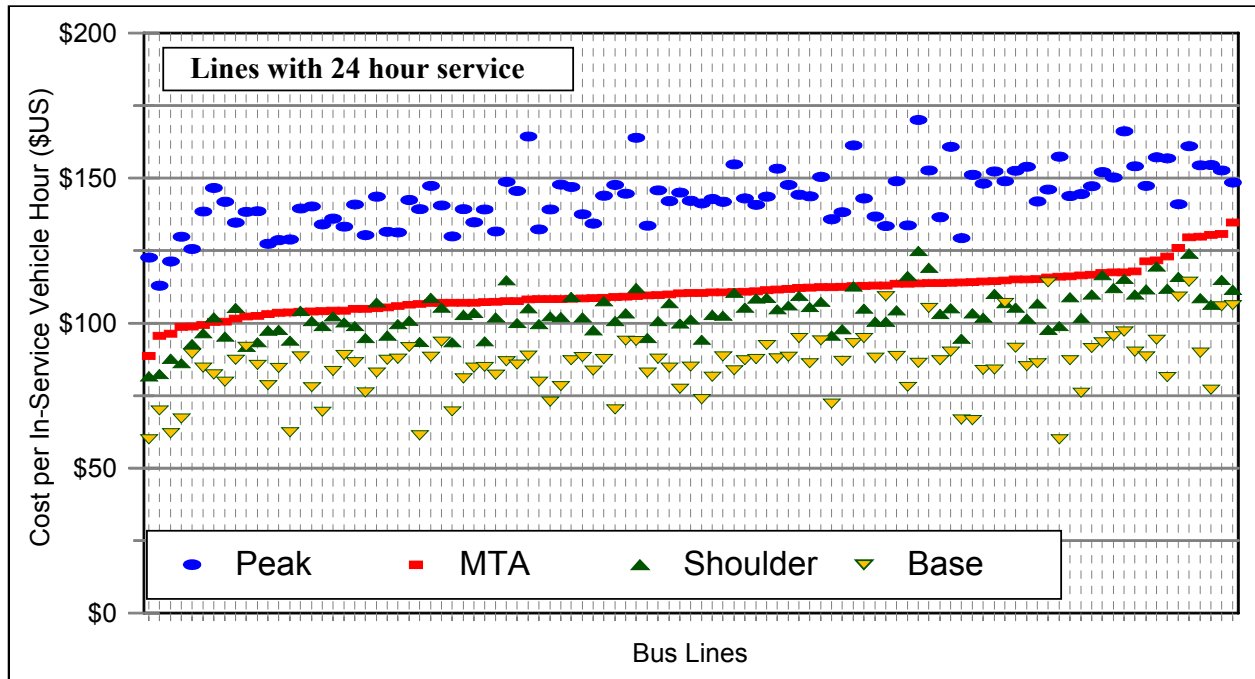
Figure 7. Comparison of Estimated Bus System and Light Rail Costs Using MTA Model and Fully-Allocated Model

Comparison of the Partially-Allocated Models with a Typical Cost Allocation Model

As noted in the opening discussion of fully- and partially-allocated models, marginal or incremental additions or deletions of service are most appropriately evaluated using partially-allocated models. Such models include only variable operating and vehicle capital costs (like driver compensation, fuel, and vehicles) which vary with incremental changes in service, but exclude most fixed and semi-fixed costs (like facilities, planning, and administration) which do not. Accordingly, *Partially-Allocated Model I* excludes non-vehicle capital costs, but includes all semi-fixed and variable costs — both operating and capital. *Partially-Allocated Model II*, excludes, in addition to non-vehicle capital, all fixed and semi-fixed operating costs (administration, marketing, etc.). In contrast, the MTA model includes all operating costs — both variable and fixed — but no capital costs, nor does it separately estimate costs by time-of-day.

To evaluate line by line variations in costs, we compared the costs per in-service vehicle hour estimated by *Partially-Allocated Model I* to the MTA model for each of the 122 bus lines in the MTA system. Figure 9 below displays the results of this comparison for the 101 MTA lines that operate around the clock, sorted by the hourly cost estimated by the MTA model. This figure shows that, as expected, the *Partially-Allocated Model I* consistently estimates higher peak-period costs — by an average of \$32.55 per hour — than the MTA model. On one bus line, peak period costs are estimated to be 49.6 percent (\$56.37) higher per hour than the costs estimated by the MTA model. On another line, the base period costs are estimated to be 48.3 percent (\$56.01) lower per hour than the MTA model. On some lines, the time-of-day variations

in costs were very large; the estimated variance in peak and base period costs ranged up to \$97.46 per hour.

