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Forecasting with Dynamic Microsimulation: Design, Implementation, and Demonstration

Final Report on Review, Model Guidelines, and a Pilot Test for a Santa Barbara County Application
University of California Transportation Center (UCTC) Research Project

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PROJECT SUMMARY

In this project we develop a new travel demand forecasting system that integrates demographic microsimulation with urban simulation and travel demand model systems. Our research objective is to identify the barriers in integrating complex simulation models and eliminate them by offering a demonstration of problems and solutions. The basic ingredients of this new model system are: a) a dynamic demographic simulator designed and tested with repeated observations of the same individuals in another context that will be transferred to a case study in Santa Barbara, CA; b) a modified version of the recently finalized Urbansim model that will also be calibrated with data from Santa Barbara, CA; and c) travel demand models that account for intra-household interactions and path based accessibility that were estimated with data from California. The model system is unique because it combines within a day and across years human behavior dynamics and it will push the frontier of modeling and simulation one step further. A demonstration of a pilot test is offered using data from Santa Barbara, CA.

KEYWORDS: Microsimulation, Demographic Forecasting, Travel behavior, UrbanSim

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INTRODUCTION

In this project we develop a new travel demand forecasting system that integrates demographic microsimulation with urban simulation and activity-based travel demand model systems. The basic ingredients of this new model system are: a) a dynamic demographic simulator called DEMOS that was designed and tested with repeated observations of the same individuals in another context that will be transferred to a case study in Santa Barbara, CA; b) a modified version of the recently finalized Urbansim model that will also be calibrated with data from Santa Barbara, CA; and c) travel demand models that account for intra-household interactions and path based accessibility that were estimated with data from California. The model system design is unique because it combines within a day and across years human behavior dynamics and expands the frontier of modeling and simulation one step further. During this first year of funding from the University of California Transportation Center we provide a synthesis of the literature and test the demographic models and a simplified urbanism application for the case study of Santa Barbara, CA. The second year of this project continues with funding from the UC MRPI Sustainable Transportation and a UC Office of the President grant on next generation agent-based simulation.

This report reviews the background research and findings on a selection of Land Use models, basic elements of demographic microsimulation that inform key modifications required for DEMOS, a pilot test of Urbansim in Santa Barbara, and lessons learned with a brief description of next steps.

LAND USE MODELS

More than ten years ago, Miller et al. (1999), identified the growing recognition that land-use transport interactions (which we knew to be significant) must be understood, analyzed and accounted for in order to ensure that land use and transportation plans and policies are effective and can succeed. Integrated land-use transport models attempt to predict the dynamics of land use patterns, travel patterns and their interactions. In fact, the development of land use-transportation integrated models experienced spectacular success. They are also beginning to experience a new cycle of application by regional planning agencies. This development is the result of more than 40 years of research as the reviews of Timmermans (2003), Waddell and Ulfarsson (2004), Hunt et al (2005), and Zhao and Chung (2006) have documented. Below we compile a summary that follows, more or less, the historical development of these models.

Spatial Interaction Models

Models based on spatial interaction include some of the earliest efforts to model systematic spatial patterns of urban land use. The principles of gravity and entropy maximization are widely used in this modeling approach. Spatial interaction models include: The Lowry-Garin model, ITLUP/DRAM/EMPAL/METROPILUS and LILT.

Lowry-Garin Model

One of the first models to have gained substantial interest was developed by Lowry (1963, 1964) for the Pittsburgh urban region. In this model a distinction is made among activities located in space as population residence, service employment and basic employment. Basic employment was treated as the employment in industries around which service employment locates. Activities are translated into appropriate land uses by means of land-use/activity ratios. The model allocates these activities to zones (i.e., convenient subdivision of space) according to the potential of zones. Population and employment is allocated in proportion to potential of each zone, the allocation is subject to capacity constraints on the amount of land use accommodated in each zone. The model ensures that population and employment distributions used to calculate potentials are consistent with predicted distributions of population (Timmermans 2003). Garin (1966) reformulated Lowry's model. He suggested replacing the potential models by production-constrained gravity models. The Lowry model can be considered to be a static equilibrium solution based model.

ITLUP/DRAM/EMPAL/METROPILUS

ITLUP (Integrated Transportation and Land-Use Package) was developed by Putman and his collaborators at the University of Pennsylvania over the course of several years. ITLUP comprises a number of submodels, the best known of which are DRAM (Disaggregate Residential Allocation Model) and EMPAL (Employment Allocation Model). DRAM and EMPAL are Lowry type models (Meyer and Miller 2001). The models allocate household categories, employment categories, and travel patterns using exogenous study-area forecasts of employment, population, trips, activity rates and household types. Putman (1995) claimed that DRAM and EMPAL were the “most widely applied models” in the U.S. This may be due to the relative simplicity and effectiveness of these models. In fact, according to U.S. DOT (2002), DRAM has been capable of capturing more than 85% of the variation in land use calibration. However, EMPAL calibration has not been as successful except for service employment. In the 1990’s METROPILUS was developed based on DRAM and EMPAL by combining employment and residential location and land consumption in a single comprehensive package. METROPILUS is also embedded in a GIS environment.

LILT

The Leeds Integrated Land-Use Transportation model (LILT) was developed by Mackett (1979, 1983). The model combines a Lowry type location model with four-stage aggregate transport model and a car ownership model. Future population, new housing and jobs are allocated to zones according to accessibility functions and the attractiveness of the zone using entropy-maximizing principles. Employment is disaggregated into twelve sectors and population is categorized into three socio-economic groups. The model handles demolition, changing occupancy rates and vacancies. LILT has been applied to several metropolitan regions including Leeds, England; Dortmund, Germany; Tokyo, Japan (Mackett 1983, 1990a,b).

IRPUD

The IRPUD model was developed for the city of Dortmund by Michael Wegener and his co-workers (Wegener, 1982a,b; Wegener, 1983; Wegener, et al., 1991). The IRPUD is a simulation model of intra-regional location and mobility decisions in a metropolitan area (Wegener, 1994). A macroanalytic model of economic and demographic change is used to simulate employment change by industry type and demographics by age, gender and nationality. A mesoscopic spatial model is used to simulate intra-regional location decisions of industry, residential developers and households. Finally, a microanalytic model of land use development within statistical tracts is used to allocate the demand generated by the mesoscopic model. The simulation involves several interlinked submodels. The submodels deal with aging of people, households, dwellings and workplaces; relocation of firms, and new jobs; non-residential construction and demolition; residential construction, and demolition; change of job; change of residence, car ownership and transport. This model was also used for an interesting multi-city comparative study in a European Union research project named Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (PROPOLIS) that demonstrates how different policies can be compared using multiple sustainability indicators.

Spatial Input-Output Models

The spatial input-output framework was developed to represent the structure of the US economy (Leontief, 1966) to address spatial patterns of location of economic activity within regions and the movement of goods and people between zones. Spatial input-output models generate a static equilibrium solution in one or more changes to inputs (Waddell and Ulfrasson 2004). The models reviewed in this context are: MEPLAN, TRANUS, PECAS and DELTA.

MEPLAN

The MEPLAN framework is contained in proprietary software developed by Marcial Echenique and Partners Ltd. in UK. Hunt (1997) describes its framework as the interaction between two parallel markets: a land market and a transport market. MEPLAN is an aggregate model: space is divided into zones, quantities of households and economic activities (factors or sectors) are allocated to these zones, and flows of interactions among these sectors in different zones give rise to flows of transport demand (Hunt et al., 2005). The heart of the framework is a spatially disaggregated input-output matrix. Temporal change is simulated by considering sequential points in time. Considering that space is non-transportable and must be consumed in the zone where it is produced. Given transport demand by type and flow, the transport model predicts modal split and assignment. Information about costs, travel time due to congestion, and any other transport level of service offered are fed back into the land-use economic model to provide time-lagged measures of accessibility.

MEPLAN can also evaluate policy decisions on land use and transportation. MEPLAN provides the following output: employment by sector, population by income group, households by car ownership, land area by activity, floor space by activity, price by floor space/land type. Hunt (1997) describes that while MEPLAN requires small amount of data to run for forecasting purposes, calibrating MEPLAN is complex and demanding. MEPLAN has been applied to many metropolitan areas including London, England; Cambridge, UK; Santiago, Chile; Sacramento, USA and many more (Zhao and Chung 2006).

TRANUS

The TRANUS integrated land-use and transport modeling system was developed to simulate the probable effects of applying land-use and transport policies and evaluate their social, economic, financial, and environmental impacts. TRANUS provides future projections based on growth of location of activities and the effects of transportation policies on the location and the land market, which influences accessibility.

The land-use model is a spatial input-output model. The activities are divided into sectors and households for which the demand determined in a flexible way. Once the demand has been determined it is distributed to production zones and sectors, according to a multinomial logit model, subject to possible constraints. A supply model is used to simulate the expected behavior of land and floor space developers. Developers in a specific zone may choose between developing new land for residential or commercial use, through the use of logit models in which the utility function includes expected price or rent, demolition costs, and building costs. The land use model generates a set of matrices of flows representing potential transport demand. The transport model transforms potential demand into actual trips and assigns these trips to transport supply options. A detailed explanation can be found in De la Barra (1989) and Modelistica (1999).

TRANUS requires the following user input: network data; travel time in previous time period; activity location and land use data by zone; activity location and land use variables. Upon these input variables, TRANUS produces the following outputs: paths between each origin-destination pair for each travel mode; traffic assignment results like - total volume, and level of service variables; activity location and land-use consumption outputs. TRANUS has been used in the Baltimore Metropolitan Areas and the Input-Output and Transport Model for the State of Oregon among other places (see also http://www.modelistica.com/english/projects).

PECAS

PECAS (Production, Exchange and Consumption Allocation System) is a generalization of the spatial input-output modeling approach used in MEPLAN and TRANUS modeling systems (Hunt et al., 2005). At its heart, PECAS is an enhanced aggregate activity allocation model. Production and consumption activities are defined, and each one is allocated via a three-level nested model, to activity locations (level one), technology options (level two - mix of commodities consumed and/or produced, given activity location), and exchange locations (level three - where the level two commodities are bought and/or sold). The activities include various industries and household types and the commodities include goods, services, labor and floorspace (Bowman 2006).

PECAS also includes a space development module that simulates changes in state of development for every unit of space modeled in the region. The state change probabilities depend on real estate prices and development costs. The activity allocation and space development modules run iteratively in yearly time steps along with the transport model. In each time period, the activity allocation model receives forecasts of aggregate economic conditions and allocates activities by achieving equilibrium. The transport model estimates the resulting travel conditions and space development model predicts state transitions in response to the allocated activities. A PECAS application is currently under development for the entire State of California by UC Davis with HBA SPECTO Inc.(the company owned by the developers of PECAS Hunt and Abrams). Another application of PECAS is also developed for the Southern California Association of Governments (SCAG) using essentially the same method of large spatial economy zones the output of which is allocated to lower level spatial units (see http://www.scag.ca.gov/modeling/mtf/presentations/092309/mtf092309_PECASlandusemodel.pdf).

DELTA

DELTA was developed by David Simmonds Consultancy, MVA Consultancy and Institute of Transport Studies, Leeds during 1995-1996. DELTA is both an urban and regional model. At the urban level, the model projects changes in the location of households, population and employment and amount of real estate development in an urban area. At the regional level, it provides the projections of changes in the regional economy and migration between urban areas.

DELTA is not an integrated package, but a link of separate models. Input to the land-use model is accessibility from the transport model. Log-sum types of accessibilities are used. Land-use change is modeled for demographic change and employment change. Demographic change models household formation, dissolution and transformation. Economic growth models sector growth, decline and mobility based on the exogenous output. The location model predicts the location of those activities that are mobile as a function of accessibility, transport-related change in local environment, and rent of space. DELTA has been applied in Greater Manchester and Trans-Pennine Corridor, England; Edinburgh, Scotland; Sardinia, Italy; and Uruguay (Zhao and Chung 2006).

Microsimulation

Microsimulation as an approach implies a model that is applied at the level of individual decision making units (Waddell and Ulfrasson 2004). Developed in the late 1950's and early 1960's, the method was initially applied to study the effects of social and economic policies (Orcutt, 1957; Orcutt et al 1961). Microsimulation models are relatively easy to understand and implement since the decision making process is modeled at an individual level and /or a household level. In contrast, aggregate approaches model the collective effects of individual behavior, and because individual actors (or agents) are not explicitly represented in the process they cannot explain phenomena using added behavioral realism. In fact, this may lead to the inability to deal with many policy issues.

With advances in the field of computer science and greater availability of micro-level data, microsimulation has become increasingly popular. The models classified as microsimulation models are: MASTER, UrbanSim, ILUTE, and ILUMASS.

MASTER

The Micro-Analytical Simulation of Transport, Employment and Residence (MASTER) model developed by Mackett (1990a, 1990b) is an integrated land-use transportation model that operates at the household level. Population growth and household structure are modeled based on lifecycle events like: aging, death, marriage, divorce and migration. The choice of residential location is a function of work related travel costs for the head of the household. The location model also predicts the location residences and employment as a function of accessibility, transport-related change in local environment, area quality and rent of space. While, the housing choice is based on household size and composition. The supplies of housing and employment are exogenous input to the model. Household's members choice of jobs, employment, retirement, education level, jobs and salary ranges are all modeled in MASTER. The transportation processes modeled include driver's license eligibility, auto ownership, car availability and work trip mode choice. The travel costs are estimated based on travel distance without considering congestion, since the model does not assign traffic to each route.

UrbanSim

UrbanSim is an urban simulation system developed over the past several years by Waddell (2002) and Waddell and Ulfrasson (2004) and co-workers at University of Washington. UrbanSim is an operational model of urban land and floor space development. The model is designed to work in conjunction with a traditional four-step model or with an activity-based travel model. UrbanSim is also including random utility discrete choice models for some of its components. Households are classified in a disaggregate manner by income, persons, workers and the presence of children. Employment is classified into disaggregate sectors based on the NAICS and SIC codes. Some of the key features of UrbanSim are as follows:

1. Urbansim simulates the key decision makers and choices impacting urban development; in particular mobility and location choices of households and businesses and development choices of developers

2. It also simulates urban development as a dynamic process over time and space as opposed to cross-sectional or equilibrium approach
3. It simulates land market as the interaction of demand (locational preferences of households and businesses) and supply (existing vacant space, new construction and redevelopment), with prices adjusting to clear market.
4. Urbansim incorporates governmental policy assumptions explicitly, and evaluates the policy impacts of modeling market responses
5. It addresses both new development and redevelopment using parcel level detail

UrbanSim has many submodels which interact with each other in modeling the overall urban system. The models are listed below:

1. Demographic transition model accounts for the changes in distribution of households by type over time. This model uses external control totals of population and households by type to add or remove from the database to be consistent with the external assumptions about growth or decline over time.
2. Economic transition model serves the same function as the demographic component, and adds or removes jobs to achieve consistency with external assumptions about growth or decline over time.
3. Household relocation model predicts the probability that a household currently located in the region will move over the period of 1 year.
4. Employment relocation model also predicts the probability that a job given a sector and location will be moved from the location during a year.
5. Household location model chooses a location for each household. The model predicts the location choice from available housing units (existing and vacant residential buildings). The location choice is modeled using a standard multinomial logit formulation, which is a function of housing characteristics (price, density, age), neighborhood characteristics (land use mix, density, average property values, local accessibility to retail) and regional accessibility to jobs by auto-ownership group, and travel times.
6. Employment location model predicts the probability that a job either new or has moved within the region will be located at a particular site (non-residential building with vacant

space). Buildings are used as the basic unit of analysis. The model is specified as a multinomial logit model, with separate functions estimated for each employment sector. The choice model is a function of real estate characteristics (prices, land use mix, and density), regional accessibility (access to population, travel times), proximity to highway and arterials, and local agglomeration economies within and between sectors.

7. Real estate price model simulates the land price of each parcel. The model uses a hedonic regression which is a function of site characteristics (development type, land use plan, and developmental constraints), regional accessibility (access to population and employment), and urban design scale (land use mix, density, proximity to highway and arterials)
8. Real estate development model simulates developer’s choice about location and type of construction to undertake. The form of model is a multinomial logit. Variables in the model include site characteristics (development constraints, land and improvement values), site location characteristics (proximity to highways, arterials, and existing development, neighborhood land-use mix and property values), regional accessibility and market conditions.

Currently, UrbanSim can be implemented at three different spatial units of analysis: zone, parcel and grid cells. UrbanSim has been validated for Eugene-Springfield Oregon, the Puget Sound region (surrounding Seattle), Washington, and Salt Lake City, Utah. The model software is distributed as open source under GNU General Public License. The source code for UrbanSim is available at www.urbansim.org.

ILUTE

Integrated Land Use, Transport, Environment (ILUTE) is an integrated urban modeling system that has been under development at the University of Toronto for the past several years. The model simulates activities of individual agents as they evolve over time. The agents include persons (within households and families) transport networks (road, transit networks, bike and walking modes), the built environment (houses and commercial buildings), firms, the economy (interests and inflation) and job market (Miller 2008). The ILUTE simulator evolves the urban system with basic time step being one month with no assumptions concerning system equilibrium.

Given that ILUTE is a microsimulation model, the system state is defined in terms of the individual persons, households, dwelling units, and firms that collectively define the urban region being modeled. Some key processes that are modeled explicitly within ILUTE in the context of the defined urban region as defined by Miller (2008) are: changes in population demographics (aging, mortality), changes in household composition (marriage, divorce, births, children leaving/returning home), supply of new housing and commercial floorspace, firm growth/decline, location/relocation resulting changes in the amount, type and location of employment, changes in labor force and school participation, changes in housing residential location, changes in household auto ownership levels (persons possession of drivers licenses and transit passes), commercial vehicle movements and person-based activity and travel.

Spatial markets play a central role within ILUTE, in that it is through market demand-supply interactions that all spatial processes of interest within ILUTE are modeled. The spatial markets include: land market, residential housing market, commercial floorspace market, labor market, regional economic (non-land/real estate) markets. Within ILUTE a consistent conceptual structure is applied in modeling individual consumers within a given market. This involves a three stage process consisting of: (1) the decision to become active in a market; (2) search; and (3) bidding and search termination. Functionality of the key components in the ILUTE model system is discussed in detail below.

1. Demographic updating component models regional population demographic processes at both person and household levels. The processes that are modeled are: aging, mortality, household formation and dissolution, labor and school participation, children leaving/returning home, possession of drivers license along with in and out migration. All changes are modeled using transition probabilities.
2. Housing market model simulates the interactions between the demand side of the market (households wishing to sell/rent new dwelling units) and supply side (agents wishing to sell/lease dwelling units). Major components of the housing market are: residential mobility (household becomes active in housing market), residential location choice

(choice set includes dwelling units), asking price model (price of each active dwelling unit in the market), new housing supply model (generates new number of dwelling units by type and zone), and market clearing model (manages buying and selling of dwellings by auction to potential buyers). Housing market is a dynamic disequilibrium model, in which prices are determined endogenously through market clearing process.

3. Commercial floor space market model simulates interactions between demand side of the market (firm mobility and location search) and supply component (development of new building space; conversion of existing buildings into commercial usage; vacancies created by relocating businesses). The commercial floor space market also consists of similar model components as in the housing market model.
4. Household auto ownership model simulates household vehicle ownership over time. This is a dynamic three-level nested logit model of household vehicle transactions (buy, sell, trade, and scrap a vehicle), vehicle type and vintage.
5. Activity/Travel model simulates individual person based activity schedules and travel patterns for a typical twenty four hour weekday. TASHA (Travel/Activity Scheduler for Household Agents) is used to model the person travel component in ILUTE (refer to Miller et al. 2006 for more information on TASHA).

