MULTIMODAL NATIONAL URBAN TRANSPORTATION POLICY PLANNING MODEL

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This multimodal version of the model system of the Transportation Resource Allocation Study employs aggregate modeling techniques that treat each urban area as a single analysis unit. A level of investment is specified, and within that level are mixes of 4 types of transportation facilities: freeways, arterials, conventional bus, and rapid transit. For each alternative, travel projections are made on the basis of both socioeconomic variables and the nature and extent of the transportation system. Travel is split between automobile and transit modes. System performance measures are estimated on the basis of the interaction of system supply and travel demand. Travel times and costs are calculated for each mode. In addition, the model calculates external effects such as land consumed, air pollution, and fatalities. The model tested the effects of 12 alternatives consisting of 4 mixes of transportation facilities for the 63 urbanized areas that will have populations of more than 500,000 in 1990.

•THE MULTIMODAL national urban transportation policy planning model is the current operational version of the continuing Transportation Resource Allocation Study (TRANS) modeling effort (1, 2). The TRANS approach has been one of designing a set of models that are responsive to the needs of urban policy planners and decision-makers; capable of dealing effectively with a large number of transportation issues quickly and efficiently; capable of assessing the consequences of alternative courses of action and of determining preferred courses of action to achieve desired goals; and capable of explicitly relating to the social, economic, and environmental impacts of each alternative under consideration.

Prior to the TRANS activity, much of the effort involved in developing urban transportation planning techniques was directed to formulating transportation plans for individual areas. Although the need for a local planning process is self-evident, its application to national policy planning was difficult. Therefore, the model described in this paper was developed.

Earlier versions (1) of the TRANS model represent developmental stages and were basically highway oriented, treating highway investment trade-offs under varying transit-usage assumptions. The later version provided the capability to analyze central cities and suburbs separately and incorporated the results of 3 specific research projects into the model system (2). These projects produced a system-sensitive model for predicting area-wide urban travel (3), an analytical model for estimating the distribution of highway travel to freeways and surface arterials (7), and a set of relations describing in detail the variation in travel demand during the course of a day (4).

The current stage of development, the multimodal model, represents a major extension of the scope of earlier versions by including transit and highways in the same

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This paper originally contained extensive additional material that has been omitted here because of space limitations. The material is available on request to the authors at the U.S. Department of Transportation.

investment analysis. This version draws on the result of a research project that produced an aggregate, area-wide modal-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 multimodal 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 U.S. Department of Transportation (6).

BASIC APPROACH

The TRANS model system comprises 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 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, mixes of 4 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 socioeconomic variables and the nature and extent of the transportation system supply alternative. The travel is distributed by time of day and mode; system performance measures (such as speed) are estimated on the basis of the interaction between supply and travel demand. User costs (such as travel time costs) and external costs (such as pollution and specified social costs for displacements and disruptions) are calculated for each mode.

For each alternative, changes in the costs are compared with changes in investment levels, and an economic analysis is performed. If the alternative passes various constraints placed on the economic analysis and also passes constraints due to "noncostable" factors (such as number of fatalities), then the alternative may be accepted. All specified investment levels and supply mixes are investigated, and the "best" alternative is selected and summarized.

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

Incrementing Structure for Testing Alternative Supply Levels

The multimodal version of the TRANS urban model considers a specified range of investment levels for each urbanized 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 for the entire forecast period. Thus, appropriate unit costs are applied to the investment in each category, and total new supply provided between base and target years is calculated. This new capacity is then added to base-year (existing) supply in each category to yield total supply available in the target year.

The application of the incrementing structure within the model system is given in Tables 1 and 2. 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) under current supply levels. The second alternative examines the do-nothing alternative under which future travel projections are derived on the assumption that no additional facilities are added to those existing in the base year. The third alternative 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 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 that would arise from the normal application of the incrementing structure under low investment levels. This alternative is

Figure 1. TRANS urban multimodal model system.

