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.

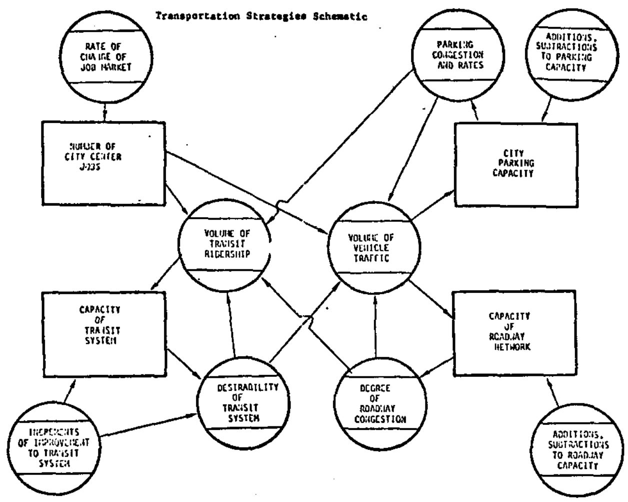
CONCEPT OF THE MODEL

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

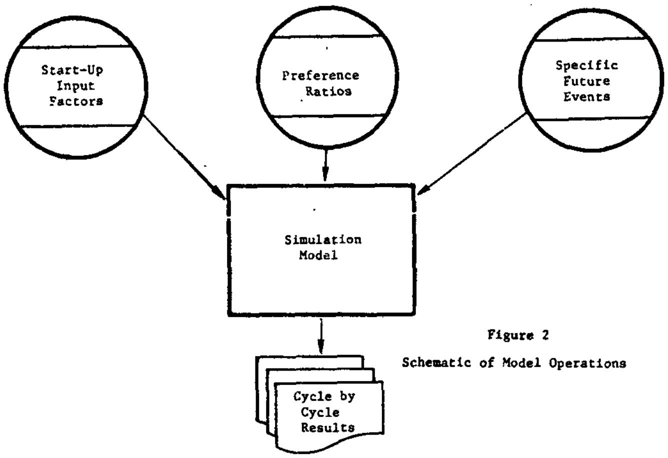


Figure 2

Schematic of Model Operations

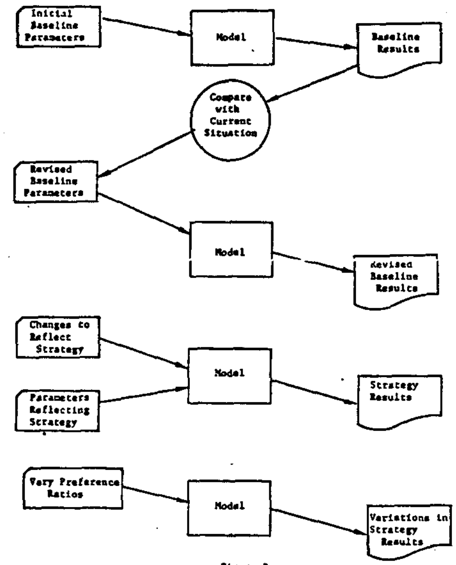


Figure 3

Strategy Simulation, Sequence of Events

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.

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.

NO. CITY JOBS	ROAD CAPACITY	CALC.VEHICLES	CONGEST FTR	PKNG SPACES	TRANSIT CAPCTY	TRANSIT RIDERS	YEAR
82833	50000	38916	78	40000	20000	16560	1973
85698	50000	40070	80	40000	20000	17451	1974
88697	50000	40422	81	40000	20000	19638	1975
91832	50000	41422	83	40000	20000	20949	1976
95014	50000	42585	85	40000	20000	22120	1977
98339	50000	43786	88	40000	20000	23332	1978
101783	50000	45017	90	40000	20000	24608	1979
105342	50000	46275	93	40000	20000	25953	1980

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 overpredict 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

