URBAN TRANSPORTATION STRATEGIES MODEL

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SUMMARY

A simulation model for evaluation of the effects of urban transportation strategies on vehicle usage has been developed. This computer program has been utilized to evaluate transportation strategies designed to reduce ambient air concentrations of pollutants. The interaction of factors such as parking availability, mass transit availability, and degree of congestion of roadways, are evaluated by a number of simulation runs which estimate citizen reaction to various mixes of these factors and estimate the degree of change in intermodal choice of transit. The range of results obtained can be quantified in terms of pollution levels utilizing standard emission rates for vehicles. A feature of the computer system is ease of application. Results are only hypothetical and depend on assumptions that are fed into the model structure. However, the user may obtain a reasonable range of likely results by varying the input factors.

NEED FOR THE MODEL

At present, many urbanized areas of the United States are evaluating the impact of transportation control alternates to achieve federal ambient air quality standards. Such plans are in addition to the federal emission control program for vehicles and are being considered in areas that cannot meet the federal standards even with inspection/maintenance systems for vehicles and retrofit of control devices. Strategies being considered include mass transit improvement, improvement of traffic flow (which reduces pollution), reduction of direct vehicle miles traveled through various means ranging from gas rationing, to highway blockage, to encouragement of car pooling, and economic incentives such as higher parking charges and tolls and gasoline taxes. In most cases, reaction by the public, which is necessary to achieve the aims of these programs, is extremely difficult to predict. Most of the techniques are untried, and effects of the strategies are largely unknown. Estimates used by the U. S. EPA to evaluate state and other plans submitted to them are of necessity inexact. The difficulty in predicting the effects of these strategies stems not only from the lack of practical experience, but also from the great complexity of factors which will effect the results. Simulation modeling techniques, such as are used here, can provide an estimate of the interaction of the various pertinent factors and supply decision makers with at least a range of estimates of likely results. The model described herein produces estimates of vehicle trip reduction, which can then be translated, using standard factors, into changes in ambient air concentrations of pollutants produced by automobile travel.

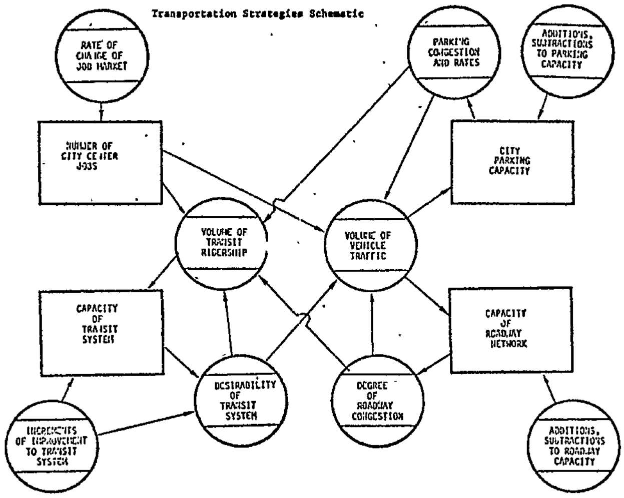
CONCEPT OF THE MODEL

The model performs an evaluation of the interrelationships of factors affecting individual decisions to utilize transit facilities or their own vehicles for transportation, primarily to their jobs. The concept of identifying the factors affecting human response to traffic control strategies and quantifying their cross-relationships involves many assumptions. In order to minimize any unrealistic effects which might result, the factors are linked together in computer routines. The computer program applies the cross-relationships on a cyclical basis, re-applying them again and again over the assumed passage of time. A number of checks are applied, and, if the calculated results become unbalanced, an additional routine is activated which re-distributes the calculated intermodal choices. This is continued over every cycle, with different routines being activated as the calculated results vary.

