From: Morlok

Transport Costs

9. The importance of costs for the transportation engineer can hardly be over-emphasized. The engineer or planner must be concerned not only with the estimation of costs of existing and proposed facilities and operations, but also with the correct interpretation and use of those costs in any analyses or evaluations. In this chapter we shall focus upon methods for the estimation of costs, building upon the characteristics of transport technology and the resources required to provide various transportation services which have been the focus of the preceding chapters. Later we shall be concerned with the evaluation of various transportation projects, including considerations of their costs as well as other characteristics relevant to public and private choices.

COST CONCEPTS

Although by virtue of living in a modern civilization everyone is familiar with many concepts of costs and economics in general, the casual use of many concepts leads to a great deal of confusion and ambiguity whenever a detailed analysis of costs is required. Therefore in this section we shall introduce many cost concepts which may seem familiar, but will attempt to do this with precision so that there will be no ambiguity in the future use of these terms in our quantitative engineering and planning analyses.

Costs to Whom?
The ease with which the term costs is often used is very misleading, in that it implies that there is a single cost associated with providing a good or service. It is true that in principle it may be possible to identify a single total cost to society resulting from producing a product or service such as transportation, but the term usually refers to the cost borne by a particular person, group, or organization, and thus may be very different from the total cost to society.
This multifaceted characteristic of cost arises because in general different costs are borne by different persons or groups, and usually such persons or groups are interested in only those costs which accrue to them. For example, in traveling to work on public transportation, the traveler typically perceives the fare charged to ride and also the travel time consumed. This time is a cost in the sense that it is a scarce resource of the traveler which is given up in order to travel. Also, the traveler may be aware of other costs such as a psychological cost associated with discomfort and perhaps loss of some physical energy in traveling, perhaps as a result of having to stand for a portion of the trip. But in general these costs—the fare plus travel time and related items—are only a small fraction of the total cost of transporting the traveler. The cost to the transit system operator will not include the traveler’s time or discomfort, but it will include operating costs which usually are substantially greater than the revenue derived from fares paid by the travelers.

Also, the operator is usually responsible for some or all of the costs of the vehicles; and in the case of transit operating on its own right-of-way (such as subways and rail rapid transit lines), the cost of providing those facilities may be borne by the authority. Very often, the costs of the facilities and vehicles are partly borne by government, often a combination of the federal, state, and local governments, and any operating deficits might be made up by subsidies from local and perhaps state governments. Thus these primarily monetary costs of providing service will in general be perceived as quite different among different groups, because they are responsible for different portions of those costs.

Furthermore, there may be other costs, such as costs perceived by persons residing near transit lines, who may experience noise and air pollution and loss of aesthetic qualities as a result of proximity to the facility. While these costs may be only indirectly measured in any market transaction, such as a possible reduction in the value of property as a result of these environmental impacts, the residents themselves may perceive a much more substantial cost. And on the other side of the coin, properties near the transit line may increase in value as a result of the greater accessibility given those properties by existence of the line, and this may in fact outweigh any negative effects due to adverse environmental impacts. In addition to these rather direct effects and costs, other effects occurring over a long time period may result in changes in the costs of providing all of the goods and services consumed by persons in the region. More specifically, for example, the presence of the system may result in persons tending to live close to the stations rather than dispersed throughout the region, and this may have a profound effect on the cost of housing as well as the cost of providing the various public and private services necessary for the maintenance of homes within the region. Any changes in the cost of maintaining a given quality of life in the region, as well as changes in the quality of life itself, which occur as a result of the existence of the new transit system, thus may be considered costs (or cost reductions) associated with that system. Even though such long-term effects may be considered very indirect costs at best and are certainly extremely difficult to identify and quantify, it is important to realize that the notion of cost is in fact much more subject to variations in interpretation than a casual user of the term might believe.

In this chapter we shall be primarily concerned with much more direct costs, and primarily with those which are reflected in identifiable market transactions where money changes hands and places a value on resources used. In later chapters we shall consider the effects of transportation systems on the pattern of human activities and the quality of life, partly in terms of costs and partly in other ways.