NO. CITY JOBS	ROAD CAPACITY	CALC.VEHICLES	CONGEST FTR	PKNG SPACES	TRANSIT CAPCTY	TRANSIT RIDERS	YEAR
82800	50000	45540	91	50000	10000	6210	1971
85698	50000	47134	94	50000	10000	6427	1972
88697	50000	48783	98	50000	10000	6652	1973
91901	50000	50052	100	50000	10000	7529	1974
95014	50000	50311	101	50000	10000	10044	1975
98329	50000	51425	103	50000	10000	11369	1976
101780	50000	52579	105	50000	10000	12740	1977
105347	50000	53774	108	50000	10000	14159	1978
108928	50000	55010	110	50000	10000	15628	1979
112343	50000	56290	113	50000	10000	17140	1980

Figure 6

Transportation Strategies Simulation Model
No On-Street Parking Strategy

NO. CITY JOBS	ROAD CAPACITY	CALC.VEHICLES	CONGEST FTR	PKNG SPACES	TRANSIT CAPCTY	TRANSIT RIDERS	YEAR
82800	50000	42203	84	40000	10000	11221	1973
85698	50000	43275	87	40000	10000	12226	1974
88697	50000	44384	89	40000	10000	13266	1975
91801	50000	45532	91	40000	10000	14344	1976
95014	50000	46721	93	40000	10000	15458	1977
98339	50000	47950	96	40000	10000	16611	1978
101780	50000	49223	98	40000	10000	17665	1979
105342	50000	50541	101	40000	10000	19540	1980

Figure 7

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

NO. CITY JOBS	ROAD CAPACITY	CALC.VEHICLES	CONGEST FTR	PKNG SPACES	TRANSIT CAPCTY	TRANSIT RIDERS	YEAR
82800	50000	41927	84	40000	10000	11637	1973
85698	50000	42920	86	40000	10000	12761	1974
88697	50000	43947	88	40000	10000	13925	1975
91801	50000	45011	90	40000	10000	15130	1976
95014	50000	46111	92	40000	10000	16377	1977
98339	50000	47249	94	40000	10000	17667	1978
101780	50000	48429	97	40000	10000	19003	1979
105342	50000	49648	99	40000	10000	20385	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
82800	50000	42478	85	40000	10000	10806	1973
85698	50000	43629	87	40000	10000	11691	1974
88697	50000	44821	90	40000	10000	12607	1975
91801	50000	46054	92	40000	10000	13557	1976
95014	50000	47331	95	40000	10000	14538	1977
98339	50000	48651	97	40000	10000	15554	1978
101780	50000	50019	100	40000	10000	16606	1979
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
82800	50000	40350	81	40000	20000	13995	1973
85698	50000	40713	81	40000	20000	16058	1974
88697	50000	41088	82	40000	20000	18195	1975
91801	50000	41612	83	40000	20000	20204	1976
95014	50000	42780	86	40000	20000	21349	1977
98339	50000	43989	88	40000	20000	22533	1978
101780	50000	45240	90	40000	20000	23759	1979
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
85698	50000	40070	80	40000	20000	17451	1974
88697	50000	40422	81	40000	20000	19638	1975
91801	50000	41422	83	40000	20000	20949	1976
95014	50000	42585	85	40000	20000	22120	1977
98339	50000	43786	88	40000	20000	23332	1978
101790	50000	45017	90	40000	20000	24608	1979
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
85698	50000	38667	77	40000	20000	24289	1974
88697	50000	40139	80	40000	20000	24964	1975
91801	50000	41661	83	40000	20000	25664	1976
95014	50000	43237	86	40000	20000	26388	1977
98339	50000	44835	90	40000	20000	27186	1978
101730	50000	46388	92	40000	20000	28619	1979
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
85698	50000	24098	48	40000	20000	24289	1974
88697	50000	25060	50	40000	20000	24964	1975
91801	50000	26055	52	40000	20000	25664	1976
95014	50000	27085	54	40000	20000	26388	1977
98339	50000	[illegible]	56	40000	20000	27137	1978
101780	50000	29254	59	40000	20000	27913	1979
105342	50000	30395	61	40000	20000	28716	1980

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