AN APPROACH TO MULTIREGIONAL URBAN TRANSPORTATION POLICY PLANNING

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This paper describes an ongoing research and development project oriented toward providing an analytical framework for broad, policy-level, transportation investment decisions that simultaneously affect a large number of urban regions. The overall effort is known as the Transportation Resource Allocation Study. The urban area models that have been developed are capable of evaluating the economic and external consequences of alternative transportation investments. In addition to incorporating the traditional user-related items (such as time, operating, and accident costs), the model attempts to dimension the urban road construction impacts that are felt by the entire community. These include air pollution, displacement, and noise. The process, which is somewhat analagous to transportation planning at the local level, proceeds from a statement of land development and transportation investment alternatives and continues through travel generation on the basis of an equilibrium demand model, development of system performance measures, economic investment-return analysis, and evaluation that provides a framework for including "noncostable" constraints. The model system is capable of determining an "optimum" highway investment level, indicating the investment required to reach a specified performance level, and providing an indication of the consequences of alternative investment strategies. A separate set of models is under development for rural areas.

•DECISIONS that are made at both the federal and the state levels of government on a continuing basis affect transportation improvement programs in a large number of urban regions. These decisions, which are frequently far-reaching and broad in scope, deserve at least as much in the way of analytical support as those made at the local level. Yet, it has become apparent over the course of the past few years that the need for a set of analytical tools capable of evaluating the consequences of a wide range of transportation-related policies affecting urban regions has not been adequately met.

Efforts in recent years toward the development of an urban transportation planning technology have been almost entirely directed at the process of formulating transportation plans for individual areas. While the need for such a technical process for local planning is self-evident, we are left somewhat short in attempting to apply these techniques to multiregional policy planning. The process that has evolved for local transportation planning is both time-consuming and costly. Even for individual urban regions, the ability to evaluate a broad range of alternative plans is quite limited. It is clear, then, that an approach tailored for planning and design of local area systems is not always appropriate for multiregional policy planning. What is needed is a process that operates at a substantially different scale.

Most importantly, such a process must be responsive to the needs of policy planners and decision-makers at the highest levels. It must be capable of dealing effectively with large numbers of transportation issues quickly and efficiently. The ability to assess the consequences of alternative courses of action must be complemented with the

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capability for determining the best course of action to achieve desired goals. Finally, the process should relate explicitly to the social, economic, environmental, and political impacts of each alternative under consideration.

The research described in this paper was undertaken with the specific objective of developing an analytical capability for multiregional urban transportation policy planning. The results of this effort have been manifested in the form of a prototype model that has been applied to all urbanized areas in the nation. It has been made operational for use in a national transportation planning study, known as the Transportation Resource Allocation Study (TRANS).

The TRANS-urban process is constituted of a set of models that operate on entire urban regions and on large portions of urban regions (such as central city and suburban areas). The models have been designed to specifically provide insight into the consequences of alternative levels of investment in transportation facilities in urban areas. In addition, the models are capable of indicating an optimum mixture among facility types based on trade-offs between investments and benefits, both direct and external.

Although the TRANS project is being conducted at a national scale, it is felt that the same or similar approaches can be applied at the statewide level. In fact, the Tri-State Transportation Commission, which has jurisdiction over an urban region of about 8,000 square miles with a population of close to 20 million persons, has developed a modeling process that treats transportation investment planning on a broad, aggregate scale. This is in addition to the planning tools that forecast volumes for specific facilities.

MODEL SYSTEM

The overall TRANS-urban model system is illustrated in the flow diagram shown in Figure 1. The process begins with a postulation of a transportation supply alternative for each urban region included in the analysis. The various components of the model system are then called into play to evaluate the alternative specified in terms of designated evaluation criteria.

The transportation supply alternative is described in terms of a possible future extension of freeway and surface arterial capacity, as well as an investment level in public transit. A travel demand forecasting function is then used to project future travel by considering the quality of the transportation system as well as the basic socioeconomic indicators of travel demand that have traditionally been used in travel forecasting, such as population and vehicle ownership. The forecast travel for the region is then distributed by time of day, direction of travel, facility type, and, ultimately, subarea within the region. The interaction of travel demand and system supply leads to the system performance submodels that yield estimates of system congestion, average speed, vehicle operating costs, accident costs, and travel time costs, as well as projections of fatalities and air pollution.

The direct costs of providing the capacity specified in the supply alternative include the costs of rights-of-way, new construction, and reconstruction. Indirect costs include, for example, costs of displacements over and above those required for the purchase of property and paying for relocations. All of

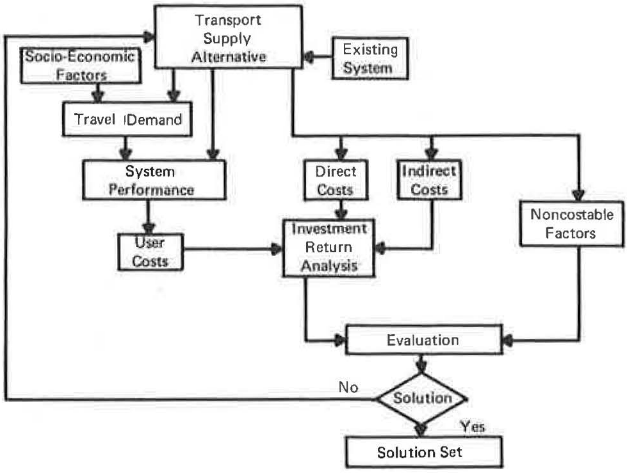


Figure 1. TRANS-urban model system.

TABLE 1

URBAN AREA HIGHWAY MILEAGE BY FACILITY TYPE

Population Group (thousands)	Freeway Mileage	Surface Arterial Mileage	Collector Street Mileage	Local Street Mileage	Total Mileage
50 to 100	473	6,140	3,209	24,892	34,714
100 to 250	1,074	8,913	4,705	36,854	51,546
250 to 500	1,032	8,468	4,488	36,512	50,500
500 to 1,000	1,021	8,340	4,045	36,431	49,837
Over 1,000	4,441	29,830	14,372	127,276	175,919
Total	8,041	61,691	30,819	261,965	362,516

Source: Federal Highway Administration 1968 National Highway Functional Classification Study data.

these so-called "costable" items are incorporated in an investment-return analysis that treats dollar benefits and dollar costs. The results of this analysis are fed into an evaluation process that explicitly considers external effects of transportation improvements such as air pollution, number and type of displacements, fatalities, and land consumption. Unless the alternative meets predetermined constraints regarding these critical factors, it can be rejected regardless of the results of the economic analysis.

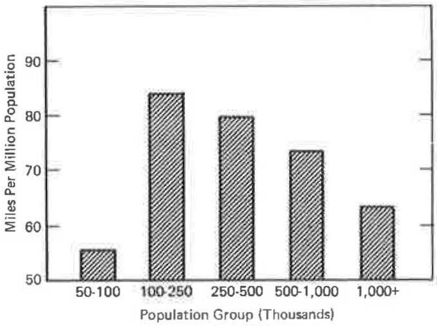
The system of models has been programmed in FORTRAN IV for operation on the IBM 360. It can process data for approximately 300 individual urban regions, evaluating about 50 transportation alternatives in each in about 15 min on the Model 65.

The following describes each major component of the model system and explains how it fits into the entire process. This begins with a brief analysis of the existing urban highway system in the nation.

