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The TRANS Urban Model System and Its Application to the 1972 National Transportation Study

by

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THE MULTI-MODAL national urban transportation policy planning model described in this paper, is the current operational version of the continuing Transportation Resource Allocation Study (TRANS) modelling effort.[1,2] The TRANS approach has been one of designing a set of models which are: responsive to the needs of urban policy planners and decisionmakers at the highest levels; capable of dealing effectively with large numbers of transportation issues quickly and efficiently; capable of assessing the consequences of alternative courses of action complemented with the ability to determine preferred courses of action to achieve desired goals; and finally, capable of explicitly relating to the social, economic, environmental, and political impacts of each alternative under consideration.

Prior to the TRANS activity, much of the effort toward the development of urban transportation planning techniques had 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, there are considerable difficulties in attempting to directly apply these techniques for national policy planning. The model structure described in this paper was undertaken to achieve this specific objective.

Earlier versions of the TRANS Model represent developmental stages of the TRANS-urban methodology.[1] These versions were basically highway oriented models primarily concerned with treating highway investment tradeoffs under varying transit usage assumptions. The later version provided the capability to analyze central cities and suburbs separately and incorporated the results of three specific research projects into the model system.[2] These projects produced: (1) a system sensitive model for predicting areawide urban travel,[3] (2) an analytical model for estimating the distribution of highway travel between freeways and surface arterials,[7] and (3) a set of relationships describing in detail the variation in travel demand over the course of a day.[4]

The current stage of development, the multimodal TRANS model, represents a major extension of the scope of earlier versions by including in the same investment analysis transit as well as highway. This version draws upon the result of a research project which produced an aggregate, areawide mode choice model capable of predicting relative transit usage for work and nonwork trips, in peak and off peak periods, on the basis of travel time and travel cost differences between private automobile and transit modes.[5] This integrated multi-modal framework has been the result of a combined effort of the Federal Highway Administration and the Office of the Assistant Secretary for Policy and International Affairs. It provided analytical support for the 1972 National Transportation Study performed by the Department of Transportation.[6]

Basic Approach

The TRANS Model system is comprised of a set of analytical procedures for evaluating alternative levels and mixes of transportation investments in urbanized areas. The model operates on an aggregate level, treating each urban region as a basic unit of analysis. It is capable, however, of treating in a single application every urbanized area in the nation.

The underlying structure of the TRANS-Urban model system, as it is applied individually to each urban region, is shown in Figure 1. The process involves specifying a range of investment levels to be tested, and within each level, alternative mixes among four types of transportation supply; freeways, surface arterials, conventional bus, and rapid transit (both bus and rail). The increments in supply are added to existing levels of each supply type (in each urbanized area) to provide a total 1990 transportation system alternative. Travel projections are made on the basis of both socio-economic variables and the nature and extent of the transportation system supply alternative. The travel is

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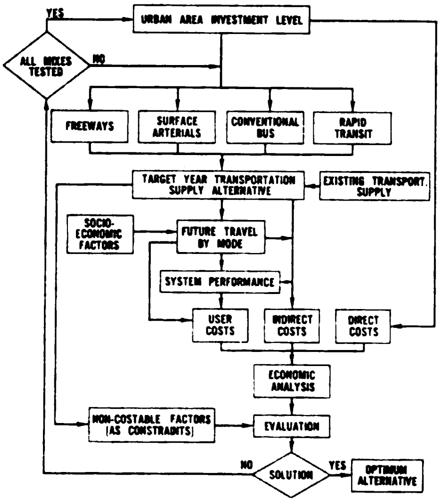
FIGURE 1

TRANS-URBAN MODEL SYSTEM
(MULTIMODAL VERSION)



distributed by time of day and mode, with system performance measures (such as speed) estimated on the basis of the interaction between supply and travel demand. User costs (such as traveltime costs) are calculated for each mode, along with external costs (such as pollution costs and specified social costs for dislocations and disruptions).

Changes in these costs between alternatives are compared with changes in investment levels and an economic analysis performed. If the alternative passes various constraints which may be placed on the economic analysis and also passes constraints due to "non-costable" factors (such as number of fatalities), then the alternative may be accepted. All specified investment levels and supply mixes are investigated, with the so-called "best alternative" selected and summarized.

The following sections describe in some detail the major elements of the TRANS-Urban model system.

FIGURE 2

OPERATION OF THE INCREMENTING STRUCTURE AT VARYING INVESTMENT LEVELS

INVESTMENT LEVEL		OPERATION
NO (k)	INVESTMENT	
1	0	EVALUATION OF BASE YEAR SYSTEM PERFORMANCE
2	0	EVALUATION OF TARGET YEAR DO-NOTHING ALTERNATIVE
3	I_S^*	ADDITION OF SPECIFIED MINIMUM SURFACE ARTERIAL SUPPLY, WHICH IS NOT SUBJECT TO ECONOMIC EVALUATION
4	I_{CB}^*	ADDITION OF SPECIFIED MINIMUM CONVENTIONAL BUS SUPPLY WHICH IS NOT SUBJECT TO ECONOMIC EVALUATION
5	I_5	NORMAL INCREMENTING STRUCTURE
↓	↓	↓
K_{max}	I_{max}	NORMAL INCREMENTING STRUCTURE**

*INVESTMENT INCREMENTS IN THE SUPPLY CATEGORIES WHICH FOLLOW IN I_5 THROUGH I_{max} ARE OVER AND ABOVE THE MINIMUM INVESTMENT LEVELS SPECIFIED FOR K=3 AND K=4

**SEE FIGURE 3.

Incrementing Structure for Testing Alternative Supply Levels

The multimodal version of the TRANS-Urban model, as it analyzes each urbanized area individually, considers a specified range of investment levels for each area. Within each investment level, the model considers a specified range of mixes in the supply of freeways, surface arterials, conventional bus transit, and rapid transit. The investments represent total expenditures for each mode and submode over the entire forecast period. Thus, by applying appropriate unit costs to the investment in each category, total new supply provided between base and target years is calculated. This "new" capacity provided is then added to base year (existing) supply in each transportation category yielding total supply available in the target year for each of the four supply categories.

The application of the incrementing structure within the model system is illustrated by Figures 2 and 3. Figure 2 primarily describes the first four alternatives considered by the model in each urbanized area. The first alternative (which is not really an alternative as such) operates on base year conditions and performs an evaluation of system performance (speeds, operating costs, accidents, mode split, etc.) under current supply levels. The second alternative examines the "do-nothing" case under which future travel projections are derived assuming no additional facilities are added to those existing in the base year.

Alternative three involves the addition of a specified minimum supply of surface arterials to be provided for the growth area between the 1968 and 1990 urban boundaries. (The unit costs associated with this minimum supply of surface arterials assumes that these roads will be reconstructed from existing outlying rural facilities.)