The model begins by accepting a set of constants which represent a "start-up" period, either from observed data, or an assumed beginning situation. Special factors, such as a highway improvement program, may be programmed to occur at various points in the future. Figure 1 shows a schematic of the interrelationships and the changes that are set into action as any one of the various factors is altered. To simulate these interrelationships, the concept of feedback loops was utilized and applied in a fashion similar to that in the World Model as operated at MIT.[1] The various feedback loops interact on each other over a number of time cycles with the results of each cycle's being retained in the model's memory and having an effect on the subsequent cycle. The overall result is something like compound interest. As interest earned on capital builds up, the interest rate also applies to past interest earned, and after a period, the rate of growth as compared to the original amount, becomes very great. In the transportation strategies model, since some

Figure 1

Transportation Strategies Schematic



factors are fixed, or only vary in specific years, the relationship between a dynamic factor and a fixed factor will vary. For example, as commuter trips rise with the number of jobs, an originally adequate amount of parking may become insufficient. Certain routines in the model only become operative when such a threshold is passed. For example, when the number of vehicle trips exceeds parking capacity, a certain percentage of the excess is diverted to other transportation modes.

The model consists of four interrelated submodels. Each of the four consists of a mechanism used to cyclically re-calculate an aspect of an urban transportation situation. In each case, the sub-model accepts both starting point data and rate of change data to enable it to predict changes over time. The four models are:

o City center job model. This model continually, on a cycle-by-cycle basis, the number of city center jobs which exist and, through a subroutine the number requiring transportation to the city center by either automobile or public facilities.

o Transit System Capacity Model. The model accepts as input increments of improvement or other change to the transit system and computes a desirability index for the system as a whole, based on a number of factors including the available capacity versus estimated usage and the age of the equipment or other facilities.

o Parking Capacity Model. This model computes an index of parking congestion based on available parking capacity as incremented by planned additions or subtractions. The effect of parking rate changes is factored in, based on capacity adjustments.

o Roadway network model. A roadway congestion index is calculated based on the preceding volume of vehicular traffic combined with any additions or subtractions to roadway capacity based on construction or other modifications.

The four sub-models interact on a cycle-by-cycle basis, in that the results of each model are compared with the results of the others and the information is fed back to be used in the calculation of traffic volumes and various other indices.

When the model begins operation, it accepts a number of factors which are fixed for the first year's time, and computes a number of trial volumes based on the interrelationships. The most important of these is the split between public transit and private vehicles. As a result of these trial volumes, desirability, congestion, and other indices are calculated and the volumes readjusted to produce final volume for the first cycle. The model then makes the appropriate adjustments for the second time cycle, and proceeds through the process again, but this time starts with the computed volumes and continues to make readjustments. The adjustments usually produce a smooth trend unless the modification introduced by the operator of the model contain a dramatic alteration at one point in time, such as the introduction of a new highway or transit system. In this case, the results would undergo a more dramatic modification.

The model is started with a set number of constants given specific quantity and proceeds to alter these based on the interaction between them and secular changes such as population increase. Fixed factors at the beginning include road network capacity, parking capacity, availability of transit, and desirability of non-automotive transit. The estimated travel is divided among the available options and compared with capacities of various resources. Also input to the model are a number of "preference ratios" for use in the computations where numbers of trips must be divided between modes. These modal choices are continually reallocated, based on the timing cycle. In actual application, a number of runs for each simulation are usually made with the preference ratios being varied over an appropriate range to produce a comparable range of results indicating the likely limits within which vehicle trip reductions can be achieved.

A one-year time cycle was chosen to allow interaction between the various factors. Future work may require a shorter interval as experience has proved that results that are desired generally are only a few years into the future. This situation means that only a few cycles will have been

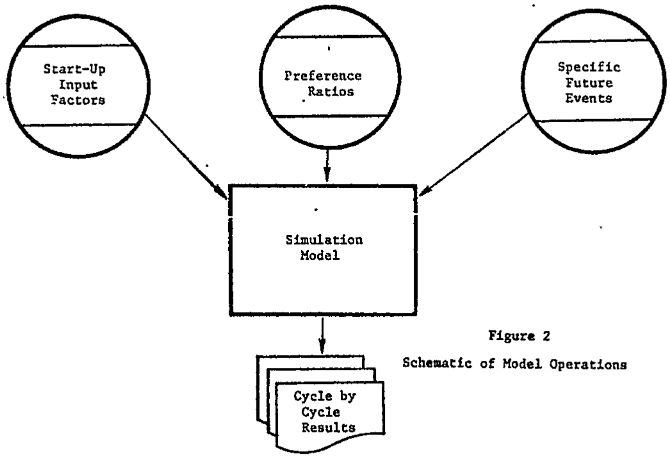


Figure 2

Schematic of Model Operations

computed by the time the most useful results are produced. The model is most effective after a substantial number of cycles have been allowed to interact with each other. The system was calibrated by producing reasonable sets of input factors and then allowing the computations to interact and analyzing the results on the basis of past experience. A number of adjustments were made in this way.

