Cost and price functions are two of the essential tools used in pricing and investment analysis. These two functions relate the total and user costs of service to the volume of service. The definition and composition of these functions were discussed in Chapters 2 to 4. Here we shall consider the techniques used to estimate the magnitude of cost and price components as well as some of the practical problems which arise in the use and estimation of these functions, such as accounting for inflation. We should emphasize that the discussion in this chapter is meant to be illustrative of the general approaches used for cost estimation. A full treatment of this topic would require a text longer than this one, even for specific facility types. Thus, our intention is to provide a convenient introduction to the techniques and problems associated with the estimation and use of cost data.

In the next section in this chapter we summarize the four most common techniques for estimating construction, operating, and external costs, namely the methods of engineering unit costs, statistical estimation, accounting cost allocations, and market equilibrium bids. One or a combination of these methods is generally used in the development of standardized cost models which are widely used for infrastructure systems. Of course, construction and facility operating costs are only two of the components of costs which must be considered by analysts; the user costs for items such as travel also constitute a major category. These user costs of travel include vehicle operating costs, as well as those for travel time and effort. While estimation of vehicle operating costs does not require special techniques, forecasting and valuing the travel time and effort incurred by users does require special attention. In Section 12-2 we describe the methods commonly used to estimate travel times on facilities, while in the following section we consider the problems of valuing travel time in dollar amounts.

In the final two sections we discuss some of the difficulties which are commonly encountered in using price and cost functions. The discussion in Section 12-4 centers on the problems associated with defining the unit of time and volume for such functions, and that in Section 12-5 focuses on the impact of inflation and other problems associated with forecasting costs in future periods.
12-1 COST-ESTIMATION TECHNIQUES

Virtually all cost estimation is performed with one or some combination of the techniques of engineering unit costs, statistical cost inference, accounting cost allocation or market equilibrium bids. These four techniques are the basis for all the standardized cost models used in infrastructure studies. As a supplement, engineering judgment may be applied as a rough means of estimating costs, but this judgment typically relies on experience with the basic four methods.

A fifth approach makes use of the microeconomic theory of production. Economists often define an initial relationship between the output of a process (such as vehicle-miles of service) and the necessary inputs of resources such as time, labor, capital, and so on. This functional relationship is termed a production function. By assuming a decision process in which the various inputs are combined to produce a given output, it is possible to derive a cost function from the underlying production function. As a parenthetical note, it is also possible to apply this approach to the development of appropriate demand functions by considering households or individuals as units of production. This is not a common method for infrastructure systems analysis, however.

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12-1-1 ENGINEERING OR ACCOUNTING UNIT COSTS

In principle, the use of engineering unit cost estimation is straightforward, although the application of the method is laborious. The initial step in the method is to break down or disaggregate a process (such as construction, maintenance, or facility operation) into a series of smaller subtasks or components. Collectively, these subtasks or components are required to complete or continue the overall process of construction or facility operation. Once the various components are defined, a unit cost is assigned to each and then the total cost of the process is determined by summing the costs incurred in each subtask or component.

The level of detail in dividing the process into subtasks typically depends upon the stage at which the cost estimate is being prepared. During early planning stages less is known about the prospective design, so that the level of detail in defining subtasks is quite coarse. Cost estimators often refer to three distinct stages at which such divisions might be made and engineering cost estimates prepared:

1. Conceptual estimate in the planning stage (often termed predesign estimate or approximate estimate).
2. Preliminary estimate in the design stage (often termed budget estimate or definitive estimate).
3. Detailed estimate for the final assessment of costs.