FIGURE 3

OPERATION OF NORMAL INCREMENTING STRUCTURE FROM K=5 THROUGH K_{max}

		INVESTMENT BY CATEGORY				
INVESTMENT LEVEL NUMBER (k)	TOTAL INVEST. LEVEL	INVEST. MIX NUMBER	FREEWAY (1)	SURFACE ARTERIAL (2)	CONVENTIONAL BUS (3)	RAPID TRANSIT (4)
5	I_5	1	$P_{11}I_5$	$P_{12}I_5$	$P_{13}I_5$	$P_{14}I_5$
↓	↓	↓	↓	↓	↓	↓
		m	$P_{m1}I_5$	$P_{m2}I_5$	$P_{m3}I_5$	$P_{m4}I_5$
K_{max}	I_{max}	1	$P_{11}I_{max}$	$P_{12}I_{max}$	$P_{13}I_{max}$	$P_{14}I_{max}$
		↓	↓	↓	↓	↓
		m	$P_{m1}I_{max}$	$P_{m2}I_{max}$	$P_{m3}I_{max}$	$P_{m4}I$

P_{ij} PERCENT OF INVESTMENT ALLOCATED IN MIX NUMBER i TO CATEGORY j

$\sum_{j=1}^{4} P_{ij} = 100.0$

NOTE BOTH THE UPPER AND LOWER BOUNDS OF THE MODAL PERCENTAGES FOR EACH MODE MUST BE INTEGER MULTIPLES OF THE MODAL PERCENTAGE INCREMENT.

The fourth alternative adds a specified minimum supply of conventional buses in order to overcome the model's inability to appraise the very low levels of conventional bus service which would arise from the normal application of the incrementing structure under low investment levels. This alternative is the base to which subsequent alternatives are compared until one is reached which is better according to the economic analysis, at which point the latter alternative becomes the new basis for comparison.

Beginning with the fifth alternative, the model's normal incrementing structure is applied, as shown in Figure 3. Initially, within each investment level, the percentage allocation to each of the modal categories is set at a pre-designated lower limit. A test is performed to determine whether or not these lower limits add to 100 percent. If not, an increment is added to the first mode leaving the other modes fixed. Increments are added to this mode until its specified upper limit is reached, whereupon the next mode is incremented and the first mode reset to its lower limit. The procedure continues until all combinations within the specified ranges have been tested, at which point the overall investment level is increased, and the process of testing the various mixes is repeated.

As indicated earlier, unit costs by mode are applied to each investment level and mix to determine the total target year supply by mode. In the cases of freeways, surface arterials, rail rapid, and the non-rolling stock portion of bus rapid this simply involves dividing the modal investment by the appropriate unit costs. In the case of buses, however, the analysis is complicated by the relatively short economic and physical life of bus vehicles. The problem is illustrated in Figure 4 which shows that buses bought in the base year may not be in service by the target year. To convert total investment in buses over the planning period to a target year supply, the following relationship was developed, assuming a linear variation in total supply between the base and target years.

$$B_n = \frac{\frac{I_b}{C_b} - \frac{B_o X_n}{X_r}}{2 - \frac{X_r}{X_n}} + B_o$$

Where

B_n = Bus fleet size in target year

B_o = Bus fleet size in base year

X_r = Number of years in the economic life of a bus

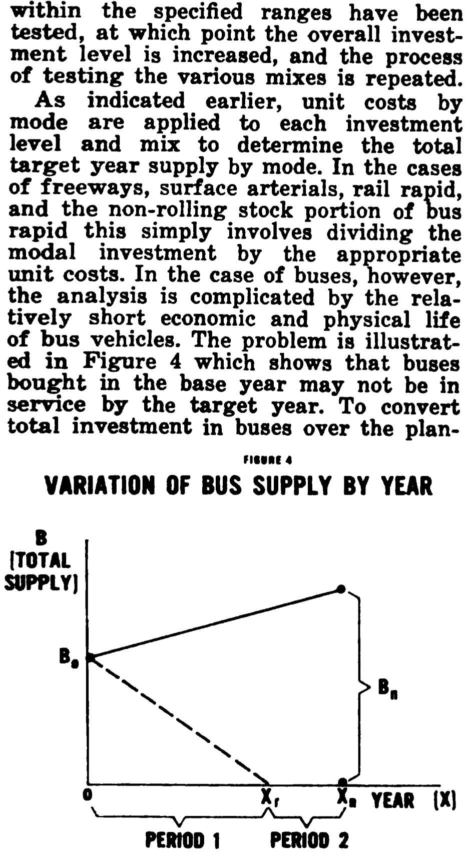
X_n = Number of years between base and target years

I_b = Capital investment in bus rolling stock between base and target year

C_B = Cost per bus

FIGURE 4

VARIATION OF BUS SUPPLY BY YEAR



For the j^th time period in the future (where each time period is the number of years in the economic life of a bus), the number of buses to be added (or deleted) annually is given by the following relationship:

$$b_{nj} - j. \frac{(B_n - B_o)}{X_n} + \frac{B_o}{X_r}$$

where

b_{nj} = Number of buses added per year in the j^{th} time period

j = Time period number.

In summary, the incrementing structure permits a systematic evaluation of specified mixes among four categories of urban transportation supply through a specified range of capital investment levels. Non-capital costs such as for highway maintenance and transit operations are derived based upon the level of supply stipulated, and incorporated in the economic analysis. However, they are not included as part of the investments specified in the incrementing structure.

Travel Subsystem

There are three alternative methods for developing the travel projections in this version of the TRANS-Urban model. These include: (1) the direct use of urbanized area travel projections submitted by the States, (2) a modification to the State's submitted projections based upon a simplified adjustment factor to reflect variations in system supply, and (3) a modification to the States' projections based upon a set of sequential models which predict person trips, trip length, and vehicle occupancy. The same mode choice model is applied regardless of which procedure is used. These three methods are described individually below:

A. Use States' Travel Projections Directly. Under this approach, forecasts of vehicle miles of travel (VMT) prepared by each State (as part of the 1990 Functional Classification and Needs Study) are entered directly into the model for each urbanized area. However, since the mode split portion of the multimodal version of the TRANS-Urban model requires total internal person trips as input, several adjustments and assumptions are required to process the States VMT forecasts. A step by step description of this process (shown by the flow diagram in Figure 5) follows:

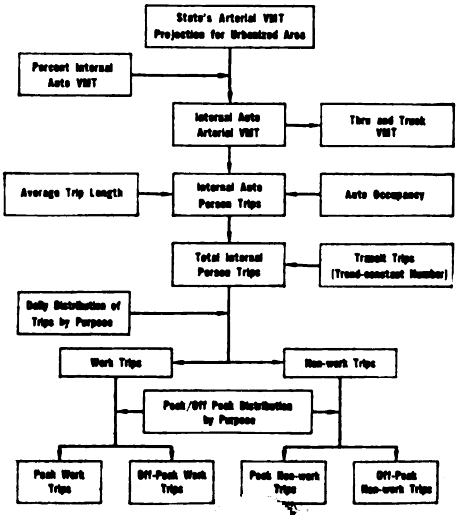
1. States' projected travel is separated into internal auto, truck and through travel by applying factors developed from urban transportation study data.

2. Internal auto travel is converted to internal auto person trips using overall average trip lengths and car occupancy rates.

3. Total projected internal person trips are calculated by adding internal auto person trips to base year estimated transit trips. Using base year transit trips in this projection assumes (1) that the states travel forecasts are trend based and (2) that the transit trend reflects a constant level of transit trips (projected transit trips equals current transit trips). Once these transit trips are merged with auto person trips they lose their identity, and the entire sum of internal person trips is subjected to the mode split analysis, described later.

FIGURE 5

Developing Internal Person Trip Estimates for Mode Split Analysis Using State's Travel Estimates



4. Daily total internal person trips are stratified by two trip purposes (work and non-work).

5. Trips by purpose are stratified into peak and off peak trips.

6. The mode split model is applied to peak and off peak trips, by purpose, excluding hours between midnight and 4 a.m.

7. Transit trips are analyzed in the transit subsystems. Auto trips are converted back to daily vehicle miles, combined with through and truck VMT, and analyzed in the highway subsystem.

