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16. Abstract This report describes the enhancement of the earlier version of CEMDAP (the activity-travel simulator that simulates the detailed activity-travel patterns of the population), the development of CEMSELTS (the system that updates the socio-demographic characteristics of the population for a time increment into the future), and the design and implementation of the SPG (the population synthesizer that creates a disaggregate representation of the population at the beginning of the simulation run).		
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ACTIVITY-BASED TRAVEL-DEMAND MODELING FOR METROPOLITAN AREAS IN TEXAS: CEMSELTS MODEL ESTIMATIONS AND PREDICTION PROCEDURES, 4874 ZONE SYSTEM CEMDAP MODEL ESTIMATIONS AND PROCEDURES, AND THE SPG SOFTWARE DETAILS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Conventional wisdom has long indicated that demographics, land use, and transportation are intimately linked. While demographics represent the characteristics of decision makers and land use represents the spatial pattern of urban development and activities, transportation serves as the mechanism for spatial interaction between geographically dispersed activity sites. Recognizing these linkages among demographics, land use, and transportation is important for realistic forecasts of travel demand. To achieve this, the current research project develops a demand forecasting approach that captures land-use and travel behavior in an integrated way while accommodating the moderating role of individuals' demographic characteristics. This behavioral approach entails integrating activity-based travel models with disaggregate models that capture the population demographic processes, the households' long-term choice behaviors, and the economic markets in which the households act (see Report 6 for more detailed description).

The proposed activity-based land-use transportation modeling system is labeled CEMDAP-II (Second Generation Comprehensive Econometric Microsimulator of Daily Activity-Travel Patterns). As depicted in Figure 1.1, CEMDAP-II takes as input the aggregate socio-demographics and the activity-travel environment characteristics for the base year as well as different policy scenarios for future years. The aggregate socio-demographic data are first run through the Synthetic Population Generator (SPG) to create a disaggregate representation of all individuals and households in the study area. The activity-travel simulator, CEMDAP, then takes the disaggregate data as input and produces as output the detailed activity-travel characteristics for each individual. These then feed into a traffic microsimulator to determine the network link flows and speeds by time of day. The evolution of the population and the urban environment is modeled by the Comprehensive Econometric Microsimulator for Socioeconomics, Land-Use, and Transportation System (CEMSELTS). Taking as input the current socio-demographics and activity-travel characteristics, prescribed policy actions, and level of service characteristics obtained from the traffic microsimulator, CEMSELTS provides as output socio-demographic characteristics of the population and the attributes of the activity-travel environment for a time increment into the future (e.g., one year). This information feeds back into the activity-travel simulator (CEMDAP) to obtain the detailed activity-travel characteristics for the future year. The loop is executed until the link flows and speeds are obtained for the forecast year specified by the analyst. The effects of the prescribed policy actions can then be evaluated based on the simulated network flows and speeds for any year between the base year and the forecast year.

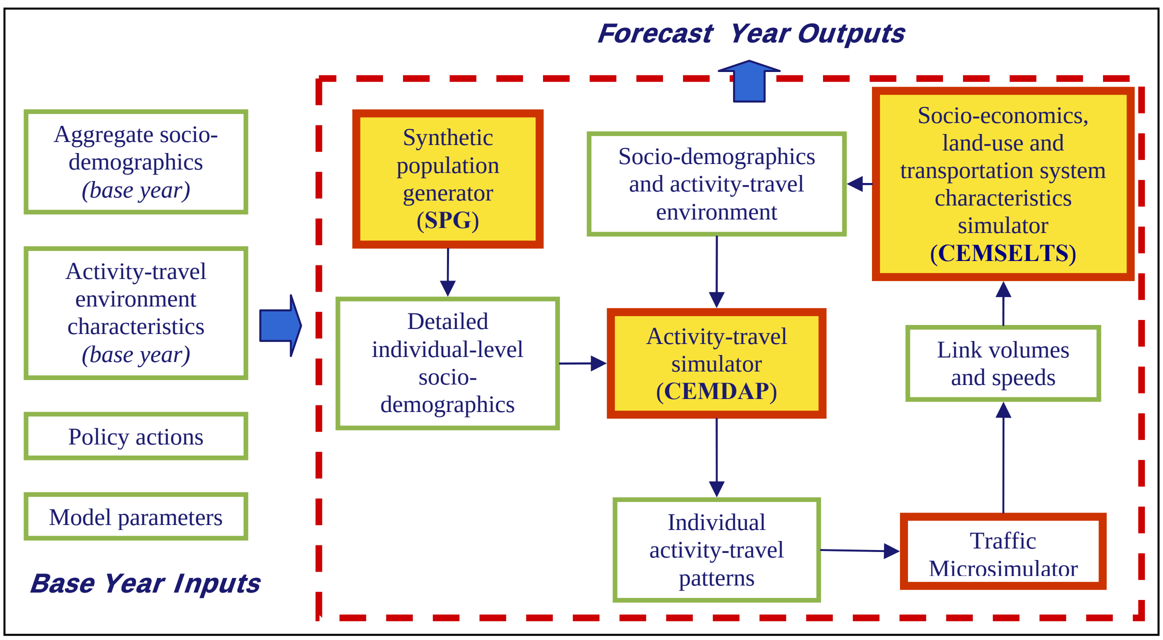

Figure 1.1 The structure of CEMDAP II

Within the overall framework of this research effort, the focus of the current report is on the enhancement to the earlier version of CEMDAP, the development of CEMSELTS, and the design and implementation of the SPG. The report is organized as follows. Chapter 2 discusses the modifications made to CEMDAP for accommodating a finer spatial resolution, children's activity-travel, and intra-household interactions. Chapter 3 presents details of the empirical models estimated for CEMSELTS and the procedure for applying these models for demographic forecasting. Chapter 4 discusses the problem of, and the methodology for, population synthesis and describes the development of SPG. Chapter 5 provides the summary and conclusions.

2. ENHANCED CEMDAP SYSTEM

This chapter describes the new econometric modeling system embedded within the latest version of CEMDAP. This new modeling system enhances the previous system in several ways. First, the new system is developed at a finer spatial resolution and applied to a 4874 zone system for the Dallas/Fort-Worth (DFW) area in Texas. Second, the activity-travel patterns of children (persons under 16 years of age) are now explicitly modeled and forecasted. Third, the interdependencies between the travel patterns of children and their parents (such as escort to and from school and joint participation in discretionary activities) are explicitly accommodated. Finally, for estimation of the models, the raw survey data obtained for the DFW area were re-processed to create a larger sample and all the model components (over fifty in all) were re-estimated. It should be noted here that the design and architecture of CEMDAP is generic; CEMDAP can be applied to any metropolitan area, as long as local area models are estimated to produce the appropriate sensitivity parameters. Currently, we have estimated all the CEMDAP models using the DFW data, and the resulting parameters are embedded in CEMDAP as default parameters. Moreover, the user can use the graphical interface of CEMDAP to modify the parameters if local area parameters are available. CEMDAP has been designed to provide a friendly diagrammatic interface to help the user understand the logic of the system.

The remainder of this chapter is organized as follows. Section 2.1 describes the representation frameworks developed to define the complete activity-travel patterns of individuals. Specifically, this section identifies all the choice elements that are predicted within CEMDAP to completely characterize the activity-travel patterns of all household members, including both adults and children. Section 2.2 is focused on the econometric modeling system. The empirical model estimation results are presented in Appendix A. Section 2.3 describes the data used in the empirical model estimations. The data sources are identified and the data cleaning procedure are used to produce the estimation sample is described briefly. Finally, Section 2.4 describes, in detail, the procedure implemented within CEMDAP for using the set of models described in Section 2.2 for predicting the complete activity-travel patterns (as defined in Section 2.1) of all household members.

2.1 Representation Frameworks

This section describes the representation frameworks developed to describe the activity-travel patterns of individuals. The purpose of developing the frameworks is to identify the complete set of attributes that is required to characterize an individual's activity-travel pattern for a given day. The simulation of an individual's activity-travel pattern then entails computing a predicted value for each of these attributes based on the underlying econometric models.

Broadly, the activity-travel pattern of an individual is defined as the sequence of activities and travel pursued during a day. Among all the different activities that an individual undertakes during the day, the work and school activities are undertaken under the greatest space-time constraints for most individuals. Also, participation in these activities significantly influences an individual's participation in all other activities during the day. Consequently, separate representations have been developed to define the daily activity-travel patterns of the workers, students, non-workers, and non-students. The workers and students include adults (persons aged 16 years or more) who go to work or school and children (persons aged 15 years or less) who go to school. The non-workers and non-students, on the other hand, include adults who neither go to work nor attend school during the day as well as children who do not go to school during the day. For ease of discussion, in the remainder of this section, we will use the term "workers" to represent the workers and students and "non-workers" to represent the non-workers and non-students. Similarly, the term "work" will be used generically to refer to either work or school as appropriate.

The representation frameworks for workers and non-workers are discussed in detail in Sections 2.1.1 and 2.1.2, respectively. In both frameworks the start of the day is defined as 3:00 a.m. and all individuals are assumed to be at home at this time.

2.1.1 Representation for the Activity-Travel Pattern of Workers

The daily pattern of workers is characterized by four different sub-patterns: before-work pattern, which represents the activity-travel undertaken before leaving home to work; commute pattern, which represents the activity-travel pursued during the home-to-work and work-to-home commutes; work-based pattern, which includes all activity and travel undertaken from work; and after-work pattern, which comprises the activity and travel behavior of individuals after arriving home at the end of the work-to-home commute. Within each of before-work, work-based, and after-work patterns, there might be several tours. A tour is a circuit that begins and ends at home for the before-work and after-work patterns and is a circuit that begins and ends at work for the work-based pattern. Each tour, the home-to-work commute, and the work-to-home commute may include several activity stops. An activity stop is characterized by the type of activity undertaken, in addition to spatial and temporal attributes. Figure 2.1 provides a diagrammatic representation of the worker activity-travel pattern.

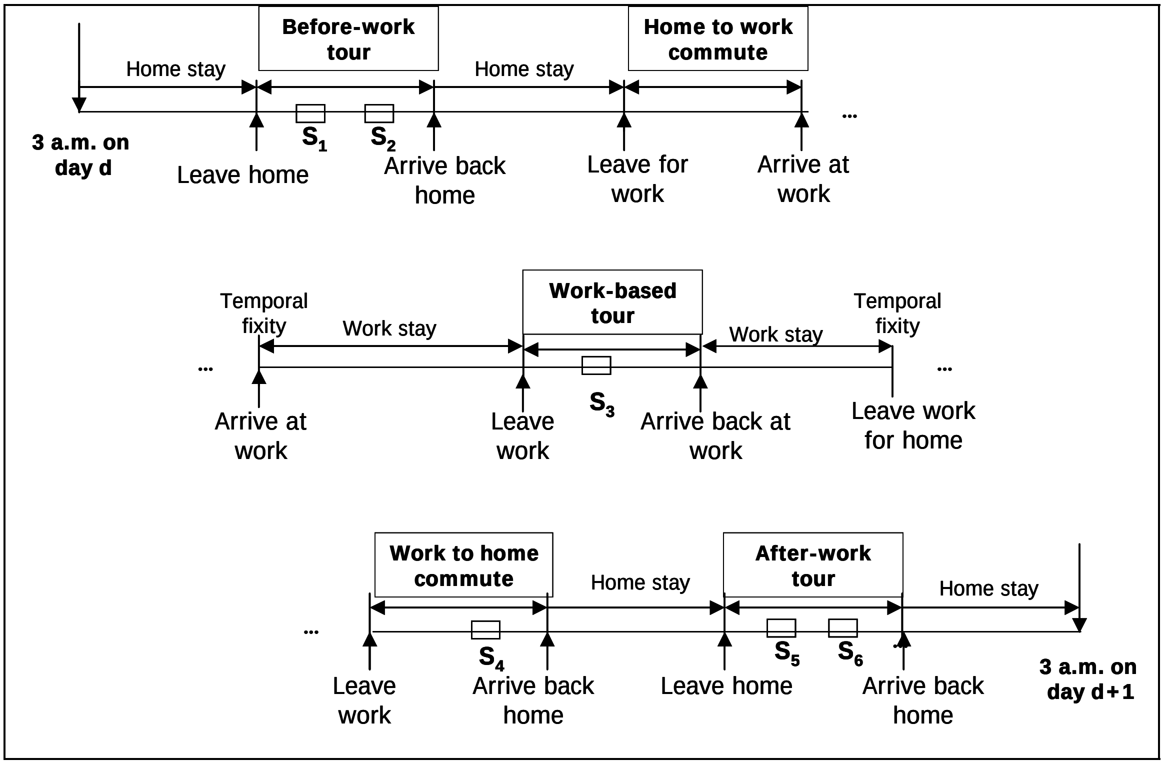

Figure 2.1 A representation for the activity-travel patterns of workers

The characterization of the complete workday activity-travel pattern is accomplished by identifying a number of different attributes. The **primary attributes** that characterize the pattern of a worker are the start and end times of the work activity. The remaining attributes may be classified based on the level of representation that they are associated with, that is, whether they are associated with a pattern, a tour, or a stop. **Pattern-level attributes** include the travel mode, number of stops, and the duration for each of the work-to-home and home-to-work commutes in addition to the number of tours that the worker undertakes during each of before-work, work-based, and after-work periods. **Tour-level attributes** include travel mode, number of stops, home-stay duration (or work-stay duration, in the case of the work-based tour) before the tour, and the sequence of the tour within the before-work, work-based, or after-work periods. After-work tours can also be pursued jointly by a parent and a child in the household. This distinction (i.e., independent versus joint tour) is also captured as a tour-level attribute. **Stop-level attributes** include activity type, duration of the activity, travel time to stop, location, and sequence of stops in a commute. In the case of adults, if the activity type is escort of children to and from school, then the child being escorted is explicitly identified.

The representation described above is generic and can be used to describe any complex activity-travel pattern (i.e., any number of stops sequenced into any number of tours). Considering practical implementation constraints, certain restrictions are imposed on the maximum number of tours and the maximum number of stops in any tour. In the case of adults who go to work or school, CEMDAP is designed to handle up to two tours during each of the before-work, work-based, and after-work periods, and up to five stops during any tour or commute. In the case of schoolgoing children, CEMDAP accommodates non-school activity participation of children only during the school-to-home commute and the after-school period. Further, only a single tour with one stop is supported for the after-school period.

2.1.2 Representation for the Activity-Travel Patterns of Non-Workers

In the case of non-workers, the activity-travel pattern is considered as a set of out-of-home activity episodes (or “stops”) of different types interspersed with in-home activity stays. The chain of stops between two in-home activity episodes is referred to as a tour. The pattern is represented diagrammatically in Figure 2.2.

A non-worker’s daily activity-travel pattern is characterized by several attributes, which can again be classified into pattern-, tour-, and stop-level attributes. The only **pattern-level attribute** is the total number of tours that the person decides to undertake during the day. The **tour-level attributes** are the travel mode, the number of stops in the tour, the home-stay duration before the tour, and the sequence of the tour in the day. Tours can also be pursued jointly by a parent and a child in the household. This distinction (i.e., independent versus joint tour) is also captured as a tour-level attribute. **Stop-level attributes** include activity type, duration of the activity, travel time to stop, location, and the sequence of stops in a tour. In the case of adults, if the activity type is escort of children to and from school, then the child being escorted is explicitly identified.

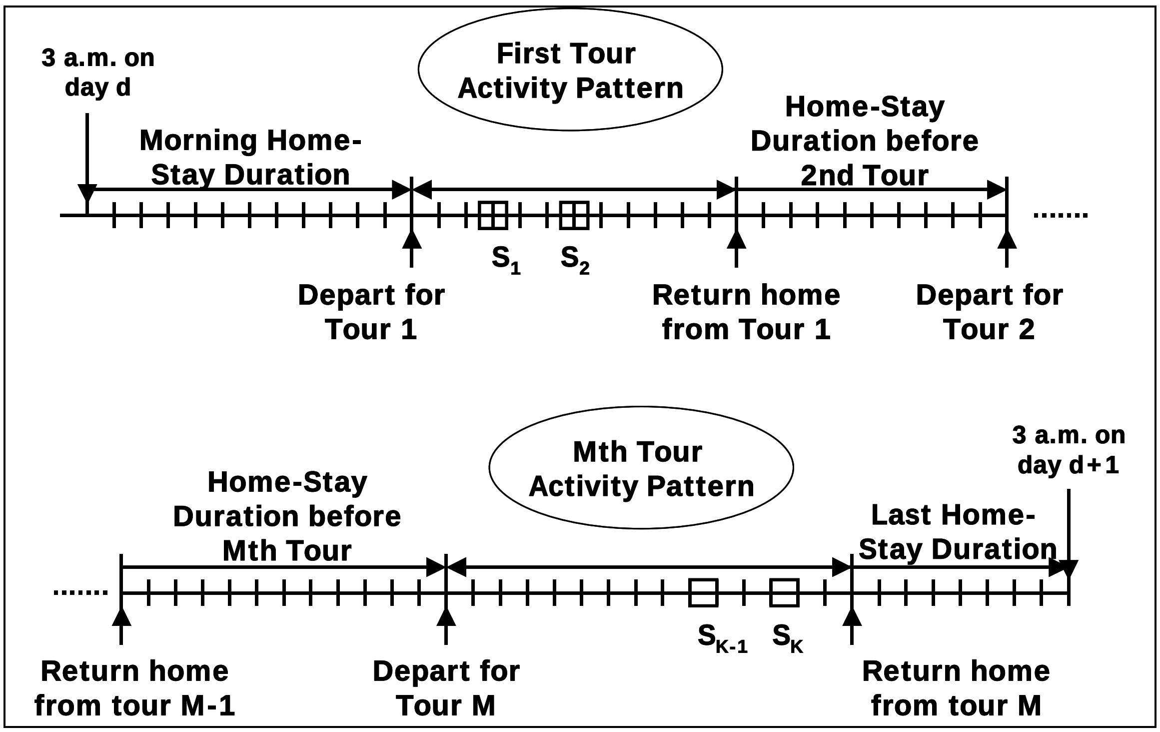

Figure 2.2 A representation for the activity-travel patterns of non-workers

The representation described above is generic and can be used to describe any complex activity-travel pattern (i.e., any number of stops sequenced into any number of tours). Considering practical implementation constraints, certain restrictions are imposed on the maximum number of tours and the maximum number of stops in any tour. In the case of non-workers who are adults, CEMDAP is designed to handle up to a total of four tours and up to five stops during each tour.

In summary, the CEMDAP representation frameworks provide a comprehensive description of the overall daily activity-travel patterns of workers and non-workers. However, there are two primary areas for future improvements. First, CEMDAP is limited in its representation of “tag-along” activities and travel pursued by children with their parents. Specifically, if a child is simply traveling along with a parent and accompanying the parent in all his or her activities, such activity-travel is not explicitly captured within the representation frameworks. Second, CEMDAP is also limited in accommodating the joint activity and travel participation of two or more household members (adults and children). Enhancements in these areas will benefit from improved travel survey methods that elicit information on the joint activity-travel participation characteristics of adults and children.

2.2 Econometric Modeling System

This section identifies all the model components that constitute the overall modeling system implemented within CEMDAP. Each model corresponds to the determination of one or more of the attributes characterizing the activity-travel pattern of a worker or a non-worker. Together, the set of all models identified in this section can be used in a systematic fashion to completely characterize the activity-travel patterns of all individuals in a household. (This systematic procedure is described in Section 2.4.) These models have to be estimated and the parameters provided as inputs in order to use CEMDAP for activity-travel predictions. The empirical model results estimated using travel survey data from the DFW region are presented in Appendix A (the data used for model estimations are discussed in Section 2.3).

The overall modeling system is broadly subdivided into the following five categories: (1) the generation-allocation model system (Table 2-1), (2) the worker scheduling model system (Table 2-2), (3) the non-worker scheduling model system (Table 2-3), (4) the joint discretionary tour scheduling model system (Table 2-4), and (5) the children scheduling model system (Table 2-5). The reader precise econometric structure and the choice alternatives are identified for each of the models in Tables 2-1 through 2-5. Further, there is a unique identifier associated with each model. (For example, "GA1" identifies the first model within the "generation-allocation" category, which is the decision of a child to go to school.) To facilitate easy cross-referencing, these identifiers have also been included in the figures presented in Section 2.4 (which describe the prediction procedure) as well as in Appendix A (where the empirical results are presented).

Table 2-1 The generation-allocation model system

Model ID	Model Name	Econometric Structure	Choice Alternatives
GA1	Children's decision to go to school	Binary logit	Yes, No
GA2	Children's school start time (time from 3 AM)	Hazard-duration	Continuous time
GA3	Children's school end time (time from school start time)	Hazard-duration	Continuous time
GA4	Decision to go to work	Binary logit	Yes, No
GA5	Work start and end times	MNL	528 discrete time period combinations
GA6	Decision to undertake work related activities	Binary logit	Yes, No
GA7	Adult's decision to go to school	Binary logit	Yes, No
GA8	Adult's school start time (time from 3 AM)	Regression	Continuous time
GA9	Adult's school end time (time from school start time)	Regression	Continuous time
GA10	Mode to school for children	MNL	Driven by parent, Driven by other, School bus, Walk/bike
GA11	Mode from school for children	MNL	Driven by parent, Driven by other, School bus, Walk/bike
GA12	Allocation of drop off episode to parent	Binary logit	Father, Mother
GA13	Allocation of pick up episode to parent	Binary logit	Father, Mother
GA14	Decision of child to undertake discretionary activity jointly with parent	Binary logit	Yes, No
GA15	Allocation of the joint discretionary episode to one of the parents	Binary logit	Father, Mother
GA16	Decision of child to undertake independent discretionary activity	Binary logit	Yes, No
GA17	Decision of household to undertake grocery shopping	Binary logit	Yes, No
GA18	Decision of an adult to undertake grocery shopping given household undertakes it	Binary logit	Yes, No
GA19	Decision of an adult to undertake household/personal business activities	Binary logit	Yes, No
GA20	Decision of an adult to undertake social/recreational activities	Binary logit	Yes, No
GA21	Decision of an adult to undertake eat out activities	Binary logit	Yes, No
GA22	Decision of an adult to undertake other serve passenger activities	Binary logit	Yes, No

Table 2-2 The worker scheduling model system

Model ID	Model Name	Econometric Structure	Choice Alternatives
WSCH1	Commute mode	MNL	Solo driver, Driver with passenger, Passenger, transit, Walk/bike
WSCH2	Number of stops in work to home commute	Ordered probit	0,1,or 2
WSCH3	Number of stops in home to work commute	Ordered probit	0,1,or 2
WSCH4	Number of after-work tours	Ordered probit	0,1,or 2
WSCH5	Number of work-based tours	Ordered probit	0,1,or 2
WSCH6	Number of before-work tours	Ordered probit	0 or 1
WSCH7	Tour mode	MNL	Solo driver, Driver with passenger, Passenger, and walk/bike
WSCH8	Number of stops in a tour	Ordered probit	1,2,3,4, or 5
WSCH9	Home/work stay duration before a tour	Regression	continuous time
WSCH10	Activity type at stop	MNL	Work-related, Shopping, Household/personal business, Social/recreational, Eat out, and Other seve passenger
WSCH11	Activity duration at stop	Regression	Continuous time
WSCH12	Travel time to stop	Regression	Continuous time
WSCH13	Stop location	MNL	Probabilistic generation of choice alternatives from all 4874 zones

Table 2-3 The non-worker scheduling model system

Model ID	Model Name	Econometric Structure	Choice Alternatives
NWSCH1	Number of independent tours	Ordered probit	1,2,3,or 4
NWSCH2	Decision to undertake an independent tour before the pick-up or joint discretionary tour	Binary logit	Yes, No
NWSCH3	Decision to undertake an independent tour after the pick-up or joint discretionary tour	Binary logit	Yes, No
NWSCH4	Tour mode	MNL	Solo driver, Driver with passenger, Passenger, and walk/bike
NWSCH5	Number of stops in a tour	Ordered probit	1,2,3,4, or 5
NWSCH6	Number of stops following a pick-up/drop-off stop in a tour	Ordered probit	0,1,2, or 3
NWSCH7	Home stay duration before a tour	Regression	Continuous time
NWSCH8	Activity type at stop	MNL	Work-related, Shopping, Household/personal business, Social/recreational, Eat out, and Other seve passenger
NWSCH9	Activity duration at stop	Regression	Continuous time
NWSCH10	Travel time to stop	Regression	Continuous time
NWSCH11	Stop location	MNL	Probabilistic generation of choice alternatives from all 4874 zones

Table 2-4 The joint discretionary tour scheduling model system

Model ID	Model Name	Econometric Structure	Choice Alternatives
JSCH1	Departure time from home (time from 3 AM)	Regression	Continuous time
JSCH2	Activity duration at stop	Regression	Continuous time
JSCH3	Travel time to stop	Regression	Continuous time
JSCH4	Location of stop	MNL	Pre-determined subset of the 4874 zones

Table 2-5 The children scheduling model system

Model ID	Model Name	Econometric Structure	Choice Alternatives
CSCH1	School to home commute time	Regression	Continuous time
CSCH2	Home to school commute time	Regression	Continuous time
CSCH3	Mode for independent discretionary tour	Binary logit	Drive by other, Walk/bike
CSCH4	Departure time from home for independent discretionary tour (time from 3 AM)	Regression	Continuous time
CSCH5	Activity duration at independent discretionary stop	Regression	Continuous time
CSCH6	Travel time to independent discretionary stop	Regression	Continuous time
CSCH7	Location of independent discretionary stop	MNL	Pre-determined subset of the 4874 zones

2.3 Data

This section discusses the data used for the estimation of all the model components identified in Section 2.2. The sources of the data are discussed first (Section 2.3.1), followed by a brief discussion of the data cleaning procedure to generate the estimation sample (Section 2.3.2).

2.3.1 Data Sources

The data used in the estimation of all the model components were obtained from three main sources: (1) the 1996 DFW household activity survey, (2) the DFW zonal land-use database, and (3) the DFW inter-zonal transportation level of service data. All three data sets were acquired from the North Central Texas Council of Governments (NCTCOG). Each of these three major data components are described below.

2.3.1.1 1996 DFW household activity survey

The data from the 1996 DFW household activity survey are available as four separate files: (1) household file, (2) person file, (3) vehicle file, and (4) activity file. The household file contains the location of each household, the housing type, tenure, and several socio-economic characteristics (such as household size and household income). The person file has socio-demographic characteristics such as age, gender, ethnicity, education level, and employment status for each person from the households that responded to the survey. For employed individuals, work location, work schedule characteristics, and income levels are available. The vehicle file contains information on the characteristics of each vehicle owned by the households. The activity file contains sequential information on all the activities pursued by the surveyed individuals on their diary day. Each data record in this file provides information for one particular activity. The available information includes the type of activity (one of about thirty different categories such as home, work, school, shopping, and pick-up), location, start time, and end time. For travel activities, data on the mode (e.g., driver of a vehicle, passenger in a vehicle, transit, and walk) are available.

2.3.1.2 DFW zonal land-use database

The DFW zonal land-use file provides information on several characteristics of each of the 4,874 zones (61 of which are external stations) in the DFW area including total population, number of households, median income, basic employment levels, service employment levels, retail employment levels, and the acreage by land-use purposes (including water area, park land, roadway, office, retail, etc.). In addition, this database identifies the zones with "special" land use, such as airports, hospitals, colleges, and major shopping malls. Finally, the parking costs for zones in the Dallas and Fort-Worth CBDs are also provided. In addition, the GIS layer of the zone boundaries was processed using a geographic information system (GIS) to identify the set of zones which are adjacent (i.e., share a boundary) to each of the 4,874 zones.

2.3.1.3 DFW inter-zonal transportation level of service data

The DFW inter-zonal transportation level of service (LOS) file provides information on several LOS characteristics for each of the highway and transit modes, and between every pair of zones (4,874 * 4,874 zonal pair combinations in all) in the DFW region. The LOS characteristics provided for the highway mode include distance, and in-vehicle and out-of-vehicle travel times for each of the a.m. peak, p.m. peak, and off-peak periods. The LOS characteristics provided for the transit mode include in-vehicle and out-of-vehicle travel times, means of accessibility to the transit stop, and the number of transfers for each of the peak and off-peak periods.

2.3.2 Sample Formation

The original raw survey data provide over 119,000 activity records for 10,607 persons from 4,641 households. Each of the household, person, vehicle, and activity files were subject to preliminary cleaning and consistency checks. If critical information (such as age, employment status, work location, school location) of one or more household members was missing, then such households were removed from further analysis. The activity records of the persons in households without any missing information were processed to generate a trip file. In this trip file, each record corresponds to a trip which is characterized by the start and end times, the start and end locations, the activity types at the origin and the destination, and the travel mode. Again, if a substantial amount of travel information was missing or inconsistent for one or more household members, then such households were removed from further analysis. The only exception to the above rule was when the missing information was activity locations. Specifically (and unlike in the development of models for the previous version of CEMDAP), households were not discarded if the location information was missing for one or more trips of its constituent members. Discarding such households would have resulted in a substantial reduction of the sample size. The implication of this approach is that our sample for the estimation of models for location choice decisions is smaller than the sample for the estimation of all other activity-travel decisions.

Several attributes of the activity-travel patterns (such as the commutes, the tours, and the identification of the tours to which each trip and stop belongs) that are not directly reported in the surveys were derived from the overall sequence of trip records for each person. Finally, the travel patterns of the parents and children were matched to identify (1) the discretionary activities pursued jointly and (2) the pick-up and drop-off activities undertaken by parents to escort children to and from school.

The final estimation data set comprises about 23,000 activity-travel records for 6,166 persons from 2,750 households. Of these 6,166 persons, 1,253 are children and 4,913 are adults. Of the 1,253 children, 939 (75 percent) are students. Of the 4,913 adults, 3,152 (64 percent) are employed, 413 are students (8.5 percent), and the rest are unemployed, retired, or homemakers.

2.4 Prediction Procedure

This section describes the micro-simulation procedure implemented within CEMDAP for using the set of models identified in Section 2.2 for predicting the complete activity-travel patterns of all individuals in a household. This procedure is repeatedly applied to each household in the input synthetic population to completely determine the activity-travel patterns of all individuals in the study area. The overall prediction procedure (for a household) can be subdivided into two major sequential steps: (1) the prediction of activity generation and allocation decisions and (2) the prediction of activity scheduling decisions. The first step predicts the decisions of household members to pursue various activities such as work, school, shopping, and escort of children during the day. This step is described in detail in Section 2.4.1. The second step predicts the sequencing of these activities, accommodating the space-time constraints imposed by work, school, and escort of children activities. This step is described in detail in Section 2.4.2. The mathematical procedures to predict the choice outcomes from various econometric models such as the multinomial logit, ordered probit, hazard duration model, and linear regression have been presented in Research Report 4080-4.

2.4.1 Prediction of Activity Generation and Allocation Decisions

The prediction of activity generation and allocation decisions comprises the following three sequential steps: (1) the generation of work and school activity participation, (2) the generation of children's travel needs and allocation of escort responsibilities to parents, and (3) the generation of independent activities for personal and household needs. Each of these steps is discussed in further detail below.

2.4.1.1 Generation of work and school activity participation

Decisions regarding work and school activities are predicted as the first activity generation decisions because these are pursued with significant regularity and also impose constraints on participation in all other activities during the day. This prediction step is presented schematically in Figure 2.3. For each child in the household who is a student, the decision to go to school and the timing (i.e., start and end times) are first determined. Next, the decision of employed adults to go to work during the day and the timing of the work activity are determined. These decisions of the adults may also be influenced by the need to take care of non-schoolgoing children at home during the day. Consequently, the work participation decisions of adults are modeled subsequent to the decisions of children to go to school. The locations of the school and work are exogenous to the CEMDAP modeling system, but are modeled and determined separately in an earlier step. Employed adults may also choose to undertake work-related activities. These are different from the main work activity in that the location of these activities is not predetermined. Finally, the school participation and timing decisions of each adult who is a student are determined. (Adults are exogenously classified into one of the following three categories: employed, student, or unemployed.) Adults who decide to undertake either work or school activities during the day are classified as "workers" and the other adults are classified as “non-workers.” For the rest of the prediction procedure, the term “work” will be used to refer to either a work or school activity of an adult as appropriate.