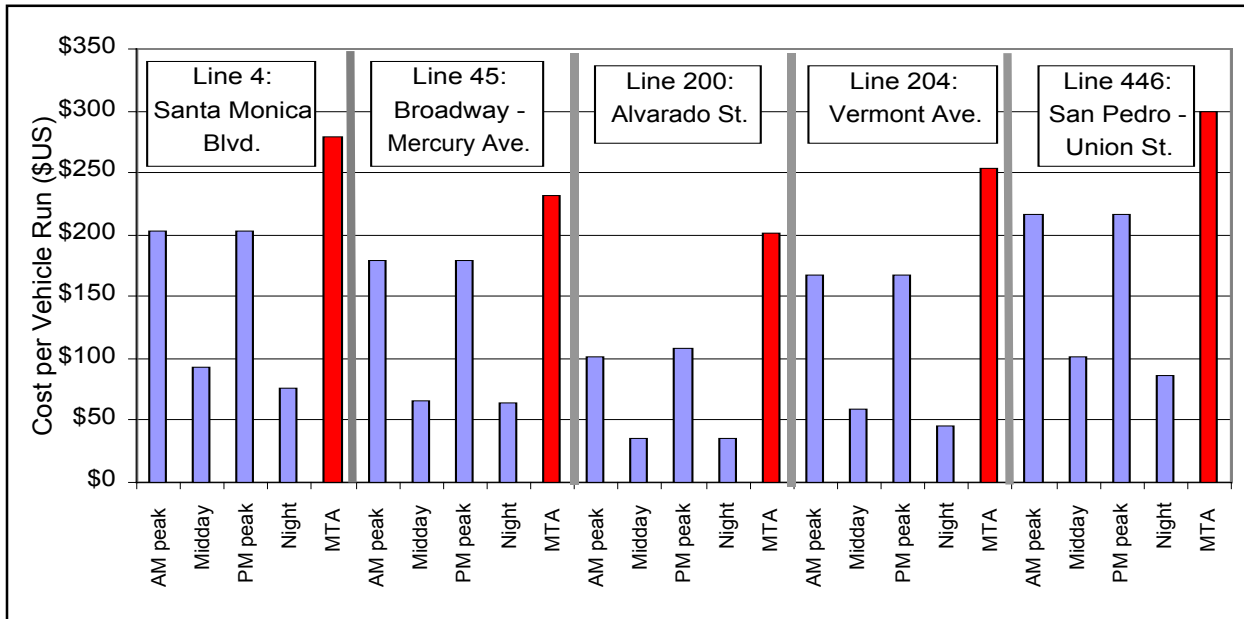


8. Comparison of Individual Line Costs Using *Partially-Allocated Model I*

To explore how using a temporally sensitive cost allocation model might affect service planning decisions, we selected five MTA lines representing a cross-section of operating conditions and calculated the cost of adding one additional vehicle run for four different time periods. Figure 10 below shows that the added costs of including variable capital costs in *Partially-Allocated Model II* are outweighed by the inclusion of semi-fixed and fixed operating costs in the MTA model. For each of the five lines examined, the MTA model estimates substantially higher costs to add a single vehicle run, even in the peak periods. For off-peak periods, when vehicles and labor are likely on-hand to add service, the MTA model estimates the

costs of an additional vehicle run to be three to five times higher than *Partially-Allocated Model*

II. In addition, Figure 10 also shows that the estimated costs of a service addition vary substantially from line to line, reflecting the differences in operating characteristics (such as route length) of each line.



9. Cost of Additional Vehicle Run for Five Sample Bus Lines by Time Period

The results suggest that erroneous cost estimates for different times of day can result in inefficient service provision and reduced efficiency. Since the cost of providing additional service during off-peak periods is normally less than the system-wide average, the failure to consider temporal and directional variation in costs may lead to off-peak service cuts that save less money than hoped or to increases in peak service that are costlier than anticipated (Cherwony et al., 1978).