B. Crude System Sensitive Adjustment to States' Highway Travel Projections. The second alternative travel subsystem involves an adjustment to the States' projection of travel to reflect the influence of different levels of system supply on the level of travel demand. The functional relationship developed from cross sectional data submitted by the States is as follows:

$$\text{VMT} = (f)\ (\Delta \text{highway capacity})$$

The change in VMT (ΔVMT) refers to the difference in travel between the travel under the alternative being considered and the States submitted travel. The change in highway capacity refers to the difference between the level of supply under the alternative being considered and the level of supply submitted by the States under 1990 Functional Plans. Thus, for example, if the highway supply of a system alternative exceeds the supply level as indicated by the States 1990 Functional Plan, the travel projection used in the model will exceed the States projection. The adjusted travel projection used in the subsequent analysis is derived knowing the difference in travel (ΔVMT) and the actual States' submitted travel projection. Following this adjustment process, this approach is identical to method A.

C. Full System Sensitive Adjustment to States Travel Projections. The third approach to developing travel projections involves the utilization of a sequence of models developed under a research contract. The project titled "A System Sensitive Approach for Forecasting Urbanized Area Travel Demands"[3] produced relationships for estimating areawide daily person trips, average trip length, mode split, and vehicle occupancy, by trip purpose.

The use of the full system sensitve approach involves sequentially the travel models to adjust States' submitted travel projections to obtain highway VMT. (Transit trips are estimated directly using the person trip and mode split models.) The adjustment factor is derived by (1) solving for the model generated internal auto person miles of travel under the system capacity in the States' submitted 1990 Functional Plan, and (2) assuming compatibility between the State's 1990 plans and the State's projected auto travel (both of which were developed together). With the assumption that the State's forecast is correct under the State's planned system, a ratio is computed between the model projection of internal auto person miles and the internal auto person miles based on the State's projections. This ratio is used to adjust raw model estimates under future systems alternatives which differ from the 1990 Functional Plans submitted by the States. Thus,

adjustment factor

$$PMT_i = \frac{PMT_{ss}}{PMT_{vs}} \times PMT_{vi}$$

where

PMT_i = Adjusted internal auto person miles used in model for supply alternative i

PMT_{ss} = States internal auto person miles from VMT submitted with States 1990 system

PMT_{vs} = Model derived internal auto person miles under State's 1990 system

PMT_{vi} = Unadjusted internal auto person miles from model for supply alternative i.

The development of the adjustment factor occurs once for each urban area. Once calculated, it is applied to the raw internal auto person mile projections for each alternative supply level being tested. The operation of the full system sensitive model is described in the following steps:

1. Internal person trips by home based work, home based non-work, and non-home based trip purposes are estimated.
2. Estimates of internal average trip lengths by the same three trip purposes are solved for.
3. The person trip estimates are combined for the mode split analysis. Person trips occurring during hours with no transit service are deducted from the daily total.
4. Person trips by the two remaining trip purposes are stratified by peak and off peak periods.
5. The mode split models are applied, by peak and off peak, and by trip purpose.
6. Transit trips are analyzed in the transit subsystem. Auto trips are combined with trip lengths yielding internal auto person miles of travel, which is the quantity subject to the adjustment process described earlier.

The selection of which of the three travel projection approaches to use is left to the discretion of the analyst. It is expected, however, that approach "C," since it reflects an attempt to explicitly include system variables in projecting travel demand, would be applied most frequently.

Macro-Level Mode Split Model

The development of a macro-level (areawide) mode choice model represented the key to providing the TRANS-Urban model with a true multi-modal capability.[5] The macro-model was formulated utilizing data from micro-level simulations using a hypothetical urbanized region of 2.5 million persons, and a generalized micro mode split model (applied to zone-to-zone trip interchanges) developed from actual applications to three real cities.

A. Micro-Mode Choice Model Used in Development of Macro Model. Thirteen test situations were formulated using the hypothetical urban region. The tests covered a range of both highway and transit levels of services, and two types of urban activity patterns. Three types of transit alternatives were considered; (1) conventional bus only, (2) bus rapid (combined with conventional bus), and (3) rail rapid (combined with conventional bus). The micro mode choice model used in the analysis estimated transit usage on the basis of (1) relative levels of service between private automobile and transit, (2) automobile ownership, and (3) trip purpose (i.e., work and other). The relative system service levels were estimated on the basis of the utility function. $U = 2.5 (Ta + TW - At) + (Tr - Ar) + (F - 0.5P - D{:}M)/C$ where U = Marginal utility, Ta = Walk time to/from transit, Tw = Wait time for transit, Tr = Running time for transit, F = Transit fare, At = Auto terminal time, Ar = Auto running time, P = Parking cost, D = Highway distance, C = Cost of time (assumed as 25 percent of income), and M = Auto mileage cost.

The concept of the micro-level model is that transit usage depends upon both the relative service levels between the private auto and transit modes, and level of auto ownership. The former factor essentially treats "choice" travelers (those having both transit and private auto available to them) and is measured by the function which relates the marginal utility between the two modes (on the basis of traveltime and travel cost parameters) to relate transit use. The auto ownership factor accounts for transit usage as it is influenced by both income level and the availability or lack of availability of private automobiles.

The application of the micro model to the 13 test systems produced a set of aggregate, areawide data containing information on travel demand, system performance, and system supply. Utilizing these data, a group of aggregate level relationships were developed to provide TRANS with the necessary macro level modeling capability.

B. Macro Models. The macro-level mode choice models consist of families of curves which relate areawide percent of internal person trips via transit to areawide traveltime and travel cost differences between transit and private automobiles. The models are stratified by trip purpose (homebased work and other) and by time period (peak and off peak).[5] Since the models were developed on the basis of a hypothetical city of 2.5 million persons, their application in TRANS is limited to only the largest urbanized areas (greater than 500,000 population). The aggregate mode choice models are applied to the peak/off peak and home based work and other internal person trips, which emanate from any one of the three travel structures. As mentioned earlier, transit trips are then analyzed in the transit subsystem while auto trips are converted to vehicle miles of travel and incorporated with truck and external VMT, yielding total area VMT, to be analyzed in highway subsystem.

Driving the macro models are four basic inputs—traveltimes and travel costs for private auto and transit.

1. Private auto traveltime. Within each alternative, private auto traveltimes are estimated using an iterative approach. For each TRANS supply alternative, the model initially assumes that all internal person travel will be via private auto.

Having made this assumption, a first estimate is made of average overall travel speed on highways for peak and off peak periods. These speeds are converted, through estimated average trip length, to average time per internal auto person trip, which is then used in the mode split model.

After the mode split calculation is made, highway travel is reassembled and highway speeds recalculated using the highway subsystem and compared to the speed used going into the mode choice analysis. If the speeds match within a specified tolerance, the model proceeds normally. If the speeds fail to match, an adjustment is made to provide a new input speed estimate, and the mode split rerun. This process continues until the input and final speeds actually balance within the tolerance limit.

2. Transit Traveltime. Transit traveltimes are estimated utilizing equations based upon the relationship between peak transit travel time (minutes) and transit supply per capita. The equations were developed to account for the effect on transit traveltime of levels of conventional bus supply which differ from those inherent in the 13 system tests as well as to incorporate logical minimum and maximum traveltimes.

Off peak transit traveltimes are derived using a relationship which relates off peak times to peak traveltimes based upon relative transit supply in the two periods, and based upon level of highway supply.

