Demand, Cost, Price and Capacity Relationships Applied to Travel Forecasting

MARTIN WOHL, Transportation Consultant to Assistant Secretary for Science and Technology, U. S. Department of Commerce

• SOME of the more recent travel forecasting research and studies have dealt with the feedback mechanism between trip distribution and capacity, and between route assignment and capacity. In other words, these studies have recognized the interdependencies among assigned or distributed volume, travel time (or travel "resistance"), and route or system capacity. A generalized form for the travel forecasting process which includes these feedback loops is shown in Figure 1.

To understand the interworkings of this forecasting model or process, and its implied interdependencies, it will be helpful to make use of some simplified capacity-demand-cost principles and relationships and to illustrate how these may in turn be used to relate explicitly the design variables. The value of this "conceptual" and "academic" exercise will be to indicate in more precise terms the nature and form of the information that will be required to make more accurate travel forecasts (or perhaps to reduce the computations involved).

GENERAL PRICE, VOLUME, AND DEMAND RELATIONSHIPS FOR FIXED CAPACITY SYSTEMS

For any particular system whose physical capacity or ability to accommodate traffic volumes is "fixed" (in the sense of having a definite number of roadways of specific widths, intersections of fixed approach widths and with specific control devices, etc.), the amount of capacity may also be described as its "supply." Although the system capacity is unchanging or fixed, the volume which uses the system at different times may, and usually does, change quite considerably. And from experience it is known that any particular system does not necessarily offer a fixed or constant level of service; in general, for a particular capacity level as the entering or input volume changes so does the resulting level of service. (The relationship between volume and speed on freeways is a well-known example.)

The level of service which the traveler experiences or must endure (at some particular level of volume for a given system capacity) shall be defined as the price of travel, where price is defined in terms of the combined difficulty of travel, required time for travel, hazard and discomfort of travel, and expense of travel as viewed by the traveler.

The price paid by the traveler need not be equal to the actual cost to provide that travel service and capacity. The price to the traveler may actually be less or more than that paid by the public at large for his using the facility. In order to predict how many travelers will use a particular facility, the actual cost of providing transportation is irrelevant; the only matter of concern is what price the motorist or traveler will have to pay if he travels (where price is stated in whatever terms the traveler imputes). Thus price of travel may be thought of as cost to the traveler and not as true cost. Also, price as described here includes much more than the out-of-pocket money expenses associated with travel.

A price-volume curve is used to show the relationship between actual price of travel and the volume using a particular facility or system of fixed capacity, and, generally,

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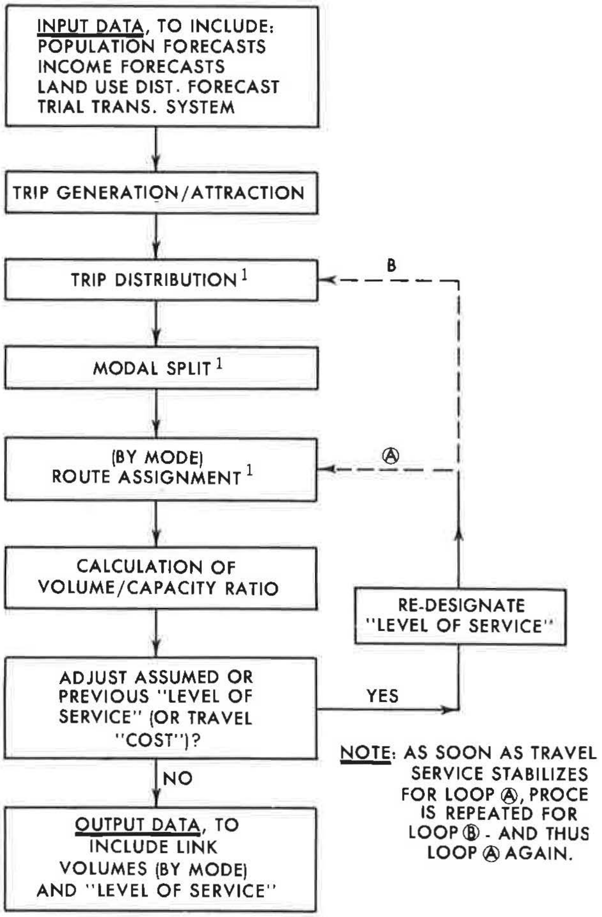


TRAVEL FORECASTING PROCESS

1/FOR THE INITIAL ITERATION, THE "LEVEL OF SERVICE" RESULTING FROM ASSIGNED FLOW AND LINK CAPACITY IS ASSUMED.

Figure 1.

the curve may be characterized somewhat as in Figure 2. This curve is just another way of saying: If the volume increases, the price of travel to the individual traveler will change as indicated. On the other hand, no information is provided or implied regarding how many travelers will use the facility or what the demand will be.

The solid curve (Fig. 2) shows the price-volume relationship for public highways operating under existing taxation methods. With these methods, the highway user and excise taxes paid by the individual traveler on using a particular facility do not vary with the construction and land acquisition cost of that facility or with the volume using the facility (except in almost negligible amounts). In such a case, the user and excise charges that the traveler pays are only a small fraction of the total price of travel; his vehicle ownership charges, time, discomfort and inconvenience costs outweigh his user charges by ten to twenty times.

