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APPLICATION OF AMOS, AN ACTIVITY-BASED TCM EVALUATION TOOL TO THE WASHINGTON, D.C., METROPOLITAN AREA

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1. INTRODUCTION

Most tools currently available for passenger travel demand forecasting and policy analysis are based on the trip-based, four-step procedure. The procedure was developed in the 1950's and 1960's during the post-war expansion period, when urban population was growing rapidly, motorization was progressing, and suburban sprawling was starting. The emphasis in transportation planning at that time was infrastructure development. The issue at hand was where to build new freeways and how many lanes were needed. In such planning contexts coarse forecasting procedures sufficed.

Planning emphasis has changed substantially since then. In the 1970's Transportation Systems Management (TSM) was promoted, and Transportation Demand Management (TDM) was proposed in the 1980's. Currently the transportation planning community embraces more inclusive Transportation Control Measures (TCM's). The measures being considered are extensive and sophisticated. They are fine-tuned to target specific traveler segments. The trip-based four-step procedure, developed to serve the planning needs of decades ago, is not well suited to address these new transportation measures.

The Activity-Mobility Simulator (AMOS) was proposed as a tool, primarily for short-term transportation policy analysis, which is capable of better addressing current transportation planning issues.[1] It is an activity-based micro-simulator of daily travel which focuses on adaptation behavior exhibited by urban residents when faced with changes in their travel environment. Its development embodies the following paradigm shifts: from utility maximization to satisficing; from deterministic demand functions to stochastic micro-simulation; and from static, cross-sectional models to dynamic models of adaptation.

At the time when the concept of AMOS was presented at the 1993 Summer Annual Meeting, it was still in a conceptual stage of development. Now an AMOS prototype has been developed and implemented in the Washington, D.C., metropolitan area, in the context of predicting traveler response to potential TDM measures. The TDM measures considered for evaluation include: parking surcharge; bicycle/pedestrian facility improvements; parking pricing with employer-paid voucher; congestion pricing; and combinations of the first and second measures, and the third and fourth measures. This paper reports on this AMOS implementation project.

Problems of the conventional trip-based, four-step procedure when applied to TDM evaluation are discussed in Section 2, which is followed by a discussion of the advantages of the activity-based approach in Section 3. Components of the AMOS prototype are described in Section 4. Discussed in Section 5 are the model implementation efforts including the telephone interview survey conducted in the study area to generate data for prototype development and the results it produced. Section 6 offers conclusions. Detailed results of policy analysis will be given at the time of presentation.

Before closing this section, it is emphasized that no single model system is suited for all study objectives, just as no single tool is sufficient for all jobs around the house. The trip-based, four-step procedure may continue to be an adequate demand forecasting procedure for certain types of problems. Yet current policy contexts call for alternative methods. The transportation planning tool box needs to be expanded.

2. A CRITICAL REVIEW OF THE TRIP-BASED, FOUR-STEP MODEL OF TRAVEL DEMAND

The simplifications incorporated into the four-step procedure made urban passenger travel demand forecasting practicable using home interview surveys, land use inventory data, network models, census and other existing data, and computational capabilities that were available decades ago. The simplifying assumptions adopted in the procedure facilitated quantitative analysis of travel demand, which is a result of complex (to analyze) travel behavior. Yet, the procedure presents serious limitations, which were extensively discussed when disaggregate choice models were proposed in the 1970's.[2] Rather than repeating these, the discussion of this section focuses on three major sources of problems that are most deleterious in the contexts of TDM evaluation: (i) incomplete structurization of travel behavior, (ii) lack of the time dimension, and (iii) trip-based model structure.

Incomplete Structurization: Attempting to represent demand by the linearly linked four model components presents problems under certain conditions. Suppose parking pricing is implemented in a downtown area, prompting some travelers to choose suburban destinations. This change in trip attraction, however, would not at all be accounted for by the four-step procedure because trip attraction is determined in the trip generation phase which is not sensitive to parking cost. Likewise, the impact of new roadway segments on trip distribution would be under-estimated, while mode shift could be over-estimated. Issues of induced trips and suppressed demand are difficult to approach within the structurization of the four-step procedure.