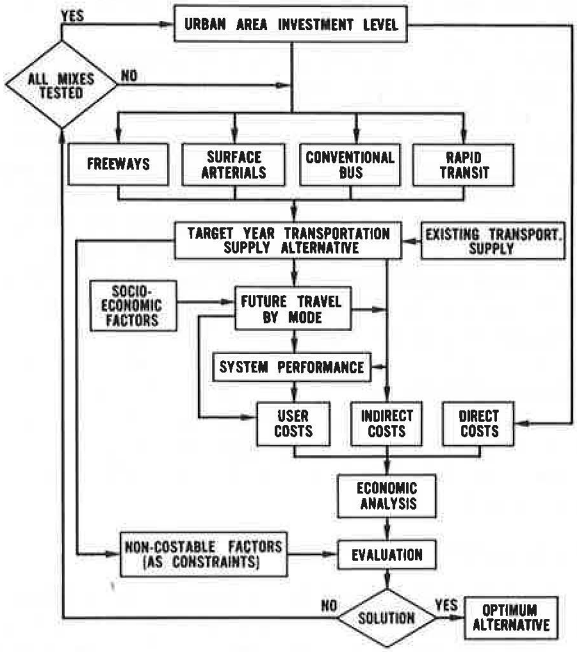


Table 1. Operation of incrementing structure at varying investment levels.

Investment Level		
Number	Investment	Operation
K_1	0	Evaluation of base-year system performance
K_2	0	Evaluation of target-year do-nothing alternative
K_3	I_s[a]	Addition of specified minimum surface arterial supply, which is not subject to economic evaluation
K_4	I_{CB}[a]	Addition of specified minimum conventional bus supply, which is not subject to economic evaluation
K_5	I_5	Normal incrementing structure
↓	↓	↓
K_{max}	I_{max}	Normal incrementing structure[b]

[a]Investment increments in the supply categories that follow in I_6 through I_{max} are in addition to the minimum investment levels specified for K_3 and K_4.
[b]See Table 2.

Table 2. Operation of normal incrementing structure from K_5 through K_{max}.

Investment Level		Investment by Category				
Number	Investment	Investment Mix Number	Freeway	Surface Arterial	Conventional Bus	Rapid Transit
K_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	$P_{m1}I_{max}$	$P_{m2}I_{max}$	$P_{m3}I_{max}$	$P_{m4}I_{max}$

Note: P_{ij} = percentage of investment allocated in mix i to category j, $\sum_{j=1}^{4} P_{ij} = 100.0$. Both the upper and lower bounds of the modal percentages must be integer multiples of the modal percentage increment.

the base to which subsequent alternatives are compared until one is reached that is better according to the economic analysis (see later section on application of model), 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 (Table 2). Initially, within each investment level, the percentage of allocation to each of the modal categories is set at a predesignated lower limit. Increments are added to that mode until its specified upper limit is reached, whereupon the next mode is incremented and the first mode is 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 summary, the incrementing structure permits a systematic evaluation of specified mixes among 4 categories of urban transportation supply through a specified range of capital investment levels. Noncapital costs, such as those for highway maintenance and transit operations, are derived based on the level of supply stipulated and are incorporated in the economic analysis. However, they are not included as part of the investments specified in the incrementing structure.

TRAVEL SUBSYSTEM

There are 3 alternative methods for developing the travel projections in this version of the TRANS urban model. These include the direct use of urbanized area travel projections submitted by the states (Fig. 2), a modification to the states' projections based on a simplified adjustment factor to reflect variations in system supply, and a modification to the states' projections based on a set of sequential models that predict person trips, trip length, and vehicle occupancy. The same modal-choice model is applied regardless of which procedure is used. The selection of which of the 3 travel projections to use is left to the discretion of the analyst.