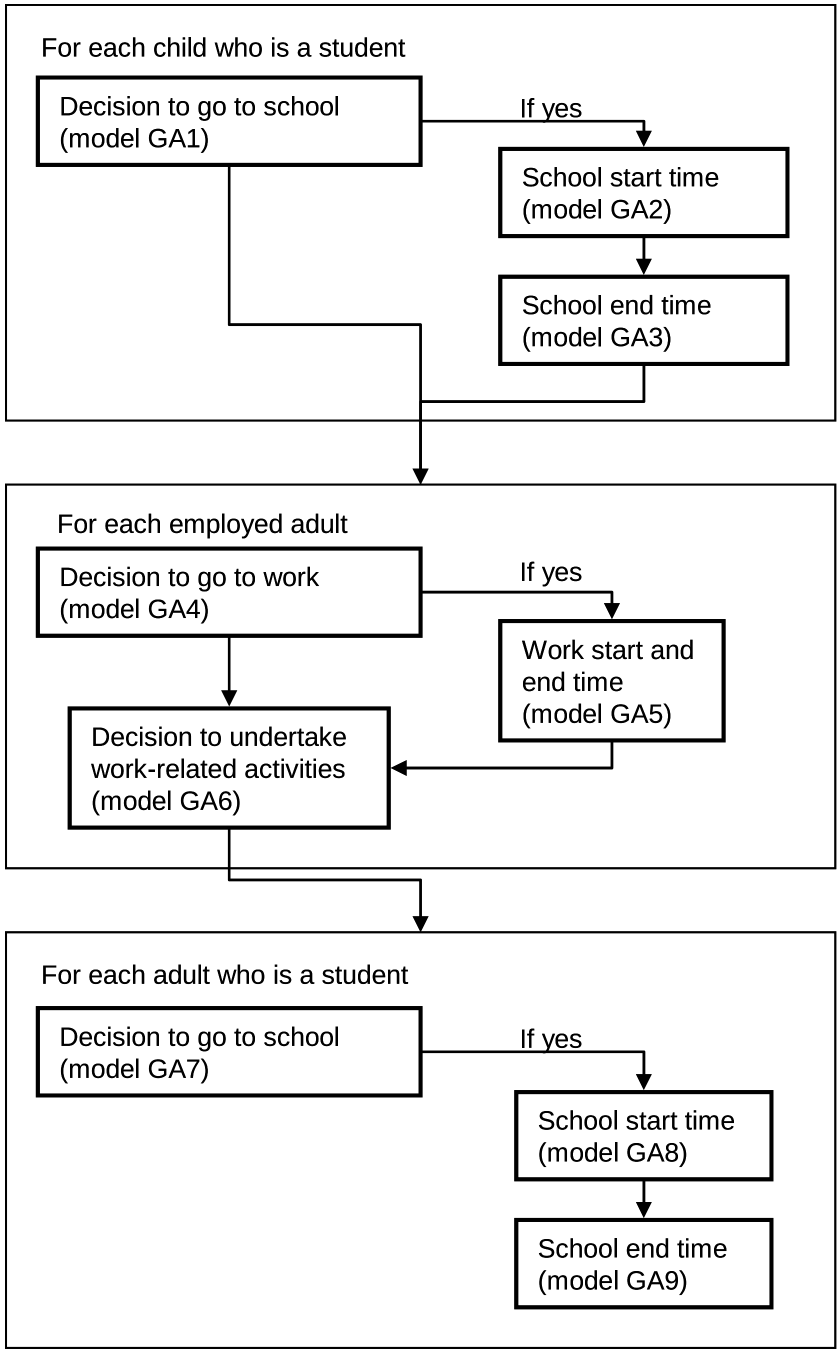

Figure 2.3 The generation of work and school activity participation

2.4.1.2 Generation of children's travel needs and allocation of escort responsibilities to parents

The second major step in the prediction of the generation-allocation decisions involves the children's travel needs (Figure 2.4). In this step, the children's travel mode to and from school are first determined. The travel mode can be one of "drive by parent", "drive by other", school bus, and walk or bike. For children driven to and from school by a parent, the escort responsibilities have to be allocated to the parents. For children in single-parent households, this allocation is trivial as there is only one parent. For children in nuclear family households (i.e., a male-female couple with children), each of the pick-up and drop-off responsibilities is allocated to either the mother or the father. The reader will note that the framework assumes that there is at most one episode each of pick-up and drop-off activities. (However, multiple children may be picked up or dropped off in a single episode.) It was necessary to impose this restriction based on data limitations. Specifically, the estimation data set did not provide data to develop models to accommodate multiple pick-up and drop-off episodes (as might be required in households with many children who go to different schools). It is also to be noted that the interdependencies between children and parents are not explicitly captured in more complex households (i.e., households other than those of the single-parent or nuclear-family types), again due to data limitations. Nonetheless, since single-parent and nuclear-family are the most common types of households with children, we believe that this is not a serious limitation. If any escort responsibility is allocated to a worker, then the work start and end times of this person are suitably updated to ensure feasibility of the escort activity. (Based on empirical analysis of the DFW travel survey data, we assume that escort activities undertaken by workers are pursued during the commute.)

In addition to going to school, children may also pursue discretionary activities (such as visiting friends and sports events) jointly with a parent. The next two model components in this overall second step determine these joint discretionary activity participation decisions of children, along with the parent participating in the joint discretionary activity. The chosen parent escorts the child to and from the activity and also participates in the activity jointly with the child. The reader will note two implied assumptions: (1) there is at most one joint discretionary episode (even if there are multiple children in the household), and (2) only one of the parents undertakes discretionary activities jointly with children. These assumptions can be relaxed if more data on the travel patterns of households with children are available.

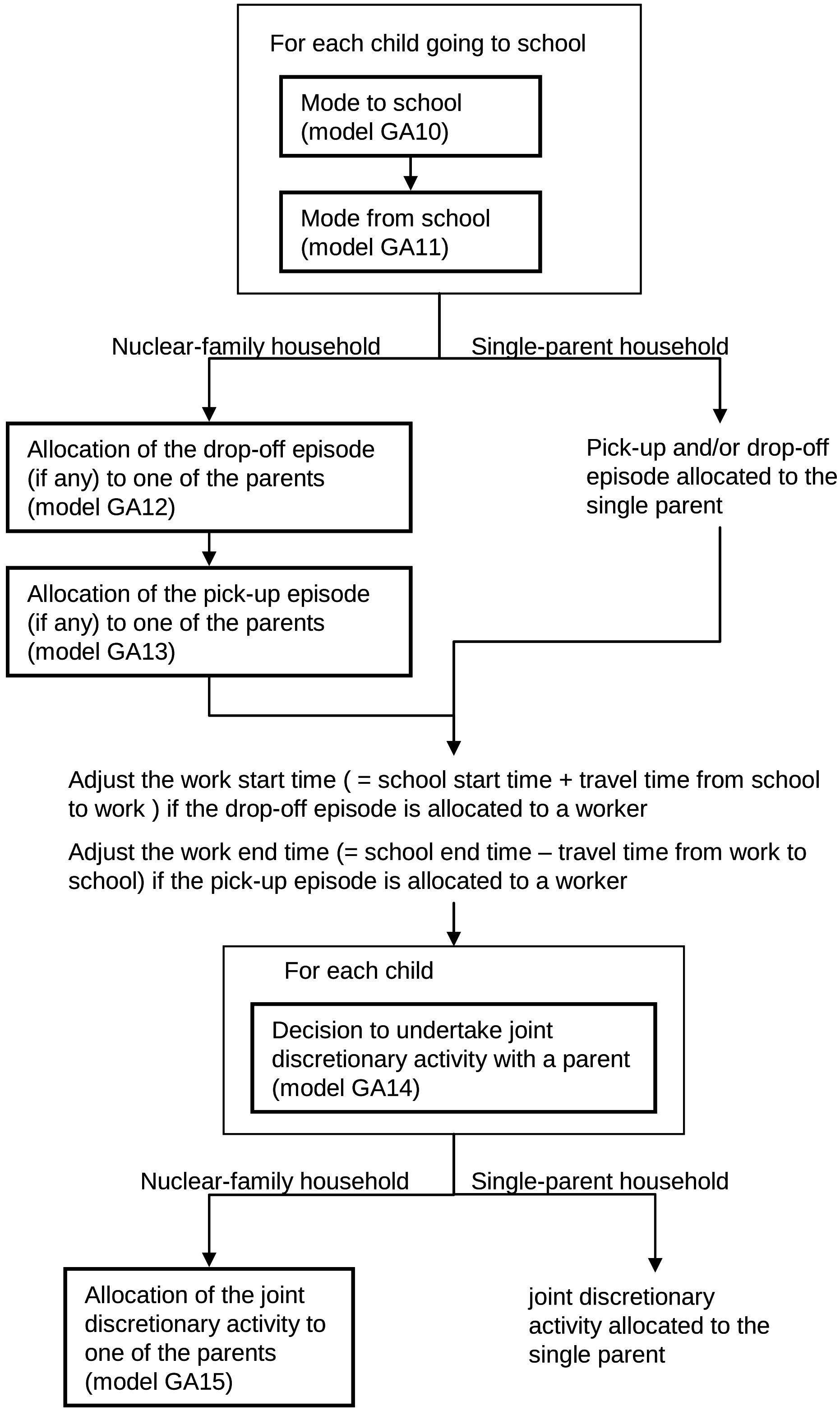

Figure 2.4 The generation of children's travel needs and allocation of escort responsibilities to parents

2.4.1.3 Generation of independent activities for personal and household needs

The third and final step in the prediction of activity generation and allocation involves decisions about independent activity participation (Figure 2.5). These independent activities may be pursued for personal needs (for e.g., recreation) or for household needs (grocery shopping). Children's decisions to undertake independent discretionary activities are determined first. For these activities, the children are not escorted by household members. Next, the household's decision to undertake grocery shopping during the day is determined. Conditional on the household deciding to shop for groceries during the day, the shopping responsibility is allocated to one or more adults in the household. The next three model components in this step determine the decisions of household adults to undertake independent activities for (1) household or personal business (such as banking), (2) social activities or recreation (such as visiting friends or going to the movies), and (3) eating out. The final model component determines the decision of adults to undertake "other serve-passenger activities." These are pick-up or drop-off activities pursued by adults other than the trips for escorting children to and from school. The person(s) being served in this case may be either household members or non-members. A more rigorous treatment of these "other serve-passenger" episodes to explicitly accommodate additional interpersonal interactions is identified as a potential area of future work. Such efforts will benefit substantially from travel-survey improvements that explicitly collect data about the persons being served.

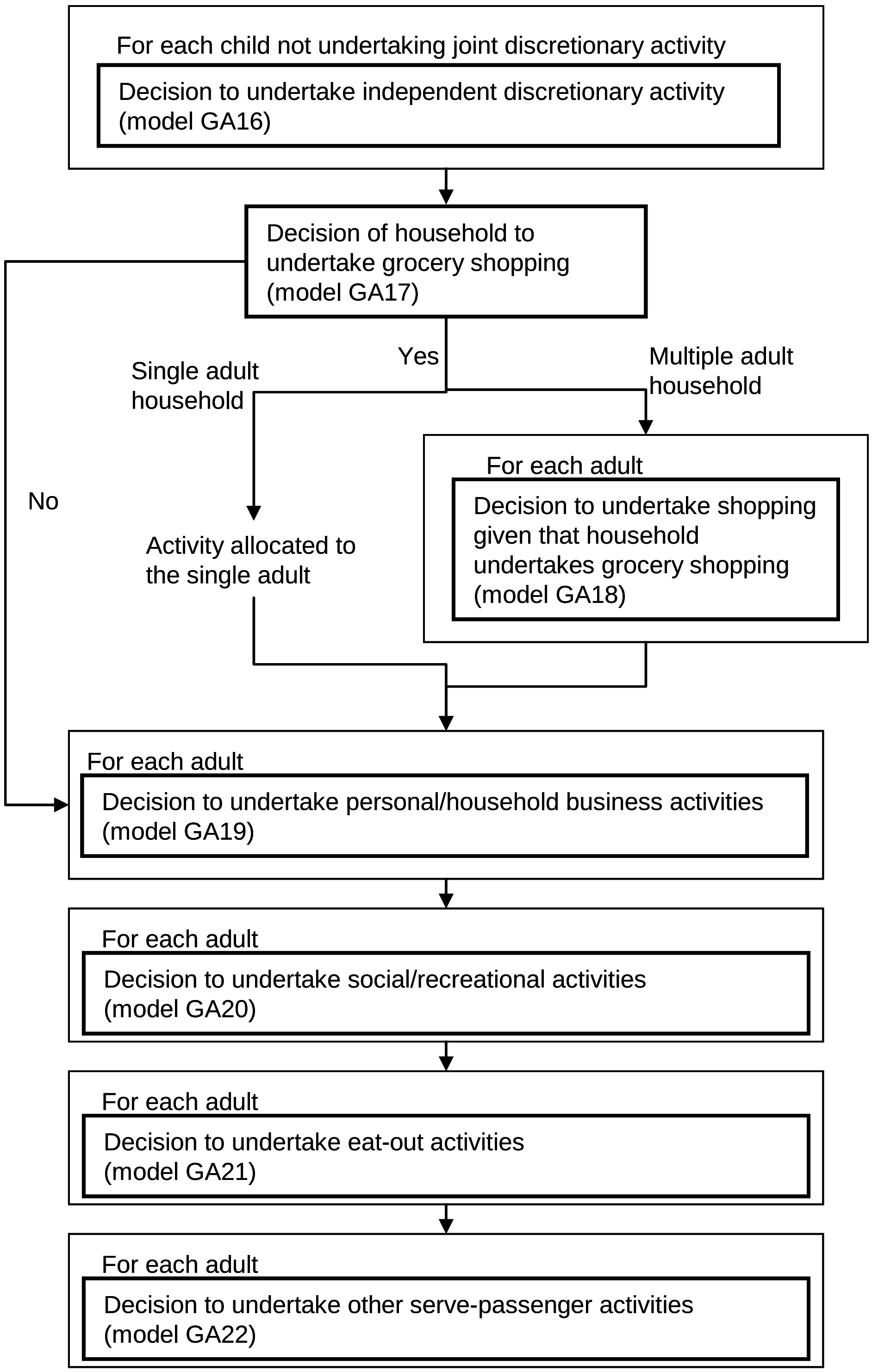

Figure 2.5 The generation of independent activities for personal and household needs

2.4.2 Prediction of Activity Scheduling Decisions

At the end of the prediction of activity generation and allocation decisions (Section 2.4.1), the following information is available: (1) each child's decision to go to school, the school start time and end time, the modes used to travel to and from school, the decision to undertake a joint discretionary activity with a parent, and the decision to undertake an independent discretionary activity; (2) which (if either) parent undertakes the drop-off activity, the pick-up activity, and the joint discretionary activity with the children; (3) each employed adult's decision to go to work, the work start time and end time, and the decision to undertake work-related activities; (4) each adult student's decision to go to school and the school start time and end time; (5) each adult's decisions to undertake grocery shopping, personal or household business, social or recreational activities, eating out, and other serve-passenger activities.

In the next broad step of predicting activity scheduling decisions, the following sequence is adopted (see Figure 2.6): (1) scheduling the commutes for each worker in the household, (2) scheduling the drop-off tour for the non-worker escorting children to school, (3) scheduling the pick-up tour for the non-worker escorting children from school, (4) scheduling the commutes for schoolgoing children, (5) scheduling the joint tour for the adult pursuing discretionary activity jointly with children, (6) scheduling the independent home-based tours and work-based tours for each worker in the household, (7) scheduling the independent home-based tours for each non-worker in the household, and (8) scheduling the discretionary activity tours for each child in the household. It is useful to note that not all eight steps are required for each household in the population. For example, steps (2), (3), (4), (5), and (8) are not necessary for households without children. Similarly, steps (2) and (3) are not needed for a household if none of the schoolgoing children are escorted to or from school by their parents. Each of the eight steps is discussed in further detail here.

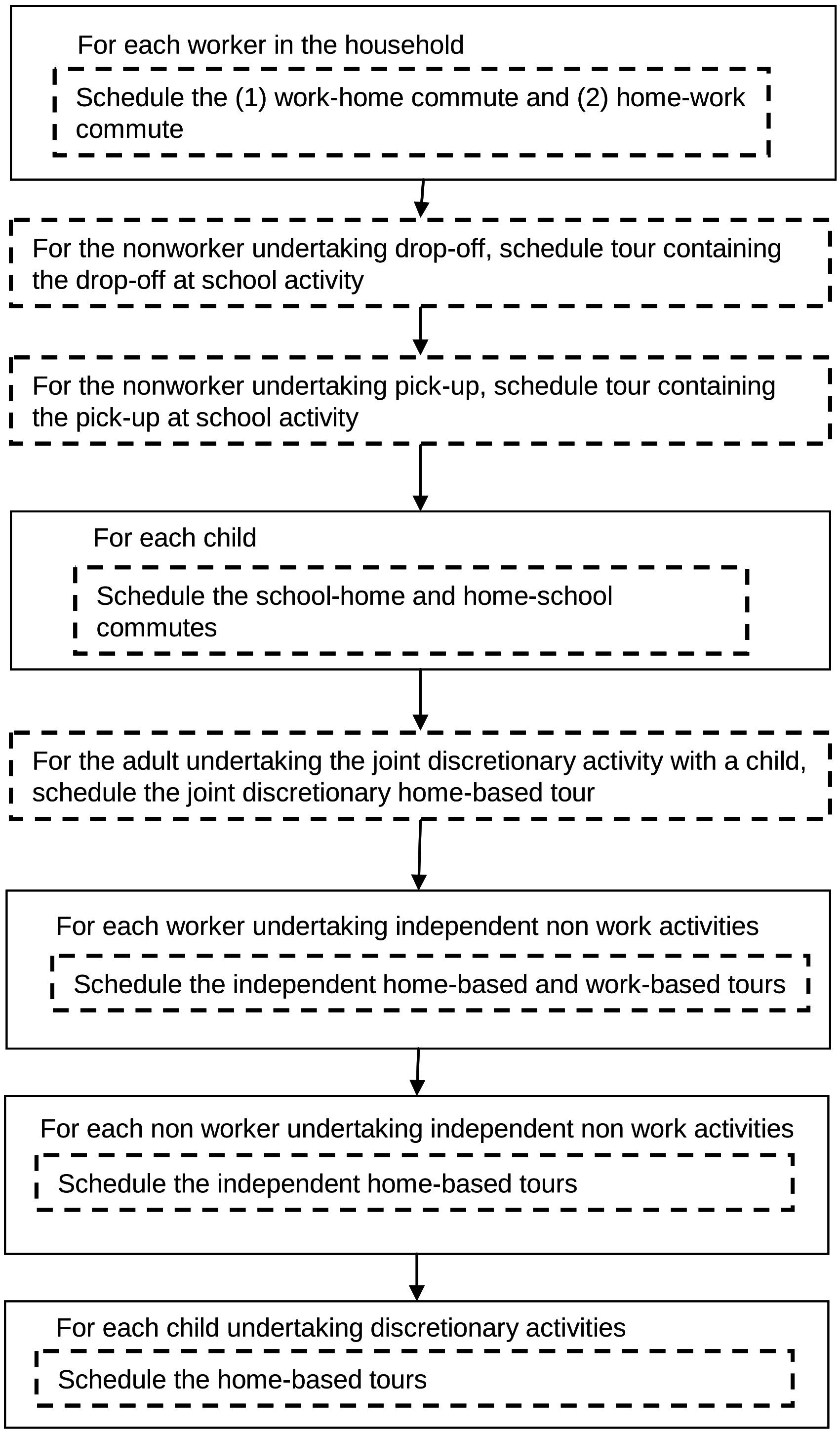

Figure 2.6 Sequence of major steps in the prediction of activity scheduling decisions

2.4.2.1 Scheduling the commutes for each worker in the household

Travel undertaken to and from work is arguably the most constrained in terms of space and time (because of the rather strict need to be at the work location during a certain period of the day). Further, as already indicated, if the worker escorts children to and from school, then these pick-up and drop-off episodes are assumed to be undertaken during the commutes. Hence, the scheduling decisions relating to the commute are determined first. The characteristics of the work-to-home segment of the commute (Figure 2.7) are determined first, followed by the characteristics of the home-to-work segment (Figure 2.8).

The first commute-related decision modeled is the travel mode. (The mode for both legs of the commute is taken to be the same, based on empirical data analysis.) If the worker is escorting children to and from the school, the commute mode is set to "driver with passenger." Otherwise, the mode is determined using a multinomial logit model. The possible modal choice alternatives are "driver-solo," "driver with passenger," "passenger," "transit," and "walk or bike."

If the worker is picking up children from school, then this pick-up activity is assumed to be the only stop during the work-to-home commute. The travel times from work to school and from school to home are determined as the prevailing inter-zonal auto travel times between the appropriate zones and at the appropriate times of day. If the worker is not picking up children from school, then the number of stops made during the work-to-home commute depends on whether the worker has decided to pursue any independent non-work activities (i.e., work-related activities, shopping, household or personal business, social or recreational activities, eating out, or other serve-passenger activities) and the commute mode. Specifically, if the worker has not decided to pursue any independent non-work activities (which has already been determined in the prediction of generation-allocation decisions), then there are no stops to be scheduled during the commute. Also, if the commute mode is either walking or transit, then the worker is assumed not to make any stops during the commute. In the case of another commute mode (e.g., commute mode is an automobile and the worker has also decided to pursue independent non-work activities during the day), the number of stops to be pursued is determined. If no stops are predicted, the work-to-home travel time is simply determined as the prevailing travel time by the chosen commute mode between the work and home locations at work end time. If one or more stops are predicted (the empirical modeling system allows a maximum of two stops during the commute), each of these stops are characterized, sequentially from the first to the last, in terms of the activity type at the stop, the duration of activity at the stop, the travel time to the stop, and the location of the stop. Once all the stops are characterized, the travel time for the last leg of the work-to-home commute (i.e., the trip ending at home) is determined as the prevailing auto travel time between the location of the last activity stop and home at the departure time from the last stop.

The home-to-work commute is characterized next (Figure 2.8). If the worker is pursuing drop-off of children at school, then this drop-off activity is the only stop during the home-to-work commute. The travel times from home to school and from school to work are determined as the prevailing inter-zonal auto travel times between the appropriate zones and at the appropriate times of day. For workers not dropping off children, the scheduling of the home-to-work commute follows a procedure which is very similar to the scheduling of the work-to-home commute discussed above.

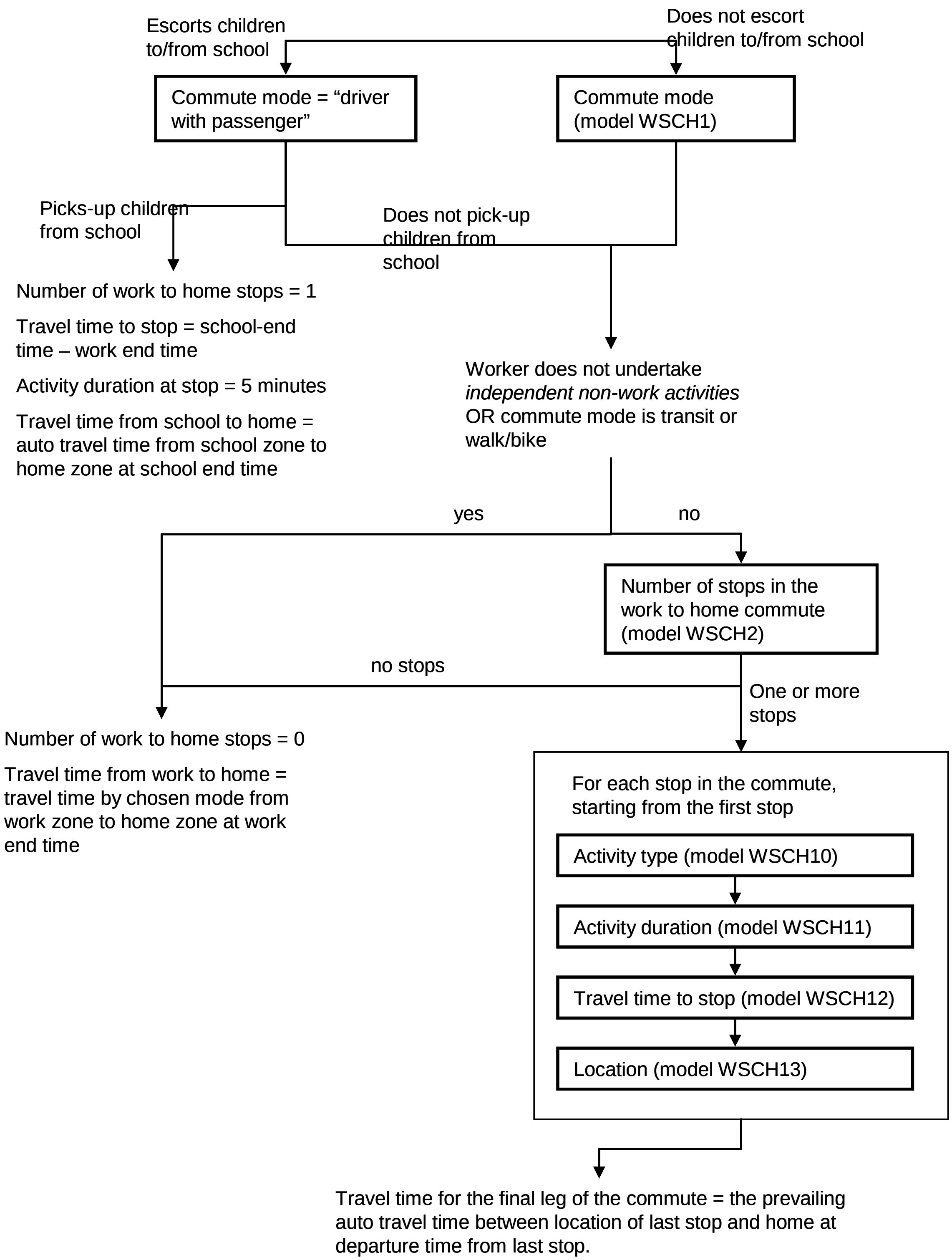

Figure 2.7 Scheduling the work-to-home commute

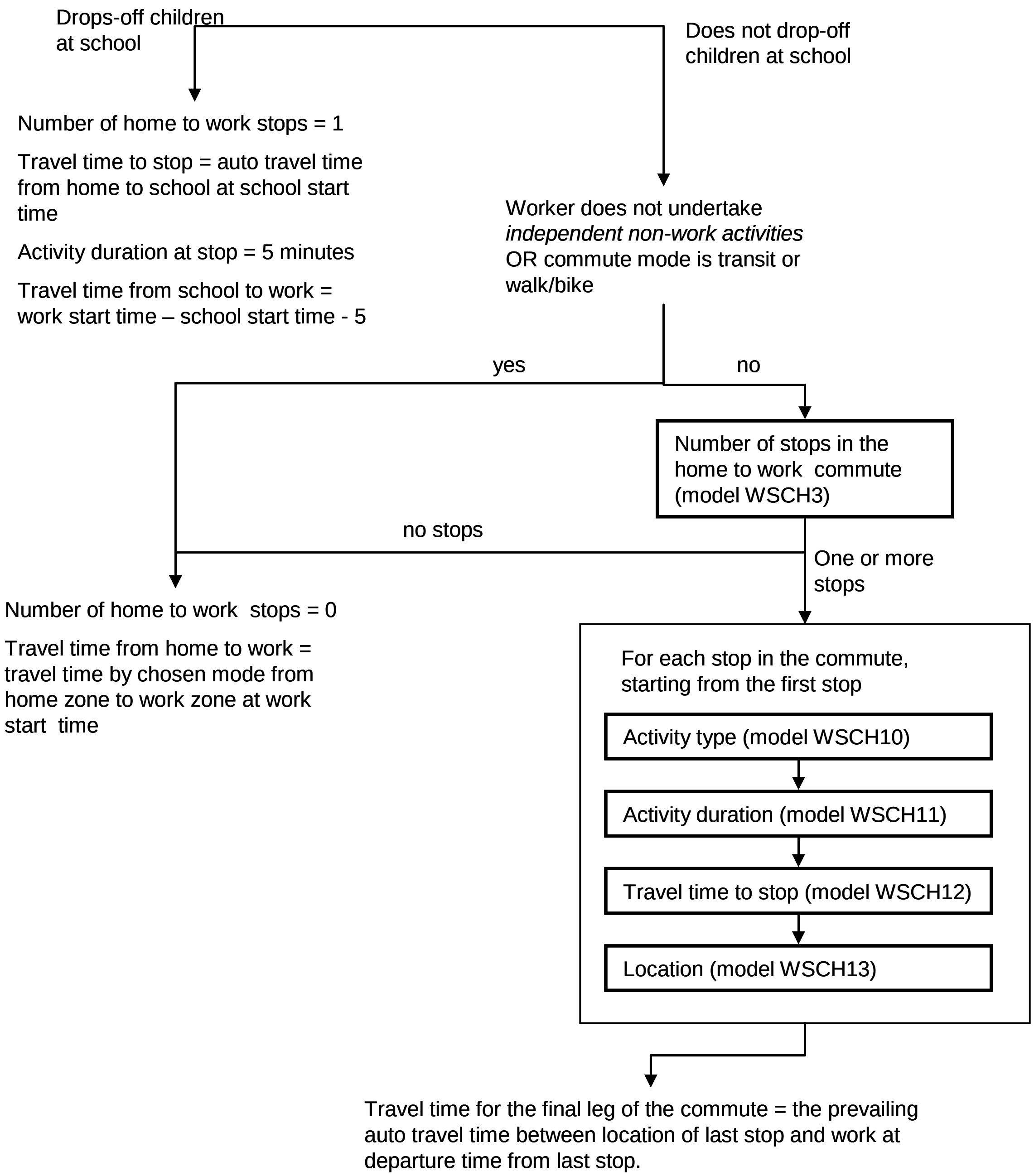

Figure 2.8 Scheduling the home-to-work commute

2.4.2.2 Scheduling the drop-off tour for the non-worker escorting children to school

Among all activities and travel pursued by a non-worker, the escort of children to and from school is undertaken with the most space-time constraints. Consequently, these activities are scheduled prior to all independent activities undertaken during the day. Of the two types of escort activities, drop-off and pick-up, the scheduling of the former is undertaken first as the drop-off activities temporally precede the pick-up activities.

Non-workers dropping off children at school are assumed to undertake this activity as the first stop of their first home-based tour for the day. The scheduling of this first tour is presented schematically in Figure 2.9. The mode for this tour is set as “driver with passenger” and the travel time is determined as the prevailing auto travel time between the home and school zones at the school start time of the children being escorted. After dropping off the children at school, the non-worker may choose to undertake other independent activities as part of this same tour. The number of such stops is determined next. The reader will note that this is applicable only for non-workers who have decided to undertake one or more independent non-work activities (i.e., work-related activities, shopping, household or personal business, social or recreational activities, eating out, or other serve-passenger activities) during the day. If one or more stops are predicted (the empirical modeling system allows a maximum of three additional stops in a tour containing a drop-off episode), then each of these stops are characterized, sequentially from the first to the last, in terms of the activity type at the stop, the duration of activity at the stop, the travel time to the stop, and the location of the stop. Once all the stops are characterized, the travel time for the last leg of the tour (i.e., the trip ending at home) is determined as the prevailing auto travel time between the location of the last activity stop and home at the departure time from the last stop. If the non-worker is not undertaking any activity other than the drop-off as part of this tour, then the return home time is determined as the prevailing auto travel time between the school location and home at the departure time from the drop-off episode.

2.4.2.3 Scheduling the pick-up tour for the non-worker escorting children from school

Non-workers picking up children from school are assumed to undertake this activity as the first stop of a home-based tour. Unlike the tour containing the drop-off episode, the tour containing the pick-up episode is not necessarily the first tour of the day. In fact, it could be any (i.e., first, second, third, etc.) of the several tours made by the non-worker during the day. However, this tour would be the first tour to be scheduled if the non-worker does not undertake drop-off episodes and the second tour to be scheduled if the non-worker is also undertaking drop-off episodes. The overall scheduling of a tour containing the pick-up activity (Figure 2.10) is very similar to the procedure described for the scheduling of a drop-off tour. In this case the tour is constrained by the school-end time of the children being escorted as opposed to the school-start time in the case of the drop-off tours.

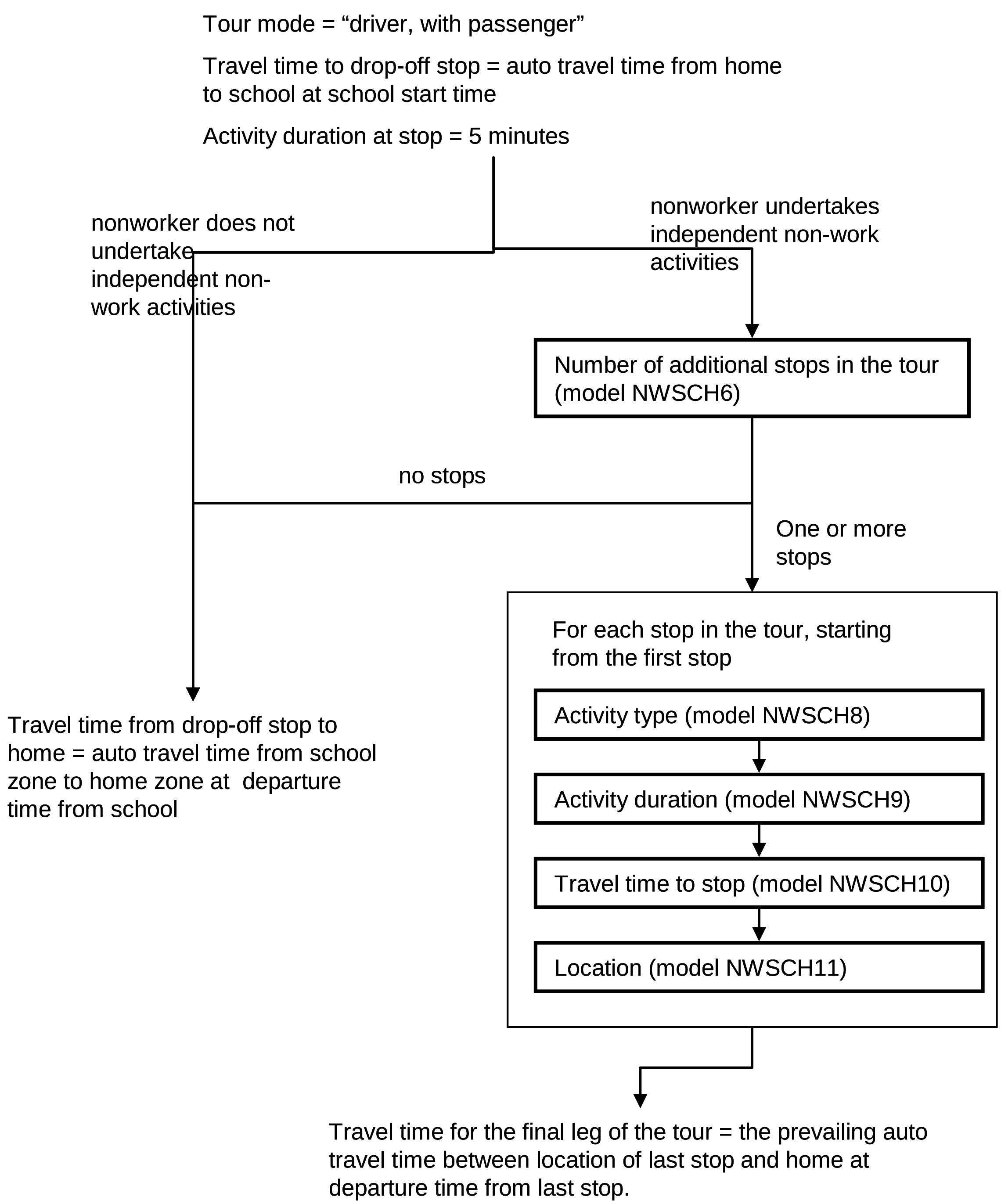

Figure 2.9 Scheduling the drop-off tour for the non-worker escorting children to school

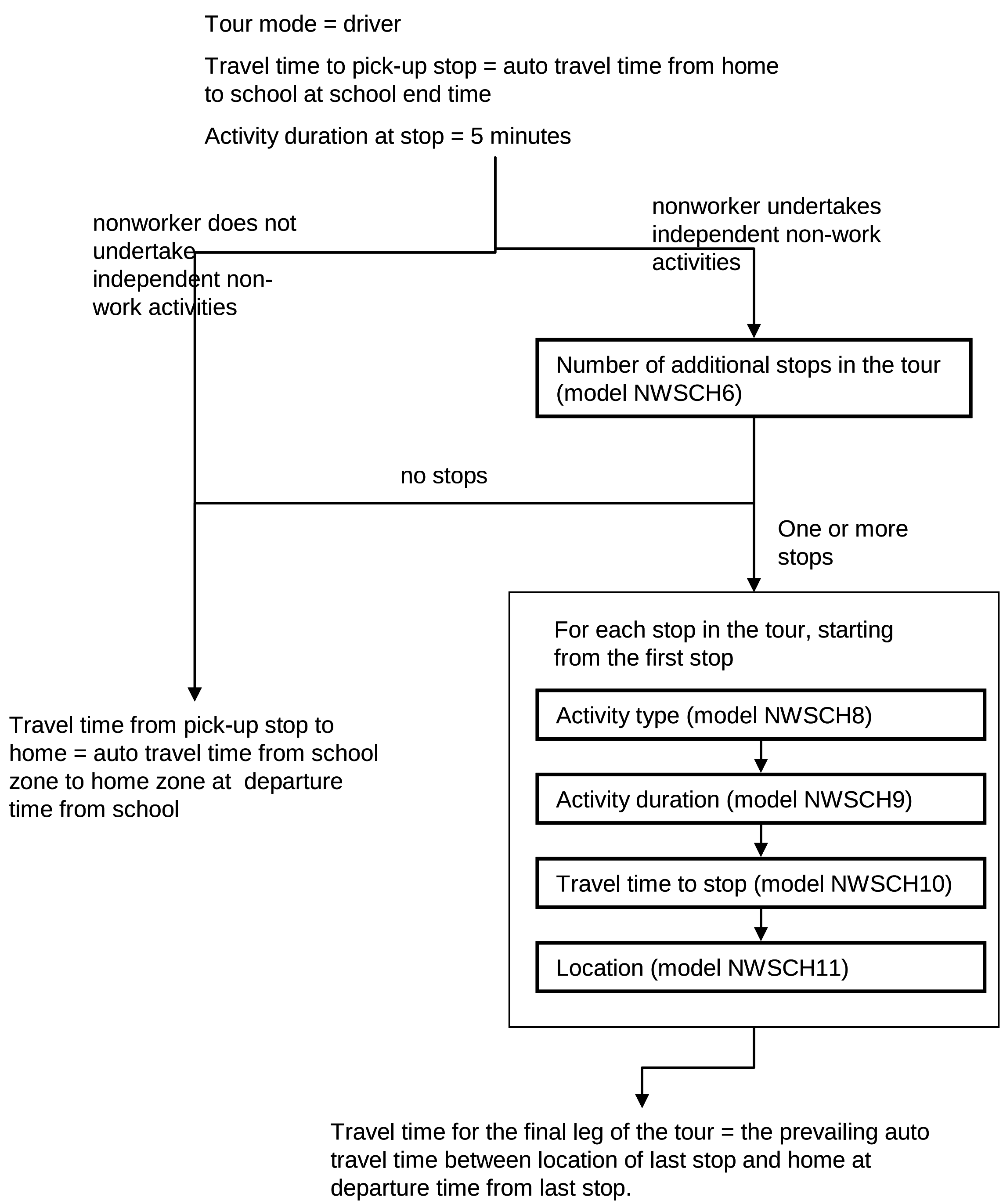

Figure 2.10 Scheduling the pick-up tour for the non-worker escorting children from school

2.4.2.4 Scheduling the commutes for schoolgoing children

In the fourth major step of scheduling, the commute for each of the schoolgoing children in the household is characterized (Figure 2.11). If a child is being escorted home from school, the school-to-home commute of this child is simply obtained as the corresponding travel pattern (i.e., the pattern from pick-up activity to arrival at home) of the escorting parent. If the child is not escorted, the travel time from school to home is determined using a regression model and the child is assumed not to make any stops during this commute. If a child is being escorted to school, the home-to-school commute of this child is simply obtained as the corresponding travel pattern (i.e., the pattern from departure from home to drop-off activity) of the escorting parent. If the child is not escorted, the travel time from home to school is determined using a regression model and the child is assumed not to make any stops during this commute.