Lack of Time Dimension: The fact that the four-step procedure does not incorporate the time-of-day dimension is curious since congestion -- which has been the single most important concern of transportation planning -- occurs with the concentration of demand in the same area at the same time. The absence of the time dimension necessitates the use of purely empirical, often dubious, procedures to determine hourly demand volume. It makes it difficult to thoroughly analyze peak spreading, congestion pricing, or cold/hot starts.

Trip-Based: The four-step procedure treats each trip as an independent entity for analysis. This assumption, on which the structure of the four-step procedure hinges, leads to a number of serious limitations which stem from the fact that trips made by an individual are linked to each other and the decisions underlying the respective trips are all inter-related. For example, consider a home-based trip chain (a series of linked trips that starts and ends at the home base) that contains two or more stops. The four-step procedure examines each trip separately and determines the best mode for it, leading to two major problems. Firstly the result may violate the modal continuity condition; mode choice for a trip with non-home origin is conditioned on the mode selected for the first home-based trip. Secondly, the result ignores the behavioral fact that people plan ahead and choose a mode while considering the entire trip chain, not each individual trip separately.

Because the trip-based structure does not recognize the mode continuity condition, it is logically expected that the four-step procedure over-predicts mode shift. The problem is compounded by the fact that the modal split phase, where disaggregate choice models are often incorporated, tends to be most sensitive to changes in the travel environment. As a result, the four-step procedure may grossly over-estimate mode shift when in fact travel mode may be the last thing travelers wish to change in response to TDM measures.

As another example, suppose a drive-alone commuter stops by at a grocery store on the way home from work. Faced with congestion pricing, this commuter may choose to take the bus to work, and go shopping by auto at a grocery store near the home after returning home by bus. The trip-based four-step procedure is not capable of addressing such repercussions brought about by the commute mode change.

While some of the problems discussed in this section may be resolved by introducing new model elements, the problems stemming from the atemporal, trip-based structure are difficult to eliminate, and developing effective tools for TCM analysis is impractical within the framework of the four-step procedure.

3. WHY THE ACTIVITY-BASED APPROACH?

The activity-based approach explicitly recognizes the fact that the demand for activities produces the demand for travel. In other words, the need or desire to engage in an activity at a different location generates a trip. Therefore a rigorous understanding of travel demand will only follow from an understanding of how activities are engaged over a day or a week. This approach is entirely different from the approach taken for the development of the four-step procedure where statistical associations, rather than behavioral relationships, drove model development. Another important distinction is the following recognition: As the activities engaged during a day are linked to each other, trips made to pursue them are also linked to each other; they cannot be analyzed independently.

Although the activity-based approach was conceived in the 1970's by a group of researchers at Oxford University,[3] it until recently remained largely within the domain of academic research. Kitamura[4] attributed this inattention by the practitioners' community to the fact that the activity-based approach is not suited for the evaluation of capital-incentive, large-scale projects, but it is better suited for refined, often small-scale trans-portation policy measures. Of course small-scale projects can hardly afford elaborate analysis. This is no longer the case, at least in the United States. The importance of refined TCM's is well recognized and efforts are being made to promote their implementation and to assess their potential effectiveness.

Aside from this rather drastic change in policy analysis needs, several important advances have taken place. They are: accumulation of activity-based research results; advances in survey methods (e.g., stated-preference (SP) and time-use survey methodologies) and statistical estimation methods; and advances in computational capabilities and supporting software (database software, GIS, etc.). All these changes have created an environment where models of travel behavior can be developed while adhering to the principles of the activity-based approach. More specifically, these changes have made activity-based micro-simulation of travel behavior a practical tool for transportation planning and policy analysis.

