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Sketch-Planning Model for Urban Transportation Policy Analysis

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ABSTRACT

In this paper the urban transportation policy analysis process (UTPAP) is described. UTPAP was developed as a sketch-planning analysis tool for the study Technology Assessment of Production Conservation in Urban Transportation (TAPCUT). TAPCUT was a comprehensive study of the potential environmental, health, and public safety impacts of various alternative productive urban transportation energy-conservation strategies. Productive conservation strategies encourage energy conservation without disrupting the economy or life-styles. The strategies that were analyzed reflected alternative national investment in infrastructure and technology and regulatory policies. The UTPAP is a sketch-planning model package that incorporates state-of-the-art, household-based, disaggregate travel demand models for mode and destination choice, with detailed specification of automobile technologies. It is useful in analyzing both the short- and long-term implications of city-specific transportation planning policies, and it provides summaries of transportation, fuel-consumption, air quality, public health, and safety impacts. Stratified by both type of household and geographic area of occurrence, these impact measures are valuable in assessing the social equity of transportation policy impacts. Preliminary sensitivity analysis indicated that nonwork travel was more responsive to price and level-of-service (LOS) change than work travel. Transit ridership was most affected by transit LOS improvements, whereas automobile vehicle miles of travel were most affected by fuel price increases. There was also a significant synergistic effect that increased nonwork transit ridership by combining transit LOS improvements with automobile fuel price increases.

In this paper the urban transportation policy analysis process (UTPAP) is described. UTPAP was developed as a sketch-planning analysis tool for the study Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT). TAPCUT was a comprehensive study of the potential environmental, health, and public safety impacts of various alternative productive urban transportation energy-conservation strategies. Productive conservation strategies encourage energy conservation without disrupting the economy or life-styles. The strategies that were analyzed reflected alternative national investment in infrastructure and technology and regulatory policies.

An in-place policy package and two alternative policy packages were defined. Both alternatives were composed of mutually reenforcing conservation strategies. Because there is a high degree of uncertainty about future conditions (exogenous variables), a scenario approach was used to analyze the range of future conditions analyzed through the year 2000. The two scenarios were distinguished by their demographics, macroeconomics, transportation fuels availability and price, and degree of social aggregation. Further details on the study structure are provided by LaBelle et al. (1).

Travel demand, fuel-consumption, and emissions estimates were determined for three prototypical cities. The cities were selected in light of major differences in their transportation-related characteristics by using a factor analysis technique for grouping cities. The first typical city, Sprawlburg, represents a relatively new, spread out, western metropolitan area. The second city, Megatown, has certain characteristics of the big, densely settled city with satisfactory transit in place. The third typical city, Slowtown, might be best described as a midwestern, industrial, middle-sized metropolitan area. Sprawlburg examples include Phoenix, Houston, Dallas, Anaheim, and Tacoma. Megatown examples include Chicago, Cleveland, Philadelphia, Boston, and Baltimore. Slowtown examples include Flint, Grand Rapids, Lima, Paterson, Norwalk, and York. The methods used to select the prototypical cities and expand city estimates to national totals are described by Peterson (2). UTPAP was developed and used to generate these city-specific estimates. The results of the UTPAP estimates were then expanded to national urban totals. The structure of UTPAP, how it was used in the analysis of alternative policies, and some examples of results generated by the process are described.

UTPAP: STRUCTURE OF THE PROCESS

The nature of the TAPCUT study design (multiple scenarios, policies, forecast years, and cities) dictated the need for a quick response, relatively low cost per forecast method of estimating travel demand and impacts. Also, the breadth of strategies required that the travel demand model be responsive to a wide range of alternatives, including new automobile designs, changing fuels mix, transit service improvements, colocation of home and work place, incentives for carpooling, and fuel tax increases. The long range (20-year) focus of TAPCUT required that the forecast reflect the full range of possible travel responses to these varied actions. Changes in trip length, trip generation, distribution, and modal split, as well as changes in automobile occupancy and the number and kind of automobiles owned by households, were all of concern. Land use impacts of the policies were not examined; however, activity patterns that were consistent with both general scenario descriptors and the policy themes were specified as analysis inputs. Also required was a level of output detail sufficient to identify impacts on subpopulations. These impacts included fuel consumption by fuel type, exposure concentrations of pollutants, and accident injuries and fatalities.