The example discussed above provides a very widely used classification of groups in terms of their perceptions of transportation costs. These groups can be identified as follows: (1) users of the system, (2) owners and/or operators of the system, (3) affected nonusers of the system (such as those living in residences near facilities), (4) government at various levels, and (5) the region as a whole. This list is in no way meant to be exhaustive or to imply that the groups are mutually exclusive. On the contrary, a person may experience a certain set of costs associated with transportation as a result of her or his use of the system and a quite different set of costs as a result of living near a link in the system, thereby experiencing nonuser costs as identified in the example above. Thus, while the classification is useful and in fact will reappear in later chapters when we discuss the benefits of transportation improvements, there is a very real possibility of double counting, which must be carefully guarded against. With these caveats, the groups are presented in Table 9-1, along with typical examples of the types of costs experienced by each group. Of course, other breakdowns could be used, and others may be more appropriate than that in Table 9-1 for particular kinds of analyses. Also, these five groups may be subdivided into finer divisions, such as into different users of the system or different levels of government, and such subdivisions may be important in particular situations.

The final important point regarding costs in general, is that many of the costs which we have been discussing are not associated with prices of items exchanged in the marketplace. Although most of the costs are quite real, such as the time travelers spend in traveling, very often the traveler is not directly paid (or charged for) the time consumed in travel. (Some obvious exceptions are the operators in the employ of transport agencies.) Thus we may have difficulty associating a money value with many of the costs which we would like to consider. Also, as indicated in the example above, money

<table>
<thead>
<tr>
<th>Table 9-1</th>
<th>Groups Which Experience Different Transport Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Users</strong></td>
<td>Direct prices (fares, tolls, etc.)</td>
</tr>
<tr>
<td></td>
<td>Time consumed</td>
</tr>
<tr>
<td></td>
<td>Discomfort of travelers (fatigue, etc.)</td>
</tr>
<tr>
<td></td>
<td>Loss and damage of freight</td>
</tr>
<tr>
<td><strong>System owner-operator</strong></td>
<td>Direct costs of construction, operation, maintenance</td>
</tr>
<tr>
<td><strong>Nonuser</strong></td>
<td>Changes in land value, productivity, etc.</td>
</tr>
<tr>
<td></td>
<td>Environmental degradation (noise, pollution, aesthetics, etc.)</td>
</tr>
<tr>
<td><strong>Government</strong></td>
<td>Subsidies and capital grants</td>
</tr>
<tr>
<td></td>
<td>Loss of tax revenues (e.g., when road or other publicly owned facility replaces tax-paying land use)</td>
</tr>
<tr>
<td><strong>Region</strong></td>
<td>Usually indirect, through reorganization of land uses, altered rate of growth, etc.</td>
</tr>
</tbody>
</table>
The transportation system and its environment

prices paid for transport services may or may not reflect the costs of providing that service. There may even be no relationship between the price paid or the total revenue received from the transportation service and the direct money cost of providing that service. Also, other costs might not be reflected in money transactions. Thus we must be careful to distinguish between the term cost and the term price.

Fixed and Variable Costs
Fundamental to any discussion of costs is the cost-output curve. This curve relates the total cost of providing a particular good or service—in our case a transportation service—to one or more measures of the amount and characteristics of the good or service provided—in this case, again, presumably a measure of the quantity and quality of transportation service. The cost is usually the total monetary cost experienced by the firm or agency providing the service, although the cost may be defined differently, perhaps as only a portion of that monetary cost or perhaps including other costs (such as a value of traveler's time, for example). Thus it is important to specify clearly what costs are included. The measure of output varies considerably among applications, but at the minimum includes a measure of the quantity of transportation service provided (e.g., the ton-miles of freight carried).

More complicated specifications of output might involve many variables, such as the tons of freight carried, perhaps broken down by commodity and distance carried, and the number of passengers carried, perhaps broken down by their origin and destination. The choices of the costs to be included and the measures of output depend very much upon the particular application.

An example of such a cost-output curve, involving a single measure of cost and a single measure of output, quantity, is presented in Fig. 9-1. In cost-output functions such as this, where there is only a quantity measure of output, it is presumed that all other characteristics of the output remain fixed; that is, the nature of the product, such as the quality of transport service, remains unchanged with quantity of output. This is often described in economic analyses as the product being homogeneous. The upper portion of Fig. 9-1 presents the total cost as a function of quantity of output. Total cost can be divided into two components: fixed cost and variable cost. As the name implies, the fixed cost remains the same regardless of the total amount of output; they are written with x, the output variable, appearing in parentheses after the designation of the two costs, as follows: TC(x) and VC(x). The fixed cost is designated FC. These and many other common symbols in economics consist of more than one letter. To differentiate these from the product of two or more symbols, we shall use roman capital letters for such multiletter symbols, in contrast to the capital and lowercase italic letters used for symbols consisting of single letters.