An example of the subtasks and components which might be defined for the construction of a rapid transit line is shown in Table 12-1. Construction of the rail line requires a series of purchases and specific tasks, and all of these various components must be defined in categories such as those of Table 12-1. The quantity of each purchase and the work entailed in each subtask must be estimated, usually using engineering principles, survey, or judgment. For example, soil borings are taken to help determine the underground soil and conditions to be encountered in tunneling, while route surveys are used to determine the amount of earthwork involved in laying out and preparing a roadbed, digging a tunnel, and so forth.
The breakdown in Table 12-1 might be appropriate for a preliminary planning study, for instance, while a much more detailed analysis of the labor and material requirements would be carried out during the engineering design phase (and prior to the preparation of contract bids). In the latter instance a take-off analysis would ordinarily be carried out from the blueprints in which the amount and type of each component of labor and material is enumerated (e.g., the number, type and size of reinforcing rods, I-bars, rivets, etc.) and then multiplied by its respective unit cost. In turn, allowances for "contingencies" are added to the accumulated cost estimates to allow for uncertainties (e.g., unexpected weather or soil conditions), inflation, and the like.
TABLE 12-1. Possible Project Components for Engineering Costing of a Rail Rapid Transit Line Construction

<table>
<thead>
<tr>
<th>Components</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed factors</td>
<td></td>
</tr>
<tr>
<td>Land for right of way</td>
<td>Area by location</td>
</tr>
<tr>
<td>Guideway</td>
<td>Dimensions, number of tracks, type of construction (at grade, subway, etc.), length by terrain and design standards</td>
</tr>
<tr>
<td>Terminals and stations</td>
<td>Number, size, design standards</td>
</tr>
<tr>
<td>Maintenance facilities</td>
<td>Number, capacity, design standards</td>
</tr>
<tr>
<td>Control and signaling system</td>
<td>Length of track, design standards</td>
</tr>
<tr>
<td>Utility relocation</td>
<td>Number, type, size, design standards</td>
</tr>
<tr>
<td>Rolling stock</td>
<td>Number by type</td>
</tr>
<tr>
<td>Vehicles</td>
<td></td>
</tr>
</tbody>
</table>

The development of cost estimates of this type requires a considerable amount of judgment to estimate the quantities of inputs. In particular, the amount of labor and time required to perform individual tasks depends upon workers' incentives and abilities, the effectiveness of management in organizing equipment, supplies and efforts, and the peculiarities of particular sites. Considering all these various factors requires considerable expertise.

Along with the various components and the quantity of each component, the unit cost of the various purchases and subtasks must be ascertained. Examples of unit costs are the cost per foot of tunneling through various types of soil, the cost of coal or the cost per transit vehicle. Unit costs may be determined by reference to historical records, by inquiry among suppliers, by engineering judgment, or by statistical estimation. Unfortunately, unit costs may change significantly in the future or due to peculiarities at the construction site, so cost estimates will not always be accurate.

With the various purchases and subtasks defined, the quantity of each estimated, and the various unit costs determined, the total cost for constructing or operating a facility may be calculated by summing all the component quantities multiplied by their respective unit costs. Often, a contingency amount is added to this total, representing unanticipated costs due to uncertainty in defining tasks, scheduling difficulties, and so on. A difficulty with the technique of engineering unit costs is the multitude of components which must be estimated and the seemingly endless ways in which the tasks can be broken down. Each of the components listed in Table 12-1 could easily be disaggregated into smaller components or tasks. For example, it is quite important to consider the type of soil or rock through which tunnels are constructed. Similarly, purchase of right of way may depend critically on the existing uses of land and particular lot boundaries. In most applications of engineering unit cost estimation for major transportation facilities, the number of components and subtasks is large, making the process of assembling cost estimates quite laborious. Since the cost of making estimates is so high, attention is often directed to only a few alternatives and the list of components or tasks is kept small.

12-1-2 STATISTICAL COST ESTIMATION

An alternative (or supplement) to the technique of engineering unit costs is that of statistical estimation. Broadly speaking, statistical estimation of cost functions uses the same statistical techniques described in the previous chapter with respect to demand functions and reviewed in Appendix III. Cost functions developed with statistical techniques typically relate the cost of constructing or operating a facility to a few important attributes of the system. For example, the cost of operating a bus system might be assumed to be a function of the number of vehicles, total hours of operation, and miles of operation.
The role of statistical analysis is to best estimate the parameter values or constants in the assumed cost function. For example, the cost of operating a bus system might be assumed to be

\[ C_o = \beta_1 V + \beta_2 H + \beta_3 B \]  

where \( C_o \) is operating cost, \( V \) is the number of vehicles, \( H \) is the annual bus hours of operation, \( B \) is the annual bus miles of operation, and \( \beta_1, \beta_2 \) and \( \beta_3 \) are constant parameters to be estimated. Using statistical techniques, it is possible to estimate appropriate values for the parameters and \( \beta_1, \beta_2 \) and \( \beta_3 \) with the use of a number of observations of actual bus system operations. Thus, statistical cost estimation relies on historical data of actual operations.