STATUS OF THE EXISTING URBAN HIGHWAY SYSTEM

The TRANS study is supported, in part, by a data base drawn from the results of the National Highway Functional Classification Study (FCS) conducted in 1969 by the states in cooperation with the Federal Highway Administration. The purpose of the FCS was to provide to the Congress a profile of the nation's highway plant in terms of the functional service it provides as well as the degree of federal interest that has been manifested. Data on system extent and travel for all rural, small urban, and urbanized areas were collected and classified by functional category and administrative class.

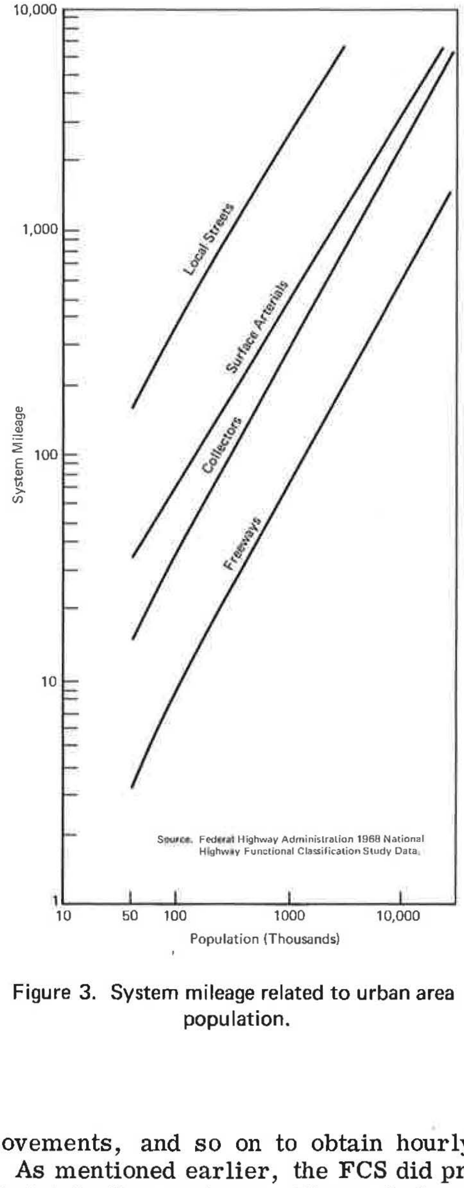
Table 1 gives a broad summary of the extent of the highway system as it existed in 1968 in the nation's urbanized areas. The data show that 23 areas of over one million population, which represent well over half the population and travel of all 284 urbanized areas, contain slightly less than half of all surface arterial miles and more than half of all freeway miles. (These are areas that reported a population of 50,000 or more within the 1968 "urban-in-fact" boundaries defined for this study.) When viewed in terms of miles per capita, however, as shown in Figure 2, the largest areas no longer seem to enjoy any special advantage.



Source. Federal Highway Administration 1968 National Highway Functional Classification Study Data.

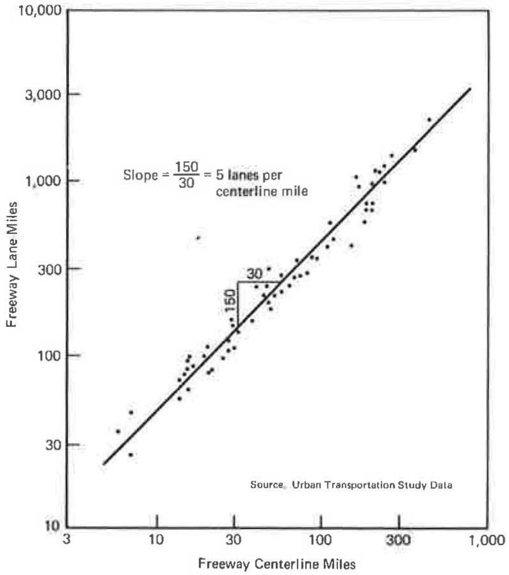
Figure 2. Freeway miles related to urban area population.

The relationship between miles of facilities (freeways, surface arterials, collector streets, and local streets) and size of urban area is shown in Figure 3. The arithmetic means for all urbanized areas indicate a freeway system of close to 30 miles and a surface arterial system of over 200 miles for a region of about 420,000 people. The most extensive networks of controlled-access facilities are found in the regions of New York (910 miles), Los Angeles (370 miles), and Chicago (247 miles).



Source: Federal Highway Administration 1968 National Highway Functional Classification Study Data.

Figure 3. System mileage related to urban area population.



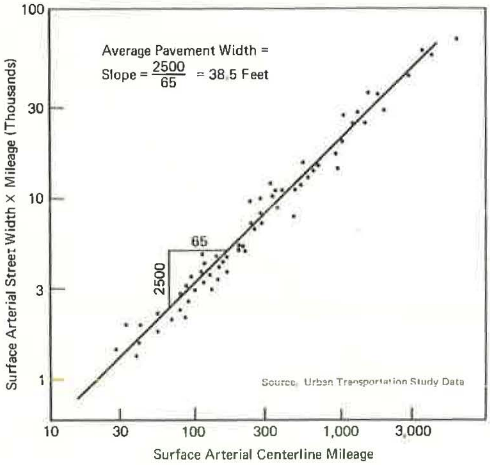
Source: Urban Transportation Study Data

Figure 4. Urban freeway miles related to centerline miles.

The functional classification data did not go beyond system mileage in measuring the extent of the nation's highway plant. The development of system capacities required some relationship between centerline-miles and lane-miles. Such a relationship for freeways is shown in Figure 4, which indicates an average of five lanes across the entire spectrum of system extent. A similar relationship developed for surface arterials (Fig. 5) gives a mean pavement width of close to 40 ft. These data were combined with assumptions concerning the distribution of vehicle types in the traffic stream, turning movements, and so on to obtain hourly capacities by facility type.

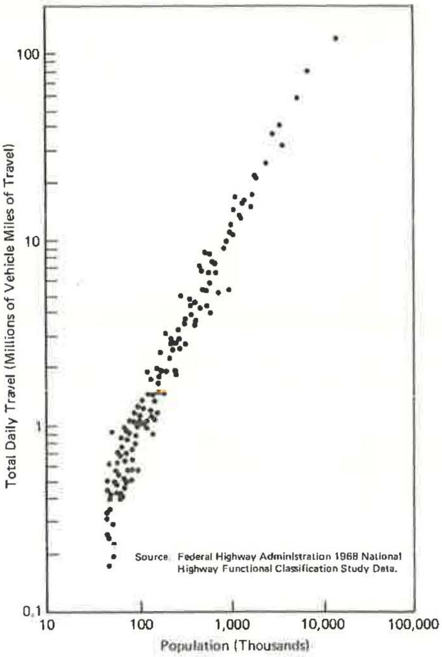
As mentioned earlier, the FCS did provide data on daily travel by functional and administrative systems. Figure 6 shows the relationship between daily travel and population. The nationwide average vehicle-miles of travel per capita is close to 10, as evidenced by the slope of the relationship defined by the points in the figure.

Figure 7 shows the average daily traffic (ADT) for surface arterials and freeways related to population. It is, of course, readily apparent that the largest urban areas experience the highest ADT on freeways, almost 45,000, and the smallest areas the lowest, 10,000. Traffic loads on conventional surface arterials remain relatively stable, increasing only about 50 percent from the smallest urban area to the largest, compared with an increase of almost 500 percent on freeways. The ability of urban freeways to serve a particularly large portion of travel in urban areas of all sizes is evidenced by the relatively high percentage of travel they serve (almost 25 percent) compared to the proportion of total mileage they represent (about 2 percent).