On the other hand, it should be evident that such a single price system of taxation for facility construction, right-of-way, maintenance and administration (regardless of

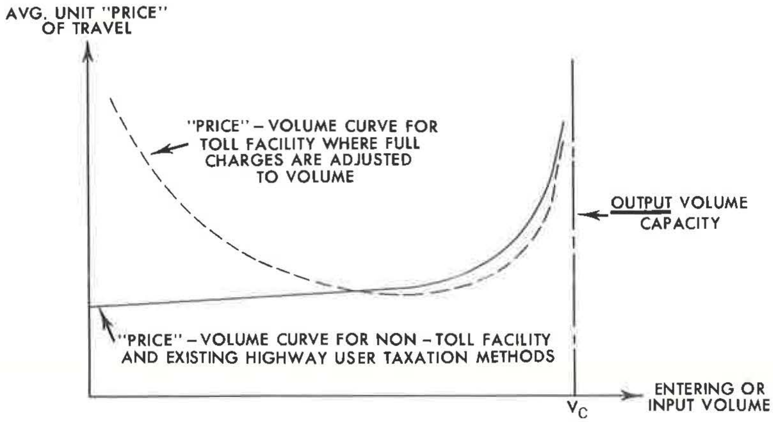


Figure 2.

the actual facility costs and regardless of the volume using the facility) produces some inequities. In short, it results in undercharging the users at low volume levels and overcharging them (for the facility costs) at high volume levels. The dashed curve (Fig. 2) indicates the price of travel for the case where the facility costs are adjusted to the particular volume using the facility. At low volume levels where the threshold or fixed costs are spread over a very low volume of traffic, the unit construction and right-of-way costs are quite high and are a major portion of the total price of travel paid by the motorist. As the volume rises these same construction and right-of-way costs are spread over a much larger volume; thus the unit cost for construction and right-of-way is reduced, and becomes a smaller portion of the total price of travel for the motorist (again, to include time, discomfort, inconvenience, etc.).

Both of the pricing systems are average cost pricing schemes; that is, at any particular volume level, the charge for facility construction and maintenance is the same to any motorist. But the latter scheme permits scale economies to be reflected in the charge to the user. Furthermore, the former scheme—where the user charge remains constant for all volume levels—is more characteristic of the present-day, public highway system and thus provides a more realistic description of the actual price of travel to the motorist. Thus the solid curve (Fig. 2) should normally be used in travel forecasting analyses. On the other hand, for toll facility forecasting, where the toll fee is adjusted according to the particular (long-run) volume level, the dashed curve would be the proper one.

Particular note should be made of the definition of volume level. The solid curve in Figure 3 demonstrates the relationship between price of travel and the entering or input volume for a facility or system of some fixed output capacity. As the arrival or input volume approaches (or exceeds) the output capacity, and is sustained at that level, the price of travel (that is, delay, etc.) becomes indefinitely large as the queue length on the approach ramps to freeways or on approaches to intersections continues to build up. A key word here is, of course, sustained. If, for example, the input volume rate exceeds the output volume rate only for a few minutes or for a fraction of an hour but then falls below the output volume rate for the remainder of the time, it is clear that the delay and thus price of travel will not become indefinitely large. Thus, it must be emphasized that the price-input volume curve is characteristic only for a given time period. If the time period changes, so will the shape of the curve, particularly as the input volume rate approaches the output rate (Fig. 4).

In all systems or on all facilities, regardless of the type of control, the arrival or input volume can and often does exceed the output volume; in fact, in urban areas evidences of this are seen almost every day during the peak periods. Traffic backs up on freeway ramps or connecting city streets; or queues build up along arterials or on ap-

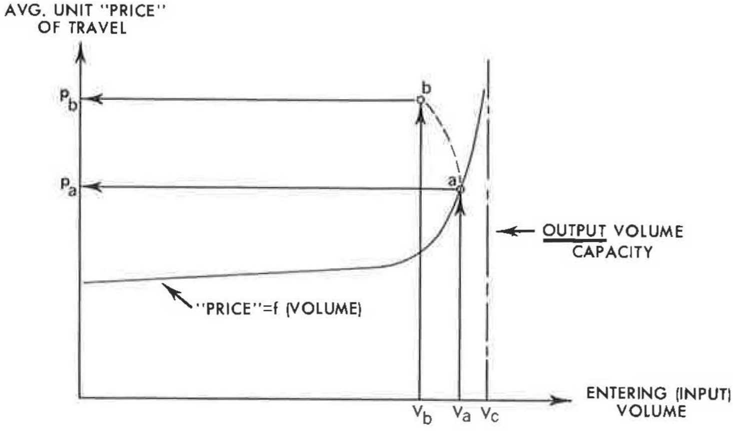


Figure 3.

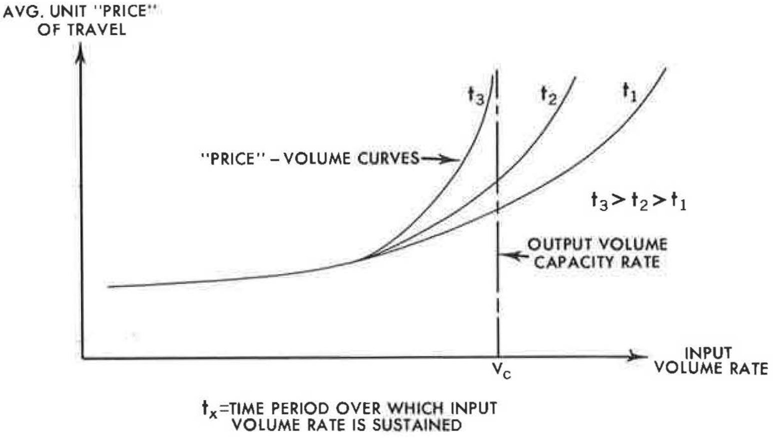
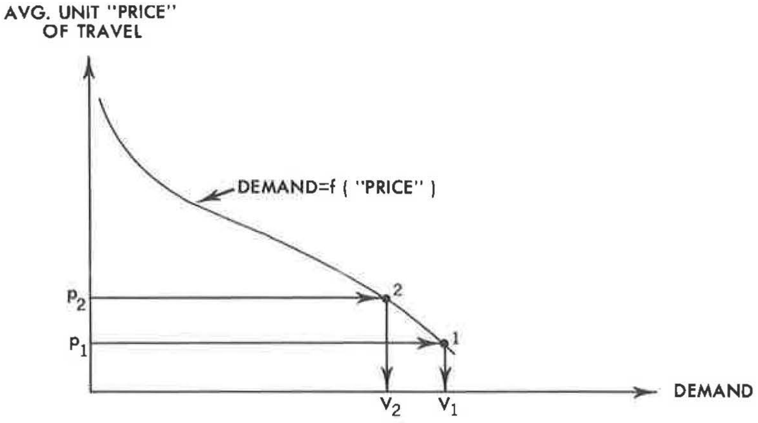