ILUTE is still a work in progress, and testing is underway for calibration and validation of the overall model system. However, some of the components in ILUTE are yet to be implemented like firmographics, commercial vehicle movements, and traffic assignment and so on although early applications using MATSIM and emissions estimation have already been produced by the Miller group in Toronto.

ILUMASS

ILUMASS (Integrated Land Use Modeling and Transportation System Simulation) developed in Germany aims at a microscopic dynamic simulation of urban traffic flows into a comprehensive model system, which incorporates both changes in land use and resulting changes in transport demand (Moeckel et al, 2007; Wegener and Wegener 2007). ILUMASS operates on a time scale of year to year with assumption of the system achieving equilibrium at each time step. ILUMASS model is divided into three modules as follows

- Land use module simulates : demographic processes (aging, birth, mortality, household formation and dissolution), firmographics (firm foundation, growth, relocation, decline and closure), residential mobility (location and housing decisions of households as transactions of households and landlords on the regional housing market), firm location/relocation (location and relocation decision of firms), residential buildings (residential development decisions by private developers), non-residential buildings (non-residential development examines demand for floor space in each zone and develops new floor space).
- Transport module simulates: daily activities of people (computed by a weekly activity plan), microscopic dynamic traffic assignment, and (freight) goods transport demand.
- Environment module simulates the environmental impact of traffic forecasts (GHG emissions, distribution of air pollution, and traffic noise).

ILUMASS operates at both zone level and grid cell of 100m by 100m size of spatial unit of analysis. ILUMASS development is still underway, although, has been applied for testing in the area of Dortmund, Germany (Beckmann et al., 2007 provide a complete documentation on ILUMASS).

Microeconomic Random Utility/Discrete Choice Models

Discrete choice models that are designed to model individual's choices by taking into account the characteristics of each choice are widely used in travel demand modeling. Discrete choice models are also used to model locations choices by households and firms. In fact, discrete choice techniques can be readily used in conjunction with other simulation approaches, like microsimulation. The NYMTC-LUM model is included in this section, although, there are other models based on discrete choice techniques such as CUF (Landis and Zhang), RURBAN (Miyamoto and Kitazume) and Boyce (Boyce). It should also be noted that URBANSIM and ILUTE also use discrete choice models and could have been classified as RUM models but they also satisfy criteria for other classes. We consider the following model to be the closest to microeconomic theory model system than any other model reviewed here.

NYMTC-LUM

New York Metropolitan Transportation Commission Land Use Model (NYMTC-LUM) is a simplified version of METROSIM (a proprietary model developed by Anas based on a series of past model development steps). The model is a large area application in a sequence of land use and housing market models developed by Anas since early 1980's. The model is consistently based throughout on microeconomic theory and uses traffic analysis zones as its spatial unit of analysis. Furthermore, the model solves for equilibrium with five year increments as the time scale (Anas 1998, and Alex Anas & Associates 2002). The model consists of several interlinked sub-models, and these are linkages that are discussed below.

- Work-Residence linkages sub-model simulates the process by which workers choose residence location and job location and determines the work-residence linkages. These linkages refer to the process by which an individual's job and residence locations are determined, a process that involves choices in housing and labor markets. This sub-model is a function of travel time based accessibilities to employment and to population, and the rents and incomes associated with residence and job locations.
- `Residence-Nonwork linkage sub-model determines the number of non-work trips originating in each residence zone and ending in each non-basic employment zone based on travel impedances, accessibilities, incomes and other characteristics of the residents.
- Housing market sub-model simulates the demand (demand of housing for each zone from work-residence sub-model) supply (stock of housing by type in each zone from building stock adjustment sub-model) interactions in the residential market. Rents are determined in the housing market sub-model by equilibrating demand and supply in each zone.
- Labor market sub-model also simulates the supply (jobs to each zone from work-residence sub-model) and derived demand (non-basic employment by type for each zone from residence-non-work sub-model) interactions. Income and commercial rents are determined by equilibrating supply and demand in each zone (number of jobs and commercial buildings).

- Market value sub-model determines the market prices of commercial and residential buildings.
- Building stock adjustment sub-model takes these market values as inputs. Based on relative valuations, developers decide how to adjust building stocks.

All the sub-models are iterated until a simultaneous labor and housing market equilibrium is achieved together with an equilibrium land use pattern and equilibrium pattern of non-work linkages from each residential location. Subsequent models were also developed based on this overall framework by Anas and his collaborators and one version of these models is currently developed for the Southern California region.

Cellular Automata Models

Cellular Automata (CA) models have emerged within the broad filed of complex systems as a means of representing the emergent properties of simple behavioral rules applied to cells within a grid (Wolfram 1984). The approach has now been widely used in urban land cover and land use change (Clarke and Gaydos 1998; Couclelis 1997). This approach is particularly useful in representing the interactions between a location and its immediate environment, but tends to reflect a fairly abstract representation of agents, decisions, and behavior, since the models focus on simulating the change of state of individual cells (Waddell and Ulfrasson 2004). There are transportation models such as TRANSIMS and MATSIM that were developed in this tradition of model building but one interesting model in land use is the Slope, Land use, Exclusion, Urban, Transportation, Hill shading (SLEUTH) model.

SLEUTH

The SLEUTH model, also commonly known as Clarke Urban Growth Model, simulates the changes for a non-urban land use type environment like agriculture, forest, wetlands etc., to a urban land-use type environment such as residential, commercial and mixed-use. These changes are based on grid of cells and their existing state set for different land uses. Cell states may evolve accordingly to transition rules, which can either be deterministic or stochastic. This evolution of the cells help in understanding how urban areas extend into their surrounding land

and the environmental impact brought by this extension on the local environment (Clarke et al, 1996).

The fundamental assumption that the model builds on is that, historical growth trends will continue and that the future may be projected based on these trends. Under this assumption, all the cells are updated in discrete time steps (one year) and the state of each cell depends on the previous state of its neighboring cells. In the model, each cell is used to model land use changes and the land use state of each cell is predicted based on local factors (roads, existing urban areas, and topography), temporal factors and random factors. Within this model, urban land is defined as residential, commercial, mixed use and industrial uses. One interesting aspect of this model building effort is te use of satellite imagery together with other land us information and network data. SLEUTH has been applied to several metropolitan areas in US: Baltimore – Washington DC; Chester County, PA; Orange County, CA; Santa Barbara CA; Greater New York Area and Detroit, MI, among many other localities worldwide.

Rule-Based Models

Rule-based land use models operate on set procedures to allocate population, employment, and/or land use (Waddell and Ulfrasson 2004). Such rule-based applications may have a useful role in making models more accessible. However, the risk associated with these models is that model users interpret the model as having more behavioral basis than their rules actually contain. Models reviewed in this context are: CUF and UPLAN.

CUF

California Urban Futures Model (CUF) was developed to simulate how growth and development policies might alter location, pattern and intensity of urban development (Landis 1994). This model differs from a typical integrated land-use transport model in a number of ways. For example, regional forecasts are not allocated, but a bottom-up approach is followed. Central to the model is the notion of profit potential of each developable land unit as a function of sales price, raw land price, hard construction costs, site improvement costs, service extension costs, development, impact, and planning fees, delay and holdings costs and extraordinary infrastructure capacity costs. The second generation of CUF called CUF-2 (Landis and Zhang, 1998a,b) consists of two multinomial logit models of land use change. The first submodel explores the determinants of land use change among previous developed sites. The probability of land use change is a function of initial site use, site characteristics, site accessibility, policy factors and relationships with neighboring sites. CUF has been applied to Solano and Sonoma counties in Northern California, while CUF-2 has been used in San Francisco Bay Region, CA.

UPLAN

UPLAN Urban Growth Model is a simple rule-based model developed by Johnston et al. (2003) based on a platform of ArcView GIS. UPLAN allocates the increment of additional land in user specified discrete categories consumed in future years. County or regional land consumptions are calculated endogenously. It allows the user to input demographic and land use density factors that are converted in hectares of land consumed for each land use. To determine the hectares needed for future housing, the user specifies persons per households, percent of households in each density class, and average parcel size for each density class. Similar conversions and method is used for industry and commercial uses. These calculations yield a table of land demand for each land use type, from which the model operates its land allocation routine (Timmermans 2003). A suitability grid influences the future land use change. Users can attach weight to indicate the attractiveness of each cell as a function of proximity to existing urban areas and transportation facilities. Users can also specify where development cannot take place. UPLAN has been used for Sacramento, CA and Espanola region of New Mexico.

Land-Use Model Comparison

Based on the proposed framework by Hunt et al (2005), urban land-use transport models can be classified as: operational (the models that are used in practical urban planning applications), comprehensive (the models that include a somewhat complete range of spatial processes) and integrated (meaning feedback exists between the transport and land use). Therefore, the following models are considered for a detailed discussion within this framework:

- ITLUP/DRAM/EMPAL
- MEPLAN
- PECAS
- UrbanSim
- ILUTE

- ILUMASS
- NYMTC-LUM

To streamline the discussion in terms of a comprehensive review and discussion, a series of tables are used to summarize the features of each model. Table 1 presents the classification category in which each of the considered models belongs to. The classification is based on Waddell and Ulfrasson (2004) and Timmermans (2003).

Table 1 Integrated Urban Models Classification

Model	Waddell and Ulfrasson (2004)				Timmermans (2003)		
	Spatial Interaction	Spatial I/O	Microsimulation	Random Utility/Discrete Choice	First Wave	Second Wave	Third Wave
ITLUP	X				X		
MEPLAN		X				X	
PECAS		X					
UrbanSim			X			X	
ILUTE			X				X
ILUMASS			X				X
NYMTC-LUM				X		X	

The models selected here are further compared based on the classification proposed by Hunt et al. (2005) in which the models are compared based on their representation of:

- Physical system being modeled (time, space, building supply and transportation system).
- Decision makers (actors/agents) whose actions influence the evolution of the physical system over time.
- Decision processes used by these actors/agents.

Tables 2a and 2b summarize how the model systems represent the physical system, this can be studied by the way in which each model treats time, land and developable space (buildings). Majority of models (ITLUP, MEPLAN, PECAS, and NYMTC-LUM) considered here are equilibrium based models with aggregate time steps (commonly 5 years), the exception being PECAS which can be modeled with one year steps. However, UrbanSim and ILUMASS are dynamic disequilibrium models which operate on a one-year step basis. ILUTE is also a dynamic disequilibrium model, which operates at the fundamental time unit of one month. Urban systems are in a constant state of evolution with actors' decisions being based on both past system states and anticipated future conditions. Thus, the models considered in the latter part have an intuitive appeal. However, there is little experience with models of this sort (Hunt et al., 2005). ITLUP, MEPLAN, PECAS and NYMTC-LUM are all aggregate zone based, whereas the land use information is provided at coarse zonal system. The second class of models (UrbanSim, ILUTE and ILUMASS) has a finer spatial unit of representation. For example, UrbanSim has two levels of spatial detail: traffic zone level for travel demand calculations, and the individual parcel for land supply and demand calculations. All the models explicitly represent developed space in one way or another. The exception being ITLUP, in which households consume land directly, with no explicit representation of the built environment. In the other models, the developed space is represented through combination of housing units and floor space for non-residential space.

All the models in some way are connected with stand alone travel demand models or have an integrated representation of transport system. However, models like ILUTE and ILUMASS have a robust integration with activity-based travel models. UrbanSim on the other hand is connected with an external travel demand model, which can be either a four-step model or an activity-based model. Furthermore, accessibilities in UrbanSim are computed based on the logsum parameters derived from mode choice models. Other models like ITLUP and MEPLAN have an endogenous representation of travel models, with network assignment capabilities; however, they have some shortcomings when compared with state of the art travel models that are either connected or are fully integrated within these systems.

Table 2a Treatment of Time, Land, Space and Transportation System

Models	Time	Land	Developed Space	Transportation System
ITLUP	Equilibrium established for each time step (normally 5 years)	Zone-based. No microscale representation	Lowry like representation. No explicit representation of buildings	Endogenous travel model. Uses road network for assignment of private vehicle trips.
MEPLAN	Equilibrium based. Normally operating for every 5 years	Zone-based. No microscale representation	Explicit representation of floor space, density, prices etc.	Network modeling capabilities. Multimodal networks used. Assignments are static.
PECAS	Equilibrium established for each time step (normally 5 years). Although can operate at one year time steps	Zone-based representation of activities	Explicit representation of floor space by industry type, and housing by household type	No explicit representation. Connected to a stand-alone travel demand model.
UrbanSim	Dynamic disequilibrium. One year time step.	Zone, grid cell, and parcel level. Zone level for travel demand calculations, and individual parcels/grid cells for land supply and demand calculations	Explicit representation of housing by type, non-residential floor space by type and price	Connected with travel demand model (activity-based in some areas). Uses to travel times and utility functions like logsum measures to develop accessibility measures

Table 2b Treatment of Time, Land, Space and Transportation System

Models	Time	Land	Developed Space	Transportation System
ILUTE	Dynamic disequilibrium. Basic time step is one month	Zonal, individual buildings are recognized	Explicit representation of housing units, and floor space	Integrated within ILUTE. Activity-based model (TASHA) for passenger travel demand. Integration is still under testing phase.
ILUMASS	Dynamic disequilibrium. One year time step.	Zones, sub-zones, grid cells (100m X 100m) and individual buildings are recognized	Explicit representation of residential and non-residential buildings by type	Integrated within ILUMASS. Activity-based approach to model passenger travel. Goods transport represented, with dynamic traffic assignment. Testing is underway.
NYMTC-LUM	Equilibrium based with implementation of multiple time steps (normally 5 years)	Small zone based. Land area categorized by housing type, basic industry, and non-basic industry. No micro-scale representation	Housing by type, number of units and floor space by zone; basic and non-basic floor space by zone	Connected to stand alone travel demand model. Accessibilities are imported from this model.

Table 3 presents the treatment of actors/agents within the urban system model design: persons, households, private establishments and public authorities. Private establishments are further divided into general (business establishments/firms) and developers as they play a major role in land-use transport interactions. Virtually all models except ILUTE and ILUMASS do not treat persons explicitly; although, they form an important component within the interest of urban systems (birth, aging, marriage, labor participation etc). All the models treat public authorities as exogenous. Although, MEPLAN and PECAS endogenously treat "Government" sector of employment as supplier/consumer of goods services and travel.

Business establishments are directly treated in most of the frameworks (except ITLUP and NYMTC-LUM). However, for these frameworks (ITLUP and NYMTC-LUM) treat employment location as aggregates of the number of jobs per zone. MEPLAN, PECAS, UrbanSim, ILUTE and ILUMASS model firms/business establishments explicitly. All the models have some form of explicit representation of building supply/development processes, with the exception of ITLUP which does not have any supply side representation. However, ILUTE does not currently implement developers' decision on non-residential supply side.

Table 4 summarizes various markets that are represented in each of the models. All frameworks include an explicit representation of housing market (housing demand-supply interactions), except ITLUP. UrbanSim, ILUTE, and ILUMASS are the models which simulate the housing market as dynamic disequilibrium, while, other models operate under the assumption of equilibrium. Similarly, all the models treat commercial floor space market in the same manner as housing market. Again ITLUP is the only framework without any explicit representation of demand-supply interactions.

Job market is represented in all models. In UrbanSim, ILUTE, and ILUMASS the complete labor market is not explicitly modeled. Individual work locations and firm locations are modeled based on the demand-supply interactions. MEPLAN, PECAS, and NYMTC-LUM explicitly model the job market by solving for equilibrium assumptions. Passenger travel market is explicitly represented in ITLUP, MEPLAN, PECAS, ILUTE and ILUMASS. However, other models (UrbanSim and NYMTC-LUM) are linked through an external travel model. Finally, the vehicle ownership market is treated exogenously in all models except ILUTE with indirect representations that could be used like categorization of the households by ownership, and possibly a vehicle ownership model represented in the travel model.

Table 3a Treatment of Actors-Agents

Models	Persons	Households	Private Establishments		Public Authorities
			General	Developers	
ITLUP	No explicit representation. Although exogenous population is used as control total	Household based. Categorization typically by households by income. Aggregate number of households per zone	Aggregate number of jobs per zone. Typically categorization based on four industry types. Firms are not represented	No explicit representation	Exogenous policy inputs. E.g. transport, developable constraints, zoning and planning regulations
MEPLAN	No explicit representation of person and their attributes	Household based. User-specified categorization. Aggregate number of households by type per zone	Explicit outputs of production processes represented by employment	Space is developed or redeveloped as a function of prices and availability	Exogenous policy inputs. Government is typically a separate category in the production processes

Table 3b Treatment of Actors-Agents

Models	Persons	Households	Private Establishments		Public Authorities
			General	Developers	
PECAS	No explicit representation. Although modeled as travelers in transport model	Household based. Aggregate number of households by type per zone	Explicit outputs represented in terms of production processes	No explicit representation. Although, implied by development actions	Explicit exogenous policy input
UrbanSim	No explicit representation at present. However currently under testing, which includes individuals work place choice for Puget Sound Region, WA	Detailed representation of households: currently 111 types for Eugene-Springfield application	Business establishments are explicitly represented, user classified by industry type and number of employees	Developers explicit as decision makers. Currently simulates development/redevelopment at the parcel level based on expected profitability.	Exogenous policy inputs

Table 3c Treatment of Actors-Agents

Models	Persons	Households	Private Establishments		Public Authorities
			General	Developers	
ILUTE	Explicit representation of persons. Uses synthetic population generated from Public Use Microdata	Explicit representation of households. Categorization consists of combinations of persons and households (single person, multi-family etc.)	Firms are recognized explicitly. Location decisions are modeled. Employment by occupation type by census tract are exogenous	Developers explicit as decisions makers for residential development only. Developers for non-residential floor space is envisioned	Exogenous policy inputs
ILUMASS	Explicit person representation.	Household based representation through synthetic population generation.	Firms are explicitly identified, that models location/relocation decisions	Developers decisions are modeled explicitly for both residential and non-residential developments and redevelopments	Exogenous policy inputs

Table 3d Treatment of Actors-Agents

Models	Persons	Households	Private Establishments		Public Authorities
			General	Developers	
NYMTC-LUM	No explicit representation	Household-based. No apparent categorization of households by type.	No explicit representation of firms. Employment explicit by zone for basic and non-basic employment	Supply of building stock in each zone responds to market values by type by zone, subject to available land	Exogenous policy inputs. Currently no sensitivity to zoning or land use controls

Table 4a Treatment of Market Processes

Models	Housing Market	Floor Space Market	Job Market	Personal Transport Market	Vehicle Market
ITLUP	Demand for land is explicit (Lowry logit formulation), allocating households to zones by type. Static equilibrium based.	Supply implicit. No price mechanism	Implicitly modeled (job and housing markets are one process). Spatial distribution determined by spatial allocation model.	Endogenous within ITLUP or exogenous linkages to external travel demand models.	Not explicitly considered in ITLUP. Although, the external travel model may include a sub-model for vehicle ownership model
MEPLAN	Supply function - developers allocate housing by type to zones, which is a function of prices, current capacity, dynamic lagged response. Demand function - amount of space consumed per household is elastic with price per zone	Same as housing market, expect the production processes is labor	Labor is supplied by households as determined by production activities.	Origin-destination demands arise from spatial distributions of flows based on the production and consumption	Not explicit representation. Can have a categorization of households by car ownership level

Table 4b Treatment of Market Processes

Models	Housing Market	Floor Space Market	Job Market	Personal Transport Market	Vehicle Market
PECAS	Developers allocate housing by type and to each zone, based on household demand which is established in the activity allocation module	Same as housing market, in this case the production processes is labor	Labor is included as a commodity that is produced by households and consumed by economic production activities	Origin-destination demands arise based on the production processes of supply and demand	No explicit representation
UrbanSim	A bid-rent model that does not impose any equilibrium assumption. Demand is based on the willingness to pay (bid function); Developers produce supply, attempting to maximize profit based on the current market conditions. Supply is inelastic within 1-year time step.	Identical to housing market. Land parcels developed into most profitable use that regulation allow, providing competition between residential and commercial land uses.	Locations of jobs and workers are determined as household firm location choices. Direct individual workplace location choice model is currently under development	External travel demand model.	Can have categorization of households by car ownership or a sub-model with exogenous travel demand model

Table 4c Treatment of Market Processes

Models	Housing Market	Floor Space Market	Job Market	Personal Transport Market	Vehicle Market
ILUTE	Households are modeled in a search process, where they become active, search and terminate upon a suitable bid. Developers supply housing based on the demand generated (new development or redevelopment) by dwelling units by type per zone. A market clearing model manages the buying and selling of dwellings by auctioning. This model is a dynamic disequilibrium based.	Similar to housing market, but the case here are firms/businesses	Location preferences of jobs and individual workers are modeled as firm location choice and work place location choice.	Explicit representation of person travel. Uses activity-based approach for travel demand.	A dynamic model of household vehicle transactions (buy, sell, trade, scrap a vehicle).
ILUMASS	Search based model for households, which is a function of location, quality, rent or price in relation to household budget. The developers supply housing by type as a function of demand and profitability.	Identical to housing market. The agents involved are firms and their decisions	Households and firms location decisions are modeled by supply demand interactions	Explicit representation. Activity-based approach with 29 different activities for a weekly schedule	Unknown

Table 4d Treatment of Market Processes

Models	Housing Market	Floor Space Market	Job Market	Personal Transport Market	Vehicle Market
NYMTC-LUM	Supply of housing is by type per zone is a function of market value (housing price and developmental costs). Demand for housing by type is determined by a logit model of worker joint choice of work place and place of residence. Housing prices are determined by equilibrium assumption.	Similar to housing market	Demand for labor in each zone is a function of wages, rent, and other factors. Supply of labor is determined by a logit model, similar to as discussed in housing market.	External travel demand model.	Dependent of specification of the external travel model.