The form of a cost function such as Equation (12-1) can be developed in a number of ways. By form, we mean the attributes which are included (such as \( V, H, \) and \( B \) above) and the functional relationship among the various attributes [which is linear in Eq. (12-1)]. The simplest method to determine a functional form is by assumption, based upon experience and engineering expertise. Most statistical studies of costs proceed in this manner, simply assuming that costs may be characterized by generally recognized attributes such as bus miles of operation, and so on, and that they are related in some (assumed) linear or nonlinear way.

A second approach is analysis of the actual components of a system operation or construction. This approach is similar to that of engineering unit cost estimation, although in this case "unit costs" are estimated indirectly by applying statistical techniques to system observations. Moreover, the number of components used is generally much fewer than the comparable number of components used in engineering unit cost estimation.

As an illustration of an engineering unit cost model with statistically derived estimates of unit parameter values, let us test a model of the form akin to that shown in Equation (12-1). Specifically, the parameters were estimated for all U.S. bus systems in 1980 having a fleet size between 125 and 250 vehicles. (The specific data are shown in Appendix III.) The resulting expression is

\[ C_o = 3*V + 23*E + 97*A \]  

\[ \begin{align*} 
\textbf{r}^2 &= 0.82 \\
(0.13) & \quad (2.79) & \quad (1.02)
\end{align*} \]  

in which \( C_o \) is the annual system operating cost (in $1,000's), \( V \) is the average weekday operating fleet size, \( E \) is the equivalent full-time employee count, and \( A \) is the average bus age (in years); the \( t \) statistics for the estimated coefficients are shown in parentheses and serve as indicators of the uncertainty of parameter estimates. Lower \( t \) statistics imply greater uncertainty in these estimates, as described below.

The low \( t \) statistics for operating fleet and vehicle age coefficients might lead one to test the statistical significance of two other simpler functions, of the following general form:

\[ Y = \alpha + \beta x \]  

or

\[ Y = \beta x \]
in which $Y$ is the dependent variable (say, total annual system operating cost), $x$ is the independent variable (say, equivalent full-time employee count), and $\alpha$ and $\beta$ are constant parameters to be estimated using least-squares regression. Both forms were tested using the data in Appendix III, with the following results:

$$C_o = -7.83 + 26.44 E \quad r^2 = 0.80$$

(12-5)

where $C_o$ is the total annual system operating cost (in $\text{1,000's}$). Also,

$$C_o = 26.42 E \quad r^2 = 0.80$$

(12-6)

In both cases much of the variation is explained by the regression and it is obvious (from the $t$ statistics) that the estimated coefficient for the employee count is highly significant statistically (i.e., significantly different from zero). Two other issues are of importance, however. One, how accurate—probabilistically speaking—are these cost estimators (i.e., the values of $C_o$)? Two, is it reasonable to conclude that the regression goes through the origin (i.e., that $C_o$ is equal to zero when $E$ is zero)? Each of these issues is discussed in Appendix III. More broadly, the estimates of costs from any statistical cost function such as Equations (12-2), (12-5), or (12-6) are subject to uncertainty, both as to the appropriate model form and estimate of costs ($C_o$).
TABLE 12-2. An illustration of an Allocated Cost Function for Turnpike Expenditures