The activity-based approach implies an expansion of the analytical scope because its subject is not limited to the trip. This naturally leads to increased levels of analytical difficulty. The activity-based approach nonetheless offers advantages that outweigh the cost of increased analytical complexity and data requirements. In fact some of the problems raised above have been resolved in the AMOS implementation project described here. The advantages of the activity-based approach include:

- *daily behavior*: treats a daily activity-travel pattern as a whole, thus avoids the shortcoming of the conventional trip-based methods;
- *realism*: incorporates various constraints governing trip making, facilitating realistic prediction and scenario analyses; and
- *induced demand*: the activity-based approach is a key to address the issue of induced or suppressed demand.

In addition, the activity-based micro-simulation approach adopted in AMOS include:

- *time of day*: predicts travel behavior along a continuous time axis;
- *TDM evaluation*: is capable of realistically assessing the impact of TDM measures on the entire daily travel demand;
- *versatile*: can address various policy scenarios using special-purpose SP surveys;
- *flexible*: can be modified for specific study objectives, e.g., to evaluate effects of day-care facilities at work, extended transit service hours, or new transit lines; and
- *accuracy control*: using synthetic household samples, can produce results with desired levels of spatial and temporal resolutions.

Another important advantage to note here is:

- *comprehensive evaluation tool*: activity-based approach simulates the entire daily activities and travel. Therefore the effect of a transportation policy on the entire daily activity, not just commute trips, can be evaluated, leading to better benefit measures.

4. AMOS COMPONENTS

AMOS comprises five main components and a reporting routine (Figure 1). In a nutshell, AMOS takes an observed ("baseline") daily travel pattern of an individual; generates an adaptation option (e.g., change commute travel mode) that may be adopted by the individual when faced with the TDM under consideration; adjusts the baseline pattern (e.g., re-sequence activities, select new destinations) to produce a modified activity-travel pattern; evaluates the utility of the modified pattern; based on a satisficing rule, accepts one of the modified patterns so far generated and terminates the search, or continues to search for alternatives. Because all TDM measures considered in the implementation project are aimed at commuters, the current prototype is formulated for commuters only. The components of AMOS are briefly described in this section.[5]

Baseline Activity-Travel Pattern Analyzer is summarized in Figure 2 with its input, output, and functions. The analyzer makes sure that the daily travel diary under consideration is complete, with all trips and pertinent information intact. It also checks whether the sample trip maker or his/her travel pattern falls in the categories marked for analysis. Another major function is to prepare indicators of travel pattern characteristics (e.g., there is a stop during the commute trip) that feed into the Response Option Generator. Trip diary data typically available from metropolitan planning organizations (MPO's) are used as input to this module.

Response Option Generator (Figure 3) is a key stochastic element of AMOS. The input to the generator consists of: household and person attributes, network and land use characteristics, TDM attributes, and the indicators of the baseline activity-travel pattern characteristics prepared by the analyzer. Given these, the generator simulates response to the TDM measure.

At the heart of the generator is a neural network which computes the probability of each possible response option based on the input variables. The use of a neural network draws from the connectionism, a branch of cognitive science. Connectionists postulate that humans process information by breaking it down into smaller elements that are inter-connected with different levels of intensity. In other words, human thinking is a process of connecting one informational element (e.g., a concept) to another. This idea can be depicted by a neural network, which can be "trained" to best replicate observed connection patterns between input (in this case TDM attributes) and output (response options).

Note that choosing a response option alone does not automatically generate a complete and feasible new activity-travel pattern. Quite often this primary change triggers secondary and tertiary changes. For example, a solo-driving commuter who stops at a grocery store on the way home from work, may choose to switch to public transit because of congestion pricing. To be able to do this, however, the commuter may also choose to make a home-based trip chain to a nearby grocery store by auto after returning home by bus. The next module performs such adjustments.

Activity-Travel Pattern Modifier (Figure 4) examines the baseline pattern and, if the response option necessitates it, performs: (i) activity re-sequencing, (ii) activity re-linking, (iii) mode and destination assignment, and (iv) trip timing adjustment. Such adjustments are needed primarily when a travel mode change or a departure time change implied by the response option makes the baseline pattern infeasible or impractical. The modifier then examines the feasibility of the resulting modified activity-travel pattern using a rule base.