USE OF THE MODEL ON THE IBM 1130

The model was programmed, run and calibrated on an IBM 1130 computer with 16K memory. It was decided to write the simulation program from scratch rather than use one of the canned languages because the basic relationships were relatively simple and would change frequently as the model was calibrated and different strategies were simulated. Adjustments were introduced by means of changing a few instructions and the data was rerun within an interval as short as a half hour. This would not have been possible using a general simulation system operating on a larger sized computer with generally slower turnaround.

Figure 2 shows the actual running of the model, in schematic form. Memory requirements were well within the capacity of the computer, and similar program could be run on any 1130 or comparable machine. Execution time was brief, averaging only 2-3 minutes for run spanning a real time period of a decade.

General use of the model is shown schematically in Figure 3. To operate the model for a specific simulation, a number of steps are required. Factors such as highway capacity, transit capacity, and number of city center jobs, are introduced via control card input to the computer. These numbers must be developed from available data regarding the city in question. Procedures here will vary based on the data that can be located within an acceptable time frame. These factors can be considered to describe the environment as it exists today. Having developed these numbers, the investigator will then perform a baseline run using the built-in preference ratios and other parameters in the model. This run is then compared with the existing situation, for example, in degree of traffic congestion and amount of transit ridership. If necessary, revisions are made to the control card numbers or to start up preference ratios imbedded in the model in order to reflect real-world conditions. A re-run is then made if required and repeated until the investigator is satisfied that he has a reasonable working model of the city in question.

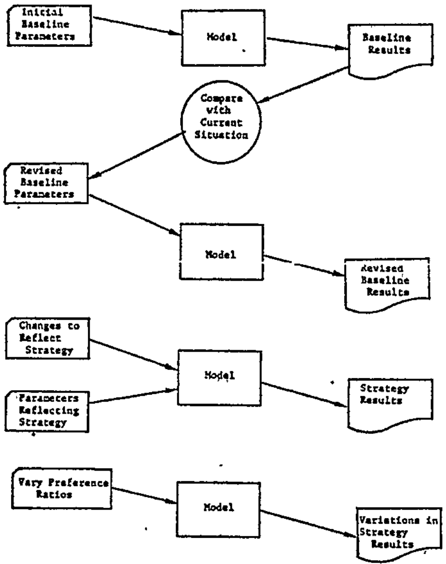


Figure 3

Strategy Simulation, Sequence of Events

At this point, the investigator must determine the transportation control strategies that he wishes to simulate. He may determine these by external factors, or he may wish to try a number of different strategies based on his own investigations. Depending on the nature of the strategies, he may make adjustments to the initial constants being fed the run, adjust the preference ratios, or introduce specific programming to apply changes at specific future increments in time. He will then make whatever computer runs are needed to produce predictions of vehicular travel reduction.

If modification of the preference ratios imbedded in the program, was a significant part of simulation of the strategy, he may want to make minor variations of these to get a feel for the sensitivity of the model for this particular prediction. For example, improvement in the transit network in areas designed to appeal to riders (such as increased scheduling frequencies) would be reflected in modification of both transit capacity and preference ratio for cars versus transit.

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NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
************* ************* *************    ***********    *********** ************** ************** ****
        82833         50000         38916             78          40000          20000          16560 1973

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
************* ************* *************    ***********    *********** ************** ************** ****
        85698         50000         40070             80          40000          20000          17451 1974

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
************* ************* *************    ***********    *********** ************** ************** ****
        88697         50000         40422             81          40000          20000          19638 1975

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
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        91831         50000         41422             83          40000          20000          20949 1976

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
************* ************* *************    ***********    *********** ************** ************** ****
        95014         50000         42585             85          40000          20000          22120 1977

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
************* ************* *************    ***********    *********** ************** ************** ****
        98339         50000         43786             88          40000          20000          23332 1978

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
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       101783         50000         45017             90          40000          20000          24608 1979

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS YEAR
************* ************* *************    ***********    *********** ************** ************** ****
       105342         50000         46275             93          40000          20000          25950 1980
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Figure 4

Transportation Strategies Simulation Model

Addition of Bus Lane Strategy to Prior Strategies

The capacity change would be introduced in a straightforward fashion by simply modifying that number in the input cards. The change of the preference ratio, however, would involve the application of the investigator's judgment to attempt to identify the degree to which the desirability of using the public transit network was enhanced. This procedure is inherently inaccurate, and as a result the investigator would probably try several runs using different variations in the ratio, and perhaps present a range of results.