These model criteria proved to be quite ambitious. A review of 12 currently available sketch-planning models demonstrated that many satisfied some, some satisfied many, but none satisfied all of the TAPCUT modeling requirements (3). Therefore, a synthesis of existing methods was developed. Where necessary, these methods were modified and in some cases enhanced. The resulting analysis procedure, UTPAP, is shown schematically in Figure 1.

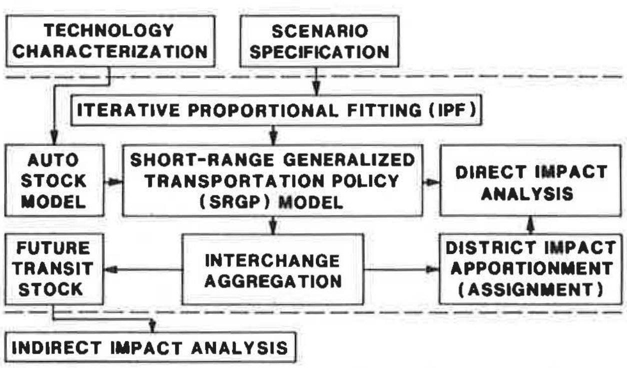

FIGURE 1 Urban transportation policy analysis process.

The central component of UTPAP is XRGP, an extended version of the computerized procedure for short range generalized transportation policy analysis (SRGP) (4,5). XRGP is a sequence of disaggregate travel demand models that estimate aggregate travel demand through a random sample enumeration process. A basic input to XRGP is the household and work trip (HHWORK) file, which contains information on household attributes and the frequency and destination of work trips. These attributes and work trip travel patterns remain constant for a household. Changes in the regionwide distribution of these attributes must be specified outside XRGP and expressed as changes in the expansion weights for the households.

In UTPAP this HHWORK file is modified by XIPF, an extended version of iterative proportional fitting (IPF), which modifies household expansion weights to reflect future, scenario-specific populations and work trip travel patterns. XRGP has the extended ability to input different vehicle ownership profiles for different household types and account for travel by as many as 10 vehicle types that are fueled by up to seven fuel types. The vehicle-ownership profiles are estimated by the disaggregate vehicle stock allocation model (DVSAM). DVSAM incorporates the Lave-Train new car purchase model (6,7) in an overall model structure to forecast household automobile holdings and purchases. This model estimates the probable automobile-type ownership profiles for 576 household types for input to XRGP.

Zone-to-zone vehicle trip tables by vehicle type are produced by XRGP. These trip tables are aggregated into district-to-district interchanges with standard Urban Transportation Planning System (UTPS) software (UMATRIX and USQUEX) (8). The district-to-district vehicle trip interchange tables are input to a desire-line projection method called CLIP. CLIP provides district level vehicle miles of travel (VMT), emissions, and accident impact measures.

HOUSEHOLD TRAVEL DEMAND MODEL (XRGP)

XRGP estimates residential travel demand in a city. The major input to the model is the household and work trip (HHWORK) file, which includes a sample of about 2,000 to 3,000 households. Each household is described by

1. Location (zone of residence),
2. Socioeconomic attributes, and
3. Attributes of each work trip made by household, which includes destination zone and level of service by all available modes.

In addition, the model needs as input mode-specific interzonal times and costs, a file that provides the distribution of activities that attract nonwork trips, and access and egress service characteristics for each zone. Each household is analyzed by the model separately. The estimated demand by individual households is aggregated (by using input expansion factors) to provide estimated demands for the whole population.

XRGP incorporates all of the capabilities of the original model. It estimates work trip modal split, as well as the generation, distribution, and modal split of nonwork trips. Submodel interactions are shown in Figure 2. Standard model outputs include travel demand, energy, and environmental impacts for the whole city and stratified by area type, income, and automobile ownership levels. Optional outputs include zonal interchange tables.

