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16. Abstract The Comprehensive Econometric Microsimulator for Daily Activity-travel Patterns (CEMDAP) is the micro-simulation implementation of the activity-travel modeling system developed for metropolitan areas. Given various land-use, sociodemographic, activity-system, and transportation level-of-service attributes as input, the system provides as output the complete daily activity-travel patterns for each individual in the sample households. This report describes the software development process. The steps involved in applying CEMDAP to predict activity-travel patterns and to perform policy analysis are also presented. Empirical results obtained from applying the software to the Dallas/Fort Worth area demonstrate that CEMDAP provides a means of analyzing policy impacts in ways that are generally infeasible with the conventional four-step approach.			
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ACTIVITY-BASED TRAVEL DEMAND MODELING
FOR METROPOLITAN AREAS IN TEXAS:
SOFTWARE-RELATED PROCESSES AND
MECHANISMS FOR THE ACTIVITY-TRAVEL
PATTERN GENERATION MICROSIMULATOR

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CHAPTER 1. INTRODUCTION

In the last few decades, activity-based methods of travel demand modeling have emerged as a powerful alternative to the conventional four-step process. Much of the research work in this area has focused on understanding one or more aspects of the activity-travel behavior of people. Efforts aimed at predicting complete travel patterns of people using activity-based methods have been limited (Bowman and Ben-Akiva 2000; Kitamura et al. 1996; Kitamura et al. 2000; Kitamura and Fuji 1998; Kulkarni and McNally 2000, 2001; Arentze et al. 2000).

This research aims to advance the state of the art and practice in daily activity-travel modeling. As part of this research project, a simulation software called the “Comprehensive Econometric Microsimulator for Daily Activity-travel Patterns” (CEMDAP) was developed to implement this prediction mechanism. As the name suggests, CEMDAP is a software implementation of a system of econometric models that represent the decision-making behavior of individuals. The system differs from its predecessors in that it is one of the first to *comprehensively* simulate the activity-travel patterns of workers as well as nonworkers. Given various land-use, sociodemographic, activity-system, and transportation level-of-service attributes as input, the system provides as output the complete daily activity-travel patterns for each individual in the household. From a software engineering point of view, CEMDAP represents a generic library of object-oriented codes that supports rapid implementation of econometric modeling systems for activity-travel pattern generation. The goal of the software development process is to lay the groundwork for the future implementation of a more

complete, long-term forecasting tool that can be easily configured for different study regions.

Detailed descriptions of the representative frameworks for activity-travel patterns, the modeling system embedded in CEMDAP, and the prediction methodologies developed are presented in previous reports. Research report 4080-3 (Bhat et al. 2002) presented the conceptual and analysis frameworks to model the different attributes to completely characterize the daily activity-travel patterns of both workers and non-workers. Results of model estimations for the Dallas/Fort Worth (DFW) metropolitan area were also included. Research Report 4080-4 (Bhat et al. 2003a) presented a framework for using such an estimated modeling system to predict the activity-travel patterns of individuals. Methodologies for the prediction of individual choice instances and the integration of all of the different choices into the complete activity-travel pattern of individuals are also described. This report describes the software development process for CEMDAP, and the steps involved in applying the software to predict activity-travel patterns and perform policy analyses.

The remainder of the report is organized as follows. Section 2 discusses software development issues, including the development paradigm, system architecture, simulation sequence, simulation mechanism, and user interface. Section 3 describes the application of the software in forecasting and policy analysis. Results from the application of the software to the DFW area in Texas are also presented. Section 4 concludes the report.

CHAPTER 2. SOFTWARE DEVELOPMENT

The primary goal of the Comprehensive Econometric Microsimulator for Daily Activity-travel Patterns (CEMDAP) is to produce simulated activity-travel patterns based on the behavioral modeling system outlined in Research Report 4080-4 (Bhat et al. 2003a). As shown in Figure 1, the system takes as input the detailed sociodemographics of individual households (such as the number of adults and kids, number of vehicles, household income, etc.) and their members (for example, age, gender, race, education level, employment status, etc.) and the characteristics of the activity-travel environment for the forecast year (including zonal descriptives such as total population and employment, zonal adjacency, and level-of-service (LOS) variables such as travel times and cost by mode). In addition, CEMDAP requires the user to configure the parameters, within certain limitations, for the underlying econometric models. The econometric models are then applied to simulate the choice behaviors of the households and individuals. The outcome of the simulation is the activity-travel patterns of the individuals. It is envisaged that CEMDAP will be used along with a dynamic traffic assignment software to determine link flows and speeds on the network.

It should be emphasized that the development of CEMDAP goes beyond a once-off implementation of a modeling system calibrated for any specific region. Rather, the software has been developed to meet a number of broader objectives:

1. To provide a friendly user interface with built-in flexibility in the specification of exogenous variables that allows model parameters to be configured for deployment to any study region after appropriate reestimations of the model components using local data.

2. To provide a generic library of routines for microsimulation to support rapid implementation of variants of the modeling system. The variants may be systems of different model hierarchy or models with different econometric structure.
3. To provide a software system in which future modifications, such as the integration with population update and household long-term choice models, can be accommodated easily.