CONCLUSION

The cost of producing public transit service is not uniform, but varies by trip type (such as local or express), trip length, time of travel, and direction of travel, among other factors. Yet the models employed by public transit operators to estimate costs generally do not account for this variation. These limitations in the cost allocation models used in practice significantly hinder the management, planning, and policy oversight of public transit systems; accurate, fine-grained cost information is essential in setting service levels, determining fare structures, and selecting transit modes. The limitations of most public transit cost allocation models has long been noted in the literature, particularly with respect to time-of-day variations in costs (Cohen et al., 1988; Kemp et al., 1981; Cervero, 1982; Cherwony and Mundle, 1978; Charles River Associates, 1989; Parody et al., 1990). But the exclusion in most models of variations in vehicle passenger capacity, capital costs, and directional peaking have been noted by others as well (Lem et al., 1994; Li, 1997; Cervero, 1980; Chomitz et al., 1985). The models developed for this analysis are unique in that they simultaneously account for variations in capital costs, vehicle passenger capacity, and time-of-day costs (unfortunately, data limitations did not allow us to account for directional peaking in these models).

This analysis used fiscal year 1994 operating and capital data for the Los Angeles MTA to develop three related fully- and partially-allocated cost estimation models. In comparison to the model currently used by the MTA, these models estimated:

1. Peak period bus costs to be higher by 35.9 percent;
2. Base period bus costs to be lower by 14.5 percent;
3. Light rail unit costs to be higher than bus costs by an average of 266 percent; and

4. The cost of small additions of bus service to be substantially lower regardless of time-of-day.

While the modified *Fully- and Partially-Allocated Models* developed in this analysis are more comprehensive than most previously developed in the literature, and substantially more sensitive than the models typically employed in practice, these models could be further improved by:

1. Accounting for the directional peaking of demand by distinguishing peak direction service in the analysis;
2. Taking weekend operation directly into account in computing vehicle and capital costs;
3. Applying a “cost centers” approach to differentiate unit costs to discrete parts of the system such as operating divisions (Cevero, 1980; Bell et al., 1983); and
4. Computing relative labor productivity factors on individual lines from the ratio of pay hours to vehicle hours by time of day to more accurately estimate vehicle hour unit costs.

To incorporate these refinements, however, additional data not typically collected by transit operators would be needed.

Finally, while this study uses Los Angeles MTA data, the focus of this analysis is not on the MTA *per se*, nor is this work intended as a critique of MTA practice. The four-factor cost allocation model currently used by the MTA is more sophisticated than the one- and two-factor models used by many transit operators. As noted earlier, the observed time-of-day cost differentials, while significant, are probably smaller than those of most other transit operators, given the MTA’s very low peak-to-base vehicle ratio. Finally, estimated modal differences in

costs are not likely unique to Los Angeles; except for exclusive busway facilities, right-of-way and capital costs are typically higher for rail transit than for buses. Rather, the focus of this study is on the limitations of the rudimentary, average cost allocation models employed by most transit operators. Toward that end, this analysis has clearly shown that an array of factors — namely capital costs, vehicle passenger capacity, and time-of-day variations in costs — which have generally been addressed separately in the cost allocation model literature, can be simultaneously and practically incorporated into a usable transit cost allocation model to provide transit systems with far better information on the highly variable costs of producing transit service.

EPILOGUE: LINKING COSTS TO PASSENGERS

Developing a cost allocation model that takes into account the variation in transit costs by mode, by line, and by time of day is just the first step in estimating the subsidy of individual riders and classes of riders. Our current research is working to link these cost allocation data with MTA ridership data.

Accounting for (1) time of day, (2) transit line, (3) trip distance, and (4) fare paid, we can estimate the cost of each passenger trip and, in turn, the subsidy for each passenger trip. We then can aggregate these individual trip data to estimate the subsidies of various classes of riders. Table 2, for example, estimates the average subsidy per bus trip by income class and shows a clear positive relationship between household income and subsidy.

Table 2. Estimated 1994 MTA per Bus Trip Subsidies by Household Income Class

1994 Household Income	Estimated per Ride Subsidy	Difference from System Average
No Answer	\$3.76	-2.5%
Less than \$15,000	\$3.69	-4.5%
\$15,000 - \$29,999	\$3.86	-0.1%
\$30,000 - \$49,999	\$4.44	15.0%
\$50,000 and above	\$4.87	26.0%
System Total	\$3.86	0.0%

Because of the imperfect quality of data in the MTA Origin-Destination survey data (such as insufficient information on origin and destination addresses, time of travel, or fare paid) and the limitation of cost information in the cost allocation model for some lines, the preparation of this data set has required painstaking and time-consuming calculations for many individual records. Currently, our working data set has been reduced from 16,016 down to 9,950 passenger trips and we are in the process of carefully developing weights to estimate the sample data to represent the entire population of the MTA transit riders.

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ENDNOTES

1. Calculated by authors from U.S. Census Bureau 2000 and Moody 1981 quoted in Jones 1985.
2. Calculated by authors from from Federal Transit Administration 2000, Table 27.