SRGP was selected as the basis for household travel demand modeling because it emphasized the effects of socioeconomic characteristics of the population on travel demand. This permitted the highlighting of differences among the scenarios, which are distinguished largely by variations in such attributes. The disaggregated demand models within SRGP were likely to be stable over time and scenarios. Limited past tests of model transfer-

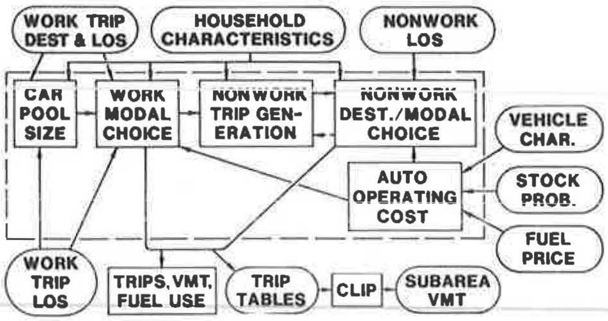

FIGURE 2 XRGP information flow.

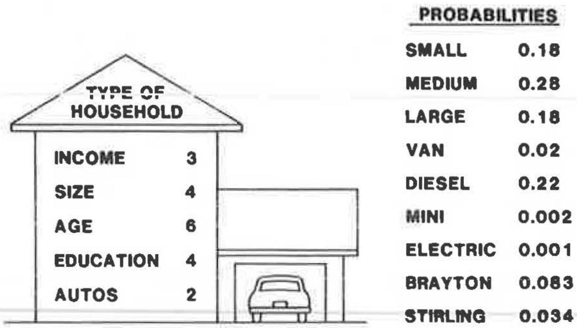

FIGURE 3 Automobile stock probabilities.

ability among cities had been quite encouraging. SRGP provided for the analysis of a wide range of strategies. The level of detail of the model was compatible with the needs of TAPCUT. Network analysis, with the corresponding data needs and analysis costs, was not a necessary part of the process. The model was well documented and had been successfully applied in several diverse cities.

As attractive as SRGP was as a sketch-planning tool, a number of deficiencies were apparent.

1. SRGP was, as its name implies, a short-range model.
2. One average composite vehicle type and fuel consumption versus speed relationship was assumed for all automobile trips, regardless of household or trip characteristics.
3. Geographic reporting of impacts was made by area of residence, not by area of occurrence.

These limitations of SRGP were overcome by providing appropriate links between SRGP and the other components of UTPAP. These links distinguish the XRGP procedure from its predecessor. The long-range forecasting ability of UTPAP is provided by linking XRGP with XIPF. The ability of XIPF to model changes in work travel patterns is described later.

Household Vehicle Disaggregation

XRGP accepts an extended HHWORK file that includes additional household attributes that are important in determining the probable automobile ownership profile of a household. XRGP also provides for the input of a household cross-classified automobile ownership profile table. This table, as generated by DVSAM, contains the probability of owning each of 10 different vehicle types for 576 different household classes. The household classes are distinguished by household size, income, number of automobiles owned, and age and education of the head of household. A detailed description of DVSAM is provided by Saricks et al. (7). A sample of the automobile stock probabilities for the highest-ranked household type in the year 2000 is shown in Figure 3. The method of specifying household automobile holdings permits XRGP to use a disaggregated representation of vehicle fuel-consumption rates.

Fuel-Consumption Calculations

The kinds of vehicles owned by a household have a direct influence on its travel behavior and a profound effect on the amount of fuel used while engaged in travel. Because the fuel economy of passenger cars varies greatly by vehicle type (principally size), the out-of-pocket automobile operating cost experienced by travelers may vary significantly from household to household. With recent rapid increases in fuel prices, out-of-pocket automobile operating cost has become an important factor influencing travel. However, significant increases in vehicle fuel economy (VFE), which occur in the long term, mitigate the price influence on out-of-pocket cost. Both VFE and fuel price were considered in determining out-of-pocket automobile operating cost, which in turn affected travel decisions.