The lower portion of this figure presents two other important ways of presenting costs as a function of output. One of these is the average total cost, which is simply the total cost of any given amount of output. In equation form, the total cost, by definition, is

\[ TC(x) = FC + VC(x) \]  

(9-1)

The average cost (average total cost) is

\[ AC(x) = \frac{TC(x)}{x} = FC \frac{1}{x} + VC(x) \]  

(9-2)

where \( AC(x) = \) average cost

The other curve presented in Fig. 9-1\( b \) is the marginal cost. The marginal cost is defined as the additional cost associated with the production of an additional unit of output. In the equation form the marginal cost of the x\( th \) unit of output is

\[ MC(x) = TC(x) - TC(x - 1) \]  

(9-3)

The equation above is for marginal cost in situations where the output must be produced in integer quantities. In most cases the quantity of output is
treated as a continuous variable. For example, in Fig. 9-1 it might be trains per day, over a given line, and the output could be measured as an average over a fairly long period of time; as a result, a noninteger output is possible. In cases where the output can vary continuously, the differential form of marginal cost is used, in which the marginal cost is the rate of change of total cost with respect to a change in output. In this form, the equation is

$$\text{MC}(x) = \frac{d\text{TC}(x)}{dx} = \frac{d\text{VC}(x)}{dx}$$

(9-4)

One additional concept often used is that of average variable cost, which is defined as follows:

$$\text{AVC}(x) = \frac{\text{VC}(x)}{x}$$

(9-5)

In this example, the average costs decrease over a range of volume from 0 to 8 trains/day, and increase thereafter. The reason for this can be understood from the geometry of Fig. 9-1a. The average is proportional to the slope of a line connecting the origin of the total cost curve with a point on that curve corresponding to the total output. The slope of such a line begins at (plus) infinity at zero output and then decreases with increasing output up to a level of 8 trains/day, at which point the line is tangent to the total cost curve. Beyond that output level, the slope is increasing again; as a result, it is shown in the total cost curve.

The marginal cost curve, as the equation above reveals, is the slope of the total cost curve. As can be seen from the total cost curve, its slope is decreasing with increasing output over a range up to approximately 3 trains/day, beyond which it increases. Furthermore, the slope of the total cost curve is less than the slope of the average cost (line from the origin to the total cost curve at the output level under consideration) up to the output level of 3 trains/day, at which point the two coincide since the average cost line is tangential to the total cost curve at that point. At this point then the marginal cost and the average total cost must be equal, which is shown in Fig. 9-1b. In fact, since the marginal cost is less than the average total cost for all output levels up to this point, the average total cost decreases over this range, for each additional unit of output adds an additional cost (a marginal cost) that is less than the average up to that point. As a result, including the unit and its associated cost reduces that average. Beyond the output level of 8 trains/day, where these two cost curves cross; the marginal cost is greater than the average total cost. As a result, increasing output tends to pull up the average total cost, again as shown in the figure. The marginal cost curve always intersects the average total cost curve at the lowest point on that cost curve.

The total cost function shown in Fig. 9-1 has the shape it does for illustrative purposes only. In many but not all situations costs is found to increase slightly with increasing output and then increase very substantially after output exceeds a certain level. The form depends upon the particular process being considered and the technology being used, as well as the way in which the costs of the various resources used vary with different amounts of those resources used.
be hauled from A to B may be much greater than that from B to A, and as a result even though trucks operate full from A to B, many may operate completely empty from B back to A. The cost of operating these trucks (which, of course, must be operated from A to B and then back to A again in order to be available for use again), necessarily involves the production of transport capacity not only from A to B, but also from B to A. If all the trucks operate loaded rather than empty from B to A, it would add only a very small amount to the total cost of operation, such as in additional fuel and wear and tear on the vehicles (remember the analyses of fuel consumption based on propulsive work, which depends in part upon the weight of the vehicle and its load, found in Chap. 4). Thus many if not most of the costs involved in movement of freight between these two towns are joint costs associated with movement of vehicles in both directions, regardless of the traffic. It might be noted that joint costs are also often termed common costs in some of the older economics literature.

It should be noted that the existence of a joint cost situation depends solely upon the necessity, due to the technology used, or perhaps institutions or regulations, of producing two or more products simultaneously, regardless of whether both or all of them are desired. It in no way relates to the difficulty of allocation of costs between two services or products. There may be many situations where it is difficult to identify exactly what costs are associated with what products, but the costs are not joint. An example in the transportation sector is the provision of a railway track maintained to standards appropriate for both freight and high-speed passenger trains. Separate maintenance is not performed on the same track for the two types of trains. As a result it may be difficult to decide exactly what additional maintenance is required to accommodate passenger trains at higher speeds. This does not mean that the maintenance is entirely a joint cost. In principle, it would be possible to conduct experiments to determine exactly what cost is incurred in maintaining the track for freight trains and then to continue that experiment with the operation of freight as well as passenger trains to determine the additional cost associated with the higher level of maintenance.