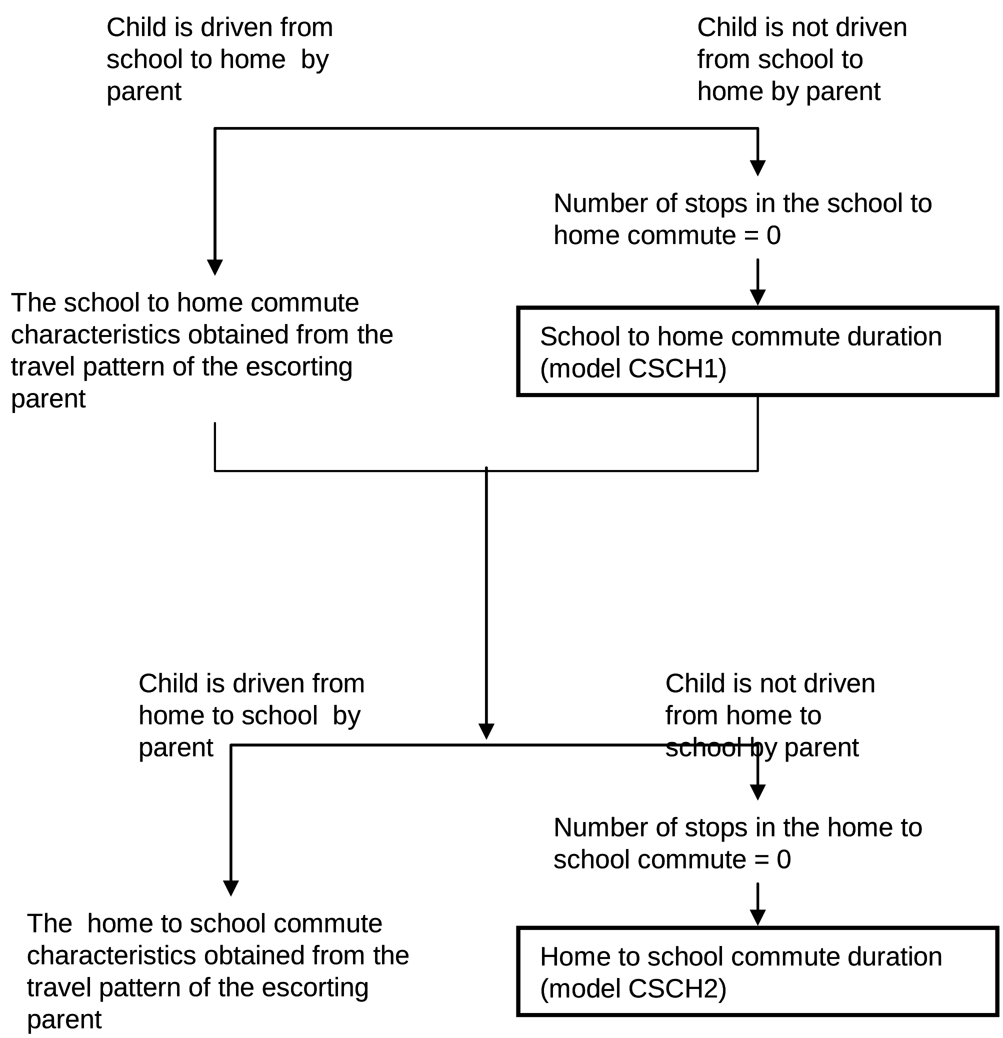

Figure 2.11 Scheduling the commutes for schoolgoing children

2.4.2.5 Scheduling the joint tour for the adult pursuing discretionary activity jointly with children

The next step in the scheduling procedure focuses on the discretionary activity pursued by an adult jointly with a child in the household. The scheduling procedure is illustrated in Figure 2.12. If this adult is a worker, then the joint activity episode is undertaken as the only stop in the first (and only) after-work tour of the worker. If this adult is a non-worker, then the joint discretionary activity is pursued as the only stop in a home-based tour. This tour could be any (i.e., first, second, third, etc.) of the several tours made by the non-worker during the day.

It is useful to point out here that the data sample did not provide cases in which adults undertook both escort to and from school activities as well as joint discretionary activities with children. Hence, the adults undertaking joint discretionary activities are assumed not to escort children to and from school. Consequently, for a non-worker undertaking a joint discretionary activity with a child, the corresponding joint tour would be the first tour that would be scheduled. From the standpoint of the child undertaking this activity, the joint discretionary activity is assumed to be undertaken after return from school. The reader will note that the return home time from work of all the workers and the return home time from school of all the children have already been determined. The scheduling begins with the determination of the departure time for the tour and is followed by the determination of the activity duration at the stop, the travel time to the stop, and the location of the stop.

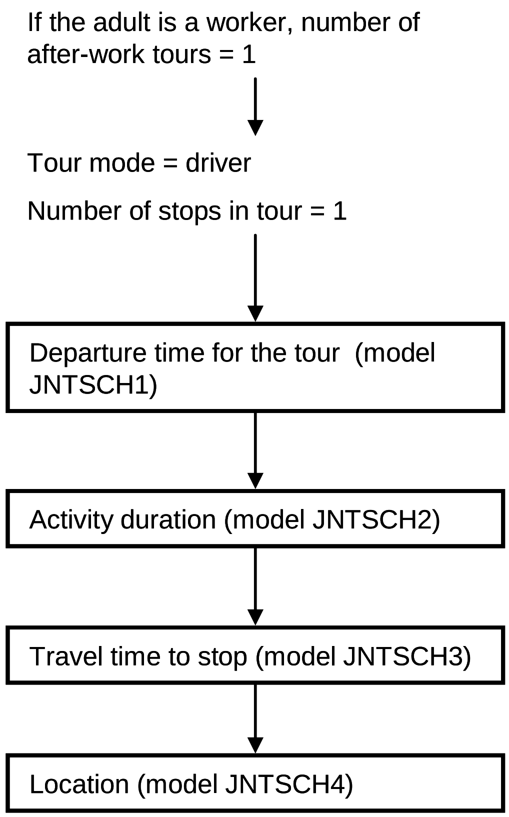

Figure 2.12 Scheduling the joint tour for the adult pursuing discretionary activity jointly with children

2.4.2.6 Scheduling the independent home-based and work-based tours for each worker in the household

At this point, scheduling of all activities which are significantly impacted by space-time constraints has been completed. The next steps in the scheduling procedure are focused on the organization of activity stops undertaken with considerable spatial and temporal flexibility. This sixth step (Figure 2.13 and Figure 2.14) of the scheduling procedure is focused on the scheduling of home-based and work-based tours undertaken by workers who choose to undertake independent non-work activities during the day. For workers not undertaking joint discretionary activities with children, the number of after-work tours is first determined (Figure 2.13). If the worker chooses to undertake one or more tours (up to two after-work tours are supported by the empirical modeling system), then each of these tours is characterized (sequentially from the first after-work tour) in terms of the tour mode, number of stops in the tour, and home-stay duration prior to the tour (Figure 2.14). The reader will note that the home-stay duration before the tour determines the time of day of departure for the tour. A maximum of five stops is supported by the empirical model system in any tour. Each of the stops in the tour is characterized (sequentially from the first to the last stop) in terms of the activity type, activity duration, travel time to the stop, and location of the stop. The attributes of all the stops in a tour are completely determined before proceeding to the subsequent tour.

As shown in Figure 2.13, once the scheduling of activities during the after-work period is complete, the decision of a worker to undertake work-based tours is determined. The empirical modeling system allows up to two tours during the work-based period. The scheduling of the tours during the work-based period follow a similar procedure to the scheduling of tours during the after-work period, which was discussed above. Finally, after the scheduling of activities during the work-based period is complete, the worker’s decision to undertake tours during the before-work period is determined (a maximum of one tour is supported). Again, the scheduling of the tours during the before-work period follows a similar procedure to the scheduling of tours during the after-work and work-based periods. With this, the complete activity-travel pattern of all workers in the household has been generated.

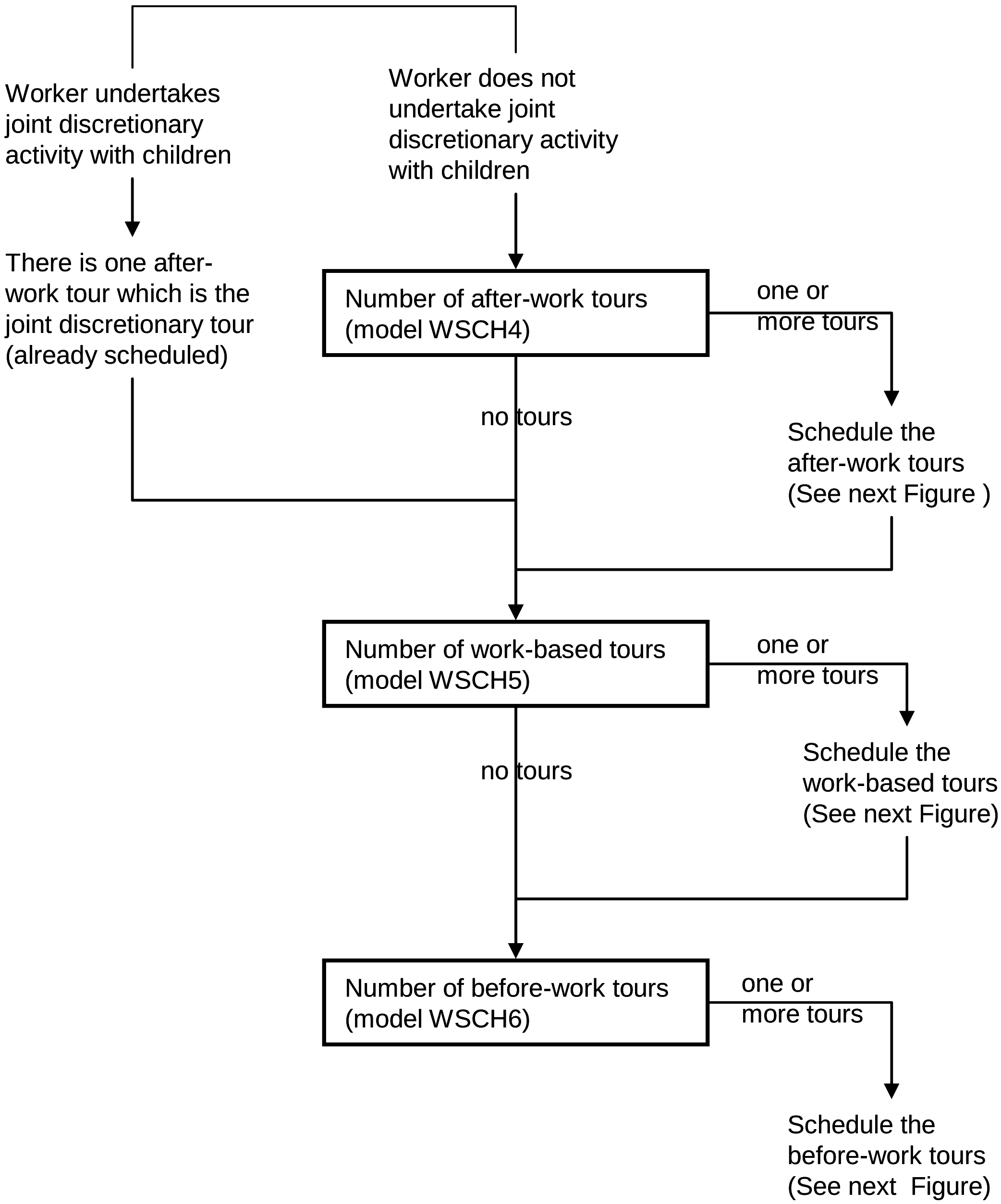

Figure 2.13 Scheduling all the independent home-based and work-based tours for workers

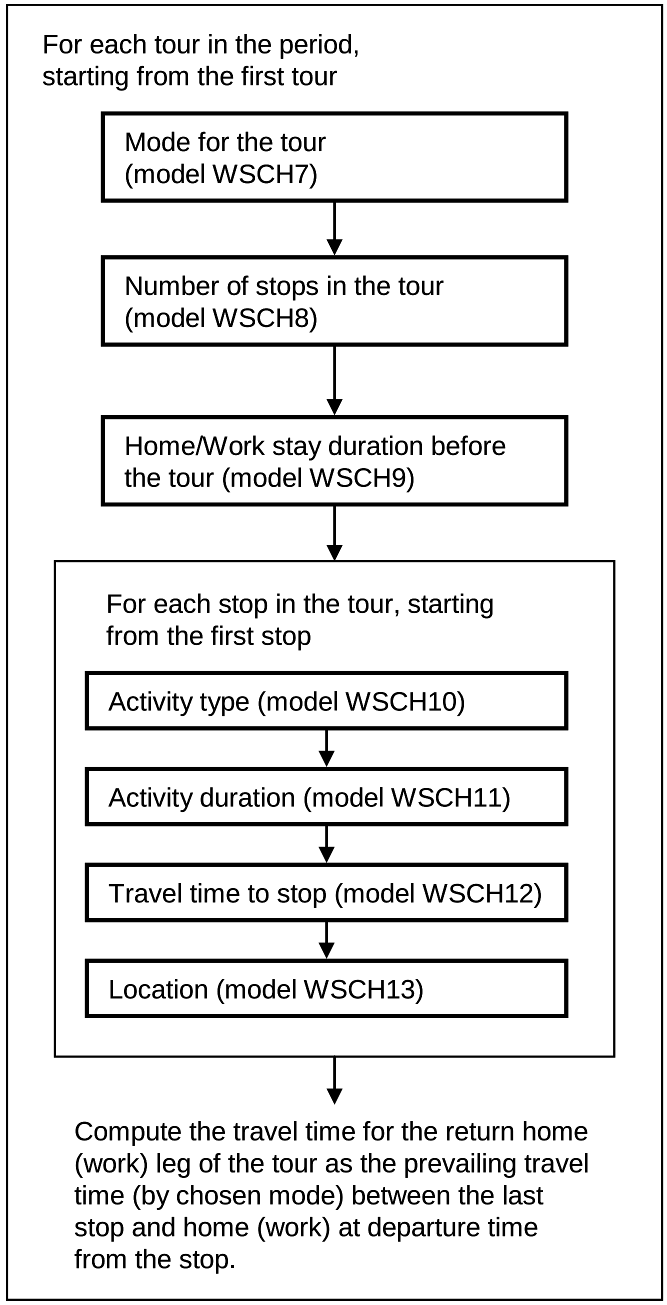

Figure 2.14 Scheduling a single independent tour for workers

2.4.2.7 Scheduling the independent home-based tours for each non-worker in the household

The penultimate step in the scheduling procedure is focused on the independent activities pursued by the non-workers in the household. If the non-worker is not pursuing pick-up or joint discretionary activities with the children, then the scheduling of independent activities begins with the determination of the total number of independent non-work tours to be undertaken by the individual. A maximum of four independent non-work tours is supported by the empirical modeling system. As depicted in Figure 2.15, each of these tours is characterized (sequentially from the first after-work tour) in terms of the tour mode, number of stops in the tour, and home-stay duration prior to the tour. The reader will note that the home-stay duration before the tour determines the departure time for the tour. A maximum of five stops is supported by the empirical model system in any tour. Each of the stops in the tour is characterized (sequentially from the first to the last stop) in terms of the activity type, activity duration, travel time to the stop, and location of the stop. The attributes of all the stops in a tour are completely determined before proceeding to the subsequent tour.

If the non-worker is undertaking pick-up (joint discretionary) activities, then the decision of this person to undertake an independent tour before and after the pick-up (joint discretionary) tour is predicted (Figure 2.16). As already discussed, non-workers will only be undertaking one of escort or joint discretionary activities. This in turn determines the position of the pick-up (joint discretionary) tour within the overall pattern of the non-worker. For example, if a non-worker who undertakes a drop-off tour also decides to undertake an independent tour before the tour for pick-up children from school, then the pick-up tour becomes the third tour in this person’s overall pattern (the drop-off tour is always the first tour). Alternatively, if a non-worker who does not undertake a drop-off tour decides to undertake an independent tour before the tour for pick-up children from school, then the pick-up tour becomes the second tour in this person’s overall pattern. Conditional on choosing to undertake a tour before and after the pick-up (joint discretionary) tour, the characteristics of these tours and the stops in these tours are determined.

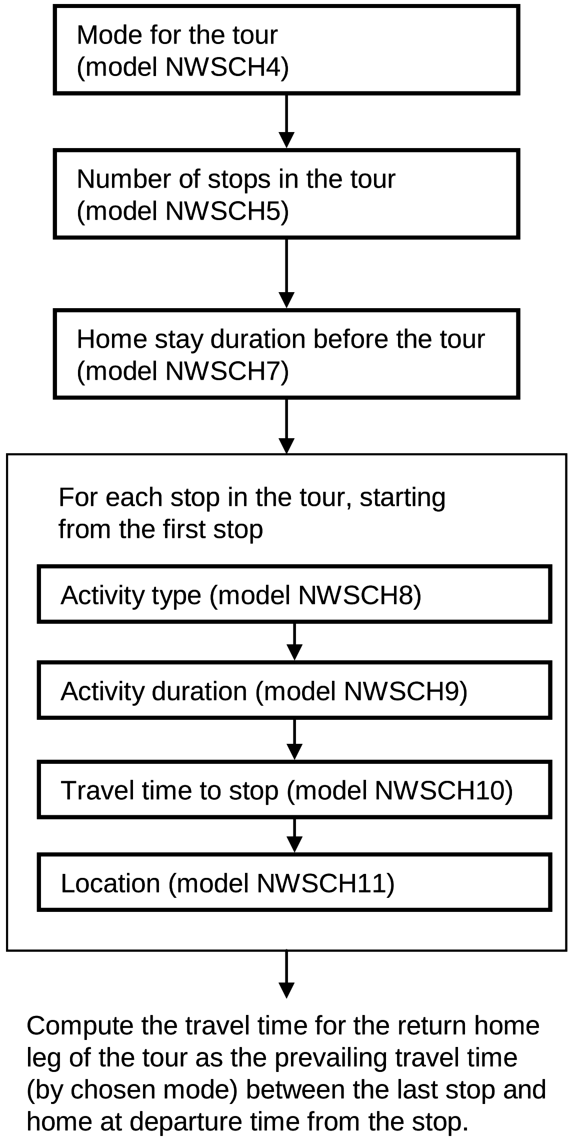

Figure 2.15 Scheduling a single independent tour for non-workers

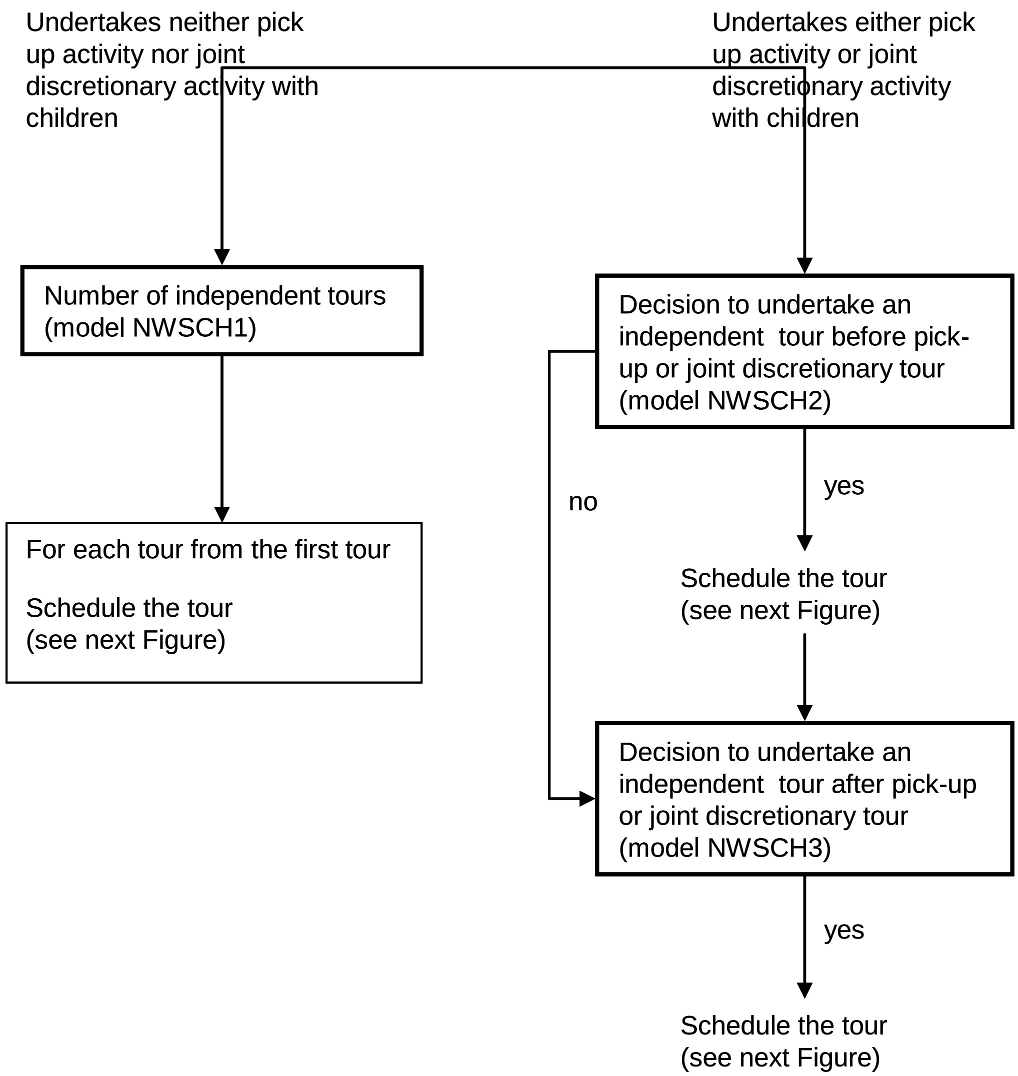

Figure 2.16 Scheduling all the independent home-based tours for non-workers

2.4.2.8 Scheduling the discretionary activity tours for each child in the household

In this last activity scheduling step, tours undertaken by the children for discretionary activity participation are predicted (Figure 2.17). If the discretionary activity is pursued jointly with a parent, then the characteristics of this tour are simply obtained from the corresponding tour of the parent. Otherwise, the characterization of the independent discretionary activity tour begins with the choice of the tour mode which can be one of "drive by other" or "walk bike." Next, the departure time from home for the tour is determined. If the child also goes to school, it is assumed that discretionary tours are undertaken subsequent to returning home from school. The characterization of the discretionary tour is completed by determining the activity duration at the stop, the travel time to the stop, and the location of the stop. The reader will note that there is only one stop in discretionary activity tours undertaken by children and each child undertakes at most one discretionary activity tour during the day, either independently or jointly with a parent.

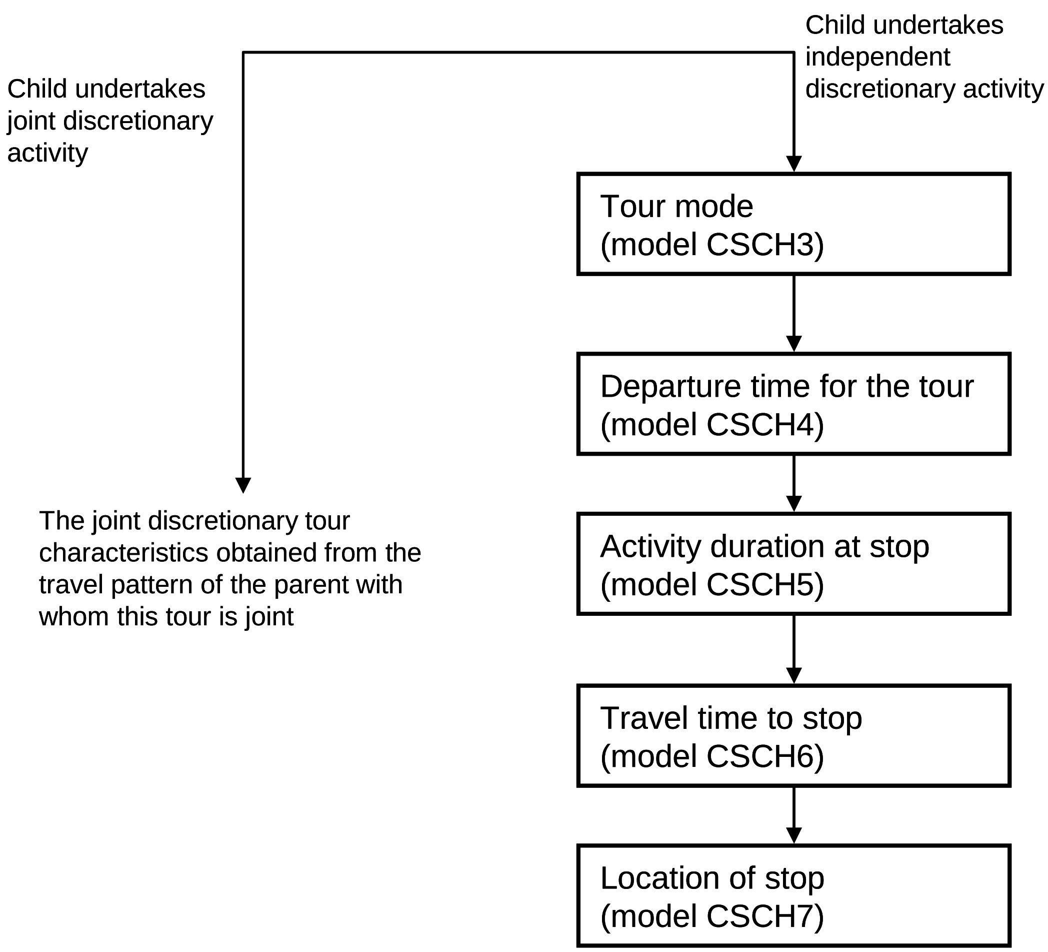

Figure 2.17 Scheduling the discretionary activity tours for each child in the household

3. CEMSELTS

The activity-travel simulator, CEMDAP, described in the previous chapter requires as input the current demographic and socioeconomic characteristics of the synthetic population at each time step within the simulation run to simulate activity-travel patterns. Therefore, once the SPG provides the base year population to the system, the population needs to be updated over the simulation run. This updating process is accomplished by CEMSELTS.

This chapter describes CEMSELTS's constituent models, each of which is associated with the updating of one of the many demographic and socioeconomic processes. Our earlier research report, 4080-6, has discussed the various household- and individual-level processes that need to be updated at each simulation time step and has presented an analysis framework that identified the various constituent models of CEMSELTS. The focus of this chapter is the mathematical structure and estimation of these models as well as the overall procedure for applying these models to achieve population updating.

The remainder of this chapter is organized as follows. Section 3.1 provides a list of household and individual characteristics that are currently used as exogenous variables in CEMDAP and therefore need to be updated. The section also identifies the model module that is responsible for updating each of these variables. Section 3.2 describes the data used for empirically developing and estimating the constituent modeling modules. Section 3.3 discusses the structure and parameters of the updating models identified in Section 3.1. The micro-simulation procedure based on which these models are applied is described in Section 3.4.

3.1 Socio-Demographic Variables and Constituent Models

The demographic and socio-economic processes that need updating are determined by the data requirement for CEMDAP. For the latest implementation of CEMDAP for the DFW area in Texas, the input data include the household- and individual-level variables listed in Tables 3-1 and 3-2, respectively. The model components responsible for updating each of these variables are identified in the second column of both tables. The nature of these model modules will be discussed later in Section 3.3.

Table 3-1 Household-level variables and corresponding updating models

Variable	Model Modules
Number of persons in household	Death, Birth, Marital Status, Migration and Immigration
Number of adults	
Number of children	
Household structure	
Total no. of household vehicles, incl. motorcycles and RVs	Vehicle Ownership
Home location (zone)	Housing Choices
Housing Type	

Table 3-2 Individual-level variables and corresponding updating models

Variable	Model Modules
Gender of the person	Birth
Age of the person	Birth
Is a parent	Birth, Marital Status
Race	Birth
Employment status	Employment Choices
Employment type	
Work TSZ	
Work flexibility	
Total weekly work duration (excluding weekend)	
Study status	Education Choices
School TSZ	
Personal income	Income
Is the person licensed to drive	Licensing

3.2 Data

Data collection for developing the various model modules outlined in the previous section was a significant challenge. Ideally, since the current implementation of CEMDAP is customized for the DFW area, disaggregate-level population data pertaining to the area should be used for developing these modules. However, such data were found to be unavailable for simulating several demographic processes such as deaths, births, and marriage. Therefore, alternative data sources at the state and national levels were used. Below, the data sources utilized for developing each of the CEMSETLS models are listed in Table 3-3. Information about the data sources are provided in Sections 3.2.1 through 3.2.7.

Table 3-3 Data used for developing CEMSELTS model components

Module	Data Source	Geography
Death	National Vital Statistics, 2002	Nation
Birth	National Survey of Family Growth Data, 2002	Nation
	National Vital Statistics, 2003 and 2004	State/Nation
Marital Status	National Survey of Family Growth Data, 2002	Nation
Migration or Immigration	Texas Population Projection Data	State
Vehicle Ownership	DFW Household Activity Survey, 1996	DFW
Housing Choices	DFW Household Activity Survey, 1996	DFW
Employment Choices	Bureau of Labor Statistics, 2004	Nation
	DFW Household Activity Survey, 1996	DFW
Education Choices	PUMS Data, 2000	DFW
	Texas Education Agency Data, 2004	State

3.2.1 National Vital Statistics

The National Center for Health Statistics (NCHS) is the nation's principle health statistics agency and is responsible for compiling statistical information to guide actions and policies to improve public health. The NCHS maintains a data warehouse known as the National Vital Statistics System (NVSS), which contains national- and state-level statistics data on annual births, deaths, marriages, and divorces. The data are available in the reports published by the NCHS.

The NVSS data about annual death rates are released in the United States Life Tables (Ref 1). The tables provide life expectancy statistics by race, age, and gender. They were used to develop the death model.

Along with the NSFG data (see Section 3.2.2), the NVSS data about annual birth rates (Ref 2 and 3) were used to develop the birth model. The rates are available for different age and race groups.

3.2.2 National Survey of Family Growth Data

As part of the NVSS, the NCHS also maintains the National Survey of Family Growth (NSFG) data (Ref 4). The NSFG includes data about 12,571 respondents, of which 7,643 were females aged 15 through 44. The survey collected socio-demographic information about each individual as well as the marital and fertility history of each female respondent. Specifically, the data set contains the following data items that support the development of the birth and marital status models:

1. the number of marriages and duration of each marriage;
2. the husband's age, education, and race;

3. the number of children.

Cycle 6 of the NSFG data from year 2002 was used for part of the model estimation.

3.2.3 Texas Population Projection Data

The Texas Population Projections Program at the Texas State Data Center produces biennial projections of the population of the state and all counties in the state by age, sex, and race or ethnicity. Part of the population project data is the net migration rates for different scenarios, such as the rapid growth of 1990–2000 and the reduced level of migration of 2000–2002. These data are used for modeling migration and immigration.

