THE UNIVERSITY OF
MEMPHIS
Dreamers. Thinkers. Doers.

Civil Engineering
Herff College of Engineering

The Intermodal Freight Transportation Institute (IFTI)
Herff College of Engineering

A GUIDEBOOK FOR BEST PRACTICES ON INTEGRATED LAND USE AND TRAVEL DEMAND MODELING

Final Report

Principal Investigator:
Mihalis M. Golias, Associate Professor,
Department of Civil Engineering, University of Memphis
104B Engineering Science Bldg.
3815 Central Avenue, Memphis, TN 38152-3170
E-mail: mgkolias@memphis.edu

Co-Principal Investigator:
Sabyasachee (Sabya) Mishra, Assistant Professor,
Department of Civil Engineering, University of Memphis
112D Engineering Science Bldg.
3815 Central Avenue, Memphis, TN 38152-3170
E-mail: smishra3@memphis.edu

Researcher:
Ioannis Psarros, Research Associate
Intermodal Freight Transportation Institute
302 Engineering Administration Building
Memphis, TN 38152-3107
E-mail: ipsarros@memphis.edu

Wednesday, December 10, 2014

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

Significant increase of automobile use had a major negative impact on the efficiency of transportation systems. This in turn increased the need for more research in transportation planning and travel demand modeling. The development of the first generation of travel demand models started in 1950s in the United States (U.S.) (Southworth, 1995). However, researchers immediately realized the interdependence of transportation and land use. Land use models were developed to determine forecasts of future changes in employment, households and land development. It was evident that changes in transport systems could affect the patterns of land development. On the other hand, household and employment location could substantially affect trip patterns leading to changes on transportation systems. The interdependence of transportation and land use patterns resulted in the development of integrated land use and transportation models.

The objective of this study is twofold. *First*, provide an overview of land use models evolution and develop a guidebook with the best practices for integrated land use-transport modeling. *Second*, suggest the application of a land use model in a case study for demonstration purposes.

The literature review performed in this project identified a significant progress in land use modeling as the first aggregate models of spatial interaction/gravity models were replaced by disaggregate micro-simulation land use models. Agent based, rule based systems and cellular automata (CA) models were also designed in an effort to develop more disaggregate and sophisticated model paradigms. The developed guidebook includes five different categories (i.e., generations) of land use models. Three models (UrbanSim, Production, Exchange and Consumption Allocation System (PECAS) and Gravity Land Use Model (G-LUM)) are selected for further evaluation.

Some of the latest land use models and planning tools were evaluated in terms of geographical coverage, spatial detail, incorporation of freight, integration with travel demand models, and considerations of multi-modality and visualization capabilities. It was found that the majority of the evaluated models offer different options of spatial analysis and output representation, efficient geographical coverage and the integration with travel demand models is on track. However, some limitations still occur. Data requirements and processing times are quite extensive, the impact of freight transportation is not efficiently represented and model validation remains an extremely challenging task.

At the second part of this study the application of G-LUM land use model at a synthetic case study is described. G-LUM is a gravity and zone based land use model and was selected as it provides a faster and relatively straightforward model implementation. The model was used to produce forecasts of employment, household and land use change for a prediction period from 2010 to 2035. The model processing times were relatively small considering the size of the study area (161,310 acres). Model output included employment by type (Basic, Non-basic and Retail), households by income (Low, Medium, Medium-High and High) and land use change by type (Land for Basic employment, Land for Non-basic employment and Land for Residential purposes).

For a more advanced and detail studies at a regional level, UrbanSim model is suggested. UrbanSim is a micro-simulation model for land use, transportation and

environmental planning. UrbanSim is one of the most lately developed land use models that keep evolving. It was selected as it promises to provide efficient geographical coverage at the regional level, different spatial detail options (Grid, Parcel and Zone), efficient integration with Travel Demand Models (including both trip based and activity based), and different visualization options for output representation (tables, graphs, animation and lately 3-D representation). However, the huge amount of data required to develop sophisticated land use models at the micro level of analysis, remain the major drawback regarding the implementation of models similar to UrbanSim.

1 INTRODUCTION

1.1 Brief Overview of Land Use – Transport Modeling

The dynamic nature of urban systems involves the interaction of different agents such as infrastructure, facilities, administration and individuals in an integrated environment (Figure 1). Transportation is crucial for sustainability of an urban system. The significant increase of private cars use had a major negative impact on the efficiency of transportation systems. The need for more research in the area of congestion management and travel demand modeling became crucial. This resulted in the development of the first generation of travel demand models in the 1950s in the U.S. (Southworth, 1995).

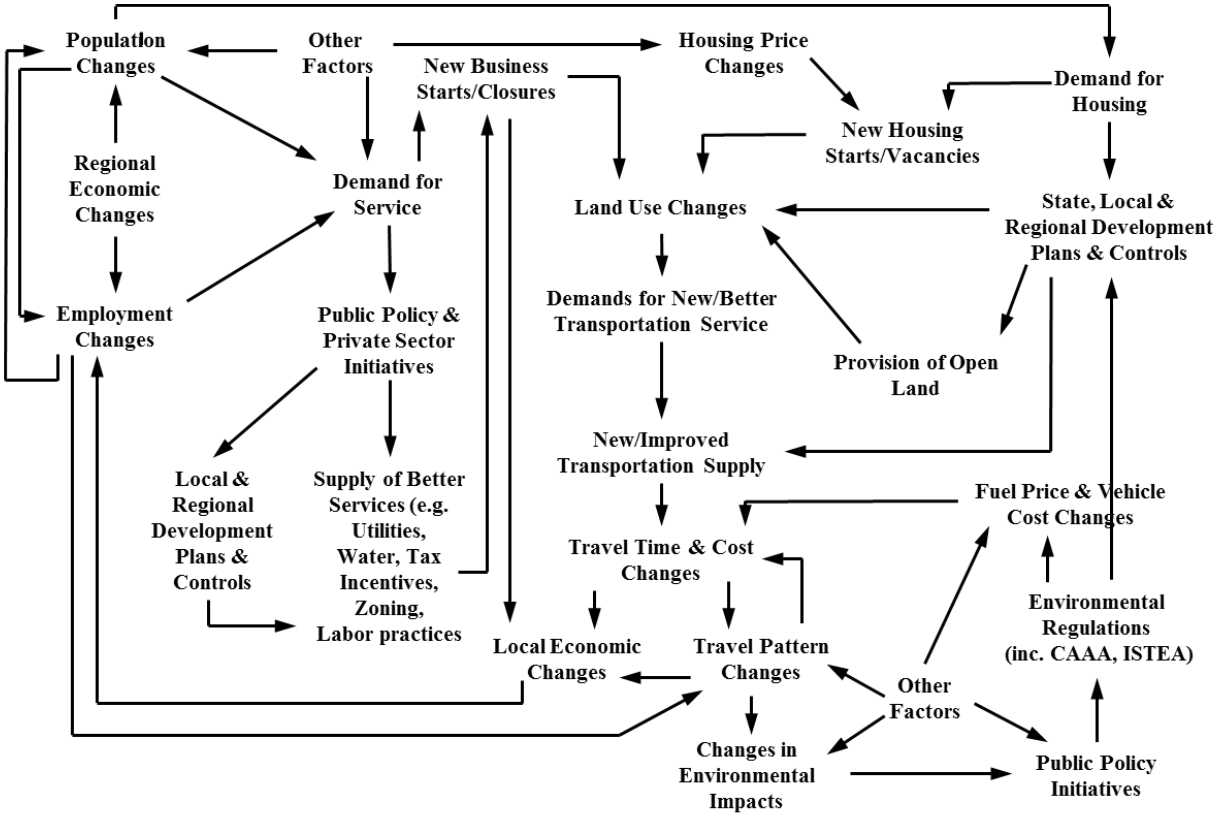


Figure 1: Interaction of Multiple Agents in Urban Systems (Source: Southworth, 1995)

Researchers immediately realized the interdependence of transportation systems and land use patterns and land use models were developed that utilized economic theory and statistics to produce forecasts of future changes in land use, demographics and socio-economic characteristics of a case study area (White, 2010). It was obvious that changes in transport systems could affect the patterns of urban development and location choices of households and employment. On the other hand, major changes in land use patterns could affect the number of trips, their destinations and modes. The interdependence of transportation and land use patterns resulted in the development of integrated land use and transportation models (ILUTM).

The first generation of land use models were introduced around 1960s and were aggregate models of spatial interaction and gravity models. Then, utility-based econometric and discrete choice models were developed. These two first classes of models mainly followed the top-down approach (Iacono et al., 2008). More advanced models were gradually developed since the late 1980s. These new models were mainly micro-simulation disaggregate models. Agent and rule based models and Cellular Automata were also designed. Many of these models are considered to follow the bottom up modeling approach. However, the classification of land use models in separate categories can be misleading as many models from different categories can share common concepts and characteristics (White, 2010).

Parallel to the evolution of land use models, travel demand models also evolved. The traditional four step urban transportation planning systems (UTPS) were replaced by the more advanced activity based models. The major concept behind the development of the activity based models was that travel behavior and trip generation is determined upon the individuals need to complete specific activities on a daily basis (Sivakumar, 2007, Mishra et al. 2011, Chakraborty et al. 2012).

The development of advanced micro-simulation land use models and activity based travel demand models created the need for a new generation of integrated land use-transport systems. New models such as ILUTE and ILUMASS were developed or existing models such as UrbanSim and MUSSA were updated to facilitate the needs for advanced research in the field of integrated land use-transport modeling.

1.2 Rationale and Objectives

The interdependence of land use and transportation has increasingly been recognized in federal legislation such as U.S. federal transportation acts TEA-21 (1998), SAFETEA-LU (2005), and MAP-21 (2012). As a result, an increasing number of U.S. transportation and planning agencies including Metropolitan Planning Organizations (MPOs) and Departments of Transportation (DOTs) are involved in establishing and operating ILUTMs. Implementing integrated land use and transportation models in a public agency remains a challenging task (Waddell, 2011). Each model has strong features and limitations considering data requirement, geographical coverage and spatial level of analysis.

The rationale for developing this report is to comprehensively review the current best practices of using ILUTMs in the U.S. and around the world and suggest the application of a land use model in a case study for the Tennessee Department of Transportation (TDOT). The research outcome will benefit both research community and state planning agencies to plan, design, and implement transportation infrastructure in TN considering the impact of land use patterns.

The major research objectives of this study include:

- Identify state-of-the-art and best practices of integrated land use and transportation models
- Provide a guidebook on land use modeling, focusing on spatial development, travel patterns, input data requirement and expected outputs
- Demonstrate a case study to show the benefits from implementing a land use model.

The rest of the report is summarized below:

Chapter 2 provides a brief overview of transport demand modeling evolution starting from the traditional four step urban transportation planning systems (UTPS) to the latest activity-based models. Some additional details of operational activity based models with U.S. agencies will be described.

Chapter 3 presents a comprehensive overview of land use models evolution. The first generation of spatial interaction/gravity models and the second generation of econometric and utility based models are described. This chapter also provides a general description of the next generation of integrated land use/ transport models (ILUTMs). This category includes micro-simulation models, agent and rule based models and cellular automata. Some information on operational ILUMTs with U.S. agencies is also provided. Chapter 3 will also include a short list with selected operational models available.

Chapters 4 and 5 include an evaluation of selected land use models and a discussion of future research challenges considering existing modeling limitations.

Chapter 6 focuses on the application of land use modeling in a synthetic case study. A description of the selected model features, data preparation, the application process and model output are provided in the same chapter.

Chapter 7 presents suggestions of the research team regarding the implementation of a more advanced integrated land use-transport model, focusing on the extended data requirements. Chapter 8 concludes the research project.

2. BRIEF OVERVIEW OF TRAVEL DEMAND MODELS

The significant growth of private cars during the mid-1950s in the U.S. created issues of increased traffic demand and congestion. The need for more research on demand modeling became obvious. The four step urban transportation planning system (UTPS) was developed as one of the major methodologies for demand modeling and travel forecasting in 1960s (Southworth, 1995). Figure 2 gives an overview of the traditional four step model.

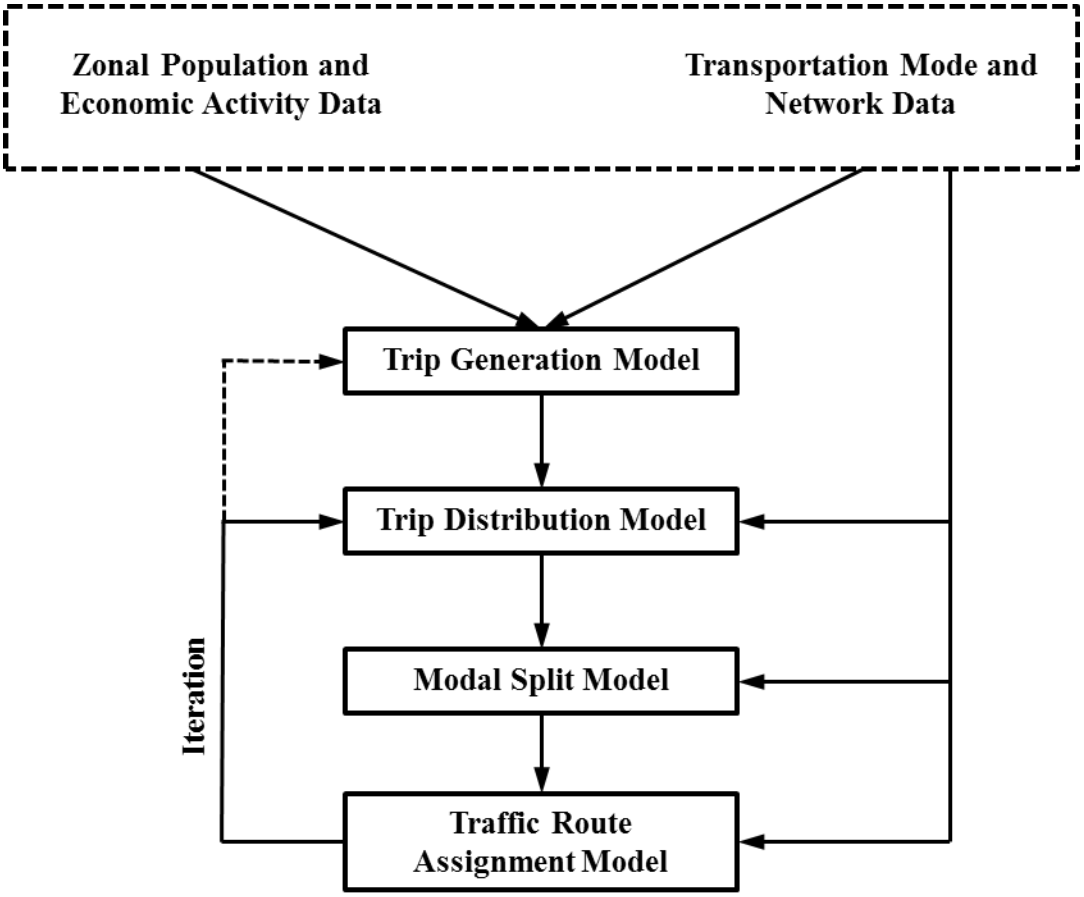


Figure 2: Traditional Four Step Planning Model (Source: Southworth, 1995)

UTPS was initially a trip based system that utilized demographics and land use data aggregated at the zonal level to produce travel demand forecasts. System structure consists of four major steps. Trip Generation determines the number of trips produced by each zone and Trip Distribution distributes these trips between origins and destinations within the borders of the study area. Mode Choice determines the mode that is used to complete each trip. The Traffic Route Assignment model identifies the vehicle routes between origin and destination points. The trip based four step planning model has been widely used by transportation agencies in U.S. however some limitations of the model resulted in the development of the tour-based systems in the 1990s (Jovicic, 2001). These systems where developed to capture the connectivity of the trips that are included in a tour.