Activity re-sequencing refers to the re-arrangement of the order in which out-of-home stops are made. Re-linking, on the other hand, refers to the re-combining of out-of-home stops into trip chains. For example, consider a sequence of three out-of-home activities, A, B and W, where W is work. Suppose these three are pursued as A-W-B. This may be re-sequenced as W-A-B. Letting H be the home base, these activities may be linked as: H-W-A-B-H or H-W-H-A-B-H. In the former case, activities A and B are pursued on the way home from work; in the latter they are pursued in a separate home-based trip chain.

While the response option from the generator may dictate which mode is to be taken for some trips, there may be some degrees of freedom associated with other trips. In the latter case the modifier simulates mode choice for the set of trips whose modes are not fixed. Likewise, new destinations may be chosen for certain types of activities when activities are re-sequenced or re-linked, and the destination location in the baseline pattern is no longer suitable.

The timing of trips is determined while using the work starting and ending times as "pegs." For example, the starting time of a home-to-work commute trip by a new mode will be determined such that the commuter will arrive at the workplace at or earlier than the time observed in the baseline pattern. The duration of each out-of-home activity is fixed in this initial prototype.

After a modified activity-travel pattern is generated, the modifier checks if it is feasible. Used in this check is the rule base, which contains several groups of rules that govern and constrain travel. For example shopping cannot be pursued outside the store hours. In fact this rule base is constantly referred to in the above process of modifying the baseline activity-travel pattern and producing an alternative.

Evaluation Routine (Figure 5) assigns a utility measure to the modified activity-travel pattern using time-use utility functions.[6] The attractiveness of the modified pattern is determined by the utility produced by allocating time to, and engaging in the in-home and out-of-home activities contained in the pattern. The utility functions are estimated using the time-use data obtained from the survey conducted as part of the study (Section 5). By using the time utility concept, AMOS evaluates TDM measures while considering their impacts on the entire daily activity, not just on the commute trips which these measures often target. The effort is ongoing to generalize the utility functions to include non-time elements such as mode attributes and monetary expenses, and sequencing and timing of activities.

Acceptance (Search Termination) Routine (also Figure 5) evaluates the set of time-utilities associated with the activity-travel patterns so far generated, and determines whether the search should continue or one of the patterns so far generated should be adopted. The routine is based on the assumption that the individual forms a subjective distribution of utilities associated with alternative patterns; assesses the likelihood of obtaining a better activity-travel pattern; and terminates the search when the cost of search exceeds the expected gain of searching further. It is assumed that the individual can determine which of the alternatives so far evaluated has the largest utility and chooses that alternative. The current AMOS prototype operates with this theoretical framework with a hypothetical parameter values. Experiments are being designed to validate this theoretical search termination model and to estimate the parameters.

Statistics Accumulator (Figure 6) performs bookkeeping functions and produces two files. One is a temporary file and contains detailed information about the alternative activity-travel patterns generated for a sample individual in the simulation. This file supports the search process described above. The other file is a permanent file which contains the attributes of the pattern adopted by each sample individual. This file is later accessed by Reporting Module to produce desired statistics and forecasts such as region-wide VMT and mode shares.

5. AMOS PROTOTYPE IMPLEMENTATION

A prototype of AMOS is being developed and implemented in the Washington, D.C., metropolitan area. The implementation effort adopts the Metropolitan Washington Council of Governments (MWCOG) traffic analysis zone (TAZ) system and zone-to-zone network travel time matrices by travel mode. Network skim data are available for: drive alone (SOV), ride-sharing (HOV), public transit with walk access, and public transit with auto access. Travel times by bicycle and walk are estimated by applying assumed speeds (6.5 mph and 2.5 mph, respectively) to the centroid-to--centroid distance. The implementation effort thus utilizes as much spatial and modal information as available from the MWCOG data base. In the future the spatial and temporal resolution of micro-simulation results can be refined by generating synthetic households distributed over the study area.