Indivisible Costs

Although in the minds of many persons fixed costs are associated with indivisible costs, the two concepts are really quite different. Fixed costs are incurred regardless of the level of output of a particular product or service. Indivisible costs refer to costs which cannot be reduced if a certain range of output is to be provided. This indivisibility presumably reflects the technology of the processes involved. All indivisible costs are not necessarily fixed, because an indivisible cost is not fixed until a commitment has been made actually to incur that cost. Furthermore, certain indivisible costs may be incurred at higher levels of output, resulting in no change in cost over some range of output, above and below which range that particular indivisible cost is not incurred, so that that indivisible cost is a variable rather than a fixed cost.

As an example, consider a railroad line between two cities. At certain ranges of traffic to be carried, a single track may be quite adequate, the cheapest possible single track representing the fixed cost of providing any railroad service whatsoever between these two points. As traffic increases, costs increase, reflecting in part additional locomotives and cars, and in part probably more sophisticated train control systems, perhaps some double track or passing sidings, etc. At some point it may be absolutely necessary to install a complete double track in order to accommodate any additional traffic, and this double track may be adequate to accommodate a considerable increase in traffic. The least expensive double-track installation then represents an indivisible cost in order to enable the provision of transport capacity over that range. However, as this discussion has clearly indicated, the cost of that double track is in no sense a fixed cost until an actual commitment has been made to install it and incur the expenditure—presumably a commitment that would not be made until there is a reasonable expectation that the double track will be necessary because of the volume of traffic.

It might be noted here that there is often considerable indivisibility in transport costs. Very often this seems to arise largely because of institutional constraints on engineering designs and the way in which systems are operated, rather than because of the technology. An excellent example is provided by the cost of road capacity. In many cases, there are design standards for lanes which require a particular lane width, such as at least 13 ft on the United States Interstate and Defense Highway System. Such lanes, at typical land and road construction costs, yield a cost versus capacity relationship as shown in Fig. 9-2. This relationship portrays capacity levels at level of service B, the most common level of service standard for traffic on that system in rural areas. However, if one were to allow lane widths to be varied, at low

Figure 9-2 Indivisibilities in transport costs and their reduction through design changes. Notes: Capacities are based on the relationships in Committee on Highway Capacity (1965). Costs are based on those for freeways in fringe areas of metropolitan areas of over one million population, of $120 million per lane-mi for construction and $1.11 million per lane-mi for land cost, assuming 13-ft lanes, taken from Sanders et al (1974, pp. 4-12 and 4-14).
traffic volumes (and hence lower design capacities), a narrower pavement could be provided, at a reduced cost. At these low volumes, that narrower pavement would still permit traffic to flow at the same speed and with the same other characteristics as level of service B. As volume and capacity increased, the width of the lanes would be increased appropriately, ultimately reaching 13 ft where required. By use of the methods presented in Chap. 5, derived from the Highway Capacity Manual (1965), the capacity of various combinations of lane widths and number of lanes up to and including a total pavement width of 39 ft (three 13-ft lanes) can be calculated. Using the same freeway cost-estimating relationships, the costs would then be as shown in Fig. 9-2. As can be seen, the costs for roads in which the widths can be varied in increments of 1 ft rather than increments of 13 ft increase much more gradually. Thus, much of the lumpiness or indivisibility of highway costs can be avoided. It is not the purpose here to argue that such a wide latitude in the design of road or transport facilities should be provided, for there are many other considerations (such as the expectations of drivers of standard lane widths and types of facilities), but merely to point out that much of the lumpiness or indivisibility in transport facilities is really due to regulations and design standards, rather than inherent characteristics of the technology.

Future Costs and Present Value

The engineer and planner must be concerned with future costs as well as present costs because so much of professional practice is devoted to planning and design, which by definition relates to future actions. It is essential that the costs as well as the benefits of transportation systems be considered through all phases in the life cycle of such systems, including planning, construction, design, operation (including maintenance, etc.), possible renovation, rehabilitation or replacement, and finally possible abandonment. While our attention in this chapter is devoted to the costs over the life cycle, similar considerations will arise in the benefits of transportation systems, so many of the concepts introduced for cost analysis will reappear when we consider benefits in future chapters.