Source: Urban Transportation Study Data

Figure 5. Urban surface arterial street width.



Source: Federal Highway Administration 1968 National Highway Functional Classification Study Data.

Figure 6. Average daily vehicle-miles of travel related to urban area population.

TRAVEL DEMAND SUBSYSTEM

The primary function of the travel demand subsystem in the TRANS-urban model is to translate a description of an urban environment, in terms of broad land development patterns, socioeconomic characteristics, and transportation system service alternatives, into estimates of travel by major area type, mode, time of day, direction, and, for highway travel, physical class of facility. The process is illustrated by the flow diagram shown in Figure 8 and is described in greater detail in the following paragraphs.

Land Development—Transportation Policies

Every transportation investment alternative examined by the TRANS-urban model lies within the context of an urban growth alternative with which it is compatible. These alternatives are described primarily in terms of the relative roles of central city and suburban areas and the development patterns toward which outlying areas might grow. For example, two urban development alternatives considered are (a) a trend assumption, which reflects a continuation of the relative and, in some cases, absolute decline of central cities, accompanied by low density growth in suburban areas; and (b) a "reconcentration" assumption, which emphasizes a regeneration of the regional significance of central cities.

Initially, these alternatives have been specified only for those urbanized areas expected to exceed a population of one million by 1990. This allows greater attention to be given to unique characteristics of individual areas than would otherwise be possible. The quantification of socioeconomic growth parameters to accompany each alternative is based largely on subjective estimates. These measures

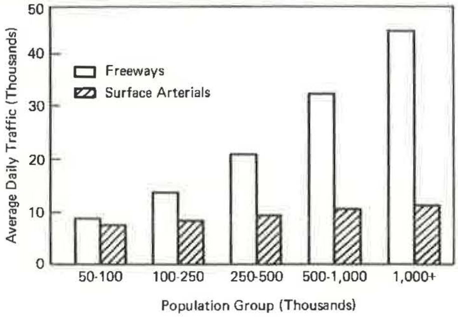


Figure 7. Average daily traffic related to urban area population.

represent the key link between compatible land development and transportation investment policies.

Alternative distributions of future population among urbanized areas are also considered, providing the capability of indicating the transportation implications of alternative national growth policies.

Socioeconomic Data

The three basic socioeconomic variables that the TRANS-urban model incorporates are population, employment, and vehicles. The distributions of population and employment between central cities and suburban areas are critical measures in the quantitative description of the land development alternatives described previously. Population and vehicles are also important in the travel projection model.

Table 2 gives a summary of the population estimates used in the TRANS-urban prototype model that dealt individually with 317 areas expected to exceed 50,000 population by 1990. The 1990 population projections were made on the basis of census series I-B assumptions. These have since been revised downward to conform with series D assumptions that, it is generally felt, reflect a more realistic growth rate.

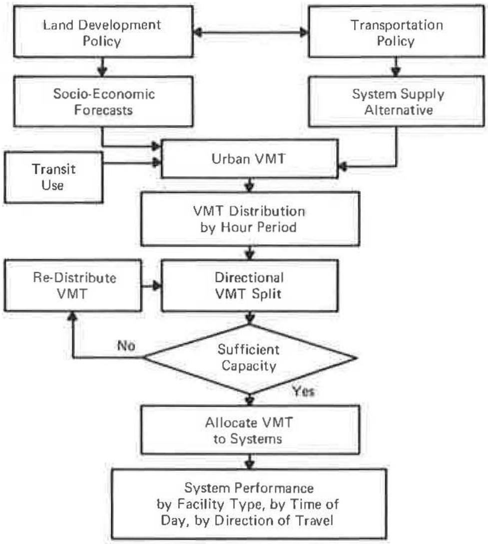


Figure 8. Travel demand subsystem.

TABLE 2

URBAN AREA POPULATION

1990 Population Group (thousands)	Number of Urban Areas	Population (millions)		Increase (percent)
		1968	1990	
50 to 100	95	4.66	6.93	48.7
100 to 250	98	10.18	15.82	55.4
250 to 500	54	11.69	19.22	64.4
500 to 1,000	30	13.09	21.82	66.7
Over 1,000	40	81.48	126.39	55.1
Total	317	121.10	190.18	57.0

Source: Federal Highway Administration data.

Forecasting Area-Wide Daily Travel

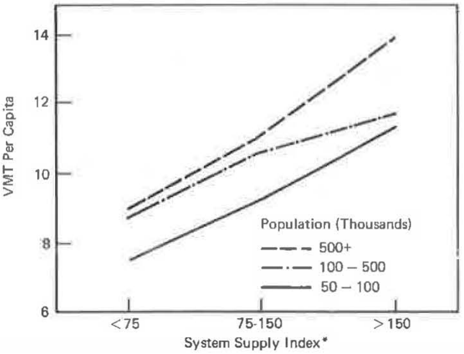
The travel-projection element of the model system has proceeded along a three-phase development process. The first phase (used in the prototype model) simply projected fixed travel demand quantities for each urban area for the year 1990. The results of this process, under two alternative transit-use assumptions, are given in Table 3.

TABLE 3

URBAN AREA VEHICLE-MILES OF TRAVEL

1990 Population Group (thousands)	Number of Urban Areas	Annual Vehicle-Miles of Travel (millions)			Increase (percent)[c]
		1968	1990[a]	1990[b]	
50 to 100	95	16,100	28,300	28,200	75.8
100 to 250	98	35,700	66,400	66,000	86.0
250 to 500	54	40,800	79,100	78,000	93.9
500 to 1,000	30	46,500	91,600	89,200	97.0
Over 1,000	40	294,300	530,500	505,200	80.3
Total	317	433,400	795,900	766,600	83.6

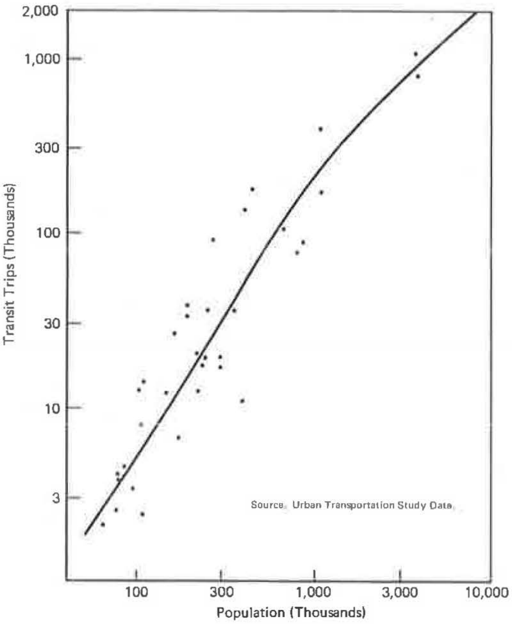
[a] Assumes transit use trend; i.e., constant number of trips.
[b] Assumes constant percentage of transit use.
[c] 1990 VMT (constant use trend transit assumption over 1968).



*$\frac{(5 \times \text{Freeway Miles} + \text{Surface Arterial Miles})\ 100{,}000}{\text{Population}}$

Source. Federal Highway Administration Data

Figure 9. Travel related to system supply.



Source. Urban Transportation Study Data

Figure 10. Transit travel related to urban area population.