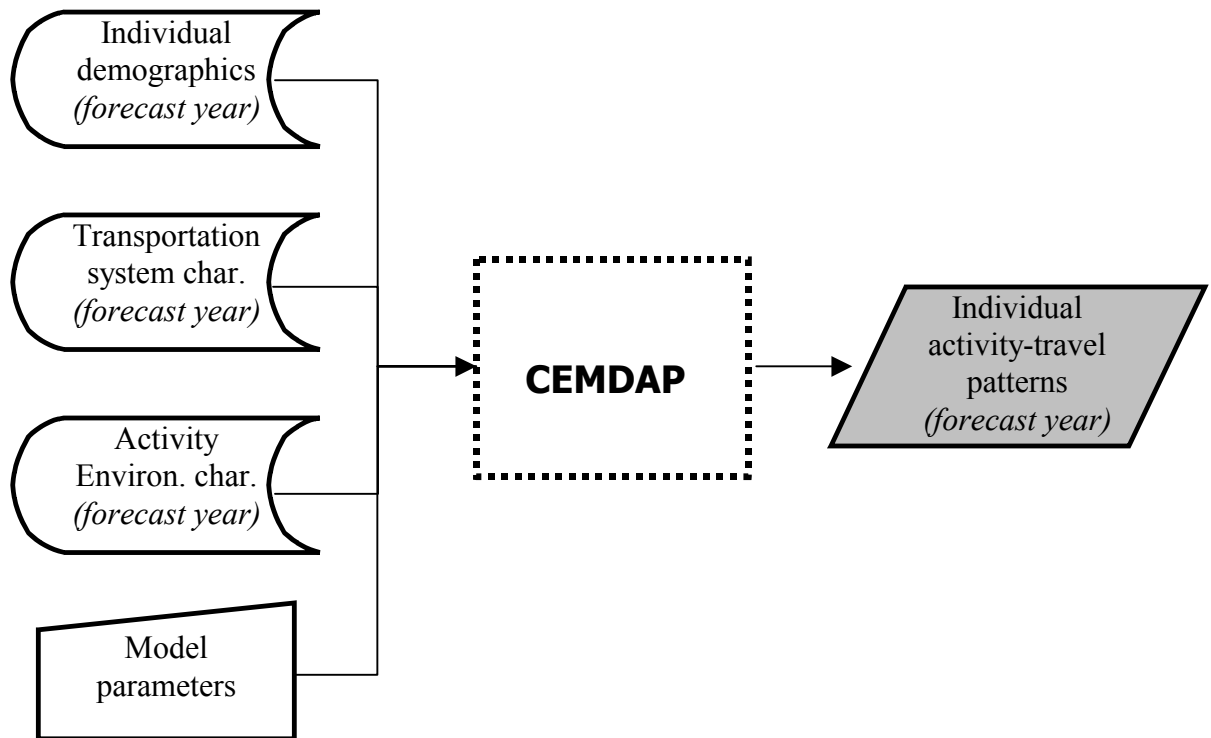


Figure 1. Overview of CEMDAP

Various aspects of the software development efforts are discussed in the following subsections, including the choice of development paradigm, the system architecture, the simulation sequence and mechanism, and the user interface design.

2.1 DEVELOPMENT PARADIGM

There are several software development paradigms currently in use. The two most popular are procedural and object-oriented (OO) paradigms. The procedural paradigm focuses on data flow and is based on performing actions on data. The approach entails three stages: (1) starting with a *structured* analysis, (2) developing a *modular* design, and (3) writing *procedural* programs. Since each stage of the process involves a different technique, the transition from one stage to the next is not direct. Therefore, it is a complex process to determine what parts of the program code are affected by a change in the requirements, and any late requirement changes in the development process are difficult to accommodate.

In contrast to the procedural paradigm, the OO paradigm focuses on *objects* and is based on the data (objects) performing actions on themselves. The OO concept is carried out throughout the development process, so there is no conversion involved in moving from one stage to the next. Consequently, it is relatively easy to accommodate late requirement changes. From this perspective, the OO paradigm better serves our goal of continuing the development of CEMDAP into a more complete, long-term micro-simulator. Additionally, the OO approach is preferred for developing CEMDAP because its fundamental concept of modeling objects parallels the purpose of micro-simulation (i.e., modeling the behavior of actors or objects in the real world).

The complexity typical of simulation systems can be managed by using two fundamental OO techniques: *abstraction* and *encapsulation*. Abstraction is a process that involves identifying the crucial behavior of an object and eliminating irrelevant and tedious details. A well-planned abstraction provides a greatly simplified representation

of the real world from the perspective of the software developer. Abstraction is implemented through encapsulation, which is the mechanism of storing as one cohesive unit the state of an object and the methods that manipulate that object. Encapsulation makes it possible to separate an object's implementation from its behavior, thus restricting access to the object's internal data. This is desirable because, while objects in the real world do not change much, the way in which they behave and interact with each other does. This separation of the *what* from the *how* is another reason that requirement changes are easily accommodated with the OO paradigm (Harrington 1995).

2.2 SYSTEM ARCHITECTURE

Through the process of OO analysis, a number of major entities involved in the micro-simulation of activity-travel patterns have been identified to arrive at the OO design for CEMDAP (Figure 2). The system architecture comprises the input database, data object coordinator, internal data entities, modeling modules, and simulation coordinator. Following is a discussion of these various system components.