3.2.4 DFW Household Activity Survey, Land Use, and LOS Data

The primary data set used for developing the vehicle ownership, housing choices, and employment choices model modules was the 1996 DFW Household Activity Survey, which was described earlier in Section 3.3.1.1. The model development also involved using the land-use data and LOS data, described in Sections 3.3.1.2 and 3.3.1.3, for the area.

3.2.5 Bureau of Labor Statistics

A look-up table providing the probability of individuals leaving their current job based on industry is obtained from the Job Openings and Labor Turnover Survey (JOLTS) program of the Bureau of Labor Statistics.

3.2.6 Public-Use Microdata Samples (PUMS)

The probability that an individual receives a bachelor’s degree, master’s degree, or doctorate is obtained using the 2000 census 5 percent PUMS files for the DFW area.

3.2.7 Texas Education Data

Additional data were required to develop the education choices model module. The drop-out probabilities for secondary education were obtained from the Texas Education Agency. The transport analysis zones (TAZ) of schools were determined by using GIS files of independent school districts and schools in the DFW area. These files were obtained from the Texas Education Agency.

A DFW school look-up table was created internally by using the statistics obtained from the Texas Higher Education Coordinating Board, College View, and the individual school's websites. This look-up table includes enrollment and degree statistics that include total enrollment, percentage of each race and sex, and percentage of associate's, bachelor's, master's, and doctorate degrees given. This look-up table was used in predicting the education attainment of each individual in the population.

3.3 Model Components

This section is focused on the model modules that support the updating of the range of socio-demographic variables identified in Section 3.1. The mathematical structure and the parameter estimates of the model modules listed in Table 3-1 and Table 3-2 are described in the subsections below. The parameter estimates have been obtained using the data sources described in the preceding section.

3.3.1 Death

The death model computes the probability that an individual will die at a given year. The model takes the form of a death probability look-up table (an excerpt is shown in Table B-1 of Appendix B), which provides the probability of death by age, gender, and race

(White, Black, or other). The probabilities were extracted from the United States Life Tables (Ref 1).

3.3.2 Birth

The birth model computes the probability of a female aged 10 through 49 giving birth to a child at a given year. Two types of structures are used for the birth model. For women between the ages of 10 through 14 and 45 through 49, a birth probability look-up table is used to determine the probability that a female will give birth in a given year (see Table B-2 of Appendix B). The probability is based on the age and race of the female. The probabilities were obtained from the NVSS (Ref 2). For women between the ages of 15 and 44 years, a multinomial logit structure is used. Data on about 7,000 respondents from the 2002 NSFG cycle 6 data (Ref 4) are used for model estimation. The estimation results are presented below in Table 3-4.

Table 3-4 Birth model parameters

	Coeff.	t-stats
Constant (no birth occurs is base)	3.861	13.36
Std deviation (no birth)	-0.820	-8.62
Age	0.043	3.45
Race		
Hispanic	0.631	4.77
Black	0.533	4.08
Female has worked	0.504	3.80
Number of children	-0.350	-4.69
Education of the female		
Associate's degree	-0.321	-1.81
Bachelor's degree	-0.492	-2.82
Master's and above degree	-0.944	-5.35

The estimation results indicate that a female's probability of giving birth increases with age. Also, Hispanics and Blacks are more likely to give birth than Whites are. It is interesting to note that females who have worked are more likely to give birth to children than those who have no work experience. As expected, the presence of children reduces the likelihood that a female will have more children. Education tends to reduce the likelihood of having a child. Master's degree holders (includes degrees beyond the master's) are the least likely to have children.

If a female gives birth in a certain year, the number of births look-up table is used to determine the probability that she has one child, twins, or triplets (see Table B-3 of Appendix B). It is assumed that the female does not have more than three children at one time. These probabilities are based on the age and race of the mother and were obtained from the NVSS (Ref 2).

For each child that is born, a child gender look-up table is used, based on the race of the mother, to determine the probability that the child is male versus female (see Table B-4 of Appendix B). These probabilities were obtained from the NVSS (Ref 3).

3.3.3 Marital Status

The marital status module is responsible for determining whether a female will change her marital status (due to marriage or divorce) at a given year. If the female is getting married, the module also determines the characteristics of her spouse, including the age, race, and education attainment. The model that predicts the marital status changes is discussed in Section 3.3.3.1 and the models that predict the characteristics of the spouse are presented in Section 3.3.3.2.

3.3.3.1 Marital status change model

The marital status change model is a multinomial logit model that predicts the probability of a female changing her marital status in a given year. The three alternatives in the universal choice set include single, married, and divorced. However, only two out of the three alternatives can be considered by an individual at any given point in time. For example, a single individual can choose between remaining single or getting married. A married individual can either stay married or become divorced. Similarly, a divorced individual can either stay divorced or become married.

The 2002 NSFG cycle 6 data that were used to estimate the birth model were also used to estimate the marriage status change model. The "divorced" alternative was chosen as the base alternative. The model parameter estimates are summarized in Table 3-5. The parameter associated with the age variable suggests that, as a single female ages, she is less likely to remain single. Yet a married female is also less likely to remain married as she ages. The education attainment parameters indicate that as a female's level of education increases, she is more likely to remain her marital status if she is currently single or married. Female individuals who have been employed in the past, are Caucasians, or have had children are less likely to remain single.

Table 3-5 Marital status model parameters

	Single		**Married**		**Divorce**	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constants (Divorce as base)	13.784	8.34	7.825	5.16	--	--
Std Deviation	0.883	4.63	--	--	3.792	9.169
Age	-0.215	-4.17	-0.115	-2.72	--	--
Education Attainment						
Bachelor's degree	4.304	5.57	2.426	4.10	--	--
Master's and above	2.624	4.05	--	--	--	--
Female worked	-1.033	-6.67	--	--	--	--
Race						
Caucasian	-0.619	-4.15	--	--	--	--
Have given birth	-0.984	-4.93	7.825	5.16	--	--

3.3.3.2 Spouse characteristics models

Three multinomial logit models were developed for determining the age (under 22, between 22 and 28, between 29 and 35, greater than 35), race (Hispanic, White, Black, and other), and education level (less than high school, associate's degree, bachelor's degree, master's degree and above) of a female's spouse, if the female decides to get married in a given year. The model parameters are shown in Table 3-6, Table 3-7, and Table 3-8.

To summarize, the results of these models indicate that the age category of husbands is substantially impacted by the age of the female. The tendency to marry within the same race is very high. White females are less likely to marry Hispanic males than non-Hispanic males. Education attainment of the husband predominantly depends on the education category of females. Other factors influencing the husband's education level include the female's age and race (Hispanic).

Table 3-6 Husband's age model

	22–28		28–35		35+		<22	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constant	-9.799	-6.77	-16.189	-9.76	-22.973	-11.54	--	--
Female Age	0.476	7.15	0.706	9.62	0.904	11.11	--	--

Table 3-7 Husband's race model

	Hispanic		White		Black		Other	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constant	-1.278	-1.37	0.070	0.12	-0.890	-1.09	--	--
Hispanic	6.478	4.60	3.604	2.92	--	--	--	--
White	3.700	3.69	4.885	7.68	2.264	2.44	--	--
Black	--	--	--	--	4.429	5.05	--	--
White with bachelor's degree	-2.542	-1.66	--	--	--	--	--	--

Table 3-8 Husband's education attainment model

	Associate's		Bachelor's		Master's and higher		Other	
	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats
Constant	-1.495	-2.84	-1.619	-7.31	-1.677	-7.05	--	--
Associate's degree	0.888	1.82	1.944	3.55	--	--	--	--
Bachelor's degree	1.487	3.75	3.206	7.58	2.751	6.10	--	--
Master's and higher	--	--	2.787	5.70	3.396	7.08	--	--
Age	0.050	2.43	--	--	--	--	--	--
Hispanic	--	--	--	--	-1.576	-2.15	--	--

3.3.4 Migration and Immigration

The migration and immigration module is responsible for determining the in- and out-flow of households in the study area. The data source for this module is the net migration rates (per person per year) provided by the Texas State Data Center through its population projections program. The data are available in the form of net migration rates by age, sex, and race or ethnicity for different growth scenarios. For example, the 1990–2000 scenario assumes that the rapid growth rate of the 1990s will characterize the growth occurring in the future of Texas. In comparison, the 2000–2002 scenario represents a more modest growth pattern.

For the purpose of CEMSELTS, we adopt the "one-half 1990–2000 migration scenario" that represents one-half of the state growth rates as of the 1990s. The net migration rates are listed in Table B-5 of Appendix B. Ideally, we would like to use the migration rates specifically for the DFW area. But since such local projection is not available, we assume that the state migration rates for Texas hold for the DFW area.

3.3.5 Vehicle Ownership

The number of vehicles owned by a household is modeled using the multinomial logit structure, where the five choice alternatives are defined as having 0, 1, 2, 3, or 4 or more cars. A sample of 3,833 households drawn form the 1996 DFW activity-travel survey was used to estimate the model. As shown in Table 3-9, the coefficient estimates represent the effect of various exogenous variables on the utility of each auto ownership alternative relative to the base alternative of zero car ownership. The signs and t-statistics of all parameters are consistent with a priori expectations.

Table 3-9 Vehicle ownership model

	1		**2**		**3**		**4 or more**	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constant (0 veh.)	-0.152	-0.60	-2.980	-8.32	-7.967	-17.63	-11.70	-21.32
Income	0.080	9.68	0.104	12.23	0.107	12.44	0.114	12.96
No. of employed adults	--	--	1.059	9.23	2.371	17.29	3.093	19.38
No. of non-working adults	--	--	0.481	4.16	1.470	10.65	2.103	12.73
Single-adult household	--	--	-2.014	-13.19	-2.014	-13.19	-2.014	-13.19
Household with children	--	--	--	--	-0.403	-3.85	-0.403	-3.85
White household	0.782	2.99	1.294	4.63	1.656	5.33	--	--
Black household	-1.274	-5.03	-1.934	-6.60	-2.777	-7.05	--	--
Own housing unit	1.002	4.62	1.868	7.73	2.796	10.28	2.796	10.28
Single-family attached or detached housing unit	0.236	1.77	--	--	--	--	--	--

3.3.6 Housing Choices

The housing choices refer to the decisions made by each household as a whole about relocation, tenure, housing type, and location. The following discussion focuses on the model structure and estimation results associated with each of these housing decisions.

3.3.6.1 Residential mobility

The residential mobility choice was modeled using a binary logit model that predicts the probability of a household moving away from its current residential location in the span of one year. Since it is possible that the household's choice of tenure and of location may influence its decision to move, an alternative approach is to model mobility conditional on the choices of tenure and location within a nested structure. Although this might be theoretically sounder than the proposed binary logit specification, the data available to us do not support estimation of a nested structure. The mobility decision is therefore treated in CEMSELTS as an independent choice.

The residential mobility model was estimated using the 1996 DFW household survey data. This model was estimated for the households that have been in the DFW area for at least the past one year. (The households that have moved from outside of DFW area into DFW within a year prior to the survey were considered as Immigrants into DFW and are separately modeled). Movers were defined as those who were living in a different house within one year prior to the survey. The DFW data provide 3,334 valid observations of which 294 (8.82 percent) are movers and the rest have not relocated within a year prior to the survey (1996). The estimation results are reported in Table 3-10. The negative and statistically significant coefficient on income indicates that high-income-earning households are less likely to relocate. This may be due to a high desire and affordability for a stable residential place among high-income households. In addition, high-income households are more likely to own a house and hence less likely to relocate. A higher number of adults in a household tends to decrease the family's tendency to relocate, perhaps due to the difficulty faced by adults to adjust their employment and travel arrangements. White households are less likely to relocate than are households of other ethnicity. Households with unrelated individuals and single-adult households are more likely to relocate. Households with senior citizens show less tendency to relocate, perhaps due to the desire for a stable residential place in the later stages of life.

Table 3-10 Residential mobility model*

	Coeff.	t-stats
Constant	-0.106	-0.39
Household annual income (in thousands of dollars)	-0.018	-6.86
No. of adults in household	-0.476	-3.76
White	-0.529	-3.87
Household with unrelated persons	0.497	2.27
Single-adult household	1.387	3.22
Household with elderly persons (Age ≥ 65)	-0.041	-4.29

*Parameter estimates indicate effects of variables on the propensity to move residence.

3.3.6.2 Residential tenure choice

The residential tenure choice was also modeled using a binary logit framework. Model estimation was carried out using the sample drawn from the 1996 DFW household survey data. The sample used for this model contained 3,833 valid observations, of which 2,602 (67.88 percent) households lived in rented houses and the rest (32.12 percent) were in their owned houses.

As shown in Table 3-11, the model estimation results indicate that households that have recently relocated are more likely to be renters. In other words, those who do not relocate are more likely to own housing. The coefficients associated with the household composition variables, including household size, number of employed individuals, and number of children, indicate that an increase in the number of employed individuals or the presence of children in a household increases the household's tendency to own housing. White households are more likely to be home owners, while Black households are the least likely to own housing. Single-adult households tend to rent, though the tendency diminishes with the individual's age. Households with unrelated individuals are more likely to rent a house, whereas households with elderly persons are more likely to own housing.

Table 3-11 Residential tenure choice model*

	Coeff.	t-stats
Constant	-0.672	-3.134
Relocated with in a year prior to survey (1996)	-1.758	-15.586
Household annual income (in thousands of dollars)	0.027	14.199
Household size	0.408	5.417
No. of employed people in the household	-0.202	-2.714
No. of children in the household	-0.417	-4.807
Caucasian household	0.331	2.672
Black household	-0.489	-3.000
Single-adult household	-2.842	-8.740
Age of the adult in the single-adult household	0.048	7.284
Household with unrelated persons	1.168	6.457
Household with elderly persons (Age ≥ 65)	-0.672	-3.134

*Parameter estimates indicate effect of variables on the propensity to own house.

3.3.6.3 Housing type choice

Household dwelling unit type choice is modeled using a multinomial logit structure and estimated using the 1996 DFW data. A descriptive analysis of the data indicates that households who own housing do not live in apartments and households who rent housing do not live in mobile homes or trailers. Hence the housing type choice models were estimated for two market segments based on housing tenure. The observed housing type shares for the two market segments are reported in Table 3-12. The models developed for housing owners and renters are presented in Table 3-13 and Table 3-14, respectively.

Table 3-12 Distribution of housing type by tenure status as found in the 1996 DFW travel survey data

Dwelling Unit Type	Market Segment Own Housing	 Rented housing
Single-family detached	94.45%	31.56%
Single-family attached	3.35%	9.8%
Apartment	0.00%	58.7%
Mobile home or trailer	2.20%	0.00%
Total number of households	2595 (100%)	1220 (100%)

Table 3-13 Housing type choice model for housing owners

	Single-family detached		Single-family attached		Mobile home or trailer	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constant	--	--	-2.554	-5.34	-2.471	-5.38
Income	0.040	5.65	0.037	4.65	--	--
Household size	--	--	-0.411	-2.63	--	--
Single-adult household	--	--	1.002	2.97	--	--
Household with elderly persons (Age ≥ 65)	--	--	--	--	-1.150	-3.10
White household	--	--	--	--	1.404	3.15
Highest education in the household is bachelor's or higher	--	--	--	--	-1.715	-3.87

Table 3-14 Housing type choice model for renters

	Single-family detached		Single-family attached		Apartment	
	Coeff.	**t-stats**	**Coeff,**	**t-stats**	**Coeff.**	**t-stats**
Constant	-1.734	-7.88	-2.023	-12.05	--	--
Income	--	--	--	--	-0.016	-5.73
Household size	0.410	7.18	--	--	--	--
Single-adult household	--	--	--	--	0.663	4.22
Household with elderly persons (Age ≥ 65)	--	--	1.116	3.42	--	--
Household with unrelated persons	-0.591	-2.87	--	--	--	--
Asian household	--	--	--	--	1.923	3.88
Black household	--	--	--	--	0.565	3.26

The estimation results for housing owners indicate that higher income is associated with a higher tendency to own a single-family detached unit followed by a single-family attached unit. Higher household size is associated with a lower tendency to own a single-family detached housing unit. Likewise, single-adult households are more likely to live in single-family detached households. Households with elderly individuals are less likely to own mobile homes or trailers. White households are more likely to own mobile homes or trailers than are households of other ethnicities. Households with at least a bachelor’s degree as the highest level of education are least likely to own mobile homes or trailers.

The estimation results for renters indicate that households with lower income have a higher tendency to stay in apartments. Larger households are more likely to live in single-family detached houses, whereas single-adult households are more likely to rent apartments. Households with elderly persons have a higher tendency to rent single-family attached housing units, while households with unrelated persons are least likely to rent single-family detached units. Asian and Black households are more likely to rent apartments.

3.3.6.4 Residential location choice

A multinomial logit model of residential location was estimated using 1,779 household records from the DFW data. The model estimation was carried out for 99 randomly sampled residential location alternatives and the chosen zone in the choice set for each employed person in the data. The universal choice set included all zones belonging to the DFW study area, excluding zones with no population.

Table 3-15 Residential location choice model

	Coeff.	t-stat
LOS		
Mean Auto a.m. peak IVTT of employed adults in Household	-0.143	-44.565
Attraction Variables		
LN(total no. of households/100)	0.953	24.556
Accessibility to total Employment	-0.184	-23.78
Presence of children * Population Density (per 100 sq mile)	-0.002	-1.737
Living in Apartment * Population Density (per 100 sq mile)	0.007	6.805
Living in Single-family detached unit * Population Density (per 100 sq mile)	-0.006	-3.055
Household Income * Population Density (per 100 sq mile)	-0.004	-1.737
Own Housing unit * Median Income of the zone	0.009	7.68
Living in apartment * Median Income of the zone	-0.017	-6.625

As expected, the negative coefficient on the average a.m. peak auto travel time variable (level of service attribute) indicates that household residential location choices are driven by a preference for shorter commutes. The positive coefficient on the attraction variable ln (number of households/100) allocates a larger number of households to zones with a higher population. Other coefficients indicate that households with children prefer to live in zones with smaller population density; households living in apartments tend to locate in zones with high population density and low median income, and households living in single-family detached units and high-income households prefer to locate in low-density regions. Households that own a housing unit live in zones with high median income.

3.3.7 Employment Choices

The employment choices module is responsible for determining the various choice dimensions related to an individual's employment. The choice dimensions include labor participation, employment industry, decision to change or quit job, employment location, weekly work hours, and flexibility of schedule. The models corresponding to these choice dimensions are described in detail below.

3.3.7.1 Labor participation model

The labor participation model determines the decision to enter or exit the workforce for each individual over 12 years of age. The model takes the binary logit structure and is estimated using person records drawn from the PUMS data.

As shown in Table 3-16, age has the expected negative effect on participation in the labor market. Years of education, on the other hand, have positive but nonlinear effect, as suggested by the years of education squared term. Gender and stage of life cycle also have significant effect on labor participation. Specifically, compared to males, females with no children and females with children between 6 and 17 years are less likely to work. On the other hand, females with young kids under 6 years of age are more likely to work. Individuals who are separated, single, widowed, or divorced all have a higher likelihood, but in a decreasing degree, to participate in the job market than those who are married.

Table 3-16 Labor participation model

	Coeff.	t-stats
Constant	1.124	18.61
Age	-0.058	-75.63
Years of education	0.025	2.27
Years of education squared	0.008	12.89
Presence and age of own children (male as base)		
Female with own children under 6 years only	0.742	17.56
Female with own children 6 to 17 years only	-1.319	-41.62
Female with own children under 6 years and 6 to 17 years	-0.072	-2.74
Female with No own children	-1.253	-37.47
Marital Status (now married but not separated as base)		
Widowed	1.293	56.05
Divorced	0.976	22.58
Separated	2.206	60.80
Never married or under 15 years old	1.743	32.33

3.3.7.2 Employment industry

Once an individual enters the workforce, the employment industry model determines the industry in which the individual works. It is assumed that, once an individual enters an industry, the individual does not change industry during his or her lifetime. The model takes the multinomial logit structure and was estimated using the 1996 DFW Household Activity-Travel Survey. The industry variable was aggregated into six categories: construction and manufacturing, trade and transportation, professional businesses, government, retail and repair, and other. The final specification for the industry model (with other industry as the base alternative) is presented in Table 3-17.

The estimation results indicate that females and Blacks are more likely to work in professional businesses or in the government than males and non-Blacks. Individuals with high school degrees and males with associate's degrees are more likely to work in the government, followed by the trade and transportation industry. Females with associate's degrees and individuals with bachelor's degrees or above are also more likely to work in the government, followed by professional businesses.

Table 3-17 Employment industry model

	Construction and Manufact.		Trade and Transport.		Professional Businesses		Government		Retail and Repair	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constant	1.60	16.91	0.64	3.21	2.13	13.16	-1.05	-2.25	2.01	22.42
Female	--	--	--	--	1.42	20.06	0.57	4.28	--	--
Black	--	--	--	--	0.23	2.16	0.50	2.73	--	--
Education Level										
High School	--	--	0.79	4.04	0.66	4.55	1.88	4.07	--	--
Associate's	0.62	3.42	1.27	4.83	0.76	6.89	2.33	4.44	--	--
Bachelor's	0.60	5.75	0.99	4.70	1.55	9.75	2.25	4.74	--	--
Master's+	--	--	0.60	2.45	1.83	10.14	1.97	3.96	-0.97	-5.45
Female with associate's degree	--	--	--	--	0.94	3.29	--	--	--	--

3.3.7.3 Employment mobility

If an individual is currently employed, then the employment separation look-up table (see Table B-6 of Appendix B) is used to determine whether or not the individual stays in his or her current job. The probabilities were obtained from the Bureau of Labor Statistics and are based on the individual's industry.

3.3.7.4 Employment location model

A multinomial logit structure is used to model the work location of an employed individual. The model was estimated using 2,368 records of employed persons from the DFW household activity survey data. The universal choice set of alternative employment locations included all zones in the DFW area that had non-zero number of employment opportunities. The choice set considered for each individual consisted of the actual chosen zone plus 99 randomly sampled non-chosen zones. The best specification of the model is shown in Table 3-18. It should be noted that, for any given simulation year, the residential location of a household is updated after an individual's employment location is updated. Thus, the employment location choice does not depend on residential location characteristics.

Table 3-18 Employment location choice model

	Coeff.	**t-stats**
LN(Total employment/100)	0.6441	26.767
Fraction of retail employment	-0.3123	-3.301
Accessibility to population	-0.0432	-3.524
Accessibility to retail employment	0.3738	5.538
Dallas CBD	0.2267	1.829
High employment zone (total employment > 200)	0.3137	4.736

3.3.7.5 Work duration model

The time an individual spends at work per week is modeled using an ordered-response probit structure, in which the dependent variable is defined as fewer than 34 hours, between 34 and 45 hours, and more than 45 hours. The estimation results obtained using the DFW household survey data are presented in Table 3-19. It is evident that males are more likely to work more hours than females. The higher the education level, the more hours an individual will work. Individuals in the construction and manufacturing sectors, and in trade and transportation industries, work longer work hours than individuals in the other industries.

Table 3-19 Work hour model

	Coeff.	t-stats
Threshold 1	-0.204	-3.21
Threshold 2	1.442	21.73
Male	0.479	13.79
Education Level		
High School degree	0.398	6.10
Associate's degree	0.462	5.26
Bachelor's degree	0.599	8.79
Master's and higher	0.631	8.39
Industry		
Construction and Manufacturing	0.297	6.62
Trade and Transportation	0.211	4.11

3.3.7.6 Work schedule flexibility

The flexibility of an individual's work schedule was modeled using a multinomial logit model. The seven choice alternatives are (1) variable by choice, (2) variable depending on the work, (3) allowed to vary within fixed limits, (4) fixed starting time but variable ending time depending on the work, (5) fixed but different hours different days of the week, (6) fixed and the same for several days or weeks, and (7) fixed and the same every day. The model was estimated using the DFW household survey data and the results are presented in Table 3-20. The parameter estimates represent the effect of exogenous variables on the propensity of each work schedule alternative relative to the fixed and the same everyday alternative. Some of the key results are highlighted below.

Table 3-20 Work schedule flexibility model

	Variable by choice		Variable depending on work		Allowed to vary within fixed limits		Fixed starting time, variable ending time depending on work		Fixed, but different hours, different days of the week		Fixed and the same for several days or weeks	
	Coeff.	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**	**Coeff.**	**t-stats**
Constant	-2.303	-10.70	-0.758	-4.12	-1.623	-7.97	-1.440	-14.47	-1.520	-6.53	-2.304	-23.72
Female	-0.440	-4.20	-0.423	-4.44	--	--	--	--	--	--	--	--
Age	0.016	3.28	-0.009	-2.30	-0.016	-3.87	--	--	-0.014	-2.72	--	--
Has child under 6 years	--	--	--	--	0.339	3.02	--	--	--	--	--	--
Ethnicity												
Hispanic	-0.486	-2.19	-0.416	-2.42	--	--	--	--	--	--	--	--
Black	-0.447	-2.54	-0.459	-3.10	--	--	--	--	-0.640	-3.12	--	--
White	--	--	--	--	1.010	7.64	0.646	6.09	--	--	--	--
Education Level												
Bachelor's degree	0.672	5.90	--		0.894	9.19	--	--	--	--	--	--
Master's or higher	0.701	4.55	0.389	2.80	1.005	7.23	0.258	2.08	--	--	--	--
Industry												
Construction and Manufacturing	--	--	--	--	0.349	3.14	--	--	-0.875	-3.36	--	--
Government	-0.686	-2.39	-0.748	-2.99	--	--	-0.517	-2.67	--	--	--	--
Professional Businesses	--	--	-0.284	-2.57	-0.499	-4.76	--	--	--	--	--	--
Retail and Repair	0.339	2.69	0.298	2.60	--	--	--	--	0.815	5.99	0.452	2.59
Hours Worked												
Part-time	1.336	10.25	0.995	7.98	0.394	2.98	--	--	1.028	6.90	--	--
Over-time	1.054	7.86	1.472	12.82	0.787	6.79	1.174	11.51	0.651	3.75	0.472	2.48

The estimation results shown in Table 3-20 indicate that compared to males females are less likely to have hours that are variable by choice or variable depending on work. As an individual ages, he or she is more likely to have variable work hours by choice, but less likely to have variable hours depending on work, varying hours within fixed limits, or fixed, but different hours, for different days of the week. An individual with a young child is more likely to have hours that vary within fixed limits than an otherwise identical individual. If an individual is Hispanic or Black, then he or she is less likely to have hours that are variable by choice or variable depending on work. Compared to other racial groups, Black individuals are also less likely to have hours that are fixed, but alter for different days of the week. If an individual is White, then he or she is more likely to have hours that are allowed to vary within fixed limits or have a fixed starting time but variable ending time depending on work. Individuals with bachelor's degrees are more likely to have hours that are variable by choice or allowed to vary within fixed limits. Individuals with master's degrees have the most work hour flexibility compared to individuals with other education levels.

Employment industry and hours worked per week both play significant roles in determining work schedule variability and flexibility. The construction and manufacturing industry tends to have hours that are allowed to vary within fixed limits and is less likely to have fixed but different hours, different days of the week. Individual employed by the government are less likely to have hours that are variable by choice or variable depending on work as well as hours that have fixed starting time but variable ending time dependent on work. Individuals in professional businesses are less likely to have hours that are variable depending on work and hours that are allowed to vary within fixed limits. The retail and repair industry is more likely to have every type of flexibility, except being allowed to vary within fixed limits or to vary work end time. Finally, individuals who work either part-time or over-time are more likely to have flexible work schedules than are those who work full time.

3.3.8 Education Choices

The education choices module is responsible for determining whether an individual pursues further education for the current simulation year and the location of the new school when applicable. As explained below, separate models have been developed for different level of educational attainment.

3.3.8.1 Primary education

By default, every child is assumed to receive kindergarten (at the age of five) and primary education until the age of 12 without dropping out. School location is determined by the DFW school look-up table (see Table B-7 of Appendix B for an excerpt of the entire table). The DFW school look-up table is constructed by assigning each student to a TAZ within the independent school district (ISD) in which he or she resides and is closest to his or her residential location. If there are two or more TAZ in one ISD, then the look-up table provides the probability associated with each TAZ in the ISD.

3.3.8.2 Secondary education

For individuals 13 to 18 of age, the probability of dropping out of school is given by the drop-out look-up table that provides drop-out rates by age, gender, and race. This table is available from the Texas Education Agency and is presented in Table B-8 of Appendix B.

When an individual remains in school and, therefore, enters a new grade, the TAZ zone of the individual's school is determined by the DFW school look-up table described earlier.

3.3.8.3 Higher education

Whether or not a person goes beyond a high school degree is determined by the education attainment table (see Table B-9 of Appendix B). The table was compiled using the 2000 census 5 percent PUMS data for the DFW area. Once the highest degree is determined at the age of 18, the number of years of education is predicted deterministically: 2 years for an associate's degree, 4 years for a bachelor's degree, 6 years total for a master's degree, and 9 years total for a doctoral degree. For each level of education, the college look-up table is used to determine the TAZ zone of the individual's school (see Table B-10 in Appendix B for an excerpt of the entire table).

3.3.9 Income

In CEMSELTS, income is modeled at the individual level and subsequently aggregated up to the household level. The personal income model takes the grouped response structure with the income defined as a 6-way variable: $0–$9,999, $10,000–$19,999, $20,000–$29,999, $30,000–$39,999, $40,000–$49,999, and $50,000 or above. The model has been estimated using the 1996 DFW household travel survey. It is evident from the estimation results, as shown in Table 3-21, that age (which may act as a proxy for job experience) has a positive impact on income level. Males tend to earn higher income than females. Compared to individuals of other races, White individuals tend to earn more, while Black individuals tend to earn less. Education level has the expected positive effect on personal income. The higher the level of education an individual attains, the more he or she earns. The income of retired individuals is lower than that of currently employed ones. It is observed that individuals in construction, manufacturing, wholesale trade, and transportation tend to earn higher incomes.

Table 3-21 Personal income model

	Coeff.	t-stats
Age	0.033	17.15
Male	1.021	19.56
Race		
Black	-0.604	-5.40
White	0.199	2.46
Education (less than high school as base)		
High school	0.542	4.80
Attended college but no degree	1.018	9.56
Associate's degree	1.327	10.00
Bachelor's	2.014	19.34
Master's and higher	2.443	19.84
Professional Degree	1.920	11.11
Employed	0.099	1.49
Retired	-2.730	-8.25
Industry (other industry as base)		
Construction and manufacturing	0.180	1.77
Wholesale trade and transportation	0.182	1.68
Professional, personal, and financial services	-0.546	-5.92
Retail and repair	-0.792	-8.45
Variance	0.973	69.30

3.4 Updating Procedure

This section describes the procedure to be implemented within CEMSELTS for updating the demographic and socioeconomic characteristics of all households and individuals using the models discussed in Section 3.3. The overall updating procedure involves performing the following two major sequential steps for each time step of the simulation run: (1) updating the attributes of all individuals and (2) updating the attributes of the households. The first step entails applying the immigration and emigration, death, birth, marital status, employment choices, education choices, and income modules to the population. This step is described in detail in Section 3.4.1. The second step involves applying the housing choices and vehicle ownership modules to existing and new households. This step is described in detail in Section 3.4.2. For the mathematical procedures to predict the choice outcomes from various econometric models, the reader is referred to our earlier Research Report 4080-4.

3.4.1 Updating Individuals

This section describes the procedure by which the various individual-level model modules are applied to update the socio-demographic attributes of individuals for each simulation time step (1 year). This procedure is presented in Figure 3.1 and described in detail below.

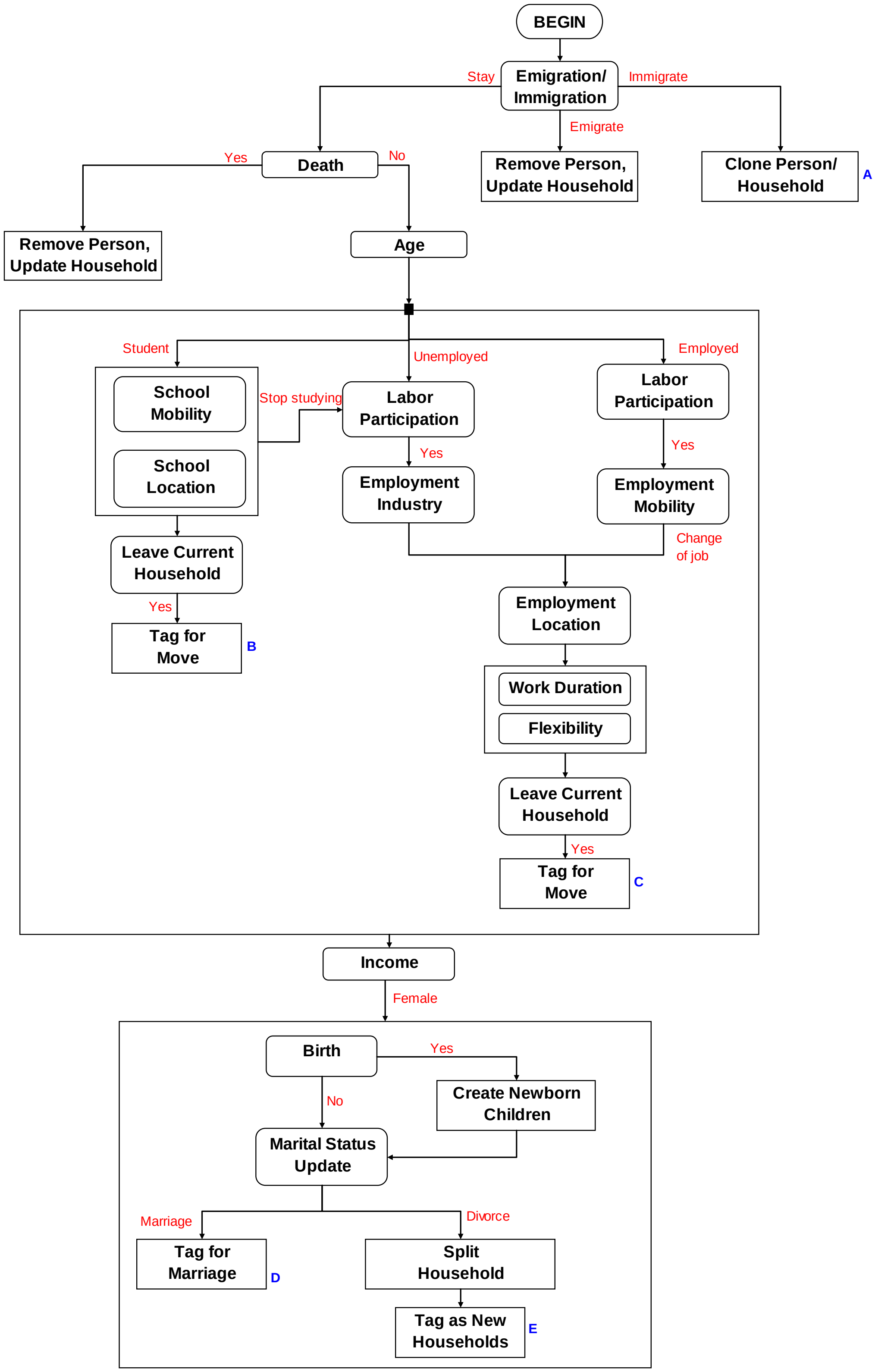

Figure 3.1 Procedure for updating individual-level attributes

3.4.1.1 Emigration and Immigration

At the beginning of every simulation year, the net migration rates table described in Section 3.3.4 is used to obtain the migration probability for a given individual. If the probability is positive, then it is used to determine whether an identical individual will immigrate into the study area. If so, the given individual will be "cloned" to create a new addition to the existing population. If the migration probability is negative, then it is used to determine whether the given individual will move out of the study area. If so, the individual will be removed from the population at this point. After the removal of the individual, if there are no more adults in the household, then the household will be removed.