Figure 4.

proaches to intersections, etc. (While the traffic in many cases cannot actually enter the facility in question, but must wait on the side street, this analysis shall consider it as entering or input volume.) Frequently, though, it is suggested that such is not the case (that is, that input does not exceed output) by considering only part of the system rather than the entire framework. For example, in examining the flow actually passing through a tunnel or through the bottleneck area of a freeway, the phenomenon described by the dashed curve in Figure 3, or the so-called backward-bending curve, is often observed. One might be led to say that the demand was being reduced. On the other hand, such is not necessarily the case. This curve, in fact, only demonstrates the relationship between price of travel and output volume; furthermore, it indicates that the performance of the facility is such that the output volume capacity is being reduced because of shock action congestion. And, again, while the output volume is being reduced (from a to b), the input volume and its price of travel can still be increasing. The dashed curve therefore only provides price of travel for the output volume—and not for the input volume. The price for the input volume still increases indefinitely as the volume approaches and exceeds the output capacity. Since the output capacity is shifting to the left (from a to b), the price-input volume curve probably also shifts to the left.



NOTE: THE DEPENDENT AND INDEPENDENT AXES ARE REVERSED FOR THE DEMAND CURVES

Figure 5.

The two curves in Figure 3 suggest, of course, inefficiency in the network design or control. It is obviously more desirable to handle greater volumes at less price to the traveler (such as at point a) than less volumes at a higher price (point b). Studies on metering or monitoring traffic flow are directed at just this problem, that is, attempting to control the output volume and capacity and avoid the backward-bending case.

The solid curve is characteristic of conditions at facilities with controlled flow (such as signalized intersections), whereas the dashed curve is more representative of flow on facilities with little or no control, or of flow on expressways with more entering lanes than through lanes.

Thus far the capacity curve utilized (in Figs. 2 and 3, for example) has been explicitly described as a price-volume curve rather than a cost-volume curve. The difference is, of course, that a cost-volume curve would include all items of cost, whether or not the traveler actually had to pay the costs, whereas the price-volume curve only includes those items of cost which the traveler actually does pay (or thinks he pays). The distinction is of obvious importance in trying to predict whether or not travel is to be made, and on what routes, etc. And it is clear that the price curve is the relevant one for travel forecasting.

To determine how many travelers will use a facility or system, the demand curve is necessary. A demand curve is, in simple terms, a graphical statement showing the numbers of travelers who will buy or purchase travel at different levels of price. In other words, it states the value which different volumes of travelers are willing to place on making a trip; Figure 5 shows such a relationship (the dependent and independent variable axes have been switched to be consistent with the usual economic theory practice). The slope of the demand curve indicates the extent to which the demand is price elastic or inelastic. Furthermore, a particular demand schedule holds valid only for specified conditions of consumer preference (alternative uses of resources, etc.), incomes, population, etc.; thus shifts in the demand curve may take place as the result of a shift in the primary determinants (such as prices of other goods, population growth, and income levels). The demand curve indicates how many consumers are willing to pay (in terms of monetary expenses and the service costs of discomfort, inconvenience, travel time, etc.), and therefore indicates the value of travel to them (as a group). (In essence, then, this implies that equivalent monetary values have been determined for service variables.)

Given a pair of price-volume and demand schedules for travel on some particular facility or system, it would be possible to determine what volume of traffic would in fact use the facility, or, to put it another way, one could determine precisely what vol-

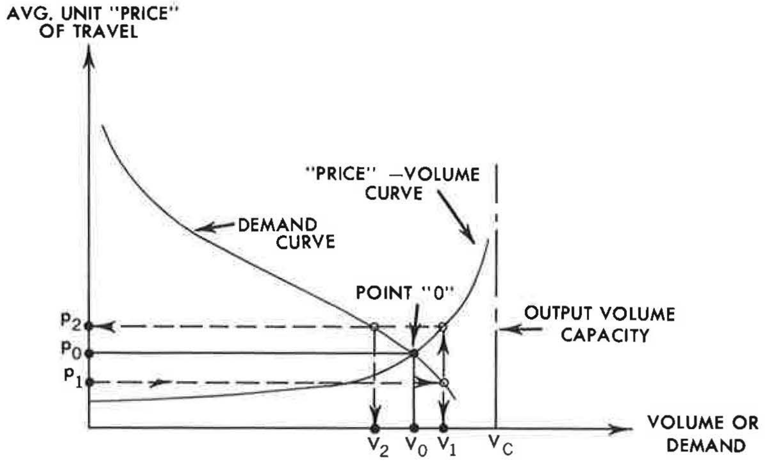


Figure 6.

ume would actually pay the price in time, discomfort, inconvenience, accident hazards, and expense associated with travel on that facility or system. Figure 6 places the price-volume and demand curves for a facility of fixed output volume capacity on comparable scales. Under the conditions shown, the resulting or actual input volume will be V_0 and will be operating at the average unit price of p_0. If, for example, a higher volume V_1 were to use the facility, this volume could only operate at the higher price level of p_2, and, at this price level, the demand schedule indicates that only volume V_2 would actually pay the price p_2—and so forth, until the volume and price stabilize as indicated by the intersection of the two curves.

It is clear that these curves should (to be realistic) include confidence limits; that is, some indication should be made of their variability. As noted, the curves are based on average unit price of travel over some time period (say, one hour, for example); during this time period the travel times, queueing waves, etc., will vary considerably around this average unit price. Thus the resulting (or expected) volume should be stated along with some estimate of the error or variability. This has been overlooked herein for simplicity.