The primary weakness of this approach lies in its lack of sensitivity to the transportation alternative under consideration. Regardless of whether a lean investment or a rather sizable program is being considered, the approach described previously provides the same estimates of future tavel.

The second phase of the travel-forecasting process overcame this weakness by correlating measures of transportation system use with measures of transportation system service. This has been done by using the travel and system data submitted in the FCS. The initial results have proved to be fruitful, as shown in Figure 9. Within each population grouping, travel per capita increases with capacity per capita. Of course, this increased travel may be influenced to some degree by nonresident travel on bypass routes that penetrate the urban boundary.

Travel response to system extent and quality is manifested in numerous ways. Trip rates, trip length, mode choice, and orientation of the trip are all affected to some degree. For example, a decline in transportation service in an urban region may result in fewer trips, shorter trips, a shift of mode, and a redistribution of origins and destinations toward corridors that offer relatively better service. This last phase of the travel-forecasting process involves the development of quantitative relationships that describe these system impacts on each of the given components of travel.

Estimating Transit Travel

Placing dimension on the region of potential trade-offs between private vehicle travel and transit travel is a principal objective of the Trans-urban effort. This was accomplished in the prototype model by projecting travel under two alternative assumptions of transit use: (a) a "trend" assumption under which the existing level of transit use (in absolute person-miles of travel) was presumed to hold to the year 1990, and (b) a "constant percent" assumption under which the existing proportionate share of travel occurring via public transportation was presumed to hold into the future.

The initial estimates of existing transit use in each urban area were made by using the relationship shown in Figure 10. The curve relates total area transit trips to urban area size. The trade-off between transit travel and private vehicle travel is achieved by estimating average trip lengths and vehicle occupancies for base and forecast years. This enables the conversion of person trips to vehicle-miles of travel and vice versa. The relationship between average trip length and population is shown in Figure 11.

An attempt was made to tie the level of transit use more closely to relative measures of highway system performance. Therefore, the model, in addition to examining the two transit-use assumptions described in the preceding, can determine a "best" estimate between these two levels based on the extent and mix of the highway system being specified.

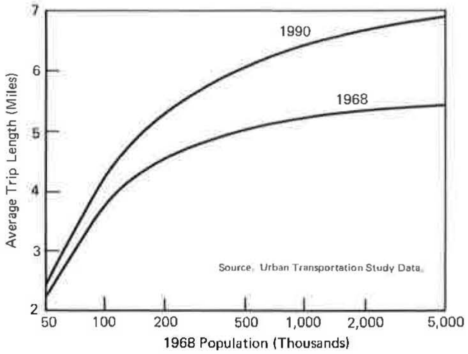


Figure 11. Average trip length related to urban area population.

Distributing Travel by Hour and Direction

The phenomenon of travel is the result of a fairly complex set of personal decisions that are, in effect, individual responses to personal needs and to the environment. A trip may be thought of as an equilibrium condition between the pressures that motivate the journey and the physical, economic, and social constraints that tend to limit travel consumption.

Travel may be defined along many dimensions, with the significance of each in the decision process varying from trip to trip, person to person, and place to place. For example, a trip may be described in terms of its primary purpose, its origin, its direction, its length (time and distance), its destination, and its time of occurrence. Depending on any particular set of circumstances, each of these factors will have a given priority and a given elasticity. In order to get from home to work, for example, there is little elasticity in any of the preceding factors. On the other hand, the desire to travel from home to a recreation area may embrace quite an elastic set of factors with a number of possible priorities among them.

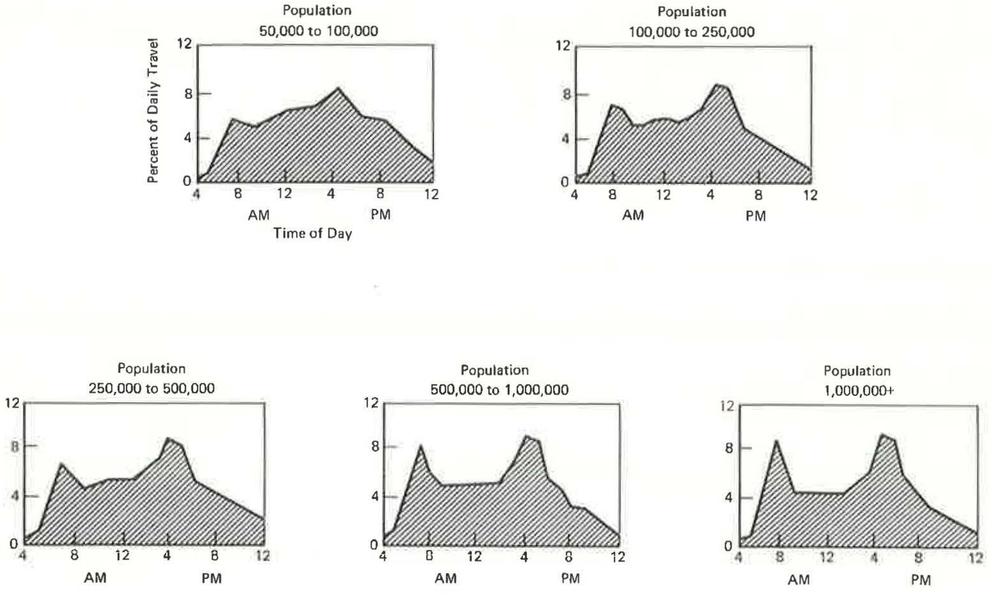
This dissection of the trip-maker's decision process becomes relevant when it is understood that the art or science of travel forecasting is currently incapable of replicating the complex phenomenon alluded to previously, and that to achieve any capability at all in making travel forecasts requires a number of simplifying assumptions. An understanding of how these assumptions are strung together is, of course, critical to a comprehension of the entire process.

The TRANS-urban approach assumes that the amount of travel made by a given population is fairly stable and repetitive on a day-to-day (weekday) basis and that this daily travel can be forecast with reasonable accuracy by using basic measures reflecting the characteristics of the population and the transportation system available to it. Once the daily equilibrium travel forecast is made, it is assumed that there remains a degree of elasticity concerning the time of occurrence and directional orientation of travel. This thesis contends that, in reacting to transportation system service, travelers will seek an equilibrium by adjusting their "within-day" behavior before they adjust their total daily travel. Thus, after a total daily travel equilibrium is reached (based in large part on the effect of the system), the daily travel generation is held constant for any particular supply alternative.

The daily travel is distributed by hour period within the day by using typical distributions (stratified by population group), as shown in Figure 12. These distributions were determined by using historical data from urban transportation studies.

Within each hour period, a directional factor is applied. The directional factor accounts for the uneven spatial distribution of travel at any point in time, because performance characteristics will be different if the travel split is anything other than 50-50. Directional split factors are specified in the model individually for each hour period within each population grouping.

Once the directional split is made within each hour period, it is assumed that the remaining elasticity lies among the hour periods within the directional categories. The assumption is essentially that choice of destination takes priority over choice of time of travel.



Source. Urban Transportation Study Data

Figure 12. Travel by time of day related to urban area population.

The shift of travel among hour periods is initiated in the model when the travel within a particular hour period and direction exceeds a specified proportion of available system capacity. For example, in the morning peak when there is a high percentage of relatively inelastic trips destined for work, it might be that the system will load to breakdown before trips are diverted to another hour period, while in off-peak periods, the tolerance of travelers may be somewhat less.