Furthermore, in evaluating urban models, Wegener (2004) proposes four groups of changes in a major urban system that are distinguished by the speed of change to include:

- Very slow change: networks and land use. The urban infrastructure (transport, communications, and networks) are most permanent elements of the urban physical system. The land use distribution is also equally stable.
- Slow changes: workplaces and housing. Buildings usually have a life-span up to 100 years. Workplaces (factories, major shopping centers, universities) exist much longer those elements that occupy them. Similar argument also holds for dwelling units.

- Fast change: employment and population. Firms are established or closed, expanded or relocated; this process affects the urban employment. Households are also created, grow or decline or dissolve eventually in each stage of their life cycle. This process determines the distribution of population and vehicle ownership in space and time.
- Immediate change: goods transport and travel. The location of human activities in space changes somewhat more often than land use and gives rise to demand for spatial interaction in the form of travel and goods transport. Portion of this demand can adjust in minutes or hours based on traffic conditions.

Table 5 provides the comparison of these models based on the changes in an urban system as identified by Wegener (2004). MEPLAN, PECAS, ILUTE, and ILUMASS are the models which encompass all the eight subsystems that were identified. UrbanSim and NYMTC-LUM provide an interface with external travel models, and thus would be able to capture the changes in networks and passenger travel over time. However, it should be noted that, the models that handle these changes over time are varying upon their capabilities. For example, PECAS models changes in population as exogenous inputs that are fed into the model; UrbanSim models changes in population (birth, aging, household formation etc) based on static transition probabilities (resembling steady state), while ILUTE models the complete population (demographic) changes within the model system in an endogenous fashion.

Table 5 Change in Urban System Processes Presented

Models	Very Slow Change		Slow Change		Fast Change		Immediate Change	
	Networks	Land Use	Workplaces	Housing	Employment	Population	Goods Transport	Travel
ITLUP	X				X	X		X
MEPLAN	X	X	X	X	X	X	X	X
PECAS	X	X	X	X	X	X	X	X
UrbanSim	(+)	X	X	X	X	X		(+)
ILUTE	X	X	X	X	X	X	X	X
ILUMASS	X	X	X	X	X	X	X	X
NYMTC-LUM	(+)	X	X	X	X	X		(+)

Note: (+) provided by linked transportation models

From another perspective, Table 6 provides a comparative matrix of the models reviewed in this section based on the following attributes: (1) agent based simulation, (2) dynamic disequilibrium, (3) market mechanism, (4) demographic processes, (5) firmographic processes, (6) GIS capability, (7) travel demand model integration (8) ongoing use, and (9) open source. Therefore, as presented from Table 6, only ILUTE and ILUMASS are microscopic agent based simulation models. Although, UrbanSim can also be considered as an agent based model, since household is the fundamental unit in simulation. Again, ILUTE, ILUMASS and UrbanSim are the only disequilibrium models. All models have some sort of market mechanisms (housing, and floor space market) except for ITLUP. As noted earlier, ILUTE, ILUMASS and UrbanSim model the demographic and firmographic changes in the region, but differ in their modeling approach. It should be noted that ILUTE and ILUMASS are still under development and these processes are in testing phase. All models provide a framework for travel model integration or have an inbuilt travel module.

Table 6 Summary of Land Use Transport Models Capabilities

Models	Microscopic Agent based Simulation	Dynamic disequilibrium	Market mechanism	Demographic processes	Firmographic processes	GIS capability	Travel demand model integration	Current use	Open Source
ITLUP						X	X	X	
MEPLAN			X			X	X	X	
PECAS			X			X	X		
UrbanSim	(+)	X	X	X	X	X	X	X	X
ILUTE	X	X	X	X	X	X	X		
ILUMASS	X	X	X	X	X	X	X		
NYMTC-LUM			X				X	X	

Note: (+) household is the agent

DEMOGRAPHIC SIMULATION

The review of the land use models above shows that demographic simulation is an important component of urban modeling. Some of the more advanced and ambitious models include household evolution among life cycle stages. In this section we review this type of models separately because a few of them do not aim at land use change but were designed to account for more detailed transitions of households and person among life cycle stages. We also include in this review models/techniques of population synthesis that are very important in providing the necessary inputs for disaggregate models of travel demand.

Population Synthesis

The emergence of activity-based microsimulation model systems has ushered in a new era in travel demand forecasting. Activity-based microsimulation model systems operate at the level of the individual traveler, and therefore one needs household and person attribute information for the entire region population to calibrate, validate and apply such model systems. However, such detailed information is virtually never available at the disaggregate level for an entire region. Although, disaggregate household and person information for a random sample may be available in the form of Public Use Microdata Sample (PUMS) or from a travel survey conducted in a region. The major challenge is to then generate a synthetic population with comprehensive data on attributes of interest in order to have the inputs needed by activity-based models that are defined at the level of individuals and their households.

Synthetic populations can be formed from random samples by choosing or selecting households and persons from random samples in a way that the joint distribution of attributes of interest in the synthetic population matches known aggregate distributions of household and person attributes available through Census (In US, Census Summary Files provide the marginal distributions of population characteristics). The joint distributions among a set of control variables can be estimated using the well known Iterative Proportional Fitting (IPF) procedure first presented by Deming and Stephan (1941). In this section we review the methods that have been applied to population synthesis. The methods under review are as proposed by: Beckman et al. (1996) for the use in TRANSIMS, Guo and Bhat (2007), Auld et al. (2007), and Ye et al. (2009).

Standard IPF Procedure

Most population synthesizers currently in use are based on the method developed by Beckman et al. (1996) for use in the TRANSIMS model. The procedure proposed by Beckman et al. (1996) matches exact large area multidimensional distributions of selected variables from the PUMS files to small area marginal distributions from Census Summary files to estimate the multidimensional distributions for the small areas.

The population is synthesized in two stages. First a multidimensional distribution matrix describing the joint aggregate distribution of demographic and socio-economic variables at household and/or individual levels is constructed. This stage makes use of the IPF procedure. In this procedure, the correlation structure of the large area and small areas is assumed to be similar. In the IPF procedure, an initial seed distribution is used and fit to known marginal totals. The difference between the current total and the marginal total for each category of the variable of interest is calculated and the cells of that category are updated accordingly. This process continues for each variable until the current totals and the known marginal totals match to some level of tolerance, producing a distribution which matches the control marginal totals.

In the second step, synthetic population is constructed by selecting entire population from the PUMS in proportion to the estimated probabilities given in the multidimensional matrix obtained by the IPF technique. The number of households to be generated of each demographic type is determined from each aggregate area (or large area). For a combination of demographic characteristics a set of probabilities is assigned to each household in the PUMS, where PUMS samples close to the combination of desired demographic characteristics are assigned higher probabilities. The households are then selected randomly according to their selection probabilities. These probabilities are computed by a weight based algorithm. For more detail overview on the probability computation and IPF procedure refer to Beckman et al. (1996).

Synthetic Population Generator

Guo and Bhat (2007) identify two issues associated with conventional approach for synthesizing population using the Beckman et al. (1996) algorithm. First issue is incorrect zero cell values: this is an issue inherent to the process of integrating aggregate data with sample data, and the problem occurs when the demographic distribution derived from the sample data is not consistent with the distribution expected of the population. A second issue arises from the fact that the approach can control for either household-level or person-level variables, but not both. If these issues are left unaddressed, may significantly diminish the representativeness of the synthesized population.

Guo and Bhat (2007) propose a new population synthesizer that addresses these issues using an object-oriented programming paradigm. The issue of incorrect zero cell values is solved by providing the users capability to specify their choice of control variables and class definitions at run time. Furthermore, the synthesizer is built with an error reporting mechanism that tracks any non-convergence problem during the IPF procedure and informs the user of the location of any incorrect zero cell values. Guo and Bhat (2007) also propose a new algorithm using IPF based recursive procedure, which constructs household-level and person-level multi-way distributions for the control variables.

The second issue is solved by controlling for both household and person-level variables/attributes. This is achieved by the two multi-way tables for households and persons that are used to keep track of the number households and individuals belonging to each demographic group that has been selected into the target area during the iterative process. At the start of the process, the cell values in the two tables are initialized to zero to reflect the fact that no households and individuals have been created in the target area. These cells are iteratively updated as households and individuals are selected into the target area. Given the target distributions and current distributions of households, each household from PUMS is assigned the weight-based probability of selection. Based on the probabilities computed, a household is randomly drawn from the pool of sample households to be considered and added to the population for the target area.

PopSyn

Building on the principle of the IPF procedure for population synthesis Auld et al. (2007) propose a new population synthesizer which consists of two primary stages: creation of multidimensional distribution table for each analysis area and the selection of households to be created for each analysis area. Auld et al. (2007) adopt the same method for creating multidimensional distributional table as in other population synthesizers (Beckman et al. 1996, Guo and Bhat, 2007). The complete distribution for all households is fit to the marginal totals through the use of IPF procedure. This creates the regional-level multi-way table that is used to see all the zone-level distribution tables. For each zone the seed matrix cell values are adjusted so that the total matches the desired number of households to generate. The zone-level multi-way distribution is adjusted to match the zone marginals by again running the IPF procedure.

The selection probability of households from the multidimensional table is performed in a similar manner as that proposed by Beckman et al. (1996), which is a weight of household divided by the sum of the total weighted households for the category variable. Auld et al. (2007) argue that there exists large variation between control marginal totals and those generated by the process so the totals are matched exactly as desired. For this reason, Auld et al. (2007) add further constraints, such that the total number of households that have been generated for each category within each control variable represented by the demographic type. If any of the totals exceed the marginal values from the zone-level marginal by more than a given tolerance, the household is rejected. This procedure works well at keeping the generated marginal totals fairly close to the actual totals. However, Auld et al. (2007) identify that this method might bias the distribution, which is an ongoing investigation.

In the population synthesis procedures, aggregating control variables within range-type control variables is primarily done to allow for the use of more control variables and to reduce the occurrence of false zero-cells. For problems with large number of control variables the size of the distribution matrix can become very large making the IPF procedure intractable. Therefore, Auld et al. (2007) address the category reduction, which occurs prior to the IPF stage. The marginal values for range variables are compared to minimum allowable totals. The minimum allowable category total is defined as the total number of households in the region multiplied by a user specified percentage. The percentage forces all categories with less than the allowable number of households to be combined with neighboring categories. The category is then removed from the multidimensional distributional table. The category aggregation threshold percentage acts as a useful limiter of the total number of categories.

PopGen

Ye et al. (2009) propose a framework by generating synthetic populations with a practical heuristic approach while simultaneously controlling for household and person level attributes of interest. The proposed algorithm is also computationally efficient which addresses the practical standpoint from the agencies perspective. The proposed algorithm by Ye et al. (2009) is termed as Iterative Proportional Updating (IPU), it starts by assuming equal weights for all households in the sample. The algorithm then proceeds by adjusting weights for each household/person constrain in an iterative fashion until the constraints are matched as closely as possible for both household and person attributes. The weights are next updated to satisfy person constraints. The completion of all adjustment weights for the one full set of constraints is defined as one iteration. The absolute value of the relative difference between weighted and the corresponding constraint may be used as goodness-of fit-measure. IPU algorithm provides a flexible mechanism for generating synthetic population where both household and person level attribute distributions can be matched very closely. The IPU algorithm work with joint distributions of households and persons derived using the IPF procedure, and then iteratively adjusts and reallocated weights across households to match closely the household and person level attributes.

As mentioned in earlier works (Beckman et al. 1996; Guo and Bhat 2007; Auld et al. 2007), the problem of zero-cells is also addressed in the population synthesis by Ye et al. (2009). Ye et al. (2009) propose an alternative method to account for the zero-cells issue. The idea underlying the approach is to borrow the prior information for the zero-cells from PUMS data for the entire region. The probabilities estimated from the PUMS representing the entire region where the zero-cells exist can be used for small geography. The authors also indicate that using this method can have a risk of over-representing a demography group, which would be rare in the small geography in the first place. Due to the proposition of the IPU algorithm, Ye et al. (2009) indicate that zero-marginal problem is encountered in this context. For example, it is possible to have absolutely no low-income households residing in a particular blockgroup. If so, all of the cells in the joint distribution corresponding to low income category will take zero values as a result of the IPF procedure. Then, when weights are computed using the IPU algorithm all the households in the PUMS contributing to zero marginal household type will take zero weight. To overcome, this problem, a small positive value (e.g. 0.001) is assigned to the zero-marginal categories. The IPF procedure will then distribute and allocate this small value to all of the relevant cells in the joint distribution.

After the weights are assigned using the IPU algorithm, households are drawn at random from PUMS (or a survey database) to generate the synthetic population. The approach Ye et al. (2009) adopt is similar to that of Beckman et al. (1996), except that the probability with which the household is drawn is dependent on its assigned weight from the IPU algorithm. Furthermore, within the framework of all the reviewed population synthesizers, PopGen (Ye et al. 2009) is a synthesizer that deviates from traditional IPF procedure in constructing multi-way distribution tables.

DEMOGRAPHIC EVOLUTION MODELS

A regions population can be evolved over time and space using a variety of methods. We review in this section briefly the cohort-based methods and give the most emphasis on demographic microsimulation techniques because they are congruent with disaggregate simulation of land use and travel. As identified in the previous sections and since the advent of activity-based approach to travel demand, behavioral approaches emphasize the interactions among population socio-economic processes, the households' long-term choice behaviors and economic agents with which households interact. Therefore, within the framework of integrated land-use transport modeling three important issues need to be considered as identified by Eluru et al. (2008). First, over a long multi-year time frame, individuals go through different life-cycle stages and household compositions. Such socio-economic processes need to be modeled endogenously with the integrated land-use transport model system. Second, as the socio-economic process unfolds, individuals begin/finish schooling, move onto different life-cycle stages, enter/exit labor market and change jobs. Similarly, households may decide to own a house, move to another location, which are long-term choices. Thus, a framework accounting for interdependency between short and long-term behaviors is required to evaluate the impacts of land-use and transport policies. Third, interactions between households and other decision makers (businesses, institutions and developers) within housing, labor and transportation markets which shape land-use patterns needs to be explicitly considered. Thus, based on the needs identified the integrated land-use transport model needs to account for demographic changes explicitly. Therefore, microsimulation plays an important role in modeling the demographic processes, which has been extensively used in the last couple of decades.

Cohort and population models

Cohort models age a single cohort (groups of person sharing an interval of birth years) over their entire lifetime, predicting each individual's major life course events. In contrast, dynamic population microsimulation models age entire cross sections. Single cohort models investigate lifetime income and interpersonal distributions. Examples of this kind include HARDING and the LIFEMOD developed for Australia and Great Britain respectively (Falkingham and Harding, 1996). This kind of models typically assumes a steady state world. Population models are usually far more complex and demanding with regard to data. Some models only focus on certain age range, like women in their reproductive age, e.g. in FAMSIM (Spielauer 2000). Cohort models, however, also need similar data about births and deaths as the microsimulation models and they are the usual comparison reference of microsimulation models.

Demographic Microsimulation Models

Microsimulation is a technique used to model complex real life events by simulating the actions of and/or impact of policy change on the individual units that make up the system where the events occur. Microsimulation is a valuable policy tool used by decision makers to analyze the distributional and aggregate effects of both existing and proposed social and economic policies at a micro level. There exist two kinds of microsimulation techniques namely, static microsimulation models and dynamic microsimulation models.

Static microsimulation models operate under the assumption that individual behavior is unchanged, and the underlying sample is not modified over time (Cassells et al. 2006 and Andreassen 1992). Static microsimulation models usually illustrate the impact of policy change only for today's world. However, many issues that concern policy makers today involve the impact of policy change in future decades or over the lifetime. For these purposes, dynamic microsimulation models provide better modeling capabilities.

Dynamic microsimulation models are the brainchild of Guy Orcutt who proposed a new type of model consisting of interacting, decision-making entities such as individuals, families and firms (Orcutt 1957). Dynamic models move individuals forward through time, by updating each attribute for each individual (micro-unit) for each time interval (Caldwell 1990). Thus individuals within the microdata or base file are progressively moved forward through time by making major life events happen in the software. These include death, marriage, divorce, fertility education for each individual, in accordance with the probabilities of such events happening to real people within a study region. Therefore, within a dynamic microsimulation model, the characteristics of each individual are recalculated for each time period. The term dynamic refers to the phenomena that evolve over time and where the pattern change at one time is interrelated with those at other times.

There are two types of dynamic micro models as defined by Andreassen (1992). The first type true state dependence contains relationships established at micro level where the current realization of the dependent variables depends on the past realizations of dependent and independent variables. This type includes inter-temporal behavioral models of consumption, and labor supply along with behavioral models incorporating learning effects. The second type caused by unobserved heterogeneity contains correlation between current and past realizations because of unobserved variables. In behavioral models these unobservables may be related to either preferences or the choice constraints of the individual agents. An example where unobserved heterogeneity may be important is the labor market behavior where the individual behavior depends on the unobserved possibilities faced by the individuals. Furthermore, microsimulation models can be classified based on the approach being adopted for demographic simulation (Spielauer 2003).