It seems reasonable to expect that the actual volume will stabilize around the intersection point of Figure 6 fairly quickly and accurately. Travelers, on deciding whether or not to make a trip, on what route to make the trip, or what mode of travel to use, are guessing or estimating in advance of the travel two things: (1) What is the trip worth?; (2) How easy, cheap, and quick will it be to travel?

With regard to the last question, intuitively the traveler is guessing what the price-volume curve will look like, how many other travelers will be using it at the same time, and therefore how easy, comfortable, convenient, quick, and cheap the trip will be. (Thus one is guessing where the intersection point will be in relation to his position on the demand schedule.) If it is felt the trip will be too expensive, too time consuming, and too uncomfortable (that is, that the resulting price of travel will be higher than the value of making the trip) then he will not make the trip; of course, this is just another way of saying that the position on the demand curve is to the right of intersection point.

It seems fair to state that most of the time urban travelers estimate the intersection point reasonably accurately, and thus make rational trip-making decisions (at least in their frame of reference). Every now and then, however, someone finds he has misjudged the circumstances and learns to his sorrow that traffic congestion was much worse than expected. And the result of this misfortune may be that the traveler is "sorry" that he took the trip (or went that route, etc.). The price of travel forced upon him was higher than what he would have paid if he had known in advance about the service. Consequently, he is one of the people to the right of the intersection point, and by

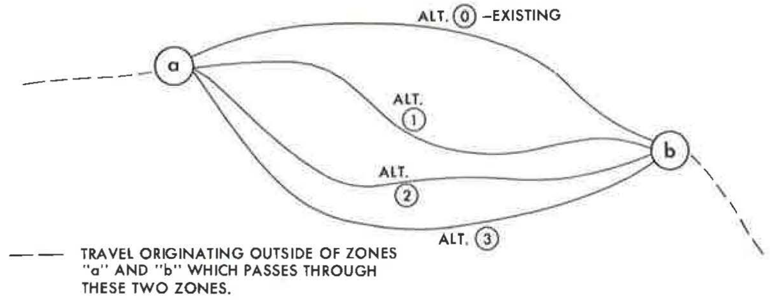


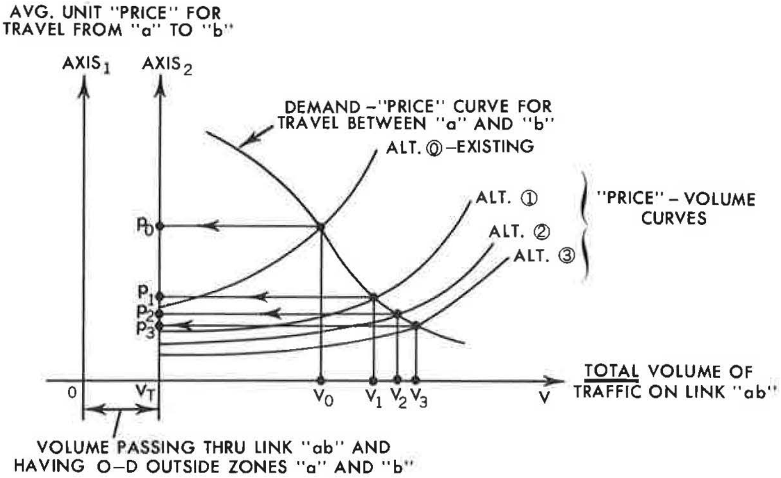
Figure 7.

virtue of having made the trip he has lost value (that is, paid an additional and what might be called an unreliability cost).

Careful examination of some recent travel forecasting models and procedures with capacity restraint features (1) will reveal that the feedback loops in these models merely provide a computational method of determining the point at which the demand and supply curves intersect; more specifically, the feedback and iterations are made to determine the actual volume and price level, such as volume V_0 at a unit price p_0 (Fig. 6). (In most of these capacity restraint models, travel time is used as the price determinant, though some recent ones permit inclusion of "out of pocket" expenses.) If through a feedback mechanism, the volume-demand levels do stabilize (or reach an equilibrium) with successive iterations, demand and price-volume curves are implied. Thus, it would seem that the point of intersection could be determined directly and uniquely without iterations.

The foregoing conclusion regarding unique determination of the actual volume using a facility (and its associated price of travel) will, however, hold true only for certain specific circumstances (though in some other instances the error introduced may be small enough to ignore). For example, in Figure 7, two trip generation zones have been isolated from the remainder of the region or community and four alternative routes for connecting these two zones are being considered (assuming one of these four is an existing roadway). If the travel originating outside of zones a and b which passes through these two zones were not dependent (or at least were dependent only to a negligible degree) on the travel conditions of the highway link between a and b, then it would be possible to make a unique and direct determination of the actual volume level and associated price of travel for each of the alternative links. For this idealized situation, it should be evident that a single demand curve for travel starting at zone a and ending at b (or vice-versa) will apply to all four alternatives; on the other hand, each of the four alternatives will (probably) have a different price-volume curve since the lengths of links will probably differ (and thus vehicle operating costs), and since travel times, discomfort, accident hazards, and travel difficulty will probably differ for each link. For this case, the existing user-charge taxation system has been assumed. Thus, differences in construction and right-of-way costs will in no way affect the price.

The effect is shown in Figure 8. The price-volume curves for the four alternatives have been plotted in terms of the total volume using each of the links between a and b, and they have been plotted with Axis_1 as the y-axis, or zero point for the abscissa. However, the demand curve for travel starting at zone a and ending at b (or vice-versa) cannot be superimposed directly on these price-volume curves without first shifting the y-axis, because the price-volume curves apply only to total volume on the link and the demand curve applies only to those trips with both ends of the trip at a and b and thus does not include the through volume. Axis_2 should be used for plotting the demand curve; obviously it will be necessary to shift the entire volume or x-axis while plotting this curve. Once the demand curve has been shifted, however, Axis_1 and the associated volume scale should be used for all calculations, because the original demand curve now includes the through travel as well.