If travel in a particular time frame exceeds the tolerance limit specified, it is redistributed to prior and subsequent hour periods according to specified proportions. Work-oriented morning peak travel, for instance, is redistributed primarily to prior hour periods because arrival time for most employees is relatively fixed. (The impact of a staggered work-hour system could be considered by simply altering the daily distribution of travel.)

While this sequence of travel allocation does not, of course, completely simulate the trip-making decision process discussed previously, it does, it is felt, come reasonably close by making assumptions that seem appropriate for the scale of analysis at which the model operates.

Allocating Travel to Systems

The last critical link in the travel demand subsystem is the mechanism by which travel is allocated to the highway system. This process is accomplished in two steps. The first involves estimating the distribution of travel between the arterial system and the collector and local systems, while the second involves allocating travel within the arterial system to limited-access and conventional surface arterial facilities.

It is inherent in the function served by arterials that, although they represent a relatively small proportion of total street and highway mileage, they carry the vast bulk of total travel in an urban region. On a national average, in fact, arterials handle almost 73 percent of total urbanized area vehicle-miles of travel while constituting less than 20 percent of the total mileage. It was found in analyzing the functional classification travel data that the mean percentage of total travel carried on the arterial system correlates fairly well with the size of urban area. This relationship, which is used in the model to estimate the proportion of total travel on arterials, is shown in Figure 13.

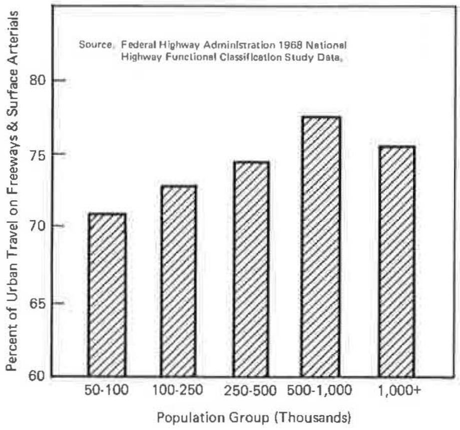


Figure 13. Travel on freeways and surface arterials related to urban area population.

The allocation of travel within the arterial system to surface arterials and freeways draws on a relationship called the "functional VMT splitter." The determination of the distribution of arterial travel between these two types of facilities is really an attempt to define those factors that influence individual travelers in their route-selection process. For example, perhaps the most important factor affecting freeway use is the very presence of freeways for serving travel. It seems logical, therefore, that the more freeways available in a particular area, the higher will be the proportionate use of freeways. Thus, the first basic relationships developed for the functional VMT splitter correlated the percentage of arterial travel on freeways with the percentage of arterial capacity on freeways.

This relationship, however, lacked a dimension that scaled the critical effect of trip length. Because freeway corridors are generally relatively few in number, the use of a freeway normally requires an investment in access time between point of origin and entrance ramp and between point of egress and destination. For long trips, the time getting to and from the freeway may be well spent in terms of net time saved through the use of the high-speed facility. For most short trips, however, particularly those that have neither origin nor destination close to a freeway, there may be no time-saving advantage to using a freeway. For very short trips, in fact, ramp spacing becomes a constraining factor. It seems reasonable to conclude that, within a group of urban areas having similar proportions of arterial system capacity on freeways, those with longer area-wide average trip lengths would have a higher proportion of travel on freeways than those with shorter average trip lengths. A third factor that probably has a significant bearing on the relative use of freeways is the level of congestion occurring on both freeways and surface arterials.

The functional VMT splitter currently incorporated in the TRANS-urban model is shown in Figure 14. The relationships are in the form of a family of curves that relate percentage of arterial travel on freeways to percentage of capacity on freeways for several population groups. The stratification by population group acts as a surrogate for the trip length and relative congestion measures discussed in the preceding. For a given percentage of capacity on freeways, the proportionate share of travel on freeways increases with the larger population groups.

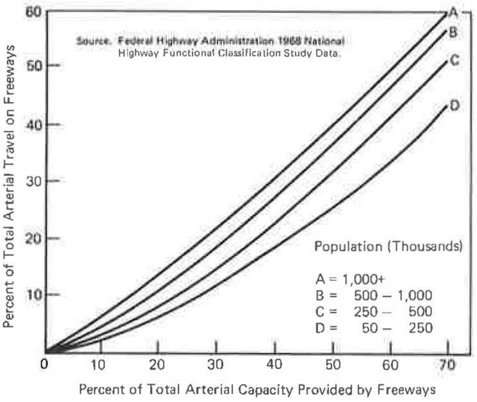


Figure 14. Functional VMT splitter.

Summary of the Travel Subsystem

The travel demand portion (Fig. 8) of the model system is constituted of the following major elements:

1. Specification of alternative growth policies in terms of relative distribution of population and employment in the central cities and suburban areas of urban regions;

2. Designation of transportation planning supply alternatives that are compatible with the land development alternative specified;
3. Projection of daily travel on the basis of an equilibrium model that incorporates the effects of the transportation system as well as the major influencing socioeconomic factors;
4. An estimate of transit use compatible with the preceding elements, or treated as a high-low specification variable;
5. Distribution of daily travel by hour period based on the characteristics of the urban area;
6. An estimate of the directional split of travel within each hour period;
7. An hour-by-hour comparison of travel demand with system capacity, redistributing travel in specified proportions to prior and subsequent hour periods when the travel-capacity ratio exceeds a designated limit; and
8. Allocation of travel within each period and directional class to the freeway and surface arterial systems.

SYSTEM PERFORMANCE

The allocation of travel within hour periods and directions to the freeway and surface arterial systems leads directly into the system performance phase of the TRANS-urban model system. In this phase, system loads are used to estimate average overall travel speeds, which in turn are used in estimating the basic elements of user costs (time, operating, and accident costs) and the magnitude of the major air pollutants that are generated (Fig. 15).

Estimating System Speeds

System speed represents a critical performance measure in the TRANS-urban model system. The two most important determinants of speed, physical class of facility and degree of system congestion, are both used in estimating these speeds.

To arrive at a system-speed estimating relationship requires a valid link-speed estimating relationship. The curves used to estimate link speeds were drawn from the 1965 Highway Capacity Manual (1) and are shown in Figure 16. The surface arterial relationship represents an average condition from among several curves in the Capacity Manual, arrived at using sampled urban area data.

The conversion of link-speed relationships to those that can be applied to entire systems depends largely on the distribution of link volume-capacity ratios for typical urban systems. Such data were compiled for a series of test networks from a number of urban regions. For each test system, the distribution of link volume-capacity ratios, by type of facility, was determined, and link-speed estimate was made by using the link speed curves. These speeds were then weighted by the vehicle-hours of travel that occurred on the link at that speed. For example, for facility type i on a typical urban system, the average system speed was determined by using the following formula:

$$\bar{S}_i = \left(\sum_j S_{ij}\ VHT_{ij}\right) \Big/ \left(\sum_j VHT_{ij}\right)$$

where

S_i = average system speed for facility type i,

S_{ij} = speed for facility type i, link j; and

VHT_{ij} = vehicle-hours of travel for facility type i, link j.

Total system congestion is measured as the ratio

$$\left(\sum_j VMT_{ij}\right) \Big/ \left(\sum_j CMS_{ij}\right)$$

where CMS refers to capacity miles of supply. For example, a 5-mile section of freeway with an hourly capacity of 7,500 vehicles would have an hourly total of 37,500 CMS.