MACROLEVEL MODAL-CHOICE MODEL

The development of a macrolevel (area-wide) modal-choice model represented the key to providing the TRANS urban system with a true multimodal capability (5). The macrolevel model was formulated by using data from microlevel simulations in a hypothetical urbanized region of 2.5 million persons and a generalized microlevel modal-split model (applied to zone-to-zone trip interchanges) developed from actual applications to 3 real cities.

The macrolevel modal-choice models consist of families of curves that relate area-wide percentage of internal person trips via transit to area-wide travel time and travel cost differences between transit and private automobiles. The models are stratified by trip purpose (home-based work and other) and by time period (peak and off peak) (5).

The aggregate modal-choice models are applied to time period (peak and off peak) and purpose (home-based work and other) of internal person trips that emanate from any one of the 3 travel structures. As mentioned earlier, transit trips are then analyzed in the transit subsystem, and automobile trips are converted to vehicle-miles of travel and incorporated with truck and external VMT to yield total VMT for analysis in the highway subsystem.

TRANSIT SUBSYSTEM

After the modal-split analysis has been completed for each investment level and 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 submode.

Transit Person-Miles

Transit person-miles of travel are computed by multiplying transit trips by average trip length.

Submodal Split

To determine the allocation of transit travel to conventional bus and to rapid transit systems, when the two are considered simultaneously, the model uses a submodal split, which was developed from the series of simulations performed to obtain the macrolevel modal-choice model. The sub-modal-split curves are shown in Figure 3 for rail and bus rapid transit systems. According to the data from which the curves were developed, a given share of seat-miles of supply on bus rapid transit attracts a greater share of the transit market than that attracted by the same share of seat-miles on a rail rapid system. That 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. The sub-modal-split curves were developed only for peak periods. For lack of any data, it is assumed that they apply to off-peak periods as well, although the model is capable of accepting any other assumed or derived relations.

Calculation of Transit Load Factors

Based on the allocation of passenger-miles to each of the 2 transit submodes, the ratio of passenger-miles to available seat-miles is calculated and compared to a specified maximum load factor. This is done for peak and off-peak time periods for both submodes. 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.

HIGHWAY SUBSYSTEM

The highway performance portion of the multimodal model is substantially unchanged from the earlier version of the TRANS model system (1, 2, 4, 7).

TRANSPORTATION COSTS

In the evaluation of the consequences of each transportation investment alternative, the TRANS urban model incorporates criteria that include factors that can be treated in monetary terms, such as user costs and construction costs, and also factors that are difficult to treat in monetary terms, such as costs of pollution, fatalities, and displacements and disruptions. These factors are usually incorporated in the analyses through sensitivity tests, for 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 a range of possible dollar values.

User Costs

The user costs in the model consist of costs of travel time, vehicle operation, accidents, parking, and gasoline tax for private vehicles on highways and costs of travel time and fare for public transportation. Gasoline tax and transit fare are included only in calculations of total value indicator.

Direct Capital Costs of Transportation Supply

The direct capital costs of providing transportation capacity for any particular investment alternative are, 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. The cost parameters are as follows:

Highways	Public Transportation
New construction	Rolling stock
Freeways	Conventional bus
Surface arterials	Rapid system vehicles
Reconstruction	Guideways for rapid systems
Freeways	Stations and terminals for rapid systems
Surface arterials	Yards and shops

Noncapital 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 capital costs are. Thus, the investment level covers only capital costs; operating expenses are derived costs based on the level of supply. The noncapital costs of transportation supply include maintenance costs for the highway system and operating and maintenance costs for both conventional and rapid transit systems.

EVALUATION PROCESS

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

APPLICATION OF THE MODEL

For the 1972 National Transportation Study, the multimodal TRANS model system was used to evaluate the effects of alternative allocations of urban transportation funding. In those analyses, the economic evaluation portion of the model and the system-sensitive travel forecasting option were not used. Twelve alternative programs were analyzed to provide a broad spectrum for comparison. Those programs were expressed by both a total dollar level and a percentage split of funds among the 4 major types of transportation facilities: freeway, surface arterials, rail and bus, rapid transit, and conventional bus transit. The analysis was conducted only for the 63 urbanized areas that will have a 1990 population of 500,000 or greater. Those are the areas in which there will be major trade-offs between highway and transit.