Disaggregate trip based models/discrete choice models were mainly used from the 1980s. These models were based on utility theory. The activity based approach was first introduced at the Third International conference on Travel Behavior in Australia in 1977 (Jovicic, 2001). However, it was during the 1990s due to the increased congestion/pollution problems and the Travel Model Improvement Program of the U.S. Department of Transportation that the activity-based models were again in the spotlight (Bhat et al., 2003). The activity-based approach describes the interaction of travel behavior and individual activity patterns. In this approach, travel demand is generated as a result of people needs to complete specific activities. Activity-based models represent the new generation of travel demand models and have been recently implemented by different transportation agencies, replacing the traditional four step planning systems.

The two most widely used operational frameworks of activity based models include: DaySIM and CT-RAMP (Srinivasan, 2012). DaySIM is an econometric travel system for micro-simulating activity patterns and its development was based on a travel model introduced by Bowman in 1995 (Bowman, 1995). The Coordinated Travel and Regional Activity Modeling Platform (CT-RAMP) is an alternative activity based framework for travel demand forecasting. CT-RAMP models consider the impact of intra-household interactions on activity patterns. The first operational CT-RAMP activity based model was developed for the Mid-Ohio Regional Planning Commission (MORPC) in Columbus, OH in 2004 (Davidson et al., 2010).The general structure of DaySIM and CT-RAMP activity based frameworks are presented in Figure 3 and Figure 4, respectively.

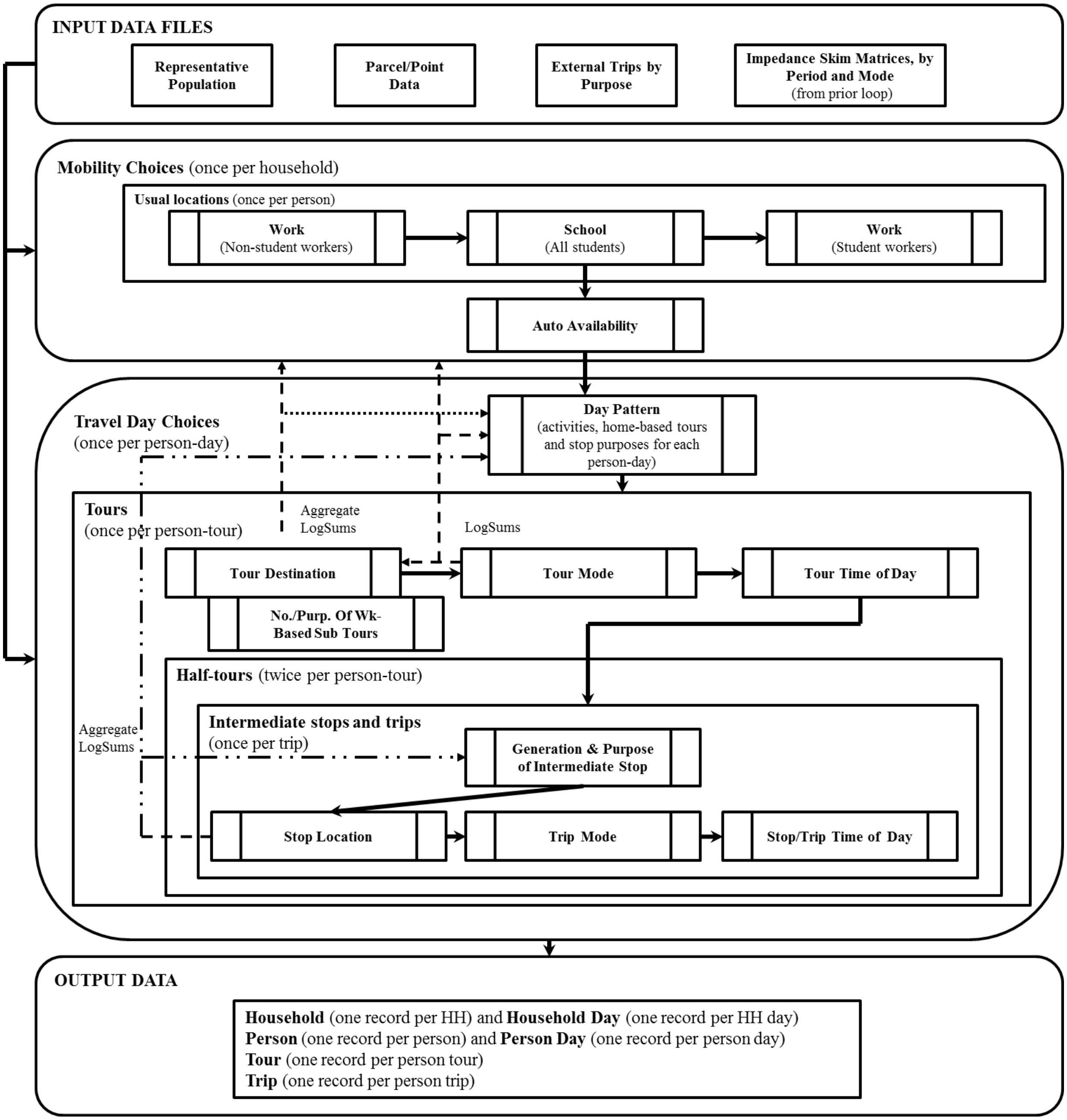


Figure 3: DaySIM System Structure (Adapted from: Bowman and Bradley, 2012)

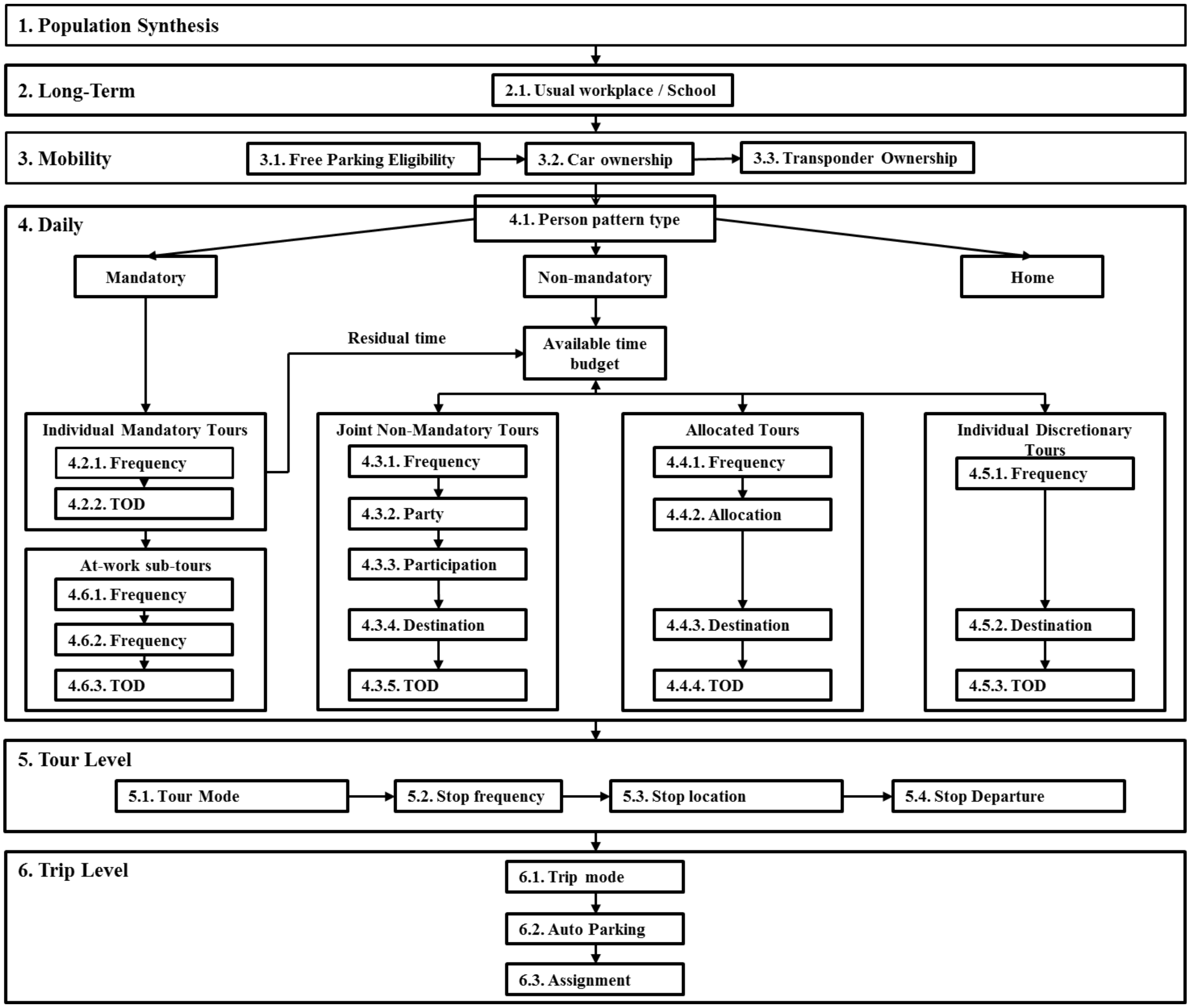


Figure 4: CT-RAMP System Structure (Adapted from: Davidson et al., 2010)

2.1 DAYSIM Activity Based Models in U.S. Agencies

DAYSIM structure has been applied for the development of activity based travel systems by different U.S. agencies such as Portland METRO, San Francisco County, Sacramento, Seattle and Denver. Some examples are presented next.

2.1.1 The Portland Day Activity Schedule Model System

The Portland Day Activity Schedule Model System was introduced by Bowman in 1998 (Bowman, 1998). Model development started in 1996, aiming to produce a complete activity based system for urban transportation planning and travel scheduling. The Portland model involves discrete choice and utility theory. The forecasting system comprises of five major models for identifying the: i) Day Activity Pattern, ii) Home-based Tour Times of Day, iii) Home-based Tour Mode and Destination, iv) Work-based Sub-tour Mode and Destination, and v) Intermediate Stop location for Car Driver Tours. Modeling process starts with the development of an activity pattern utilizing the household and demographic input data. Activities are split into primary (e.g. household subsistence and maintenance activities, leisure activities) and secondary (any secondary maintenance and leisure activity). This activity pattern serves as an input for identifying tour decisions, including tour time of the day and duration. The tour destinations and mode choice of Home-based tours and work sub-tours are then determined. Also, the intermediate activities/stops of drivers are analyzed.

2.1.2 The San Francisco Model

SF-CHAMP (San Francisco County Chained Activity Modeling Process) is a travel demand forecasting model developed for the San Francisco County Transportation Authority (Cambridge Systematics, 2002; Outwater and Charlton, 2006). SF-CHAMP is an activity and tour based micro-simulation model and its development was based on a household survey carried out in the greater San Francisco Area. The model structure was based on the “full day pattern” approach, introduced by Bowman and Ben-Akiva. Full day pattern predicts all trip types of an individual daily schedule. It includes Home-based Work, Education and Other primary tours, Home-based secondary tours and Work-based sub-tours. Different models determine the employment location, the vehicle availability and the tour characteristics (number of trips, time of day, destination, and mode choice) using as inputs the characteristics of a synthesized population. Separate models determine the visitor and the non-local demand.

2.1.3 Denver Model

The Denver model is an activity and tour-based model developed for the Denver Regional Council of Governments (DRCOG) (Cambridge Systematics, 2010). Model development followed a similar structure to the previously developed San Francisco and Sacramento models. Modeling process starts with some pre-run steps that determine population synthesis and input data. DRCOG model closely interacts with TransCAD software. Activity patterns, activity locations and mode availability are determined using logit models. Then, the model identifies all the tour parameters, including location, destination, time-of-day and mode choice. The same set of parameters is also estimated for each separate trip within an activity tour. Trip assignment includes a Multi-Modal Multi-Class (MMA) assignment procedure that is based on a user-equilibrium algorithm.

2.2 CT-RAMP Activity Based Models in U.S. Agencies

CT-RAMP structure has been applied for travel demand modeling and forecasting by different U.S. Agencies in New York, Columbus, Atlanta, San Diego and Phoenix. Some examples are discussed next.

2.2.1 New York Model

An updated activity model was developed for the New York Metropolitan Transportation Council (NYMTC) during the period 2000-2002 (Parsons Brinckerhoff Quade & Douglas, 2005; Vovsha and Chiao, 2006). NYMTC system is an activity and tour based micro-simulation model that includes four major modules: i) Tour Generation, ii) Mode and Destination Choice, iii) Time of Day Choice, and iv) Assignment. Tour generation comprises of three models which determine household synthesis, auto ownership and tour frequency. Mode choice and trip destination are determined through the use of logit models. The last parts of the modeling process include the Time of Day selection (based on pre-defined data) and the tour assignment, respectively.

2.2.2 MORPC Model

MORPC is a travel demand forecasting model, developed for the Mid-Ohio Regional Planning Commission in 2002 (Anderson, 2006). Researchers tried to incorporate lessons learned from previously developed similar models such as the SF-CHAMP and the NYMTC models. MORPC is an activity and tour based model that provides micro-simulation options. Model development was based on a household survey carried out in 1993 by the Ohio transportation authorities. Modeling process initiates with the identification of household and population information for the study area. A set of three different models are then applied to determine: the car ownership, the individual activity pattern and the joint activities/trips. A forth model is used for estimating the secondary tours for leisure activities. Two logit based models determine tour mode and trip destination. The time of the trip occurrence depends on the available time windows. A last model estimates the potential stops between origin and destination points and the transportation mode used in each part of the trip.

2.2.3 ARC Model

The Atlanta Regional Commission (ARC) model is a demand forecasting activity based system, considering the impact of new transportation projects and policies (Atlanta Regional Commission, 2012). The model structure follows the CT-RAMP (Coordinated Travel Regional Activity-Based Modeling Platform) approach of activity based models. Different modeling tools such as multinomial and nested logit models, micro-simulation and entropy-maximization models are included in the general framework of ARC system. Modeling process starts with the population synthesis (household location, population zonal distribution) that serves as input for determining other parameters such as the employment/school location (mandatory activities of household individuals) and the car ownership level. Then, the individual daily activity schedule is created. This pattern includes mandatory, non-mandatory and home activities. Different sub-models specify the frequency and the destination of the required tours to accomplish the previously described activities. Additional sub-models focus on the characteristics of potential joint tours or work sub-tours.