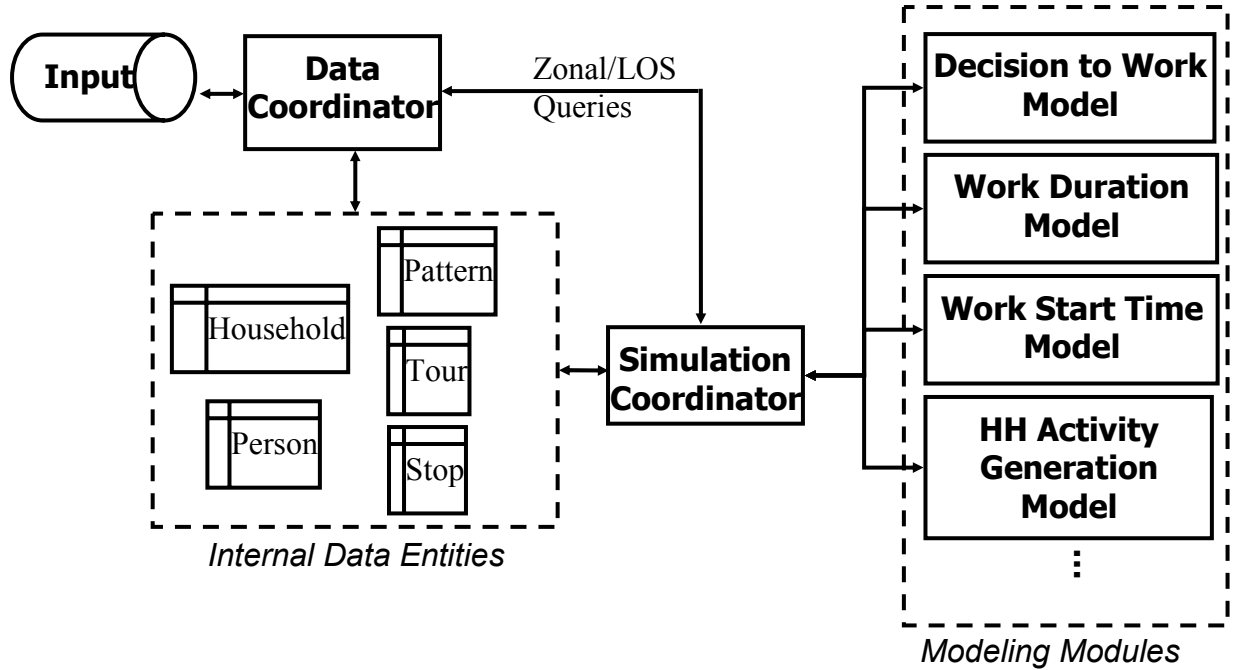


Figure 2. Software Architecture of CEMDAP

2.2.1 Input database

The simulation of activity-travel patterns is a data-intensive exercise. Three sets of data are required: (1) disaggregate socioeconomic characteristics of the population; (2) aggregate zonal-level land-use and demographic characteristics; and (3) zone-to-zone transportation system LOS characteristics by time of day. These input data are organized into a relational database. Through the Open DataBase Connectivity (ODBC) interface, CEMDAP can then access the data from database management systems (DBMS), such as Microsoft Access, to alleviate data management operations within CEMDAP.

2.2.2 Data object coordinator

The data object coordinator is the component responsible for establishing the ODBC with the external database that contains the input data. It extracts the content and structural information of the data tables and converts data into their corresponding

structures as used within CEMDAP. Queries to the database during the process of simulation are handled through the data object coordinator.

2.2.3 Data entities

These are the main data structures that CEMDAP internally operates upon. Instances of household and person entities are created by the data object coordinator from the input data. The remaining entities (i.e., pattern, tour, and stop) are created by the simulation coordinator as required during the simulation process.

2.2.4 Modeling modules

Each modeling module in the system corresponds to a behavioral component model in the framework described in Research Report 4080-4. Although there are many component models, they are derived from a limited number of econometric structures. Currently, six types of econometric models are implemented in CEMDAP as model templates: regression, hazard duration, binary logit, multinomial logit, multinomial logit with probabilistic choice set generation (used exclusively for spatial location choice; Bhat and Misra 2002) and ordered probit models. Additional econometric structures may be added to this library of model templates. Some such structures have been identified in Research Report 4080-4. Each decision variable is associated with an instance of one of these model templates. For example, mode choice is associated with an instance of the multinomial logit modeling module. Once a module is configured through the user interface, it possesses knowledge about the econometric structure and all the relevant parameters required to produce the probability distribution for the given variable. When called upon, the module executes a prediction algorithm to determine the corresponding choice.

2.2.5 Simulation coordinator

The simulation coordinator is responsible for controlling the flow of the simulation. It coordinates the logic and sequence in which the modeling modules are called. Data entities are created and manipulated as the corresponding choice outcomes are predicted. The simulation coordinator also performs any required consistency checks.