3.4.1.2 Death and age

Next, we predict whether an individual will continue to exist based on the death model. If not, the individual is removed from the population and the corresponding household attributes are updated (for example, household size and marital status of the spouse). If an individual continues to exist, then we increment the age by 1 and proceed to update his or her schooling or employment status.

3.4.1.3 Education

Once age is updated, for any individual who was a student in the previous year or who is under the age of 13, we update the schooling status as follows:

- If age is under 5, the individual does not study.
- If age equals 5, assign the person to Grade K and use the DWF school look-up table to determine school location (see Section 3.3.8.1).

- If age is greater than 5 and less than 13, move the grade up by 1 and use the school look-up table to determine school location.

- If age is greater than or equal to 13 but less than 18, determine whether or not the person drops out of school based on the school drop-out look-up table (see Section 3.3.8.2). If the person is to drop out, the schooling status is changed to negative and the labor participation model is executed (see Section 3.3.7.1). Otherwise, update the school location based on the DFW school look-up table.

- If age equals 18, determine the highest degree the person will obtain based on the education attainment table (see Section 3.3.8.3). Note that for the purpose of CEMSELTS, we assume that it takes 2, 4, 2, and 3 years to complete an associate's, a bachelor's, a master's, and a doctorate degree, respectively. An individual must complete a bachelor's degree before pursuing a master's degree and must complete a master's degree before pursuing a doctorate degree. If the individual's final degree is an associate's degree, use the college look-up table to determine the school location and the location is fixed for 2 simulation years. If the individual is to start with a bachelor's degree, use the college look-up table to determine the school location. The location will remain unchanged for 4 years.

- If the individual is scheduled to start a new graduate program (master's or doctorate) this year, the college look-up table is used to determine the school location. Again, the location remains the same for the duration of the graduate program.

- If the individual is in the middle of pursuing an associate's, a bachelor's, a master's, or a doctoral degree, increment the degree year counter by 1. If the counter reaches the number of years required to complete the final degree, set the schooling status to negative and proceed to the labor participation model.

3.4.1.4 Employment

The employment module is run for individuals aged over 12 and not in school. If an individual is currently unemployed, then the labor participation model is used to see whether or not an individual enters the workforce. If so, the individuals work industry is determined.

If the individual is already employed, then the labor participation model is applied to determine whether or not he or she will stay in the workplace. If the individual continues to work, then his or her decision about a job change is determined based on the employment separation look-up table.

If there is a change of job or if the individual is (re-)entering the workforce, then we determine the work location using the employment location model. Then the work duration model is used to predict the weekly work hour so that the individual's full- or part-time status can be subsequently determined. Also, the work schedule flexibility model is used to identify the flexibility of the individual's work schedule.

3.4.1.5 Leave current household

When there is a change in an individual's school or work location, the individual will leave the current household if (a) the individual is an unmarried adult son or daughter, or an unmarried adult in a multi-adult household; and (b) the change in school or work location results in a longer commute than before. At this point, such an individual will be tagged as a "moving" individual and form a new household with or without other "moving" individuals later in the household formation process.

3.4.1.6 Income

Once the schooling- and employment-related attributes are determined, the income model is used to determine the personal annual income.

3.4.1.7 Birth and marital status

Once income is determined, all females aged 10 through 49 are considered for giving birth based on the birth model and the birth probability look-up table described in Section 3.3.2. If the female individual is predicted to give birth in the current simulation year, then the number of births look-up table is used to determine the number of children she will have from the birth. An entity is created to represent each child and the child gender look-up table is then used to determine the gender of each newborn child. If a female is married, then the husband is assigned as the father of each child. If she is not married, then the father is assigned as unknown. The race of each child is determined based on the parents' race. Any relevant household and system attributes are also updated.

The marital status of the female individual is then updated using the marital status change model described in Section 3.3.3.1. If the status changes from single to married, then the individual is tagged for marriage and the actual marriage will take place later during the household formation process. If the status changes from married to divorced, then the female's current household is split into two. One household includes the female and any biological children or relatives. The other household includes the now ex-husband, any relatives of the ex-husband, and any children whose biological mother is not the female individual. The new households are to be processed later during the household formation process.

3.4.2 Updating Households

This section describes the procedure by which the various household-level model modules are applied to update the socio-demographic attributes of households for each simulation time step (1 year). This procedure is depicted in Figure 3.2 and described in detail below.

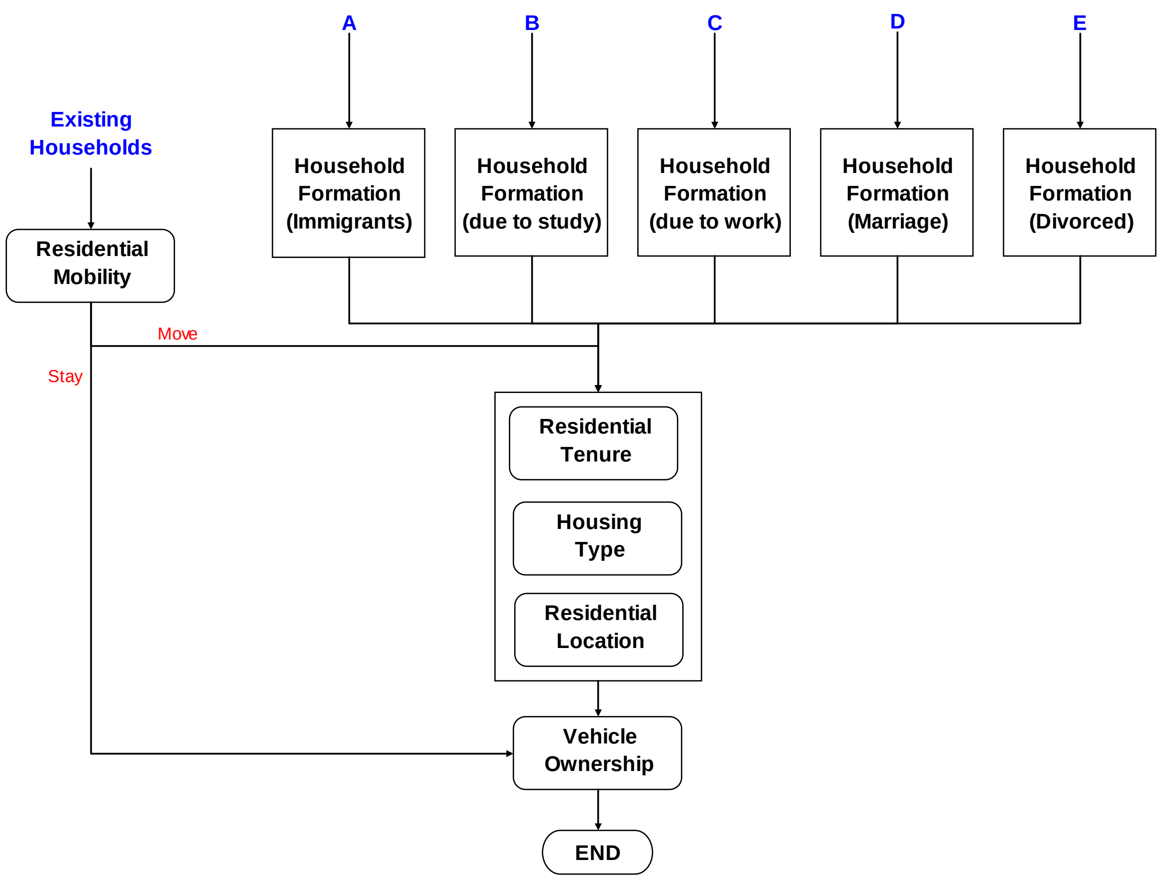

Figure 3.2 Procedure for updating household-level attributes

3.4.2.1 Household formation

The first step in the procedure for updating household-level attributes is forming new households from individuals that are new immigrants, individuals that have been tagged to move out of their existing households, and individuals that are to be married.

In this step, the immigrants that are "cloned" from the existing population are considered as candidates for becoming roommates with existing individuals (who have been tagged as movers due to school or work relocation) and as potential spouses for existing female individuals (who have been tagged for marriage). Any immigrants who are not matched with existing individuals will be merged into households so as to satisfy the projected number of households for that year. If it happens that all the individuals or all the adults in a household are cloned, then a similar new household is formed. Children are not allowed to immigrate unless an entire household is cloned.

Individuals who have been tagged as "moving" individuals due to their change of school or work location are merged into households as follows. Students going to the same school zone are randomly merged into new households such that 25 percent, 50 percent, 12.5 percent, and 12.5 percent of the new households are of size 1, 2, 3, and 4, respectively. Similarly, employed individuals working in the same zone are randomly merged into households of size 1 and 2 with respective shares of 75 percent and 25 percent.

As part of the household formation process, female individuals who are tagged to be married are matched with a male spouse. This is achieved by determining for each marrying female individual the preferred age, race, and education attainment level of her spouse using models described in Section 3.3.3.2. A single male satisfying these characteristics is randomly picked from the population (except those who have just updated as divorcees) to be paired with the female and together form a new household.

The household formation process also deals with creating the households resulting from divorces. Households to which the divorced females belong are updated. New household entities are created to represent the divorced male and any of his biological children and relatives.

3.4.2.2 Residential mobility

Once the new households are created, the existing households are considered for moving. The decision to move is determined by the residential mobility model described in 3.3.6.1. If the outcome is to stay in the existing residence, then the only household attribute remaining to be updated is the vehicle ownership. If the household is to move, then it is considered for emigration.

3.4.2.3 Housing choices

When a household is tagged to move within the study area, its tenure status, housing type choice, and new residential location are updated by using the models described in Sections 3.3.6.2, 3.3.6.3, and 3.3.6.4.

3.4.2.4 Vehicle ownership

The number of vehicles owned by a household is updated in the last step of the household-level updating procedure. The updating is based on the vehicle ownership model described in 3.3.5.

4. SYNTHETIC POPULATION GENERATOR

The preceding chapter discussed the modeling system, CEMSELTS, which is responsible for updating the demographic and socio-economic characteristics of the agents whose activity-travel patterns are simulated by CEMDAP. The current chapter is devoted to describing SPG, the component in CEMDAP-II that has been developed for creating the base-year initial population. Section 4.1 discusses the data requirements of SPG. Section 4.2 presents an overview of the logic and algorithm embedded in SPG. Section 4.3 explains in details the core of the algorithm that is responsible for estimating a multi-way distribution of household and person attributes.

4.1 Data Requirements

The goal of SPG is to synthesize the households and individuals that, together, represent the entire population within a given study area for the base year. The synthesizing procedure relies on two sources of data: the 2000 census data given in summary files SF1 and SF3, and the 2000 5 percent PUMS data. SF1 and SF3 are collections of summary tables of household and individual demographic variables for either census tracts, block groups, or blocks. SF1 is based on a 100-percent population survey and SF3 contains projected population figures based on sample households. Some of the summary tables describe the distribution of a single variable, while other tables are cross-tabulations describing the distribution of multiple variables. Depending on the demographic and socio-economic attributes that are considered relevant to the simulation exercise at hand, the user of SPG selects a set of summary tables from SF1 and SF3 to provide the marginal totals of the full multi-way distribution across all attributes of interest.

The PUMS data contain 5 percent representative samples of census records of households and individuals. Each household and individual is geographically referenced by a PUMA (public use micro area), which is typically larger in size than a census tract. A weight is provided for each household (individual) as an expansion factor, so that the sample households (individuals) can be expanded to represent all the households (individuals) in the PUMA.

The records in the PUMS data are used as “seeds” to inform the correlation structure of the full multi-way distribution. They are also used as the “original copies” from which additional households and individuals are created to population the study area. The “copying” process is carried out to satisfy the multi-way distribution to the greatest extent possible.

4.2 Algorithm Overview

In the current implementation of SPG, it is assumed that the target areas for which synthetic populations are constructed are the census block groups. Thus, the users are required to specify summary tables for the block groups of interest. The user also needs to supply the PUMS data for the PUMA corresponding to each of the target block groups. For each pair of target block group area and seed PUMA, the algorithm depicted in Figure 4.1 is executed to synthesize the households and individuals for the target area. The steps involved in the algorithm are discussed below.

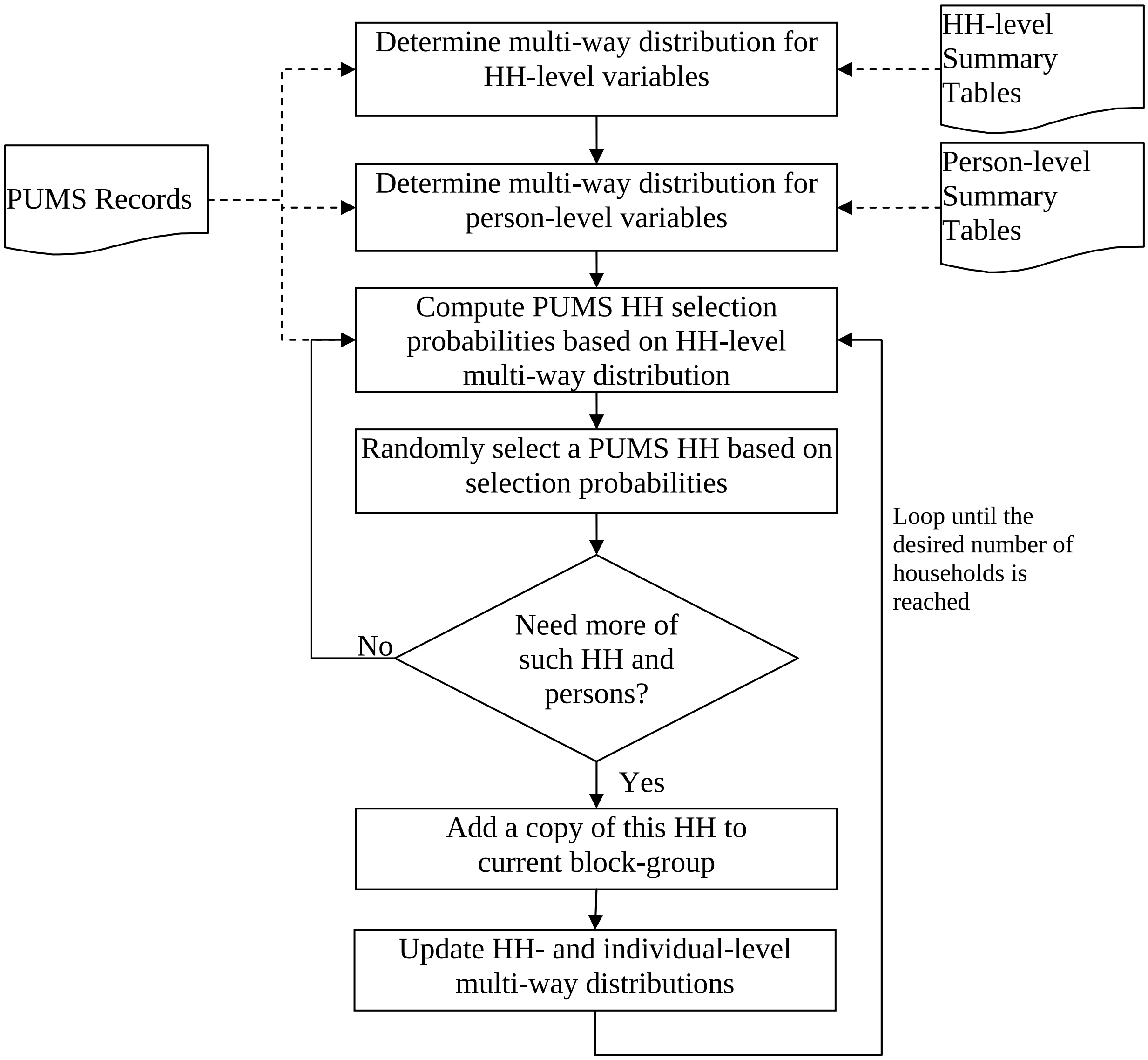

Figure 4.1 Overview of the population synthesis algorithm

4.2.1 Determine Household-Level Multi-Way Distribution

This step creates the full multi-way distribution across all the household-level attributes in the user-supplied summary tables. For example, if the user requires data about household size, household type, and age of householder, then the two-dimensional summary tables P21 and P26 can be used to construct a three-dimensional table (see

Table 4-1 and

Table 4-2 for the structures of these two tables). The correlation among the three variables is then informed by the PUMS records. The method used for constructing the full multi-way distribution given the marginal totals and the correlation structure will be discussed in detail in Section 4.3. For the ease of our subsequent discussion, we denote each cell in this household-level multi-way distribution by HH[v_1, v_2, …, v_k, …], where the index v_k denotes the value of the k^{th} household-level variable, $v_k = 1, \ldots, M_k$. Thus, HH[v_1, v_2, …, v_k, …] gives the number of such households in the target area.

Table 4-1 Structure of summary table P21

Family households
Householder 15 to 24 years
Householder 25 to 34 years
Householder 35 to 44 years
Householder 45 to 54 years
Householder 55 to 64 years
Householder 65 to 74 years
Householder 75 to 84 years
Householder 85 years and over
Non-family households
Householder 15 to 24 years
Householder 25 to 34 years
Householder 35 to 44 years
Householder 45 to 54 years
Householder 55 to 64 years
Householder 65 to 74 years
Householder 75 to 84 years
Householder 85 years and over

Table 4-2 Structure of summary table P26

Family households:
2-person household
3-person household
4-person household
5-person household
6-person household
7-or-more person household
Non-family households:
1-person household

2-person household
3-person household
4-person household
5-person household
6-person household
7-or-more person household

4.2.2 Determine Individual-Level Multi-Way Distribution

This step creates the full multi-way distribution across all the individual-level attributes in a way similar to that described above for the household-level attributes. For example, given summary tables P7 and P12 (see Table 4-3 and

Table 4-4 for the table structures), this step constructs a three-dimensional table describing the joint population distribution by race, age, and sex. For ease of our subsequent discussion, we denote each cell in this individual-level multi-way distribution by POP[v_1, v_2, …, v_l, …], where the index v_l denotes the value of the l^{th} individual-level variable, $v_l = 1, \ldots, N_l$.

Table 4-3 Structure of summary table P7

Single race
White alone
African-American alone
American-Indian and Alaska Native alone
Asian alone
Native Hawaiian and other Pacific Islander alone
Some other race alone
Two or more races

Table 4-4 Structure of summary table P12

Male:
Under 5 years
5 to 9 years
10 to 14 years
15 to 17 years
18 and 19 years
20 years
21 years
22 to 24 years
25 to 29 years
30 to 34 years

35 to 39 years
40 to 44 years
45 to 49 years
50 to 54 years
55 to 59 years
60 and 61 years
62 to 64 years
65 and 66 years
67 to 69 years
70 to 74 years
75 to 79 years
80 to 84 years
85 years and over
Female:
Under 5 years
5 to 9 years
10 to 14 years
15 to 17 years
18 and 19 years
20 years
21 years
22 to 24 years
25 to 29 years
30 to 34 years
35 to 39 years
40 to 44 years
45 to 49 years
50 to 54 years
55 to 59 years
60 and 61 years
62 to 64 years
65 and 66 years
67 to 69 years
70 to 74 years
75 to 79 years
80 to 84 years
85 years and over

4.2.3 Compute Household Selection Probabilities

Based on the household- and individual-level multi-way distributions, HH and POP, each PUMS sample household in the seed area is assigned with a probability of being selected into the target area. The probability of household i being chosen is computed by

$$P_i = \frac{w_i}{\sum_j w_j \cdot Y^j_{v_1,v_2,\cdots,v_k,\cdots}} \cdot \frac{\mathrm{HH}[v_1,v_2,\cdots,v_k,\cdots]}{\sum_{u_1,u_2,\cdots,u_k,\cdots} \mathrm{HH}[u_1,u_2,\cdots,u_k,\cdots]},$$

where w_i is the PUMS weight associated with household i and elements of the vector (v_1, v_2, …, v_k, …) take the values that reflect the characteristics of household i. $Y^j_{v_1,v_2,\cdots,v_k,\cdots}$ takes a value of 1 if the j^{th} household is characterized by(v_1, v_2, …, v_k, …) (i.e., the same as the i^{th} household), and a value of 0 otherwise.

4.2.4 Randomly Select a Household

Based on the probabilities computed in the previous step, a household is randomly drawn from the pool of sample households to be considered for "cloning" and added to the population for the target block group area.

4.2.5 Check Household Desirability

Given a randomly selected household i, we will add a copy of the household into the population for the target area if the following conditions hold:

1. The corresponding cell in the household-level multi-way table, HH[v_1,v_2,…, v_k,…], is greater than a predefined threshold. In theory, the threshold should be zero so that the number of households characterized by (v_1,v_2,…, v_k,…) is never higher than desired (as given by the multi-way distribution table). However, this condition may need to be relaxed by allowing a small negative threshold value to accommodate any convergence problem due to rounding errors and inconsistency between summary tables and PUMS data.

2. For each person in the household, the corresponding cell in the individual-level multi-way table, POP[v_1, v_2, …, v_l, …], is greater than a predefined threshold. Again, the threshold is set to a small negative value.

If any of the above conditions fails, then the household is removed from the consideration set so that it will never be selected again. The selection probabilities of the households remaining in the consideration set are then updated before the next household is randomly selected.

4.2.6 Add Household

If the selected household satisfies the conditions described in Section 4.2.5, then the household is added to the pool for the current block group area. Meanwhile, the weight associated with the household is decreased by one.

4.2.7 Update Multi-way Distributions

The cell value, HH[v_1,v_2,…, v_k,…], that corresponds to the selected household and the cell value, POP[v_1, v_2, …, v_l, …], that corresponds to each of the individuals in the household are decreased by one to reflect the reduced desirability of such a household and such individuals for the subsequent iterations.

4.3 Construction of Multi-Way Distributions

This section describes the method developed to construct the household- and individual-level multi-way distributions discussed in Sections 4.2.1 and 4.2.2. The problem here is to merge multiple single- or multi-dimensional distributions, which may or may not share common variables, into one fully joint multi-way distribution. The method entails applying a recursive merge procedure and the iterative proportional fitting (IPF) procedure. The two procedures are described in Sections 4.3.1 and 4.3.2 below.

4.3.1 Recursive Merge Procedure

Assume that there is a queue of K tables, each of which represents an initial distribution. The following pseudocode describes the merge procedure that ultimately results in one single table that represents the final joint distribution:

PROCEDURE *JoinTables*
  WHILE no. of tables in queue > 1
    Get the two tables in the front of the queue, *Table1* and *Table2*
    CALL *MergeTables* with *Table1* and *Table2* RETURNING *NewTable*
    Remove *Table1* and *Table2* from the queue
    Insert *NewTable* to the front of the queue
  END-WHILE
END-PROCEDURE

PROCEDURE *MergeTables*
  IF *Table1* and *Table2* have a variable V_k in common, THEN
    Initialize *NewTable* to an empty table
    FOR each value (denoted as i) of V_k
      Extract *Table1'* from *Table1* that satisfies $V_k=i$
      Extract *Table2'* from *Table2* that satisfies $V_k=i$
      CALL *MergeTables* with *Table1'* and *Table2'* RETURNING *NewTable'*
      Append *NewTable'* to *NewTable*
    END-FOR
  ELSE
    DETERMINE *NewTable* by performing IPF on *Table1* and *Table2*
    RETURN *NewTable*
  END-IF
END-PROCEDURE

4.3.2 IPF Procedure

To describe the IPF procedure, we adopt the following notation:

v_k : the observed value of the kth variable, $v_k = 1, 2, \ldots, M_k$

NewTable: the resulting joint distribution table of dimension $v_1 \times v_2 \times \ldots \times v_k$

$N_{v_1, v_2, \ldots v_k}$: the estimated count in cell ($v_1, v_2, \ldots, v_k$) of *NewTable*

$N_{v_k = j}$: the sum over cells corresponding to $v_{k=j}$ in *NewTable*,

$$N_{v_k = j} = \sum_{v_1} \cdots \sum_{v_{k-1}} \sum_{v_{k+1}} \cdots \sum_{v_h} N_{v_1, v_2, \cdots, v_k = j, \cdots, v_h}$$

T_{kj}: the marginal total for $v_k = j$ as given by the input summary tables, *Table1* and *Table2*

N: the total count as given by $\sum_{k,j} T_{kj}$

The IPF procedure begins by initializing each cell value in *NewTable*, $N_{v_1, v_2, \ldots v_k}$, by the observed counts of corresponding PUMS records. Then, the following loop is executed:

REEPEAT

FOR each value j of each variable k

Update $N_{v_1, v_2, \ldots, v_k = j, \ldots, v_h}$ by $N_{v_1, v_2, \ldots, v_k = j, \ldots, v_h} \dfrac{T_{kj}}{N_{v_k = j}}$

END-FOR

UNTIL the relative change in all cell values between iterations is small enough

5. SUMMARY

This report has described the development of three major components of CEMDAP-II: (1) CEMDAP, the activity-travel simulator that simulates the detailed activity-travel patterns of the population; (2) CEMSELTS, the system that updates the socio-demographic characteristics of the population for a time increment into the future (e.g., one year); and (3) SPG, the population synthesizer that creates a disaggregate representation of the population at the beginning of the simulation run.

Chapter 2 discussed the enhancement made to CEMDAP for (1) accommodating a finer spatial resolution (4,874 zones instead of 919 zones for the DFW area in Texas), (2) explicitly accounting for children's activity-travel patterns, (3) explicitly capturing the interdependencies between the travel patterns of children and their parents (such as escort to and from school and joint participation in discretionary activities), and (4) using the DFW household travel survey data in a statistically more efficient way. The revised representation frameworks for defining the complete activity-travel patterns of individuals—including workers and non-workers, students and non-students, and children and adults—as well as the choice elements that completely characterize these patterns were discussed. The newly developed econometric modeling system, the data used in the empirical model estimations, and the empirical model estimation results were described briefly. Also, the procedure implemented within CEMDAP for applying the new models to predict the complete activity-travel patterns was explained in details.

Chapter 3 discussed the modeling system developed for CEMSELTS and the application procedure. The constituent models that are responsible for updating the many household- and individual-level demographic and socioeconomic attributes were identified. These models include the immigration and emigration, death, birth, marital status, employment choices, education choices, income, housing choices, and vehicle ownership modules. Several data sources were used to support the development and estimation of the models and have been described in this chapter. The econometric structures and the estimation results of the models, as well as the overall procedure for applying these models to achieve population updating, have also been discussed. The chapter thus provides the necessary information for implementing and executing CEMSELTS software.

Chapter 4 of the report discussed the problem of synthesizing a population based on census summary tables and the PUMS data for the purpose of activity-travel simulation. While the lowest spatial level at which the PUMS data are available is the PUMA level, the summary tables are available from the census tract level down to the block level. The software program developed for solving the population synthesis problem is intended for producing population at the census block group level. The chapter presented the algorithm based on which the software program was developed. Moreover, the chapter described the recursive and the IPF procedures that are central to the proposed algorithm. The SPG program developed was generic enough to be applied to different study areas.

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Appendix A: Model Estimation Results for CEMDAP

This appendix presents the complete set of empirical models estimated using travel survey data from the DFW region that constitutes the overall CEMDAP modeling system. This overall modeling system is broadly subdivided into five categories, each of which is discussed in a separate section below. The five categories are (1) the generation-allocation model system (Section 1), (2) the worker scheduling model system (Section 2), (3) the non-worker scheduling model system (Section 3), (4) the joint discretionary tour scheduling model system (Section 4), and (5) the children scheduling model system (Section 5).

1. Generation-Allocation Model System

The generation-allocation model system comprises a suite of twenty-two models (Models GA1 through GA22). These models together determine the decisions of all household members to pursue various types of activities during the day. Each of these models is presented below.

1.1 Child's decision to go to school (Model GA1)

Model GA1 is a binary logit model that determines the decision of children who are students to go to school. The model was estimated using data from 939 children in the sample who are students. Of these children, 716 (76.25 percent) went to school on the diary day. The empirical results (Table A-1) indicate that this decision is significantly influenced by the children's level of education completed. Specifically, we find that children who have completed no school (or equivalently who are currently in preschool) or preschool are less likely to go to school than are children in higher grades in school.

Table A-1 Child's decision to go to school (Model GA1)

Explanatory variables	**Param.**	**t-stat**
Constant	-0.5765	-2.184
Highest level of education completed		
No school (base)	--	--
Preschool	0.9046	3.319
Kindergarten to grade 4	1.9349	7.321
Grade 5 to grade 8	1.8628	6.775
Grade 9 or higher	1.6204	3.375
Household income (in thousands of dollars)	0.0056	2.197

1.2 Child's school start time (Model GA2) and end time (Model GA3)

The next two models determine the school start time (Model GA2) and end time (Model GA3) for children deciding to go to school. These models have a hazard-duration econometric structure with non-parametric baseline hazard functions and gamma heterogeneity. These models were estimated using data from the 716 children in the sample who went to school on the diary day. As per the econometric specification, a positive sign on a covariate in these models implies a lower hazard rate or a later start and end of school. Conversely, a negative sign on a covariate implies a higher hazard rate or an early start and end of school.

Table A-2 presents empirical estimation results for Model GA2. The school start time is measured in minutes from 3:00 a.m.. The threshold parameters determine the shape of the baseline hazard (Figure A.1). The covariates found to influence the start and end times of school include the age of the child and the level of education completed. Specifically, younger children start school later in the day, whereas children in higher grades (grade 5 or higher) start school earlier. In addition, the start and end times are found to vary based on the child's ethnicity.

Table A-2 Child's school start time (Model GA2)

Explanatory variables	Param.	t stat
Threshold parameters		
THRESH01 (0 to 260.5)	-2.5892	-17.193
THRESH02 (260.5 to 270.5)	-1.9999	-16.794
THRESH03 (270.5 to 280.5)	-1.4535	-14.449
THRESH04 (280.5 to 285.5)	-0.9721	-10.542
THRESH05 (285.5 to 290.5)	-0.6452	-6.79
THRESH06 (290.5 to 295.5)	-0.4148	-4.118
THRESH07 (295.5 to 300.5)	-0.0264	-0.216
THRESH08 (300.5 to 310.5)	0.2779	1.828
THRESH09 (310.5 to 320.5)	0.5515	2.908
THRESH10 (320.5 to 330.5)	0.7849	3.395
THRESH11 (330.5 to 350.5)	1.0679	3.589
THRESH12 (350.5 to 400.5)	1.3303	3.658
Age ≤ 5 years	0.5034	3.417
Highest level of education completed		
Kindergarten to grade 4	-0.2604	-2.579
Ethnicity		
African-American	-0.2393	-2.198
Asian	0.8228	2.597
Number of unemployed adults in household	0.1314	1.404
Variance of the heterogeneity term	0.2153	0.477

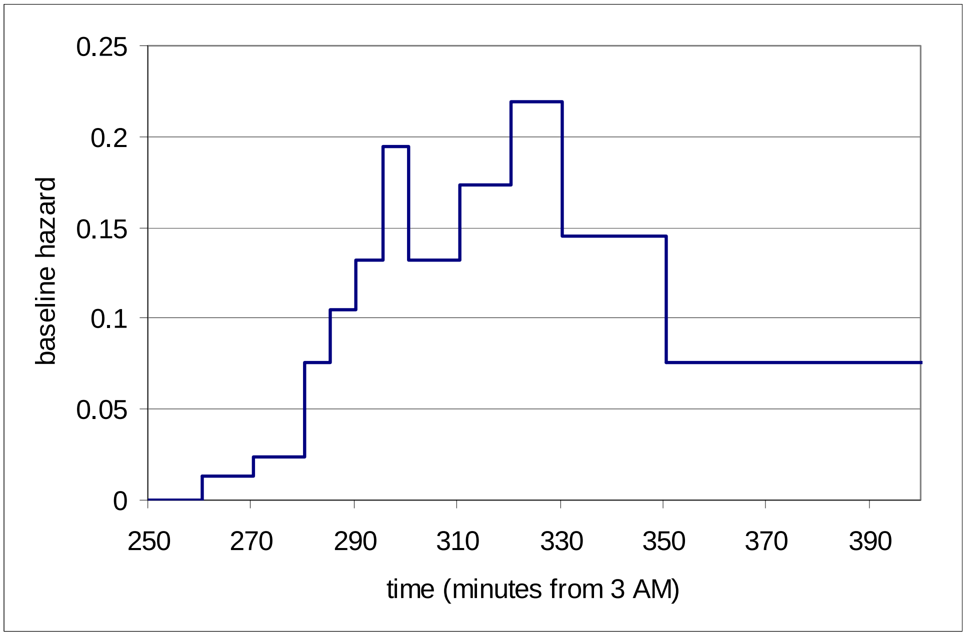

Figure A.1 Baseline hazard function for child's school start time

Table A-3 presents empirical estimation results for Model GA3. The school end time is measured in minutes from school start time (i.e., the model determines the school-based duration). The threshold parameters determine the shape of the baseline hazard (Figure A.2). The covariates found to influence the start and end times of school include the age of the child, the level of education completed, and the number of employed adults in the household. Specifically, younger children are found to stay in school for longer durations if one or more of the household adults are employed. Further, children in lower grades are found to end school earlier than are children in higher grades.