Human Life Course

The term 'life course' was first used by Cain (1964) to encompass anthropological, sociological and psychological concepts of aging, particularly as they were related to the maturing individuals' movement through an expected sequence of social roles. The life course refers to a sequence of socially defined events and roles that the individual enacts over time. The roles and transitions from one role to another is a central issue in family demography in a time sequenced pattern: childhood, partnership formation and dissolution and so on. The life course concept permits us to study the changing role patterns and interactions in different related domains such as education, jobs, partnerships (e.g., cohabitation and marriage), births and disability. Spielauer (2003) identifies four key factors that constitute the key elements of the life course paradigm: (1) location, (2) social integration, (3) goal orientation and (4) strategic adaptation.

The location in time and place or the cultural background constitutes the first key element that determines the individual life course and closely corresponds to the demographic concept of period effects as a dominant concept. The second key element is social integration or the concept of linked lives. It closely corresponds to cohort effects as used in demography. Individual age is of primary importance in demography and changing age distributions are of central importance in population studies. In fact, the demographic pyramid (an age by gender classification of the population) is one of the most important summary indicators of populations. These issues also play major roles within the broader nature of social and economic change and the impact of demographic change on the environment. The fourth component of the life course framework is mainly brought in by longitudinal surveys and associated methods: strategic adaptation or the time of lives in the adjustment to major changes in the environment where people live.

Open and closed population models

In microsimulation the terms open and closed population usually correspond to whether the matching of spouses is restricted to persons within population or whether spouses are imputed. In open population models partners are usually attached as attributes to the dominant individuals of the population with characteristics synthetically generated or sampled from host population. In closed population models, the models allow to track kinship networks and also enforce more consistency, given a large enough population to find appropriate matches. Major drawbacks of closed models are the computational demands associated with mate matching and sampling problems.

Continuous and discrete time

Microsimulation models can be distinguished based on the treatment of time. Time can be treated either as continuous or discrete. Continuous time is usually associated with statistical models of durations to an event, following a competing risk approach. Continuous models are technically very convenient, as they allow to add new life course processes without changing the models of existing processes as long as statistical requirements for competing risk models are met (Galler 1997). An interesting problem arises when introducing time dependent covariates like periodically updated economic indices. Discrete time models determine the states and transitions for every time period, while disregarding the exact points of time within the interval. Events are assumed to happen just once in a time period. Discrete time frameworks are used in most dynamic models, with yearly or monthly time steps. An example of combination of both continuous and discrete time events is the Australian DYNAMOD model.

Demographic Microsimulation Examples

There are many models implemented in the context of socio-demographic modeling using dynamic microsimulation techniques. Based on a few key literature surveys and reviews of dynamic microsimulation models (Zaidi and Rake 2001; Cassells et al. 2006 and Spielauer 2003), this review focuses on models that have been developed and implemented in practice and include DYNASIM, CORSIM, DYNAMOD, LifePaths, MOSART, CEMSELTS, DEMOS, HMHD, SimBritain and SMILE.

DYNASIM

The Dynamic Simulation of Income Model (DYNASIM) was amongst the first micro models to use the dynamic microsimulation approach. It was developed by the creator of this method Guy Orcutt and other researchers in the early 1970s at the Urban Institute in Washington D.C. The first version of the model consisted of behavioral relationships for leaving home, divorce, birth, death, marriage and remarriage, disability, education, location, labor force participation. All these modules were included in a single model and were executed for each person every year (Orcutt et al. 1976). The second version DYNAMSIM2 was subsequently developed and improved the operating characteristics and other features of the original model. The most significant improvement was the simulation process was subdivided into two smaller models: the Family and Earnings History model (FEH) and the Job and Benefit History model (JBH).

The FEH processes the full sample once for each year for simulation. The JBH model, on the other hand processes the synthetic family and earnings history generated by FEH. The FEH model simulates demographic and labor market behavior characteristics like: death, birth, marriage, divorce, education, labor participation, hours worked etc. Similarly, JBH simulates individuals life careers at once like: job change, pension, retirement, benefits etc. The model uses the alignment technique that forces the models aggregate predictions to match up with external forecasts. The model employed discrete dynamic processes with time unit being a single year. Additionally, Cross-Section Imputation model (CSIM) a static model is used to impute additional information like: health status, institutionalization for persons aged 60+, financial assets etc. DYNASIM model was the first microsimulation model developed for the US.

CORSIM

The CORSIM (Corsim, 2002) project began in 1987 and was originally based at Cornell University. The CORSIM model has been much influenced by the content and design of DYNASIM and DYNASIM2. CORSIM has been instrumental in assisting the US Social Security Administration in their Social Security Reform Analysis (Zaidi and Rake 2001). CORSIM is also the first PC-based dynamic microsimulation model. The base year database for CORSIM is the 1960 Census PUMS consisting of 180,000 person records. CORSIM makes an extensive use of grouping of the population into sub-groups for which the behavioral equations are separately estimated. CORSIM is the amongst the largest microsimulation models. Individual and family behavior is represented in approximately 1100 equations and 7000 parameters as well as dozens of algorithms (Spielauer 2003).

Individual behaviors modeled include schooling, labor supply, demographic characteristics and risk factors such as smoking, alcohol or diabetes. Family behaviors and attributes include wealth represented asset types and debt types, different taxes and benefits, demographic attributes such as family links and economic behavior such as consumption and savings. CORSIM is a fully dynamic and integrated simulation model. It is organized in approximately 26 behavioral modules and several rule-based accounting routines. One of the key features of the model is the use of 40 year old starting population that contributes to its usability as a study tool, both with regard to study of socio-economic processes and model accuracy.

DYNAMOD

DYNAMOD is the dynamic model of the Australian population. It is designed to project characteristics of the population over a period of up to 50 years (King et al. 1999). The working version of the DYNAMOD is known as DYNAMOD-2. The base microdata for DYNAMOD-2 is one percent sampled file from the 1986 census. In order to achieve computational efficiency, the DYNAMOD project followed the DYNASIM2 approach and split the simulation of the synthetic population from simulation for policy analysis. The split resulted in a self contained population simulator, referred to as PopSim. PopSim runs individual person-level and models: demographics, education, labor market and earnings (refer to Abello et al. 2002 for more details on PopSim).

Two distinguishing features of DYNAMOD-2 are the use of "pseudo-continuous" time, using month instead of a year as the time unit, and survival functions. Survival functions are used to simulate fertility, mortality, couple formation and dissolution and disability. Survival functions predict the hypothetical realization times for the duration time before the occurrence of the event. It should be noted here that DYNAMOD-2 by using survival function approach, adopts the simulation approach in which the life-span of each individual is aged in one pass (referred as longitudinal simulation), whereas the approach used in DYNASIM2 and CORSIM are cross-sectional simulation (i.e., each individual is aged for one year at a time).

LifePaths

LifePaths (Statistics Canada, 2002) is a dynamic microsimulation model developed at the Canadian Statistical Office. There are three important features in which LifePaths distinguished itself from other existing models: (1) the LifePaths model operates in continuous time, (2) the LifePaths model is an open population model and (3) the LifePaths model uses a synthetic initial database that is created using various overlapping birth cohorts. The benefit of using continuous rather than discrete time in LifePaths is that an event can occur at any instant during the life time of an individual, and therefore allows modelers to more accurately represent causation and behavior. LifePaths is structured with an explicit event orientation. Behavioral equations together with their stochastic components determine the distribution of waiting times to events.

A LifePaths simulation consists of set mutually independent cases. Each case contains exactly one dominant individual in the first generation. The spouse and children of the dominant individual are simulated as part of the case and created to satisfy the marriage and fertility equations. This approach determines the order of the simulation. LifePaths simulates the completion of one case before moving on to the next. LifePaths contains modules that represent a number of demographic and economic events. The demographic module includes equations that simulate pregnancy, birth, common-law union formation, marriage, separation, divorce and mortality. The education module contains a highly detailed progress towards various levels of education attainment. The employment module simulates entry into and exit from the employment market. The earnings module projects earnings trajectories of lifetime hourly earnings.

MOSART

MOSART (Andreassen et al., 1994) is dynamic model for Norway developed by Statistics Norway to investigate policy options with regard to financing public expenditure. In the first version, the model focused on demographic behavior, education and labor participation in order to study the impact of demographic change on labor force and education attainment. The second version extends the model, allowing for pension modeling. The current version includes more detailed behavioral modules with regard to household formation and disability. The base dataset of the model consists of 12 percent of the Norwegian population in 1993 containing more than 500,000 observations. This database is equivalent to a longitudinal database that contains rich information on many variables (labor income, pension etc).

All events and consequences linked with the occurrence and non-occurrence of an event is simulated in the model in one year steps. The life course events simulated in MOSART are mainly represented by transition matrices or by multinomial logit relationships which are assumed to be constant over time. The only exception is for the mortality rate which is assumed to decrease over time. One strong feature of MOSART is that it is based on a very reliable initial database. The transition probabilities are estimated using the same database.

CEMSELTS

Comprehensive Econometric Microsimulator for Socioeconomics. Land-use and Transportation System (CEMSELTS) a module of Comprehensive Econometric Microsimulator for Urban Systems (CEMUS) is a population updating model system (Eluru et al. 2008). The model system consists of two major subsystems: (1) migration model and (2) socioeconomic evolution model system. On the one hand, the migration model system comprises models that determine the movement of existing households out of the region and the movement of new households and individuals into the study region. On the other hand, the socioeconomic evolution model system focuses on simulating the changes in population. This model system in turn comprises of three major components: (a) individual level evolution and choice models (modeling births, deaths, schooling, and employment); (b) household formation models (modeling living arrangement, divorce, move-ins, and move-outs from a family); and (c) household-level long term choice models (modeling residential moves, housing characteristics, automobile ownership, information and communication technology adoption and bicycle ownership). Together, the migration and socioeconomic model systems determine the changes in population characteristics, residential pattern, and employment patterns over the course of one simulation year.

A major distinction of the CEMSELTS model system is that it models the evolution of households' long-term decisions in space (residential, workplace and school location decisions). In contrast, other simulation models reviewed here do not model spatial evolution explicitly. CEMSELTS employs different modeling frameworks during simulation which include: rule-based models, rate-base probability models, binary logit models, multinomial logit models and ordered-response probit models. CEMSELTS model system has been implemented for the Dallas – Fort Worth, TX, and it is used in the new activity-based model for the Southern California Association of Government model called SimAGENT.

DEMOS

Demographic Microsimulation (DEMOS) system is a microsimulator of social, economic and demographic attributes describing an individual and household. The microsimulator is primarily built using the longitudinal data from the Puget Sound Transportation Panel (PSTP). The model combines the unique concepts of microsimulation and object-oriented programming. During the microsimulation process an individual will be born and progressed through different life cycle stages. While progressing through these life cycle stages the individual is exposed to different events in the form of death, giving birth to a child, leaving the nest and living elsewhere, marrying or divorcing, acquiring a license and a job, buying a new vehicle and so on. All these changes are simulated probabilistically in DEMOS (Sundararajan and Goulias 2003). Most of the transition probabilities are obtained by cross-classification of the variables between two successive years of the PSTP data.

DEMOS is a longitudinal, dynamic, complex and stochastic microsimulator. The model is dynamic in the sense that the attributes describing an individual are updated after every simulation period. DEMOS captures all the complex correlation between the person and household attributes which makes the model complex, and finally it is stochastic-every individual is simulated 100 times to account for inherent random processes underlying human lifecycle evolution. Furthermore, to demonstrate the long-term forecasting capability of DEMOS, the model was executed for 20 years along with models developed for predicting the probability of market penetration of Information and (tele) Communication Technology and its use. Currently, the model does not simulate migration and DEMOS employs an open population microsimulation technique.

HMHDS

Hazard Models of Household Demographic Simulator (HMHDS) developed by Kazimi (1994) is a dynamic microsimulation model by using continuous time hazard models and allowing for inter-dependencies across the various types of changes that a household undergoes during a lifecycle process. The model system employs a cross-sectional microsimulation technique, with the model being a closed population system.

The model simulates demographic transitions at the household level, in which an individual is also part of the household. The lifecycle events that are modeled in HMHDS are: birth, death, household formation (marriage, cohabitation) and dissolution (divorce), presence of children, child leaves home, child custody and education. This model system does not simulate economic variables like labor participation, employment status and so on.

SimBritain

SimBritain developed by Ballas (2005) and other team members in the UK, is a dynamic spatial microsimulation model of demography. SimBritain aims at simulating the entire population of Britain at the small geographical unit (e.g. ward level). The two key data sources that were used in building SimBritain are: (1) 1991 UK Census Small Area Statistics consisting of a subset of 86 demographic and socioeconomic data tables for Great Britain and (2) British Household Panel Survey drawn from a representative sample of over 5000 households. The basic methodology underlying SimBritain relies on traditional IPF procedure in generating vectors of individual characteristics based with an associated geographical unit of analysis (in this case Small Area Statistics) (Ballas et al. 2007).

SimBritain models different lifecycle stages in the form of demographic variables: birth, death, aging, and internal migration and socioeconomic variables: household composition (married couple, lone parent and other), presence of children, income classes, car ownership, housing tenure and employment status. However, in the current version of SimBritain does not model migration explicitly. The model system treats time as discrete with a closed population system.

SMILE

Simulation Model for the Irish Local Economy (SMILE) is a dynamic spatial microsimulation model designed to analyze the impact of policy change and economic development on rural areas in Ireland (Ballas et al. 2005). SMILE model is heavily based on the framework of SimLeeds (refer to Ballas 2001 for further reading on SimLeeds). However, SMILE adds the dynamic dimension to SimLeeds framework by modeling the demographic processes explicitly at the micro-level. SMILE is constructed using the Census of Population Small Area Population (SAPS). SMILE model system consist of two processes: (a) static process creates the base population at District Electoral Division (DED) level and assigns census attributes to individuals, this is achieved by adopting the IPF procedure and (b) dynamic process ages the population by evaluating individuals for fertility, mortality and migration.

SMILE explicitly models mortality, fertility and internal migration only. Mortality of an individual surviving for the five-year simulation period is a function of age, gender and location. Fertility and mortality are functions of age, marital status and location. Births are modeled using five-year age group and marital status data. In SMILE, migration is modeled on the basis of random sampling from calculated migration probabilities derived from 1991 and 1996 Census of Population data at county level. Probability of migration is a function of age, gender and county location. Furthermore, SMILE is a closed population system with time treated as discrete with five year simulation periods.

Criteria of Demographic Model Comparison

Based on the key factors that shape up an individual's lifecycle as identified in previous sections, a taxonomy is constructed here to compare the demographic models. The comparison of the models is built on different events that an individual goes through his lifecycle. These lifecycle stages are identified as follows: (1) Birth, (2) Death, (3) Sex of the new born, (4) Aging, (5) Disability, (6) Single, (7) Cohabit (8) Marriage, (9) Divorce, (10) Widowed, (11) Presence of kids, (12) Child leaving parental home, (13) Child custody, (14) Institutionalization of the elderly, (15) Education attainment, (16) Student employment, (17) Labor participation, (18) Employment status, (19) Employment type, (20) Employment by industry type, (21) Occupation type, (22) Work duration, (23) Income, (24) Employment spell, (25) Job change, (26) Residential location, (27) Workplace location, (28) School location, (29) Asset/debt ownership, (30) Pension benefits, (31) Social Security benefits, (32) Residential mobility, (33) Driver license, (34) Vehicle ownership and (35) ICT adaptation.

Similarly, the models are also compared on the basis of the microsimulation technique that each of the model uses. The microsimulation techniques that have been identified for the comparative purposes are: (1) Continuous time, (2) Discrete time, (3) Open population, (4) Closed population, (5) Data driven, (6) Rule-based, (7) Mate matching, (8) Steady state and (9) Macrodynamic effects.

Tables 7a, 7b, and 7c illustrate the comparison of demographic microsimulation models based on the lifecycle events. The models can be divided into spatial and aspatial microsimulation models. The aspatial demographic microsimulation models (DYNASIM, CORSIM, DYNAMOD, MOSART, LifePaths, DEMOS, and HMHDS) in which spatial representation is not modeled explicitly. The majority of these aspatial models simulate most of the individual lifecycle events (birth, death, marriage, divorce etc.); these do not simulate some key socioeconomic events which play a significant role in the context of activity-based approaches to travel and integrated land-use transport models. However, DEMOS is the only aspatial microsimulation model that explicitly models some key socioeconomic events like employment status, occupation type, driver license, vehicle ownership and ICT adaptation. In contrast, spatial microsimulation models (CEMSELTS, SimBritain, and SMILE) explicitly model spatial changes during simulation. The spatial event that is explicitly simulated in these models is residential location, which is a household long-term decision. However, CEMSELTS is the only microsimulation model that explicitly models workplace and school location decisions. Furthermore, SimBritain and SMILE although being a spatial microsimulation model, do not completely simulate all the key lifecycle events that are identified in Tables 7a, 7b, and 7c.

Table 7a Demographic Model Comparison based on Life Course Events

Life Course	DYNASIM	CORSIM	DYNAMOD	MOSART	LifePaths	CEMSELTS	DEMOS	HMHDS	SimBritain	SMILE
Birth	X	X	X	X	X	X	X	X	X	X
Death	X	X	X	X	X	X	X	X	X	X
Sex of new born	X	X							X	X
Aging	X	X	X	X		X	X	X	X	X
Disability	X	X		X						
Single	X	X	X	X	X	X	X	X	X	
Cohabit				X	X	X		X		
Marriage	X	X	X	X	X	X	X	X	X	
Divorce	X	X	X	X	X	X	X	X	X	
Widowed		X			X					
Presence of kids								X		
Child leaving parental home	X	X	X	X	X		X	X		
Child custody		X						X		
Institutionalization of the elderly					X					
Education attainment	X	X	X	X	X	X	X	X	X	
Student employment			X		X					
Labor participation	X	X		X		X			X	

Table 7b Demographic Model Comparison based on Life Course Events

Life Course	DYNASIM	CORSIM	DYNAMOD	MOSART	LifePaths	CEMSELTS	DEMOS	HMHDS	SimBritain	SMILE
Employment status		X	X		X		X			
Employment type (full time/part time)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Employment Industry Type						X				
Occupation Type							X			
Work duration	X	X	X			X				
Income	X	X		X	X	X	X			
Employment spell					X					
Job change	X					X				
Residential location									X	X
Workplace location						X				
School location						X				

(+) None of the models simulate employment type

Table 7c Demographic Model Comparison based on Life Course Events

Life Course	DYNASIM	CORSIM	DYNAMOD	MOSART	LifePaths	CEMSELTS	DEMOS	HMHDS	SimBritain	SMILE
Asset/debt ownership		X								
Pension benefits	X	X								
Social security benefits		X								
Residential mobility						X				
Driver's License						X	X			
Vehicle ownership						X	X		X	
ICT Adaptation						X	X			

Table 8 further presents the comparison of the demographic models based on the microsimulation techniques used. Many of the microsimulation models reviewed here treat time as discrete during simulation. However, LifePaths and HMHDS treat time as continuous by modeling the events as survival functions. Similarly, all the models adopt the closed population system, while DEMOS and LifePaths adopt open population system. CORSIM, CEMSELTS, DEMOS and HMHDS are the only models that adopt both data-driven and rule-based techniques for microsimulation. Mate matching is considered in most of the microsimulation models except for DYNAMOD, HMHDS, SimBritain and SMILE. Furthermore, none of the models assume steady state and enable shifting of important parameters. Macrodynamic effects are not explicitly modeled during microsimulation; however, they are considered implicitly in the macroeconomic model that provides the control totals for the simulation year (this applies to closed system population models only).