AMOS Survey: A three-phase survey, using computer-aided telephone interview (CATI) techniques was conducted to generate a data set to calibrate AMOS components. The survey included a *time-use* section which collected data on both in-home and out-of-home activities as well as details of each trip made. Also in the survey was a set of customized stated-preference (or "stated adaptation"[7]) questions which asked respondents how they would respond to each of a set of TDM measures. Adult commuters who commuted at least three days a week were the target of the survey. The three phases of the survey included:

- *Phase 1. Initial CATI*: Screening, commute characteristics, work schedules, demographics and socio-economics, assign travel dates, etc.

- *Phase 2, Mail-out*: Memory joggers, etc.
- *Phase 3, Second CATI*: Time-use survey, customized TDM stated-adaptation questions.

The survey was conducted in November and December of 1994, using both random digit dialing and reverse directories to efficiently obtain an unbiased sample of listed and unlisted telephone numbers. With a Phase-1 response rate of 48% and a Phase-3 rate of 65%, the survey produced a total of 656 completed interviews. Details of the survey design, administration and descriptive analyses of the data, are reported elsewhere.[8]

TDM Measures Considered: In the survey, respondents were given a description of a TDM measure, then asked in an open-ended format "What would you do?" if the measure was in fact implemented. Follow-on questions were asked to probe into details of the stated behavioral adjustment (e.g., how to drop off a child at day-care when public transit is used to commute). Commute travel time and other pertinent parameters were customized such that the hypothetical scenario would closely represent each respondent's commute situation. The TDM measures included in the survey are described in Table 1.

Neural Network: Results of the TDM section were used to train the neural network used in the Response Option Generator. The resulting network consists of 45 input nodes and 8 output nodes with two hidden layers. The input nodes may be grouped as: personal and household attributes, work schedule characteristics, commute characteristics, trip chaining characteristics, mode characteristics, and TDM scenarios. The eight output nodes comprise: change departure time, use transit to work, ride-share to work, ride bicycle to work, walk to work, work at home, do nothing different, and other (long-term responses treated as doing nothing in short-term policy analysis).

Using the AMOS prototype described in this section, analysis is ongoing to evaluate the effectiveness of the TDM measures. Results will be presented at the seminar.

Table 1
TDM Measures Included in the AMOS Survey in the Washington, D.C. Metropolitan Area

TDM 1:	**Parking Tax.** Incremental parking tax at work place at - $1 to $3 per day in suburbs* - $3 to $8 per day in D.C. and central areas
TDM 2:	**Improved Bicycle/Pedestrian Facilities.** Well-marked and well-lighted bicycle paths and a secure place to park a bicycle wherever respondent went.
TDM 3:	**"Synergy" Combination of TDM 1 and TDM 2.**

TDM 4: **Parking Charge Combined with Employer-Supplied Commuter Voucher.** Employers provide employees with a commuter voucher while employees must pay for a parking surcharge.
- $40 to $80 per month for both voucher and surcharge

TDM 5: **Congestion Pricing.** Area-wide implementation of congestion pricing, effective from 6:00 AM to 9:00 AM and from 4:00 PM to 7:00 PM.
- $0.15 to $0.60 per mile
- 10% to 30% travel time savings

TDM 6: **"Synergy" Combination of TDM 4 and TDM 5.**

*Different parameter values are assigned to respondents randomly within the range shown.

6. CONCLUSIONS

This implementation project demonstrates that a micro-simulation model system of daily travel behavior, which adheres to the principles of the activity-based approach, is not only feasible but also serves as a practical tool for policy analysis. The implementation of the AMOS prototype in the Washington, D.C., metropolitan area utilizes the data base maintained by the planning organization of the area. The medium scale survey (about 650 respondents) used in this study can be modified to entertain a wide range of TCM and TDM measures, making AMOS a flexible and realistic tool for transportation policy analysis. Efforts are ongoing currently on several fronts to expand the scope of AMOS by incorporating: vehicle transaction and utilization behavior, vehicle allocation, synthetic generation of households and their activity-travel patterns. Planned research activities include the development and incorporation of models for: search termination, activity engagement, time allocation, inter-person interaction, and multi-day behavior.