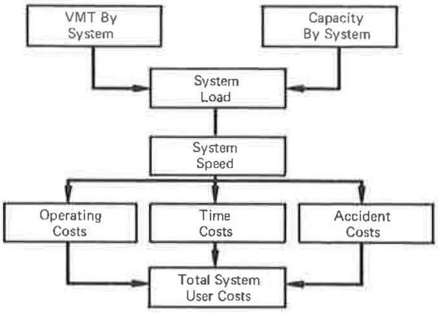
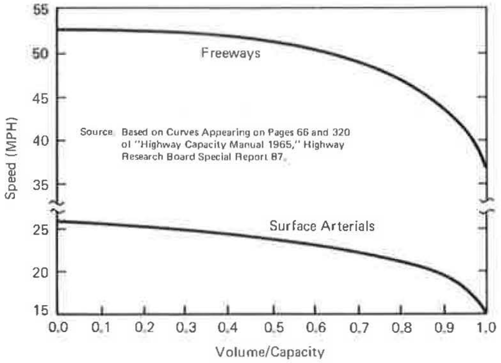


Figure 15. System performance subsystem.



Source: Based on Curves Appearing on Pages 66 and 320 of "Highway Capacity Manual 1965," Highway Research Board Special Report 87.

Figure 16. Estimating travel speed.

Figure 17, which was drawn from the TRANS-urban results produced for an individual urbanized area of about 4 million population, shows the future improvement in system speed that can be realized at various levels of annual investment.

Estimating Time Costs

Time costs can be estimated directly from speed, as shown in Figure 18. As implied in this figure, the value of time is, in itself, a variable, and a major policy variable at that. Most, if not all, transportation investment can be judged primarily on the basis of the value that is placed on savings of this scarce resource. Man has evolved a transportation system for himself and the goods he produces from primitive footpaths to a system on which movement occurs at speeds several times that of sound, all based on the value he places on mobility and accessibility or the ability to move from place to place within a specified time frame. Thus, the specification of an explicit pecuniary value on time has a profound influence on the magnitude and composition of transportation investments that can be justified. Rather than attempt to dictate a single measure, the TRANS-urban model treats the value of time as an explicitly defined specification variable.

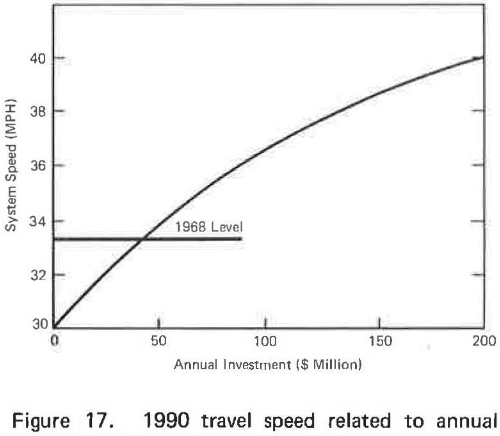


Figure 17. 1990 travel speed related to annual investment for a selected urban area.

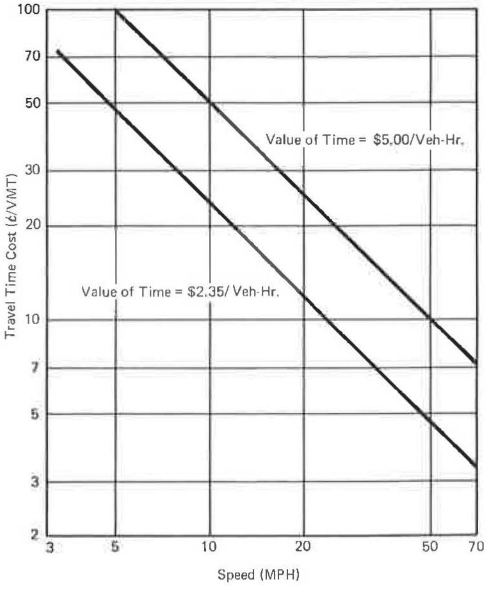


Figure 18. Travel time cost related to speed.

It is recognized that the true savings in travel time cannot be based entirely on differences in average speeds. For example, an addition of a freeway route will cause some diversion from previously used surface arterials that were more direct routes. Therefore, additional time and travel must be spent in gaining access to the less direct freeway route.

Estimating Accident Costs

Accident costs are currently incorporated in the TRANS-urban model as a rate per vehicle-mile, stratified by facility type. These were developed from previous studies that examined motor vehicle accident rates and average dollar costs associated with accidents (Table 4).

Fatalities are estimated separately. However, no value has been designated to place on the cost of a fatality other than direct measurable costs. Nevertheless, the model can incorporate any value of human life a user may wish to specify. It seems more reasonable, however, to treat fatalities as a "non-costable" factor and to examine alternative solutions to meeting specified constraints that reflect society's tolerance of highway deaths.

Figure 19 shows the reduction in annual fatalities indicated by a run of the TRANS-urban model that can be realized as a function of annual investments in freeway capacity for a selected urbanized area.

Computing Pollution Index

The national commitment toward conservation and protection of our environment has focused increased attention on the internal combustion engine and its affect on air quality in areas of intensive motor vehicle travel. As a nation, we seem to be passing from the problem-identification stage into a more action-oriented phase in dealing with air pollution. While it is still unclear precisely what shape this action will take in terms of a 20-year time horizon (the range of possibilities extends from the development and production of a totally clean internal combustion engine to a total ban on fossil fuels as a source of power for transportation vehicles), the TRANS-urban model can incorporate a number of possible assumptions.

The key relationships that make it possible to evaluate transportation investments in terms of pollution characteristics are those that correlate generation rates, by type of pollutant, with vehicular speed. Several of these relationships are shown in Figure 20 for the major pollutants generated by the internal combustion engine: carbon monoxide, unburned hydrocarbons, and oxides of nitrogen. These are shown for both pre-1968 and post-1975 conditions, the latter based on emission standards set by Congress. The curves show that the production of carbon monoxide and hydrocarbons decreases with increasing speed, while the production of oxides of nitrogen increases with increasing speed.

The problem of scaling the effect of air pollution generated by the internal combustion engine is most difficult. For example, looking at pollution generation alone can be misleading, because the impact from the same level of pollution can

TABLE 4
ACCIDENT COST IN CENTS PER VMT

Accident Type	Freeways	Surface Arterials
Fatality	0.088	0.147
Injury	0.153	0.436
Property damage	0.259	0.888
Total	0.500	1.471

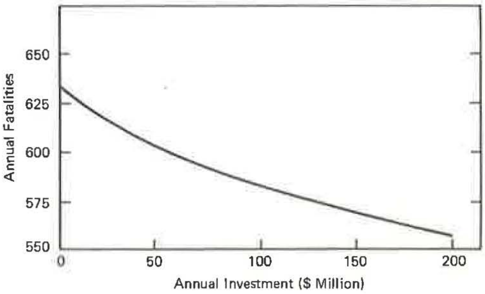
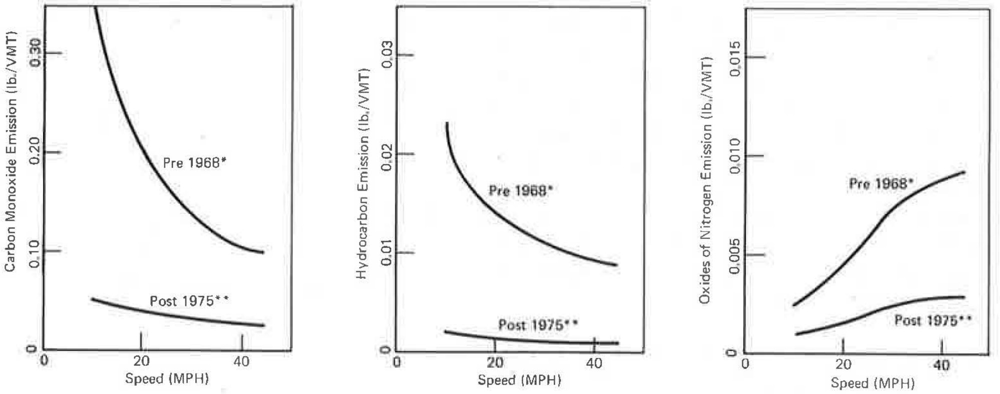


Figure 19. 1990 annual fatalities related to annual investment for a selected urban area.