Table 8 Demographic Model Comparison based on Microsimulation Techniques

Microsimulation Technique	DYNASIM	CORSIM	DYNAMOD	MOSART	LifePaths	CEMSELTS	DEMOS	HMHDS	SimBritain	SMILE
Continuous time			X		X			X		
Discrete time	X	X	X	X		X	X		X	X
Open population					X		X			
Closed population	X	X	X	X		X		X	X	X
Data driven	X	X	X	X	X	X	X	X	X	X
Rule based		X				X	X	X		
Mate matching	X	X		X	X	X	X			
Steady State	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Macrodynamic effects	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

(+) None of the models consider steady state evolution during microsimulation
(-) None of the models explicitly simulate macrodynamic effects

MODEL SELECTION

Based on the taxonomy proposed by Miller et al. (1999) and the fundamental properties of an idealized integrated urban model, many models (which differ in their spatial and temporal detail) are required to address planning issues across the wide range of urban areas that exist worldwide. The taxonomy proposed and the evolving models desribed imply a strong preference for a microsimulation approach to modeling urban systems.

Thus, based on the comparison of models in the previous sections UrbanSim, ILUTE and ILUMASS point the way to more disaggregate and dynamic, non-equilibrium models. UrbanSim is the model that was selected based on its relative merits as identified by Miller et al. (1999). Also, UrbanSim models on spatial markets, are applied in Eugene-Springfield, Oregon, Puget Sound Region, WA, and tested. The method is also supported by an open source software. However, it should be noted that ILUTE and ILUMASS also have some similar merits (both models are disaggregate, spatial market representation and microsimulation based), but were not selected because both models are still under development and are not readily available.

Furthermore, planning support systems (PSS) as described by Waddell et al. (2008) are gaining a considerable attention and interest from a wide variety of potential users (planners in cities, counties, and MPO's), and for a wide array of applications (infrastructure investments and land use plans). Planning Support Systems (PSS) cover the spectrum from (a) visualization tools that make it possible to distinguish between one alternative future and another might look like (b) sketch planning tools that allow users to input rules and then to visualize the outcomes of those assumptions, (c) simulation systems that attempt to model the behavior of urban agents and the potential effects of the alternative policy actions. In this context, UrbanSim falls under the third category, but also provides visualization capabilities. Since, UrbanSim is open source and evolving with technology, the software system would be capable of addressing the gamut of PSS.

An important component of the integrated model system is the dynamic demographic simulator of social, economic, and demographic attributes describing an individual and a household. During the process of simulation an individual will be born and progressed through different life cycle stages. This simulation is achieved through the model system DEMOS. The integrated model system incorporates the interactions between urban systems simulation, demographic simulation, coupled with travel demand model systems. A demonstration of the new system capabilities will be offered using data from Santa Barbara, CA.

Based on the review and comparison of the different demographic models in the context of integrated land-use transport models, DEMOS is the most suitable model that can be tested in integrating with the UrbanSim application. DEMOS provides a unique platform for integration, because the model system simulates key individual lifecycle events along with major socioeconomic events that are applicable to integrated land-use transport models. Furthermore, the model uses rate-based transitional probabilities in simulating these events based on the Puget Sound Transport Panel. DEMOS has been implemented, validated (see Sundarajan and Goulias 2003 for further details) and provides forecasting capabilities. DEMOS was used in predicting market penetration of ICT adaptation for the Puget Sound region. However, DEMOS has a few shortcomings which can be modified further using concepts from CEMSELTS. Currently, DEMOS does not incorporate spatial events during microsimulation (residential location, workplace location and school location). DEMOS does not simulate migration events (immigration and emigration), which can be incorporated in further development.

Furthermore, UrbanSim also includes the demographic transitions as part of the model system. Although, it does not completely model all the person and household life cycle events. The platform does provide an opportunity to interface the demographic microsimulator

(DEMOS) developed by Sundararajan and Goulias (2003). DEMOS will function as a standalone simulation system providing input to UrbanSim; similarly, UrbanSim would provide the land use information as input for the subsequent simulations in DEMOS.

URBANSIM IMPLEMENTATION DETAILS

When UrbanSim was first developed it was at the grid-cell unit of geographical analysis for land use simulation. However, with recent developments UrbanSim is now capable of and substantially flexible in the use of any geographic unit of analysis, (e.g., the parcel and zonal - traffic analysis zones levels). The grid-cell based UrbanSim, begins with the decision of a resolution to use for a grid to overlay the study area. In order to reach a compromise between the high level of resolution and computational demands a pragmatic choice of 150 meters by 150 meters grid-cell was chosen for early UrbanSim applications (Userguide, 2011). The main disadvantage of the grid-cell structure requires unnaturally splitting the underlying parcel information and recombining it in ways that create artificial representations of the data. This problem also makes it difficult to apply information on development regulations like general plans. Therefore, to address some of these limitations the parcel version of UrbanSim application uses land use parcels when available. An alternative version for parcel and grid-cell is the current zone-based version of UrbanSim which uses zones based on a regional travel model when available for the study area. In this section we discuss in detail the model structure of the parcel-based version and zonal-based version of UrbanSim respectively.

Parcel-based UrbanSim

UrbanSim is the only land use simulation system that has attempted to use parcels as unit of analysis (Waddell 1998, 2000). It used parcels to simulate land development, but zones as the unit of location choice. Parcels have a natural attraction for use as a foundation for land use modeling, because they are consistent with behavior, but until recently their potential benefits have been overshadowed by the data complications for modeling purposes (Waddell et al., 2010).

The data structure representation for the parcel-based version of UrbanSim takes in very detailed level of data. For example, in representing the location decisions of the households, jobs or developers, the location unit of analysis is represented by a building that belongs to a parcel. This building database is represented in a fine spatial detail with its corresponding location to the parcel, building type, year built, residential and non-residential square footage. With the detailed representation at the parcel level, UrbanSim application for parcel version also incorporates detailed behavioral decision making processes by the agents (households, jobs and developers) within the urban system. Some of these decision processes are: household location choice and housing type choice for households. Employment location choice home-based or non-home based for jobs. Development project proposals choice and development project locations choice for the developers. For visualization purposes it can also be seen from Figure 1 that households and jobs are located in a building, which in turn is spatially located in a parcel.

Zonal-based UrbanSim

Given the available flexibility in configuring models in OPUS, zones used in travel models can be used for configuring the UrbanSim application at the zonal level, which makes them consistent with the regional travel models. This approach is also used to create a rather simple model system using less geographic detail. For example, an application in Paris used Communes or administrative areas roughly equivalent to traffic analysis zones in number.

Data representation in the zonal-version of UrbanSim is fairly limited when compared to the parcel-version. For example, the buildings represented in the zonal version are aggregate representation of individual buildings located on parcels within a zone. Through this coarse representation, the behavioral models incorporated during the microsimulation are also fairly limited when compared with the parcel version. Furthermore, the agents household and jobs are still located in a building; however, these buildings are now linked spatially to these aggregate zonal representations, as shown in Figure 2.

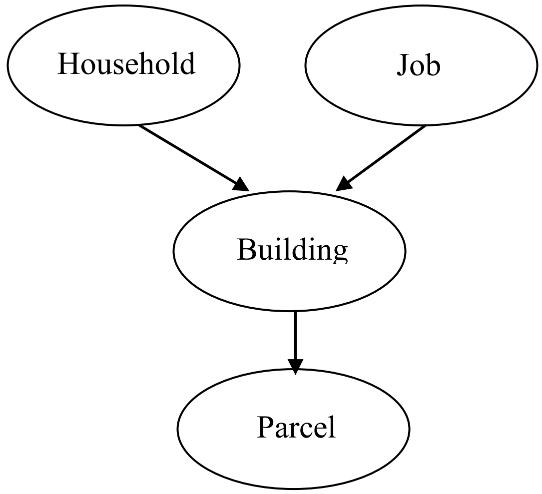


Figure 1 Parcel Representation for UrbanSim

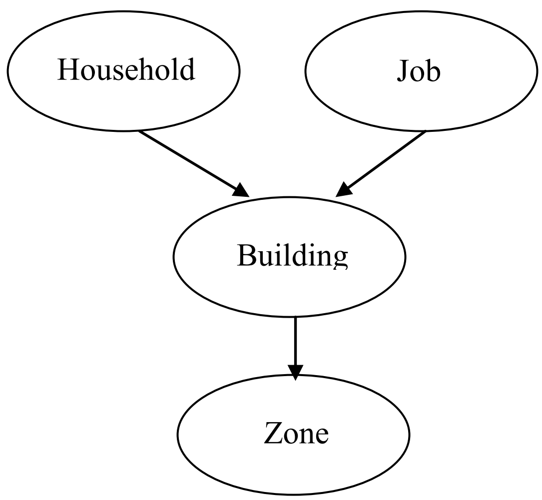


Figure 2 Zonal Representation for UrbanSim

Model Comparison

To further compare the model structure for parcel and zone-based versions of UrbanSim, Table 9 illustrates the models that are implemented in the parcel and zonal version of UrbanSim. The models that are shown in Table 9 are based on the example projects provided by the UrbanSim community. Furthermore, it should be noted that the models provided in these examples can be further modified based on the type of the application. The parcel version of the example is based on the Puget Sound Regional Council (PSRC) parcel based application and the zonal version is based on the San Antonio example. From Table 9, parcel-based version of the model has a detailed representation of the models used during the land use simulation. The models discussed in Table 9 can be categorized based on the agent's decision (household, job or business establishment and developer) and their related models implemented in parcel and zonal versions of UrbanSim. Also, the individual modules of the UrbanSim model system are explained in further detail in the next section.

Household's decision in an urban system changes with the change in urban environment which also results in changes within the household structure. However, exceptions to these changes are households' fertility and mortality structures. From the table, household transition model accounts for households in-migrating into and emigrating from a region. The fertility and mortality models predict the birth and deaths of individuals within a household in a given study area. It should be noted that these models are not currently implemented to the best of the authors knowledge. The household decision on housing tenure (rental or owning a house), residential building type choice (single family, multi family etc.), auto-ownership choice (one vehicle, two vehicles etc.) along with household relocation and household location choice are implemented in the parcel version (PSRC parcel example). However, in the zonal version the household relocation and household location choice models are only implemented. Furthermore, parcel-version also models the individual's workplace decisions, which are captured in work at home choice model and workplace location choice model. The parcel-version also models the mode choice of the individual workers for home-based work trips during simulation. The zonal-version currently does not implement any of the individual's workplace decisions. Also, in order to implement the individual's decision processes the synthetic population for individuals should be generated. Therefore, it should be noted that the individual's decision processes implemented in the parcel-based version are experimental.

Table 9 UrbanSim Model Comparison for Parcel and Zonal Versions

Agent	Model	Parcel-Based	Zonal-Based
Household	Household transition	X	X
	Fertility		
	Mortality		
	Housing tenure choice	X	
	Residential building type choice	X	
	Household location choice	X	X
	Household relocation	X	X
	Auto ownership choice	X	
	Work at home choice	X	
	Workplace location choice	X	
	Home-based Work Mode Choice	X	
Job or Business Establishment	Employment transition	X	X
	Employment relocation	X	X
	Employment location choice	X	X
Developer	Development proposal choice	X	
	Building construction	X	
	Development project transition		X
	Development project location choice		X
	Real estate price	X	X
	Expected sales price	X	

UrbanSim currently implements individual jobs as the unit of analysis. This is under the assumption that businesses are making individual choices about location or relocation of each, and are not constrained to moving an entire establishment (Userguide, 2011). Employment transition model serves the same purpose as that of the household transition model, with the unit of analysis being the individual jobs that are coming into or leaving a region by employment sector. Employment relocation and location choice models are implemented in both the parcel and zonal versions of UrbanSim. It should be noted that the location set of the choice processes are individual buildings.

The developer's decision making process within an urban system is influenced by the change in supply and demand of the real estate stock within a given year. These decisions are implemented in both parcel and zonal versions of UrbanSim. In the parcel-version the developers' actions that are implemented are: (1) development proposal choice which predicts the selection of the proposed development projects to be constructed on parcels. The prediction is based on the vacant land, development type, zonal and other environmental constraints for the given simulation year and (2) building construction model adds buildings based on the projects selected by the development proposal choice model. However, the zonal-version due to its aggregate geography implements the developers' decision in a different manner. The models that are implemented in the zonal version are: (1) development project transition model predicts new development that needs to be built to satisfy the market demand. The prediction can be either having new construction or no construction and (2) development project location choice model predicts the location choice of the developers to build new real estate for both residential and non-residential type. Thus, the agent's decisions are modeled during the simulation year; the UrbanSim model also predicts the real estate price of the existing and future market conditions along with the expected sales price for future development projects. The zonal-version of UrbanSim does not implement expected sales price model.

UrbanSim does not have any provisions for an internal demographic model. Although, the models fertility and mortality models have been included they have not been implemented in a published version of the model. However, we know that population growth and consequent formation of new households through matching of individuals is the main determinant of demand in the residential real estate market. The current version of UrbanSim does not include any internal demographic model, but is flexible to be adapted to work with any demographic model that delivers consistent and complete demographic inputs (Morand 2010).

In this context, the demographic microsimulator developed by Sundarajan and Goulias 2003 provides a potential candidate to integrate with existing UrbanSim models to build a comprehensive land use simulation system. DEMOS currently models the life cycle events, as described in Table 10 and these events are compared with the existing models that UrbanSim captures. Overall, UrbanSim models only birth, death and vehicle ownership life course events which belong to the household attributes. However, as identified earlier it is important to capture the dynamic changes in regional population which can occur through different life course events (e.g. marriage, divorce, birth of child).

There is a strong relationship between life-cycle stage and propensity to move (Coulombel 2010). As stated by Long (1992) "In all developed countries, young adults aged between 20 and 35 years are by far the most mobile population segments, and residential mobility typically falls as one gets older". Therefore, within this context the life course events like aging and child leaving parental home as modeled by DEMOS would enhance the existing residential market in UrbanSim. By including this model, we would be able to better capture the spatial distribution of housing market and residential location preferences about mobility and location choice for this population segment. Furthermore, the life course events like changes in education attainment, employment status, and driver's license would commonly trigger a change in residential locational preferences (Dieleman, Clark and Deurloo 2000). For example, an individual graduating with a college degree who is employed would most likely be influenced to change his current state of residential location. Changes in the personal domain (education attainment, employment status etc.) can trigger a demand for vacant or new housing. Incorporating these life-cycle events in the existing UrbanSim model would greatly enhance real estate market. Furthermore, life course events like changes in occupation type and increases in household income also greatly influence the residential preferences. For example, households of higher income category would have significantly different preferences when compared to low income group. Including this life course event from DEMOS in UrbanSim would greatly enhance the existing residential real estate market. The model would also be able to capture the spatial segregation by income groups.

Table 10 Life Course Events in DEMOS and UrbanSim

Type of Attributes	Life Course Event	DEMOS	UrbanSim
Household Attributes	Birth	X	X
	Death	X	X
	Single	X	
	Marriage	X	
	Divorce	X	
	Child leaving parental home	X	
	Income	X	
	Vehicle Ownership	X	X
Person Attributes	Aging	X	
	Education attainment	X	
	Employment status	X	
	Occupation type	X	
	Driver's License	X	

Based on our review earlier in this report, household composition has an impact on residential location preferences in various ways. For example, households of two employed adults that move to places that make distances to employment longer are also increasing the probability of one spouse becoming unemployed or inactive (Courgeau and Meron 1995). The impact of children is more complex as they tend to increase mobility at first, but ultimately decrease it (Gobillon 2001). Furthermore, household composition also influences residential decision making process itself. For example, households are mainly concerned with elements of tenure, dwelling type, number of rooms and price along with the locational characteristics. Therefore, incorporating the demographic transitions as obtained from DEMOS into UrbanSim would greatly enhance the existing residential and non-residential market simulation.

Integration of the demographic model with land use can be implemented by interfacing DEMOS and UrbanSim (also previously identified in Morand et al. 2010). An exchange routine needs to be built to update, using the demographic information from DEMOS, the UrbanSim models. If no feedback effect is considered from the UrbanSim model to DEMOS, then the population features can be considered as exogenous to the model. Alternatively, to capture the dynamic interactions between population dynamics and land use model, it would be desirable to have a feedback effect from the UrbanSim model to the demographic model, in such a way that the exchange of data are included in the yearly loop. Furthermore, the outputs from the demographic model would serve as input to the UrbanSim model that produces yearly estimates of the population, similar to the census database. These estimates can be produced for the entire simulation period if no feedback effect is considered, or on a yearly basis if the feedback effect is considered. From these data, UrbanSim will locate the individuals in order to integrate them into other modules.

SANTA BARBARA CASE STUDY

Santa Barbara County is the test bed in integrating UrbanSim with DEMOS with existing travel demand forecasting model as used by Santa Barbara County Association of Governments (SBCAG) in developing the new travel demand forecasting system. As identified by Waddell (2004) UrbanSim data needs can be broadly classified into the following categories.

1. Employment.

- Categories of employment used to classify the jobs using standard SIC or NAICS guidelines.
- The control totals for each employment category by home-based and non-home-based within the region for the simulation year. For example, if the simulation year is 2001, the control totals for that year by employment category need to be provided.
- Annual relocation rates for jobs by employment category.
- Jobs in the region by employment sector that belong to a building type and the square footage (area) used by a job.

2. Households.

- Control totals of total number of households in the region by simulation year.

- Annual relocation rates for households by combination of age and income of household.

3. Parcels: This section describes the data that is required at the parcel level of geography in the region.

- Assessor parcel level information like: parcel area, tax exempt information, land value, total number of residential and non-residential units etc.
- The land use type the parcel belongs to, and the regional specific land use type classifications used.

4. Buildings.

- Building type information like: residential, commercial, mixed etc., building improvement value, land area used by building, number of stories, year built.
- The building area used per job by employment category.
- Demolition cost per area (square-feet) for a building type.
- Target vacancies in the region by building type.

5. Development Projects.

- Development project proposals in the region that known to be coming in the future
- Details of the proposal like: planned number of units, building type, construction cost, land area utilized for the development, density type, development type, construction schedule and progress etc.
- Development projects that have been built over a period for time (for example) of 10 years.

6. Development Constraints.

- Constraints adopted in the region. For example, advocating more mixed density type developments.
- Maximum and minimum value for the development. For example, number of residential units per acre or floor area ratio

7. Travel data.

- Geographical unit (TAZ) of analysis for model development, travel times from origin to destination zones
- Identification of special generators, travel time from zones to these special generators like: airport, CBD.

Data were provided by Santa Barbara County Association of Governments and Santa Barbara County Office. In the first version UrbanSim is implemented at the zonal level due to data constraints, as the agencies did not have a complete inventory of buildings data, which is primarily required for running the parcel version of UrbanSim. It is anticipated that the zonal version of UrbanSim is sufficient for the feasibility testing phase during this first year. Figure 3 represents the Santa Barbara County study area with the incorporated cities, along with the SBCAG traffic analysis zones. The SBCAG traffic analysis zones are the geography of analysis for the UrbanSim application in this case study. Figure 4 presents the spatial distribution of average square footage for single family and multifamily residential housing units per traffic analysis zone (TAZ). The data were obtained from the assessor's parcel level data and converted to TAZ's. Similarly, Figure 5 provides the spatial distribution of average nonresidential square footage per TAZ. Nonresidential land use type included commercial, retail, office buildings, vineyards and so forth. This information was also obtained from assessor's parcel level data. Figure 6 provides land use type distribution across the Santa Barbara County.