$AXIS_1$ —ZERO POINT OR y-AXIS FOR PLOTTING "PRICE" - VOLUME CURVES

$AXIS_2$ —ZERO POINT OR y-AXIS FOR PLOTTING DEMAND CURVE

Figure 8.

The situation wherein the amount of through travel was considered independent of any changes in travel service or price may, of course, represent such an idealized case as to be of little use. But in these cases where corridors are sharply defined and particularly where the system has a limited number of links (that is, in rural or intercity areas, or corridors where virtually all travel has common origins and destinations, and where there are few cross-linkages), application might seem more reasonable. Or to be more precise, the method becomes more and more useful as the demand for outside travel passing through the link becomes more and more inelastic.

An obvious question arises regarding the usefulness of price-volume and demand curves for forecasting urban travel. In the first instance, it appears that they would have application, at least in terms of explaining the forecasting process and the way in which the different prediction phases are interrelated. For example, in some of the more recent travel forecasting and modal split models, the capacity restraint feature insures a balance between link capacity and the volume that is assigned to that link, and insures that the assumed travel speed over that link is equal to the actual travel speed that can be maintained. The iterative process used to determine this balance between volume and capacity and between assumed and actual speed is analogous to determining the intersection point between price-volume and demand curves. But can the latter be substituted for the former in the travel forecasting process?

Figure 9 depicts on a small scale a region having five zones of travel generation or attraction and served by a simple right-angle transport system (but one of many links and possible travel paths). It is assumed that there is no traffic on the transport system which is external to the five zones of travel generation/attraction, and that the external-internal movement can be considered negligible.

For most present-day travel forecasting processes, the major steps are as shown in Figure 10. In step I, the number of trips generated and attracted by each zone is calculated. Unfortunately, though, in virtually every present-day forecasting process these trips are assumed to be independent of the travel conditions or price of travel (as previously defined); that is, travel starting or ending at a zone is considered to be perfectly inelastic. In some instances, though, the zonal trips'ends are regarded as a function of the transportation "accessibility," and thus this statement would be inaccurate. On the other hand, even in these instances, the total trip ends for the region as a whole are held constant; consequently, the criticism would still hold true but at a higher level.

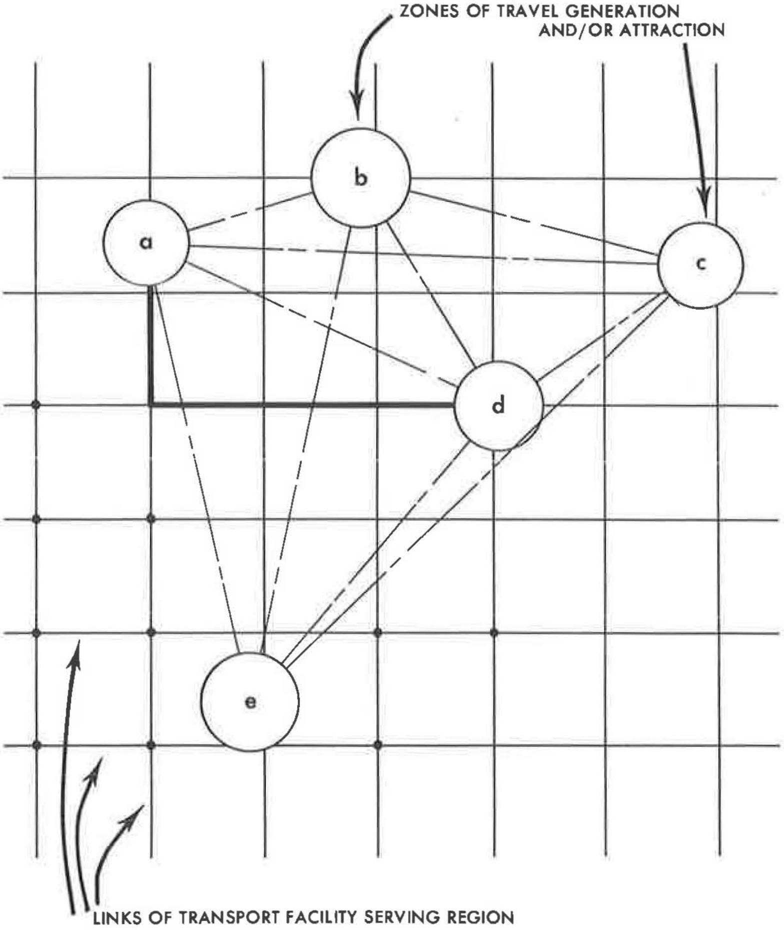


Figure 9.

Certainly, it might be argued that work trip ends are inelastic, and that the only problem is that of splitting work trip ends which start at zone a among each of the other zones and among each of alternative travel paths. It is difficult to imagine, though, that business trip ends, or shopping trip ends, for example, are not a function of the price of travel. Infinite cross-elasticity seems out of the question for all trip purposes, and it is suggested that a feedback link may be necessary between step V and step I (Fig. 10), at least for certain trip purposes.

Step II (Fig. 10) corresponds to the trip distribution phase, or computation of interzonal transfers between all pairs of zones. Often these transfers are calculated using a so-called gravity model, in which zone-to-zone travel time and zonal trip ends are usually the prime determinants for splitting the trips generated at zone a, for example, among each of the regional zones of attraction. In a very real sense, the trip distribution "gravity" model operates as a demand curve wherein the assumed travel times for the first iteration serve as estimates of the intersection point of price-volume and demand curves; successive iterations between steps V and II only refine the initial guesses. Such an analogy falls short, though, in that demand and price (or travel time for most models) are measured on a relative rather than absolute scale.