Three program levels were analyzed for the 22-year period from 1968 to 1990: $45 billion, $135 billion, and $225 billion. For each program level, there were 4 allocation alternatives for the 4 major types of transportation facilities (Table 3):

1. Needs alternative—funds allocated according to needs estimates returned by states and urbanized areas;
2. High highway alternative—half of public transportation allocation reallocated to highways;
3. High transit alternative—half of highway allocation reallocated to public transportation; and
4. Rapid transit alternative—100 percent increase in bus and rail rapid transit allocation.

The different program levels and funding allocations resulted in substantially different amounts of facilities. Figures 4 and 5 show the 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, ranging from 38 to 164 percent. The increase in freeways is lowest under the high transit alternative, ranging

Figure 2. Process for estimating internal person trips based on travel estimates by states.

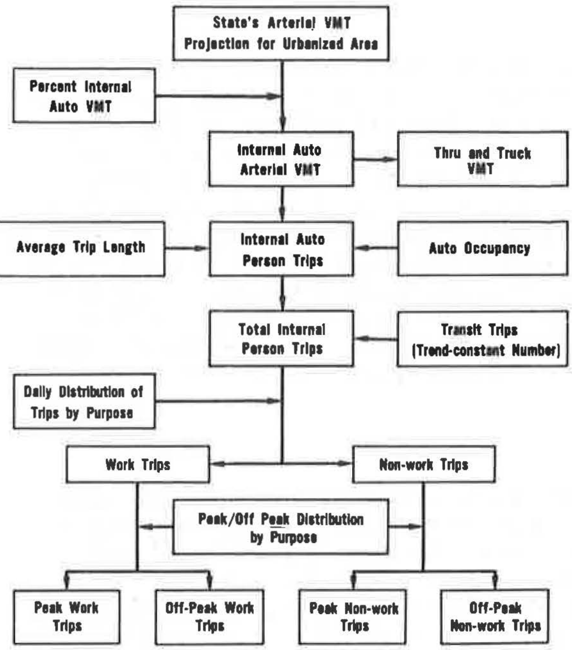


Figure 3. Peak passenger-miles of travel and seat-miles of rapid transit systems.

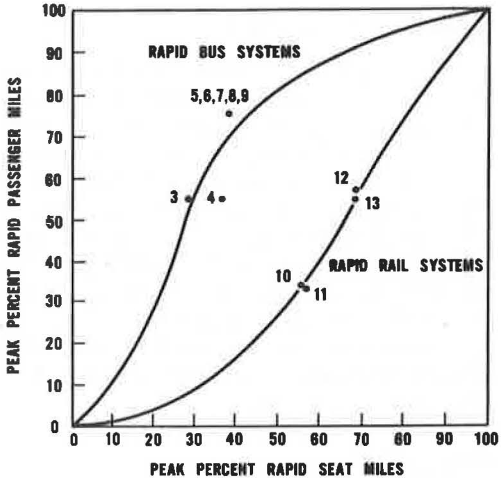


Table 3. Percentage of funds allocated for transportation alternatives.

Alternative	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

Note: Percentages are averages for all 63 urbanized areas.

Figure 4. 1968-90 freeway miles.