3. Private Auto Travel Costs.[1] Cost per internal auto trip for the purposes of the mode split analysis include perceived vehicle running costs and parking costs.[2] Perceived running cost per vehicle mile is divided by vehicle occupancy and multiplied by the average trip length (by trip purpose) yielding the running cost per trip. This cost, which is initially input on a per vehicle trip basis, represents an estimate of the sum of all parking costs incurred (by trip purpose for peak and off peak periods) divided by the sum of all trips taking place (by trip purpose for peak and off peak periods). Parking costs are calculated external to the model by estimating the percentage of auto trips in a metropolitan area which end in the central business district (CBD), by trip purpose and in the peak and off peak periods. (It is assumed that only CBD trips incur parking costs.) The actual parking fee which is charged is then multiplied by this percentage to arrive at an average cost spread over all internal automobile trips within a particular trip purpose and time period. A vehicle occupancy factor is then applied to convert to cost per person trip.

4. Transit Travel Costs. The perceived cost to transit users is represented solely by the average areawide fare. Transit fares are specified separately for peak and off peak periods.

In summary the macro level mode choice model is applied to each urbanized area for each supply alternative, and produces estimates of the split of internal person trips between the transit and private automobile modes.

Transit Subsystem.

Following the mode split analysis for each investment level and unique mix of investments, an analysis of transit use is performed in the transit subsystem. This consists of computing transit person miles of travel, performing a "submodal" split, and calculating load factors by sub-mode.

A. Transit Person Miles. Transit person miles of travel are computed by multiplying transit trips by average trip length. When using the first travel subsystem (which incorporates the States' travel projections directly) a single average trip length is used, as read in from the urban area data record, for all transit trips. The second travel subsystem (crude system sensitive adjustment) operates in the same way.

The third travel subsystem (which utilizes the full system sensitive models) uses average trip length by trip purpose. The home based work trip length is derived from the equation for that trip purpose, while the trip lengths from the home based non-work and the non-home based equations are weighted to obtain an average trip length for the "other" trip category.

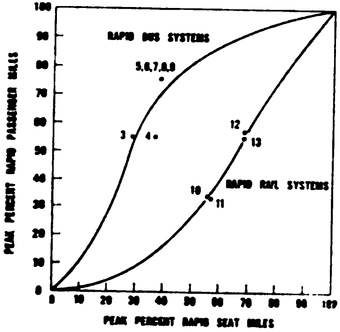
B. Sub-modal Split. The macro mode choice model is bi-modal; i.e., it distinguishes between basically two modes of travel—private automobile and transit. In order to determine the allocation of transit travel to conventional bus and to rapid transit systems, when the two are considered simultaneously, the model utilizes a sub-modal split analysis which was developed from the series of simulations performed to obtain the macro mode choice model. The sub-mode split curves are shown in Figure 6 for rail and bus rapid systems. According to the data from which the curves were developed, a given share of seat miles of transit supply on bus rapid attracts a greater share of the transit market than that attracted by the same share of seat miles on a rail rapid system.

This is perhaps a reflection of the ability of bus rapid systems to perform a collection/distribution function as well as provide rapid line haul service. (In fact, the rapid bus seat miles include those seat miles which occur during collection and distribution of passengers on conventional streets.)

The sub-mode split curves were developed only for peak periods. For lack of any data, it is assumed that they apply to off peak as well, although the model is capable of accepting any other assumed or derived relationships.

FIGURE 6

PEAK PERCENT RAPID PASSENGER MILES OF TRAVEL VERSUS PEAK PERCENT RAPID SEAT MILES



C. Calculation of Transit Load Factors. Based upon the allocation of passenger miles to each of the two transit sub-modes, the ratio of passenger miles to available seat miles, by sub-mode is calculated and compared to a specified maximum load factor. This is done for peak and off peak time periods for both sub-modes. If any of the computed load factors exceed the maximum allowed, a message is printed to that effect and the model proceeds to the next highest investment alternative without further consideration of the alternative being examined. The only exception to this rule occurs for the do-nothing alternative. If, in this case, any maximum load factor is exceeded, the model proceeds through the incrementing structure until a transit supply level is provided which accommodates all demands. This supply level is then adopted as the new do-nothing alternative.

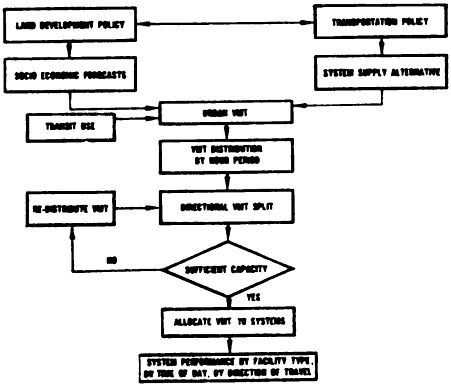
Highway Subsystem.

Once the mode split process is completed for peak and off peak periods, highway travel is "reassembled" for the full day. This involves converting internal auto person trips (which are output from the mode split) to internal auto vehicle miles of travel, estimating truck and external vehicle miles, and applying a factor to transform total vehicle miles of travel to arterial travel (on freeways and surface arterials).

Whereas the mode split process and the transit subsystem operate on the basis of three time periods (peak, off peak, and the "wee hours" during which there is no transit service), the highway subsystems is capable of dividing the average day into as many as 24 hour periods. This disparity in the temporal

FIGURE 7

HIGHWAY TRAVEL DEMAND ELEMENT



stratification of private vehicle and public transportation travel reflects both limitations of technical procedures (for example, it would have been difficult if not impossible to develop separate mode choice models for 24 distinct time periods) as well as the greater variation in the performance characteristics of private vehicles by hour of the day. That is, the characteristics of transit operation (such as load factors, supply levels, speeds, fares, etc.) can be sufficiently categorized into two time periods (peak and off peak) whereas motor vehicle running costs vary considerable more hour by hour based upon relative speeds and levels of congestion. Figure 7 shows the travel element of the highway subsystem.

The multimodal TRANS-Urban model has adopted a stratification of 20 time periods throughout the day. Data which reflect this variation were drawn from a contract research project performed for TRANS titled "An Analysis of Urban Travel by Time of Day."[4]

Within each time period travel is allocated to each of two directions. This directional stratificaton recognizes that while system capacity is usually fairly evenly split 50/50 by direction within most hours of the day, and particularly during peak periods, highway travel is rather unevenly distributed, in a directional sense. Thus, for each time period a directional factor is applied which stratifies total arterial travel into two categories, the first accounting for one radial direction and one circumferential direction, and the second accounting for the opposite radial and circumferential directions. These directional factors were also provided by the above mentioned study.

Within each hour period and direction the model computes the ratio of highway travel to available highway capacity. The ratio is then compared to specified maximum travel to capacity ratios for each time period. If the latter is exceeded, the model attempts to redistribute travel to prior and subsequent hour periods (in specified proportions) having excess capacity. If all hour periods are at this maximum level of congestion, the program prints an appropriate message, and proceeds to the next supply alternative.