Step III (Fig. 10) is similar in many respects to the trip distribution phase; it serves to split the interzonal transfers (calculated in step II) for each interzonal pair among the alternative travel paths. For most studies, either the route travel time or the

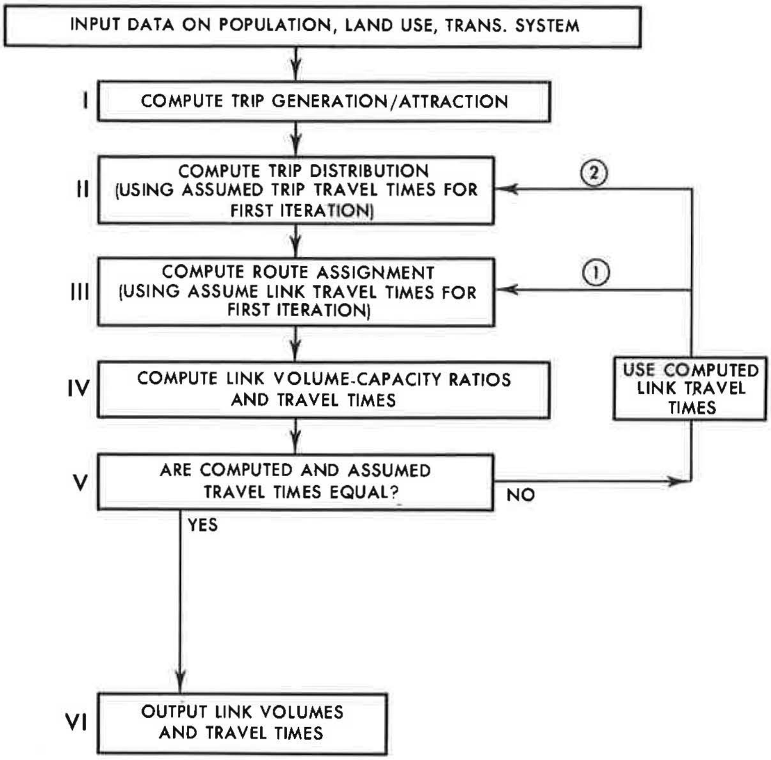


Figure 10. Simplified travel forecasting process.

route travel time plus terminal time is the prime (and only) determinant of the route splitting. Where the so-called capacity restraint feature, or feedback loop such as ① , is included as part of the travel forecasting process, individual link travel times are used and accumulated in computing route travel times and, in turn, in computing the assigned route volumes. Again, the route assignment procedure is somewhat analogous to the price-volume and demand curve intersection procedure, except that relative rather than absolute scales are used.

Step IV of the procedure differs distinctly from the other parts of the process. In essence, it is at this stage of the procedure that system capacity or price-volume relationships are introduced and related to the demand characteristics. There is an important difference, however, between price-volume curves for a simple link system such as in Figure 7 and those for a multiple link system such as in Figure 9. In Figure 7 (and the relationships previously described), the price-volume and demand curves can be reconciled; that is, the volume in both the price-volume curve and demand curve will represent the same travelers. In Figure 9, however, there are two problems: (a) the price-volume curve for travel between any pair of zones can only be represented by a series of price-volume curves; that is, by the accumulation of price-volume curves for the links between the pair of zones; and (b) the volume on any one or all of the links between the pair of zones will seldom be the same volume represented in the demand curve. Thus the two sets of curves cannot ordinarily be reconciled.

Considering the travel between zones a and d (Fig. 9), there is a certain utility associated with people traveling from zone a to zone d (or vice-versa)[1]; however, the

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[1] Obviously the utility is not associated with the travel but with the arrival at a destination where desirable goods or services (in a broad sense) will be obtained; the utility or satisfaction or value received from the trip in a real sense depends on each individual, on his own value scale, on the nature of the trip purpose, and on the effort and/or cost expended at the destination to acquire the goods or services.

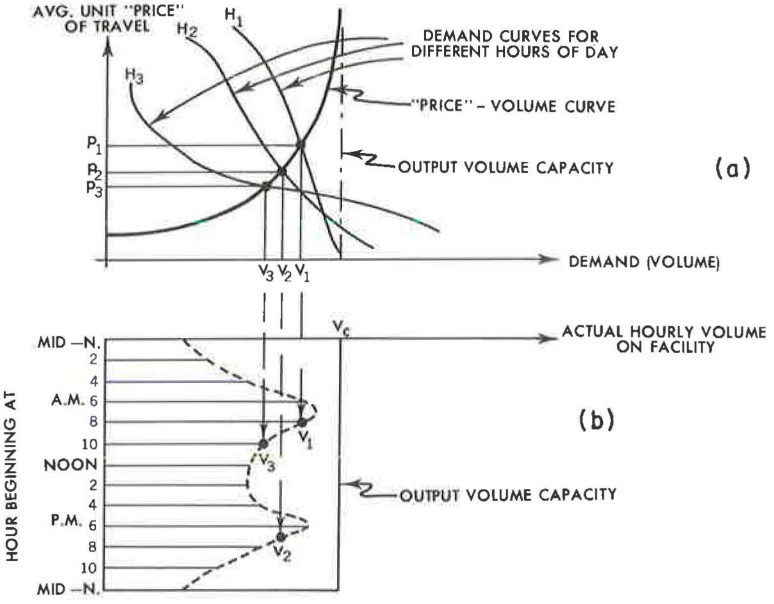

Figure 11.

net gain to the traveler from making the trip is a balance between this utility and the price of making the trip. As the price increases, there is decreasing net gain and thus decreasing demand. However, it must be recognized that the price of travel between zones a and d is not just dependent upon the amount of travel between these two zones (which, for example, takes place along the travel path marked by the heavy line in Fig. 9). It is also dependent on travel moving along this travel path or parts of it from other pairs of zones. In other words, travel between a and e, or between d and e, which uses portions of this travel path can also congest the travel and thus increase the price of travel between zones a and d, and thus affect the demand for travel between zones a and d.