Table A-3 Child's school end time (Model GA3)

Explanatory variables	Param.	t-stat
Threshold parameters		
THRESH01 (0 to 300.5)	-2.6203	-17.108
THRESH02 (300.5 to 400.5)	-2.1629	-16.45
THRESH03 (400.5 to 420.5)	-1.5867	-14.9
THRESH04 (420.5 to 430.5)	-0.9619	-10.778
THRESH05 (430.5 to 440.5)	-0.4141	-5.018
THRESH06 (440.5 to 450.5)	-0.0992	-1.174
THRESH07 (450.5 to 460.5)	0.1091	1.231
THRESH08 (460.5 to 480.5)	0.5927	5.222
THRESH09 (480.5 to 550.5)	1.0309	6.413
Age ≤ 5 years	-2.3404	-1.676
Age ≤ 5 years * one employed adult	3.0147	2.15
Age ≤ 5 years * two employed adults	3.5208	2.51
Highest level of education completed		
Preschool	-0.4673	-3.892
Kindergarten to grade 4	-0.4006	-3.913
Variance of the heterogeneity term	0	0

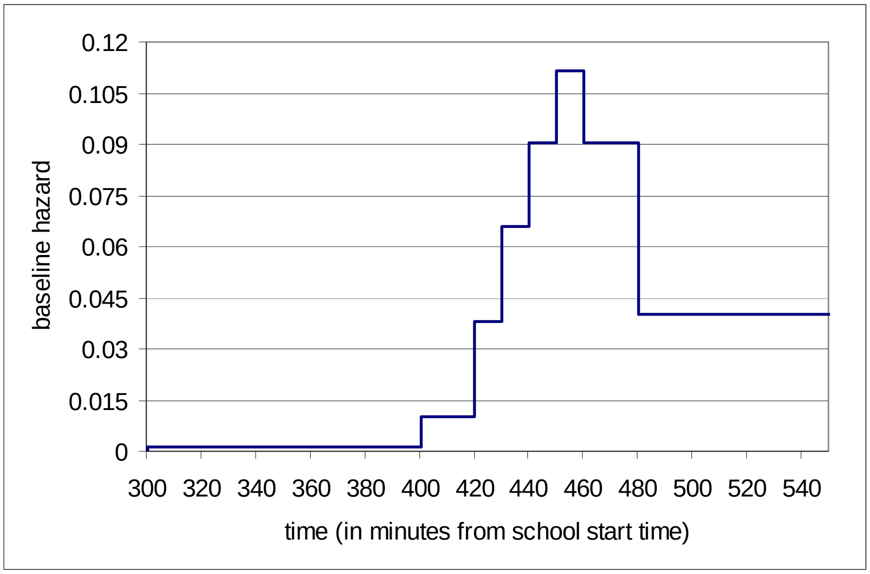

Figure A.2 Baseline hazard function for child's school end time

1.3 Decision to go to work (Model GA4)

Model GA4 is a binary logit model that determines the decision of employed adults to go to work. The model was estimated using data from 3,152 employed adults in the sample. Of these persons, 2,348 (74.5 percent) went to work. The empirical results (Table A-4) indicate that elderly adults are less likely to go to work on any day, whereas those contributing a greater fraction of the household income are more likely to go work. Further, the greater the number of non-schoolgoing children in the household, the less likely it is that the mother will work outside the home. In addition to the impact of these socio-economic characteristics, the employment-related attributes also determine the decision to go to work. Specifically, full-time workers (i.e., those who work at least 40 hours a week) are more likely to go to work than are part-time or occasional workers. Individuals with high work flexibility are less likely to go to work than are those with more rigid schedules. Finally, the decision to work is also influenced by the type of employment, with individuals working in the service sector being the most likely to work on any day.

Table A-4 Decision to go to work (Model GA4)

Explanatory variables	Param.	t-stat
Constant	1.5424	6.201
Age	-0.0087	-2.35
Ratio of personal income to household income	0.4492	3.001
Female	0.242	2.402
No. of non-schoolgoing children * Mother	-0.489	-2.805
Weekly work duration		
Between 0 and 20 hours	-1.7547	-12.191
Between 20 and 40 hours	-0.4237	-4.096
High work flexibility	-1.1526	-12.484
Employment type		
Construction and manufacturing	0.4508	2.457
Wholesale and transportation	0.3642	1.863
Personal, professional, and financial services	0.6539	3.84
Retail and repair	0.2885	1.627

1.4 Work start and end times (Model GA5)

The start and end times of work are determined simultaneously using a multinomial logit model. The 24-hour period is divided into 32 discrete periods. Model GA5 determines the choice of the combination of the discrete periods for the work start time and the work end time. Each worker has a choice set comprising of 32 * 33/2 = 528 alternatives (each alternative is a feasible combination of a work-start discrete period and a work-end discrete period). The discrete periods and the frequency of work episodes starting and ending in each period is presented in Table A-5.

Table A-5 Number of work episodes starting and ending in each discrete period

ID	Discrete period		Work start time		Work end time	
	Start time	End time	Freq.	%	Freq.	%
1	3:00	6:00	85	3.62		
2	6:00	6:30	83	3.53		
3	6:30	7:00	211	8.99		
4	7:00	7:30	322	13.71	3	0.13
5	7:30	8:00	497	21.17		
6	8:00	8:15	375	15.97	1	0.04
7	8:15	8:30	123	5.24		
8	8:30	8:45	130	5.54	2	0.09
9	8:45	9:00	74	3.15		
10	9:00	9:15	111	4.73	3	0.13
11	9:15	9:30	39	1.66	1	0.04
12	9:30	10:00	67	2.85	2	0.09
13	10:00	11:00	66	2.81	7	0.30
14	11:00	12:00	36	1.53	21	0.89
15	12:00	1:00	23	0.98	36	1.53
16	1:00	2:00	30	1.28	35	1.49
17	2:00	3:00	37	1.58	90	3.83
18	3:00	3:30	14	0.60	102	4.34
19	3:30	3:45	1	0.04	132	5.62
20	3:45	4:00	4	0.17	59	2.51
21	4:00	4:15	4	0.17	158	6.73
22	4:15	4:30	1	0.04	63	2.68
23	4:30	4:45	2	0.09	205	8.73
24	4:45	5:00	5	0.21	77	3.28
25	5:00	5:15	1	0.04	360	15.33
26	5:15	5:30	2	0.09	119	5.07
27	5:30	5:45			200	8.52
28	5:45	6:00			67	2.85
29	6:00	6:30	3	0.13	229	9.75
30	6:30	7:00	1	0.04	103	4.39
31	7:00	8:00	1	0.04	108	4.60
32	8:00	3:00			165	7.03

The empirical model results are presented in Table A-6. The reader will note that in order to accommodate the continuous nature of the choice modeled (i.e., the start and end times are essentially continuous variables), the alternative-specific constants have been replaced by continuous functions of arrival time, departure time, and duration.

Specifically, we use a trigonometric function for the arrival and departure time functions and a power-series function for the duration function. The mid-point time of the work start discrete period is represented by t_a, whereas t_d represents the mid-point time of the work-end discrete period. The duration is the difference between t_d and t_a. Further, all alternative specific variables are introduced by interacting the corresponding variable with the arrival and departure functions. Finally, the specification also enables us to examine the impact of level-of-service on the work timing decisions. Specifically, the results indicate that discrete periods when the travel time from work to home is higher are less preferred as work-end times.

Table A-6 Work start and end times (Model GA5)

Explanatory variables	Param.	t-stat
Arrival-time function		
Sin(2πt_a/24)	-1.7860	-0.969
Sin(4πt_a/24)	2.4210	4.059
Sin(6πt_a/24)	1.0544	5.737
Cos(2πt_a/24)	-7.9729	-5.786
Cos(4πt_a/24)	-4.4596	-6.054
Cos(6πt_a/24)	-1.3319	-4.75
Departure-time function		
Sin(2πt_d/24)	7.2221	3.43
Sin(4πt_d/24)	3.5539	4.259
Sin(6πt_d/24)	0.5903	2.231
Cos(2πt_d/24)	-4.0386	-2.74
Cos(4πt_d/24)	-0.1547	-0.176
Cos(6πt_d/24)	0.2284	0.743
Duration function		
Duration	3.5328	5.515
Duration^2	-1.4707	-5.856
Duration^3	0.3339	7.093
Duration^4	-0.0341	-7.745
Duration^5	0.0016	7.917
Duration^6	-0.00003	-7.796
Expected Home-to-Work Travel Time	-0.0283	-1.816
Size variables		

No. of 15 min. periods in the arrival time period	0.5932	15.091
No. of 15 min. periods in the departure time period	0.3697	5.81
Mother		
Sin(2πt_a/24) * Mother	0.6426	0.157
Sin(4πt_a/24) * Mother	-0.7253	-0.332
Sin(6πt_a/24) * Mother	0.4692	0.601
Cos(2πt_a/24) * Mother	-0.3359	-0.153
Cos(4πt_a/24) * Mother	-0.7466	-0.346
Cos(6πt_a/24) * Mother	-1.0187	-1.126
Sin(2πt_d/24) * Mother	-7.0432	-1.572
Sin(4πt_d/24) * Mother	-7.9421	-1.769
Sin(6πt_d/24) * Mother	-3.0161	-1.803
Cos(2πt_d/24) * Mother	-14.9568	-1.853
Cos(4πt_d/24) * Mother	-7.0119	-1.839
Cos(6πt_d/24) * Mother	-1.5218	-1.592
High work flexibility		
Sin(2πt_a/24) * High work flexibility	**7.4352**	2.874
Sin(4πt_a/24) * High work flexibility	**4.6864**	3.415
Sin(6πt_a/24) * High work flexibility	**-0.1633**	-0.511
Cos(2πt_a/24) * High work flexibility	**-4.3353**	-3.45
Cos(4πt_a/24) * High work flexibility	**2.701**	2.343
Cos(6πt_a/24) * High work flexibility	**2.4802**	4.256
Sin(2πt_d/24) * High work flexibility	**0.2014**	0.347
Sin(4πt_d/24) * High work flexibility	**0.0121**	0.018
Sin(6πt_d/24) * High work flexibility	**0.2189**	0.64
Cos(2πt_d/24) * High work flexibility	**-0.2292**	-0.153
Cos(4πt_d/24) * High work flexibility	**-0.4476**	-0.428
Cos(6πt_d/24) * High work flexibility	**-0.1387**	-0.341
Work duration > 40 hours/week		
Sin(2πt_a/24) * Work duration > 40 hours/week	**2.6046**	1.302
Sin(4πt_a/24) * Work duration > 40 hours/week	**-1.8474**	-2.247
Sin(6πt_a/24) * Work duration > 40 hours/week	**-0.9726**	-2.527
Cos(2πt_a/24) * Work duration > 40 hours/week	**2.8858**	3.81
Cos(4πt_a/24) * Work duration > 40 hours/week	**2.2124**	1.999
Cos(6πt_a/24) * Work duration > 40 hours/week	**-1.0121**	-2.742
Sin(2πt_d/24) * Work duration > 40 hours/week	**-1.0774**	-1.891
Sin(4πt_d/24) * Work duration > 40 hours/week	**0.0287**	0.044
Sin(6πt_d/24) * Work duration > 40 hours/week	**-0.0802**	-0.234
Cos(2πt_d/24) * Work duration > 40 hours/week	**-0.0863**	-0.059
Cos(4πt_d/24) * Work duration > 40 hours/week	**-1.0276**	-1.002
Cos(6πt_d/24) * Work duration > 40 hours/week	**-0.0398**	-0.101

1.5 Decision to undertake work-related activities (Model GA6)

Model GA6 is a binary logit model that determines the decision of employed adults to pursue work-related activities. (The location for work-related activities are not exogenous to CEMDAP, as is the case for the location for the main work activities.) The model was estimated using data from 3,152 employed adults in the sample. Of these persons, 560 (17.76 percent) undertook work-related activities. The empirical results (Table A-7) indicate that women, in particular those with non-schoolgoing children at home, are less likely to pursue work-related activities. Employed adults who go to work during the day are more likely to pursue work-related activities than are those who do not go to the primary work location. However, the likelihood decreases with increasing time spent at the primary location. Persons with high work flexibility are also found to be more likely to pursue work-related activities than are persons with strict schedules.

Table A-7 Decision to undertake work-related activities (Model GA6)

Explanatory variables	Param.	t-stat
Constant	-0.1891	-1.736
Female	-0.7027	-6.459
No. of non-schoolgoing children * Mother	-0.6691	-2.27
Worker	0.9542	3.701
Work-based duration	-0.0054	-10.764
High work flexibility	0.3193	2.946
Employment type		
Wholesale and Transportation	-0.3304	-2.000

1.6 Adult's decision to go to school (Model GA7)

Model GA7 is a binary logit model that determines the decision of adults who are students to go to school on any day. (CEMDAP assumes a three-way classification of adults into employed, student, and unemployed.) Of the 413 adults in the sample who are students, 311 (75.3 percent) went to school. The empirical results (Table A-8) indicate that Caucasians are more likely to go to school than are adults of other ethnicity. Further, the highest level of education completed (or alternatively the level of education being pursued) is also found to influence the decision to go to school. Specifically, high school students are most likely to go to school on any day, whereas those pursuing higher degrees (such as bachelor's or master's) are least likely. Finally, the number of non-schoolgoing children in the household also negatively impacts the adults' decision to attend school.

Table A-8 Adult's decision to go to school (Model GA7)

Explanatory variables	Param.	t-stat
Constant	1.0114	3.724
Caucasian	0.5604	2.105
Highest level of education		
Some college, no degree	-0.8609	-2.985
Associate's or bachelor's degree	-1.1302	-3.265
Master's or PhD degree	-1.9828	-3.705
Household income	0.0056	1.487
Presence of non-schoolgoing children	-0.8104	-1.904

1.7 Adult's school start and end times (Models GA8 and GA9)

The next two models determine the school start times (Model GA8) and end times (Model GA9) for adults going to school. The econometric structure of these models is linear regression with the logarithm of the start and end times being the dependent variables. The start time is measured in minutes from 3:00 a.m. and the end time is measured in minutes from school start time. The estimation results (Table A-9) indicate that that the school timing is determined significantly by the highest level of education completed by the adult. Specifically, adults pursuing higher degrees start school later in the day and end earlier than do those pursuing bachelor's degrees or high school diplomas. Further, the start and end times are also found to vary based on the socio-economic characteristics of the individual and the household.

Table A-9 Adult's school start and end times (Models GA8 and GA9)

Explanatory variables	**School start time (Model GA8)**		**School end time (Model GA9)**	
	Param.	**t-stat**	**Param.**	**t-stat**
Constant	5.7896	113.6948	5.9989	71.4422
Highest level of education				
Some college, no degree	0.1696	3.8009	-0.4650	-6.8100
Associate's or bachelor's degree	0.1696	3.8009	-0.4650	-6.8100
Master's or PhD degree	0.2757	3.5759	-0.7282	-6.1944
Adult son or daughter in a single-parent or nuclear family household	-0.1389	-2.4760	--	--
Adult in "other" household type	-0.1280	-2.3710	--	--
Household income (in thousands of dollars)	0.0011	2.4369	-0.0018	-2.1864
Vehicles per licensed driver			0.1196	1.6315

1.8 Child's travel model to and from school (Model GA10 and GA11)

Models GA10 and GA11, respectively, determine the children's travel mode for travel to and from school. Each of these is a multinomial logit model. Table A-10 identifies the four choice alternatives and the sample shares (as a cross-tabulation between the mode to school and mode from school).

The empirical estimation results (Table A-11) indicate that the travel mode is significantly impacted by the number of schoolgoing children and the number of workers and non-workers in the household.

Table A-10 Child's mode of travel to and from school: Sample shares

		Mode of travel from school				
		Drive by parent	**Drive by other**	**School bus**	**Walk or bike**	**Total**
Mode of travel to school	**Drive by parent**	254	66	40	43	403
	Drive by other	17	48	6	8	79
	School bus	6	6	99	6	117
	Walk or bike	11	1	2	103	117
	Total	288	121	147	160	716

Table A-11 Child's travel model to school (Model GA10) and from school (Model GA11)

Explanatory variables	**Mode to school (Model GA10)**		**Mode from school (Model GA11)**	
	Param.	**t-stat**	**Param.**	**t-stat**
Drive by parent				
Number of workers	0.5565	4.387	0.3837	2.314
Number of non-workers	—	—	0.3564	1.717
Number of female workers	—	—	-0.4394	-2.451
Drive by others				
Constant	-0.6645	-2.601	-0.4456	-1.45
Number of non-schoolgoing children	0.5553	2.712	—	—
Number of non-workers	-0.8464	-2.842	—	—
School Bus				
Constant	-0.401	-1.853	-0.251	-0.823
Walk or bike				
Constant	-0.8821	-2.881	-0.7282	-2.016
Number of schoolgoing children	0.229	2.319	0.2692	3.014

1.9 Allocation of escort responsibilities to parents (Models GA12 and GA13)

Model GA12 allocates the drop-off responsibility to one of the parents (i.e., the father or the mother) in the household, whereas Model GA13 allocates the pick-up activity to one of the parents. Each of these models has a binary logit structure.

Model GA12 was estimated using data from the 119 nuclear family households in the sample in which there was one or more children choosing to be driven to school by a parent. In about 70 percent of these cases, the drop-off responsibility was assigned to the mother. The empirical results (Table A-12) indicate that, in addition to the generic preference of the mother to undertake drop-off episodes, the allocation is also influenced by the work start time and the work duration of the parents. Specifically, the adult starting work later and working for shorter durations is more likely to be assigned the drop-off responsibility.

Table A-12 Allocation of the drop-off episode (Model GA12)

Explanatory variables	Father		Mother	
	Param.	**t-stat**	**Param.**	**t-stat**
Constant	-0.5807	-2.333		
Work start time	0.0041	2.44	0.0041	2.44
Work duration	-0.0047	-4.065	-0.0047	-4.065
Employment type: personal/professional/transportation	0.9955	2.491	0.9955	2.491

Model GA13 was estimated using data from the 89 nuclear family households in the sample in which there was one or more children choosing to be driven from school by a parent. In about 78 percent of these cases, the pick-up responsibility was assigned to the mother. The empirical results (Table A-13) indicate that, in addition to the generic preference of the mother to undertake drop-off episodes, the allocation is also influenced by the work duration of the parents. Specifically, the adult starting work later and working for shorter durations is more likely to be assigned the drop-off responsibility.

Table A-13 Allocation of the pick-up episode (Model GA13)

Explanatory variables	**Father**		**Mother**	
	Param.	**t-stat**	**Param.**	**t-stat**
Constant	-0.7536	-1.471		
Age	0.1626	2.182	0.1626	2.182
Bachelor's degree or higher education completed	-1.5661	-2.12	-1.5661	-2.12
Multiple schoolgoing children in household	-1.755	-2.249		
Work duration	-0.0031	-2.963	-0.0031	-2.963

1.10 Child's decision to undertake joint discretionary activity with parent (Model GA14)

Model GA14 determines the decision of a child to undertake joint discretionary activities with a parent using a binary logit econometric structure. Of the 1,253 children in the sample, 222 (17.72 percent) pursued joint discretionary activities with their parent during the survey day. The empirical model results (Table A-14) indicate that children in high-income or high automobile ownership households are more likely to pursue joint discretionary activities. The presence of a female worker and increasing number of schoolgoing children in the household negatively influences the joint activity participation decisions of children. Similarly increasing school-based duration decreases the likelihood of the pursuit of joint discretionary activities.

Table A-14 Child's decision to undertake joint discretionary activity with parent (Model GA14)

Explanatory variables	Param.	t-stat
Constant	-1.1545	-4.171
Individual- and household-level characteristics		
Education level completed: grade 9 or higher	0.654	1.526
Household income (in thousands of dollars)	0.0045	1.76
Number of vehicles	0.1542	1.519
Household-level activity participation characteristics		
Number of schoolgoing children	-0.1572	-2.048
Number of non-workers	-0.5302	-2.804
Presence of a female worker	-0.9222	-4.691
School-related characteristics		
School start time	0.0023	2.649
School-based duration	-0.0021	-3.132
Mode of travel from school: Driven back by parent	0.3427	1.634

1.11 Allocation of the joint discretionary episode to one of the parents (Model GA15)

Model GA15 determines the parent with whom the joint discretionary activity of the child (determined in the previous model) is pursued. This model has a binary logit structure and is estimated using data from the 65 nuclear family households in which children decided to pursue joint discretionary activities. In 45 (69.2 percent) of these households, the responsibility was allocated to the mother. The empirical results (Table A-15) indicate that the allocation is most significantly and negatively influenced by the work duration of the parents.

Table A-15 Allocation of the joint discretionary episode to one of the parents (Model GA15)

Explanatory variables	**Father**		**Mother**	
	Param.	**t-stat**	**Param.**	**t-stat**
Constant	0.0893	0.209		
Number of schoolgoing children	-1.2656	-1.573		
Work duration	-0.002	-1.932	-0.002	-1.932

1.12 Child's decision to undertake independent discretionary activity (Model GA16)

The decision of children to undertake independent discretionary activities is determined using a binary logit model (Model GA16). This model is estimated using data from the 1,031 children who did not pursue joint discretionary activities during the day. Of these children, 126 (12.22 percent) undertook independent discretionary activities during the survey day. Empirical model results (Table A-16) indicate that older children, Caucasians, and children from high-income households are more likely to pursue discretionary activities independently. Further, the children in households with greater numbers of children are more likely to pursue independent activities. However, the presence of a female worker in the household decreases the likelihood of the pursuit of independent discretionary episodes.

Table A-16 Child's decision to undertake independent discretionary activity (Model GA16)

Explanatory variables	Param.	t-stat
Constant	-2.8507	-5.882
Individual- and household-level characteristics		
Age	0.0876	3.17
Male	0.2557	1.288
Caucasian	0.4053	1.545
Household income (in thousands of dollars)	0.0077	2.252
Household-level activity participation characteristics		
Number of schoolgoing children	0.243	2.892
Number of non-schoolgoing children	0.3173	2.103
Number of workers	-0.4581	-2.132
Number of non-workers	-0.8421	-2.806
Presence of female workers	-0.5176	-1.796
School-related characteristics		
Mode of travel from school to home		
Driven back by parent	-1.0913	-3.278
Driven back by others	0.9155	3.444
Log likelihood at convergence	-348.8368	
Log likelihood (constants only)	-382.8185	
Number of cases	1031	

1.13 Decision of household to undertake grocery shopping (Model GA17)

Model GA17 determines the decision of households to pursue grocery shopping during the day using a binary logit structure. Of the 2,750 households in the sample, 850 (31 percent) undertook shopping. The empirical model results (Table A-17) indicate that single-person households are less likely to pursue shopping on any day, whereas households with more vehicles are more likely to undertake shopping. Proximity to a major shopping mall favors frequent grocery shopping. Finally, households with a greater number of non-workers are more likely to pursue shopping, whereas presence of non-schoolgoing children is detrimental to the household's pursuit of grocery shopping.

Table A-17 Decision of household to undertake grocery shopping (Model GA17)

Explanatory variables	**Param.**	**t-stat**
Constant	-1.0189	-7.097
Individual- and household-level characteristics		
Number of vehicles	0.1695	3.128
Single-person household	-0.2563	-2.227
Household location characteristics		
Distance to nearest major shopping zone	-0.0306	-3.565
Household-level activity participation characteristics		
Presence of non-schoolgoing children	-0.1798	-1.415
Number of non-workers	0.26	4.684

1.14 Decision of an adult to undertake grocery shopping given household undertakes it (Model GA18)

Model GA18 allocates the household's shopping episode to one of the household adults. Specifically, this binary logit model determines the decision of an adult to pursue shopping conditional on the household choosing to pursue shopping. This model was estimated using data from the 1,377 adults in the 850 households that undertook shopping during the day. Empirical results (Table A-18) indicate that older adults and licensed individuals are more likely to undertake the household's shopping responsibility, whereas men and high-income persons are less likely to pursue grocery shopping. The greater the number of non-workers in the household, the lesser is the likelihood of any adult pursuing shopping. Finally, the allocation is also negatively impacted by the need to go to work and the time spent at work.

Table A-18 Decision of an adult to undertake grocery shopping given household undertakes it (Model GA18)

Explanatory variables	Param.	t-stat
Constant	1.3027	3.164
Individual- and household-level characteristics		
Age	0.0079	1.9
Income (in thousands of dollars)	-0.0037	-1.708
Male	-0.7266	-3.838
Licensed	1.3951	5.726
Household-level activity participation characteristics		
Number of workers	-0.1664	-1.377
Number of non-workers	-0.8928	-7.481
Number of female workers	-0.3839	-2.342
Individual-level activity participation		
Worker	-0.7821	-1.968
Worker * female	0.4339	1.492
Work-based duration	-0.0019	-2.964
Undertakes work-related activities	-0.6865	-3.255
Drops off children at school	0.8233	2.254

1.15 Decision of an adult to undertake household or personal business activities (Model GA19)

Model GA19 determines the decision of adults to undertake household or personal business activities during the day using a binary logit structure. Of the 4,913 adults in the sample, 1,677 (34.13 percent) pursued this activity type during the survey day. Empirical model results (Table A-19) indicate that elderly persons are less likely to pursue household or personal business, whereas licensed adults and Caucasians are more likely to do so. The number of children in the household negatively influences household or personal business participation, as does the work duration of the adult.

Table A-19 Decision of an adult to undertake household or personal business activities (Model GA19)

Explanatory variables	**Param.**	**t-stat**
Constant	-0.8284	-5.003
Individual- and household-level characteristics		
Age	-0.0069	-3.197
Licensed	0.4652	3.678
Caucasian	0.4762	5.24
Household-level activity participation characteristics		
Number of schoolgoing children	-0.1534	-3.049
Number of non-schoolgoing children	-0.2409	-3.967
Another household adult works	-0.1679	-2.078
Individual work characteristics		
Worker	0.7516	4.054
Work duration	-0.0026	-7.259
Expected no-stop total auto commute time	-0.003	-1.676
Individual non-work participation		
Work-related activities	-0.1852	-1.845
Joint discretionary activities with children	1.0266	4.445
Shopping	0.6491	8.61

1.16 Decision of an adult to undertake social or recreational activities (Model GA20)

Model GA20 determines the decision of adults to undertake social or recreational activities during the day using a binary logit structure. Of the 4,913 adults in the sample, 1,206 (24.55 percent) pursued this activity type during the survey day. Empirical model results (Table A-20) indicate that elderly persons and high-income earners are less likely to pursue social or recreational activities, whereas licensed adults and Caucasians are more likely to do so. The number of children and the number of workers in the household negatively influences social or recreational activity participation, as does the work duration of the adult.

Table A-20 Decision of an adult to undertake social or recreational activities (Model GA20)

Explanatory variables	Param.	t-stat
Constant	-1.4599	-7.36
Individual- and household-level characteristics		
Age	-0.0115	-4.714
Income (in thousands of dollars)	-0.0031	-2.181
Household income (in thousands of dollars)	0.0036	3.063
Male	0.1056	1.443
Licensed	0.6263	4.13
Caucasian	0.3181	3.064
Household-level activity participation characteristics		
Another adult undertakes shopping	0.287	1.954
Number of workers	-0.157	-2.9
Number of non-schoolgoing children	-0.2417	-3.452
Individual work characteristics		
Worker	1.5797	4.793
Work end time	-0.0014	-2.918
Work duration	-0.0015	-3.175
Individual non-work participation		
Work-related activities	-0.2882	-2.447
Drop off children at school	-0.4207	-2.009
Joint discretionary activities with children	3.0146	9.353
Shopping	0.2265	1.803
Household or personal business activities	0.5456	6.578
Shopping and household or personal business activities	-0.3611	-2.173

1.17 Decision of an adult to undertake eat-out activities (Model GA21)

Model GA21 determines the decision of adults to eat out during the day using a binary logit structure. Of the 4,913 adults in the sample, 1,206 (24.55 percent) pursued this activity type during the survey day. Empirical model results (Table A-21) indicate that elderly persons are less likely to pursue household or personal business, whereas licensed adults, Caucasians, and high-income persons are more likely to do so. The number of non-schoolgoing children and the number of workers in the household negatively influences eating out. Adults traveling farther to work and those pursuing shopping or social or recreation activities during the day are found to be more likely to eat out. Finally, better accessibility to activity opportunities from the home zone favors eating out.

Table A-21 Decision of an adult to undertake eating out activities (Model GA21)

Explanatory variables	Param.	t-stat
Constant	-3.4759	-11.72
Individual- and household-level characteristics		
Age	-0.0072	-2.759
Income (in thousands of dollars)	0.0026	2.435
Household income (in thousands of dollars)	0.0057	4.955
Licensed	0.7425	3.783
Caucasian	0.6021	5.233
Household-level activity participation characteristics		
Number of workers	-0.143	-2.635
Number of non-schoolgoing children	-0.1695	-2.415
Another adult undertakes shopping	0.4468	3.003
Individual work characteristics		
Worker	-0.6296	-1.931
Work end time	0.0007	1.579
Work duration	0.0006	1.343
Expected no-stop total auto commute time	0.0068	3.745
Individual non-work participation		
Work-related activities	0.7713	7.35
Shopping	0.3284	2.97
Household or personal business	0.8461	11.373
Social or recreational activities	0.52	5.739
Shopping and social or recreational activities	-0.6135	-3.345
Household location characteristics		
Accessibility to retail and service employment	0.0214	2.23

1.18 Decision of an adult to undertake other serve-passenger activities (Model GA22)

Model GA22 determines the decision of adults to undertake other serve-passenger activities during the day using a binary logit structure. Of the 4,913 adults in the sample, 713 (14.5 percent) pursued this activity type during the survey day. Empirical model results (Table A-22) indicate that elderly persons are less likely to pursue other serve-passenger activities, whereas adults with a personal vehicle available are more likely to do so. The number of children in the household positively influences other serve-passenger activities, as does the number of workers in the household. However, the number of non-workers in the household decreases the likelihood of adults undertaking serve-passenger activities. Finally, the model also indicates that adults who escort children to school, or undertake household or personal business, or social or recreational activities are more likely to undertake other serve-passenger episodes.

Table A-22 Decision of an adult to undertake other serve-passenger activities (Model GA22)

Explanatory variables	**Param.**	**t-stat**
Constant	-2.3871	-9.734
Individual- and household-level characteristics		
Age	-0.0116	-3.513
Personal vehicle availability	0.3517	3.431
Household income (in thousands of dollars)	0.0023	1.689
Individual work characteristics		
Work duration	-0.0017	-6.314
Expected no-stop total auto commute time	0.0062	2.885
Household-level activity participation characteristics		
Another adult undertakes shopping	0.4009	2.271
Number of workers	0.3775	6.131
Number of non-workers	-0.2688	-3.402
Number of schoolgoing children	0.5592	10.282
Number of non-schoolgoing children	0.413	6.501
Individual non-work participation		
Drop off children at school	0.4278	2.297
Household or personal business	0.4438	4.82
Social or recreational activities	0.4953	4.688
Eating out	0.1474	1.329
Shopping and social or recreational activities	-0.3006	-1.526
Shopping and eating out	0.3752	1.921

2. Worker Scheduling Model System

This section of the appendix presents the scheduling model system for workers (Models WSCH1 to WSCH13). These models together determine the scheduling of the various activities that a worker decides to undertake during the day.

2.1 Commute mode (Model WSCH1)

The first model in the worker scheduling model system determines the commute travel mode using a multinomial logit model. This model is estimated using data from the 2,548 workers who did not undertake pick-up or drop-off of children from or to school. The sample shares are as follows: 79.7 percent solo driver; 4.7 percent driver with passenger; 7.5 percent passenger; 5.7 percent transit; and 2.4 percent walk or bike. The solo driver and driver with passenger modes are assumed to be available to all persons with a driver's license. The passenger mode is available for all. The transit mode is assumed to be available if the home and work zones are connected by the transit service and the walk or bike mode is assumed to be an option if the distance between the home and work zones is less than 22.5 miles.

The empirical model results (Table A-23) indicate that availability of a personal vehicle favors a person to drive to and from work. Students are more likely than employed adults to ride as passengers to and from work, as are persons in households with several adults. The presence of multiple workers in the households favors the "driver with passenger" and the "passenger" modes. The decision of an adult to pursue work-related activities decreases the likelihood of "passenger" being chosen as the commute mode, whereas those undertaking shopping during the day are less likely to walk or ride the bus to and from work. Finally, the travel time by each of the modal alternatives decreases the utility of the corresponding alternative as a commute mode.

Table A-23 Commute mode (Model WSCH1)

Explanatory variables	Driver, solo		Driver with passenger		Passenger		Walk or Bike		Transit	
	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Constant	-0.2453	-0.745	-1.8883	-3.482	-0.9197	-2.822			0.2488	1.055
Individual- and household-level characteristics										
Age	—	—	-0.029	-3.423	--	--	--	--	--	--
Female	--	--	--	--	--	--	--	--	0.3187	1.543
Personal vehicle availability	2.1364	8.31	1.5487	4.061	--	--	--	--	--	--
Employed	--	--	--	--	-0.8914	-4.758	--	--	--	--
Multiple adults in household	--	--	--	--	0.6875	2.228	--	--	--	--
Household-level activity participation decisions										
Number of schoolgoing children	--	--	--	--	0.2027	1.738	--	--	--	--
Multiple workers in household	--	--	0.4273	2.765	0.4273	2.765	--	--	--	--
Individual activity participation										
Work-related activities	--	--	--	--	-2.2716	-2.258	--	--	--	--
Shopping	--	--	--	--	--	--	-0.7166	-2.57	-0.7166	-2.57
Other serve-passenger activities	--	--	0.9931	4.812	--	--	--	--	--	
Joint discretionary activities with children	--	--	1.4391	2.945	--	--	--	--	--	
Level-of-service										
Travel time	-0.0116	-6.293	-0.0116	-6.293	-0.0116	-6.293	-0.0116	-6.293	-0.0116	-6.293

2.2 Number of stops in the work-to-home (Model WSCH2) and home-to-work (Model WSCH3) commutes

The next two models in the overall worker scheduling model system determine the number of stops in the work-to-home (Model WSCH2) and the home-to-work (Model WSCH3) commutes for workers who also chose to pursue independent non-work activities during the day. Further, the commute mode for these workers is one of solo driver, driver with passenger, or passenger (the persons choosing transit or walk or bike as the commute modes are assumed not to make stops during the commute). The econometric structure of each of these models is ordered probit.

The model for the number of stops in the work-to-home commute was estimated using data from the 1,623 adults. In addition to the two conditions identified above, these adults also do not undertake pick-up of children from school (if so, the pick-up is the only stop during the work-to-home commute). The sample shares are 55.45 percent zero stops and 29.4 percent one 1 stop, and the rest make two or more stops. The model for the number of stops in the home-to-work commute was estimated using data from the 1,590 adults. In addition to the two conditions identified above, these adults also do not undertake drop-off of children from school (or if they do, the drop-off is the only stop during the home-to-work commute). The sample shares are 77.3 percent zero stops and 17.6 percent one stop, and the rest make two or more stops.