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NOTES

[1] See RDC, 1992, 1993, and Kitamura et al., 1993. AMOS is a component of a more comprehensive urban transportation model system, SAMS. See Kitamura et al., 1995.

[2] See, for example, Domencich and McFadden, 1975.

[3] See Jones et al., 1983.

[4] See Kitamura, 1988.

[5] For details, see RDC, 1995, and Pendyala et al., 1995.

[6] See Kitamura, van der Hoorn and van Wijk, 1995.

[7] See Lee-Gosselin, 1995.

[8] See RDC, 1995.

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Figure 1. Activity-Mobility Simulator

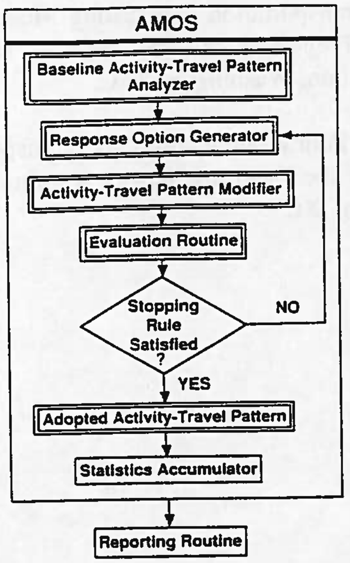


Figure 2. Baseline Activity-Travel Pattern Analyzer

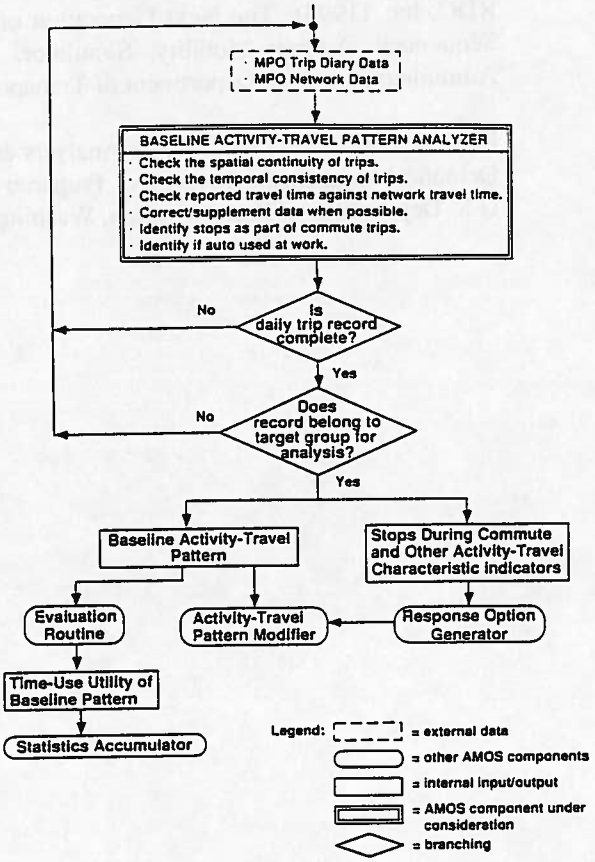
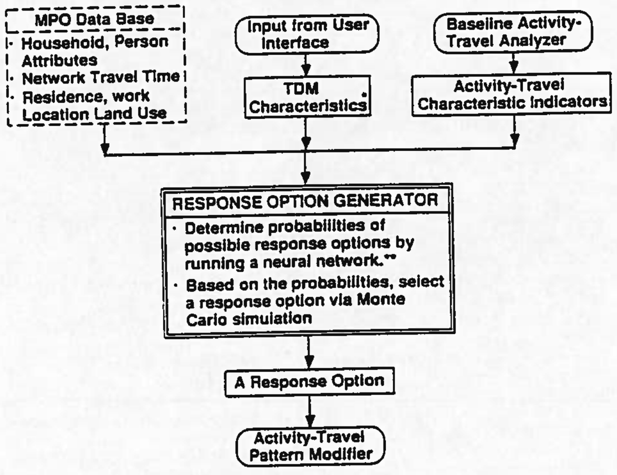


Figure 3. TDM Response Option Generator



- See Table 1 for a description of the TDM measures included in the prototype application

**The response options considered in the prototype include: No Change; Change Work Trip Departure Time; Switch to Transit; Switch to Car/Vanpool; Switch to Bicycle; Switch to Walk; and Work at Home.