2.3 Activity-Based Models around the World

A significant number of activity based approaches have been developed the last decades around the world. Two examples of these approaches are presented below:

2.3.1 ALBATROSS

ALBATROSS (A Learning Based, Transportation Oriented Simulation System) was introduced in 2000 as part of a research project sponsored by the Dutch Ministry of Transport (Arentze et al., 2000). ALBATROSS is an activity, mainly rule-based model that focuses on modeling household activities and their impact on transport demand. Rules guide travelers in adjusting their activity patterns. ALBATROSS includes a set of thirteen different agents/tools (Sylvia, Rachel, Sandra, etc.) for processing data, applying formulations, simulating, model evaluation, scenario analysis and activity pattern development. Input information is available in the format of an activity diary.

The major system component is the Scheduler Engine that utilizes the available agents and tools to apply an iterative process for activity scheduling. The first step of the scheduling process includes the identification of an initial schedule with fixed activities as they are determined by the activity diary. Then, the model tests if an additional activity has to be included in the initial schedule of fixed activities. If yes, the next task includes the identification of the person that is carrying out an activity and the activity duration. The start time of an activity and its potential connectivity with a previous activity are also specified. The last steps of the scheduling process determine the mode choice and the activity location. Model Details are provided in Figure 5.

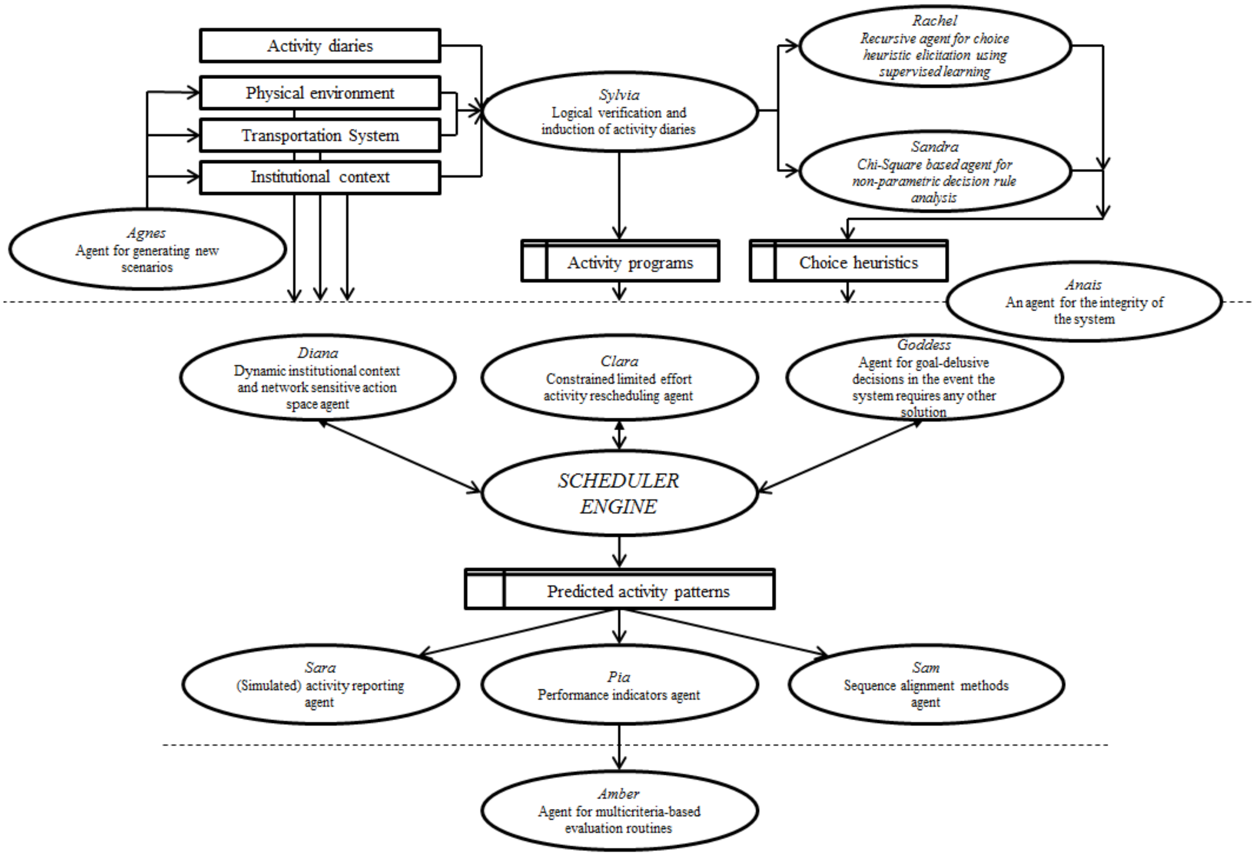


Figure 5: ALBATROSS Framework (Source: Arentze et al., 2000)

2.3.2 TASHA

TASHA (Toronto Area Scheduling Model for Household Agents) is an activity-based, micro-simulation model for scheduling activities and developing trip patterns (Miller and Roorda, 2003). Trip patterns and schedules are produced for each member of a household and for a typical 24-hour weekday. The rationale for the model development was to group household activities in activity projects (group of common activities) that one or more members of a household are involved. These Common activities result in the development of activity episodes in trip schedules. TASHA development was based on household trip data from a transportation survey carried out in 1996. These data included household information, population and people characteristics. Modeling process starts with the development of activity episodes based on the default survey data. These activity episodes are then combined with other episodes from a project agenda. Schedules are created by adding activity episodes from the project agendas to a household member schedule. The last part of the modeling process includes the application of an algorithm for incorporating the final scheduling. A model overview is provided in Figure 6.

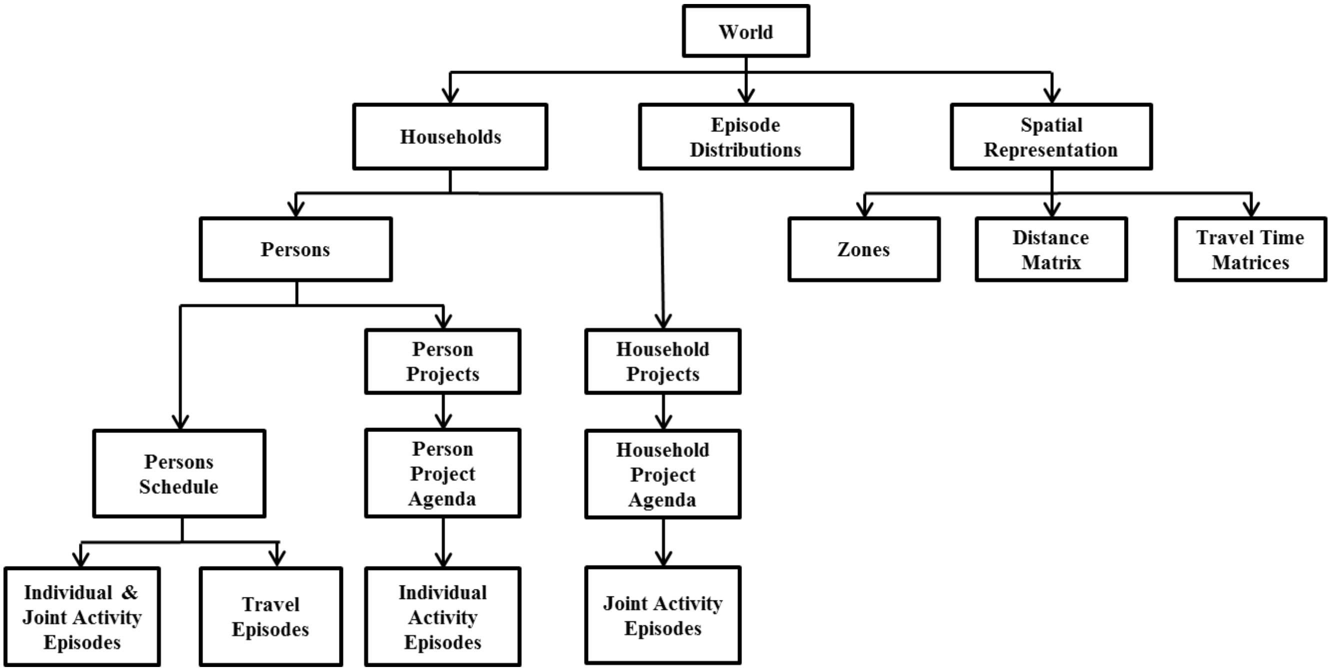


Figure 6: TASHA Model (Source: Miller and Roorda, 2003)

3. THE EVOLUTION OF LAND USE-TRANSPORT MODELS

Land use models utilize economic theory and statistics to produce forecasts of future changes in land use, demographics and socio-economic characteristics (White, 2010). The first Land use models were introduced around 1960s and were aggregate models of spatial interaction and gravity models (Iacono et al., 2008). The model of Metropolis developed by Lowry in 1964 is the first operational land use model. A new approach regarding the development of land use models was introduced around the 1980s. This new approach suggested the development of econometric and discrete choice models that were based on utility theory. The first two categories that include the spatial interaction and the econometric models are considered to follow the top-down modeling framework (Iacono et al., 2008). More advanced models were gradually developed since the late 1980s. These new models were mainly micro-simulation disaggregate models, including agent and rule based systems and cellular automata. Many of these models are considered to follow the bottom up modeling approach. Figure 7 provides an overview of the evolution of land use models.

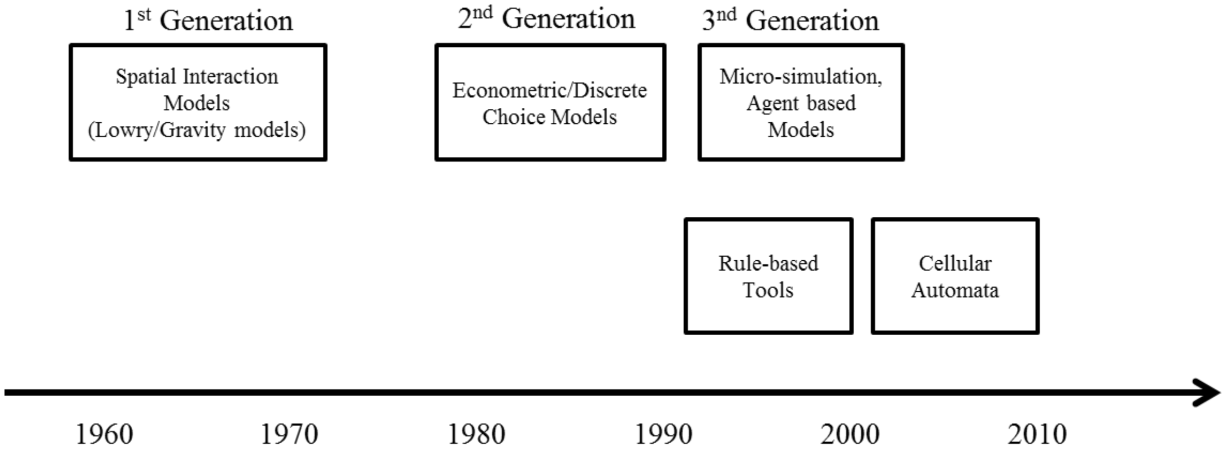


Figure 7: Land Use Models Evolution

3.1 First Generation Models

The first generation mainly included aggregate models of spatial interaction. These first models were based on gravity and entropy maximization and were characterized by the introduction of the Lowry model in 1964. Most of the first models were derivatives of the Lowry model.

3.1.1 Lowry/Lowry-Garin Models

Lowry (1964) developed a simple spatial interaction model, the “Metropolis Model” which is widely used by many agencies in the U.S. primarily because of its simplicity and transparency. The model was designed to evaluate future changes of retail employment, residential population and land use in the greater Pittsburgh Area. The Lowry model can also be a useful tool for evaluating future policies related to transportation planning and land use development. Activities are classified into three categories: basic sector (industrial, business and administrative activities related to non-local customers), retail sector (industrial, business and administrative activities related to local customers) and household sector (focuses on the residential population). Employment is divided into Basic and Non-Basic (services). A singly constrained Lowry model spatially fixes the Basic employment. The Non-Basic employment and households are allocated to zones based on attractiveness coefficients derived from gravity model estimates, till convergence occurs.

Garin in 1966 suggested a significant revision of the model’s structure (Goldner, 1971). A vector and matrix version of the Lowry Model was introduced. Matrix operations were found to produce exact solutions, improving the performance of the model in total. The general framework of the Lowry model is presented in Figure 8.

3.1.2 TOMM

TOMM (Time-Oriented Metropolitan Model) was initially introduced in 1964 as the first Lowry-derivative model (Crecine, 1968). TOMM is a spatial location model that shares many common characteristics with the Lowry/Metropolis model. The major difference between the two models is the more disaggregate nature of the TOMM model (e.g. classification of facilities, households, population, employment, etc.). The structure of the model includes the Exogenous employment sector (employment and activities outside the borders of an urban area), the Endogenous commercial employment sector (employment and activities inside the borders of a metropolitan area) and the household or population sector (classification of households based on socio-economic characteristics).

3.1.3 PLUM

PLUM (Projective Land Use Model) was developed for the Bay Area Transportation Study Commission in 1968 (Goldner, 1968). It is a spatial model for activity and land use planning. PLUM has an incremental structure that utilizes land use data, market economics and demographics to forecast future development. The inputs of the model include dwelling units, population and employment data. The economic framework of the model includes the “population-serving” activities/employment (based on household and employees spatial distribution) and the “basic” employment that describes the spatial allocation of endogenous industries.