From these remarks, one must conclude that when forecasting travel for networks, it is probably advantageous to use iterative procedures rather than to try and determine the intersection points for demand and price-volume curves by analytical or graphical procedures.

OTHER DEMAND-PRICE RELATIONSHIPS

In an urban society, it is seldom that any given facility or system or individual link of a system operates at just one level of volume and price, as suggested by the intersection point in Figure 6. Usually, volume and travel price will vary considerably throughout the day, with high service (or low price) during off-peak hours and low service (or high price) during peak hours. Essentially, this may be interpreted to mean that the demand-price relationship is changing throughout the day (the changes being the result of different trip purposes, and income levels, for example). Figure 11a characterizes one possibility for the changing demand-price curve, and helps explain the occurrence of several actual demand or volume points for a given facility during the course of a day. Assuming that there is an individual link of a system which can be isolated from the remainder of the region, and which can be represented by a simple price-volume curve, the varying demand curves can be interpreted to mean that different kinds of trips are made at different hours of day, and that these various kinds of trips have varying degrees of utility or satisfaction associated with them. The demand curve for hour H_1, for example, might represent the situation from 8:00 to 9:00 AM, when most of the travel is from home to work and therefore has high utility. (This is just another way of saying that these people will endure consider-

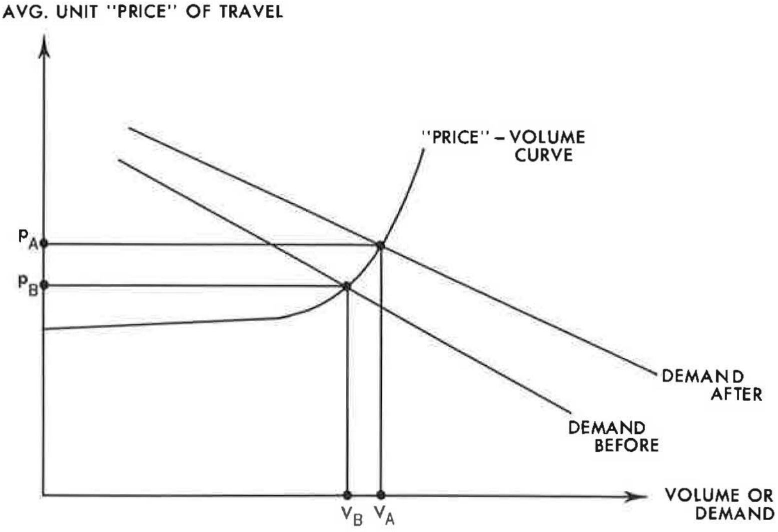

Figure 12.

ably more congestion than people whose trip purpose has less utility.) The other two demand curves might be applicable, for example, to 7:00 to 8:00 PM travel when many travelers are making social-recreational trips (curve H_2), and to midmorning 10:00 to 11:00 AM travel when trips consist mainly of business and shopping purposes.

The intersections between the price-volume curve and the three hourly demand curves have been projected on a volume-time plot (Fig. 11b). If all the 24-hr demand curves were available and if their intersections with the price-volume curve were similarly plotted, a distribution somewhat similar to that shown in Figure 11b might be expected.

At this point, it is useful to ask what changes might occur over time—that is, over the years—and how these changes might affect these relationships. First, with population increases it seems reasonable to expect shifts in the demand curves; that is, each year will have a higher volume of people willing to pay a given unit price for a particular trip, everything else remaining equal. As a consequence, the volume-time of day distribution (Fig. 11b) will gradually increase over the years. However, as the volume during the heaviest hour approaches the output volume capacity of the facility, further shifts in that demand curve may not occur but travelers may shift to other facilities, or may travel during other hours of the day. Indeed, a phenomenon often experienced in many urban areas is that over the years little increase is recorded during peak hours, and most of the increases occur during off-peak hours.

Similar shifts in demand curves may occur as a result of changes in consumer preference patterns, or perhaps as a result of real income increases. These changes may produce uniform shifts, but it seems more likely to expect disproportionalities. For example, income effects might shift the demand curve for shopping and business type travel to a larger degree than the demand curve for work trips.

These types of shift may be illustrated somewhat as in Figure 12, which includes demand curves before and after income and population increases. The net result of this increase would be a rise in the unit price of travel from p_B to p_A and in the volume of travel from V_B to V_A.

EFFECTS OF CHANGING SYSTEM CAPACITY

To understand the consequences of changes in capacity that result from improvements in the transportation system, Figures 13 and 14 are helpful. Figure 13 represents the relationship between the unit price of travel and the system capacity for a fixed or constant volume of travel. This curve depicts three things of importance:

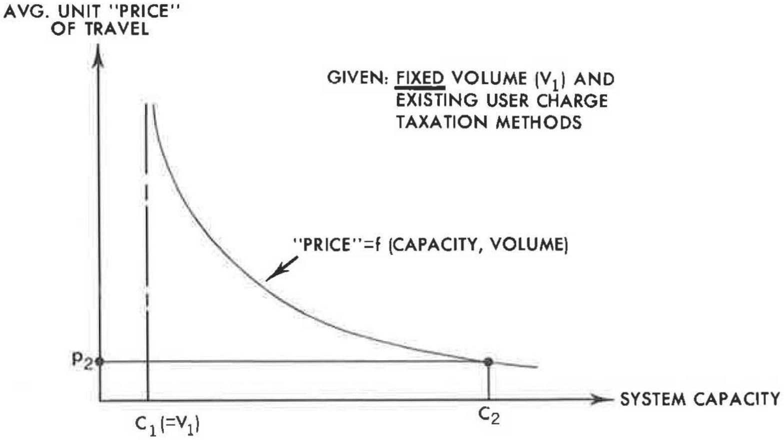

Figure 13.