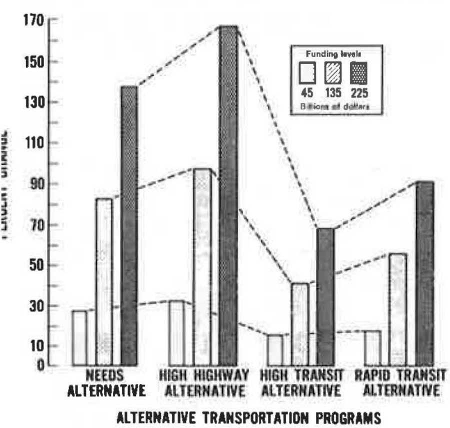
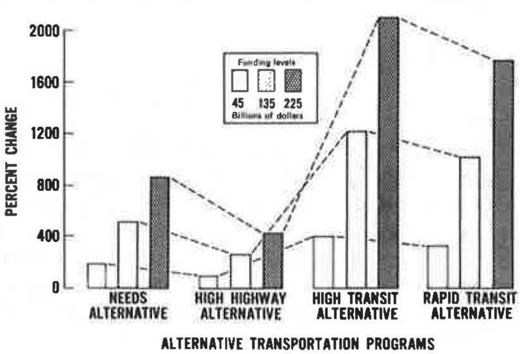


Figure 5. 1968-90 rapid transit miles.



from 14 to 69 percent. For rapid transit facilities, the largest increase occurs for high transit alternative, ranging from 412 to 2,056 percent.

Speed and Travel Time

Figures 6 and 7 show the change in area-wide peak travel speeds for automobiles and in peak travel times for transit during the 22 years. As the level of funding increases, the speeds and travel times improve as a result of additional facilities being provided at the higher funding levels. For automobiles, peak travel speeds improve by 2 and 7 percent under needs and high highway alternatives respectively at the $225-billion funding level. There is a 7 and a 4 percent decrease in peak automobile speeds at the $135-billion funding level for needs and high highway alternatives respectively. The most severe drop in automobile peak speeds occurs under high transit and rapid transit alternatives for the lowest funding levels. For transit, decreases in peak travel times result for only 3 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 result in an increase in transit travel times.

Modal Split

The modal split increases over 1968 conditions for all alternatives, for both daily and peak travel (Figs. 8 and 9). The increases are most dramatic for the high transit alternative under which daily modal split increases from 28 to 71 percent and peak modal split increases from 38 to 112 percent. Large increases occur for the rapid transit alternative also, in particular at the $135-billion and $225-billion funding levels. Figure 10 shows that daily transit trips 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. Total person trips during this same 22-year period increase 62 percent.

Relocations

The number of residential relocations (Fig. 11) is related directly to the level of funding. As the new facilities increase, so does the number of relocations. The increases are greatest under the high highway alternative.

Fatalities

Under all 12 alternatives, annual fatalities increase (Fig. 12). The largest increase occurs under the high transit alternatives for all program levels and results from 2 factors. First, with large amounts of money reallocated from highways to transit, fewer freeways can be constructed. As a result, a higher proportion of highway travel takes place on arterial streets, which have a higher fatality rate than freeways. The increase in fatalities is lower, however, for the higher funded programs because of the increased construction of freeways and rapid transit, which have lower fatality rates than arterials and conventional bus.

Air Pollution

Figures 13, 14, and 15 show the change in the daily tons of 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 area-wide differences in air pollution among alternatives and funding levels are small. The CO and HC levels decrease slightly with increased funding levels. This decrease is the result of higher speeds that occur when more money is invested. The NO_x levels increase with increased automobile travel and increased proportions of automobile travel on arterial streets. The levels are highest for the high highway alternatives for all funding levels because of the large amount of automobile travel. The high transit and rapid transit alternatives result in higher CO and HC levels because of lower speeds and increased starting, stopping, and accel-

Figure 6. 1968-90 peak automobile speeds.

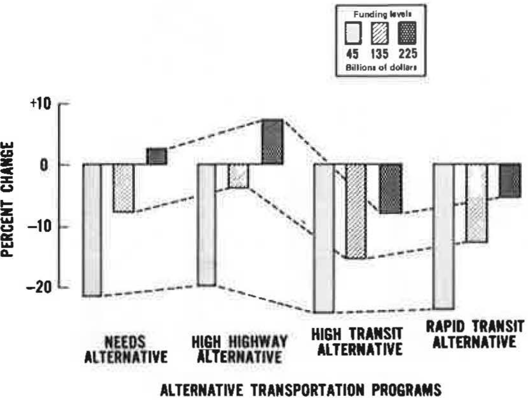


Figure 7. 1968-90 peak transit travel.