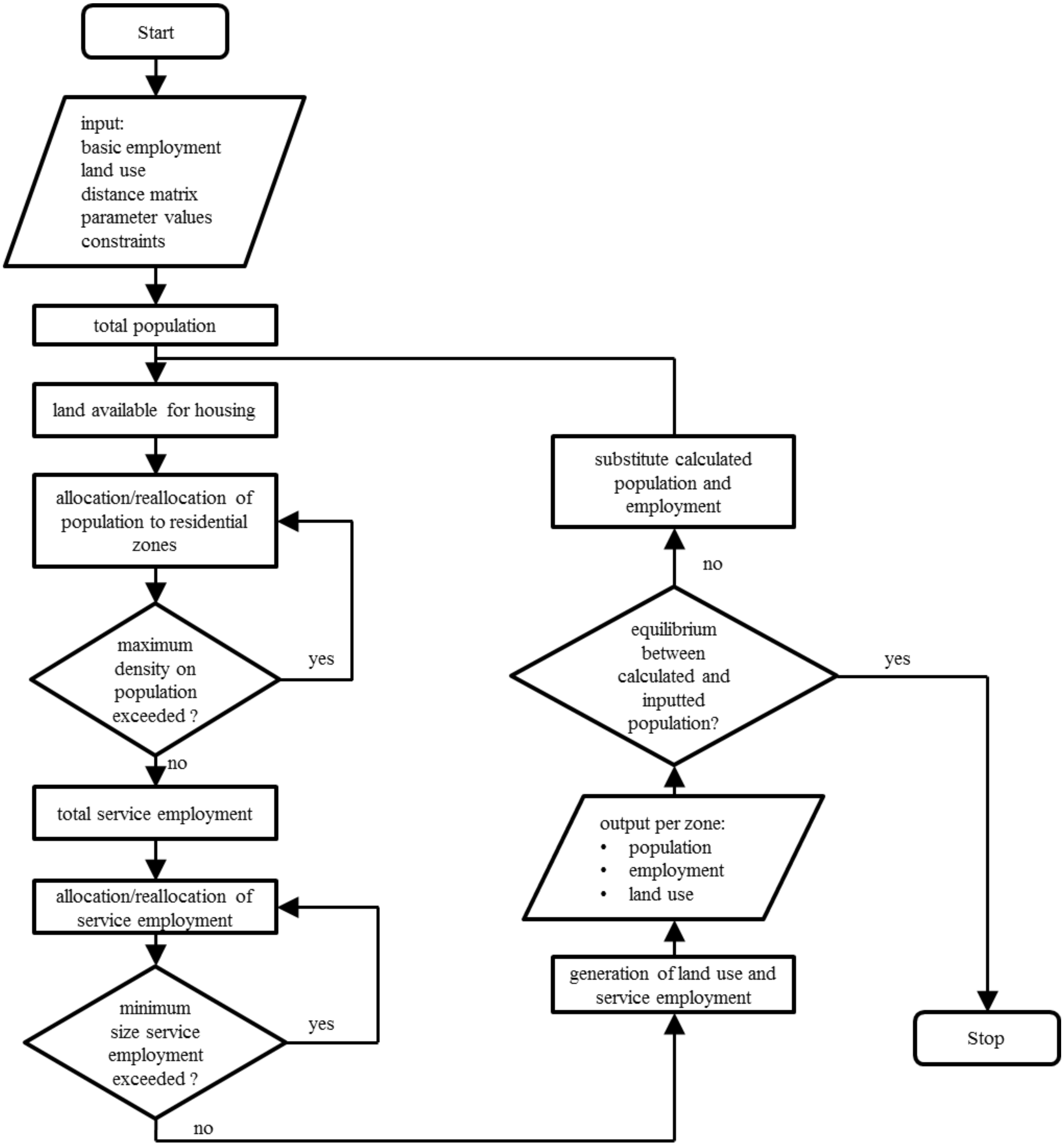


Figure 8: The Lowry Model (Source: Pfaffenbichler, 2003)

3.1.4 TOPAZ/TOPMET

TOPAZ is an optimization model for identifying activity locations, designed at the Division of Building Research of the Commonwealth Scientific and Industrial Research Organization, Australia in 1970s. TOPMET, a planning version of TOPAZ also became available (Cambridge Systematics, Inc., 1991). TOPAZ was developed using FORTRAN programming language. The required input data include among others: employment and population forecasts, transportation network characteristics, car ownership and activity costs. The modeling process in TOPAZ starts with allocating employment and housing to the zonal level in such a way to minimize infrastructure and transportation costs. Then trip patterns are created based on the assumption that demand can be predicted from spatial activity locations using entropy-maximization. Then mode choice and travel costs are calculated. At the last part of the modeling process, data types are further aggregated at the urban or regional level. The outputs of the model include employment and population data, number of houses and vacant land. The transport module of TOPAZ produces outputs such as trips per mode, emissions and energy consumed. Economic results such as travel and activity costs and accessibility measures can also be provided. TOPAZ has mainly been applied in different case studies in Australia.

3.1.5 IRUPD

The IRUPD model is a simulation land use and transport model, initially introduced in Germany in 1977 (Wegener, 1998). It’s a spatial interaction and zone based model and the major stock variables include population, employment, housing and non-residential buildings. Model structure consists of six sub-models that are applied to identify employment and demand pattern changes. These Submodels involve a Transport Submodel for estimating trips, submodels for identifying the stock variables changes and the results of public programmes (e.g. infrastructure investments). Additional submodels focus on identifying employment changes and residential/non-residential changes (e.g. new buildings, new houses, etc.). The outputs from the Transport sub-model include the number of trips and different measures of performance such as trip time, trip costs and emissions. The model structure is presented in Figure 9.

3.1.6 LILT

LILT (LEEDS Integrated Land Use-Transportation) model was introduced by Dr. Mackett in 1979 at the University of Leeds, England (Zhao and Chung, 2006). LILT is an entropy-maximization system for predicting future population, residential and employment changes. It consists of three major components: a Lowry derivative location model, a four step travel model and a car ownership model. Depending on the level of accessibility, employment is defined as primary, secondary and tertiary. LILT has been applied in different case studies in Germany, Japan, England and Greece.

3.1.7 POLIS

The Projective Optimization Land Use Information System (POLIS) is a land use-transport model mainly applied in the greater San Francisco Bay Area (Prastacos, 1986). It was designed by the Association of Bay Area Governments and replaced previous models such as PLUM (Goldner, 1968). POLIS is a non-linear mathematical optimization model for producing forecasts of land use, employment, housing, population and transportation changes. The optimal solution maximizes the profitability of employers and the utility related to travel choices for work and shopping. POLIS was different comparing to the traditional Lowry derivative models as it integrated basic/non basic employment and housing and it applied short of micro-economic theory. Housing choices are determined by the travel-to-work behavior and housing availability. The location of retail facilities is affected by the proximity to areas with increased population. Additional parameters that are considered include the shopping centers attractiveness, the accessibility to work location and the economy of the study region.

3.1.8 HLFM Model

The Highway Land use Forecasting Model (HLFM) is a spatial interaction, Lowry derivative land use model, introduced by Alan Horowitz (Dowling et al., 2005). HLFM utilizes land use, demographic and socioeconomic data to forecast future employment and population changes of a study area. HLFM is an equilibrium model since it focuses on the land use demand and supply equilibrium. Modeling in HLFM is an iterative process that starts with determining the number and the location of the basic industry employment in the study area. The allocation process follows and the model estimates the conditional probabilities related to worker residential and service employment locations. The model then identifies the employment and the population of each district depending on the corresponding attractiveness of each choice. HLFM was designed to fully interact with travel demand models.

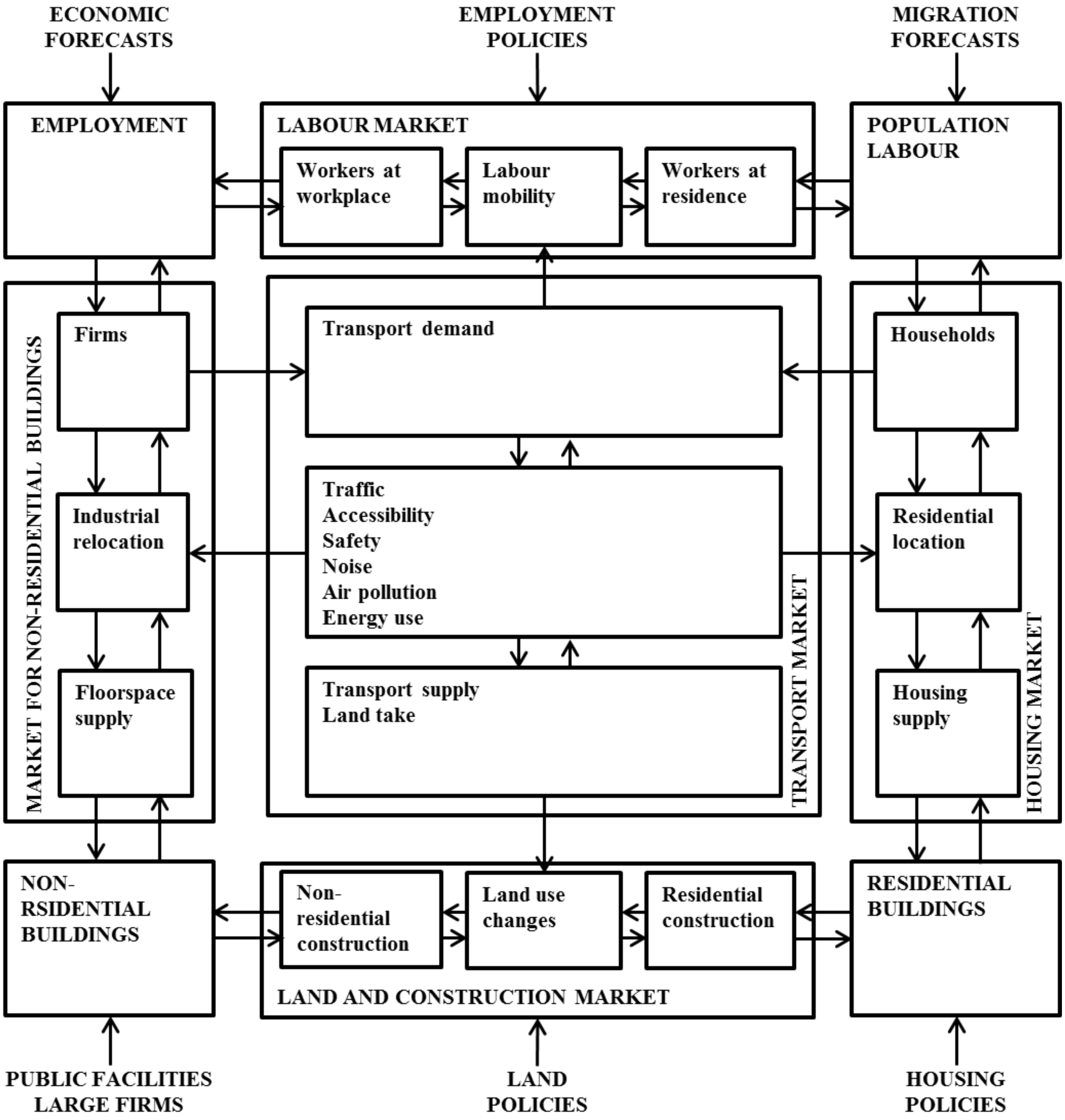


Figure 9: The IRUPD Model (Adapted from: Spiekerman & Wegener, 2011)

3.1.9 ITLUP/DRAM/EMPAL/METROPILUS

Putnam (1983) developed a derivative of Lowry Model, the Integrated Transportation Land-Use Package (ITLUP). ITLUP includes two major models: the Disaggregated Residential Allocation Model (DRAM) and Employment Allocation model (EMPAL) model. DRAM works by allocating households based on the zonal attractiveness considering current residential development, the capacity derived from vacant and developable land and other socio-economic characteristics of the zone. EMPAL also works in the same way by allocating employment based on the attractiveness of zones, considering an impedance cost matrix. DRAM/EMPAL has less data requirements comparing to the original Lowry model. DRAM/EMPAL is sensitive to changes in the basic sector employment and other investments that can potentially change the economic geography of the area. An important advantage of DRAM/EMPAL is its basis on generally available data such as population, households and employment (Southworth, 1995). The market clearing process is not modeled. A software based version of ITLUP, called METROPILUS was later introduced. An overview of ITLUP is provided in Figure 10.

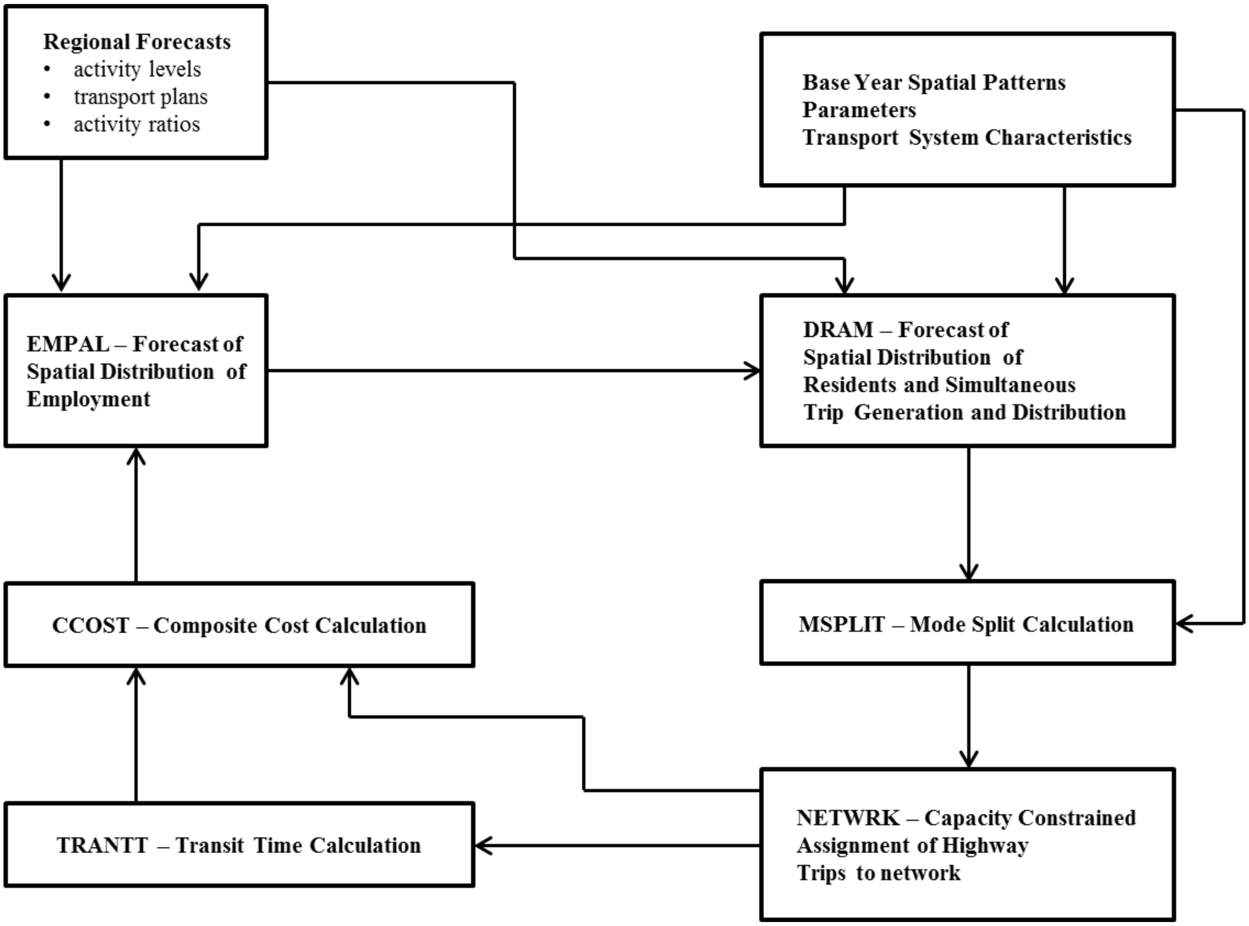


Figure 10: Overview of DRAM/EMPAL – ITLUP (Source: Putman, 1991)

3.2 Second Generation Models

The second generation of land use - transport models mainly includes models with a more disaggregate nature. These models are logit based and have an econometric structure, searching for land use and transportation choices that maximize the corresponding utility.