After arterial highway travel has been distributed by hour and direction the model allocates travel to the two classes of arterial facilities—surface arterials and freeways. This is accomplished through the use of one of two alternative "functional splitters." The first functional splitter, simply allocates proportionate shares of travel to freeways and surface arterials based upon their respective proportionate shares of arterial highway capacity, and the population group in which the urban area under consideration lies. The second functional splitter is considerably more sophisticated. This functional splitter allocates travel to freeways and surface arterials based upon relative speeds on the two types of roads, overall average trip length, average ramp spacing, and the relative supply of freeways and surface arterials.[7]

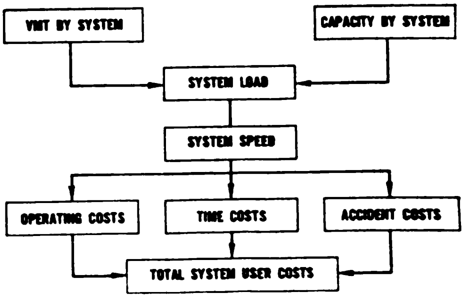
The specificaton of which functional splitter is to be used in a particular application is made by the user of the program. With daily arterial travel stratified according to 20 time periods, two directions, and two facility types, the TRANS-Urban model is able to estimate indicators of highway system performance for 80 individual categories. The system performance element of the highway subsystem is illustrated in Figure 8. In the system performance subsystem systemwide travel to capacity ratios are used to arrive at individual estimates of average freeway and surface arterial overall travel speed. Also estimated are vehicle running costs, which vary by speed and facility type, (and are based on speeds) traveltime costs (based upon a specified composite private auto/truck value of traveltime per vehicle hour) and accident costs (which vary by facility type).[1] To these three basic elements of user costs can be added pollution costs, by three types of pollutant, at the specification of the user. Total user costs are summed within and across all hour periods, directions, and facility types, producing an estimate of total daily user costs on the highway system. These costs, along with various performance indicators such as peak hour and daily speeds, and peak hour and daily travel to capacity ratios, are reported in the output.

Transportation Costs

The TRANS-Urban model incorporates a host of costable criteria in at-

FIGURE 8

HIGHWAY SYSTEM PERFORMANCE ELEMENT



tempting to evaluate the consequences of each transportation investment alternative. These criteria include not only those which are readily amenable to treatment in dollar terms such as user costs and construction costs but also those factors which are normally somewhat difficult to measure in terms of costs. The latter include such items as pollution costs, cost of a fatality, and costs of dislocations and disruptions in excess of direct right-of-way costs. These factors are usually incorporated in the analyses through sensitivity tests, since costs associated with them are either subjective or difficult to identify. By treating them as policy variables, however, the model is capable of indicating the effect on an overall optimum solution of assigning any of range of possible dollar values.

A. User Costs. The treatment of user costs in the multimodal version of the TRANS-Urban model was discussed previously. In essence, user costs consist of those items listed in the table 1 for transit and highways.

B. Direct Capital Costs of Transportation Supply. The direct capital costs of providing transportation capacity for any particular investment alternative is, in fact, determined by the investment level under which the alternative is being considered. Within each investment level, and for each mix (or allocation) of this investment among freeways, surface arterials, conventional bus transit, and rapid transit, unit costs are applied to determine the amount of supply purchased. These cost parameters are shown in Table 2. Costs of private vehicles were not explicitly included since no data could be found which indicated the variation in vehicle ownership with transportation system service. By implication, therefore, ownership of private vehicle is assumed not to vary among transportation supply alternatives. The model, of course, can be readily updated to include these costs if the necessary relationships become available.

C. Non-Capital Costs of Transportation Supply. Costs associated with the operation of the transportation system are included in the analysis. However, they are not a part of the investment level of each supply alternative, as are the capital costs. Thus, the investment level covers only capital costs, while operating expenses are derived costs based upon the level of supply. The non-capital costs of transportation supply include maintenance costs for the highway system, and operating and maintenance costs for both conventional and rapid types of transit systems.

TABLE 1

USER RELATED COSTS

PRIVATE VEHICLE	PUBLIC TRANSPORTATION
TRAVELTIME COSTS	TRAVELTIME COSTS
VEHICLE RUNNING COSTS	FARE*
ACCIDENT COSTS	
PARKING COSTS	
GAS TAX*	

*INCLUDED ONLY IN CALCULATIONS OF "TOTAL VALUE INDICATOR"

** DESCRIBED IN SECTION IX, BUT NOT IN TOTAL TRANSPORTATION COST CALCULATIONS

TABLE 2

CAPITAL COSTS

HIGHWAYS	PUBLIC TRANSPORTATION
• NEW CONSTRUCTION	• ROLLING STOCK
a) FREEWAYS	a) CONVENTIONAL BUS
b) SURFACE ARTERIALS	b) RAPID VEHICLES
• RECONSTRUCTION	• GUIDEWAYS FOR RAPID SYSTEMS
a) FREEWAYS	• STATIONS AND TERMINALS FOR RAPID SYSTEMS
b) SURFACE ARTERIALS	
	• YARDS AND SHOPS

D. Indirect Costs. As stated earlier, the model is capable of including costs which are normally considered to be "external;" i.e., they are not strictly user costs, nor are they a part of the capital costs of providing system capacity. These consist of (1) cost of fatalities which exceed directly measurable costs (hospital and funeral expenses, etc.), (2) costs of dislocation of households and businesses in excess of fair market payments included in right-of-way costs, and (3) air pollution costs by individual pollutant. When included these costs are directly incorporated in the economic evaluation process.

Evaluation Process

The approach to evaluation in the multimodal version of the TRANS-Urban model is to identify an optimum investment level, and mix of investments among modes, subject to meeting certain predetermined constraints. The optimum investment strategy is determined on the basis of economic efficiency considerations, with comparisons among alternatives made in terms of dollar costs and savings. The use of constraints enables the explicit incorporation of evaluation criteria which are not suitably expressed in dollar terms. Thus, if an alternative succeeds in terms of the economic based criteria, but fails any of the constraints which are imposed, it is rejected as a possibility for optimality.

A. Economic Evaluation. The economic evaluation process developed for TRANS utilizes a "net value" approach. The net value concept is based upon the concept that a transportation investment is worthwhile if the value derived from such an investment is in excess of the costs associated with it. Thus: Net Value = Total Transportation Cost.

Under this approach, the optimum transportation investment is achieved when the net value is maximized. At this point, a marginal investment exceeds the marginal gain in net value, and the additional cost is not justified.

In applying the net value approach, the assumption is made that the value of a commodity or service (in this case, transportation) is indicated by the price consumers are willing to pay to acquire it. Thus, if an individual is just willing to pay x dollars and no more, to be able to take a trip, it is fair to say that the value of the trip to him in monetary terms is x dollars.

This concept may be illustrated further by referring to the transportation demand curve shown in Figure 9. Here it is shown that the number of trips is related to the perceived price per trip; i.e., the higher the price the fewer the trips and the lower the price the more trips are consumed. Thus, if price is established at P_1, the resulting demand in terms of number of trips is D_1. The total value of the D_1 trips occurring at the P_1 price is equal to the areas A plus B. The traveller who is just willing to pay price P_1 and no more values his trip at P_1. In a sense, he receives zero **net** value since the price he perceives paying is capturing all of the value he ascribes to the trip. All those tripmakers who are to the left of D_1 on the demand curve are in fact paying less than they would be willing to pay. The difference between what the entire group of travellers is willing to pay and what they actually do pay is shown by area A alone and is known as consumer's surplus.