2.3 SIMULATION SEQUENCE

CEMDAP takes a sequential approach to simulating the activity-travel patterns of individuals. The simulation logic embedded in the simulation coordinator is depicted in Figure 3, where each iteration corresponds to the simulation of one household. During each iteration, the input data for a particular household and all of its adult members are loaded into the system. The generation-allocation model system is first applied to the household. The scheduling model systems are then applied to each of the household adults, with the workers processed before the non-workers. Application of a scheduling system involves the sequential application of its three components: the pattern-level subsystem, the tour-level subsystem, and the stop-level subsystem. Once the simulation is complete for the given household, the activity-travel patterns of the household members are recorded before the next household is processed.

A possible alternative to the proposed simulation sequence is one in which each model component is applied to the complete subset of persons making the corresponding choice. Such an approach would need a programming environment that supports efficient matrix manipulations. We choose not to adopt this process for three reasons:

(i) Given our problem's context, the subset of people making any particular choice will be very large and, hence, the process may be extremely demanding in terms of memory.

(ii) The proposed simulation sequence is more amenable to parallel processing techniques, which may be a serious consideration when attempting to apply CEMDAP to large populations consisting of several million individuals.

(iii) We envision enhancements to CEMDAP to accommodate interactions among household members in scheduling (for example; joint tours). This would require ensuring consistency across travel patterns of members within the household. Our approach can handle such intra-household interactions more efficiently.

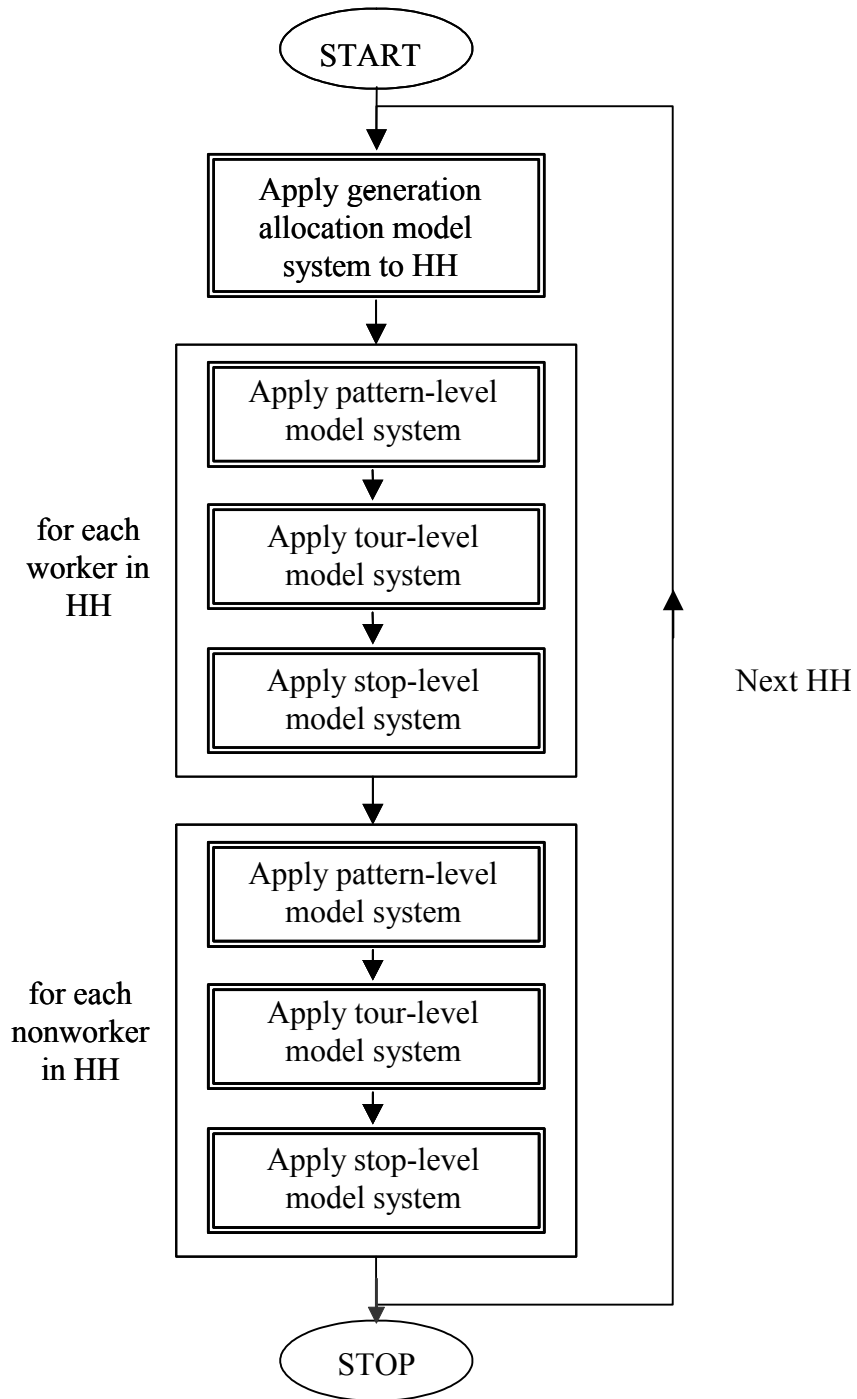


Figure 3. Sequential Simulation of Households and Individuals within Households

2.4 SIMULATION MECHANISM

In the preceding discussion on simulation sequence, the phrase ‘application of a modeling system’ refers to the process of stepping through each of the modeling module instances in the system to predict the corresponding choice outcome. There are two aspects to the prediction process: the determination of each individual decision instance (i.e., each component model) and the integration of the different decision instances into one final activity-travel pattern.