3.2.1 HUDS

The Harvard Urban Development Simulation (HUDS) model was developed in three different phases starting in the 1960s as The Detroit Prototype of the NBER Urban Simulation Model (Kain and Apgar, 1985). HUDS was the result of two major revisions in 1972 and in 1977 of the Detroit Prototype model. It was developed to simulate market dynamics and predict land development based on demographics and employment data. Analysis focuses on the interaction of the demand, the supply and the market sectors. Each sector involves a set of different submodels. The demand sector includes submodels for determining changes in the employment (location, job change, number of workers), demographics and housing (demand, movers, tenure). The supply sector includes five submodels to analyze land owner decisions, the investor expectations, the profitability of structure conversions, investments in maintenance capital and the profitability of new constructions. The market sector utilizes three submodels to estimate market costs, rents for different housing types and the quantity of services provided during a rent period. Details are provided in Figure 11.

3.2.2 CATLAS

The Chicago Area Transportation/Land use Analysis System (CATLAS) is a land use and transport system introduced in 1983 (Anas, 1983). CATLAS includes an economic simulation model for identifying the impact of transport on land use and mode choice. CATLAS structure includes four sub-models: the Demand Sub-model, the Occupancy or Existing Housing Supply Sub-model, the Creation of New Dwellings and the Demolition of Old Dwellings Sub-models. The Demand sub-model focuses on identifying the probability of an employee to choose a specific residence area and mode of transport. Probabilities are predicted by applying a utility function and a logit model for identifying the attractiveness of each alternative option. The Occupancy or Existing Housing Supply Sub-model uses a binary logit model to identify the dwelling owner decision to rent or hold the related property. The Creation of New Dwellings or the Demolition of Old Dwellings is decided based on the outputs of the applied economic models and the corresponding market costs.

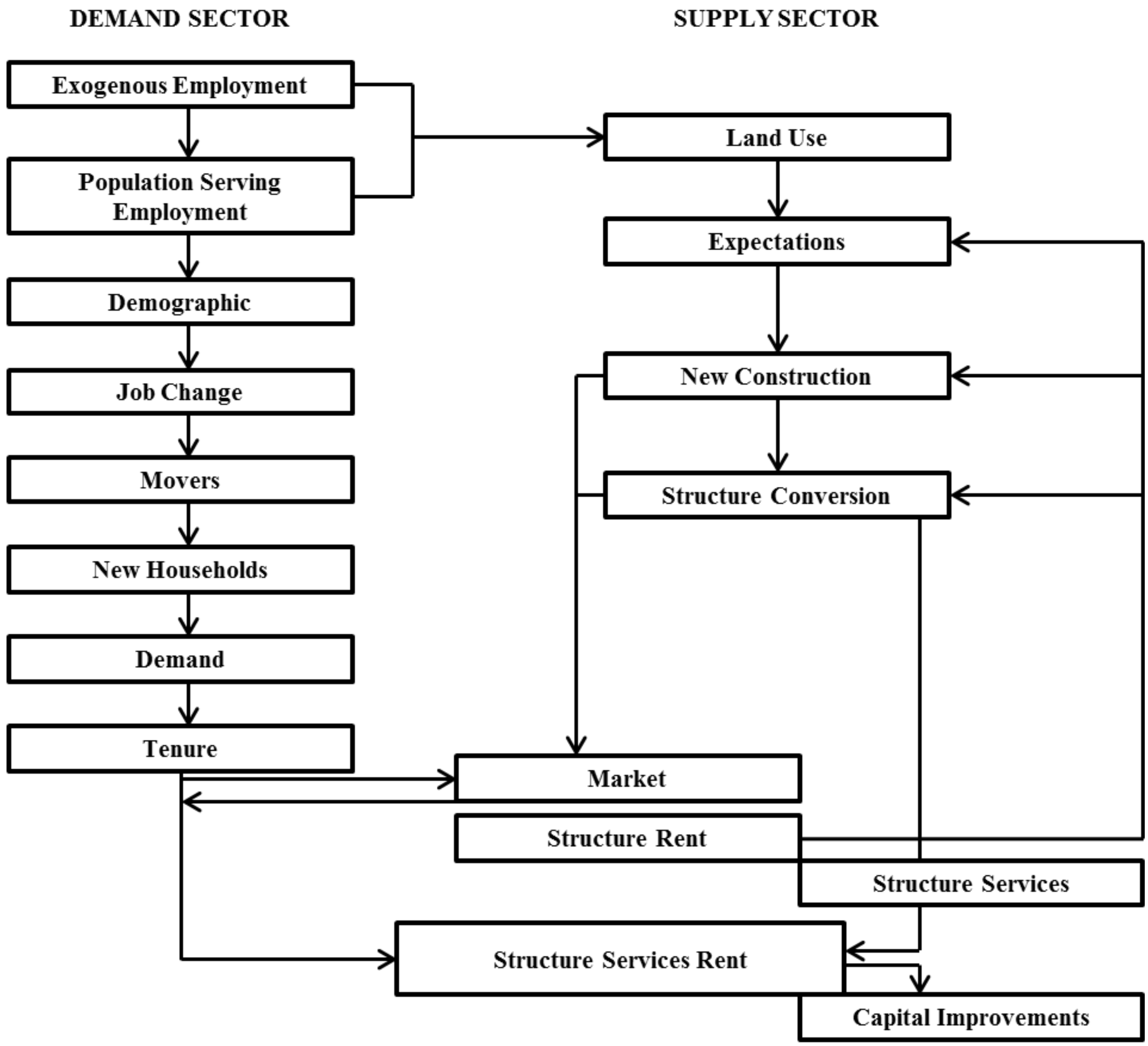


Figure 11: HUDS Model Overview (Adapted from: Kain and Apgar, 1985)

3.2.3 TRANUS

TRANUS is an urban land use and transport model, initially developed by de la Bara and Perez in 1982 (de la Barra, 1989). This system focuses on identifying and analyzing the social and economic impact of different land use and transport policies. The model's framework comprised of two different parts, the land use analysis and the transportation modeling. During the land use analysis, the location of the activities is specified for each zone of the study area. These activities are represented through matrices that include the so-called functional flows between the zones of the study area. Transportation modeling is an iterative process and its first step focuses on identifying the available paths between origins and destinations. Then, the transportation costs per each path and travel mode are calculated. Trip generation and distribution include the transformation of the estimated functional flows (from the land use analysis) to trips per time period and travel mode based on the corresponding costs. Mode choice involves a Logit model and the related utility functions. Trip assignment also considers a utility function that evaluates the travel cost of each path. The last part of transportation modeling focuses on adjusting the travel and waiting times based on demand/capacity ratios functions.

3.2.4 RURBAN

RURBAN (Random Utility/Rent-Binding Analysis) is a land use model introduced in 1986 (Miyamoto et al., 2007). An updated version of the model was released in 2007. RURBAN has been designed to operate in an integrated environment with transportation models. GIS is used for visualization purposes. RURBAN predicts land development based on market rules as the model searches for the optimal solution that satisfies the equilibrium between supply and demand profits. Utility theory is applied to evaluate the alternative sites that are candidates for future development. Rent-bidding analysis is used to identify the land price of each zone. If a site is finally chosen for future development, this means that the specific choice maximizes the utility for the locator; however, the locator has to provide the highest rent for the specific site comparing to the other locators. The updated version of RURBAN model has been applied for a case study at the Sapporo Metropolitan area of Japan. RURBAN model is presented in Figure 12.

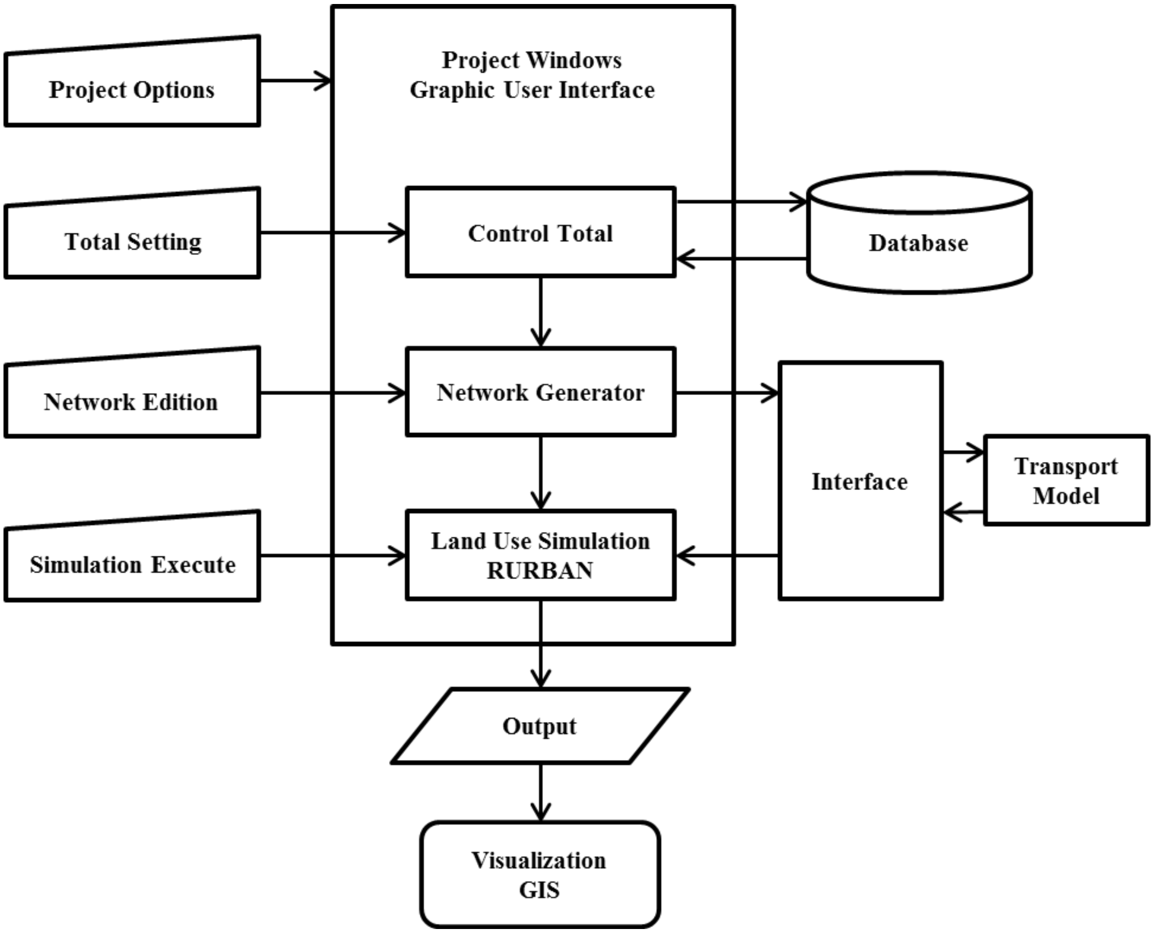


Figure 12: RURBAN Model (Adapted from: Miyamoto et al., 2007)

3.2.5 MEPLAN

MEPLAN is another Lowry-derivative model that uses economic base theory in an input-output model framework with price functions (Echenique et al., 1990) to model the interactions between the land and transport markets. The coefficients of the input-output model (or Social Accounting Matrix - SAM) are used to calculate prices that then determine land allocation within zones. Random utility is used to model the location decisions of households and firms using a constrained utility maximization framework. Social accounting matrices are derivatives of an Input Output model and an important distinction is that SAM accounts for consumption of household as well as industries. The key advance of the model is the use of land prices for modeling purposes. Land prices are hard data to gather for large scale models and it remains challenging to model their change over time. However, prices provide an economic basis through which the effects of decisions interaction are analyzed. The MEPLAN framework is presented in Figure 13.

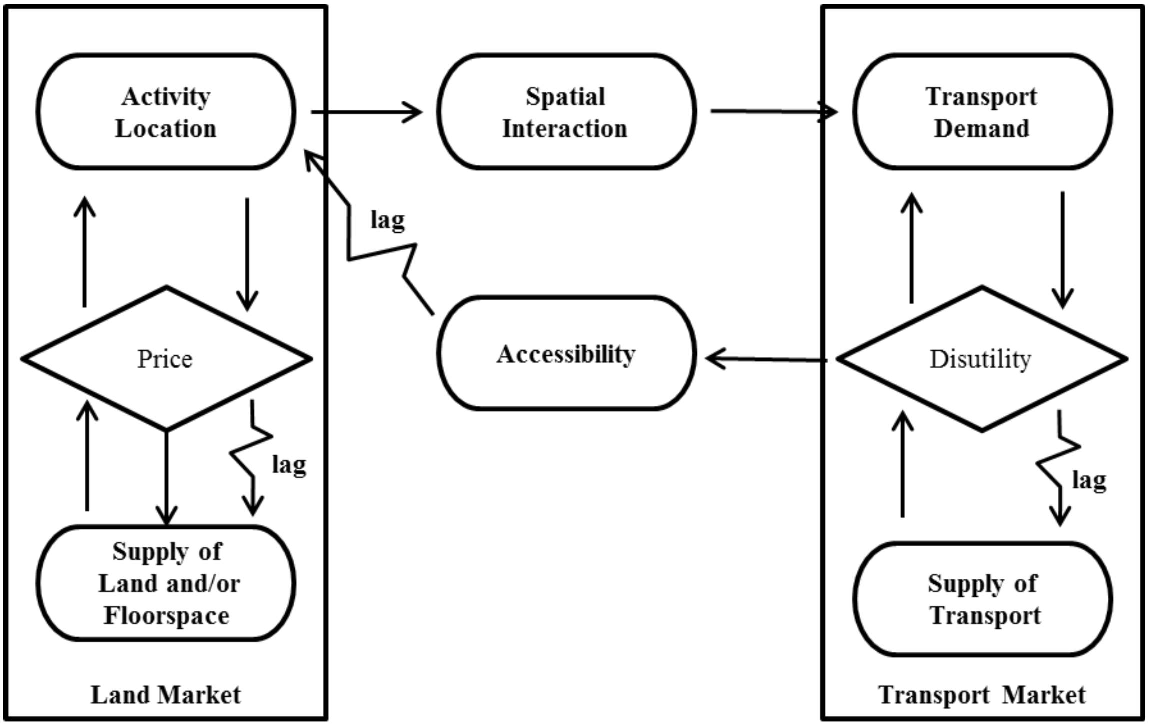


Figure 13: MEPLAN Framework (Adapted from: Johnston et al., 2000)

3.2.6 MUSSA & ESTRAUS

MUSSA is a land use model developed by Martinez in the early 1990s to interact with a transport model, ESTRAUS, as parts of an integrated land use-transport system for the Santiago City in Chile (Martinez, 1997). MUSSA is a disaggregate model for forecasting land use change through the identification of future activities location and housing choices. The economic framework of the system is based on a bid choice utility model that considers income and prices to determine land market sales. This process is iterative and terminates when the equilibrium between supply and demand is reached and the optimal solution that balances the maximum possible profits of consumers and property owners is found. Model outputs include among others building rents and land use information. The integrated land use transport system also allows users to evaluate the impact of different transportation policies and projects. More details are provided in Figure 14.