In general, costs vary considerably from one stage in the life cycle to another. For example, in the case of a new highway facility, a relatively small cost would be incurred during the planning and design phases, and this cost would increase to a very large amount during the construction period (involving purchase and clearing of right-of-way, as well as direct facility construction), and then typically a somewhat lower cost would be incurred during the period of use, this cost increasing as traffic increases and as maintenance becomes more intensive with age, and then this entire cycle of costs may reappear with substantial renovation or replacement of the facility. If the facility were ever abandoned, then there would be a negative cost in the form of revenue accruing from the sale of land and positive costs associated with possible demolition and readying of the land for alternative uses.

It would be inappropriate simply to sum the costs occurring in different years. The reason this is incorrect can be understood by considering a hypothetical situation in which the value of $1 now is compared with its value in the future. Specifically, that dollar will be invested in a savings account or other suitable investment medium so that it earns interest with the passage of time. As a result of the earning of interest, the $1 deposited now, earning an interest of (10%) percent per year, will yield the following amounts:

- 1 year hence: $1(1 + i)
- 2 years hence: (Value of $1 one year hence)\(\left(1 + i\right)\)\(\left(1 + i\right)\) = $1(1 + i)^2
- 3 years hence: $1(1 + i)^3
- N years hence: $1(1 + i)^N

It is thus apparent that the future value \(FV\), of an amount of money \(N\) years from now is related to its present value \(PV\) by the equation:

\[ FV = PV(1 + i)^N \]

where \(FV\) = future value \(N\) years hence
\(PV\) = present value
\(i\) = interest rate per year, decimal fraction

Rearranging this relationship, we can specify the present value of any future amount of money:

\[ PV = \frac{1}{(1 + i)^N} \]

The factor \( (1 + i)^{-N} \) is the factor which relates the future value to the present value. This factor is called the present worth factor and it is given by the following equation:

\[ PWF_{i,N} = \frac{1}{(1 + i)^N} \]

where \(PWF_{i,N}\) = present worth factor at interest \(i\) for \(N\) years

When multiplied by the appropriate present worth factor the future value is converted to its present value, or more generally, a given amount of money is converted to its value \(N\) years earlier given the interest rate \(i\). For ease of reference to other books, it might be noted here that two other common symbols for the present worth factor are \(PWFR\) which differs from our notation only in the use of lowercase symbols, and \(P\) \(F\), where \(P\) is present value, \(F\) is future amount, \(r\) is interest rate, and \(n\) is years in the future, the latter notation having been suggested by the Engineering Economy Division of the American Society of Engineering Education.

The effect of the present worth factor is to decrease the value of an amount of money exchanged in the future to its equivalent present value. The extent to which future values are reduced, or discounted, to present value is revealed by Fig. 9-3. The present value of $1 twenty years from now is only 31 cents at an interest rate of 6 percent, and only 15 cents at an interest rate of 10 percent. Thus the greater the interest rate, the lower the present value of any future amount of money. Similarly, the greater the number of years in the future when $1 is received, the lower the present value. Table 9-2 presents the present value factors associated with various numbers of years into the future and various interest rates.
tained. Also, it is very easy with this type of cost model to estimate marginal costs, variable costs, etc., since this usually is simply a matter of combining the costs of certain portions of all of the factors of production used. These concepts can be illustrated by considering an example.

**Example of Rapid Transit Costs**

In order to illustrate the use of engineering cost models, we will develop the total cost and various cost components of the rail rapid transit line which served as an example for describing the operation of plans and integrating the various relationships from Chaps. 4 through 7, in Chap. 8. As you may recall, this line is 15 mi in length and is to be operated with a required capacity of 32,000 persons/day in each direction. During each of the two 2-h peak periods, 8000 passengers/h in the peak flow direction are to be accommodated; this is done by operating 5-car trains, each with a capacity of 500 passengers at a headway of 3.75 min for a train flow volume of 16 trains/h. During the other periods of the 16-h operating day, 3-car trains, seating a total of 156 passengers, are operated on an 8-min headway for a capacity of 1170 passengers/h, somewhat in excess of the required 1143 passengers/h. To operate this service requires a fleet of 120 cars. During each weekday, 4620 train-miles are operated, and 17,700 car-miles are operated. On this line there are 30 stations.