RESULTS OF THE SIMULATION MODEL

The model has been applied to evaluate various transportation control strategies for two medium-sized cities in the Northeast under sponsorship of the Environmental Protection Agency. This application was particularly appropriate as the time fram available to develop real data was limited. Many of the constant input factors which were set up at the beginning of each model run had to be estimated from handbooks rather than produced from actual measurement or by review of existing data from sources in the cities themselves. In a simulation of this type, absolute values for the first cycle are not necessarily required as long as the various factors are in approximate balance. The range of results produced should be expressed in terms of percentages or other relative characteristics rather than absolute numbers. This is probably true even when starting positions of the various factors are known with certainty since this technique is necessarily rather inexact. Results of the simulation modeling were produced in the format shown in Figure 4. Early runs in the project produced results indicating only minor reduction in automobile travel. Therefore, as the project proceeded, various strategies were combined and the factors were adjusted to show highest expected reductions, as recommendations not to implement strategies would need to be supported by a statement of maxium achievable results. In this application, the simulations tended to indicate that most strategies produced only minor reductions in vehicle travel due to the interaction of the various factors discussed.

Validation of the model consisted of comparing results of the run with similar applications of transportation control strategy that have been carried out in other areas. For example, effects on transit ridership due to the establishment of a bus-only lane were reviewed and compared with run results. The comparison showed a similar percentage increase in transit ridership. Of somewhat more importance, the imposition of various traffic control strategies and their effect on total vehicular traffic was analyzed. Model runs versus actual results indicated a tendency of the model to over-predict reductions. Detailed statistical analysis has not been possible due to the small number of instances in which appropriate strategies have been applied as of this time. It can be said, however, that the percentage reductions predicted by the model appear in the same range as those observed in other situations, indicating the soundness of the basic approach. At this stage, the computer model is capable of producing gross estimates of the effect of a single strategy or combinations of strategies.

It is important to be aware, in using a simulation such as this, that manipulation of the various ratios and input factors can have a substantial effect on the results. Therefore, both confirmation from other sources and a series of runs with variation in the input are needed. When such comparisons were made, the reductions, although small, were still greater than those observed in real-life situations, perhaps due to adjustments that were made in the preference ratios. Another factor which may be at work, and which is an important element in any evaluation of transportation control strategies, is that of induced traffic; that is, any reduction in congestion may create additional traffic as the desirability of this mode is improved. For example, a strategy that successfully increases the use of car pooling may not necessarily reduce the number of automobiles on the highway as additional traffic may be induced by the improved traffic situation. Introduction of such a latent demand factor into the model is planned for the future.

Figure 5 shows the baseline run developed in this series, and Figures 6 through 12 show the key results runs. The single most important number is the "calculated vehicles." Figure 12 is the only run showing a large reduction. Later extrapolation to air pollutant concentration reductions indicated only a minor effect, due to the preponderance of other (non-vehicular) sources in these instances.

In analyzing the output from the simulation model, it is necessary to review the numbers which are included in the printout. Figure 5 represents the baseline run for the model. The number of city jobs shown in the left most column is started at a figure obtained from local handbooks and then modified based on job population trends which have been predicted. As each yearly cycle is completed, (years are shown in the rightmost column) the new number of jobs is re-computed and used in further calculations. Road capacity is given as fixed and is initially based on traffic counts and other data which may be available to the investigator. Only major improvements create modifications in the actual capacity of the roadway network.

Calculated Vehicles is the estimated number of vehicles on the highway at the end of each cycle. It is calculated for one direction of the rush hour, and represents the sum of the various sub-model interaction. A good check on model operation is to compare the calculated number with the observed date for the current year.

Congestion Factor is a simple ratio of calculated vehicles to road capacity and is only printed to give empirical representation of the degree of highway congestion.