A simple approach to predicting individual decision instances involves selecting the alternative with the highest utility for each of the model components with discrete outcomes. Continuous choice variables may be assigned the expected value predicted by the model. An alternate approach is to develop a full decision tree where the probabilities of all the alternatives are carried over to the root node of the decision tree. The chosen set of alternatives can be subsequently determined by extracting the path with the highest path probability in the decision tree. The relative merits and demerits of each of these approaches is discussed in detail in Research Report 4080-4.

The simulation mechanism adopted in CEMDAP eliminates the bias of the simplistic approach while avoiding the computational complexity of the decision-theoretic approach. It differs from the decision-theoretic approach in that the choice outcome from each model is uniquely determined and carried over to the next model component. In the case of discrete choices, the chosen alternative is determined through a random draw from a pseudo sample containing all the alternatives in proportion to their probabilities as predicted by the corresponding model (detailed methods for different kinds of econometric models are presented in Research Report 4080-4). This eliminates

the systematic bias problem found in the simplistic approach because each alternative appears in the pseudo sample in proportion to its probability of being chosen (Bhat and Misra 2001). For the continuous choice instances, the choice is determined by a random draw from the probabilistic distribution of the choice variable defined by the associated econometric model. Thus, it is ensured that the chosen continuous outcome is not the same for all observationally similar decision makers.

The appropriate process for determining the choice outcomes is embedded within each of the five model types supported by CEMDAP. We use the combined multiple recursive random number generator (L'Ecuyer 1999) to generate the uniform random variates needed for simulation.

2.5 USER INTERFACE

The main interface for CEMDAP is a MS Windows framework (Figure 4) with menu items that provide a means of accessing various functions of the software, i.e., loading the input database, specifying paths for the output files, loading/saving or configuring models, and running the simulator.

Accessible through the menu are a set of model editors. There is one model editor corresponding to each of the model components in the activity-based travel analysis framework. The editors allow the user to configure the model specifications. The information collected in the editors is passed on to the corresponding modeling modules. In order for the system to “remember” model configurations from one run to the next, the information collected from the model editors can be saved into an ASCII file, which is loaded into the system whenever required.

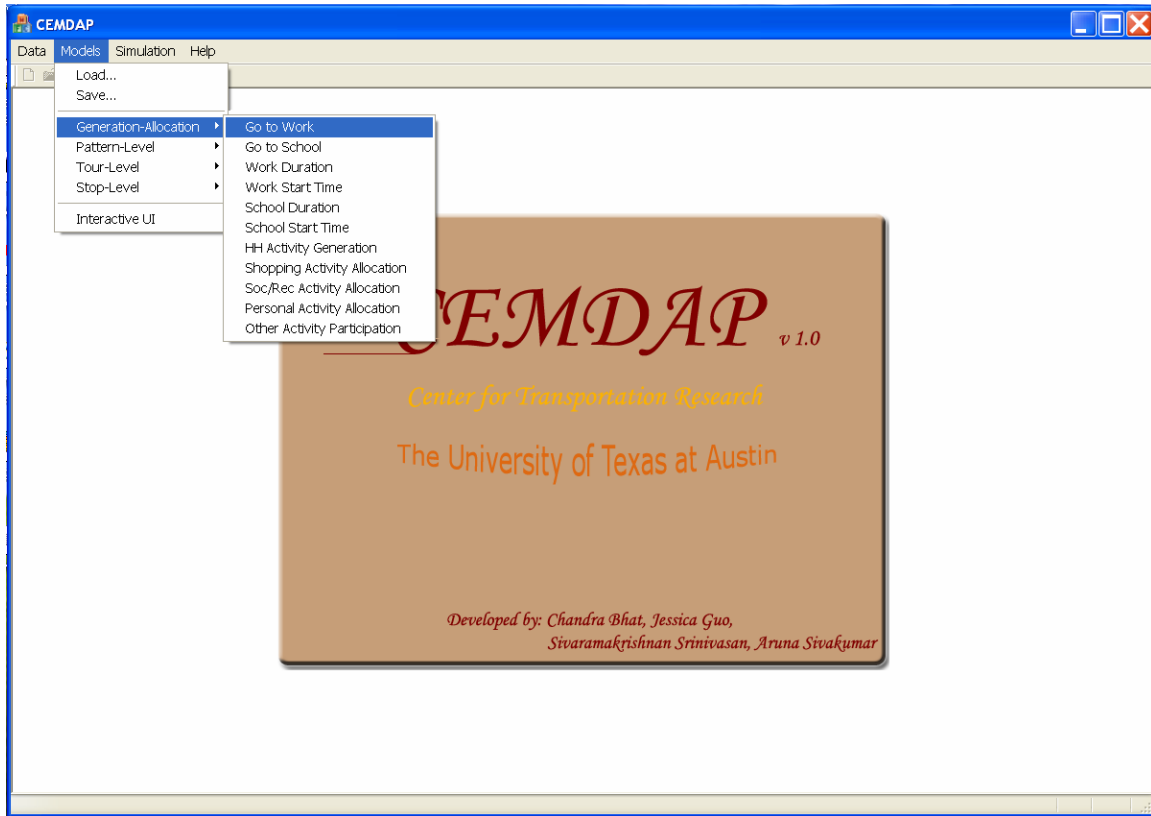


Figure 4. Screenshot of CEMDAP User Interface

The main menu of the software also provides a user-friendly diagrammatic interface composed of dialog boxes and buttons that guides the user through the model configuration process. This interface ties up the model editors using the micro-simulation framework.