The typical form in which unit costs are used for the estimation of transit costs is shown in Table 9-7. Fixed facility costs are estimated on the basis of the costs of two-track lines recently constructed. In 1973 the cost of surface, grade-separated line construction averaged $4.22 million/mi. Using a life of 30 years and an interest rate at 10 percent, which results in a capital recovery factor of 0.106079, the cost per day (365 days/year) of such a guideway is $1226.45. Stations for 5-car trains cost $1 million each, which, with the same life as the guideway, results in the cost shown. The cost of vehicles of the type used (50 seats, with room for about 25 standees) was about $300,000, which, with a 25-year life, a 10 percent interest, and a maintenance reserve of an additional one-sixth of the fleet, yields a daily cost of $105.64. Closely related to this cost is the cost of yards and shops for the cars, which, at $15,000/car and a life of 15 years, results in the costs shown. Thus the cost of fixed facilities and vehicles is directly related to the miles of double-track route, the number of stations, and the number of cars required.

Operating and maintenance costs are divided into a number of components. In transit, usually the costs of operating labor—train operators, guards, and station attendants—are separated from the other costs, primarily because these costs depend very much upon the peak of traffic and the size of trains operated, items which may vary from year to year and with management policies. The maintenance of track, structures, and stations has been found by statistical analysis to depend in part upon the passage of time and in part upon the traffic on the line. Thus this cost consists of two components, $28.70/day/double-track mi and $0.239/car-mi. The maintenance of cars is a function of their usage, as shown. Other costs of vehicle operation, mainly electricity and the costs of various train control activities, is $0.433/car-mi. Train crews, consisting of a motor operator and a guard, cost $121.92/day, with the requirement that once called on duty, a crew must be paid a minimum of 8 h. Also, in this particular case, crews are allowed to work for any length of time up to and including 8 h within a period of 12 h, enabling one crew to cover both morning and evening peak operations with a rather lengthy break in between. On some transit properties, the fraction of crews that work such split or "swing" shifts is limited to 30 to 50 percent. The cost of station agents depends upon the number of such agents, each of whom works an 8-h day. Finally, there is the administration cost, which is taken as 10 percent of all other operating costs. The resulting costs, then, are unit costs which are multiplied by the number of the various units involved, such as double-track route-miles or car-miles. The exact form of the resulting cost equation is

$$TC = L + 111.04c + 0.982m + 134.11d + 41.29d,$$

where

- $L = \text{one-way line length, mi}$
- $c = \text{number of cars required}$
- $m = \text{number of car-mi/day}$
- $d = \text{number of paid train-crew-days/day}$
- $d = \text{number of paid station-agent-days/day}$

In order to use these unit costs and the above model, all of the factors or units are known from the analysis previously conducted in Chap. 8 with the exception of the number of crew-days and station-agent-days. Since there are 30 stations, each of which is open 16 h/day, a minimum of 60 station-agent-days/day of operation will be required if fares are to be collected at the stations (although on some rapid transit lines fares are collected on board the train at lightly used stations during low-traffic periods). Here we shall assume 60 station-agent-days are required per day; 12 trains are in operation

### Table 9-7: Unit Costs for Example Rail Rapid Transit Line†

<table>
<thead>
<tr>
<th>Category</th>
<th>Daily cost ($/route-mi)</th>
<th>Cost ($/car-mi)</th>
<th>$/crew-day</th>
<th>$/station-agent-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guideway (at grade)</td>
<td>1228.45</td>
<td>105.64</td>
<td>5.49</td>
<td></td>
</tr>
<tr>
<td>Stations (2 mil)</td>
<td>581.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>1867.71</td>
<td>111.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating and maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance of way and structures</td>
<td>28.77</td>
<td>0.239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance of cars</td>
<td>31.65</td>
<td>0.211</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle operation</td>
<td>31.65</td>
<td>0.211</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Train crews (2 people)</td>
<td>121.92</td>
<td>37.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Station agents</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administration and other</td>
<td>2.68</td>
<td>0.089</td>
<td>12.19</td>
<td>3.75</td>
</tr>
<tr>
<td>Subtotal</td>
<td>31.65</td>
<td>0.982</td>
<td>134.11</td>
<td>41.29</td>
</tr>
<tr>
<td>Total expenses</td>
<td>1693.36</td>
<td>111.04</td>
<td>134.11</td>
<td>41.29</td>
</tr>
</tbody>
</table>

† Adapted from Marick (1965) and Sanders et al. (1974), both in 1973 prices.
throughout the 16-h operating period at any one time, with an additional 12 trains being in operation during each of the two peak periods. Given the possibility of swing shifts, a reasonable way to staff these trains is to employ two groups of 12 train crews each, one for the first 8 h of operation and one for the second 8 h of operation, plus additional 12 crews on a swing shift covering both peaks. This results in a need for 36 train-crew-days/day.