Parking Spaces are handled in much the same way as the road capacity, being entered as a constant, and only modified based on adjustments which are introduced by the program in a future time frame to reflect a certain strategy or major construction.

Transit Capacity represents the estimated ability of public transportation systems to handle one-way rush hour trips as its present level. Initial model runs introduced a time factor as the equipment became older to reduce capacity. However, this routing was eliminated as ridership data which were analyzed showed no relationship to age of equipment.

Transit Riders is a corollary of the calculated vehicles result. The number of persons to be transported is divided between the public transportation system and the private vehicle sector based on the interaction of the sub-models, the preference ratios, and other routines. Normally, the model uses a constant for the number of riders per private vehicle. However, in some cases this has been varied to reflect transportation control strategies which encourage car pooling or only provide parking to vehicles carrying a number of riders.

Analyzing results of a number of runs for a real city has produced the results shown in Figures 4 through 12. Figure 5 shows the baseline run used both as a check-out of the model, and to predict results which might occur if no changes are introduced. Subsequent runs indicate the addition of various transportation control strategies to the model calculations. In general, various combinations of strategies produced vehicle traffic reductions by 1980 of 20% or less. The one exception which produced reductions of close to 50% was based on a parking sticker strategy. This strategy limited the number of cars which were allowed to park in the city center area by direct means, as opposed to indirect strategies such as improving public transit, adding outlying parking and limiting the number of available parking spaces indirectly. Of particular interest are Figures 7 and 8, which are identical runs (no on-street parking strategy) with the preference ratios varied to give an estimate of the model sensitivity in this area. Final results in 1980 varied by about 4% for calculated vehicles, but by about 15% for transit ridership. This is a fairly large difference considering the relatively small range of variations which are predicted from most model runs. However, the preference ratios were considerably modified for these two simulations. Further analysis is being performed to improve the operation of the model in the area of these preference ratios.

CONCLUSION

The urban transportation strategies model can provide an important assist to the evaluation of proposed control strategies in urban areas. It is particularly helpful in providing a range of expected realistic reductions in vehicle transit. Use of the model does not replace the application of judgment, however, since results are highly dependent on the way the problem is structured for the model and indeed can be adjusted to produce any result by the designer. The real value of the technique lies in its ability to permit the setting up of the interrelationships between the transportation-oriented parameters and viewing interaction between them over a number of time cycles and through a number of variations in the preference ratios built into the program.

Figure 5

Transportation Strategies Simulation Model

Baseline Run

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NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
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        82800          50000          45540            91         50000          10000           6213       1971

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
.............  .............  .............   ...........   ........... .............. ..............       ....
        85678          50000          47134            94         50000          10000           6427       1972

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
.............  .............  .............   ...........   ........... .............. ..............       ....
        88657          50000          48783            98         50000          10000           6652       1973

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
.............  .............  .............   ...........   ........... .............. ..............       ....
        91801          50000          50052           100         50000          10000           7529       1974

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
.............  .............  .............   ...........   ........... .............. ..............       ....
        95014          50000          50311           101         50000          10000          10044       1975

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
.............  .............  .............   ...........   ........... .............. ..............       ....
        98329          50000          51425           103         50000          10000          11369       1976

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
.............  .............  .............   ...........   ........... .............. ..............       ....
       101785          50000          52579           105         50000          10000          12740       1977

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
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       105347          50000          53774           108         50000          10000          14159       1978

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
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       108728          50000          55010           110         50000          10000          15628       1979

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS       YEAR
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       112343          50000          56290           113         50000          10000          17149       1980
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Figure 6

Transportation Strategies Simulation Model
No On-Street Parking Strategy

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NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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        82800         50000         42203             84         40000          10000          11221          1973

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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        85698         50000         43275             87         40000          10000          12226          1974

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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        88697         50000         44384             89         40000          10000          13266          1975

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
        91801         50000         45532             91         40000          10000          14344          1976

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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        95014         50000         46721             93         40000          10000          15458          1977

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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        98339         50000         47950             96         40000          10000          16611          1978

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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       101780         50000         49223             98         40000          10000          17805          1979

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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       105342         50000         50541            101         40000          10000          19040          1980
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Figure 7

Transportation Strategies Simulation Model
No On-Street Parking Strategy - Variation A

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NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
        82800         50000         41927             84         40000          10000          11637          1973