FIGURE 9

TRANSPORTATION DEMAND CURVE

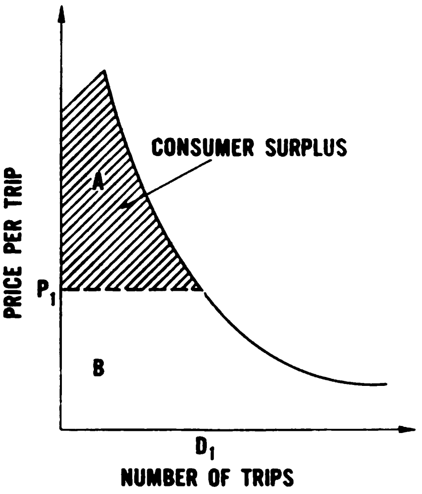
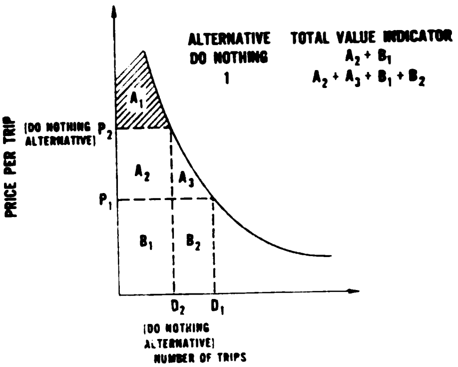


FIGURE 10

ILLUSTRATION OF TOTAL VALVE INDICATOR



With most travel demand functions it is impossible to define the entire consumer surplus area since it is rarely determined where the demand curve intersects the "price" axis. Under the TRANS analysis, the investment alternative which involves the highest price per trip is the do-nothing alternative which leads to high traveltime and operating costs. Thus, as shown in Figure 10 there will always be an area of consumer surplus which cannot be defined (area A_1). However, this area of consumer surplus, A_1, will be common to all alternatives. It can therefore be ignored. Thus, while under the do-nothing alternative (with price P_2 and demand D_2) total value is actually $A_1 + A_2 + B_1$, is used. Under the alternative which yields price P_1 and demand D_1, the total value equal to $A_1 + A_2 + A_3 + B_1 + B_2$ becomes $A_2 + A_3 + B_1 + B_2$. The gain in total value going from alternative 2 (the do-nothing alternative) to alternative 1 is equal to $A_3 + B_2$. The surrogate for total value (which equals total value minus area A_1) is called the total value indicator.

The price per trip used to estimate the total value indicator is equal to user costs plus other costs borne by the user which are not included as user costs, such as gas tax and fare. (Gas tax and fare are normally not included as user costs since it would involve double counting of transportation costs and revenues.) The model begins by estimating the total value indicator under the do-nothing alternative, adding and subtracting net changes in this indicator as subsequent alternatives are examined to arrive at total value indicators for each alternative investment level.

As indicated earlier, the economic evaluation considers the difference between total value and total transportation cost. The total value indicator, as just explained, is a surrogate for the sum of the prices which all travellers are willing to pay. Total transportation cost is defined as the sum of all costs associated with the provision of transportation improvements—capital, operating, and user costs.

The net value indicator upon which the economic evaluation is based is the difference between the total value indicator and the total transportation cost In the computer program this indicator has been normalized such that it is set equal to zero at the do-nothing alternative. As a result, any net value indicator which is positive is superior to the do-nothing alternative while those alternatives with negative indicators are not as good. The economic optimum is that alternative which maximizes the net value indictor.

B. Consideration of Constraints. The effects of impacts which are not strictly costable in the selection of alternatives are accounted for by applying constraints. Thus any alternative which violates one or more of these constraints is no longer considered. Impact measures which can be constrained include air pollution concentrations, by each of three types of pollutants, fatalities, dislocations of residences and businesses, and land consumption.

Application of the Model

For the 1972 National Transportation Study, the multimodal TRANS model system was utilized to evaluate the effects of alternative allocations of urban transportation funding. In these analyses, the economic evaluation portion of the model and the system sensitive travel forecasting option were not utilized.

A. Limitations of Analytical Approach. The TRANS analytical approach is reasonably comprehensive, includes many of the relevant factors for such an analysis, and permits the analysis of a large number of alternatives quickly. Any analytical approach, however, requires simplification and exclusion of some factors to make the analysis task manageable. These simplifications should be considered in interpreting the results of the analysis.

First, in this analytical approach, each urban area was treated as a single analysis unit. For the most part, therefore, the results are areawide averages. No attempt was made to determine how the results would vary within urban areas.

Second, the analysis was performed nationwide, and the results are most valid for the Nation as a whole or for groups of urban areas. Third, several factors were held constant over the analysis period, 1968-90, to maintain comparability of results and because of the difficulty in forecasting changes. These factors include parking rates, transit fares, air pollution emission rates, and fatality rates. All of these factors would probably change over the 22-year analysis period.

Fourth, several factors were held constant between the various alternatives tested. In particular, the total number of trips in each urban area was not varied. As the level of funds and the supply of transportation increase, an increase in the number of trips could be expected.

Changes in any of these factors would affect the results of the analysis and, thereby, may change the conclusions that are reached.

B. Alternative Programs. Twelve alternative programs were analyzed in order to provide a broad spectrum for comparison. These programs were expressed by both a total dollar level and a percentage split of funds among the four major types of transportation facilities: freeway, surface arterials, rapid transit (both by rail and bus),[8] and conventional bus. The analysis was conducted only for the 63 urbanized areas that will have a 1990 population of 500,000 or greater—those in which there would be major tradeoffs between highway and transit.

Three program levels were analyzed for the 22-year period 1968-90, $45 billion, $135 billion, and $225 billion. For each program level, four allocations of funds among the four major types of transportation facilities were specified as follows (see Table 3):

Needs alternative: the percentage split of funds inherent in the needs estimate returned by the States and urbanized areas.

High highway alternative: half of the percent allocation of funds for public

TABLE 3

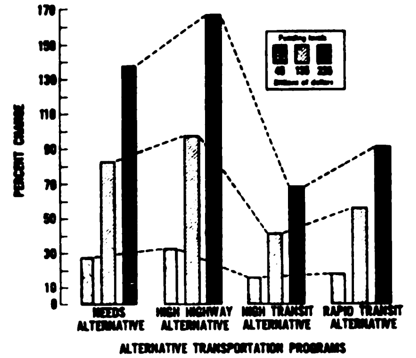
ALLOCATION OF FUNDS FOR ALTERNATIVE FOUR TRANSPORTATION FACILITY TYPES

ALTERNATIVE	PERCENT OF FUNDS[1]			
	FREEWAYS	ARTERIALS	RAPID TRANSIT	CONVENTIONAL BUS
NEEDS	39	32	26	3
HIGH HIGHWAY	47	38	13	2
HIGH TRANSIT	19	16	56	9
RAPID TRANSIT	24	22	51	3

[1] AVERAGE PERCENT ALLOCATION FOR ALL 63 URBANIZED AREAS OVER 500,000 IN POPULATION IN 1990.

FIGURE 11

PERCENT CHANGE IN MILES OF FREEWAY FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.



transportation reallocated to highways.

High transit alternative: half of the percent allocation of funds for highways reallocated to public transportation.

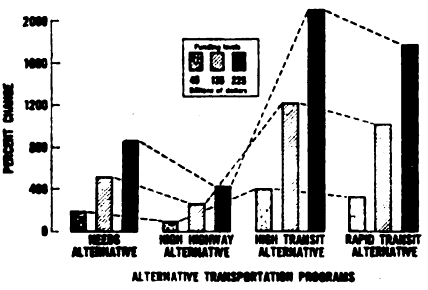
Rapid transit alternative: 100-percent increase in the allocation of funds to rapid transit (bus and rail).