Figure 3 Santa Barbara County Study Area for UrbanSim Application

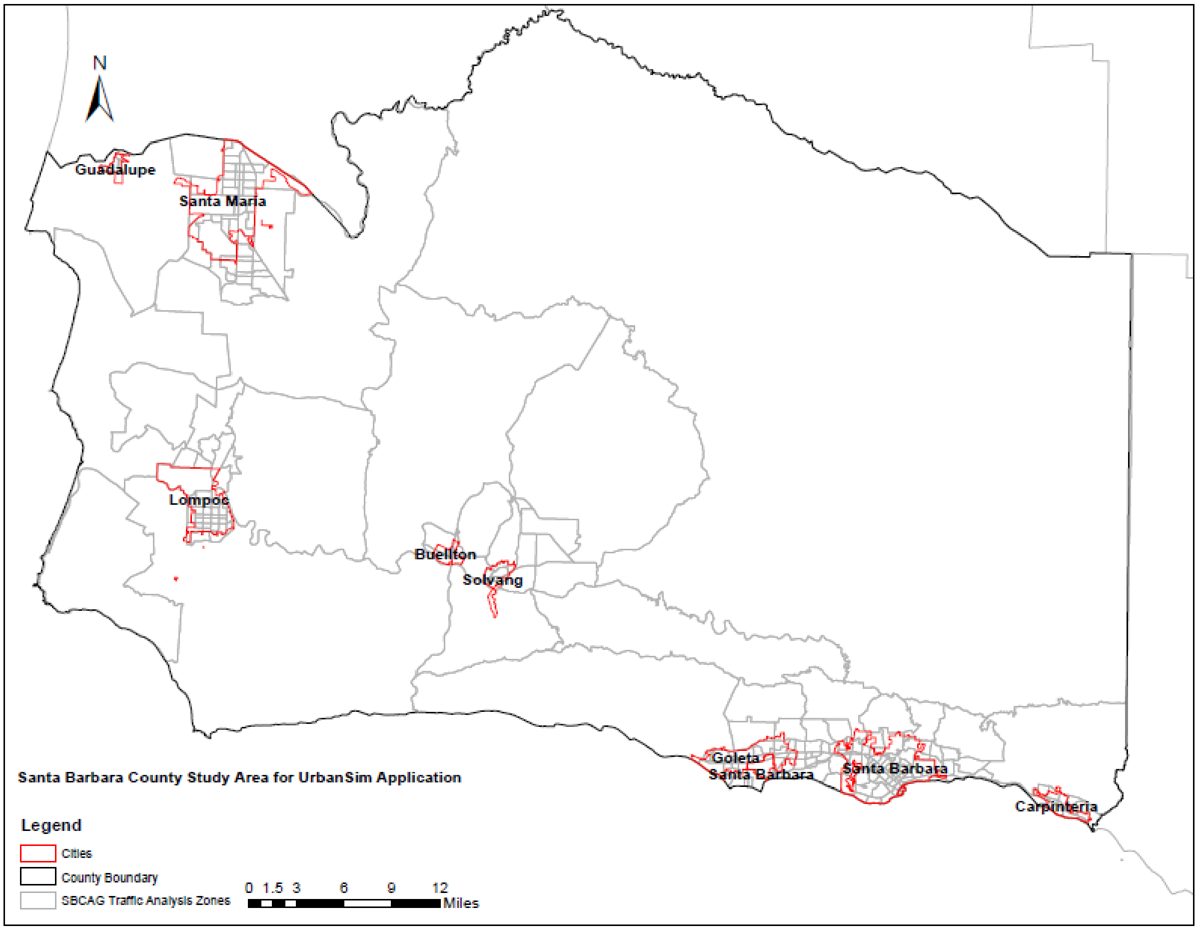


Figure 4 Spatial Distributions of Average Square Feet per Zone for Single and Multifamily Residential Housing (Southern Portion of Santa Barbara County)

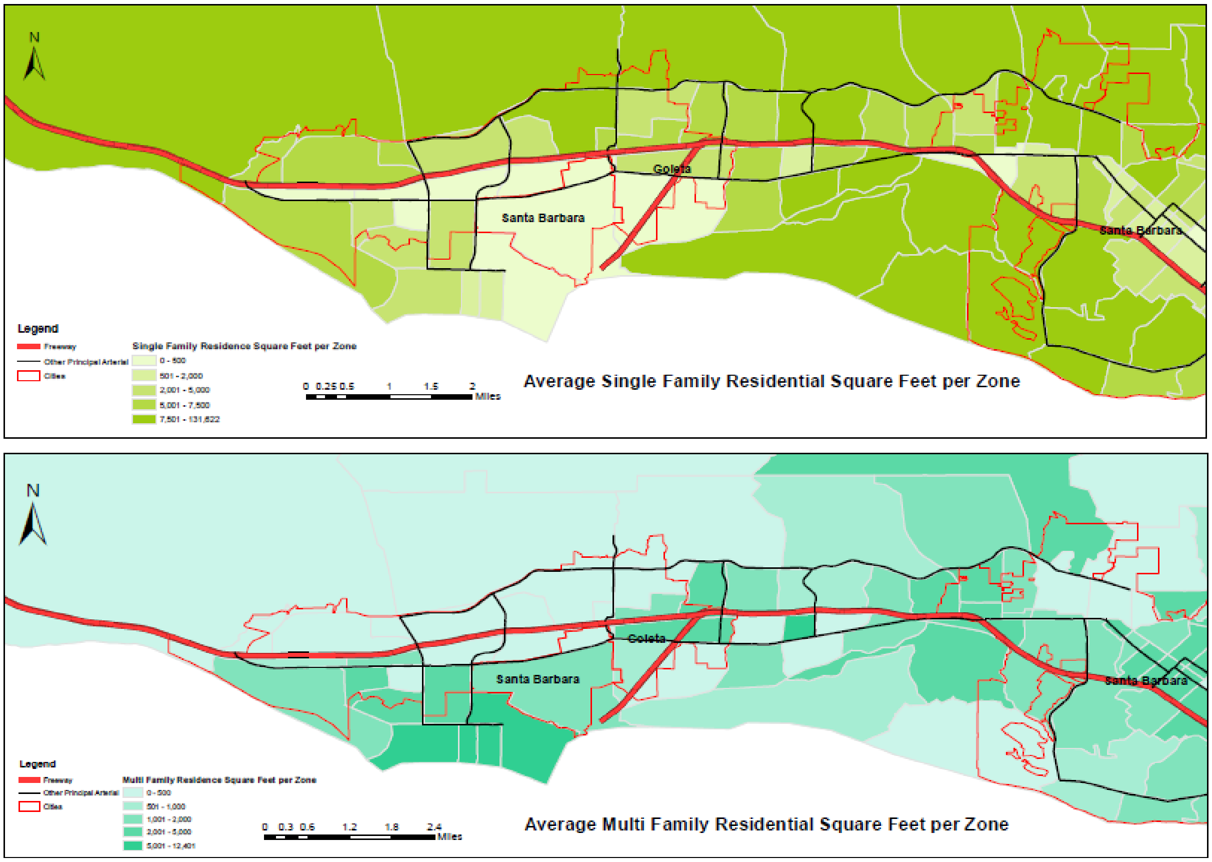


Figure 5 Spatial Distribution of Average Non-Residential Square Feet per Zone (Southern Portion of Santa Barbara County)

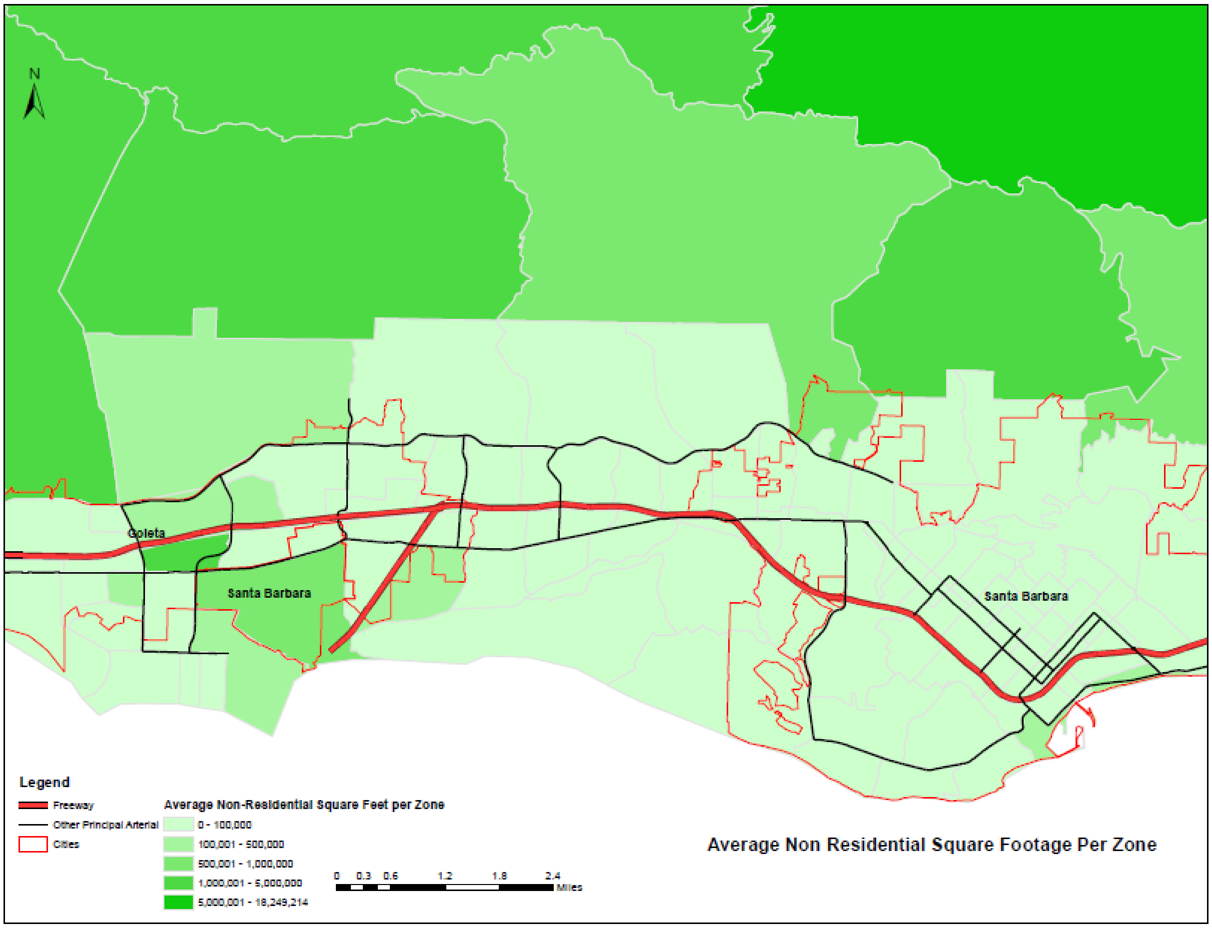
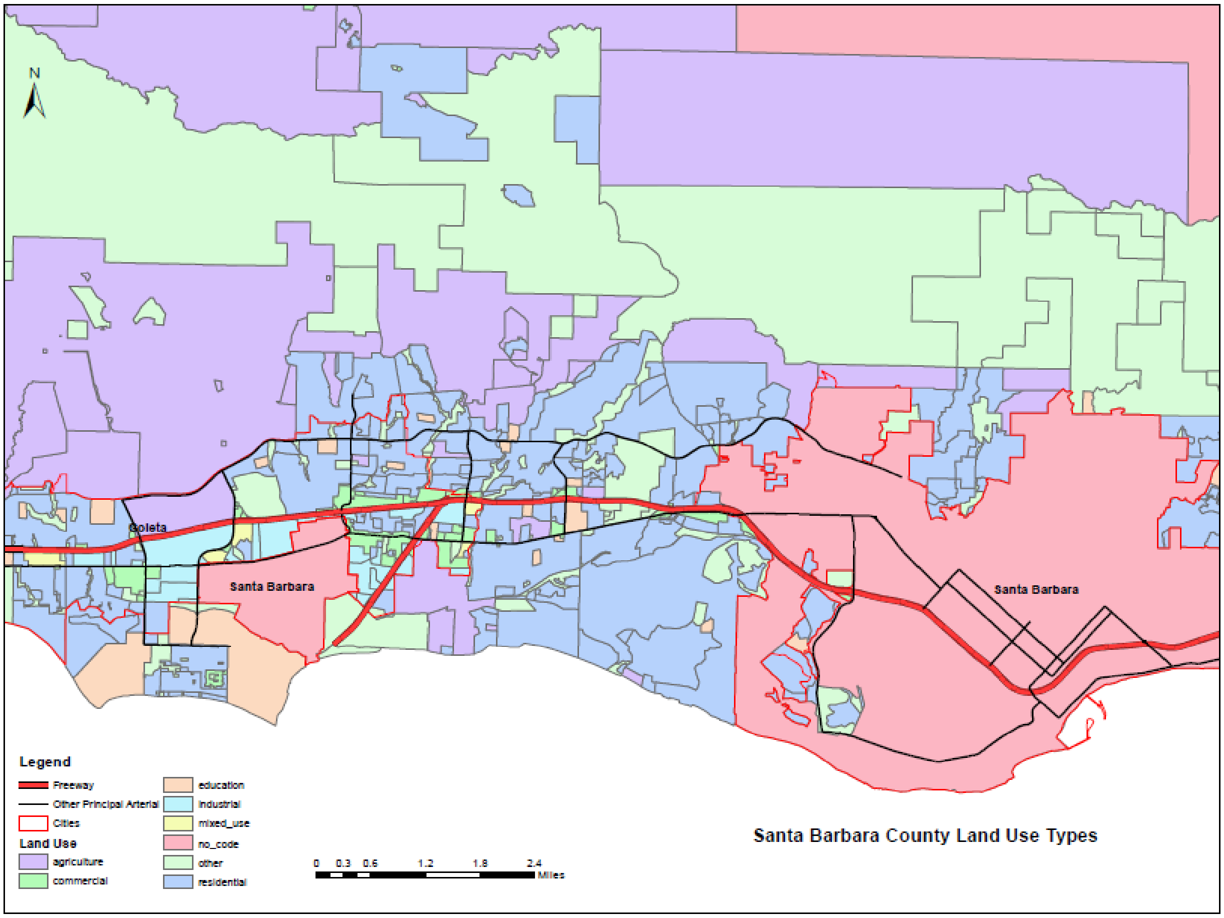


Figure 6 Spatial Distribution of Land Use Type in the Southern Portion of Santa Barbara County



Population Synthesis for Santa Barbara County Application

In order to operationalize the land use microsimulation models it is necessary to input a synthetic household population. Therefore, the open source household population synthesizer PopGen (reviewed in the demographic simulation section in this report) was used in this task. The synthesizer needs the following data tables as input.

Sample Table – The sample files provide a snapshot of population living in the region for any given year. There are three types of sample files that are required by PopGen, are household sample, person sample and groupquarter sample. These sample files can either be from travel surveys or Census 2000 database. For the Santa Barbara County application, we use the Public Use Micro Sample (PUMS) data which is representative of 5% of the total population. This data is represented at Public Use Microdata Area (PUMA). This sample table provides a starting point of the cross-classification of different variables in the population.

Marginals Table – These are the univariate distributions of each variable and each US Census blockgroup (we use 317 block groups in this application) in the study region for the any given year. There are three types of marginal files that are required by PopGen. They are, household marginals, person marginals and groupquarter marginals. These marginals provide the distribution of each variable at each geographical unit of analysis. For example, the gender marginal is the percent of males and females that live in each block group. In this way the produced synthetic population "obeys" the aggregate and assumed known characteristics of the population residing in the study area.

PopGen uses an Iterative Proportional Updating (IPU) algorithm that iteratively adjusts and allocates weights among households of each type from a cell in the initial joint distribution of characteristics until both household and person-level attributes are matched. This algorithm was Used in three real-world applications using blockgroups in the Maricopa County of Arizona, The Southern California Association of Governments and the Baltimore Metropolitan Commission. One key advantage of this procedure is its ability to control for both household-level and person-level characteristics at Census block group level of analysis. Table 11 and Table 12 below show the characteristics used in the population synthesis for the Santa Barbara County application for 317 blockgroups, with a total population of 383,885 persons in 136,967 households and 16,447 persons living in group quarters. The synthetic population generated is checked against the recommended performance measures including average absolute relative difference, chi-square statistic and the geographical distribution of household and person characteristics at the Census blockgroup level of analysis.

Table 11 Sample Household Characteristics Used for Santa Barbara County Application

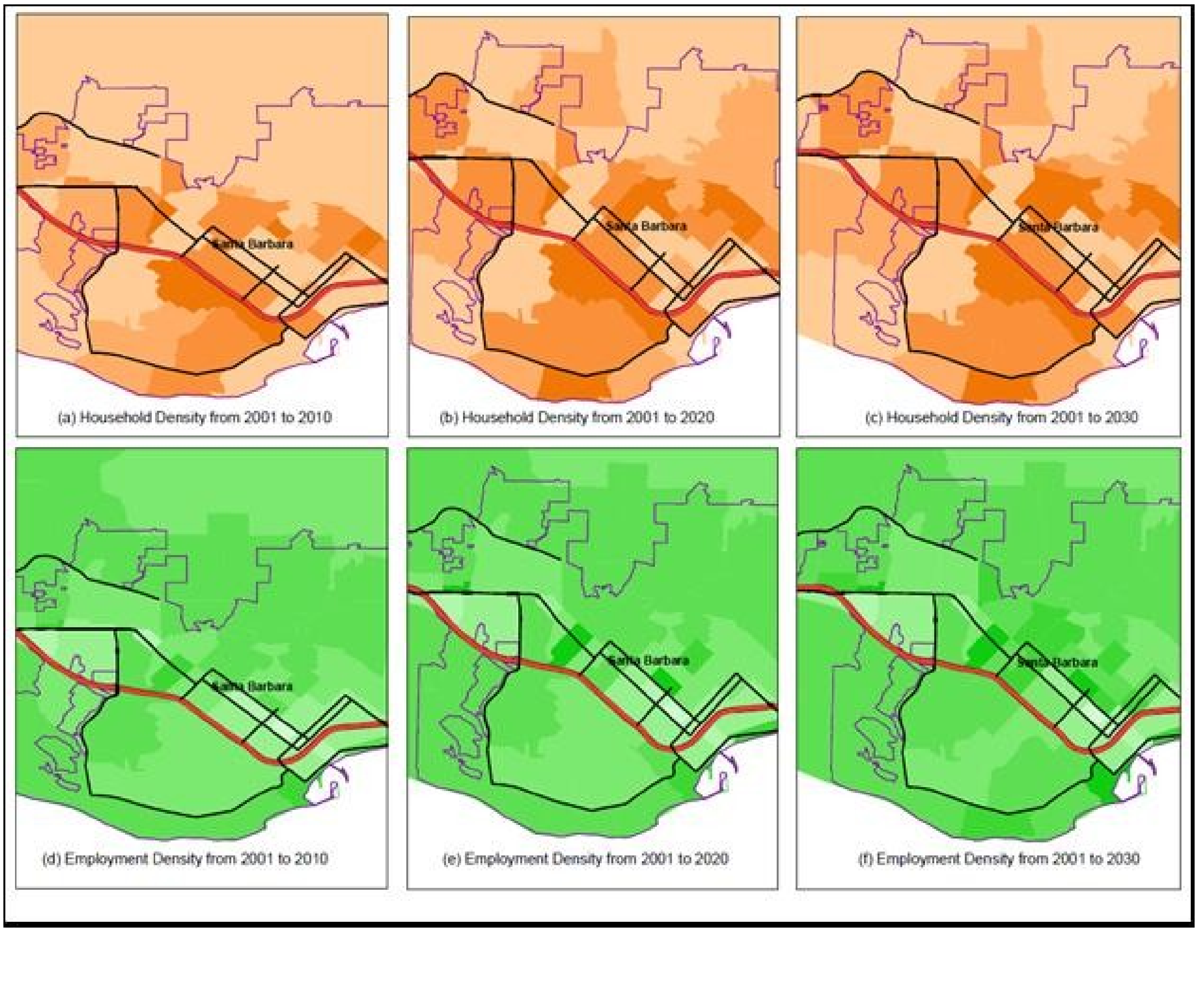
Household Characteristics	Description
Household type	Family: Married couple
	Family: Male householder, No wife
	Family: Female householder, No husband
	Non-family: Householder alone
	Non-family: Household, not alone
Household size	1 Person
	2 Persons
	3 Persons
	4 Persons
	5 Persons
	6 Persons
	7 or more Persons

Table 12 Sample Person Characteristics Used for Santa Barbara County Application

Person Characteristics	Description
Gender	Male
	Female
Ethnicity	White alone
	Black or African American alone
	American Indian and Alaskan Native alone
	Asian alone
	Native Hawaiian and Other Pacific Islander
	Some other race alone
	Two or more races

The synthetic population created with PopGen is used as input in the pilot test of Urbansim. The simulation results from UrbanSim for years 2001 through 2030 are presented in Figure 7 illustrating the change in household density (number of households per square mile) and the change in employment density (number of employees per square mile) at the TAZ level for years 2010, 2020 and 2030 respectively when compared with base year 2000. Darker colors in the figure indicate an increase in household and employment density. Santa Barbara downtown as shown in the figure experiences an increase in household density as we move from years 2010 through 2030. However, the change in employment density is fairly stable for years 2010 and 2020; but, increases slightly for year 2030.