XRGP permits the input of as many as 10 sets of the linear coefficients for the fuel-consumption rate versus speed relationship. Fuel-consumption rate (FCR) by vehicle class is determined as a linear function of the inverse of average trip speed (9):

$$FCR = a + b*(1/S) \quad (1)$$

Because certain characteristics of future vehicles can be hypothesized for a scenario or strategy, but empirical data on their operation were not available, formulas for relating these characteristics to the values of the FCR versus speed relationship equation coefficients (a and b) were developed (10). According to these formulas:

1. a was evaluated as a function of vehicle curb weight, energy content of the propulsion fuel, system efficiency during acceleration, and system efficiency during cruise; and
2. b was evaluated as a function of drag coefficient, frontal area, fuel-flow rate at idle, fuel-flow rate during braking, and system efficiency during cruise.

Based on these estimates of FCR, trip length, a cold-start adjustment, and the household's vehicle type distribution, the expected out-of-pocket automobile operating cost for each trip is computed uniquely for each household type by XRGP.

Although gasoline is the primary automobile fuel, diesel fuel and gasohol have made notable entries into the market. The introduction of proposed alternative engine technologies offers the prospect of other fuels such as methanol and electricity. Each vehicle type has an expected fuels distribution. These distributions represent the proportion of VMT attributed to each fuel for each vehicle type. For each of the 10 possible types of vehicles, up to seven fuels shares may be specified. For example, it may be expected that in 2000 a Stirling engine vehicle would be propelled 70 percent of its VMT by kerosene, 20 percent by diesel, and 10 percent by methanol. Prices for each of these fuel types are specified.

XRGP Outputs

In addition to considering the effects of alternative vehicle technologies, fuel use, and fuel cost in determining out-of-pocket automobile operating costs, the XRGP program traces all travel by vehicle type and reports trips, VMT, and fuel consumption [in British thermal unit (Btu) x 10,000] by vehicle type. Fuel consumption is also reported by fuel type. As with the original SRGP outputs, these measures are stratified by trip purpose and market segment. XRGP also outputs zonal interchange trip tables by any combination of vehicle types. These specific trip tables by vehicle type are useful for emissions analysis when different vehicle technologies exhibit different emissions characteristics. These trip tables are the link between XRGP and the CLIP method used for district impact apportionment.

EXTENDED ITERATIVE PROPORTIONAL FITTING

Standard Procedure

IPF is an effective and widely used tool in modeling. It has been used to correct survey data for sampling bias (11). The FRATAR trip distribution procedure is a special case of IPF application (12).

The input to the procedure includes a base sample, which consists of a set of observations and target frequency distributions (FDs) of various attributes of the sample. IPF changes the weights of individual observations, so that the modified sample possesses the target FDs. The problem that is solved by IPF can be formulated as an optimization problem with a closed solution. However, for computational efficiency, IPF uses an iterative heuristic.

Many aspects of IPF made it suitable to UTPAP for modifying the base sample file (HHWORK) to represent different scenarios and future years. The target FDs were of a type, complexity, and specificity compatible with procedures for specifying scenarios. The flexibility in the selection of the attributes to be controlled, and in the level of detail of specifying the FDs, made IPF easily adaptable to a wide range of problems. One particular advantage of IPF was that it preserved individual observations and retained important intercorrelations among variables embedded in the observed data.

In adapting IPF to the needs of UTPAP, two major issues were resolved. First was the method of treating work trips. The second problem was the selection of variables for which FDs were to be specified, and in particular, the method for achieving spatial consistency. A description of each issue follows.

Treatment of Work Trips: Extended IPF

The standard IPF procedure operated on only one entity type. Every observation described one such entity, and target FDs were specified for that entity. For example, the basic entity type in the HHWORK file was a household; standard IPF can be applied to modify FDs of household attributes such as the number of persons, number of workers, income level, and so forth. The HHWORK file, however, described also another type of entity--work trips. Each household may produce between zero and nine work trips. The characteristics of work trips in the different scenarios might affect significantly the effectiveness of various strategies. For example, the effectiveness of policies that support transit depend largely on the spatial distribution of work trip destinations (jobs), and in particular the amount of work travel to the central business district (CBD). Moreover, some strategies call specifically for changes in work trip attributes (e.g., residence-job colocation). The procedure for specifying scenarios provided estimate target FDs for major attributes of work trips. A procedure that modified the sample toward those FDs had to be devised. Ignoring this issue would have amounted to leaving the determination of important scenario aspects to the random performance of a mechanical process.