2.6 DEVELOPMENT PLATFORM

CEMDAP was developed using Visual C++ programming language within the Visual Studio .NET development platform. The software can run on MS Windows-based systems, including Windows NT 4, Windows 2000, and Windows XP.

CHAPTER 3. SOFTWARE DEPLOYMENT

In the following subsections, we first present an overview of the different steps involved in running the software, and its application to the Dallas/Fort Worth (DFW) metropolitan area. This is followed by a discussion of policy evaluations using the Comprehensive Econometric Microsimulator for Daily Activity-travel Patterns (CEMDAP) and a case study.

3.1 PREDICTING ACTIVITY-TRAVEL PATTERNS USING CEMDAP

Three major steps are involved in predicting activity-travel patterns using CEMDAP. First, all of the different model components that constitute the overall modeling framework must be estimated for the study region using local travel survey data. The model parameters then must be input into the simulator using the software's graphical user interface and saved to a model configuration file. Second, the necessary input data must be prepared. This input data is in the form of an MS Access database with one table for each of household, person, zonal, and level-of-service (LOS) data in the planning year, and one table for the static interzonal descriptives, such as adjacency. The user manual accompanying the software details the format of the input data. The LOS data may be specified at any level of temporal resolution (i.e., it is not restricted to only "peak" and "off-peak" measures). In the third and final step, the simulation is actually run after loading the model parameters and the input database into the software using the graphical user interface. The output from the micro-simulator is in the form of predicted activity-travel patterns for all the individuals. This is written out to six prespecified ASCII files. Table 1 presents the structure of the output files. These ASCII

files may be easily ported into a relational database software, such as MS Access, or a statistical software, such as SPSS, and analyzed. The complete activity-travel string of each person can actually be reconstructed using the output files.

Table 1. Output File Formats

HOUSEHOLDS.OUT

Column No.	Description
1	Household identification number
2	Number of workers in household
3	Household makes shopping activity
4	Household makes social/recreational activity
5	Household makes personal activity

PERSONS.OUT

Column No.	Description
1	Household identification number
2	Person identification number
3	Person goes to work on the day
4	Person makes shopping activity
5	Person makes social/recreational activity
6	Person makes personal activity
7	Person makes other activity

WORKERS.OUT

Column No.	Description
1	Household identification number
2	Person identification number
3	Work duration
4	Work start time
5	Worker makes a Before-Work tour
6	Worker makes a Between-Work tour
7	Worker makes a After-Work tour
8	Total number of tours made

NONWORKERS.OUT

Column No.	Description
1	Household identification number
2	Person identification number
3	Total number of tours made

TOURS.OUT

Column No.	Description
1	Household identification number
2	Person identification number
3	Tour identification number
4	Home stay start time
5	Home stay duration
6	Tour mode
7	Tour duration
8	Number of stops in tour
9	Available tour time
10	Available home stay time

STOPS.OUT

Column No.	Description
1	Household identification number
2	Person identification number
3	Tour identification number
4	Stop identification number
5	Activity type
6	Start time
7	Travel Time to stop
8	Stop duration
9	Available stop time
10	Available travel time
11	Stop location (zone ID)
12	Location of origin zone (zone ID)

3.1.1 DFW Application

We have used hypothetical, small samples derived from the DFW survey in testing and studying policy evaluation applications using CEMDAP. Figure 4 is the activity-travel string of a nonworker reconstructed from the output files of one of the test runs, and presented on a Geographic Information System (GIS) map of the DFW area. The simulator predicts that the individual makes one multiple-stop tour during the course of the day, starting from home at 7:30 a.m. and reaching her first stop at 8:20 a.m., where she spends 56 minutes undertaking personal business. She arrives at her next stop at 9:40

a.m. and spends an hour and 57 minutes on personal business, and finally arrives back home at 12:30 p.m.

Currently, we are developing CEMDAP for use in predicting complete activity-travel patterns for the DFW metropolitan area. Model parameters have been estimated for the complete modeling system, input in the software, and saved in a model configuration file. Detailed input data has also been prepared. The zonal and LOS tables were prepared using data provided by the North Central Texas Council of Governments (NCTCOG). Complete individual and household sociodemographics of the population of the DFW area for the year 2000 has been synthesized using synthetic population generation techniques. An internal technical document (Bhat et al. 2003b) describes the process of preparing the input population data for CEMDAP. Work on fine-tuning the software for speed and efficiency for large-scale processing is underway. Actual simulation runs for the entire population of the DFW metropolitan area will be undertaken shortly.