Figure 7 Spatial Distribution of Change in Household and Employment Density for years 2010 and 2020 and 2030 obtained from UrbanSim simulation results



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NEXT STEPS

In this project we reviewed a variety of methods to integrate demographic simulation with a microanalytic land use model that provides the necessary support for microsimulated activity and travel behavior. The pre-project selection of Urbansim and DEMOS as the modeling methods and platforms were confirmed as the right choices based on their characteristics and potential for integration. We added synthetic population generation using Popgen and made preliminary testing runs of Urbansim using data provided by public agencies in Santa Barbara County to confirm the feasibility of the idea. In this section we outline the next steps in model building to make the system operational and to move to a testing and experimentation phase for policy analysis.

Spatial Clustering

Figure 1 is an indication of spatial clustering and possible segregation of major activity centers in Santa Barbara county. The county contains two major cities that are Santa Maria in the North and Santa Barbara in the South with an estimated by the American Community Survey 2009 population of 85,528 and 85,662 persons respectively. It also contains a few smaller urban environments such as Buelton, Carpinteria, Goleta, Guadalupe, Lompoc, and Solvang all of different sizes and sociodemographic compositions as well as economic activities. For these reasons we expect location choices of households and businesses may require model building that is tailored to this region and that not only accounts for the difference among its cities but also accounts for neighboring counties such as San Louis Obispo in the North and Ventura in the South. In this next step spatial clustering will be used to first study Santa Barbara county and then relate the clusters derived to the neighboring counties.

Accessibility Measurement

In a parallel model building application for the Southern California Association of Governments we developed a new method for accessibility measurement that is sensitive to traffic patterns by time of day and to the opportunity for activity participation by time of day. We also developed models that show strong correlation between accessibility and activity participation and travel. We also tested models of location choice and real estate prices with explanatory variables these time-of-day varying accessibility indicators. It is therefore important to transfer this knowledge possibly developing new techniques to the Santa Barbara case study in this second next step.

New Models in Urbansim

In Appendix A of this report we provide a summary of the processes simulated within Urbansim. At the very center of each process is a behavioral model including household transition, relocation, and location choice models. It also includes employment transition, relocation, and location choice models. For development the process includes project transition, project location choice, and real estate price models. All these models may require tailoring to the county but even tailoring to each urban cluster mentioned above. To judge this sensitivity analysis using local data is required and different model formulation testing will strengthen the application. Moreover, the relationship between turning points in life and decision to relocate and select a specific residence require further study and the development of models for employment advancement, education achievement, car ownership, and car allocation, as well as car ownership and related mobility tools acquisition, disposal, and replacement.

Activity and Travel Simulation

When the proposal for this project was written we assumed that as a first approximation we will use the four-step travel model of SBCAG. In the meantime we developed an activity and travel microsimulator for an adjacent region (called SimAGENT) that offers a unique opportunity to test it in Santa Barbara county. To do this, however, the input databases will need to be prepared and these include the PopGen synthetic population with added attributes such as employment, education, driver's license among others.

Travel Model and Route Choice

Our plan is to use the static assignment of the four-step model that includes Origin-Destination matrices of external to the region trips, special generators, and freight. In parallel, we plan to develop experiments using MATSIM, which is a route choice microsimulator developed by a European team in Switzerland and Germany.

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APPENDIX A: UrbanSim Model System Processes

In this appendix we discuss in detail the UrbanSim model structure that has been implemented from the agent's (households, jobs and developers) decision making processes. We also discuss the challenges that currently exist in implementation of household's decision making processes within the system. The UrbanSim model system processes can be classified into three categories based on the agents that are involved: (1) Household processes (2) Employment processes and (3) Developers processes.

Household Processes

Household Transition Model

The household transition model as shown in Figure A.1 accounts for changes in the distribution of the households over time. Household transition model uses external totals of population and households by type (if available) for that year. The role of this model is to keep the household data in the simulation synchronized with aggregate control totals of the population. This model takes in as input the datasets (1) annual household control totals and (2) households. These datasets go through the household transition model with output being the households table for the simulation year that controls for the annual household totals for that year. This is achieved either by adding or removing households based on the control totals but it is not a demographic transition model with explanatory variables as in demographic microsimulation.

Household Relocation Model

The household relocation model predicts the probability of a household moving in a region. However, in this case the rates are applicable to each household type. Household relocation model requires subtracting mover households by type from the housing stock by building, and adding them to the pool of new households estimated in the household transition model. The combination of new and moving households serves as population of households to be located by the household location choice model. Housing vacancy is updated as movers are subtracted, making the housing available for occupation in the household location choice model. The working of this model is shown in Figure A.2. In this model, the input data are (1) annual household relocation rates and (2) regional households, with the output being the pool or queue of moving households to be relocated in the next simulation year.

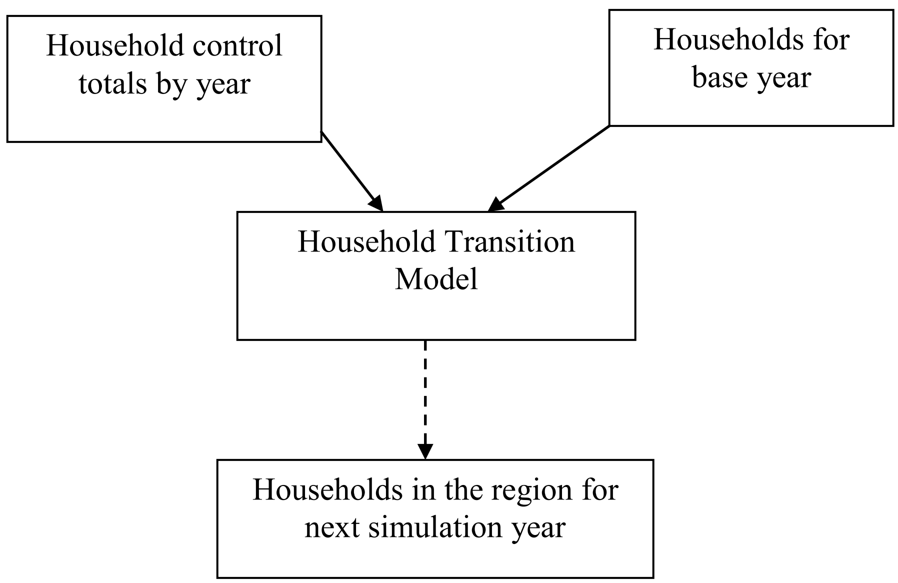

Figure A.1 Household Transition Model Architecture

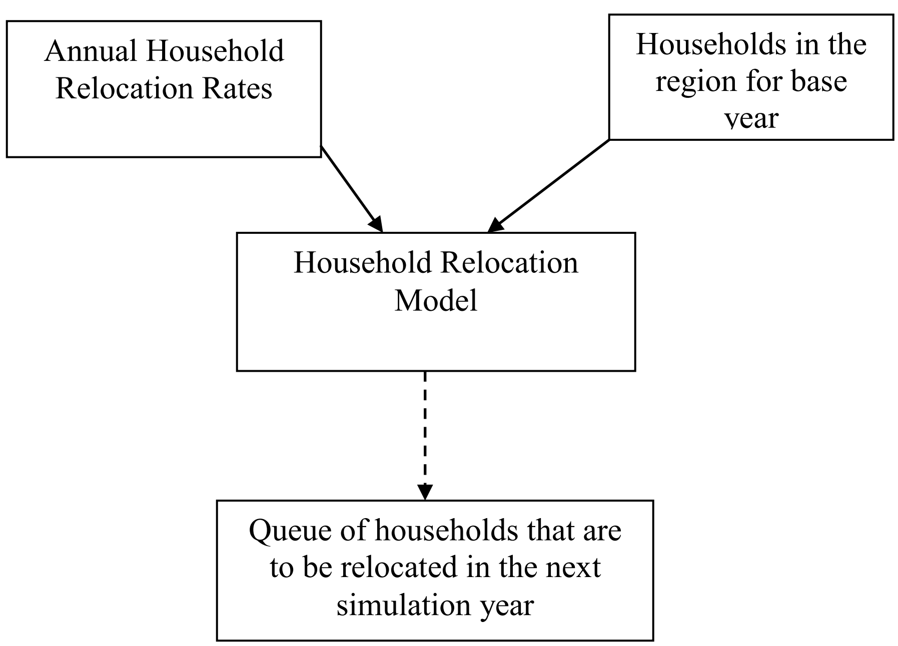

Figure A.2 Household Relocation Model Architecture

Household Location Choice Model

The household location choice model predicts the probability that a household that is either new (from the household transition model) or relocating household (from household relocation model) will select a particular location defined by residential building. The model is specified as a multinomial logit model, with random sampling of alternatives from the universe of available (vacant) housing units, including those vacated by movers in the current year. The model architecture is shown in Figure A.3. The model parameters are usually estimated using a sample of households from a regional travel survey. The independent variables that determine the household location choice can be categorized as: housing characteristics (price, density, land-use mix etc.) and regional accessibility (job accessibility, travel time to CBD and airport etc.). The model uses the following datasets as input during simulation.

(1) residential buildings which form the location (unit of analysis),
(2) pool of new and moved households as determined from transition and relocation models,
(3) zones for computing the density, accessibility and other variables and
(4) travel data or skims from the travel model.

During the simulation, this model produces an output that locates the households as obtained from the transition and relocation models into residential buildings for the current simulation year.

Employment Processes

Employment Transition Model

Employment is classified by the user into employment based on the aggregations of NAICS codes. Aggregate forecasts of economic activity and sectoral employment are exogenous inputs to this model system. The model as shown in Figure A.4 compares the total number of jobs by sector in the jobs table at the beginning of the simulation year, to the total number of jobs specified by the control totals for that year. If the control total is higher, the model adds the necessary number of jobs to the existing jobs table by sampling from the jobs table. If the control totals are lower, the appropriate number of jobs in the data is randomly removed. The role of this model is to keep the jobs synchronized with aggregate number of employment by sector in the region. The input datasets for this model are: (1) annual employment control totals by sector and (2) regional jobs by sector for the base year. Once, these data are fed as input into the employment transition model. The output of this model produces data set of regional jobs by sector for the next simulation year that synchronizes with the annual control totals for the corresponding simulation year.

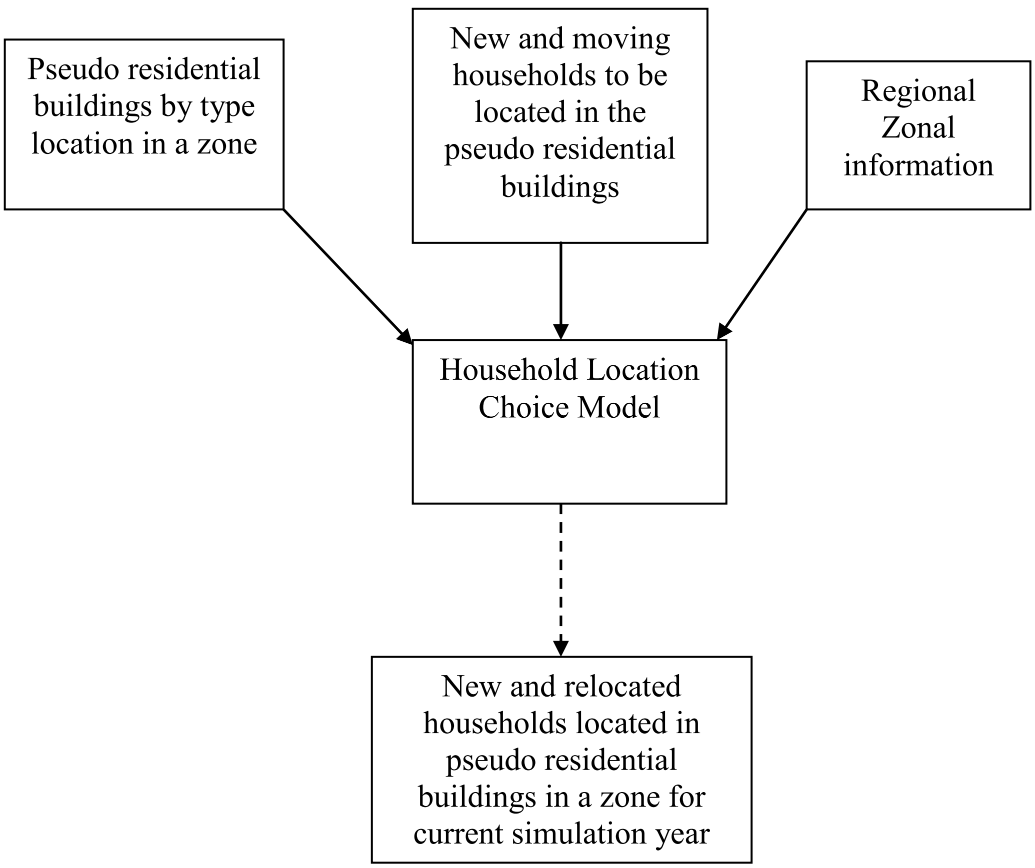

Figure A.3 Household Location Choice Model Architecture

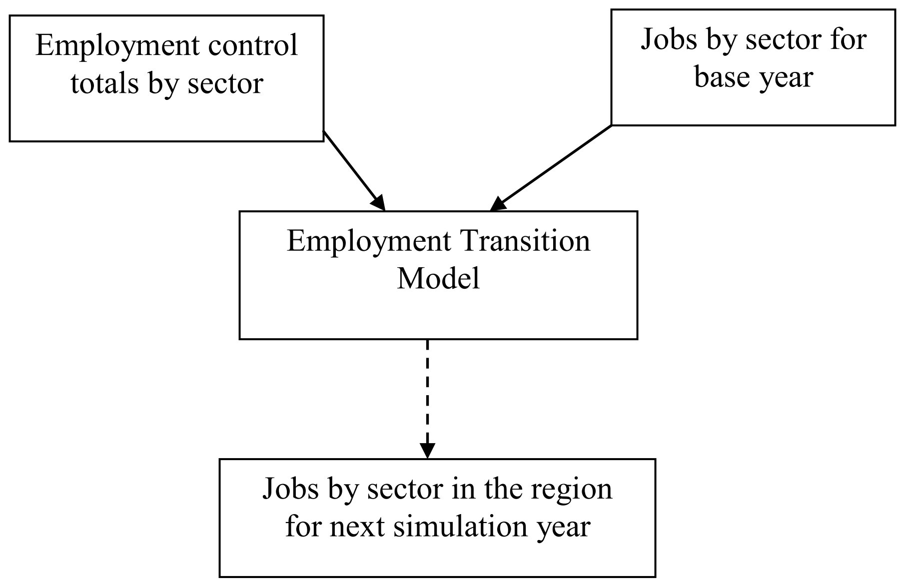

Figure A.4 Employment Transition Model Architecture

Employment Relocation Model

Employment relocation and location choices are made by the firms. However, in the current version of UrbanSim uses jobs as unit of analysis. The employment relocation model as described in Figure A.5, predicts the probability that jobs of each sector type will move over their current location or stay during a particular simulation year. For example, if a job is in retail sector, their probability of moving would be looked up by finding a retail sector entry in the annual job relocation rates table. In our example, let us assume there is a 25% chance that the job will move in a given year and 75% chance that they will not move in that year. The model uses Monte Carlo sampling to determine the outcome.

The outcome of the model is implemented as follows. If a job is determined to be a mover because the random draw is great than their move probability, then they are moved out of their current location. In the model, their building unique id is set to null. They remain in the jobs table but do not have a location. The model takes in input datasets that are: (1) annual job relocation rates by sector and (2) jobs in the region. The output of the model is a list of jobs that are queued to be relocated from their current location for the next simulation year.

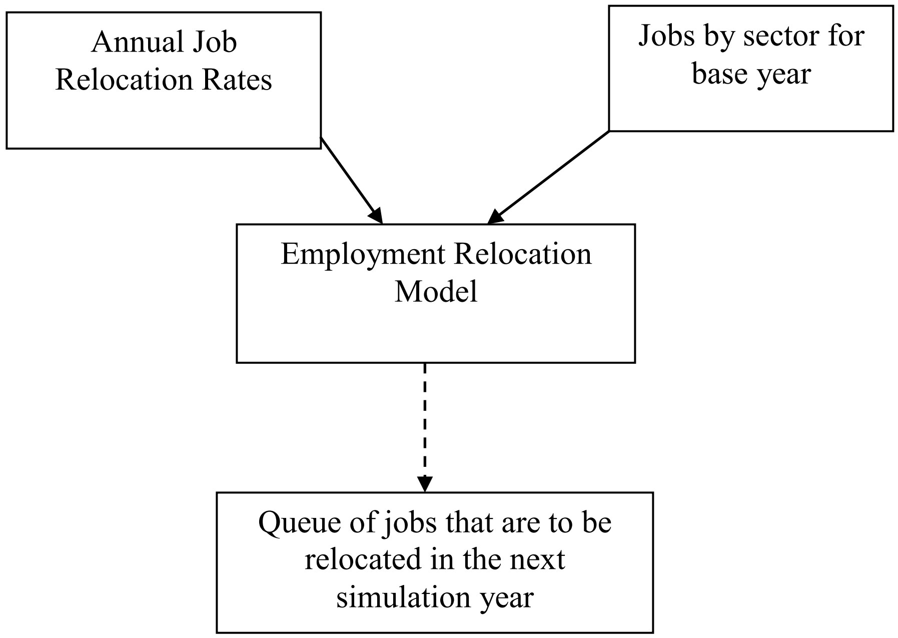

Figure A.5 Employment Relocation Model Architecture

Employment Location Choice Model

This model predicts the probability that a job that is either new (from the employment transition model) or that has moved within the region (from the employment relocation model), will be located at a particular site. Buildings are used as the basic geographic unit of analysis in the current model implementation. Each job has an attribute of space it needs and this provides a simple accounting framework for space utilization within buildings. The number of locations available for a job to locate within a building will depend mainly on the total non-residential square footage in the building and the square feet per employee. The model workings is illustrated in Figure A.6.