<table>
<thead>
<tr>
<th>Expenditure Item</th>
<th>Allocation Factor</th>
<th>Allocated Amount ($ M)</th>
<th>Per Unit Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration</td>
<td>VMT</td>
<td>1.7</td>
<td>0.0011</td>
</tr>
<tr>
<td>Pavement Maintenance</td>
<td>VMT</td>
<td>3.2</td>
<td>0.0020</td>
</tr>
<tr>
<td></td>
<td>ESAL</td>
<td>1.1</td>
<td>0.0018</td>
</tr>
<tr>
<td>Other Maintenance</td>
<td>VMT</td>
<td>3.2</td>
<td>0.0020</td>
</tr>
<tr>
<td>Services and Toll Collection</td>
<td>VMT</td>
<td>7.7</td>
<td>0.3182</td>
</tr>
<tr>
<td>Traffic Control and Safety</td>
<td>VMT</td>
<td>3.8</td>
<td>0.0024</td>
</tr>
<tr>
<td>Major Repairs and Resurfaction</td>
<td>VMT</td>
<td>7.5</td>
<td>0.0047</td>
</tr>
<tr>
<td></td>
<td>ESAL</td>
<td>6.0</td>
<td>0.0101</td>
</tr>
<tr>
<td>Bond Payments and Interest</td>
<td>VMT</td>
<td>2.7</td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td>ESAL</td>
<td>10.8</td>
<td>0.0181</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>47.8</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)VMT: annual vehicle miles of travel; ESAL: annual equivalent standard axle miles of travel; V: annual vehicle trips.

\(^b\)Calculated as the allocated amount divided by the amount of the allocation factor, with VMT = 1583 million miles, ESAL = 595.9 million miles, and V = 24.2 million vehicle trips.

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12-1-3 ACCOUNTING COST ALLOCATION

To develop a cost function for ongoing operations, allocations of cost from existing accounts may be employed. While this procedure has been used in practice, it relies upon a very restrictive assumption concerning the form of the cost function. Since this assumption is not likely to be true except as an approximation for most transportation services, allocated cost functions should be used with caution.

The basic idea in accounting cost allocations is that each expenditure item can be assigned or allocated to particular characteristics of service, such as vehicle-miles of operation or miles of pavement maintained. A possible list of such assignments for the case of a turnpike authority is shown in Table 12-2. In this list pavement maintenance expenditures are divided into components assigned or allocated to vehicle-miles of travel and the total volume of equivalent standard axle loads (ESALs) of travel on the turnpike. Toll collection expenditures are assumed to vary with the number of vehicles. By dividing the total of each expenditure category by the total of the allocation factor (such as number of vehicles or ESALs), the per unit allocated cost for each expenditure category is calculated.

Ideally, the allocation factor should be causally related to the category of expenditures in an allocation process such as the one illustrated in Table 12-2. For the allocation of maintenance costs in this case, for example, statistical analysis has indicated that $1.1 million of expenditure is
related to the number of \( ESAL \) miles of travel. In many instances, however, a causal relationship between the allocation factor and the expenditure item cannot be identified or may not exist.

Once the per unit allocations to each factor are calculated as shown in Table 12-2, a total cost function may be calculated by summing up each of the per unit costs. For example, the cost function corresponding to the example in Table 12-2 would be

\[
C = 0.0139* VMT + 0.03*ESAL + 0.318* V \tag{12-7}
\]

In this case the turnpike expenditures have been allocated on the basis of annual \( ESAL \) miles of travel, the total number of vehicles \( (V) \), and vehicle miles of travel \( (VMT) \).

Note that the allocated cost function [Eq. (12-7)] assumes that the expenditure items allocated to each factor are strictly proportional to the level of each factor. That is, the function assumes that there are no economies of scale or nonlinear effects in any of the expenditure categories, such as toll collection. Thus, the cost function represents a linear approximation of what may be quite nonlinear relationships. Indeed, an increase in vehicles at toll booths with excess capacity available would be unlikely to increase toll collection costs, in contrast to the model assumptions. For this reason allocated cost functions should always be used cautiously in developing cost estimates or in estimating marginal or incremental costs. To the extent that the allocation factors are causally related to expenditure items or that a linear relationship is correct, then the allocated cost function will be an accurate representation of the true costs of operations. Unfortunately, this happy circumstance is not necessarily true.

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### 12-1-4 Market Equilibrium Bids

For some infrastructure services, market equilibrium bids from private providers can provide a means of estimating the costs of providing service. For example, electricity grid managers may receive bids from different power generators to provide a specific amount of power for a bid price. The accumulation of all the bids shows the cost of providing different amounts of power.

Of course, in the case of market equilibrium bids, each of the service providers needs to estimate their own costs (including any desired profit) using the preceding methods.