1. It exhibits a general reduction in price as the system is improved (roads widened, radii increased, vertical curves lengthened, etc.).
2. Once the capacity is increased above a certain level (for example, C_2), further improvements to the system would have little effect on unit travel prices. Essentially, this describes the point at which this particular volume of traffic is suffering only a negligible amount of discomfort, the point at which the traffic is moving almost as fast as desired, the point at which the accident rate is extremely low, and the point at which substantial reduction in travel price can be achieved only by very large improvements or capital investment (such as installing an electronic highway-vehicle control system).
3. With a system capacity equal to or less than C_1, which is equivalent to the fixed volume of travel V_1, the unit price would be extremely large; in fact, with a sustained volume level which is equal to or greater than capacity, the unit price would approach infinity.

The effects of increasing system (or link) capacity can also be illustrated (Fig. 14). The price-volume curve$_1$ represents the relationships before improvement (or adding capacity), and curve$_2$ the situation after improvement. Such improvements will generally reduce the travel times, the accident hazards, discomfort, and inconvenience; also, under existing methods of taxation, and except for toll road travel, the price charged for the roadway construction, maintenance, and administration will remain virtually unchanged, thus the total unit price of travel will be reduced by the improvement.

In this illustration it is suggested implicitly that additional investments to increase capacity will generally lower the price-volume curve. One might argue, then, that since the unit price includes the costs for construction, maintenance, and administration, additional investment is always justifiable. However, recalling previous discussion, it was noted that the price-volume curves to be used in most of this paper would include only the costs of construction, maintenance, and administration which the user is actually charged under existing taxation methods. As a consequence, any additional capital or maintenance costs which are incurred to improve the facility are not included in the new price-volume curve (that is, curve$_2$), except for the user charges paid in by entirely new or additional travel. Thus, the curves (Fig. 14) by themselves will not permit any conclusions regarding the justification of improvement.

BENEFITS FROM IMPROVEMENT OF SYSTEM CAPACITY

Under the conditions in Figure 14, the volume of travel will increase from V_1 to V_2, while the unit price of travel will decrease from p_1 to p_2. The additional volume added after improvement (V_1 - V_2) represent travelers diverted from other facilities, those making more frequent trips, those switching from other modes of travel, or those mak-

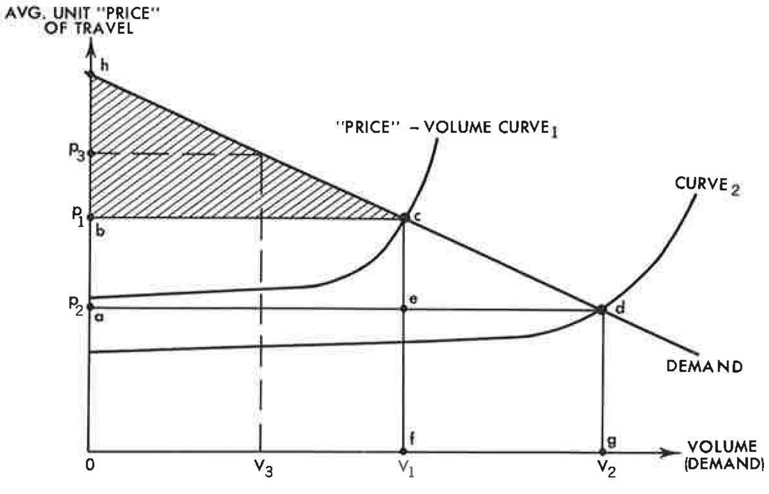

Figure 14.

ing entirely new trips. The existence of each of the new trips may be interpreted to mean that in each case the benefit achieved by virtue of making this trip is greater than that which can be obtained by an alternative use of the time, effort, and expense involved (which in this case would be p_2). In the sense used herein, benefit is defined as the difference between the value or satisfaction afforded the traveler (and described by the demand curve) and the unit price he must pay for the trip.

Certainly, each traveler using the facility must be receiving a benefit from the trip (exception for the trip at the margin), unless he misjudged the actual unit price he would have to pay. For example, prior to improvement, a traveler willing to pay a unit price of p_3 would experience a benefit of $p_3 - p_1$; after improvement, his benefit (ignoring any changes because of interpersonal comparisons) would increase to $p_3 - p_2$. Extending this to the entire volume V_1 using the facility before improvement, the total benefit of these travelers is equal to the shaded area, or triangle hbc. After improvement, the benefit to the volume V_2 would be represented by the triangle had. Thus, the additional benefit afforded these travelers by the improvement would be the difference, or area badc.

The extra volume ($V_1 - V_2$) added as a result of the improvement is handled differently than the original volume in computing additional benefit. The additional benefit for each traveler in the original volume V_1 is equal to price before p_1 minus the price after p_2 ($p_1 - p_2$); but the additional benefit for each extra traveler ranges from that same value ($p_1 - p_2$) down to zero, and on the average will probably be about one-half the additional benefit of each original traveler or $\frac{1}{2}$ ($p_1 - p_2$). The exact value, of course, will depend on the shape of the demand curve. One-half is suggested merely as an approximation. Study of some engineering economics reports will show that the entire difference is often incorrectly regarded as additional benefit for these extra travelers.

Finally, it must be emphasized that the additional benefit described does not represent net value added as a result of the improvement. First, any effects of traffic diversion and the additional benefits that might accrue to the remaining (and new) travelers on other facilities as a result of former travelers diverting to the improved facility have been ignored. Second, all the additional construction, maintenance, and administration costs required to improve the facility have probably not been included.

This paper is probably more notable for what it does not say, and for the variables and interrelationships that it does not treat, than for what it actually accomplishes. (For example, the intricate problem of handling modal cross-elasticities is scarcely mentioned.) Even so, it is hoped that some insight is provided and that perhaps a slightly improved way of examining and dealing with an old problem might result. Certainly, there is no intention or hope of solving the problem.

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