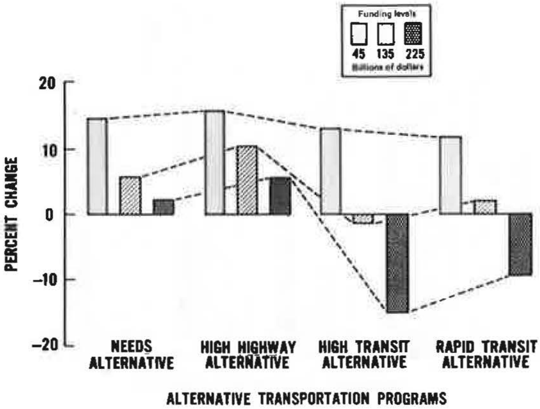


Figure 8. 1968-90 daily modal split.

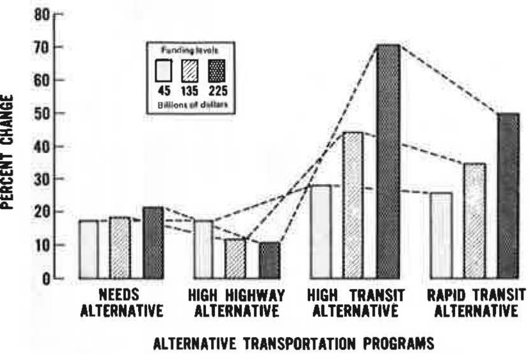


Figure 9. 1968-90 peak modal split.

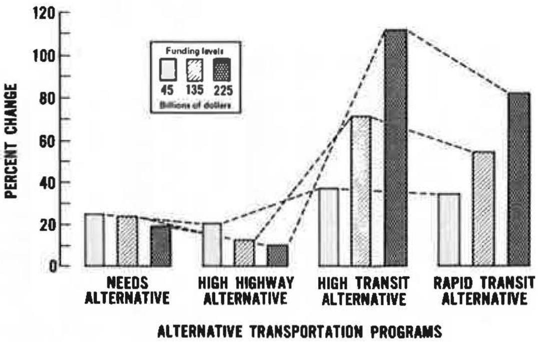


Figure 10. 1968-90 daily transit trips.

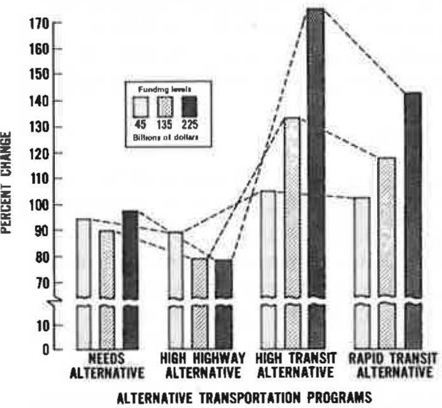


Figure 11. 1968-90 residential relocations.

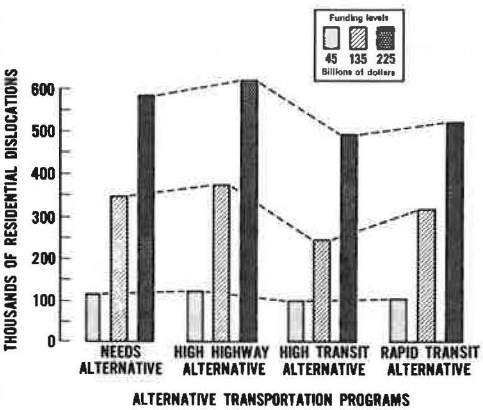


Figure 12. 1968-90 annual fatalities.