With these computations of the number of units or factors required, Eq. (9-18) can be entered and the resulting total costs estimated, as below.

\[
TC = \$1839.36/\text{route-mi-day}(15 \text{ mi}) + \$111.04/\text{car-day}(120 \text{ cars}) \\
+ \$0.982/\text{car-mi}(17,700 \text{ car-mi/day}) \\
+ \$134.11/\text{crew-day}(36 \text{ crew-days/day}) \\
+ \$41.29/\text{station-agent-day}(60 \text{ station-agent-days/day}) \\
= \$65,601.96/\text{day}
\]

Thus the total costs of operation of this system are \$65,601.96/day. This results in a cost per seat-mi of exactly 7 cents, where the seat-miles are estimated on the basis of the required levels of capacity, some of which are exceeded for operating convenience. It is interesting that of this total cost, \$40,915.20 is due to the cost of fixed facilities, the minimal maintenance required to keep the line ready for use, and the cost of ownership of the cars, this being about 62 percent of total cost. Only 37.6 percent of the total cost is devoted to the actual operation of these trains, labor costs, etc. For more typical rapid transit lines, which involve some elevated or subway construction at a much higher cost than \$4.22 million/double-track mi and \$1 million/station, the ratio of fixed costs to variable costs would be even greater.

Another interesting analysis is that of the marginal cost of accommodating additional traffic in the peak and base periods. In the midday period the cost of operating an additional train trip is only \$85.38, this being the additional cost associated with the additional car-miles operated, since both vehicles and crews are available and stations are fully staffed in that period. This results in a cost of 29.5 cents/seat in each direction. In the peak period, however, to operate an additional train requires the purchase of the cars for that train and the hiring of an additional crew. If a 3-car train were added, the additional cost for two round trips, one in the morning and one in the evening, would be \$643.96. The cost per seat provided in the peak direction would be \$1.073, all the cost being associated with the peak direction since excess capacity is provided in the other. This graphically illustrates the disparity in marginal costs of accommodating additional traffic between the peak and the midday period, which is often the reason why transit lines charge much lower fares in the midday period.

Figure 9-6a presents the relationship between total cost of this transit operation and the daily volume of traffic. Trains are operated at the same headway as assumed for the preceding example, with train length being varied to achieve variations in peak capacity. Also, where possible, trains during the off-peak period are reduced in length, under the assumption of the same ratio of required capacity in the midday period to that in the peak as was used in the preceding example. The cost relationship takes the form of a step function because of the discrete variations in train length possible. Also shown in Fig. 9-6b is the cost per seat-mile as required by capacity considerations. The high portion of fixed cost is very evident, but it results in a cost per seat-mile which drops markedly with increasing traffic. It should be noted that in general the utilization of seat-miles on urban public transit is quite low, because of the inherent peaking and directional split of traffic, as discussed in Chap. 8, which results in a cost per passenger-mile often three or more times the cost per seat-mile. The magnitude of these costs and the effect of increasing required capacity (or traffic) graphically indicates why rapid transit lines are generally limited to routes with fairly high volumes of passenger traffic.

Now that the two approaches to cost estimation and the examples have been introduced, it is appropriate to turn to typical cost models.
extremely cheap, pipeline and rail movement are typically somewhat more expensive. Water carriage is also among the cheapest for merchandise traffic, although under favorable conditions rail movement can be as inexpensive. However, these values underestimate the true cost of water transport because water carriers use government-provided waterways free of charge. The cost of moving freight by truck varies considerably, primarily because much truck traffic consists of small packages which, due to the extra handling involved and a typical low density, results in a high cost per ton-mile. Trucking costs per ton-mile also increase as shipment size decreases and length of haul decreases. In these estimates of rail costs, 30 percent has been added to the line-haul cost to reflect yard and local freight cost, this being typical of the values found in the study. trailer on flat car (TOFC) or "piggyback" service appears quite attractive according to these estimates; it achieves costs almost as low as regular rail carload for merchandise movement and also has the ability of the truck to pick up and deliver freight to destinations removed from rail lines.