The different program levels and funding allocations resulted in substantially different amounts of facilities. Figures 11 and 12 show the percent change in freeways and rapid transit facilities between 1968 and 1990 for the 12 alternatives. The increase in freeway miles is greatest under the high highway alternative, which halved the transit allocation and placed it on highways, ranging from 38 to 164 percent. The increase in freeways is lowest under the high transit alternative, ranging from 14 to 69 percent. For rapid transit facilities, the largest increase occurred for high transit alternative, which halved the highway allocation and placed it on transit, ranging from 412 to 2,056 percent.

C. Speed and Travel Time Results. Figures 13a & 13b display the percent change in areawide peak travel speeds over 22 years for automobiles and the percent change in area wide peak travel times over 22 years for transit. As the level of funding increases, the speeds and travel times would improve—the result of additional facilities being provided at the higher funding levels.

FIGURE 12

PERCENT CHANGE IN RAPID LINE-MILES FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.



For automobiles, peak travel speeds would improve slightly under two alternatives, needs and high highway by 2 and 7 percent, respectively, at the $225 billion funding level. There would be small decreases in peak automobile speeds at the $135 billion funding levels of 7 percent for the needs alternative, and 4 percent for the high highway alternative. The most severe drop in automobile peak speeds would occur under the high transit and rapid transit alternatives for the lowest funding levels.

For transit, decreases in peak travel times would result for only three alternatives; 0.2 percent for the high transit alternative at $135 billion, 15 percent for the high transit alternative at $225 billion and 10 percent for the rapid transit alternative at $225 billion. All other alternatives would result in an increase in transit travel times.

D. Modal Split Results. The percent of transit trips of all trips, termed, "modal split," would increase over 1968 conditions for all alternatives, for both

FIGURE 13a

PERCENT CHANGE IN PEAK AUTOMOBILE SPEEDS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90

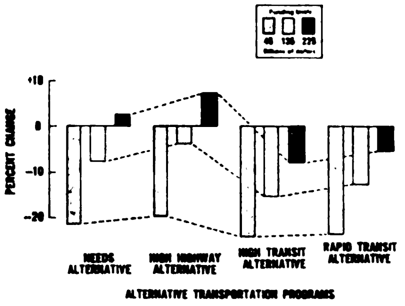


FIGURE 13b

PERCENT CHANGE IN PEAK TRANSIT TRAVEL TIMES FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90

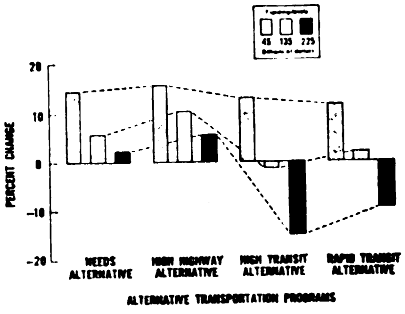


FIGURE 14a

PERCENT CHANGE IN DAILY MODAL SPLITS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90

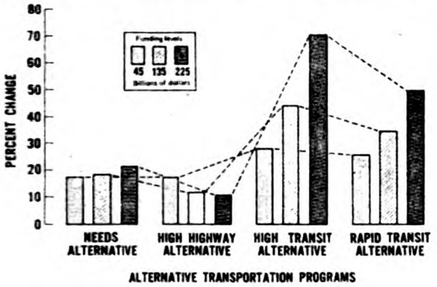
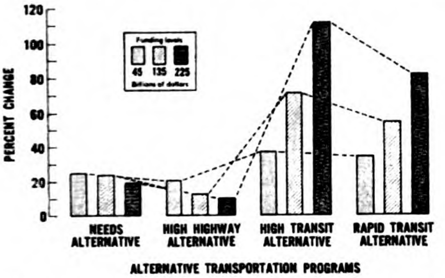


FIGURE 14b

PERCENT CHANGE IN PEAK MODAL SPLITS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90

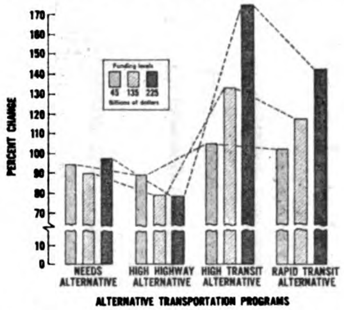


daily and peak travel (Figures 14a & 14b). The increases would be more dramatic for high transit alternative; daily modal split would increase 28 to 71 percent and peak modal split would increase 38 to 112 percent. Large increases would occur for the rapid transit alternative also, in particular at the $135 billion and $225 billion funding levels. Figure 15 shows the percent change in the number of daily transit trips. These would increase from a low of 79 percent under the high highway alternative at $225 billion to 174 percent under the high transit alternative at $225 billion. For comparison, total person trips over this same 22-year period would increase 62 percent.

E. Dislocations. The number of residential and business dislocations that would result from the 12 alternatives are shown in Figures 16 and 17. The number of dislocations is related directly to the level of funding. As the new facilities increase, so does the number of dislocations. The increases would be greatest under the high highway alternative followed by the needs and rapid transit alternatives.

FIGURE 15

PERCENT CHANGE IN THE NUMBER OF DAILY TRANSIT TRIPS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.



F. Fatalities. Under all 12 alternatives, there are increases in annual fatalities (see Figure 18). The largest increase in annual fatalities occurs under the high transit alternatives for all program levels. This increase results from two factors. First, with large amounts of money reallocated from highways to transit, a smaller amount of freeways can be constructed. As a result, a higher proportion of highway travel takes place on arterial streets rather than freeways. Since arterial streets have a higher fatality rate than freeways, highway fatalities increase.

Second, the fatality rate on transit is constant over the period 1968 to 1990 (as it is for highways) and is related to the amount of transit service provided. As the amount of transit service

FIGURE 16

CHANGE IN THE NUMBER OF RESIDENTIAL DISLOCATIONS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.

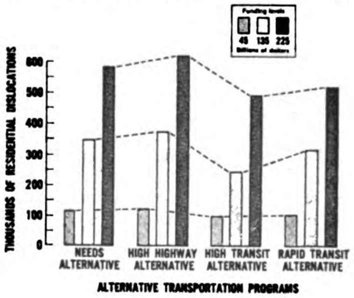


FIGURE 17

CHANGE IN THE NUMBER OF BUSINESS DISLOCATIONS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.

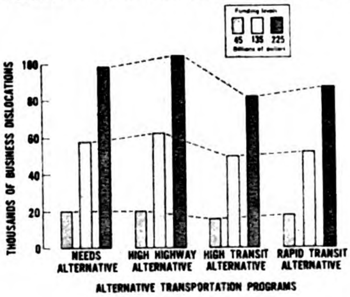
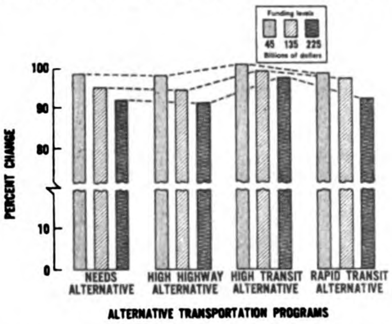


FIGURE 18

PERCENT CHANGE IN ANNUAL FATALITIES FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.



increases, the transit fatalities increase.

The percent increase in fatalities is lower, however, for the higher funded programs due to the increased construction of freeways and rapid transit, which have lower fatality rates than arterials and conventional bus.