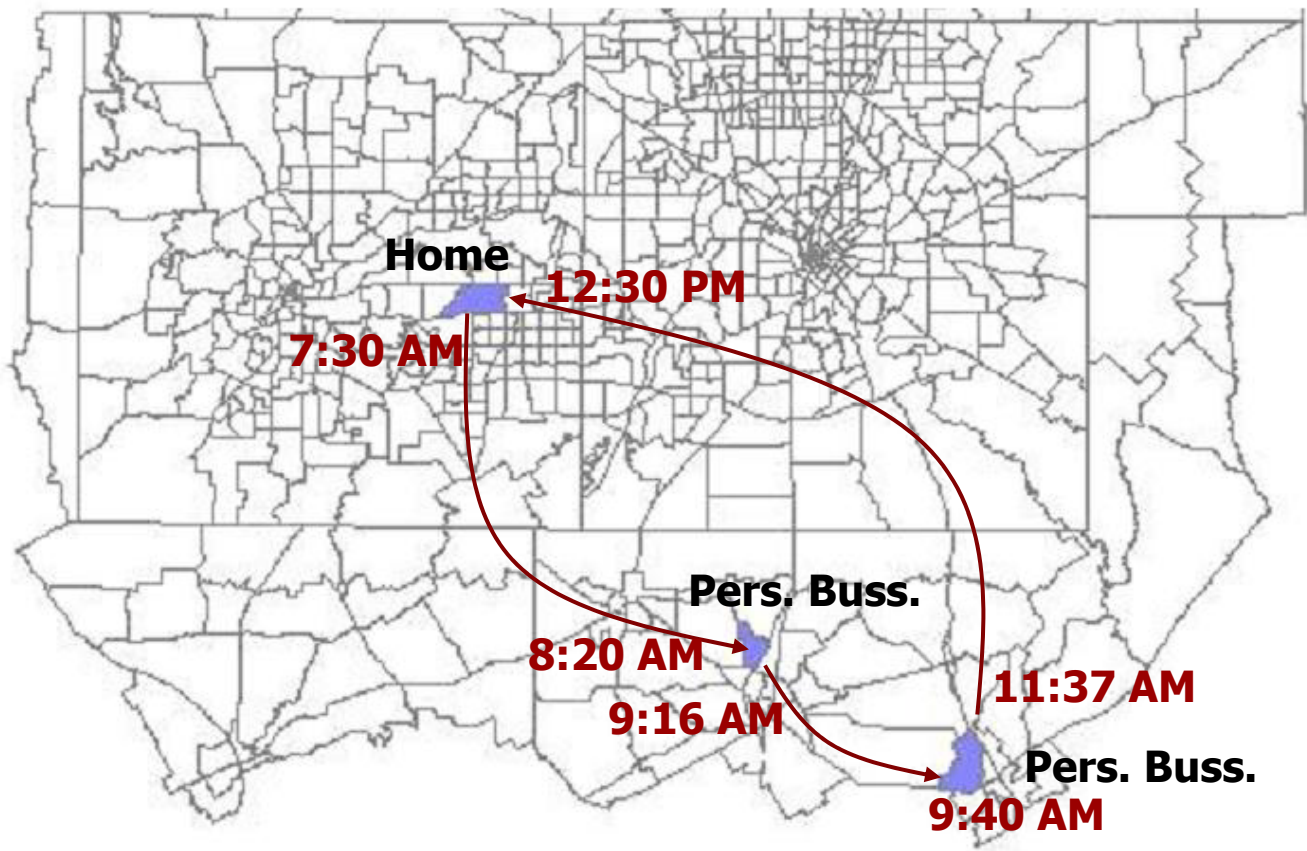


Figure 5. Predicted Activity-travel Pattern of a Nonworker: Multiple Stop Tour

3.2 POLICY TESTING

The previous section described the steps involved in using CEMDAP to simply predict the activity-travel patterns of a population. CEMDAP can be used further to assess the impact of various Transportation Control Measures (TCMs) and policy scenarios (including noncapital improvement measures such as ridesharing incentives, congestion pricing, and employer-based demand management schemes) on the activity-travel characteristics of the population. This is achieved by comparing the simulated patterns for the base case against those for the proposed scenario in which the appropriate TCM has been implemented. Generally, most TCMs can be implemented in CEMDAP using one or more of the following methods: (a) modifying input data such as land-use, LOS, or individual characteristics (e.g., work flexibility); (b) using externally calibrated models with different explanatory variables or different sensitivities to existing variables; or (c) modifying the software code to achieve either random or rule-based constraints of decisions.

3.2.1 Case Study

An application of CEMDAP to policy testing is illustrated in this section by predicting the activity-travel choices of a worker and studying the effects of an employer-based demand-management strategy that releases this person from work earlier than usual. The econometric models required for CEMDAP were estimated using the 1996 DFW travel survey data, and a hypothetical data set was assembled for a single individual.

Implementation of the chosen TCM requires simple modifications to the code to constrain the decisions related to work start and end times. For all simulations runs, the

work start-time was fixed at 8 a.m. The work end-time was fixed at 5 p.m. for the base-case simulations, and at 2:30 p.m. for the policy scenario. Fifty simulation runs were made each for the base case and the policy case.