To bring these costs up to date, average revenue per ton mile in 1973 for these carriers is shown in the last column. This is, of course, an underestimate of cost, the amount of the overestimate being equal to profit and general taxes (as opposed to taxes for the use of facilities such as highways). However, profits in the transportation sector, as well as general taxes, are not so great that this significantly distorts the relative costs of the carriers. In interpreting these averages, though, one must recognize that differences in the length of haul, size of shipment, and the types of commodities shipped can make it appear as though there are more substantial differences between modes than actually exist. In particular it is likely that the long haul and relative high density of many commodities moving by rail in contrast to truck, in addition to the use of truck for a substantial amount of small parcel freight, magnifies the difference between rail and truck costs considerably. Also, the same differences probably make comparisons between water and pipeline on one hand, and railroad on the other, somewhat misleading.

General Relationships
In discussing the cost characteristics of various modes of transportation, the reader has undoubtedly noticed a number of relations between cost and characteristics of the transportation service provided which are common to all modes. While there are always exceptions to generalizations, many seem to hold rather widely, so it is useful to summarize them here.

One important generalization is that average total cost on any given transport system tends to decrease with increasing volume, holding level of service constant, up to a fairly high volume. This reduction in average cost is termed an economy of scale in economics. It usually results from the presence of some fixed costs spread over more units of output with increasing volume, and also from an ability to use resources more efficiently with more traffic. However, at some point diseconomies set in, such as might be due to problems of congestion or difficulties in managing effectively a large enterprise, resulting in an increase in average costs. Of course, the exact form of the cost curves, and the point where diseconomies set in, depends on the technology of transport, the network, characteristics of the traffic, the effectiveness of the management, and many other factors. The general form of the cost curve is illustrated in Fig. 9-1.

Figure 9-10 Typical relationship between cost and traffic volume, (a) Total cost vs. volume, (b) Average total cost vs. volume. Note: Level of service held constant.

Often scale economies can be increased by altering the technology used at high volumes. This is usually accomplished by investments which increase fixed costs but decrease variable costs. This is illustrated in Fig. 9-9 by a road example, but the same principle applies to all modes. Figure 9-10 portrays this for a more general case in which diseconomies are also portrayed, for two different levels of investment, system A having a lower investment than system B. Sometimes A and B are interpreted as different technologies, such as truck (A) and rail (B), but one must guard against excessive generalization, particularly between such different technologies.

Also, usually there is an increase in cost with improved levels of service, such as reduced travel time or increased reliability. In the case of speed, this is due to the need for a guideway designed for higher speeds, more powerful vehicles, greater fuel consumption, a more sophisticated control system, and so on. However, it is important to note that at some point, decreases in the level of service will result in increases in costs. This usually results from such factors as low utilization of equipment and labor resulting from low speeds, and the consequent need for more resources to handle any given amount of traffic. Thus the general relation between cost and level of service appears as in Fig. 9-11. Only average total cost is shown in this figure, since total cost exhibits exactly the same relation because the total volume is fixed. Of
Transport costs

Figure 9-12  Typical relationship between average cost and freight shipment size or number of persons traveling together. Average cost per ton-mile or person-mile

![Graph showing the relationship between average cost and freight shipment size or number of persons traveling together.]

Another useful generalization is that the average cost of transport per unit carried decreases with increasing size of shipments or number of persons in a party traveling together. In the case of persons, an obvious example is the reduction in the cost per person of automobile travel resulting from more persons in the car. The cost increase due to more passengers is so small it is hardly noticed, resulting in average costs essentially inversely proportioned to the number in the car. For large groups, a bus can be chartered, usually with further savings. In freight transport, some of the costs are fixed per shipment regardless of its size, resulting in reduced cost per ton-mile with increasing size, holding length of haul and other factors constant. And when the shipment is sufficiently large to fill an entire vehicle, terminal handling is reduced or eliminated, further reducing average costs. Thus the general relationship portrayed in Fig. 9-12 holds for most transport situations. Different technologies possess different characteristics in this regard, as illustrated by curves A and B in the figure. Curve A might reflect auto travel, while B might reflect charter bus travel.

A final generalization is one made in Chap. 2: the transport cost for any shipment (or person(s) traveling together) consists of a component which is invariant with distance and another which increases with increasing distance. This is illustrated in Fig. 9-13. Total cost thus increases with distance, but average total cost (e.g., per ton-mile or passenger-mile) will decrease with distance. Again the relationship will vary by mode, size of shipments, etc. Often curves such as A and B will be used to describe difference between modes, curve A representing a system with low non-distance-related costs and relatively high distance-related costs, compared with a system described by curve B. For example, curve A might represent truck movement and curve B "piggyback" movement, the extra non-distance-related cost reflecting the added terminal cost of drayage to and from the rail terminal and the loading and unloading process, and the lower distance-related cost reflecting rail movement in trains vs. single trucks.