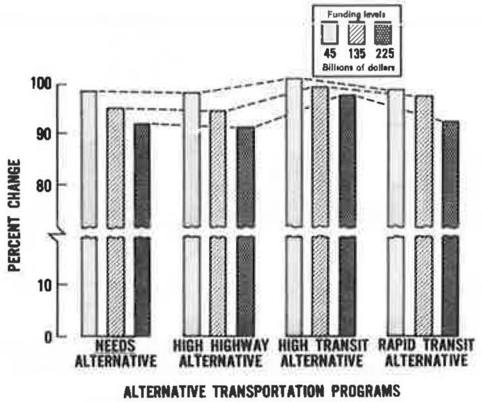


Figure 13. 1968-90 daily tons of carbon monoxide.

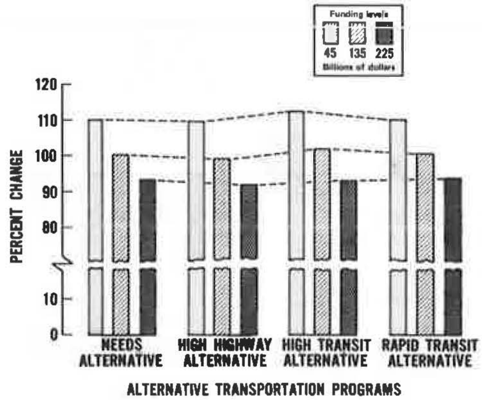


Figure 14. 1968-90 daily tons of nitrogen oxides.

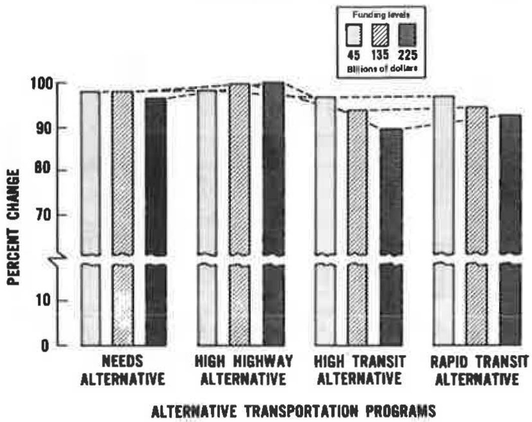
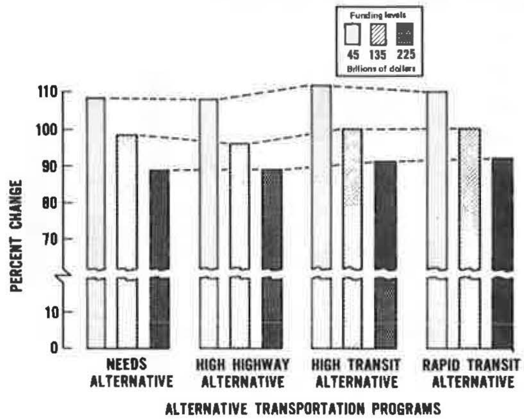


Figure 15. 1968-90 daily tons of hydrocarbons.



erating on the highway system as a result of less money being spent on highway facilities. Transportation is, of course, 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.

SUMMARY AND APPLICATIONS

The purpose of the multimodal version of the TRANS urban model system is to afford an insight into the consequences of alternative levels and distributions of future transportation resource allocations. The model is capable of treating the 2 principal modes of urban transportation, transit and highways; transit is characterized in terms of conventional bus and rapid transit, and highways are characterized in terms of freeways and surface arterials. Analyses can be made either to derive optimum future levels and mixes among the 4 submodes for each urban area or to 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.

The macrolevel analyses typified by the TRANS approach can in no way substitute for the more detailed planning tools that 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. The TRANS system is a technique that can respond to the need for a wide range of planning information for transportation resource allocation.

ACKNOWLEDGMENTS

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