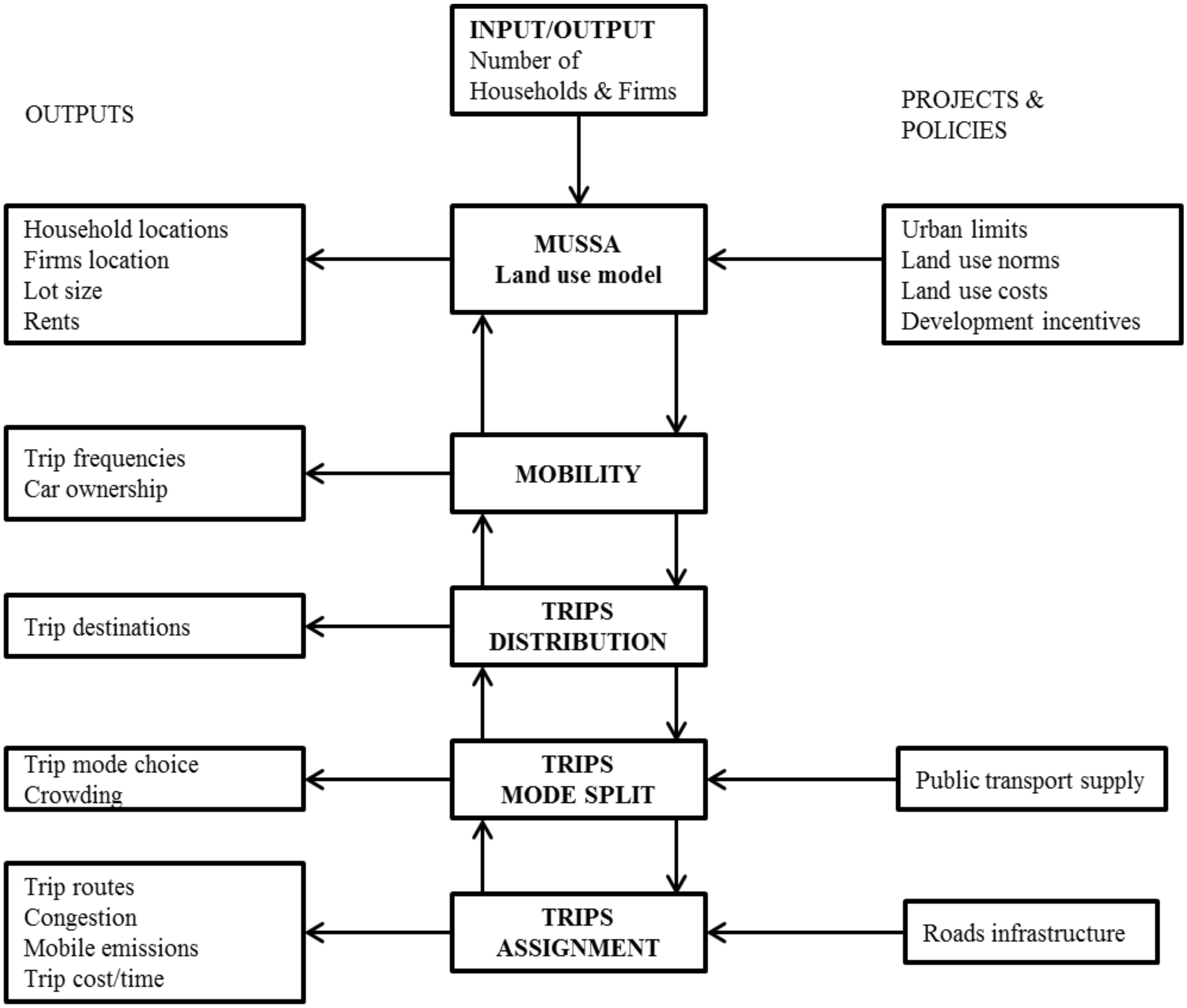


Figure 14: MUSSA-ESTRAUS System (Adapted from: Martinez, 1997)

3.2.7 CUF

The California Urban Futures (CUF) model was introduced in 1994 (Landis, 1994). CUF is a forecasting and simulation model that focuses on identifying the impact of population growth on urban development. The application area included specific counties of the Northern California Bay region. CUF model innovations at this time period included the population growth estimation and allocation in a more disaggregate level, following a bottom-up approach. A major difference comparing to previous land use models was the consideration of a wider set of factors except from accessibility that could potentially affect urban growth. Other advanced characteristics of CUF model included the compatibility with GIS tools, the faster processing times and the introduction of effective visualization tools. CUF developers focused on producing a user-friendly model that was able to simulate and evaluate future development policies.

Also, the modular approach of CUF system allowed the easier future model update and expansion. CUF comprised of 4 sub-models: a bottom-up population growth sub-model, a spatial database, a spatial allocation sub-model and an annexation-incorporation sub-model (rules for incorporating new developable land uses). Updated versions of the CUF model were also developed with advanced characteristics and capabilities (Landis and Zhang, 1998).

3.2.8 METROSIM

METROSIM is an econometric land use model developed by Alex Anas at the State University of New York (Parsons Brinckerhoff Quade and Douglas, Inc., 1998). It was developed to replace other land use models developed by Alex Anas such as CATLAS and NYSIM models. System development was based on utility theory and microeconomic principles. METROSIM structure consists of a set of sub-models for determining basic/non basic industry, available land, travel characteristics and traffic assignment. The model operates until equilibrium is reached. Nested logit models are applied to determine residential and work locations, travel mode, housing, route to work and shopping, etc. Some of the model outputs include Basic and Non-Basic Employment parameters (floor space consumption, wages, number of workers), Real estate measures for commercial and residential sectors (occupied/available space, rents) and travel characteristics (routes, mode choice, etc.) METROSIM was not integrated with GIS at this time period. METROSIM was also not integrated with travel demand models however this option was available.

3.2.9 DELTA

DELTA is related with the land use part of an integrated land use-transport system developed by the David Simmonds Consultancy and the University of Leeds in 1995 (Simmonds, 1999). Delta can be described as an econometric system as it models the interaction between buildings and activities based on rents and prices. Land use modeling focuses on predicting the space changes (available floor space) and the activities changes (household changes and employment status, market changes and individuals employment). The system comprises of a set of sub-models such as the Transition and Growth sub- model, the Employment and the Area-quality sub-models, etc. The land use part interacts with the transport model through exchanging information regarding accessibility and environmental values and home-work relationships. Accessibility is calculated in two steps; the first one focuses on estimating the accessibility from each origin to destination zone and the next step calculates a total accessibility value for each activity separately. The major factors for analyzing household and population changes include the area demographics, housing location and employment status. To analyze employment, three different parameters are considered: economic growth/decline, activity locations and employment/unemployment rates. The DELTA framework is presented in Figure 15.

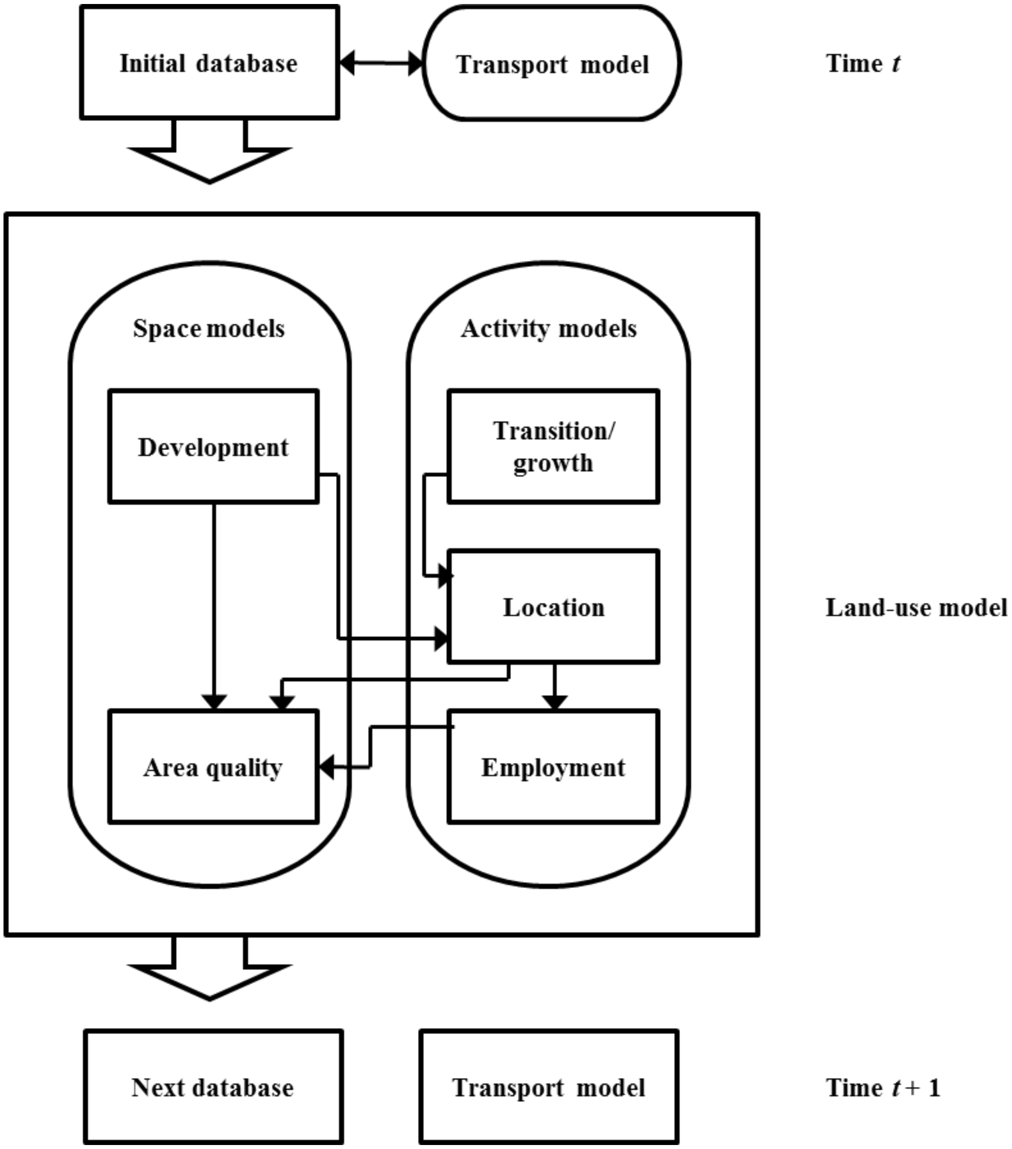


Figure 15: DELTA Framework (Adapted from: Simmonds, 1999)

3.2.10 NYMTC-LUM

NYMTC-LUM is another land use model suggested by Anas in 1998 (Anas, 2002). NYMTC-LUM development was affected by similar models such as CATLAS and METROSIM, aiming to produce predictions of land use and demographics change. NYMTC-LUM can be applied as a one-step long run model and iterates till equilibrium is achieved or can be applied incrementally. The system consists of sub-models such as the Work-Residence Linkages Sub-model for identifying the workers decisions regarding housing and job locations and the Residence-Non-work Linkage Sub-model for estimating the non-work trips. Additional sub-models such as the Housing Market, the Labor Market and the Building Stock Adjustment Sub-model are also included in the NYMTC-LUM structure. Figure 16 shows the model framework.

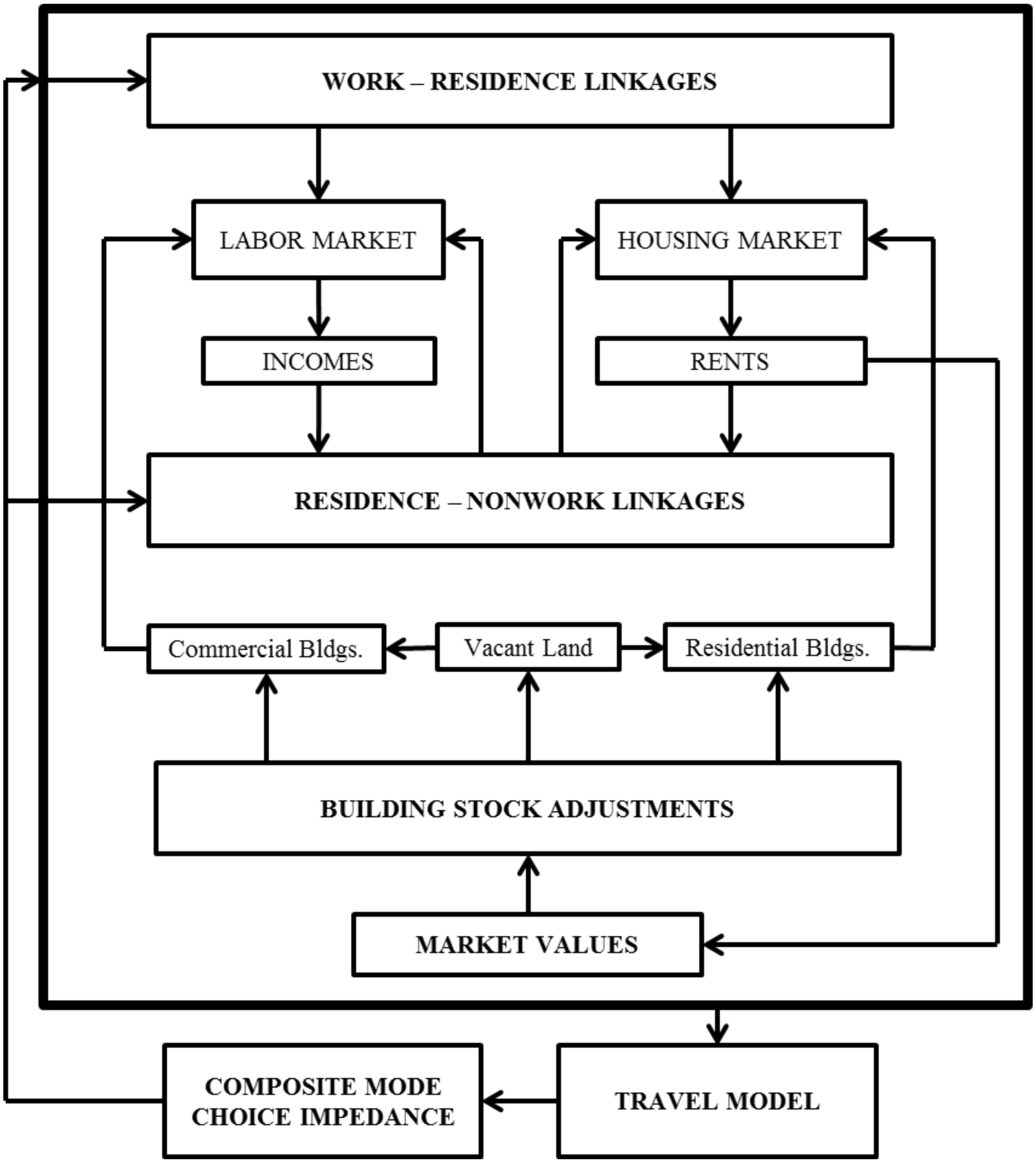


Figure 16: NYMTC-LUM Model (Adapted from: Anas, 2002)

3.2.11 IMREL

IMREL is a land use model introduced by Anderstig and Mattsson in 1991 (Svalgard, 1994). The model was designed to operate in an integrated environment with travel demand models such as the T/RIM (Transport/Residence Integrated Model), a traditional 4-step demand model developed by the Institute of regional Analysis and the Royal Institute of Technology in Sweden. IMREL structure is based on the residential location sub-model (RES) and the employment location sub-model (EMP). RES is multinomial logit model that determines the residential locations and mode choice of households. EMP is also a logit based model for developing workplace patterns. Workplaces are allocated to zones based on different parameters such as accessibility, zonal conditions, etc. The major inputs to the system include population, employment data and travel characteristics. Figure 17 describes the structure of IMREL.