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### 12-2 ESTIMATING TRAVEL TIMES

Travel times are important for transportation decision making, both for customers (travelers) and providers. Included in both the price and user cost functions are all the various costs associated with vehicle operation (gasoline, maintenance, etc.) and the user costs for the time and effort involved in travel. In addition, the price function includes the amount of any tolls, parking fees, or fares which tripmakers must pay (as described in Chapter 4). Each of these various costs must be valued in dollar amounts. In this section we shall discuss techniques usually employed for estimating travel times over facilities. In the following section we consider the problem of valuing the estimated travel
times in dollars. Both subjects are important because changes in travel times represent a major impact of many transportation investment and pricing decisions.

For existing facilities, travel times may be estimated by observing actual trip times on a facility. Unfortunately, for large transportation networks direct observation of each link under all conditions would be prohibitively expensive. Moreover, observations cannot be made of conditions which will exist after a proposed investment or policy change is made. As a result, models of transportation facilities and services have been developed to estimate travel times indirectly. These models are generally called performance functions, and they relate the travel time on a particular type of facility to the characteristics of the facility, vehicle fleet mix, and the volume of travel. For some applications performance functions may be developed which estimate separate types of travel time, such as the time spent in walking, waiting, and riding for a particular trip.

An example of a performance function used for estimating the travel time on a roadway appears below:

\[
t = \frac{1}{V_{\text{max}} - \delta q} \quad \text{for } q < \frac{V_{\text{max}}}{\delta}
\]

where \( t \) is the travel time per mile over the link, \( V_{\text{max}} \) is the average speed on the link with very low volume, \( q \) is the volume actually using the link, and \( \delta \) is a parameter related to the capacity of the link. The travel times indicated by Equation (12-8) for different volumes are graphed in Figure 12-1. Another commonly used model for estimating travel time on a link is

\[
t = t_0 + \delta q^p
\]

where \( t \) is the travel time, \( t_0 \) is the travel time at low volumes, \( q \) is volume, and \( S \) and \( p \) are parameters specific to the roadway link.

Both of these performance functions (and virtually all others) share some common characteristics. First, travel time on the facility or service is related to the travel time at very low volumes. Second, to capture the effects of congestion, each function includes the volume of travel as a variable. As the volume of travel increases, travel time increases, and this increase is generally in a nonlinear manner; at high volumes travel times may increase dramatically with a small amount of additional traffic.
This increase is especially notable in cases in which the volume entering a facility exceeds the capacity of the facility for a period of time, leads to a shock wave, reduces facility capacity, and increases delay. In this case and others a queue forms on the roadway. This shock wave and queuing phenomenon is not captured by the steady-state model in Equation (12-8) or (12-9), but was described in Section 6-5.

Figure 12-2 illustrates the effect of queue formation. Appearing on this figure are the cumulative number of arrivals at the facility over time \( A(t) \) and the cumulative number of departures from the facility \( D(t) \). At any time \( t \) the queue length on the facility is given by the vertical distance between these curves, \( A(t) - D(t) \). The waiting time for an arrival at time \( t \) is given by the horizontal distance to the departure curve. The total waiting time in queue for all the users is given by the area between the \( A(t) \) and \( D(t) \) curves in Figure 12-2.

A number of modeling techniques are used to develop performance functions such as Equations (12-8) and (12-9). These techniques include statistical estimation, simulation, and analytical models. Statistical estimation is similar in nature to the use of statistical techniques for demand and cost function estimation which were described earlier. Statistical analysis of observations of existing facilities and services can be used to infer the performance of all similar facilities and services. Simulation requires the use of a model or direct experimentation at different volume levels in order to observe the resulting travel times. The most common means of simulation involves large models formulated for manipulation by digital computers. Analytical models are based upon engineering or mathematical principles and vary substantially in their level of sophistication and accuracy. Simple analytical models involve little more than intuition, while others may employ stochastic processes and queuing theory. Finally, some of the most effective performance models are developed by using a combination of these methods.
Whichever method is used, the estimates of travel times developed from performance functions share some common features. First, the travel times are only estimates of actual times and, thus, are uncertain. As a result, the estimated costs associated with travel times will also be uncertain. Second, the actual travel times on a facility (and the estimated travel times) are likely to differ from the perceived travel times reported by travelers since they typically make errors in estimating their travel times. Finally, most performance functions estimate average travel times on a facility. Since there is likely to be considerable variation in the actual travel times, individuals may experience much shorter or much longer travel times. This variation in travel time is one aspect of the reliability of a particular transportation facility or service. Greater reliability is a desirable attribute in itself, but the estimation and valuation of system reliability is still in an embryonic stage.