The empirical model (Table A-24) indicates that women make more stops in the work-to-home commute than men do. Students are less likely to make commute stops than are employed adults. The decision of the adults to pursue various types of activities, in general, positively impacts the propensity to make stops during the commute. Finally, a later work start time positively impacts stop making during the commute to work, whereas a late work end time negatively impacts stop making during the commute from work.

Table A-24 Number of stops in the work-to-home (Model WSCH2) and home-to-work (Model WSCH3) commutes

	Work-to-home commute (Model WSCH2)		**Home-to-work commute (Model WSCH3)**	
Explanatory variables	**Param.**	**t-stat**	**Param.**	**t-stat**
Individual- and household-level characteristics				
Female	0.2199	3.459	--	--
Student	-0.3082	-2.599	--	--
Employed	--	--	0.3595	2.742
High work flexibility	-0.185	-2.326	--	--
Person's income (in thousands of dollars)	0.0016	2.092	--	--
Household-level activity participation				
No. of schoolgoing children	-0.1387	-3.137	0.1156	2.359
No. of non-schoolgoing children	--	--	0.1097	1.794
Individual activity participation				
Work-related activities	0.6199	6.665	0.4402	4.196
Shopping	0.7711	9.052	--	--
Household or personal business	0.6108	8.118	0.1884	2.075
Social or recreational activities	0.363	4.727	--	--
Other serve-passenger activities	0.7726	10.477	1.2709	15.6
Shopping and social or recreational activities	-0.3259	-1.972	--	--
Household or personal business and eating out	0.3959	4.154	0.3651	3.268
Work and commute				
Work start time	--	--	0.0024	8.434
Work end time	-0.0018	-6.903	--	--
Commute mode is driver, solo	-0.4961	-5.264	-0.1673	-1.516
Expected work-to-home commute time *Auto mode	0.0074	3.239	--	--
Threshold parameters				
0 and 1 stop	-0.7477	-2.962	2.3955	12.915
1 and 2 stops	0.3541	1.403	3.5246	17.738

2.3 Number of after-work, work-based, and before-work tours (Models WSCH4, WSCH5, and WSCH6)

The three ordered probit models presented in this subsection determine the number of tours undertaken by workers during the after-work (Model WSCH4), work-based (Model WSCH5), and before-work (Model WSCH6) periods. The sample shares for the after-work period are 57 percent zero tours, 37 percent one tour, and the rest two tours. The shares for the work-based period are 60.5 percent zero tours, 35.7 percent one tour, and the rest two tours. The shares for the before-work period are 94.2 percent zero tours and the rest one tour.

The empirical results (Table A-25) indicate that parents are more likely to make tours during the before-work period than adults without children are. Employed adults are more likely to pursue after-work tours and less likely to undertake work-based tours than students are. The decision of adults to undertake various types of activities during the day in general favors undertaking tours during all the periods of the day. The amount of time available during each period increases the propensity to undertake tours during the corresponding period (the available time for the before-work period is the start of the day to the departure from home for work, the available time for the work-based period is from the start to the end time of the work activity, and the available time for after-work period is from the arrival time at home from work to the end of the day). Finally, the greater the number of stops an individual undertakes during the commute, the lower the propensity to undertake tours during any other period.

Table A-25 Number of after-work, work-based, and before-work tours (Models WSCH4, WSCH5, and WSCH6)

Explanatory variable	Number of after-work tours (Model WSCH4)		Number of work-based tours (Model WSCH5)		Number of before-work tours (Model WSCH6)	
	Param.	**t stat**	**Param.**	**t stat**	**Param.**	**t stat**
Person and household level characteristics						
Age	-0.0114	-3.799				
Female	-0.228	-3.33				
Mother					0.5871	2.169
Father					0.8667	2.95
Licensed			0.5756	2.343		
Employed	0.4715	3.773	-0.3471	-2.341		
High work flexibility			0.2589	3.191		
Single person household	-0.2217	-2.461				
Household-level activity participation						
Number of school going children			-0.1274	-2.491	0.2427	2.803
Number of workers in household					-0.2031	-1.87
Number of non-workers in household					-0.7393	-2.874
Individual activity participation						
Work related	0.2698	2.522	1.3095	12.749	0.3983	2.008
Drops-off children at school			0.4466	2.315	0.8688	3.301
Picks-up children from school	0.5352	2.34	0.457	1.738		
Shopping	0.9769	11.471	0.2882	3.417		
Household/personal business	0.7718	10.397	0.554	7.6		
Social/recreation activities	1.4227	17.647			0.2929	1.946
Eat-out activities	0.3964	5.553	1.279	18.024	-0.2931	-1.799
Other serve passenger	0.6229	6.746	0.2705	2.887	0.6815	3.98
Pattern-level attributes						
Available time in this period	0.006	17.919	0.0049	14.783	0.0088	13.802
Number of work-to-home commute stops	-0.5068	-11.574	-0.2892	-6.802	-0.1417	-1.628
Number of home-to-work commute stops	-0.4359	-6.513	-0.1674	-2.485	-0.4524	-3.049
Commute mode is driver, solo			0.2859	2.747		
Threshold parameters						
0 and 1 tour	4.2124	16.119	4.1975	14.846	4.5495	13.79
1 and 2 tours	6.4673	21.945	6.3798	20.607		
Log likelihood at convergence	-964.1681		-983.6382		-178.0829	
Number of observations	1725		1761		1761	

2.4 Tour mode (Model WSCH7)

Model WSCH7 determines the mode for each of the worker's tours. This model has a multinomial logit econometric structure. The sample shares are 53.22 percent solo driver, 24.21 percent driver with passenger, 16.28 percent passenger, and 6.27 percent walk or bike. Transit is assumed not to be an option for the home-based and work-based non-work tours of workers. The solo driver and the driver with passenger modes are assumed to be available for all adults with a driver's license. The passenger and walk or bike modes are assumed to be available options for all persons.

The empirical model results (Table A-26) indicate that personal vehicle availability decreases the propensity for the walk or bike mode, whereas the presence of multiple adults in the household favors shared-ride modes (i.e., driver with passenger and passenger). Similarly, the presence of a higher number of children in the household also increases the propensity of the driver with passenger mode. Before-work tours are found to be less likely to be undertaken as a passenger. Work-based tours are more likely to be undertaken using the non-motorized modes than are tours undertaken during the other periods of the day.

Table A-26 Tour mode (Model WSCH7)

Explanatory variables	Driver, solo		Driver with passenger		Passenger		Walk or Bike	
	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Constant	0.7772	2.347	0.003	0.008	-0.2611	-0.696		
Individual- and household-level characteristics								
Personal vehicle availability							-0.5252	-1.817
Multiple adults in household			0.1109	1.858	0.1109	1.858		
Household-level activity participation								
Number of schoolgoing children			0.1664	2.253				
Individual activity participation								
Work-related activities							-0.9733	-2.331
Other serve-passenger activities			0.2343	1.692				
Tour-level characteristics								
Before-work tour					-1.3073	-2.784		
Work-based tour			-0.9305	-7.212	-0.2647	-1.767	1.4521	5.415
Pattern-level characteristics								
Commute mode is								
Driver, solo	2.138	6.402	2.138	6.402	1.67	4.019		
Driver with passenger	3.2164	3.044	3.2164	3.044	2.7551	2.471		
Passenger					1.7197	4.563		
Walk or Bike							0.7873	1.697

2.5 Number of stops in a tour (Model WSCH8)

Ordered probit Model WSCH8 determines the number of stops in any tour undertaken by a worker. The sample shares are 76.4 percent one stop, 16 percent two stops, 4.97 percent three stops, 1.4 percent four stops, and the rest five stops.

The empirical model (Table A-27) indicates that employed adults are less likely to undertake multiple stops in a tour than students are. On the other hand, adults in single-person households are more likely to chain multiple stops as part of the same tour. The decision of an adult to pursue various kinds of non-work activities positively impacts the propensity to undertake several stops in a tour. The results also indicate that the greater the number of tours in a period, the fewer the number of stops in any tour during that period. Further, the greater the number of stops a worker undertakes during the commute, the lesser the propensity to undertake stops in other home-based or work-based tours. Stop-making is also positively impacted by the total time available for the tour. Finally, work-based tours are found to contain fewer stops than are tours during the other periods of the day, and tours undertaken using the walk or bike mode have fewer stops than do tours undertaken using the auto mode.

Table A-27 Number of stops in a tour (Model WSCH8)

Explanatory variables	Param.	t-stat
Individual- and household-level characteristics		
Employed	-0.2135	-1.885
Single-person household	0.2483	2.641
Household-level activity participation decisions		
Number of non-workers in household	0.1465	1.641
Individual activity participation decisions		
Work-related activities	0.8791	8.827
Shopping	0.6869	8.198
Household or personal business	1.0051	12.878
Social or recreation activities	0.6032	7.754
Eat-out	0.5741	7.421
Other serve-passenger activities	0.8444	9.003
Pattern-level attributes		
Number of before-work tours * current tour is in the before-work period	-0.728	-4.043
Number of work-based tours * current tour is in the work-based period	-0.2603	-1.924
Number of after-work tours * current tour is in the after-work period	-0.7433	-5.981
Number of work-to-home commute stops	-0.2946	-5.916
Number of home-to-work commute stops	-0.3462	-4.596
Available time	0.0024	7.615
Tour-level attributes		
Work-based tour	-0.631	-3.112
Second tour	0.402	2.593
Tour mode		
Driver, solo	0.763	3.785
Driver with passenger	0.7391	3.476
Passenger	0.5848	2.698
Threshold parameters		
1 and 2 stops	3.1768	9.572
2 and 3 stops	4.0896	12.101
3 and 4 stops	4.7494	13.718
4 and 5 stops	5.194	14.581

2.6 Home or work stay duration before the tour (Model WSCH9)

Model WSCH9 determines the departure time for each of the home-based and work-based tours. The duration is measured in minutes from the arrival time at home or work from the previous commute as appropriate. The logarithm of the duration is taken as the dependent variable and the econometric structure of this model is linear regression. Separate models were estimated for home or work stay durations before tours undertaken during each of the after-work, work-based, and before-work periods (Table A-28). The models indicate that before-work tours undertaken in households without children depart earlier than those undertaken in households with children. Men spend less time at work before a work-based tour than women do. Individuals undertaking work-related activities during the day are also found to spend shorter durations at work before a work-based tour. Those undertaking multiple tours in a period spend shorter durations at home or work before departing for the tour than do adults undertaking only a single tour. The available time for the tour has a positive influence on the home or work stay duration before the tour. Finally, individuals are found to spend more time at home prior to tours undertaken using the solo driver mode.

Table A-28 Home or work stay duration before the tour (Model WSCH9)

Explanatory variables	Before-work tours		Work-based Tours		After-work tours	
	Param.	t-stat	Param.	t-stat	Param.	t-stat
Household- and individual-level characteristics						
No children in the household	-0.162	-2.067	--	--	--	--
Male	--	--	-0.125	-3.244	--	--
Employment type: public and military	--	--	-0.178	-2.066	--	--
Individual activity participation decisions						
Work-related activities	--	--	-0.356	-6.543	--	--
Shopping	0.206	2.628	--	--	--	--
Household or personal business	--	--	--	--	-0.217	-2.848
Social or recreational activities	--	--	0.094	2.017	--	--
Eating out	--	--	0.109	2.584	--	--
Pattern-level attributes						
Number of tours	--	--	-0.231	-4.480	--	--
One tour	--	--	--	--	0.297	3.469
Number of stops in WH commute fewer than two	--	--	--	--	-0.298	-2.157
Tour-level attributes						
Available time for the tour	0.002	10.042	0.002	9.811	0.003	8.178
Tour mode						
Driver, solo	0.166	2.202	--	--	0.143	1.981
Passenger	--	--	-0.146	-2.680	--	--
First tour in this period	--	--	0.284	3.092	--	--
Number of stops in this tour	--	--	-0.104	-4.274	-0.111	-2.507
Constant	4.616	42.515	4.411	34.358	2.709	11.402

2.7 Activity type at a stop (Model WSCH10)

Multinomial logit Model WSCH10 determines the activity type at any stop in a worker's commute. The different non-work activities that an adult has decided to undertake during the day (as determined in the generation-allocation model system) constitute the set of available alternatives. The empirical model is presented in Table A-29. The number of episodes of the same type already undertaken negatively impacts the utility for each of the activity type alternatives. In addition, the utility of each of the different activity types is also found to be impacted by the commute to which the stops belong, the position of the stop in the commute (i.e., whether this is the first stop, second stop, etc.), and the mode of travel to the activity stop.

Table A-29 Activity type at a stop (Model WSCH10)

	Work related		Shopping		HH/personal business		Social/ recreational		Eat out		Other serve passenger	
Explanatory variables	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**
Number of episodes of this type already undertaken	-0.889	-17.345	-0.889	-17.345	-0.889	-17.345	-0.889	-17.345	-0.889	-17.345	-0.889	-17.345
Tour-level attributes												
Number of stops in the tour/commute			-0.8019	-6.236	-0.1424	-1.881	-0.287	-3.166	-0.2631	-2.948	-0.1962	-2.333
Tour mode												
Driver, solo			0.5927	2.124					-1.011	-7.071	0.6566	2.576
Driver, with passenger			0.7909	2.534			-0.2323	-1.129			1.0543	3.766
Passenger												
Stop-level attributes												
Stop is in												
Home-to-work commute			-1.5692	-5.119			-1.3887	-4.363				
Work-based tour 1			-1.7611	-5.708	-0.7282	-4.464	-1.3773	-4.813				
Work-based tour 2			-2.9073	-2.686	-0.8696	-2.059	-2.2173	-2.107				
After-work tour 1			1.1566	3.103	1.332	3.924	1.8304	5.131	1.1481	3.325	1.0518	2.926
After-work tour 2							1.1224	3.905			1.0724	3.175
Position of stop within tour/commute												
Second stop			1.1595	4.84	0.3268	1.867	0.2298	1.084	0.3579	1.866		
Third stop			1.4764	3.118	0.5737	1.524	0.8128	1.869	0.4051	0.997	0.5407	1.359
Constant			0.6079	1.614	0.3588	1.788	0.0605	0.253	0.5286	2.343	-0.0117	-0.038
Log likelihood at convergence	-2109.654											
Log likelihood constants only	-2523.102											
Number of cases	2710											

2.8 Activity duration at a stop (Model WSCH11)

This model determines the time spent in activity participation at any stop. The logarithm of activity duration is taken as the independent variable in this linear regression model. Separate models were estimated for the durations spent in stops undertaken in (1) before-work tours, (2) home-to-work commute, (3) work-based tours, (4) work-to-home commute, and (5) after-work tours. The estimation results are presented in Table A-30. The activity duration is found to be longer if there is only one tour during the corresponding period. Similarly, the activity duration is also found to be greater when there is only one stop in the corresponding commute. Available time positively influences activity duration in stops undertaken in all commutes. Finally, the activity duration is also found to vary depending on the position of the stop in the commute (i.e., whether this is the first stop, second stop, etc.) and based on the activity type pursued at the stop. In particular, the activity duration is found to be the shortest for the other-serve passenger activities, as would be expected.

Table A-30 Activity duration at a stop (Model WSCH11)

Explanatory variables	Before-work tour stops		Home-to-work commute stops		Work-based tour stops		Work-to-home commute stops		After-work tour stops	
	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Pattern-level attributes										
One tour in this period	--	--	--	--	0.445	4.527	--	--	0.384	5.087
Tour-level attributes										
Tour mode										
Driver, solo	0.618	1.837	--	--	--	--	--	--	--	--
Driver with passenger	0.618	1.837	0.331	1.996	0.268	2.585	--	--	--	--
Passenger	--	--	--	--	0.392	3.554	--	--	0.202	2.503
One stop in the tour	--	--	0.487	3.960	0.671	8.250	0.508	6.284	0.335	3.942
Stop-level attributes										
Available time	0.004	4.066	0.009	16.033	0.002	5.047	0.006	18.613	0.002	6.353
First stop in the commute	--	--	-0.373	-2.701	--	--	-0.210	-2.524	0.275	2.107
Second stop in the commute	--	--	--	--	--	--	--	--	0.290	2.264
Activity type at destination										
Work-related activities	--	--	--	--	1.038	9.601	--	--	--	--
Grocery shopping	--	--	--	--	--	--	-0.375	-3.704	-1.281	-13.059
Eating out	--	--	--	--	0.605	6.641	--	--	-0.674	-6.994
Household or personal business	--	--	-0.533	-4.227	--	--	-0.577	-7.038	-1.136	-13.195
Other serve-passenger activities	-2.712	-10.692	-1.843	-15.96	--	--	-1.830	-18.96	-2.996	-27.044
Constant	2.087	5.524	2.100	16.162	1.219	7.753	2.738	31.403	2.705	14.832

2.9 Travel time to a stop (Model WSCH12)

This model determines the travel time a person desires to spend in traveling to a stop. The logarithm of travel duration is taken as the independent variable in this linear regression model. Separate models were estimated for the travel time to stops undertaken in (1) before-work tours, (2) home-to-work commute, (3) work-based tours, (4) work-to-home commute, and (5) after-work tours. The estimation results are presented in Table A-31. The travel duration is greater if there is only one tour during a period or if there is only one stop in the corresponding commute. The travel time to any stop in tours undertaken using the automobile are, in general, found to be greater than the travel times to stops in tours undertaken using the walk or bike mode. The available time is found to have a positive impact on the travel duration and as in the case of activity duration, the desired travel time is also found to vary based on the position of the stop in the commute (i.e., whether this is the first stop, second stop, etc.) and based on the activity type pursued at the stop.

Table A-31 Travel time to a stop (Model WSCH12)

Explanatory variables	Before-work tour stops		Home-to-work commute stops		Work-based tour stops		Work-to-home commute stops		After-work tour stops	
	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Pattern-level attributes										
One tour in this period	--	--	--	--	0.239	3.396	--	--	0.231	3.177
Tour-level attributes										
Tour mode										
Driver, solo	--	--	--	--	--	--	--	--	0.349	2.505
Driver with passenger	0.518	2.876	--	--	--	--	--	--	0.494	3.499
Passenger	--	--	--	--	--	--	--	--	0.549	3.795
Walk or bike	--	--	--	--	-0.568	-6.226	--	--	--	--
Stop in Tour 1 of this period	--	--	--	--	--	--	--	--	-0.201	-2.122
One stop in this commute	--	--	0.170	1.639	--	--	0.100	1.629	--	--
Stop-level attributes										
Available time	--	--	0.004	5.691	--	--	0.002	6.537	0.001	4.122
First stop in the commute	--	--	--	--	--	--	0.424	6.875	--	--
Second stop in the commute	--	--	-0.211	-1.696	-0.318	-4.460	--	--	--	--
Activity type at destination										
Work-related activities	--	--	--	--	0.505	6.543	--	--	--	--
Grocery shopping	--	--	--	--	--	--	--	--	-0.330	-4.650
Eating out	--	--	--	--	-0.188	-3.162	--	--	-0.158	-2.262
Household or personal business	0.252	1.383	--	--	--	--	-0.092	-1.749	-0.220	-3.518
Other serve-passenger activities	--	--	-0.252	-3.091	--	--	0.112	1.812	-0.137	-1.691
Constant	2.128	16.491	2.228	19.814	2.143	28.003	2.241	44.531	1.777	10.759

2.10 Location of a stop (Model WSCH13)

This last model in the worker scheduling model system determines the location of the stops. The set of choice alternatives available for any stop is determined from the universal set of alternatives (i.e., all the zones in the study region) using a probabilistic choice set generation procedure. The probability that every set of zones includes the choice set is determined based on the inter-zonal travel times and the desired travel time to the stop (as determined from the previous model). Conditional on the probabilistic choice set, this model assumes a multinomial logit econometric structure.

The empirical results are presented in Table A-32. We find that, overall, closer zones are preferred to zones farther away from the origin zone. In addition, the results also indicate that zones closer to the ultimate destination are preferred (the ultimate destination is the work zone for stops in the home-work commute and work-based tours, and home for the other stops). The CBD is found to be less attractive for pursuing non-work activities. The extent of activity opportunities in a zone, measured in terms of the logarithm of the retail plus service employment, is found to positively impact the utility of the zone as a candidate destination for the stop.

Table A-32 Location of a stop (Model WSCH13)

Explanatory variables	Param.	t-stat
Impedance measures		
Auto IVTT at start of trip	-0.2495	-20.203
Auto IVTT at start of trip * Walk mode	-0.6848	-6.28
Distance to the ultimate destination	-0.1684	-13.221
Distance to the ultimate destination * shopping	-0.163	-4.006
Destination zone adjacent to the origin zone	0.4021	4.37
Destination zone same as the origin zone	1.2076	10.919
Attraction variables		
Destination zone is the CBD	-1.259	-3.997
LN (service + retail employment) at destination zone	0.2544	6.687
LN (service + retail employment) at destination zone * Work-related activities	0.2024	1.874
LN (service + retail employment) at destination zone * Household or personal business	0.1577	2.584
LN (service + retail employment) at destination zone * Eating out	0.2264	3.487
LN (population) at destination zone * Other serve-passenger activities	0.2287	4.606

3. Non-worker Scheduling Model System

This section of the appendix presents the scheduling model system for non-workers (Models NWSCH1 to NWSCH11). These models together determine the scheduling of the various activities that a non-worker decides to undertake during the day.

3.1 Number of independent tours (Model NWSCH1)

The first non-worker scheduling model (with an ordered probit econometric structure) determines the number of independent tours undertaken by non-workers who decide to pursue one or more activity types during the day. The observed sample shares are 54.44 percent one tour, 32.34 percent two tours, 9.4 percent three tours, and the rest four tours. The empirical model results (Table A-33) indicate that women undertake fewer tours than do men, and licensed individuals undertake more tours than do adults without a driver's license. Adults in single-person and single-parent households undertake fewer tours during the day. The greater the number of schoolgoing children in a household, the greater the number of tours undertaken by the non-workers in the household. Finally, the decision of the non-worker to pursue various activities during the day, in general, positively impacts the propensity to undertake tours during the day.

Table A-33 Number of independent tours (Model NWSCH1)

Explanatory variables	Param.	t-stat
Personal and household characteristics		
Female	-0.1456	-2.284
Licensed	0.5742	3.76
Student	0.3243	2.186
Single-person household	-0.3134	-3.852
Single-parent household	-0.2959	-1.856
Household-level activity participation decisions		
Number of schoolgoing children	0.2149	3.993
Individual activity participation decisions		
Work-related activities	0.3351	3.894
Shopping	0.8321	7.744
Household or personal business	0.8221	9.592
Social or recreational activities	1.025	13.048
Eating out	0.6341	7.177
Other serve-passenger activities	0.8803	10.772
Shopping and household or personal business activities	-0.3234	-2.449
Shopping and eating out activities	-0.3949	-2.971
Thresholds		
1 and 2 tours	2.0147	11.483
2 and 3 tours	3.2973	17.872
3 and 4 tours	4.1029	21.149

3.2 Decision to undertake an independent tour before (Model NWSCH2) and after (Model NWSCH3) a pick-up or joint discretionary tour

The next two models in the non-worker scheduling system are applied to those who pick up children from school or pursue joint discretionary activities with children.

These models determine the position of the pick-up or joint discretionary tour within the overall schedule of the non-worker by determining the decision to pursue independent tours before and after the pick-up or joint discretionary tour. Of the persons in the sample, 50 percent pursued a tour before the pick-up or joint discretionary tour, whereas 37.23 percent pursued a tour after the pick-up or joint discretionary tour. The empirical models for the decision to undertake a tour before and after are presented in Tables A-34 and A-35, respectively. Overall, available time is found to be an important determinant of these decisions. In addition, the decision to undertake a tour before the pick-up or joint discretionary tour is also found to be influenced by the activity participation decisions for the day.

Table A-34 Decision to undertake an independent tour before a pick-up or joint discretionary tour (Model NWSCH2)

Explanatory variables	**Param.**	**t-stat**
Available time before pick up or joint discretionary tour	0.0116	4.6081
Individual activity participation decisions		
Drops off children	2.6234	2.6967
Picks up children	1.8099	2.0676
Shopping	1.6412	2.3096
Household or personal business	1.3454	2.0566
Constant	-9.6114	-4.3382

Table A-35 Decision to undertake an independent tour after a pick-up or joint discretionary tour (Model NWSCH3)

Explanatory variables	**Param.**	**t-stat**
Available time after the pick-up or joint discretionary tour	0.0059	3.8070
Constant	-4.4884	-4.0712

3.3 Tour mode (Model NWSCH4)

Model NWSCH4 determines the mode for each of the non-workers' tours. This model has a multinomial logit econometric structure. The sample shares are 59.65 percent solo driver, 22.39 percent driver with passenger, 14.97 percent passenger, and 2.97 percent walk or bike. Transit is assumed not to be an option for the home-based and work-based non-work tours of workers. The solo driver and the driver with passenger modes are assumed to be available for all adults with a driver's license. The passenger and walk or bike modes are assumed to be available options for all persons.

The empirical model results (Table A-36) indicate that women are more likely than men to travel as passengers in a personal automobile. The availability of a personal vehicle favors automobile modes over the walk or bike mode. The greater the number of people (workers, non-workers, schoolgoing children, or non-schoolgoing children) in a household, the greater is the likelihood of traveling with other passengers in the car. Finally, persons who undertake multiple tours during the day are less likely to travel as a passenger in any of the tours.

Table A-36 Tour mode (Model NWSCH4)

Explanatory variables	Driver, solo		Driver with passenger		Passenger		Walk or Bike	
	Param.	**t-stat**	**Param.**	**t-stat**	**Param.**	**t-stat**	**Param.**	**t-stat**
Constant	-0.3103	-1.22	-2.1934	-7.766	-0.2192	-0.799		
Individual- and household-level characteristics								
Female	--	--	--	--	1.1923	8.854	--	--
Personal vehicle availability	3.3504	11.122	3.3504	11.122	1.1603	3.781	--	--
Student	-0.7251	-3.42	--	--	--	--	--	--
Household-level activity participation decisions								
Number of schoolgoing children	--	--	0.4561	6.184	--	--	--	--
Number of non-schoolgoing children	--	--	0.6932	8.478	--	--	--	--
Number of workers	--	--	0.2089	2.735	--	--	--	--
Number of non-workers	--	--	0.3767	5.332	--	--	--	--
Individual activity participation decisions								
Household or personal business	0.8677	3.374	0.7562	2.824	0.548	2.034	--	--
Eating out	0.6567	1.766	1.1643	3.07	1.4952	3.926	--	--
Other serve-passenger activities	--	--	--	--	-0.6606	-3.783	--	--
Pattern-level characteristics								
Two or more tours	--	--	--	--	-0.3615	-2.745	--	--

3.4 Number of stops in a tour (Model NWSCH5)

Ordered probit Model NWSCH5 determines the number of stops in any tour undertaken by a non-worker. The sample shares are 59 percent one stop, 19.84 percent two stops, 11.06 percent three stops, 4.57 percent four stops, and the rest five stops.

The empirical results (Table A-37) indicate that elderly people undertake fewer stops in any tour, whereas male parents undertake more stops in a tour. Employed persons who do not go to work are more likely to undertake several stops in a tour. In contrast, students who do not go to school undertake fewer stops in any tour. The greater the number of adults in the household (workers or non-workers), the fewer the stops made in a tour by any of these adults. The decision to undertake different kinds of activities during the day, in general, increases the propensity to undertake more stops in any tour. Among the pattern-level attributes, the time available for the tour is found to positively impact the number of stops in the tour. The greater the total number of tours pursued by a non-worker, the fewer the stops in each of these tours. The number of stops in a tour is also found to depend on the position of the tour within the overall pattern (i.e., whether this is the first, second, third, or fourth tour). Finally, tours made using the walk or bike mode are likely to have fewer stops than tours made using the auto mode.

Table A-37 Number of stops in a tour (Model NWSCH5)

Explanatory variables	Param.	t-stat
Individual- and household-level characteristics		
Age	-0.005	-2.636
Father	0.3289	2.305
Employed	0.1688	2.059
Student	-0.343	-2.282
Household income	0.0014	1.853
Household-level activity participation decisions		
Number of workers	-0.1422	-3.302
Number of non-workers	-0.1384	-2.605
Individual activity participation decisions		
Shopping	0.4693	4.627
Household or personal business	0.9602	11.094
Social or recreational activities	0.5553	10.19
Eat-out	1.1819	11.627
Other serve-passenger activities	0.6451	9.847
Shopping and household or personal business	0.2786	2.474
Shopping and eating out	-0.2395	-2.274
Household or personal business and eating out	-0.5062	-4.464
Pattern-level attributes		
Available time	0.0014	5.439
Total number of tours		
Two	-0.5756	-8.306
Three	-0.9813	-10.22
Four	-1.5083	-11.736
Tour-level attributes		
Second tour	0.4265	2.646
Third tour	0.4695	2.111
Fourth tour	0.5588	1.818
Tour mode is walk or bike	-1.2306	-4.677
Thresholds		
1 and 2 stops	2.6945	6.793
2 and 3 stops	3.427	8.604
3 and 4 stops	4.0454	10.099
4 and 5 stops	4.4677	11.093

3.5 Number of stops in a tour following a pick-up or drop-off stop (Model NWSCH6)

This ordered-probit model determines the number of additional stops undertaken by a parent following a drop-off at school or pick-up from school episode. Of the parents in the sample, 58.8 percent did not undertake additional stops as part of their escort tour and 42.2 percent undertook one or more stops.

The empirical model (Table A-38) indicates that employed persons are more likely to chain additional stops with the pick-up or drop-off stop. If non-schoolgoing children are present in the household, parents are less likely to undertake additional stops. A decision of parents to undertake work-related activities or household or personal business activities increases their propensity to undertake additional stops. Finally, the later the start time of the tour, the less likely the parent is to make further stops.

Table A-38 Number of stops in a tour following a pick-up or drop-off stop (Model NWSCH6)

Explanatory variables	**Param.**	**t-stat**
Individual-level characteristics		
Employed	0.5995	1.967
Household-level activity participation decisions		
Presence of non-schoolgoing children	-0.7533	-2.421
Individual activity participation decisions		
Work-related activities	0.7837	1.695
Household or personal business	0.6663	2.371
Tour-level characteristics		
Drops-off children in tour	-1.2942	-2.383
Tour start time	-0.0034	-2.531
Threshold		
0 and 1 stop	-1.5389	-1.693

3.6 Home-stay duration before a tour (Model NWSCH7)

Model NWSCH7 determines the departure time for each of the home-based tours. The duration is measured in minutes from the arrival time at home from the previous tour. The logarithm of the duration is taken as the dependent variable and the econometric structure of this model is linear regression. Separate models were estimated for the home-stay duration before each of the first, second, third, and fourth tours (Table A-39). We find that men are more likely to depart earlier for the first tour, whereas employed persons are more likely to depart later in the day for the first tour. The decision to undertake various types of activities during the day impacts the departure time for the first two tours. Further, the greater the total number of tours to be pursued during the day, the shorter the home-stay duration before the tours. The available time positively impacts home-stay duration before the second and later tours. Finally, home-stay duration prior to single stop tours tends to be longer than home-stay periods before tours with multiple stops.

Table A-39 Home-stay duration before a tour (Model NWSCH7)

Explanatory variables	Tour 1		Tour 2		Tour 3		Tour 4	
	Param.	t-stat	Param	t-stat	Param	t-stat	Param	t-stat
Constant	5.932	138.991	3.133	13.191	2.102	6.916	2.215	3.891
Individual- and household-level characteristics								
Male	-0.089	-4.369	--	--	--	--	--	--
Employed	0.074	2.909	--	--	--	--	--	--
Student	-0.179	-3.517	--	--	--	--	--	--
No children in household	--	--	--	--	0.301	2.259	--	--
Couple household	--	--	-0.194	-2.646	--	--	-0.393	-1.661
Individual activity participation decisions								
Work-related activities	-0.490	-15.231	-0.364	-3.654	--	--	--	--
Shopping	0.066	3.034	--	--	--	--	--	--
Household or personal business	--	--	-0.175	-2.115	--	--	--	--
Eating out	0.069	3.002	-0.165	-2.130	--	--	--	--
Social or recreational activities	--	--	0.134	1.776	--	--	--	--
Other serve-passenger activities	-0.136	-4.804	--	--	--	--	--	--
Pattern-level attributes								
One Tour	0.282	8.923	--	--	--	--	--	--
Two Tours	0.122	3.817	--	--	--	--	--	--
Three or more tours	--	--	-0.825	-9.563	--	--	--	--
Tour-level attributes								
Available time for the tour	--	--	0.002	10.526	0.003	8.650	0.003	3.778
Tour mode								
Driver, solo	-0.041	-1.925	-0.243	-3.206	-0.346	-2.100	--	--
Passenger	--	--	--	--	-0.346	-1.831	-0.447	-1.935
One stop in tour	0.058	2.741	0.225	2.813	--	--	--	--

3.7 Activity type at a stop (Model NWSCH8)

Multinomial logit Model NWSCH8 determines the activity type at any stop in a non-worker's tour. The different non-work activities that an adult has decided to undertake during the day (as determined in the generation-allocation model system) constitute the set of available alternatives. The empirical model is presented in Table A-40. The number of episodes of the same type already undertaken negatively impacts the utility for each of the activity type alternatives. In addition, the utility of each of the different activity types is also found to be impacted by the tour to which the stops belong, the position of the stop in the tour (i.e., whether this is the first stop, second stop, etc.), and the mode of travel to the activity stop.

Table A-40 Activity type at a stop (Model NWSCH8)

Explanatory variables	Work related		Shopping		Household/personal business		Social/ recreational		Eat out		Other serve passenger	
	Param	**t stat**	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**	**Param**	**t stat**
Number of episodes of this type already undertaken	-0.4693	-15.646	-0.4693	-15.646	-0.4693	-15.646	-0.4693	-15.646	-0.4693	-15.646	-0.4693	-15.646
Tour-level characteristics												
First tour							-0.3437	-3.258				
Number of stops in tour			-0.4607	-8.559	-0.1119	-3.527	-0.2909	-7.362	-0.2462	-6.307	-0.25	-6.425
Tour mode												
Driver, solo			0.2575	2.051	0.2866	2.923			-0.349	-2.737		
Undertakes pick-up in this tour			-2.2649	-2.301	0.5082	1.216	-3.5146	-2.906	-2.9131	-2.475		
Undertakes drop-off in this tour					-1.6508	-2.553						
Stop-level characteristics												
Second stop			0.6222	4.375					0.6651	5.329	-0.5101	-3.045
Third stop			1.0745	5.727							-0.4691	-2.251
Fourth stop			1.1321	4.472								
Fifth stop			1.762	5.751								
Constant			-0.0257	-0.138	-0.0357	-0.226	0.355	2.21	-0.2646	-1.476	0.7474	4.235
Log likelihood at convergence	-3513.297											
Log likelihood constants only	-3795.883											
Number of cases	3892											

3.8 Activity duration at a stop (Model NWSCH9)

This model determines the time spent in activity participation at any stop. The logarithm of activity duration is taken as the independent variable in this linear regression model. Separate models were estimated for the durations spent in stops undertaken in (1) tour1, (2) tour2, (3) tour3, and (4) tour 4. The estimation results are presented in Table A-41. The greater the number of stops in a tour, the shorter the duration of activity at any stop in that tour. Available time positively influences activity duration in stops undertaken in the first and second tours. Finally, the activity duration is also found to vary depending on the activity type pursued at the stop. In particular, the activity duration is found to be the shortest for the other serve-passenger activities, as would be expected.