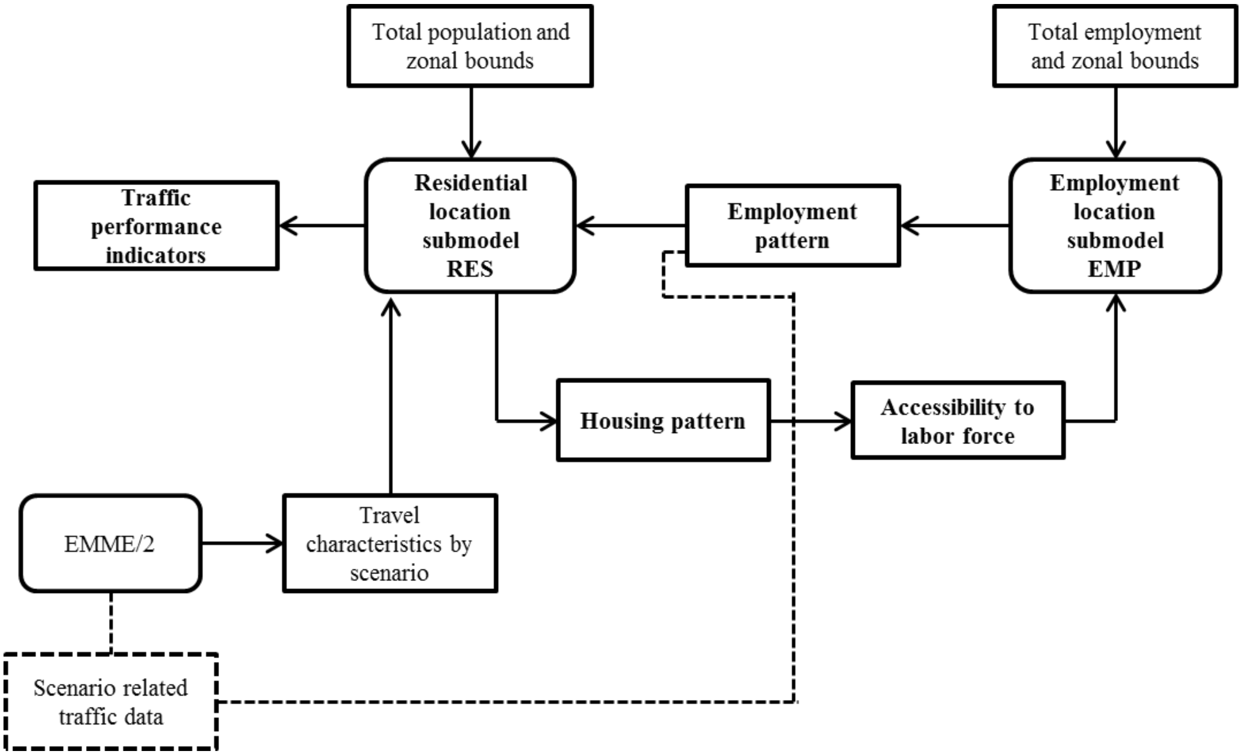


Figure 17: IMREL Overview (Adapted from: Svalgard, 1994)

3.2.12 METROSCOPE

METROSCOPE is an integrated land use-transport model, developed by the Portland METRO, the Portland-Oregon Regional Government. METROSCOPE has been used for land use/transport planning and evaluation of the economic impact of different land use/transport policies (Conder, 2000). Model development was based on the integration of four separate models; a regional econometric model (MARIO), a residential real estate model (RELM), a nonresidential real estate model and a transportation model. A set of GIS tools were also incorporated in the system. The economic model focuses on producing employment and household forecasts and the transportation model provides mode choice information and travel time/cost estimates. Two real estate location models (residential, non-residential) are utilized to predict the household and employment locations and provide information regarding land consumption, land prices, etc. GIS tools are mainly used for data processing and representation.

3.2.13 PECAS

PECAS (Production, Exchange and Consumption Allocation System) is an aggregate, econometric model, developed by Hunt and Abraham (Hunt and Abraham, 2003; Hunt and Abraham, 2007). The model is based on allocating flows of exchanges (goods, services, labor and space) from production points to exchange and consumption points. Flow allocation is completed using nested logit models that consider the exchange prices and transport dis-utilities. Then exchange flows are turned into travel demand. PECAS model comprises of two major modules, the Space Development (SD) and Activity Allocation (AA) modules. PECAS iterates till equilibrium is reached. The Flow Allocation of PECAS is presented in Figure 18.

3.3 Third Generation of Models

The swift to the activity-based framework of travel demand modeling created the need to develop a new generation of integrated land use-transport models. This section provides information for micro-simulation, agent based and cellular automata land use models and tools.

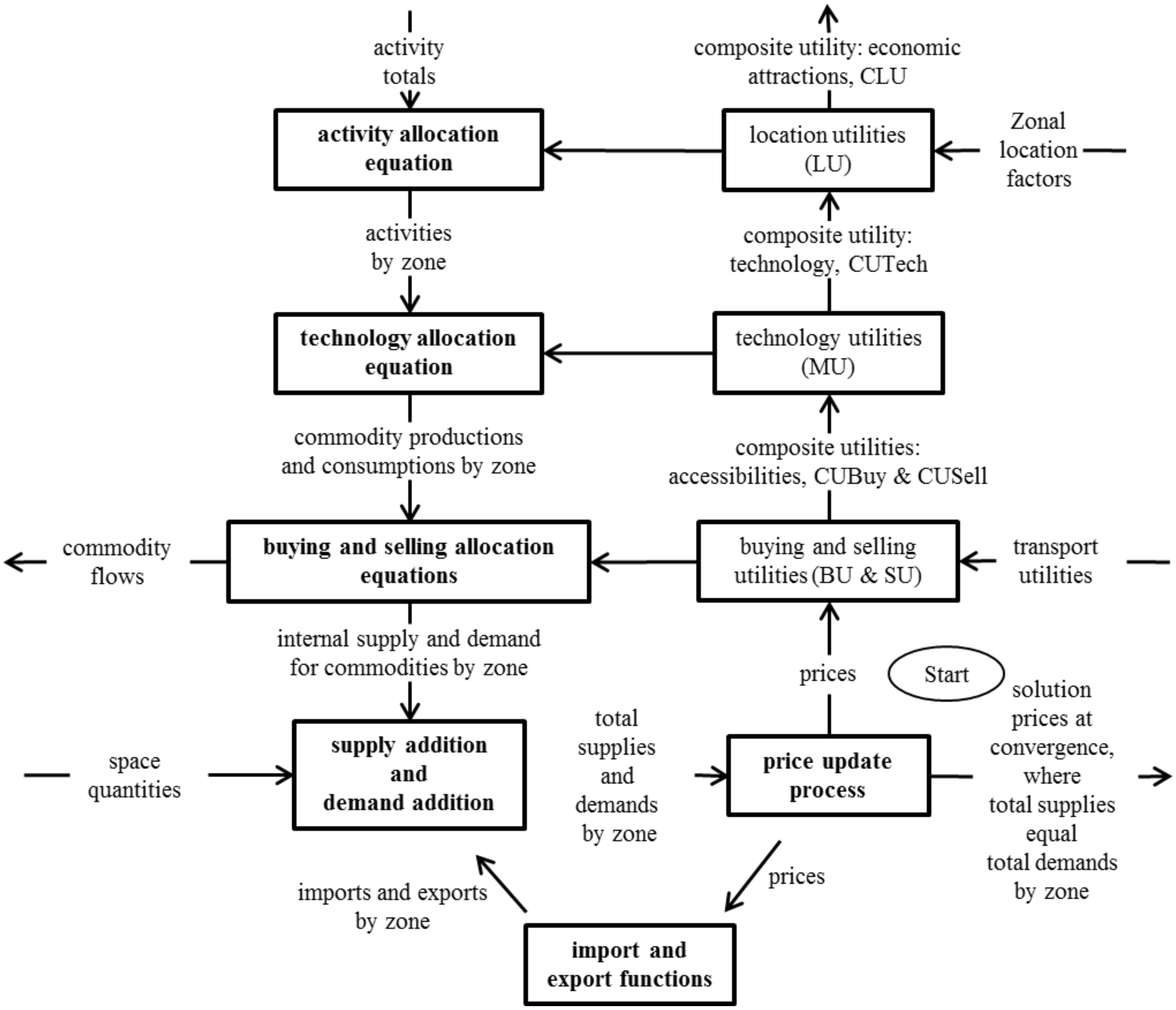


Figure 18: PECAS - Flow Allocation (Adapted from: HBA Specto Incorporated, 2007)

3.3.1 SMART

The Simulation Model for Activities, Resources and Travel (SMART) was introduced in 1996 (Stopher et al., 1996). SMART is an activity based model that focuses on land use analysis, household activities and demand modeling. It was suggested as a new alternative comparing to the traditional four step model. SMART is a GIS-compatible, disaggregate system; however, an option to operate in an aggregate mode is also available. According to the model concepts, the household is the major decision unit and the accomplishment of household activities creates travel demand. Household activities are separated into three different categories: mandatory, flexible and optional. Other major concepts include the repetitive nature of household travel patterns. Figure 19 describes the model's structure.

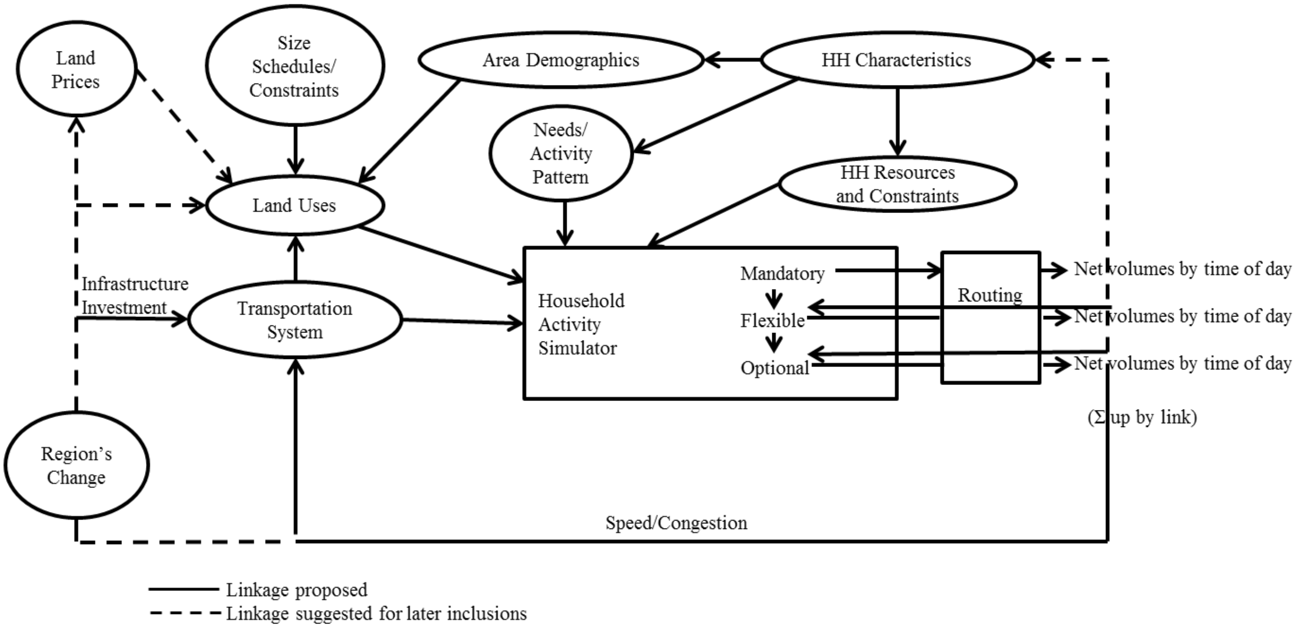


Figure 19: SMART Model (Adapted from: Stopher et al., 1996)

3.3.2 SAMS and AMOS

The Sequenced Activity-Mobility Simulator (SAMS) is a micro-simulation forecasting tool that integrates transportation and environmental planning with land use (Kitamura et al., 1996). Major changes in modeling brought by SAMS include a change from aggregate to simulation forecasting, a shift from static trip based to dynamic activity based models and the interaction with GIS tools. SAMS is a complete simulation forecasting system that includes a set of different simulators (Socio-economic and demographic simulator, urban system simulator, Dynamic network simulator) and an Emissions module.

The major element of SAMS system is the AMOS Simulator. The Activity-Mobility Simulator (AMOS) is an activity based model that focuses on travel behavior and the ability of travelers to adjust their behavior based on information regarding the travel environment. AMOS consists of four major components. The baseline activity-travel pattern synthesizer is utilized for estimating out-of home activities and constraints of the corresponding trips and response option generator for producing alternative options for drivers due to changes to the travel environment. The activity travel adjuster in AMOS can be used to simulate activity-travel patterns and the evaluation module can be applied to evaluate traveler options. Details are provided in Figure 20.