Figure 4. Activity-Travel Pattern Modifier

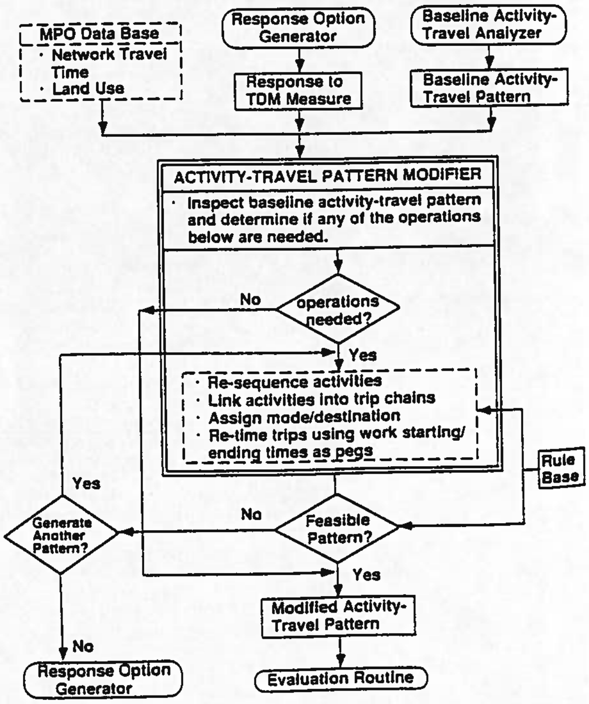


Figure 5. Evaluation and Acceptance (Search Termination) Routines

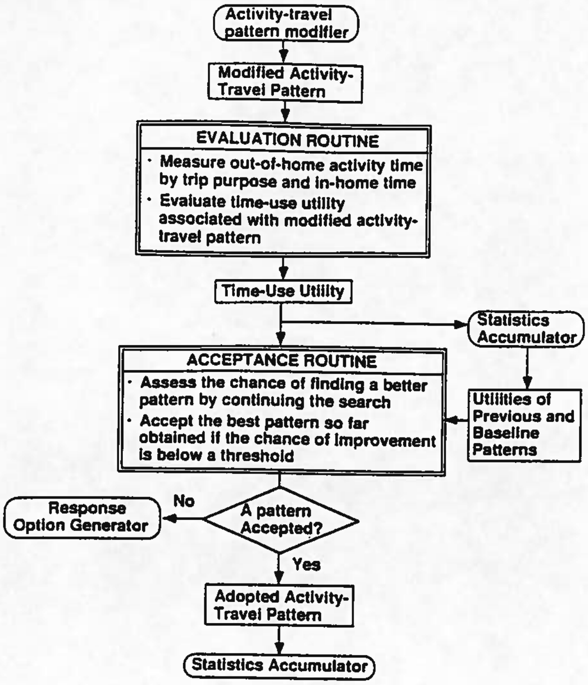
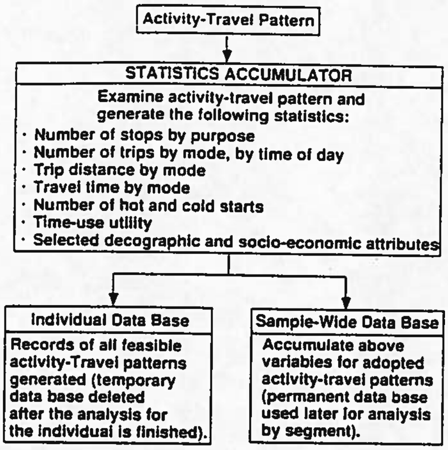


Figure 6. Statistics Accumulator*



* This routine is accessed at several locations in AMOS