*Source. Second Report of the Secretary of Health, Education, and Welfare to the U.S. Congress pursuant to Public Law 88-206 Clean Air Act.
**Based on the 1975 Emission Standards Set by the U.S. Congress.

Figure 20. Vehicular emissions of carbon monoxide, hydrocarbon, and oxides of nitrogen related to speed.

be radically different in areas where the composition and distribution of human, animal, and plant life differ, or where different meteorological conditions have varying effects on the dissipation of pollution. Furthermore, the harmful effects of pollution differ by individual pollutants, and placing a dollar cost on these effects, particularly where environmental and health factors are involved, is extremely difficult, if not impossible.

Significant progress has been made in the development of pollution generation and diffusion models that simulate conditions within an urban region. However, in a multiregional analysis, such as that performed by the TRANS-urban model, this approach is prohibitive. Instead, the model computes a "pollution index" for each transportation supply alternative and each of the major pollutants. The pollution index is defined as the ratio of future average area-wide pollution concentrations to existing average area-wide concentrations. The mathematical formulation is

$$I_{ij} = \underset{\text{(future)}}{\left[\left(\sum_k P_{ijk}\right)\Big/A_i\right]} \Big/ \underset{\text{(existing)}}{\left[\left(\sum_k P_{ijk}\right)\Big/A_i\right]}$$

where

I_{ij} = pollution index in urban region i, pollutant j;

$\sum_k P_{ijk}$ = total daily pounds of pollutant j generated on facility type k in urban region i; and

A_i = urban-in-fact area, urban region i.

As indicated previously, such an index cannot, in itself, adequately reflect the problems of air pollution caused by the internal combustion engine. Efforts are under way to attempt to place a measure on some of the impacts of air pollution. Also, the costs of overcoming the problem through technological change can be estimated. The index itself, however, does provide some insight. Figure 21, based on a run of the TRANS-urban model, shows the decline of the carbon monoxide index in sample regions as the percentage of capacity (and therefore travel) on freeways increases.

Summary of System Performance Measures

The system performance portion of the TRANS-urban model proceeds from the travel demand subsystem by first estimating system speeds for each facility type from measures of system congestion and subsequently estimating most of the elements of user costs and computing an index of air pollution by using speed as a basic input variable. The costable measures produced here are input to a cost-based investment-return analysis. Noncostable measures (such as fatalities or pollution effects that cannot be priced) are treated in an overall investment-return evaluation as constraints or are subjectively traded off against costable measures.

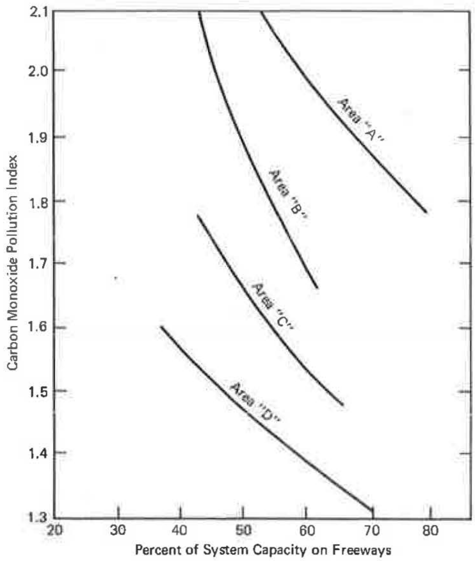


Figure 21. Pollution index related to freeway supply.

TRANSPORTATION FACILITIES COSTS

While the system performance phase of the TRANS-urban model deals largely with measures related to the users of transportation systems, this part of the model of directed toward estimating the costs associated with the provision of physical improvements. These include the direct costs such as construction and rights-of-way and the indirect costs such as land consumption and neighborhood disruption. These costs must be balanced against the benefits to users as well as the impact on nonusers in arriving at a rational level of transportation investment.

Direct Costs

The most visible costs of implementing a transportation improvement program are the costs of constructing, reconstructing, and maintaining the physical plant. These costs are usually of most concern to the decision-maker. The TRANS-urban model, as a multiregional planning tool, relies on the use of average cost figures, stratified in such a way as to eliminate as much variation as possible.

Determining what costs to use in a planning exercise that projects 20 or more years into the future is a difficult problem. As values, attitudes, and priorities change, factors that have a direct bearing on the costs of a transportation improvement also change. This is illustrated by data given in Table 5 that indicate the national average percentage distribution of existing and planned freeway miles by design type for central cities of one million or more people. These data clearly show that the less costly design types (such as at-grade), and the less aesthetic (such as elevated) are yielding to design categories reflecting the ever-increasing constraints imposed by the scarcity of potential rights-of-way, as well as the demand that freeways be designed as a visually pleasing and integrated component of the urban environment. Future requirements for minimizing neighborhood disruption, noise, pollution, and so on will surely be reflected in the design types and, hence, in the costs of transportation improvements.

TABLE 5

DISTRIBUTION OF FREEWAY MILEAGE BY DESIGN TYPE IN CENTRAL CITIES OF OVER ONE MILLION POPULATION

Design Type	Existing Freeways (percent)	Planned Freeways (percent)
At-grade	63	40
Depressed	7	20
Elevated	28	25
Tunnel	2	5
Joint development	0	10
Total	100	100

Source: Federal Highway Administration data.

The costs associated with various types of freeway improvements, as currently incorporated in the TRANS-urban model, are given in Table 6. For the larger urban areas, where freeways are more prevalent and the contraints imposed on freeways are perhaps more severe, freeway construction costs are stratified into a relatively fine level of detail. (This, of course, requires that the specification of supply alternatives include a designation of the distribution of

TABLE 6

URBAN FREEWAY COSTS

1968 Population Group (thousands)	Location	Design Type	Average Cost per Mile (millions of dollars—1970 prices)	
			Construction	Construction, Right-of-Way, and Engineering
50 to 500	All	All	4.7	5.7
500 to 1,000	Central city	At-grade	5.7	7.2
		Elevated	25.1	31.7
		Weighted mean	7.2	10.3
	Suburbs	All	3.9	4.9
	Total area	Weighted mean	5.6	7.1
Over 1,000	Central city	At-grade	14.7	18.5
		Elevated	38.7	48.7
		Depressed	27.4	34.5
		Corridor joint development	39.1	49.1
		Tunnel	86.7	95.5
		Weighted mean	28.8	35.4
	Suburbs	All	7.6	9.6
	Total area	Weighted mean	12.9	16.3

Source: Federal Highway Administration data.

freeway design types.) Within an urban area having one million or more people, the range of cost per mile for freeways extends from $9.6 million for suburban freeways to almost $100 million for a tunnel section in the central city.