**12-3 VALUING TRAVEL TIME AND EFFORT**

Once estimates of travel time for particular facilities or services are made, it is necessary to value these times in dollar amounts in order to construct the social cost and price functions. This problem has received a great deal of attention in the transportation literature, particularly since a major impact of most urban transportation investments is that of reduction in average travel time.

Observations of individuals in choice situations is one practical way in which estimates are made of the valuation or weight to place on different user cost components. For example, suppose that various individuals are faced with the choice between traveling on a turnpike with a toll or on a freeway which does not have a toll but is slower. In making a decision between these two alternatives, individuals must weigh the value of reaching their destination sooner (that is, a shorter travel time) against additional monetary expenses (that is, the toll charges). Illustratively, an individual might choose the tollroad if he pays only $1.00 and saves 1 hour. At zero or very low tolls all or most travelers would be expected to choose the toll road, since their travel time would be lower. With very high tolls, travelers would be likely to choose the free road, since the extra travel time is less
costly (that is, valued lower) than the cost of a (high) toll. At some intermediate toll the traveler might be indifferent between the routes since the savings in time on the toll road would be just balanced by the payment of the toll. For example, this intermediate point might occur with a toll of $1.00 and a travel time savings of 20 minutes. In this situation the analyst would conclude that the motorist would be willing to pay $1.00 to save 20 minutes of driving time. In turn, many analysts (by imputation) use such data to estimate the value of other times saved, or

$$\bar{v} = \frac{$1.00}{(20 \text{ minutes})} = $3.00/\text{hour} \quad \quad (12-10)$$

where $\bar{v}$ is the implied or estimated value of saving an hour of driving time. Such imputed values should be scrutinized carefully rather than used haphazardly.

In practice, a large number of similar observations would be used to derive an estimated value or formula for the value of time using statistical techniques. At the heart of these methods, however, are the individual observations of traveler preferences when faced with competing travel choices.

A few comments may be helpful in interpreting estimates of travel time values which are derived from this type of analysis:

1. The value of travel time is likely to vary according to the socioeconomic conditions of the tripmaker. For example, it seems plausible to assume that high-income individuals would be willing to pay more to save time than would low-income individuals. To capture this effect, the value of travel time is occasionally modeled as proportional to income, so that the individual's value of time is a constant parameter times household income. With this formulation, high-income individuals have a higher expected time value than do low-income individuals.

2. The value of travel time is likely to vary according to the characteristics of the trip itself. For example, time spent waiting outside a vehicle is likely to be valued higher than time spent riding in a vehicle (that is, individuals would be willing to pay more to avoid waiting or walking outdoors than to spend a comparable amount of time riding in a vehicle). In fact, waiting or walking time outdoors has generally been found to be valued at roughly 2.5 to 3 times more than comparable times spent in riding vehicles. In addition to the comfort and level of effort involved in different components of the trip time, other characteristics of the trip which influence the value of time include trip purpose (work vs. recreational, etc.) and the number of individuals traveling together.

3. The value of travel time is likely to vary according to trip duration. For very long trips it is likely that small changes in travel times have little value. For example, a 5-minute delay in a 5-day trip is not likely to influence travel choices to any great extent, but a 5-minute delay in a 10-minute trip may be quite irksome. To capture this effect, the value of travel time is occasionally modeled as inversely proportional to trip length, so that the individual's value of time is some constant parameter divided by the total trip length or time.