One alternative was to follow the household IPF by another procedure (FRATAR, IPF, or a trip-distribution model) to control the attributes of work trips. This alternative was rejected because it destroyed the internal consistency of the sample file.

The solution involved an enhancement to the IPF procedure. The enhanced procedure--extended IPF (XIPF)--considers simultaneously FDs of the two entity types. The household expansion factors are modified to preserve both FD types. XIPF is also an iterative heuristic, but it is less robust than IPF; it is not difficult to find hypothetical examples of cases where the procedure misperforms. Nevertheless, in numerous actual applications the procedure has proved efficient and reliable.

With the introduction of XIPF, UTPAP became a significantly more powerful tool. It permitted the specification and analysis of inputs of a variety of policies and assumptions on work travel in the various scenarios.

Selection of Controlled Attributes

The second important issue was the various spatial aspects of the problem. The attributes that are controlled by XIPF are given in Table 1. The list covers most of the attributes that are included in the various XRGP demand models. Four FDs address the spatial aspects: district of residence (a household attribute), district of destination, area type of origin, and corridor orientation (work trip attributes).

TABLE 1 XIPF-Controlled Attributes

Attribute	Maximum No. of Classes
Household	
District of residence	100
Household size	20
Annual household income	3
No. of workers in household	20
Age of head of household	20
No. of automobiles	20
No. of work trips	20
Education of head of household	20
Work trip	
Ring of origin	10
District of destination	100
Trip length	10
Corridor orientation	2
Size: number of households	-

Work trip origins were controlled at the more aggregate level of area type (CBD, urban, suburban, exurban) because of the high correlation with residence. The major reason for its inclusion was the need to control the distribution of zero-worker households (primarily retirees). This was in response to scenario statements that in some cases predicted concentration of the elderly in dense areas that are well served by transit, whereas in other cases the scenario predicted more even distribution of such households.

The extent to which work travel is concentrated along corridors is a major determinant of the comparative advantage of fixed guideway transit versus buses. Conversely, it is expected that in the long run the work travel patterns will change to match

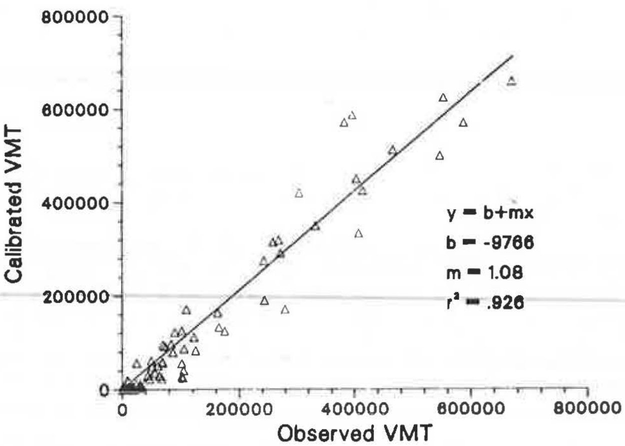

FIGURE 6 Sprawlburg-district VMT comparison.

note that there existed a pronounced synergistic effect between the two types of policies on transit use. Transit increases for shop trips with policy 6 are 50 percent greater than the sum of increases by the component policies 3 and 5. The synergism for social-recreational and work transit travel was 28 and 8 percent, respectively. There was, however, some policy redundancy evident on other travel responses, including total VMT and fuel use.

The results presented in this section reflect short-term responses to postulated fuel price and transit improvement policies. Neither work trip destinations nor household vehicle holding profiles were changed. Also, this brief analysis only examined aggregate measures of travel demand and energy impact. Variable responses by households of different socioeconomic categories or aggregate manifest travel through particular subregions have not been examined. This sensitivity test served, however, as a guide for interpreting the results of