G. Land Consumed. Figure 19 shows the amount of land in square miles taken to construct transportation facilities under the 12 alternatives. It is clear that the amount of land taken increases as the level of funding increases. The high highway alternative would consume the most land, followed by the needs and rapid transit alternatives. The amount of land consumed is related to the miles of freeways, arterials, and rapid transit facilities constructed. By comparing Figure 19 with Figures 11 and 12, it can be seen that the amount of land taken is affected to a greater degree by the miles of freeway than the miles of rapid transit constructed.

H. Air pollution. Figures 20, 21 and 22 show the percent change in the daily tons of three types of air pollutants: carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (HC). Current air pollution emission rates and controls were used throughout the analysis to maintain comparability of the results from 1968 to 1990. The differences in air pollution among alternatives and funding levels would be small areawide. The CO and HC levels would decrease slightly with increased funding levels. This decrease is the result of higher speeds on the transportation system that occur when more money is invested. The NO levels would increase with the increasing automobile travel and increasing proportions of automobile travel on arterial streets. They would be highest for the high highway alternatives for all funding levels, which would have the largest amount of automobile travel.

FIGURE 19

CHANGE IN SQUARE MILES OF LAND CONSUMED FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.

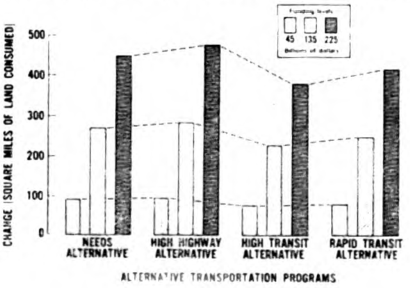
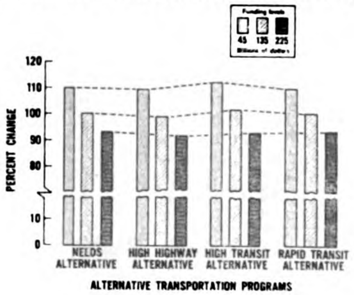


FIGURE 20

PERCENT CHANGE IN DAILY TONS OF CARBON MONOXIDE FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.



The high transit and rapid transit alternatives would result in higher CO and HC levels due to lower speeds and increased starting, stopping, and accelerating on the highway system as a result of less money being spent on highway facilities.

It should be remembered that transportation is only one contributor to air pollution. A more sophisticated analysis is required, therefore, to determine the effect of alternative transportation funding levels and program composition on overall air pollution levels. Further, it was beyond the scope of this analysis to determine the various losses that

FIGURE 21

PERCENT CHANGE IN DAILY TONS OF NITROGEN OXIDES FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90

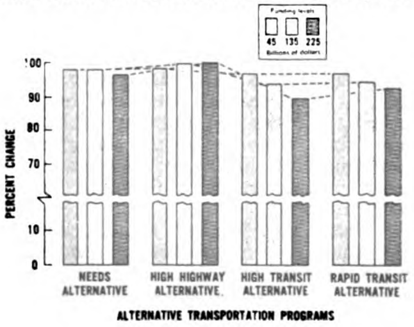
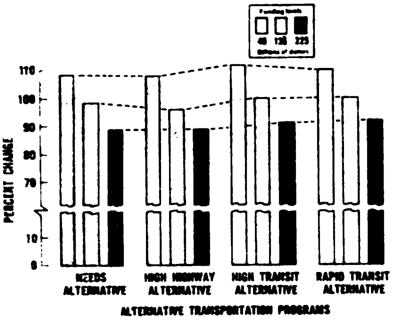


FIGURE 11

PERCENT CHANGE IN DAILY TONS OF HYDROCARBONS FOR ALTERNATIVE TRANSPORTATION PROGRAMS, 1968-90.



would result at different air pollution levels.

Summary and Applications

The purpose of the multimodal version of the TRANS-Urban model system is to afford an insight, at the national level policy planning scale, into the consequences of alternative levels and distributions of future transportation resource allocations. As described in this paper, the model is capable of treating the two principal modes of urban transportation, transit and highways, with transit characterized in terms of conventional bus and rapid transit, and highways in terms of freeways and surface arterials. Analyses can be made to either derive optimum future levels and mixes among the four submodes for each urban area, or evaluate the impacts of specific investment strategies. The efficiency of the model system at its current state of development lies not in its application to any unique, individual urban situation, but rather in its ability to treat many urban regions simultaneously in assessing national program alternatives.

There are two major applications to which the multimodal version of the TRANS-Urban model can be directed. The first application of model system is its continuing use, and improvement as warranted, for national transportation planning studies and analyses. Experience with the 1972 National Transportation Studies has demonstrated the useful role which such policy planning tools can play. While they may not be an adequate substitute for collecting detailed information from local levels of government concerning future transportation plans and needs, it is clear that detailed "field oriented" studies are extremely limited in terms of (1) the degree of local effort which can be expected in support of a national policy planning effort, (2) the number of future transportation alternatives which can be considered by each jurisdiction, and (3) the frequent lack of uniformity in interpretation and application of purported uniform standards by the thousands of individuals involved in conducting such a national study.

The 1972 studies conducted by the Department of Transportation have shown that what the field studies lack in terms of breadth of alternatives and speed of analyses can be provided by national level policy planning tools such TRANS-Urban. The TRANS effort was not intended, nor was it used, to supplant the local inputs from States and urban areas, which could only have come from some form of field study. The role of TRANS-type procedures then becomes one of examining the implications of a much wider range of alternatives (some of them perhaps extreme) and analyzing effects of changing assumptions and projections, in order to broaden the perspective of transportation policy planning beyond what might otherwise have been possible.

The second application of the TRANS-Urban approach is to major sub-areas within metropolitan areas. The relative ease of application of the TRANS approach compared with the more time consuming and costly network approach offers the possibility of using an aggregate model for sketch planning studies which can supplement the more detailed network oriented techniques. A similar process has, in fact, been developed and applied in both the New York and Washington, D.C., regional transportation planning programs.[8,9] While certain conceptual problems remain (such as the degree of interaction of travel demand and system supply among subareas), the fact that a similar approach has found application and acceptability, despite its limitations to only the highway mode, indicates that some effort to develop a multimodal TRANS-Urban model for local applications may be warranted.

Finally, it should be stressed that the macro-level analyses typified by the TRANS approach can in no way substitute for the more detailed planning tools which support specific plans and project level recommendations. The TRANS approach arose from the recognition that the level of analytical effort must be commensurate with the magnitude, level of aggregation, and complexity of the problem to be tackled. TRANS-Urban is a technique which can respond to the need for a wide range of planning information for transportation resource allocation.

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FOOTNOTES

1 These relationships as well as the family of macro-level mode choice curves are presented in reference 5.

2 These running costs are not exactly the same as those used in the economic analysis of total travel costs. For example, since the mode split analysis attempts to replicate behavior, a measure of perceived vehicle running costs is used, whereas in the economic analysis estimated actual costs are included.

3 The urbanized areas that specified rail transit in the needs returns from the States and urban areas as part of the 1972 National Transportation Study were assumed to have rail rapid transit in these analyses. All others were assumed to have bus rapid transit, where there were funds allocated to rapid transit.

ACKNOWLEDGEMENTS

While the work reported on in this paper is the result of a team effort, the author wants to recognize the particular efforts of David S. Gendell and Harold Kassoff of the Federal Highway Administration who made substantial contributions to the direction and content of the TRANS program and Robert Davis of the Office of Systems Analysis and Information in the Office of the Secretary of Transportation and Samuel L. Zimmerman of the Federal Highway Administration who served as project leaders on various phases of the work.