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
        85698         50000         42920             86         40000          10000          12761          1974

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
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        88697         50000         43947             88         40000          10000          13925          1975

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
        91801         50000         45011             90         40000          10000          15130          1976

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
        95014         50000         46111             92         40000          10000          16377          1977

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
        98339         50000         47249             94         40000          10000          17667          1978

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
       101780         50000         48429             97         40000          10000          19003          1979

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR   PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••   ••••••••••• •••••••••••••• ••••••••••••••          ••••
       105342         50000         49648             99         40000          10000          20365          1980
```

Figure 8

Transportation Strategies Simulation Model
No On-Street Parking Strategy - Variation B

```
NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        82600         50000         42478             85          40000          10000          10806            1973

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        85698         50000         43629             87          40000          10000          11691            1974

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        88697         50000         44821             90          40000          10000          12607            1975

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        91801         50000         46054             92          40000          10000          13557            1976

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        95014         50000         47331             95          40000          10000          14538            1977

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        98339         50000         48651             97          40000          10000          15554            1978

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
       101780         50000         50019            100          40000          10000          16606            1979

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
       105342         50000         51433            103          40000          10000          17694            1980
```

Figure 9

Transportation Strategies Simulation Model
Improved Mass Transit, Plus No On-Street Parking

```
NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        82600         50000         40350             81          40000          20000          13995            1973

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        85698         50000         40713             81          40000          20000          16058            1974

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        88697         50000         41088             82          40000          20000          18195            1975

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        91801         50000         41612             83          40000          20000          20204            1976

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        95014         50000         42780             86          40000          20000          21349            1977

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
        98339         50000         43989             88          40000          20000          22533            1978

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
       101780         50000         45240             90          40000          20000          23759            1979

NO. CITY JOBS ROAD CAPACITY CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS            YEAR
••••••••••••• ••••••••••••• •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••            ••••
       105342         50000         46536             93          40000          20000          25028            1980
```

Figure 10

Transportation Strategies Simulation Model
Addition of Bus Lane Strategy to Prior Strategies

```
NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        82800          50000          38916             78          40000          20000          16560          1973

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        85698          50000          40070             80          40000          20000          17451          1974

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        88697          50000          40422             81          40000          20000          19638          1975

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        91801          50000          41422             83          40000          20000          20949          1976

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        95014          50000          42585             85          40000          20000          22120          1977

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        98339          50000          43786             88          40000          20000          23332          1978

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
       101780          50000          45017             90          40000          20000          24608          1979

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
       105342          50000          46275             93          40000          20000          25950          1980
```

Figure 11

Transportation Strategies Simulation Model
Addition of Outlying Parking Facilities to Prior Strategies

```
NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        82800          50000          37246             74          40000          20000          23636          1973

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        85698          50000          38667             77          40000          20000          24289          1974

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        88697          50000          40139             80          40000          20000          24964          1975

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        91801          50000          41661             83          40000          20000          25664          1976

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        95014          50000          43237             86          40000          20000          26388          1977

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
        98339          50000          44835             90          40000          20000          27186          1978

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
       101780          50000          46088             92          40000          20000          28619          1979

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES    CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS          YEAR
•••••••••••••  •••••••••••••  •••••••••••••    •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••          ••••
       105342          50000          47383             95          40000          20000          30102          1980
```

Figure 12

Transportation Strategies Simulation Model

Addition of Parking Sticker Strategy to Prior Strategies

```
NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
        82800          50000          23170            46          40000          20000          23636        1973

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
        85698          50000          24098            48          40000          20000          24289        1974

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
        88697          50000          25060            50          40000          20000          24964        1975

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
        91801          50000          26055            52          40000          20000          25664        1976

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
        95014          50000          27085            54          40000          20000          26388        1977

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
        98339          50000          28151            56          40000          20000          27137        1978

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
       101780          50000          29254            59          40000          20000          27913        1979

NO. CITY JOBS  ROAD CAPACITY  CALC.VEHICLES   CONGEST FTR    PKNG SPACES TRANSIT CAPCTY TRANSIT RIDERS        YEAR
•••••••••••••  •••••••••••••  •••••••••••••   •••••••••••    ••••••••••• •••••••••••••• ••••••••••••••        ••••
       105342          50000          30395            61          40000          20000          28716        1980
```