TABLE 3 XRGP Calibration Results

	Sprawlburg		Megatown		Slowtown	
Calibration Criteria	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
Work trip shares						
Drive alone	84.17	83.95	58.49	58.97	70.53	70.68
Shared ride	15.03	15.02	21.07	21.40	28.26	28.11
Transit	0.80	0.81	20.45	19.63	1.21	1.21
Shop trip shares						
Automobile	99.77	99.76	94.18	94.21	95.53	95.73
Transit	0.23	0.24	5.82	5.79	4.47	4.27
CBD	2.02	2.03	4.7	4.57	7.84	8.14
CBD automobile	-	-	55.97	55.73	-	-
CBD transit	-	-	44.03	44.27	-	-
Social-recreation trip share						
Automobile	99.79	99.76	96.85	96.98	99.75	99.73
Transit	0.21	0.24	3.15	3.02	0.25	0.27
CBD	3.45	3.54	3.68	3.80	7.84	8.14
CBD automobile	-	-	80.53	80.57	-	-
CBD transit	-	-	19.48	19.42	-	-
Nonwork average trip length	3.834	3.847	5.62	5.83	3.47	3.68

TABLE 4 1976 Sprawlburg XRGP Sensitivity Analysis of Percentage Change from Base

	Policy[a]					
Travel Measure	1	2	3	4	5	6
Work travel						
VMT	-0.2	-0.4	-0.8	-0.1	-0.4	-1.3
Fuel	-0.2	-0.4	-0.8	-0.1	-0.4	1.3
Transit	+2.0	+4.3	+9.0	+23.4	92.4	+109.0
Drive alone	-0.3	-0.5	-1.1	-0.1	-0.5	1.6
Shared ride	+1.3	+2.7	+5.5	-0.7	-2.1	3.22
Vehicle trips	-0.2	-0.3	-0.7	-0.1	-0.6	-1.3
Nonwork travel						
Shop person trips	-0.2	-0.3	-0.6	-0.04	+0.06	-0.5
Shop vehicle trips	-0.2	-0.3	-0.7	-1.0	-1.4	-2.3
Shop transit trips	+8.3	+8.2	+20.6	+458	+616	+950
Social-recreation person trips	-1.0	-1.6	-2.6	-0.5	-0.5	-2.5
Social-recreation vehicle trips	-1.0	-1.6	-2.7	-0.9	-1.0	-3.3
Social-recreation transit trips	+8.2	+12.4	+34.7	+172	+232	+341
CBD person trips	-2.1	-3.8	-6.8	+8.9	+11.4	+8.3
CBD vehicle trips	-2.6	-4.7	-8.6	-3.1	-3.7	-12.7
PMT	-2.4	-5.5	-10.3	-0.1	-0.05	-10.2
VMT	-3.1	-6.7	-12.4	-1.0	-1.0	-13.1
Fuel	-2.6	-4.7	-8.6	-0.9	-1.1	-9.5
Total travel						
VMT	-1.9	-3.5	-6.5	-0.5	-0.7	-7.0
Fuel	-1.5	-2.7	-5.0	-0.4	-0.8	-5.6

[a]See text for the definitions of the policies.

the scenario forecasts combined with the TAPCUT policies, where more variables were changed between successive model runs. As the project was particularly concerned with synergistic effects from demographic, land use, and vehicle changes in addition to the transportation energy-conservation policy actions, this sensitivity analysis was essential in understanding the more complex and comprehensive analysis reported in a paper by Stuart, LaBelle, Kaplan, and Johnson elsewhere in this Record.

In summary, the UTPAP is a sketch-planning model package that incorporates state-of-the-art, household-based, disaggregate travel demand models for mode and destination choice, with detailed specification of automobile technologies. It is useful in analyzing both the short- and long-term implications of city-specific transportation planning policies, and it provides summaries of transportation, fuel-consumption, air quality, public health, and safety impacts. Stratified by both type of household and geographic area of occurrence, these measures are valuable in assessing the social equity of transportation policy impacts.

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Technology Assessment of Productive Conservation in Urban Transportation: An Overview

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ABSTRACT

Travel within urban areas accounted for about one-third of all the person miles of travel and about 5 quads of energy in 1975. Two energy-saving strategies were designed for this sector that were aimed at minimal disruption to life-styles and the economy while achieving the reductions in aggregate energy, especially petroleum, consumption. These productive conservation strategies