Table A-41 Activity duration at a stop (Model NWSCH9)

Explanatory variables	Stops in Tour 1		Stops in Tour 2		Stops in Tour 3		Stops in Tour 4	
	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Constant	2.440	22.776	2.626	18.133	2.708	6.553	3.733	18.123
Tour-level attributes								
Number of stops in tour								
One	0.717	12.260	0.713	8.099	0.456	3.106		
Two	0.312	5.035	0.325	3.332	0.288	1.748		
Three	0.308	5.004	0.298	2.821				
Tour mode								
Driver, solo	-0.424	-6.922	-0.147	-2.168	1.104	2.825	-0.509	-2.298
Driver with passenger	-0.320	-4.364			1.205	3.002		
Passenger					1.540	3.721		
Stop-level attributes								
Available time for activity and travel	0.001	8.686	0.000	1.886				
Destination activity type								
Constant	1.458	22.535	0.706	5.568				
Household or personal business					-1.155	-7.471		
Eating out	0.309	4.089	0.420	3.902	-0.589	-3.349		
Social or recreational activities	1.053	16.261	1.037	12.128			0.942	3.569
Other serve-passenger activities	-2.226	-26.906	-1.830	-18.309	-2.968	-18.123	-2.227	-8.417

3.9 Travel time to a stop (Model NWSCH10)

This model determines the travel time a person desires to spend in traveling to a stop. The logarithm of travel duration is taken as the independent variable in this linear regression model. Separate models were estimated for the travel time to stops undertaken in (1) tour1, (2) tour2, (3) tour3, and (4) tour 4. The estimation results are presented in Table A-42. The desired travel time is found to depend on the tour mode, the number of stops in the tour, the position of the stop in the tour (i.e., whether this is the first stop, second stop, etc.), and the activity type pursued at the stop.

Table A-42 Travel time to a stop (Model NWSCH10)

Explanatory variables	Stops in Tour 1		Stops in Tour 2		Stops in Tour 3		Stops in Tour 4	
	Param.	**t-stat**	**Param.**	**t-stat**	**Param.**	**t-stat**	**Param.**	**t-stat**
Constant	2.699	59.897	2.284	36.226	1.646	5.212	1.570	5.627
Tour-level attributes								
Two or more stops in tour	--	--	--	--	--	--	0.469	2.213
Tour mode								
Driver, solo	-0.316	-7.003	-0.120	-2.485	0.706	2.216	--	--
Driver with passenger	-0.243	-4.568	--	--	0.706	2.216	--	--
Passenger	--	--	--	--	0.706	2.216	--	--
Stop-level attributes								
First Stop in Tour	0.207	6.361	--	--	--	--	0.484	1.955
Destination activity type								
Work-related activities	0.532	11.612	0.588	5.862	--	--	--	--
Shopping	-0.195	-4.226	--	--	-0.300	-2.155	--	--
Household or personal business	--	--	0.233	3.374	--	--	--	--
Eating out	--	--	0.182	2.037	--	--	--	--
Social or recreational activities	--	--	0.242	3.229	--	--	0.466	2.714
Other serve-passenger activities	--	--	0.270	3.181	--	--	--	--

3.10 Location of a stop (Model NWSCH11)

This last model in the non-worker scheduling model system determines the location of the stops. The set of choice alternatives available for any stop is determined from the universal set of alternatives (i.e., all the zones in the study region) using a probabilistic choice set generation procedure. The probability that every set of zones includes the choice set is determined based on the inter-zonal travel times and the desired travel time to the stop (as determined from the previous model). Conditional on the probabilistic choice set, this model assumes a multinomial logit econometric structure.

The empirical results are presented in Table A-43. We find that, overall, closer zones are preferred to zones farther away from the origin zone. In addition, the results also indicate that zones closer to the ultimate destination are preferred (the ultimate destination is home as all tours are home-based). The impact of the distance to ultimate destination is also found to vary depending on the activity type pursued at the stop. Specifically, individuals are willing to travel farther away from home for work-related and social or recreational activities. However, people prefer locations closer to home for shopping. The CBD is found to be less attractive for pursuing non-work activities. The extent of activity opportunities in a zone, measured in terms of the logarithm of the retail plus service employment, is found to positively impact the utility of the zone as a candidate destination for the stop.

Table A-43 Location of a stop (Model NWSCH11)

Explanatory variables	Param.	t-stat
Impedance measures		
Auto IVTT at start of trip	-0.248	-17.005
Auto IVTT at start of trip * Walk mode	0.0337	1.794
Auto IVTT at start of trip * Household or personal business	-0.5814	-4.492
Distance to the ultimate destination	-0.1465	-7.913
Distance to the ultimate destination * work-related activities	0.1634	4.455
Distance to the ultimate destination * shopping	-0.1585	-4.422
Distance to the ultimate destination * social or recreational activities	0.0603	1.839
Destination zone adjacent to the origin zone	0.4314	4.89
Destination zone same as the origin zone	1.3071	12.384
Attraction variables		
Destination zone is the CBD	-1.3657	-3.284
LN (service + retail employment) at destination zone	0.2835	7.182
LN (service + retail employment) at destination zone * Shopping	0.268	3.8
LN (service + retail employment) at destination zone * Household or personal business	0.2493	4.264
LN (service + retail employment) at destination zone * Eating out	0.3843	4.435
LN (population) at destination zone * Other serve-passenger activities	0.1805	3.213

4. Joint Discretionary Tour Scheduling Model System

The joint discretionary tour scheduling model system determines the characteristics of the single-stop tours undertaken by a parent with children for pursuing discretionary activities. This model system comprises four models, each of which is discussed in separate subsections below.

4.1 Departure time for the tour (Model JNTSCH1)

The first model in this system determines the departure time for the joint discretionary tour. The departure time is measured in minutes from 3:00 a.m. and the logarithm of the duration is taken as the dependent variable in this linear regression model. The empirical model results (Table A-44) indicate that the departure time is positively impacted by the adult's arrival time at home from work and the child's arrival time at home from school.

Table A-44 Departure time for the tour (Model JNTSCH1)

Explanatory variables	Param.	t-stat
Constant	6.50992	124.156
Adult's arrival time at home from work	0.00026	2.779
Child's arrival time at home from school	0.00027	2.705

4.2 Activity duration at the stop (Model JNTSCH2)

The second model determines the duration of the activity at the stop. The logarithm of activity duration is taken as the dependent variable in this linear regression model. The empirical results (Table A-45) indicate that the later the departure for the tour, the shorter is the activity duration. In addition, we also find that workers spend longer durations than do non-workers.

Table A-45 Activity duration at the stop (Model JNTSCH2)

Explanatory variables	Param.	t-stat
Constant	5.2332	12.7662
Departure time for the tour	-0.0014	-2.6967
Adult is a worker	0.7073	3.2295

4.3 Travel time to the stop (Model JNTSCH3)

The third model determines the desired travel time to the activity stop. The logarithm of the travel time is taken as the dependent variable. The estimation results are presented in Table A-46.

Table A-46 Travel time to the stop (Model JNTSCH3)

Explanatory variables	Param.	t-stat
Constant	2.3371	18.8666
Adult is a worker	0.3887	1.9163

4.4 Location of the stop (Model JNTSCH4)

This last model in the joint discretionary tour scheduling model system determines the location of the stop. The set of choice alternatives available for any stop is determined from the universal set of alternatives (i.e., all the zones in the study region) using a probabilistic choice set generation procedure. The probability that every set of zones includes the choice set is determined based on the inter-zonal travel times and the desired travel time to the stop (as determined from the previous model). Conditional on the probabilistic choice set, this model assumes a multinomial logit econometric structure.

The empirical results are presented in Table A-47. We find that, overall, closer zones are preferred to zones farther away from the origin zone. The extent of activity opportunities in a zone, measured in terms of the logarithm of the retail plus service employment and the logarithm of the population, is found to positively impact the utility of the zone as a candidate destination for the stop.

Table A-47 Travel time to the stop (Model JNTSCH3)

Explanatory variables	Param.	t-stat
Auto in-vehicle travel time at trip start time	-0.2671	-4.122
Destination zone same as origin zone	2.4203	4.489
Destination zone adjacent to origin zone	1.2385	2.6
LN (retail + service employment) at destination zone	0.4366	2.982
LN (population) at destination zone	0.2439	2.033

5. The children scheduling model system

The children scheduling model system includes the last component of the overall CEMDAP modeling system. This comprises seven models to completely determine the characteristics of the activity and travel undertaken by children independently. Each of these seven models is discussed below.

5.1 School-to-home (Model CSCH1) and home-to-school (Model CSCH2) commute durations

The first two models in the children scheduling model system determine the commute durations for children who are not escorted to or from school. The logarithm of the school-to-home travel time and home-to-school travel time are used as independent variables in Models CSCH1 and CSCH2, respectively. The estimation results (Table A-48) indicate that commute durations are positively impacted by the distance between the home and school. Further, the travel times are also found to vary depending on the travel mode. Specifically, the durations are found to be greatest for those traveling by the school bus and the least for those driven by non-household members.

Table A-48 School-to-home (Model CSCH1) and home-to-school (Model CSCH2) commute durations

Explanatory variables	**School-to-home duration (Model CSCH1)**		**Home-to-school duration (Model CSCH2)**	
	Param.	**t-stat**	**Param.**	**t-stat**
Constant	2.4324	37.6210	2.2961	38.4712
Travel mode from or to school				
Drive by other (base)	-	-	-	-
School bus	0.6350	8.2869	0.9422	13.0799
Walk or bike	0.3086	3.9087	0.3773	5.0598
School and home zones are the same	-0.2766	-2.9026	-0.5159	-5.8475
School and home zones are adjacent	-0.1692	-2.1647	-0.3801	-5.3242
Distance between school and home zone	0.0486	6.3189	0.0378	5.4659

5.2 Mode for the independent discretionary tour (Model CSCH3)

The remaining models in the children scheduling model system characterize the independent discretionary tour undertaken by children. Model CSCH3 determines the travel mode for this tour using the binary logit structure. The choice alternatives assumed to be available to all children are “walk or bike” and “drive by other.” The observed sample shares are 46.5 percent walk or bike and the rest drive by other. The empirical model (Table A-49) indicates that male children are more likely to walk, whereas schoolgoing children are less likely to choose walk as the tour mode.

Table A-49 Mode for the independent discretionary tour (Model CSCH3)

Explanatory variable	Drive by other		Walk or bike	
	Param.	t-stat	Param.	t-stat
Constant	--	--	0.13	0.37
Male	--	--	0.835	2.44
Goes to school	--	--	-1.14	-3.202

5.3 Departure time for the independent discretionary tour (Model CSCH4)

This model determines the departure time for the independent discretionary tours. The departure time is measured in time from 3:00 a.m. and the logarithm of the time duration is taken as the dependent variable in this linear regression model. Empirical results (Table A-50) indicate that the arrival time at home from school positively impacts the departure time for discretionary tour. Further, elderly children and male children are likely to depart for discretionary activities later in the day than are younger children and female children, respectively.

Table A-50 Departure time for the independent discretionary tour (Model CSCH4)

Explanatory variable	Param.	t-stat
Constant	6.1785	66.5412
Arrival time at home after school	0.0001	1.5466
Age	0.0255	2.7127
Male	0.0775	1.1950

5.4 Activity duration at the independent discretionary stop (Model CSCH5)

Model CSCH5 determines the activity duration at the discretionary stop using a linear regression econometric structure. The logarithm of the activity duration is taken as the explanatory variable. The empirical results (Table A-51) indicate that the later the departure for the tour, the shorter the activity duration.

Table A-51 Activity duration at the independent discretionary stop (Model CSCH5)

Explanatory variable	Param.	t-stat
Constant	5.0449	19.9522
Start time of the tour	-0.0009	-2.8716

5.5 Travel time to the independent discretionary stop (Model CSCH6)

Model CSCH5 determines the desired travel time to the discretionary stop using a linear regression econometric structure. The logarithm of the travel duration is taken as the explanatory variable. The empirical results (Table A-52) indicate that the travel time is shorter if the travel mode is walk or bike. Further, schoolgoing children are found to undertake shorter travel for discretionary activities than non-schoolgoing children are.

Table A-52 Travel time to the independent discretionary stop (Model CSCH6)

Explanatory variable	Param.	t-stat
Constant	2.4408	13.1308
Travel mode is walk or bike	-0.2696	-1.5163
Child goes to school	-0.2493	-1.3372

5.6 Location of the independent discretionary stop (Model CSCH7)

This last model in the children scheduling model system determines the location of the discretionary activity stop. The set of choice alternatives available for any stop is determined from the universal set of alternatives (i.e., all the zones in the study region) using a probabilistic choice set generation procedure. The probability that every set of zones comprises the choice set is determined based on the inter-zonal travel times and the desired travel time to the stop (as determined from the previous model). Conditional on the probabilistic choice set, this model assumes a multinomial logit econometric structure.

The empirical results are presented in Table A-53. We find that, overall, closer zones are preferred to zones farther away from the origin zone, and more so when the travel mode is walk or bike. The extent of activity opportunities in a zone, measured in terms of the logarithm of the population, is found to positively impact the utility of the zone as a candidate destination for the stop.

Table A-53 Location of the independent discretionary stop (Model CSCH7)

Explanatory variables	**Param.**	**t-stat**
Auto in-vehicle travel time at trip start time	-0.1593	-3.033
Auto in-vehicle travel time at trip start time * Walk or bike mode	-0.3315	-3.328
Destination zone same as the origin	2.9524	6.224
Destination zone adjacent to the origin	1.1686	2.585
LN (population) of the destination zone	0.347	2.634

Appendix B: Look-Up Tables for CEMSELTS

This appendix presents several look-up tables referred in Section 3.3.

Table B-1 Death probability look-up table excerpt

Age	White Male	White Female	Black Male	Black Female	Other Male	Other Female
0	0.006417	0.005124	0.015395	0.01322	0.00735	0.00632
1	0.000467	0.000384	0.000815	0.000613	0.00059	0.00043
2	0.000328	0.000258	0.00054	0.000408	0.00042	0.00029
3	0.000249	0.000184	0.000427	0.000272	0.00028	0.00023
4	0.000209	0.000146	0.000373	0.00027	0.00025	0.00022
5	0.000173	0.000153	0.000263	0.000209	0.00020	0.00018
6	0.000155	0.000117	0.0002	0.000185	0.00016	0.00013
7	0.000153	0.000113	0.000186	0.000177	0.00018	0.00013
8	0.00015	0.000128	0.00027	0.000167	0.00018	0.00013
9	0.000138	0.00012	0.000279	0.000186	0.00016	0.00015
10	0.000161	0.000113	0.000252	0.0002	0.00018	0.00013
11	0.000158	0.000116	0.000268	0.000189	0.00019	0.00016
12	0.000202	0.000128	0.000354	0.000219	0.00023	0.00017
13	0.000244	0.000182	0.000352	0.000207	0.00028	0.00019
14	0.000296	0.000204	0.000455	0.000254	0.00032	0.00020
15	0.000426	0.000248	0.000518	0.000284	0.00041	0.00025
16	0.000734	0.000405	0.000906	0.000328	0.00069	0.00035
17	0.000885	0.000448	0.001132	0.000419	0.00083	0.00041
18	0.001151	0.000464	0.001649	0.000512	0.00114	0.00043
19	0.001325	0.000457	0.001912	0.000513	0.00132	0.00040
20	0.001294	0.000435	0.00206	0.000604	0.00130	0.00042
21	0.001338	0.000487	0.002258	0.000664	0.00129	0.00043
22	0.001253	0.000424	0.002306	0.000714	0.00131	0.00048
23	0.0013	0.000415	0.002336	0.000723	0.00125	0.00042
24	0.001257	0.000457	0.002438	0.000698	0.00116	0.00045
25	0.001202	0.000458	0.002484	0.000808	0.00109	0.00043
26	0.001233	0.000459	0.002584	0.000891	0.00108	0.00044
27	0.001145	0.000441	0.002593	0.000927	0.00100	0.00049
28	0.001173	0.00053	0.002439	0.000925	0.00098	0.00042
29	0.00123	0.000515	0.00267	0.001229	0.00102	0.00048
30	0.00129	0.00056	0.002561	0.001153	0.00099	0.00055
31	0.001316	0.000594	0.002724	0.001205	0.00104	0.00058
32	0.001252	0.000629	0.002547	0.001367	0.00110	0.00066
33	0.001465	0.000697	0.002695	0.001487	0.00115	0.00063
34	0.001482	0.000758	0.003123	0.001581	0.00117	0.00071
35	0.001578	0.000855	0.003457	0.001746	0.00133	0.00080
36	0.001683	0.000929	0.003521	0.00185	0.00139	0.00086
37	0.001866	0.001003	0.003356	0.001989	0.00157	0.00097
38	0.002025	0.001081	0.003931	0.00228	0.00170	0.00102
39	0.002226	0.001292	0.004018	0.002617	0.00183	0.00112
40	0.002507	0.00136	0.00425	0.002615	0.00199	0.00119
41	0.002649	0.001468	0.004682	0.003126	0.00209	0.00132

Source: NCHS, 2005. United States Life Tables, 2002. National Vital Statistics Reports, Volume 53, Number 6.

Table B-2 Birth probability look-up table

Age	Non-Hispanic White	Non-Hispanic Black	American Indian	Asian or Pacific Islander	Hispanic
10–14	0.0005	0.0018	0.0009	0.0003	0.0014
45–49	0.0005	0.0004	0.0003	0.0009	0.0007

Source: NCHS, 2003. Births: Final Data for 2002. National Vital Statistics Reports, Volume 52, Number 10.

Table B-3 Number of births look-up table

Non-Hispanic White

Age	Single Birth	Twins	Triplets
10–14	0.9652	0.0348	0
15–17	0.9873	0.0127	0
18–19	0.984584	0.0152	0.000216
20–24	0.977941	0.0215	0.000559
25–29	0.967177	0.0308	0.002023
30–34	0.953306	0.0429	0.003794
35–39	0.941906	0.0533	0.004794
40–44	0.932007	0.0629	0.005093
45–49	0.736742	0.2379	0.025358

Non-Hispanic Black

Age	Single Birth	Twins	Triplets
10–14	0.9882	0.0118	0
15–17	0.9822	0.0178	0
18–19	0.975528	0.0241	0.000372
20–24	0.966643	0.0328	0.000557
25–29	0.960141	0.0387	0.001159
30–34	0.956242	0.042	0.001758
35–39	0.952059	0.0454	0.002541
40–44	0.962898	0.0353	0.001802
45–49	0.899177	0.0795	0.021323

Hispanic

Age	Single Birth	Twins	Triplets
10–14	0.9872	0.0128	0
15–17	0.9877	0.0123	0
18–19	0.985735	0.014	0.000265
20–24	0.982446	0.0172	0.000354
25–29	0.978117	0.0211	0.000783
30–34	0.9722	0.0264	0.0014
35–39	0.966582	0.0309	0.002518
40–44	0.968164	0.0279	0.003936
45–49	0.899177	0.0795	0.021323

Other

Age	Single Birth	Twins	Triplets
10–14	0.9878	0.0122	0
15–17	0.9862	0.0138	0
18–19	0.982935	0.0168	0.000265
20–24	0.9771	0.0224	0.0005
25–29	0.969465	0.029	0.001535
30–34	0.958123	0.0389	0.002977
35–39	0.94824	0.0477	0.00406
40–44	0.943564	0.0525	0.003936
45–49	0.779677	0.199	0.021323

Source: NCHS, 2003. Births: Final Data for 2002. National Vital Statistics Reports, Volume 52, Number 10.

Table B-4 Child gender look-up table

	Non-Hispanic White	Non-Hispanic Black	American Indian	Asian or Pacific Islander	Hispanic
Male	0.51179821	0.51052374	0.506660089	0.517063748	0.509724

Source: NCHS, 2004. Trends in Characteristics of Births by State: United States, 1990, 1995, and 2000–2002. National Vital Statistics Reports, Volume 52, Number 19.

Table B-5 Net migration rates table

	Caucasian		African American		Hispanic		Other	
Age	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
0	0.000057	0.000057	0.000693	0.000347	0.000057	0.000057	0.000057	0.000057
1	0.00011	0.00011	0.00198	0.00141	0.00011	0.00011	0.00011	0.00011
2	0.00017	0.00017	0.00248	0.00253	0.00017	0.00017	0.00017	0.00021
3	0.00023	0.00023	0.00317	0.00304	0.00023	0.00023	0.00129	0.00064
4	0.00028	0.00028	0.00499	0.00412	0.00091	0.00062	0.00530	0.00703
5	0.00034	0.00034	0.00331	0.00357	0.00185	0.00184	0.00665	0.00760
6	0.00040	0.00040	0.00393	0.00325	0.00261	0.00285	0.00989	0.01101
7	0.00046	0.00046	0.00346	0.00368	0.00455	0.00409	0.01404	0.01384
8	0.00051	0.00051	0.00308	0.00330	0.00608	0.00616	0.01577	0.01574
9	0.00057	0.00057	0.00377	0.00384	0.00787	0.00765	0.01851	0.02003
10	0.00157	0.00174	0.00784	0.00727	0.01420	0.01306	0.02500	0.02500
11	0.00203	0.00202	0.00813	0.00680	0.01420	0.01458	0.02500	0.02500
12	0.00246	0.00253	0.00704	0.00816	0.01451	0.01457	0.02500	0.02500
13	0.00251	0.00267	0.00859	0.00738	0.01462	0.01517	0.02500	0.02500
14	0.00219	0.00226	0.00801	0.00721	0.01377	0.01334	0.02500	0.02500
15	0.00257	0.00227	0.00799	0.00726	0.01615	0.01474	0.02500	0.02500
16	0.00243	0.00236	0.00869	0.00752	0.01836	0.01466	0.02500	0.02500
17	0.00196	0.00176	0.00875	0.00679	0.02150	0.01562	0.02500	0.02500
18	0.00430	0.00395	0.01141	0.00949	0.02500	0.01913	0.02500	0.02500
19	0.00058	0.00029	0.00540	0.00628	0.02188	0.01493	0.02500	0.02500
20	0.00005	0.00002	0.00520	0.00557	0.02400	0.01722	0.02500	0.02500
21	0.00027	0.00014	0.00454	0.00641	0.02500	0.01842	0.02500	0.02500
22	0.00005	0.00002	0.00323	0.00466	0.02500	0.01880	0.02500	0.02500
23	0.00085	0.00042	0.00328	0.00615	0.02500	0.02085	0.02500	0.02500
24	0.00235	0.00330	0.00298	0.00149	0.02500	0.02188	0.02500	0.02500
25	0.00343	0.00440	0.00362	0.00696	0.02500	0.02193	0.02500	0.02500
26	0.00298	0.00379	0.00328	0.00164	0.02500	0.02164	0.02500	0.02500
27	0.00268	0.00430	0.00350	0.00687	0.02363	0.02108	0.02500	0.02500
28	0.00346	0.00479	0.00191	0.00096	0.02398	0.02183	0.02500	0.02500
29	0.00107	0.00181	0.00114	0.00057	0.01931	0.01788	0.02500	0.02500
30	0.00368	0.00290	0.00501	0.00683	0.02268	0.01988	0.02500	0.02500
31	0.00324	0.00332	0.00339	0.00574	0.01936	0.01795	0.02500	0.02500
32	0.00457	0.00346	0.00604	0.00839	0.01912	0.01910	0.02500	0.02500
33	0.00353	0.00253	0.00490	0.00626	0.01542	0.01592	0.02500	0.02500
34	0.00197	0.00190	0.00537	0.00498	0.01520	0.01482	0.02500	0.02500
35	0.00343	0.00260	0.00606	0.00757	0.01446	0.01537	0.02500	0.02500
36	0.00219	0.00196	0.00417	0.00603	0.01216	0.01268	0.02500	0.02500
37	0.00175	0.00134	0.00558	0.00490	0.01123	0.01122	0.02500	0.02500
38	0.00404	0.00350	0.00701	0.00798	0.01374	0.01392	0.02500	0.02500
39	-0.00021	-0.00010	0.00369	0.00214	0.00780	0.00850	0.02500	0.02500
40	0.00180	0.00096	0.00639	0.00414	0.01118	0.01025	0.02500	0.02500
41	0.00091	0.00046	0.00456	0.00392	0.00891	0.00797	0.02351	0.02500
42	0.00150	0.00115	0.00442	0.00310	0.00928	0.00887	0.02500	0.02487

43	0.00135	0.00114	0.00591	0.00296	0.00852	0.00833	0.02391	0.02393
44	-0.00010	-0.00006	0.00240	0.00120	0.00656	0.00644	0.02088	0.02188
45	0.00180	0.00158	0.00506	0.00324	0.00821	0.00694	0.02305	0.02252
46	0.00073	0.00072	0.00398	0.00227	0.00705	0.00637	0.02097	0.02076
47	0.00149	0.00131	0.00431	0.00260	0.00638	0.00591	0.01913	0.02010
48	0.00397	0.00373	0.00685	0.00516	0.00863	0.00822	0.02076	0.02104
49	-0.00037	-0.00020	0.00221	0.00110	0.00462	0.00476	0.01729	0.01545
50	0.00214	0.00151	0.00552	0.00314	0.00665	0.00672	0.02005	0.01957
51	0.00140	0.00127	0.00465	0.00234	0.00674	0.00517	0.01866	0.01838
52	0.00203	0.00137	0.00576	0.00313	0.00655	0.00656	0.01963	0.01942
53	0.00170	0.00165	0.00416	0.00208	0.00445	0.00380	0.01564	0.01797
54	0.00074	0.00086	0.00396	0.00296	0.00733	0.00723	0.02036	0.01760
55	0.00159	0.00148	0.00443	0.00322	0.00567	0.00545	0.01757	0.01877
56	0.00274	0.00199	0.00548	0.00333	0.00633	0.00654	0.02221	0.01929
57	0.00119	0.00116	0.00438	0.00219	0.00390	0.00464	0.01798	0.01506
58	0.00474	0.00384	0.00860	0.00482	0.00835	0.00832	0.02041	0.02456
59	-0.00028	-0.00014	0.00262	0.00142	0.00244	0.00382	0.01180	0.01516
60	0.00154	0.00120	0.00642	0.00400	0.00608	0.00596	0.01849	0.01957
61	0.00206	0.00179	0.00725	0.00362	0.00523	0.00543	0.02085	0.02384
62	0.00282	0.00219	0.00725	0.00402	0.00660	0.00648	0.02500	0.02500
63	0.00265	0.00227	0.00818	0.00464	0.00726	0.00679	0.02323	0.02500
64	0.00251	0.00171	0.00779	0.00390	0.00576	0.00582	0.01695	0.02198
65	0.00300	0.00263	0.00695	0.00492	0.00739	0.00707	0.02500	0.02201
66	0.00236	0.00166	0.00949	0.00474	0.00710	0.00634	0.02277	0.02194
67	0.00308	0.00230	0.00621	0.00571	0.00482	0.00326	0.02478	0.02500
68	0.00550	0.00445	0.01279	0.00640	0.01039	0.00920	0.02500	0.02252
69	0.00184	0.00124	0.00631	0.00316	0.00449	0.00375	0.02500	0.02067
70	0.00356	0.00288	0.00822	0.00660	0.00771	0.00710	0.02340	0.02500
71	0.00397	0.00208	0.00702	0.00465	0.00593	0.00409	0.02374	0.02168
72	0.00272	0.00171	0.00371	0.00222	0.00564	0.00381	0.01994	0.02105
73	0.00318	0.00287	0.00733	0.00367	0.00518	0.00395	0.02147	0.01931
74	0.00311	0.00216	0.00560	0.00280	0.00506	0.00253	0.01329	0.01605
75	0.00250	0.00223	0.00553	0.00276	0.00291	0.00381	0.01651	0.01161
76	0.00293	0.00212	0.00319	0.00159	0.00236	0.00185	0.01593	0.01536
77	0.00281	0.00225	-0.00002	-0.00001	0.00270	0.00135	0.01647	0.01750
78	0.00329	0.00241	0.00686	0.00343	0.00272	0.00141	0.01791	0.00961
79	0.00148	0.00231	0.00516	0.00258	-0.00047	-0.00024	0.00906	0.00966
80	0.00378	0.00412	0.00447	0.00224	0.00331	0.00336	0.00708	0.01324
81	0.00274	0.00250	0.00097	0.00049	-0.00439	-0.00369	0.00214	0.00107
82	0.00279	0.00357	0.00233	0.00116	0.00257	0.00128	0.00796	0.01336
83	0.00515	0.00504	0.00138	0.00069	-0.00256	-0.00175	-0.00072	-0.00036
84	0.00393	0.00442	0.00485	0.00242	-0.00117	-0.00059	0.00621	0.00909
85+	-0.00386	-0.00193	-0.00526	-0.00269	-0.01061	-0.00974	-0.00104	-0.00052

Table B-6 Employment separation look-up table

Industry	Probability
Construction or Manufacturing	.0385
Trade and Transportation	.0390
Professional Businesses	.0390
Government	.0130
Retail or Repair	.0390
Other	.0374

Table B-7 DFW school look-up table excerpt

Residential TAZ	Decimal Percent	Elementary School (K–5) TAZ	Middle School (6–8) TAZ	High School (9–12) TAZ
2032	1.00	0	40123	40123
2034	0.64	41183	40123	40123
	0.13	2019	2019	0
	0.23	2067	2078	40055
2039	1.00	2046	2039	40045
2040	1.00	2046	2039	40045
2042	0.98	0	40123	40123
	0.02	2181	2373	2181
2046	1.00	2046	2039	40045
2050	0.99	2046	2039	40045
	0.01	30300	2078	2148
2053	1.00	0	40123	40123
2056	0.78	2067	2078	40055
	0.22	41183	40123	40123
2061	0.97	30300	2078	2148
	0.03	2046	2039	40045
2064	0.60	40055	2134	40055
	0.40	41183	40123	40123
2065	1.00	40055	2134	40055
2067	1.00	2067	2078	40055
2070	1.00	30300	2078	2148
2071	1.00	30300	2078	2148
2074	1.00	40055	2134	40055
2075	1.00	40055	2078	40055
2076	1.00	2067	2078	40055
2077	1.00	2067	2078	40055
2078	1.00	2067	2078	40055
2079	1.00	2080	2078	40055
2080	1.00	2080	2078	40055
2081	1.00	2082	2078	40055
2082	1.00	2082	2078	40055
2084	1.00	2082	2078	2148
2092	0.55	0	40123	40123
TAZ = 0: School lies outside of NCTCOQ area				

Table B-8 Drop-out rate look-up table

Male

Age	Black	Asian or Pacific Islander	Hispanic	Native American	White
13	0.001	0.001	0.003	0.002	0.001
14	0.004	0.002	0.005	0.002	0.001
15	0.018	0.005	0.02	0.01	0.005
16	0.019	0.006	0.021	0.011	0.006
17	0.023	0.007	0.022	0.018	0.008
18	0.021	0.006	0.022	0.017	0.009

Female

Age	Black	Asian or Pacific Islander	Hispanic	Native American	White
13	0.002	0.001	0.003	0.004	0.001
14	0.003	0.002	0.006	0.008	0.001
15	0.014	0.004	0.018	0.008	0.005
16	0.014	0.003	0.017	0.014	0.005
17	0.013	0.005	0.018	0.011	0.006
18	0.015	0.005	0.016	0.008	0.007

Table B-9 Educational attainment table

Male

	White	Black	Hispanic	Asian	Am. In.	Other
High School	.6667	.7866	.7060	.3140	.8000	.9137
Associate's	.0501	.0418	.0442	.0349	.0667	.0208
Bachelor's	.2146	.1506	.1858	.3721	.1333	.0476
Master's	.0651	.0209	.0615	.2791	.0000	.0149
Doctorate	.0036	.0000	.0025	.0000	.0000	.0030

Female

	White	Black	Hispanic	Asian	Am. In.	Other
High School	.6125	.7470	.6598	.5364	.9000	.9041
Associate's	.0576	.0643	.0590	.3000	.1000	.0753
Bachelor's	.2699	.1678	.2258	.1364	.0000	.0103
Master's	.0584	.0209	.0533	.0182	.0000	.0068
Doctorate	.0016	.0000	.0021	.0091	.0000	.0034

Table B-10 College look-up table excerpt

Associate's Degree—Male

Zone	White	Black	Hispanic	Asian	Other
6821	0	0	0	0	0
6354	0.064887	0.061803	0.105657	0.145728	0.204583
40690	0.021825	0.081062	0.023647	0.009075	0.026613
3067	0.127693	0.022914	0.038251	0.055102	0.02828
40497	0.006692	0.006258	0.003839	0.002365	0.002036
8177	0.019523	0.018905	0.01006	0.004878	0.009612
6444	0	0	0	0	0
6390	0.084724	0.117531	0.111153	0.217976	0.340521
7159	0.072601	0.089385	0.093483	0.07032	0.024333
7531	0.039971	0.139316	0.054488	0.026214	0.018196
8078	0.040067	0.10075	0.109145	0.026956	0.018686
6738	0.075803	0.072013	0.078032	0.136813	0.148239
8660	0.006486	0.004347	0.005396	0.001	0.001939
8482	0	0	0	0	0
7010	0.033702	0.010309	0.014819	0.021418	0.008209
16101	0.005059	0.002997	0.003427	0.001171	0.001512
41072	0.011728	0.003138	0.006174	0.001488	0.002904
40989	0.130142	0.052102	0.074845	0.093224	0.051867
41005	0.064199	0.0193	0.084098	0.028051	0.021047
10540	0.073442	0.090729	0.087496	0.036791	0.030375
10727	0.075364	0.086418	0.074002	0.105681	0.045713
10040	0.019556	0.014668	0.014089	0.010367	0.009337
10327	0.026537	0.006053	0.0079	0.005383	0.005998
9949	0	0	0	0	0
10218	0	0	0	0	0
2100	0	0	0	0	0
6861	0	0	0	0	0
2164	0	0	0	0	0
10262	0	0	0	0	0
3462	0	0	0	0	0
7227	0	0	0	0	0