This observation concerning the importance of trip duration may also be applied to minor changes in travel time. It is likely that individuals place very little value on saving very small increments of time, such as a few seconds or less than a minute. Moreover, the value of 1 second is likely to be less than $\frac{1}{8}$ of the value of a minute and less than $\frac{1}{300}$ the value of an hour. The implications of this observation for pricing and investment analysis will be considered in the next chapter.
12-4 TRANSPORTATION OUTPUT UNITS AND NONHOMOGENEOUS COSTS

Specification of appropriate output units is of critical importance for cost, price, and demand functions for transportation services. Determining the appropriate units becomes particularly difficult and complex as the links being analyzed for possible improvement serve the traveler for only a portion of the entire door-to-door trip and as the links are utilized by travelers from a wide variety of origin and destination zones. In the text we have generally used vehicle or person trips between specific points at a particular time, but other units may be appropriate in specific cases. Since the choice of output units does affect an investment or pricing analysis, this issue deserves some discussion.

To properly specify the output units, four aspects of travel must be accounted for: (1) the trip unit (i.e., persons, vehicles and their classification, tons, etc.); (2) the origin and destination of the trip; (3) the links over which trip is made; and (4) the time interval over which the trips are made, as well as the time of day and time period or year during which they are made.

The necessity for making the above distinctions is, of course, that cost and price-volume functions will vary from link to link and with changes in the trip unit and time interval, and that demand will vary for different origins and destination node pairs, times of day, and time periods, as well as for other factors. Determining equilibrium volumes and costs requires that the cost, price-volume, and demand functions are all consistently stated in terms of equivalent output measures accounting for these four aspects.

It is important to characterize the differences among individual travelers with respect to the way in which they perceive and evaluate certain travel costs (e.g., those for time, crowding, and discomfort) and with respect to auto purchases, car pooling, and other significant preferences and trade-offs. As noted above, there are wide variations in the manner and extent to which travelers consider and are affected by travel time and congestion, by vehicle ownership and accident payments, by inconvenience, by walking and waiting, and so forth. While it is clear that travelers whose trip value (i.e., the value of making a specific trip to some particular destination) is high will be willing to endure higher private travel prices in order to make the trip than will those with lower trip values, it cannot be assumed that those with higher trip values will necessarily regard the private inconvenience or discomfort of car pooling or of congestion as being more “costly” than will those travelers having low trip values. Thus, since the output consists of travelers having different trip values and having different travel service preferences and since the trip values and travel service preferences are only partly dependent on income level, equilibration cannot be accomplished accurately by simply stratifying demand and price-volume functions by income level. However, one might attempt to equilibrate demand and price-volume functions stratified by income level as a first approximation for more accurate estimates (which, say, are to be determined by iterative procedures).

It appears that satisfactory treatment of these variations in travel price which are dependent both on the level of output and on the particular groups of people and goods involved in tripmaking require disaggregate forecasting models to accurately accomplish equilibration; and it would appear that iterative procedures offer the only hope for simultaneously satisfying the intricate demand and price-volume conditions. However, even these sorts of procedures may lead to multiple solutions and ambiguities.

The type of analysis which is possible in this manner has been outlined in Chapter 3. Briefly, it is possible to identify equilibrium conditions and summarize costs using a series of
performance/traveler categories and separate performance functions for each link. For example, it is possible to stratify by trip purpose (as a proxy for time of day) and traveler groups, as well as travel time components such as waiting time, riding time, and reliability. Equilibration in this case requires a substantial number of iterations, which can best be performed on a computer.

Of course, in many instances the desired accuracy of forecasts may not be sufficiently high to warrant such expensive analysis procedures. For example, minor highway investments might not be expected to alter the extent of car pooling, so auto occupancy might be assumed to be constant in such cases. In other circumstances input data are so uncertain that a detailed, disaggregate analysis might not enhance the accuracy of results, so simpler analysis methods might be used, such as the illustrative diagrams used throughout this text.

12-5 FORECASTING COSTS

For the analysis of alternative investments it is essential to develop some estimate of the costs associated with the construction, operation, and use of facilities. In most cases preparing such estimates requires the use of forecasts of costs in future years. As we have emphasized in the foregoing discussion, any such forecasts of costs will be uncertain; the actual expenses may be much lower or much higher than those forecasted. This uncertainty arises from technological changes, changes in relative prices, difficulties in valuing travel time, inaccurate forecasts of underlying socio-economic conditions (which affect the volume and thus the user costs experienced), analytical errors, and other factors. While many of these factors are self-evident, a few deserve a brief discussion here.