Table 7 gives the surface arterial improvement costs used in the model, stratified by population group and type of improvement. Here, the range of costs within each improvement type is considerably less than that for freeways, as would be expected. Costs within urban areas having the largest populations are roughly twice those in areas having the smallest.

Indirect Costs

Indirect costs are those that are over and above the expenditures necessary for the direct physical transportation improvement. They are no less important than direct costs and, in fact, may be considered the most significant of all. Society is increasingly demanding that these costs be borne by the highway program before investments in new urban facilities are considered.

A good example of this is reflected by a recent U.S. Department of Transportation policy decision stating that no transportation improvements involving federal funds can

TABLE 7

URBAN AREA ARTERIAL COSTS

Population Group (thousands)	Type of Improvement	Average Cost per Mile (thousands of dollars—1970 prices)	
		Construction	Construction, Right-of-Way, and Engineering
50 to 100	New location	860	1,060
	Reconstruction	670	750
	Widening and resurfacing	450	490
100 to 500	New location	950	1,160
	Reconstruction	720	820
	Widening and resurfacing	480	530
500 to 1,000	New location	1,210	1,470
	Reconstruction	920	1,040
	Widening and resurfacing	620	680
Over 1,000	New location	1,640	2,000
	Reconstruction	1,240	1,400
	Widening and resurfacing	840	910

be made before it is demonstrated that safe, sanitary, and decent quarters are available to those who have to be relocated. In many cases this involves an expenditure of funds over and above that necessary to merely purchase rights-of-way at fair market value. In fact, the 1968 Federal-Aid Highway Act authorizes payment of up to $5,000 in excess of payments necessary to purchase a private dwelling unit if such a sum is required for the purchase of comparable replacement housing. Some states, in fact, are actually financing the construction of replacement housing for families that are displaced as a result of a highway improvement.

The TRANS-urban model currently incorporates the costs of displacements of families and businesses by applying an average per mile rate derived from historical data. These rates are as follows.

Type of Displacement	Displacements per Mile
Persons	160
Dwellings	55
Businesses	6.5

It should be emphasized that these indirect costs are separated from direct costs simply to distinguish the investments required to physically providea facility from those investments required as a result of the impact of providing a facility. Other indirect costs include the loss of tax revenues from property taken for highway purposes and the costs of reducing noise, of overcoming pollution damages, or of overcoming a possible reduction in accessibility. Some costs are in fact "negative costs" or windfalls that should also be taken into account. These include net rises in property values producing increased tax revenues and advertising value gained by business establishments visible from a new facility. Obviously, many of these are difficult to include even in an analysis at the project level, much less in a model system such as TRANS. Others are difficult to estimate in dollar terms. The approach taken by the TRANS-urban model is to identify as many of the significant impacts of transportation improvements as possible and to place dollar values on those improvements lending themselves to a cost-based analysis.

Non-Costable Factors

As the term implies, non-costable factors include those costs that either do not lend themselves to measurement along a monetary scale or do lend themselves to measurement but that also require additional consideration in more subjective terms. In the TRANS-urban model, these include the number of highway-related fatalities, the air pollution indexes, the number of displaced homes and businesses, the acres of land consumed by transportation improvements, and the employment generated by construction programs. As with indirect costs, it is becoming increasingly common that factors such as these are most influential in determining the feasibility of a project or a policy. They are treated in the model both as informational outputs and as constraints. As constraints, it is possible to specify any tolerance limit desirable and discard alternatives that fall outside these limits. The effects of relaxing or tightening these constraints can also be measured.

EVALUATION PROCESS

The evaluation process in the TRANS-urban model system is a two-phase analysis. The first phase is constituted entirely of those factors that lend themselves to measures of worth in terms of dollars. These include the direct, indirect, and user costs as discussed previously. The second phase brings to bear those factors that are difficult or impossible to measure in terms of dollars, or those that can be priced but are more significant in other terms (Fig. 22).

The economic analysis, which is the first phase of the evaluation process, is, in essence, a marginal dollar investment-return analysis. The return can be either positive, such as savings in user costs, or negative, such as possible increased costs incurred because of air pollution. Investment measures include both direct costs, such

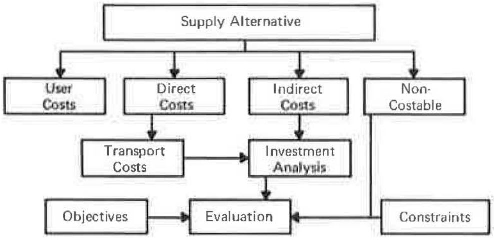


Figure 22. Evaluation process.

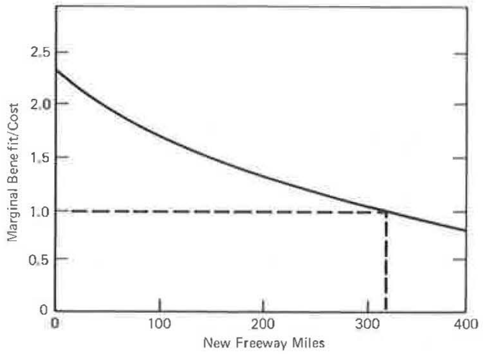


Figure 23. Investment analysis for a selected urban area.

as construction costs, and indirect costs, such as the excess costs of providing replacement housing. All costs are converted to an equivalent annual basis with the discount rate treated as an input parameter. If an optimum solution is sought in terms of purely economic criteria, incremental supplies of transportation facilities are provided until a marginal investment-return ratio of 1.0 is reached. This process is shown in Figure 23 for a sample area with a 1990 population of about 4 million. In this case the TRANS-urban model indicated that, based purely on economic criteria, slightly more than 300 additional freeway lane-miles could be justified.

Other criteria used in the evaluation process enter in the second phase of the analysis. In this phase specifications are invoked in terms of constraints on non-costable items, such as fatalities, or the several air pollution indexes. Transportation investment alternatives that fail to meet these designated constraints are ignored regardless of their economic viability. If more than one alternative meets these constraints, then the choice of an optimum reverts to a process of trading off the more economically oriented items against the non-costable considerations.

SUMMARY

The TRANS-urban model system is a policy-planning tool capable of providing insight concerning transportation investment alternatives for a large number of individual urban regions. It operates at a fairly high level of data aggregation and treats entire urban areas or large subareas as basic analysis units. The analytical framework includes the designation of compatible land development and transportation supply alternatives; the projection of future travel on the basis of an equilibrium travel demand model; the allocation of travel to hour periods, directions, and functional systems; the development of system performance and system cost measures that reflect consequences both to users of the system and to society in general; and an evaluation process that aids in the selection of alternatives on the basis of established criteria and constraints.

The determination of long-range government priorities, policies, and programs is a complex process that blends hard politics with occasional naive idealism, trades off narrow interests against the common good, and balances facts with feelings. It is a process taken for granted when it succeeds, and it is subject to relentless attack when it bogs down or fails. There is no formula for success. It remains the responsibility of transportation planners, however, to maintain a firm philosophical and functional commitment to provide policy formulators and decision-makers with a continuous flow of information and an objective capability for digesting and evaluating this information as they gather whatever inputs they need for setting policies and reaching decisions. The TRANS-urban approach must be viewed in this context. It is not an automatic policy-making tool. It is intended solely as a mechanism that can provide rational information that was perhaps not previously available.

REFERENCE

1. Highway Capacity Manual, 1965. HRB Spec. Rept. 85, 1965, 418 pp.