Furthermore, since there is a possibility that some jobs will be home-based and other non-home based, the current version of UrbanSim allows users to specify control totals for employment by sector for these two categories. The employment location choice model is specified as a multinomial logit model, with separate equations estimated for each employment sector.

Estimation of the parameters of the model is based on the geo-coded establishment file. A sample of geo-coded jobs in each sector is used to estimate the coefficients of the location choice model. The independent variables used in the employment location choice model can be grouped into the categories of: real estate characteristics (price, land use mix, density etc.), and regional accessibility (travel time to CBD, travel time airport, access to population etc.)

The model uses the input datasets (1) buildings which form the location (unit of analysis) that are located in zones, (2) jobs in the region by employment sector form the agent in the location choice model, (3) zones are used to compute density, accessibility and other variables and (4) travel data or skims from the travel model are used to compute accessibility measures. Once, the model estimated the output of this model is the location attributed (probability of selection) to each job by employment sector that have been newly added or relocated by employment transition model and reemployment relocation model respectively. The employment location choices for these jobs are estimated in the current simulation year.

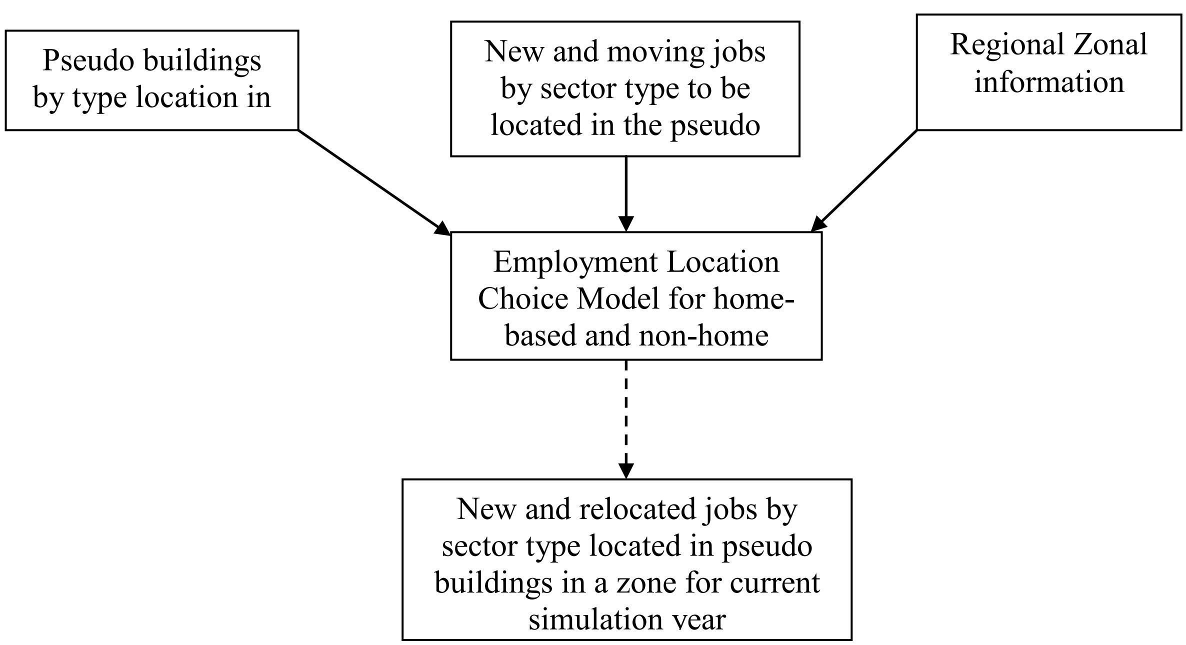

Figure A.6 Employment Location Choice Model Architecture

Development Processes

Development Project Transition Model

This model predicts new development projects that need to be built to satisfy market demand as shown in Figure A.7. The model compares the current vacancy rate for each building type to the target vacancy rate, and generates new buildings when current vacancy rate falls below the long-term structural vacancy rate. UrbanSim assumes the structural vacancy rate as the threshold or trigger that provides a market signal to developers that conditions are profitable to begin new projects. This model does not actually build the projects, but creates them by sampling previously built buildings and placing them in a queue to be located in the residential and non-residential development location choice models.

This model is uses the following datasets as inputs during the simulation (1) buildings dataset by building type, (2) development event history of projects that have been built during a historical period by building type and (3) target vacancies for building types. At the end of the simulation, this model produces a pool of building projects by building type sampled from development event history table, by checking of target vacancy rates during the current simulation year.

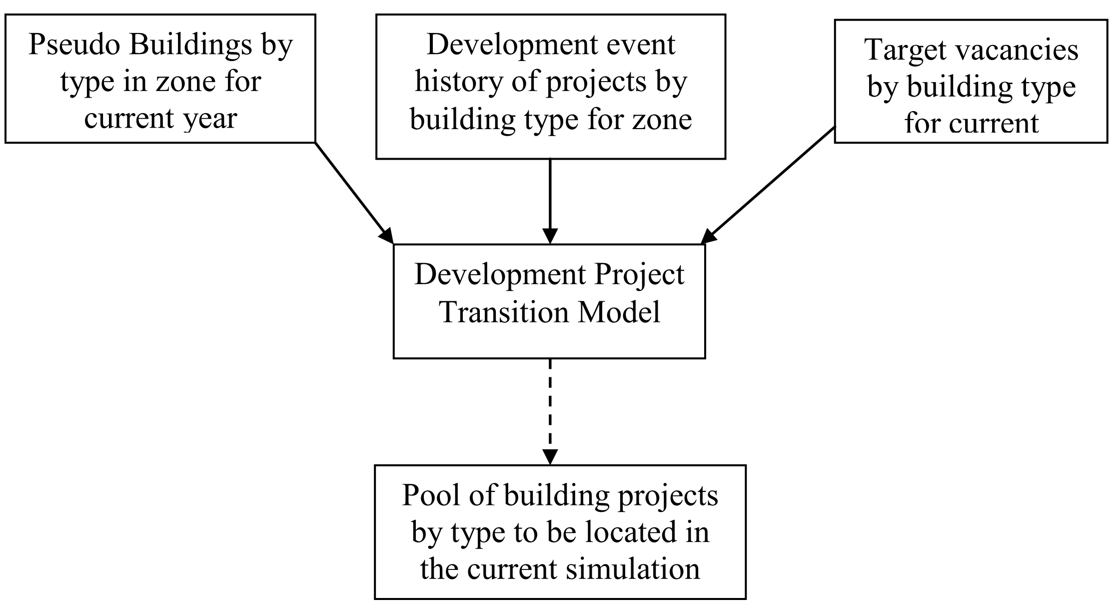

Figure A.7 Development Project Transition Model

Development Project Location Choice Model

This model predicts real estate development as a process where real estate developers seek the best available site for their real estate projects. A collection of real estate projects are sampled from recent real estate development history according to the market conditions (as sampled in development project transition model), and then are assigned to most favorable location available. Similar to the other location choice models, the prediction is the probability that a project will choose a particular location. The form of model is specified as a multinomial logit, with random sampling of alternatives from universe of feasible locations. Figure A.8 describes the working of this model.

The independent variables used in development project location choice model are: site characteristics and regional accessibility measures. During the simulation, this model uses the following datasets as input (1) development event history and (2) buildings by type. After the simulation, the model predicts the location of the projects sampled from the development project transition model to be located by building type in the current simulation year. The development project location choice model is developed for both residential and non-residential building project types.

Real Estate (Hedonic) Price Model

UrbanSim uses real estate prices as the indicator of the match between demand and supply of land at different locations for different land use types. Since prices enter the location choice utility functions for jobs and households, an adjustment in prices will alter location preferences. Similarly, any adjustment in land prices alters the preferences of developers to build new construction by type of space and the density of construction.

Real estate prices as shown in Figure A.9 are modeled using a hedonic regression of the log-transformed property value per square foot for non-residential properties and log-transformed property value per unit for residential properties. Explanatory variables of these models include average household income for the zone where the priced units is, travel time to the CBD, population density, residential density, and number of jobs in the zone where the unit is located. Other variable can be added at will and based on available data for the estimation of the regression equations. Real estate prices are updated by UrbanSim annually after all construction and market activity is completed. These end of the year prices are then used as the values of reference market activities in the subsequent year. The independent variables influencing land prices can be categorized into site characteristics and regional accessibility measures. The real estate price model is developed for each land use type (or building type).

To implement this model during simulation the following datasets are used as input (1) buildings data with newly located jobs and household along with new construction, (2) zones for accessibility and density variables, (3) households data for socioeconomic and density variables and (4) employment data for density and accessibility measures.

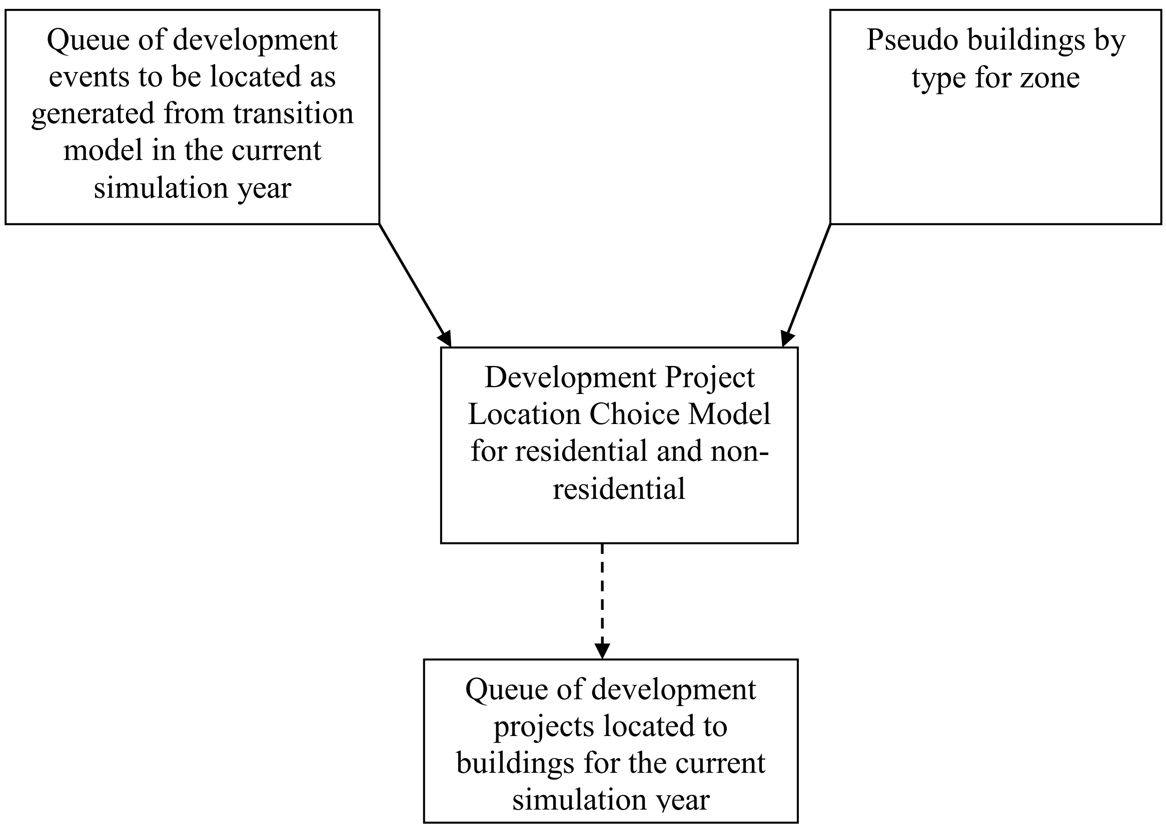

Figure A.8 Development Project Location Choice Model Architecture

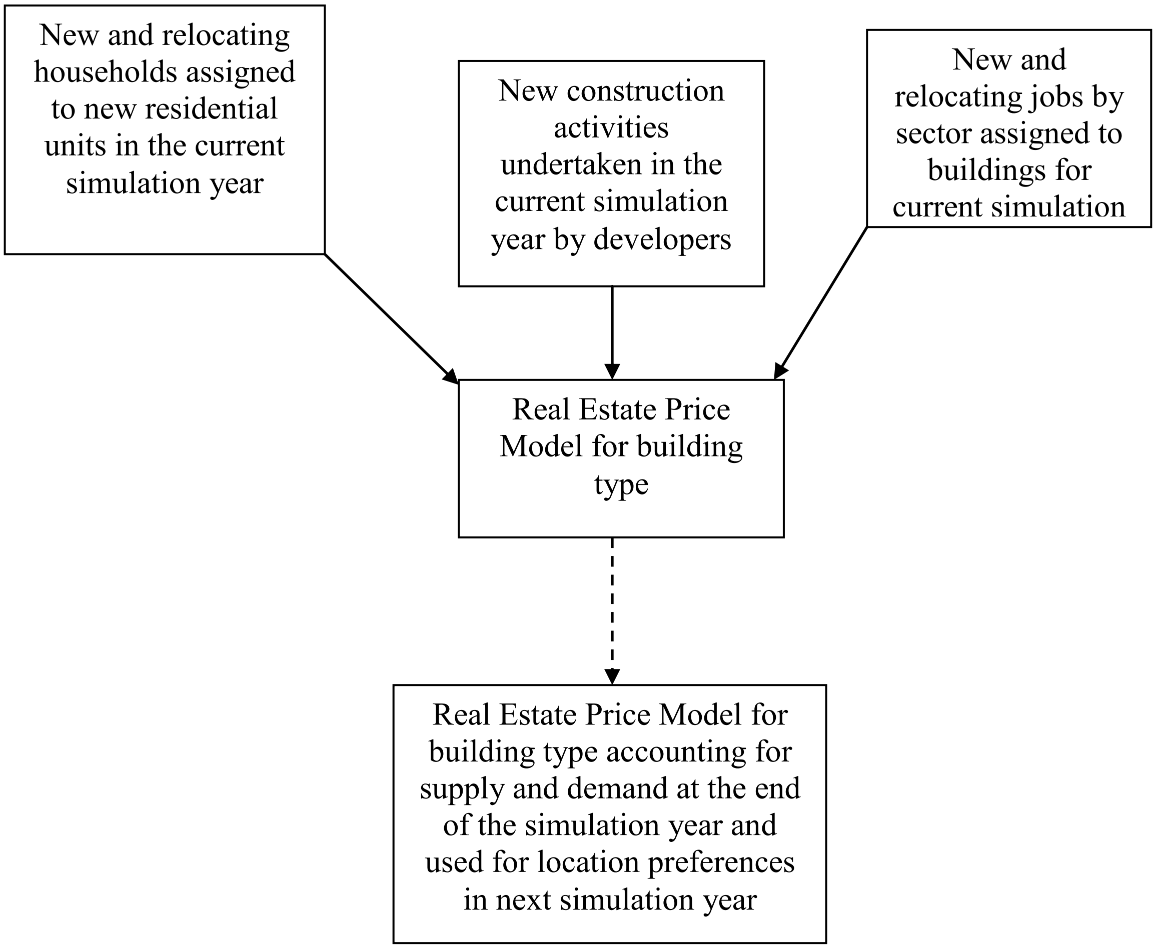

Figure A.9 Real Estate Price Model Architecture

Based on the aforementioned processes within UrbanSim, the overall implementation of the model system is described as in Figure A.10 as described by Waddell et al. (2008). Overall, UrbanSim takes as input the annual employment and household control totals along with the travel model outputs. These control totals are then synchronized for each simulation year by the employment and household transition models. These transition models determine the pool of new households and employment, which are then located to vacant buildings (or locations) as estimated by the location choice models. Thus, with the change in the market demand, developers construct new buildings which are determined the real estate development model.

Subsequently, these developments are located by the location choice models. All these events are stored in the cache data directory.

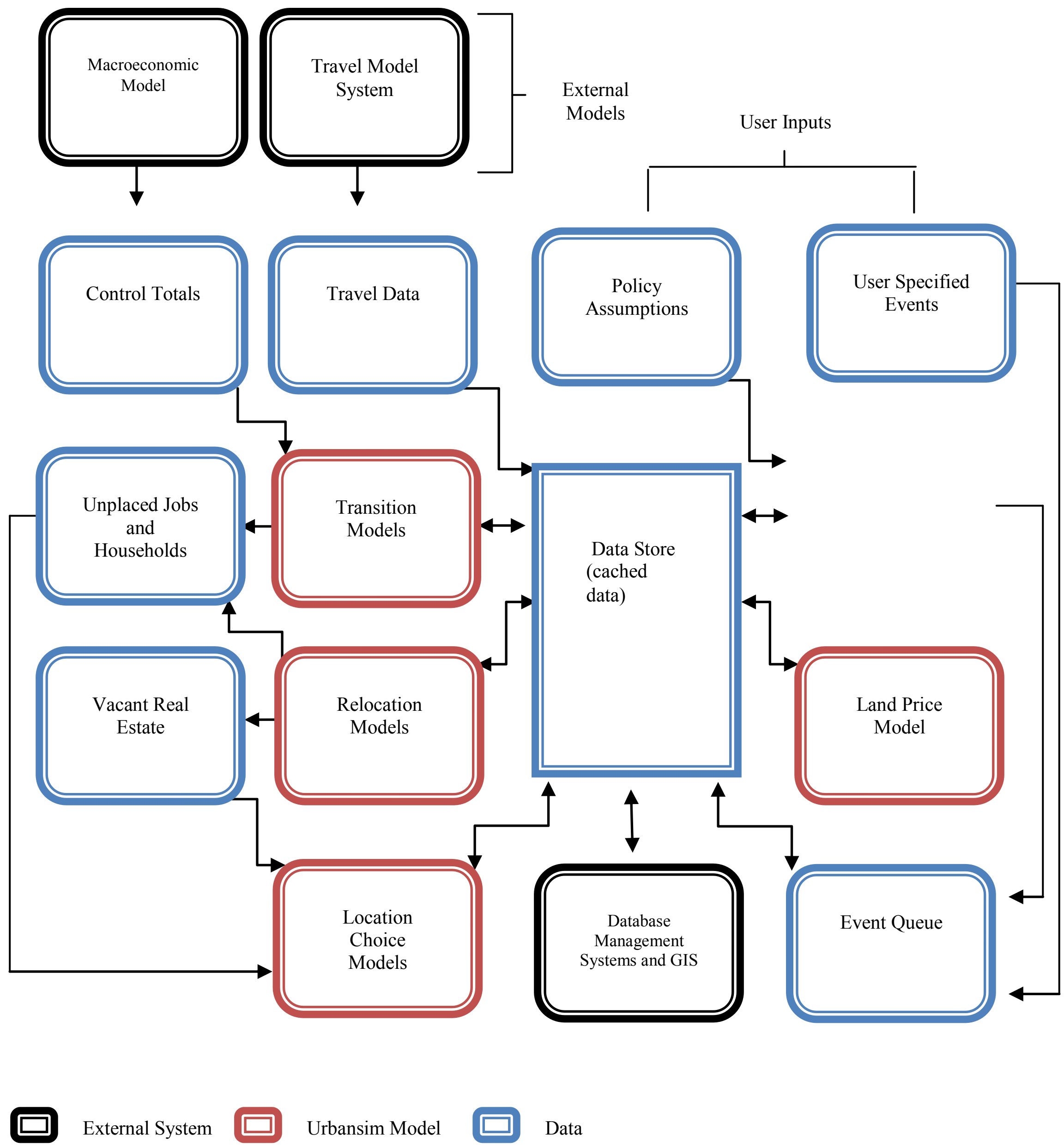

Figure A.10 UrbanSim Model Architecture
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