Changes in relative prices may have substantial impacts on the costs of particular alternatives which, in turn, may affect the final choice of a project. A most dramatic example of such a change was the increase in gasoline price in the 1970s and 2000s after several decades in which the relative price of gasoline had declined. This increase led to a series of important changes in the transportation industry (especially in the motor-vehicle and air sectors). Another cost component which has increased in relative price is that of construction costs, as evidenced by the increase in the construction price index compared to the consumer or wholesale goods price indices. Unfortunately, systematic changes over a long period of time for such factors are difficult to predict.

The difficulties associated with valuing travel time have already been noted above. One special problem in forecasting travel time is the effect of incomes. Generally, higher-income individuals place a higher value on travel time savings, and it is generally expected that the average income of the population will be rising over time. Whether or not the value of time will increase correspondingly is debatable.

Finally, errors in analysis also serve to introduce uncertainty into cost estimates. It is difficult, of course, to foresee all the problems which may occur in construction and operation of facilities. There is some evidence that estimates of public infrastructure construction and operating costs have tended to consistently underestimate the actual costs. This is due to the effects of greater than anticipated increases in costs, changes in design during the construction process, or overoptimism.

In this discussion of the sources of uncertainty for forecasting costs, it is important to also note the effect of equilibrium volumes and user costs. The costs associated with a particular alternative are likely to vary with the volume which is attracted, and this volume is, in turn, dependent upon the price of service and underlying socioeconomic conditions. As we noted in the previous chapter, the
socioeconomic conditions cannot be forecast with certainty, so the demand function and, consequently, the equilibrium volume and costs are also uncertain.

While forecasts of costs must be uncertain to some degree, there are a few factors which mitigate this problem. First, the use of a positive discount factor implies that costs which are incurred farther in the future are valued relatively less than costs which are incurred nearer the present. Forecasts of costs in the next few years are likely to be much more accurate, so the overall present value of costs is more accurate than it otherwise would be. Second, given that a number of alternatives are desirable (that is, have positive net present values), the analyst's problem is often one of choosing the best alternative. In this situation the comparison of the differences in costs between alternatives is important, and estimating differences in costs may be more accurate than forecasting their total.

As a final note, the effect of inflation might be mentioned. The analysis of construction, maintenance, and operating costs or of travel time costs should be performed using real or constant value dollars. This may be accomplished by always making cost estimates in real dollars (that is, values in some particular year) and then discounting them to their present value or, less preferably, by making estimates for the dollar amounts actually charged (that is, including inflation) and then discounting these amounts back to the base year at a discount factor which includes not only the rate of time preference (or social rate of discount) but also the rate of inflation. The former method requires fewer calculations and is generally preferable. One qualification in this procedure should be noted, however: over the course of time the price of some factors relative to all others may change. This problem was discussed above. A change in relative price may also be reflected in a differential rate of inflation, so that, for example, the rate of inflation for construction may exceed the general cost-of-living inflation. In discounting future construction costs, the specific rate of inflation might be used. Alternatively, the real increase in relative price of construction might simply be reflected in forecasts of increasing unit construction costs.¹

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12-6 Problems

P12-1. Gillen and Levinson (Transportation Research Record 1662) estimated the following air terminal cost equation from observations obtained from a set of 22 airports for five years each:

\[ TC = 120,000 + 5.7 \times PAX - 0.00000014 \times PAX^2 \quad R^2 = .82 \]

Where TC is total cost and PAX are annual passengers.

a. Suppose you have an airport with four million passengers. Estimate total costs.
b. Again for the four million passenger airport, estimate average total costs and marginal costs.
c. Are average costs rising or falling for this four million passenger airport with respect to passengers served?
d. Suppose you are interested in estimating the total social costs of air travel. What additional categories of costs should you include?

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¹ For those unfamiliar with inflation and discounting, see Cost Estimation (http://pmbook.ce.cmu.edu/05_Cost_Estimation.html) and Economic Evaluation of Facility Investments (http://pmbook.ce.cmu.edu/06_Economic_Evaluation_of_Facility_Investments.html).