Table 2. Frequency of Generation of Different Patterns for the Base Case and Policy Case

Pattern	Base Case	Policy Case
H → W → H No stops	21	16
H → W → S → W → S → H Work-based tour and stop(s) in work to home commute	13	11
H → W → S → W → H Only work-based tour	6	3
H → W → H → S → H Only after-work tour	3	5
H → W → S → H Stop(s) only in the work to home commute	1	9
All other patterns	6	6

Key: **H** : Home; **W** : Work; **S** : Stop(s)

The frequency of generation of the different activity-travel patterns for the base case and policy case is presented in Table 1. In both scenarios, the simplest pattern (travel to work and back with no activity stops) is found to be the most likely pattern. However, when released early from work, the person is more likely to undertake activity

stops, as indicated by a decrease in the number of patterns with *no* stops (16 in the policy case versus 21 in the base case). The most likely pattern with one or more activity stops has a work-based (WB) tour in addition to stop(s) during the work-to-home commute. The tendency to make WB tours decreases in the policy case when compared to the base case (refer to the second and third patterns), presumably owing to the decreased time available when at work. Finally, one observes a greater tendency to make stops during the later part of the day (i.e., during the work-to-home commute or as an after-work tour; refer to the fourth and fifth patterns) in the policy case, perhaps as a consequence of an “increased” availability of time.

It is also useful to examine changes to the work-to-home commute characteristics in detail, as the policy action has the most direct impact on this part of the worker’s overall activity-travel pattern. In the base case, 40% of the patterns generated had one or more stops during the work-to-home commute. The percentage increases to 52% in the policy case. Thus, if a person is released early from work, there is a greater likelihood of his/her making stops during the work-to-home commute.

The average work-to-home commute duration for the cases with *no* stops during the commute, is lower during the policy case when compared to the base case (31.49 minutes during the policy case versus 41.63 minutes during the base case). This is intuitive, as the travel from work to home is made during the peak period in the base case, whereas it is made during the off-peak period in the policy case. On the other hand, the average commute duration for cases with stops during the commute is greater for the policy case (158.27 minutes) when compared to the base case (144.48 minutes). It is to be noted here that the commute duration includes both the travel time and the time spent at activity

stops. In this experiment, the average time spent in activity participation during the work-to-home commute was not found to be significantly different across the base and policy cases (approximately 66 minutes in each case). However, the travel times were found to be longer during the policy case, suggesting travel to more distant locations.

Additionally, in the base case, the most common activity type predicted to be undertaken during the work-to-home commute is “personal business.” In the policy case, however, other “miscellaneous” activity types were found to be as likely as “personal business.” Thus, the increased travel durations and differences in the activity types strongly suggest that spatial attributes of travel when released early from work could be significantly different from that of the base case.

In summary, the experiment demonstrates that an employer-based demand management strategy like early release from work can significantly impact the overall activity-travel patterns of workers. Specifically, such a strategy could lead to the increased likelihood of undertaking stops after work, possibly entailing travel to more distant locations. Hence, it is erroneous to assume that the original patterns simply will be translated back in time. This study highlights the importance of explicitly accommodating temporal constraints and time-of-day effects in modeling activity-travel choices.

CHAPTER 4. CONCLUSION

This report provides an overview of the software development of the Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns (CEMDAP), a micro-simulator designed to comprehensively model the daily activity-travel patterns of individuals, including both workers and non-workers. The simulator implements a predefined econometric modeling system that represents choice behavior, but no model parameters calibrated for any specific region are hardwired in the system. Instead, CEMDAP is a flexible tool that can be configured to any study region with the required, available input data and model parameters. The system generates as output the predicted activity-travel patterns for all individuals in the simulation sample. Traffic assignment methods can be applied to determine travel demand patterns on the network. By adjusting input data, modifying model parameters, or imposing explicit choice constraints within the program, policy analysts can employ CEMDAP to assess the impact of various Transportation Control Measures (TCMs).

This report also presented a demonstration study that predicts the activity-travel patterns of a worker using model parameters estimated for the Dallas/Fort Worth (DFW) area in Texas. A simulation experiment was performed to study changes to these patterns as a consequence of an employer-based demand management strategy. The results clearly indicate significant changes to the overall activity-travel behavior of a worker as a consequence of early release from work, thereby highlighting the need to explicitly account for temporal constraints and time-of-day effects in modeling travel choices. Moreover, the exercise demonstrates that an activity-travel micro-simulator such as

CEMDAP allows policy actions to be analyzed in ways generally infeasible with the conventional four-stage modeling approach.

The current demonstration experiment was performed at a disaggregate level, studying the activity-travel choices of a single individual. Such studies can also be extended to the entire population. For this purpose, the research team has already generated a synthetic population for the DFW area for the year 2000 and has assembled all required input data files. Experiments on simulating the travel patterns for the entire population and studying impacts of policy actions at an aggregate level will be undertaken shortly.

The development of CEMDAP is an ongoing effort and the system will be enhanced in several directions. First, new modeling modules that represent interdependent choice behavior and joint decision making will be developed as alternatives to existing modules. Second, additional user interface will be incorporated to aid the analysis of specific (commonly encountered) policy actions. Third, CEMDAP will be integrated with a dynamic traffic assignment software to predict link flows and speeds by time of day. Fourth, research is currently underway to incorporate modeling components within CEMDAP that simulate population evolution and long-term household choices, as well as those of businesses and firms. The incorporation of these additional components will produce a complete micro-simulator that accounts for land-use and transportation interaction at the disaggregate level.

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