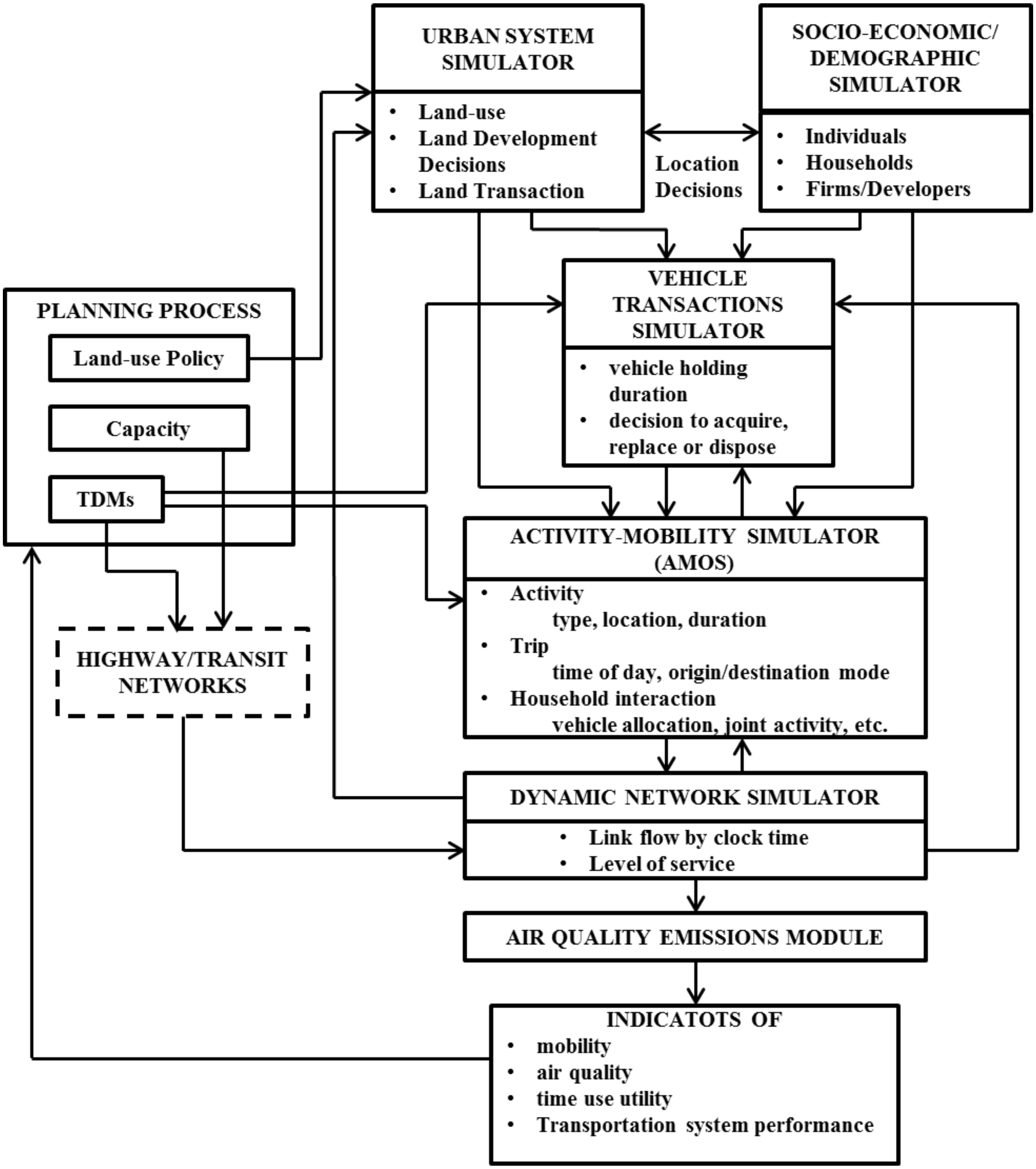


Figure 20: SAMS & AMOS System (Adapted from: Kitamura et al., 1996)

3.3.3 ILUTE

ILUTE (Integrated Land Use, Transportation, Environment) model was developed in its initial format by researchers in Canada (Miller and Savini, 1998). The Updated version of ILUTE (Savini and Miller, 2005) is an agent based micro-simulation model for transportation and land use planning. Potential agents/areas for analysis include persons, households, road networks, housing/buildings, market and the economy. The model structure comprises of four major components: land use, location choice, auto ownership and activity/travel. Five sub-models (Housing Market, Auto Transactions, Activity, Output, Demographics) are utilized for accomplishing tasks. ILUTE includes an activity-based model for activity scheduling and travel demand modeling. Advanced visualization tools for data representation are also available. An overview of ILUTE is provided in Figure 21.

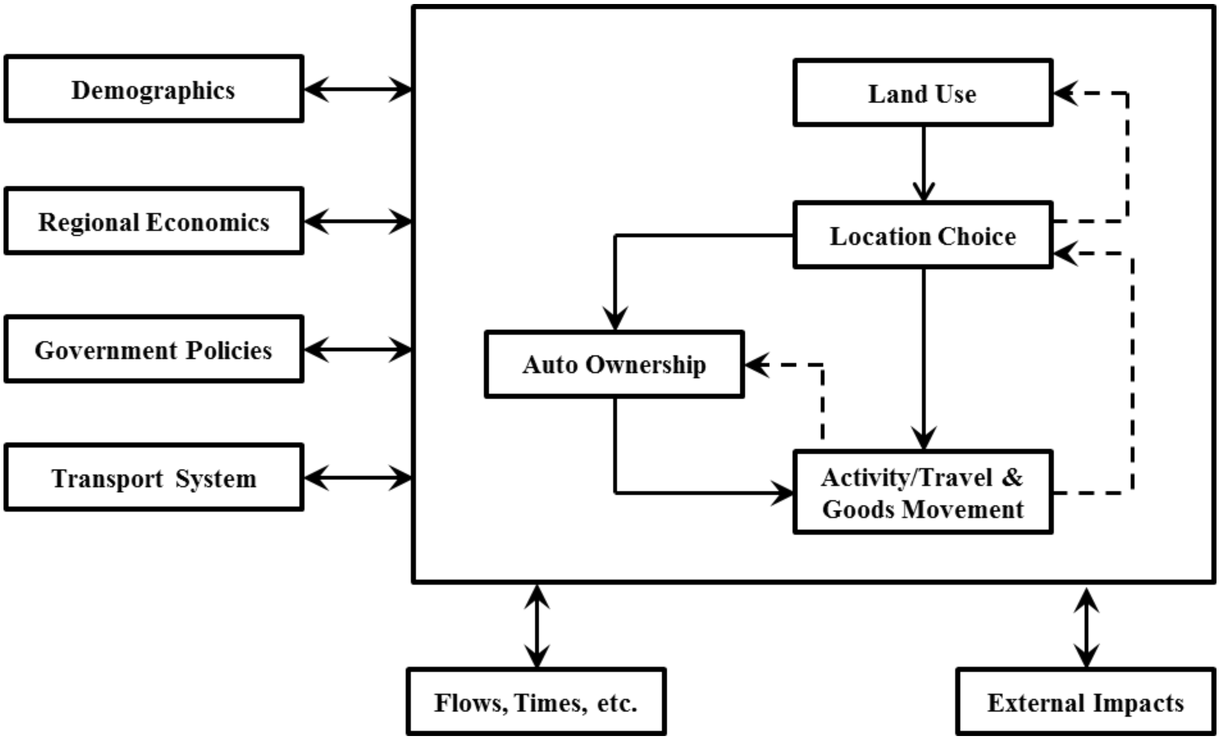


Figure 21: ILUTE System (Adapted from: Miller et al., 1998)

3.3.4 Whatif?

Klosterman (1999) following the principle of `Keep it Simple, Stupid', developed a rule based land allocation model called `Whatif?'. The allocation model is based on evaluating the suitability of land polygons for further development. These rankings are dependent on various physical, socio-economic and regulatory factors as specified by the user. The population and employment projections are exogenous to the system. Since it does not pretend to be a sophisticated model, the allocation mechanism is straightforward; it allocates one type of land use (commercial) and then proceeds to allocate other land uses, sequentially. The model can also evaluate alternative scenarios and future policies.

Similar rule based models has also been developed such as the Maryland Department of Planning's Growth Model, that allocates residential growth based on the available capacity of development and proximity to roads, availability of current and future networks, etc. However, unlike Whatif?, the model allocates growth to the points that represent parcel boundaries. As a result, parcel changes (such as aggregation, subdivision) are not modeled.

3.3.5 RAMBLASS

RAMBLASS (*R*egional Pl*a*nning *M*odel *B*ased on the Micro-Simu*l*ation of Daily *Activity Patterns*) was developed in the Netherlands (Veldhuisen et al., 2000) as an update of an older regional location model (Veldhuisen and Kapoen, 1977; 1978). RAMBLASS is an activity, GIS-based micro-simulation model for analyzing activity data to predict traffic demand change. The model provides the option to determine the impact of land-use and transport plans on activity patterns and traffic demand. Analysis is based on existing national data that include activity household and population information. Utilizing these data, population segments are developed to classify individuals. The activity agenda, the mode choice and the destination of each individual are randomly determined. The next step includes the identification of the corresponding travel times between origins and destinations, using a speed flow calculation method introduced by Dios Ortuzar and Willumsen (1994). Due to the random character of simulation analysis and the use of general, nationwide data, the need for validating the model outputs emerges.

3.3.6 URBANSIM

UrbanSim was developed at the Center for Urban Simulation and Policy Analysis (CUSPA), University of Washington (Borning et al., forthcoming, Waddell, 2002). UrbanSim can primarily evaluate the impact of alternative transportation, land use, and environmental policies. UrbanSim is an open source tool that allows data analysis and processing at the grid, parcel and zone level. The option of integrating UrbanSim with travel demand models is available to users. UrbanSim is a microsimulation model and its modular structure is based on utility theory. Household and employment location choices, real estate development and prices can be modeled. A disaggregate classification of households is carried out, considering the number of individuals, workers, children and the income of each household. Employment is also classified in a disaggregate way. The model can also be used to simulate disequilibrium conditions. The model structure is presented in Figure 22.

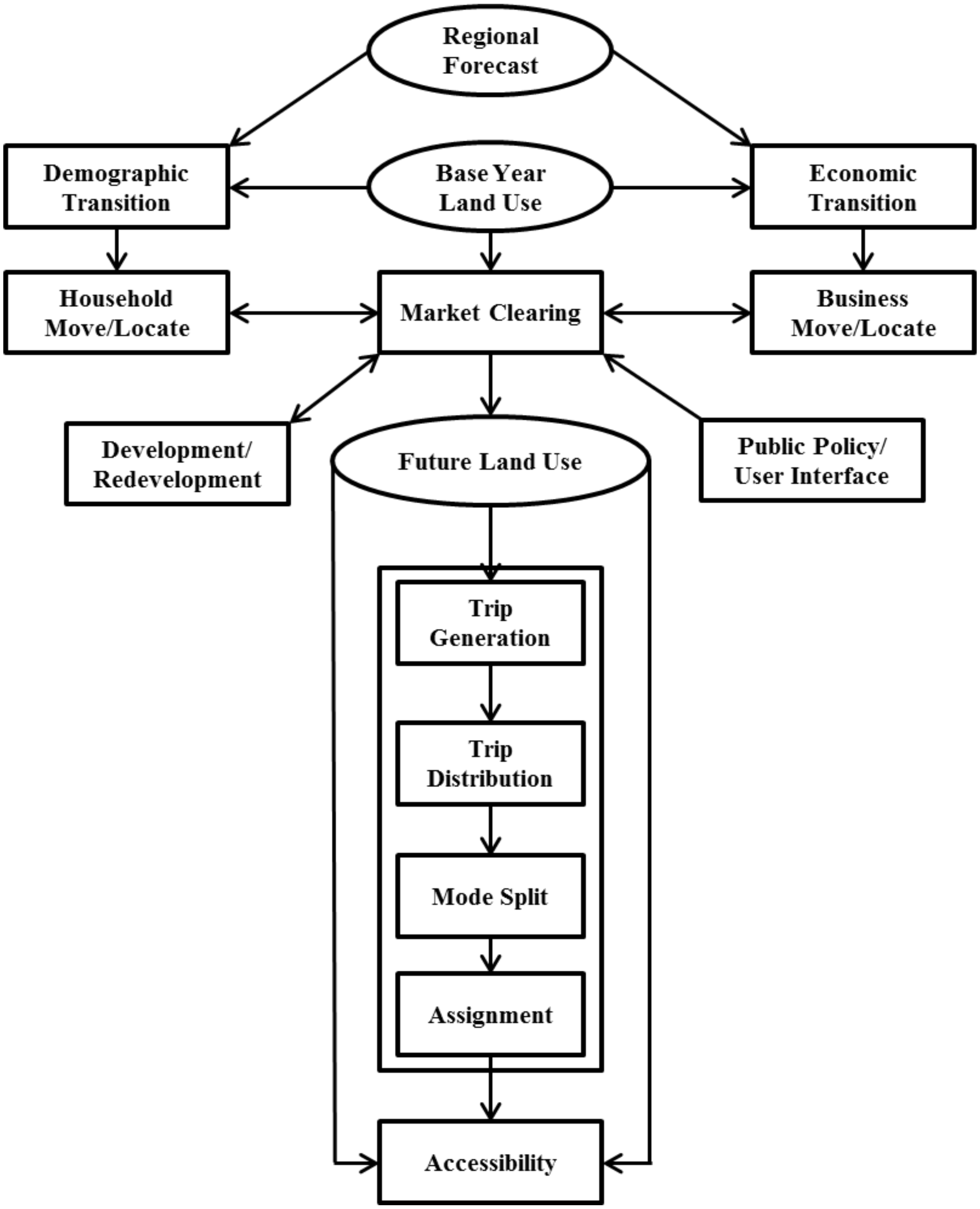


Figure 22: UrbanSim Model (Source: Waddell, 2002)

3.3.7 U-Plan Urban Growth Model

U-Plan is a GIS based system for land use modeling and was introduced in 2002 (Johnston et al., 2002). It’s a rule-based model, aiming to identify the effects of urban growth on land use (Industrial, Commercial, Residential areas). The major concept of the model structure is to forecast the future land consumption due to urban growth. County or regional land consumption is predicted based on demographic data and density factors (households, workers, etc.). GIS analysis is based on raster data for faster data processing. Model application starts with identifying the attractive areas in terms of land development (Attraction Grid) and the areas such as lakes and farmlands with low potential of future development (Mask Grid). Then the projected land consumption/future development is allocated starting from the highest-valued areas/cells. The previously described process is not applied to low-density residential areas where the projected future development is randomly allocated. Historical census data can be utilized for model calibration. U-Plan can be integrated with others models such as TRANUS.

3.3.8 PUMA

PUMA (Predicting Urbanization with Multi-Agents) is an agented based system for predicting land use change impact (Ettema et al., 2007). PUMA takes into account different parameters that can affect urban patterns such as population and demographics change, land use change, firm development and relocation and activity/travel patterns of individuals and workers. All these parameters interact between each other. PUMA is a grid based system and different information such as number of inhabitants, houses, firms, jobs and accessibility is provided for each grid. Some of the major agents of the system include households/individuals, firms/institutions and land owners. The model was developed in C++ programming language. PUMA was applied for a case study at the northern part of the Dutch Randstad, in Netherlands. The model run time was quite extensive as it took approximately 12 hours to complete a 30 years period simulation run. System developers were planning to integrate PUMA with AURORA, an activity based transport model for developing daily activity and travel patterns. Figure 23 shows an overview of PUMA.

3.3.9 LEAM & SLEUTH

Cellular Automata (CA) are models that simulate urban growth in a particular area by looking for information within the immediate and local neighbourhood. Chief among these models are the Land use Evolution and Impact Assessment Model (LEAM) (Deal and Schunk, 2004) and the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hill-shade (SLEUTH) models (Clarke and Gaydos, 1998). Since SLEUTH is a public domain model different model versions such as Regional Simulation model (RSIM) by Oak Ridge National Laboratory have been developed.

Two main differences exist between LEAM and SLEUTH. While SLEUTH performs calibration by an exhaustive search on four parameters (slope, land cover, urbanization and transportation) between two time periods, LEAM estimates different parameters such as accessibility weights to schools, road intersections, parks etc. at one time period. Furthermore, the probability of a cell becoming urbanized in SLEUTH is entirely dependent on the neighborhood characteristics of that cell at a particular time step. LEAM computes the initial probability considering different attractors (such as schools, parks, airports etc.) and augments the probability dynamically by evaluating the neighborhood characteristics in each time step.

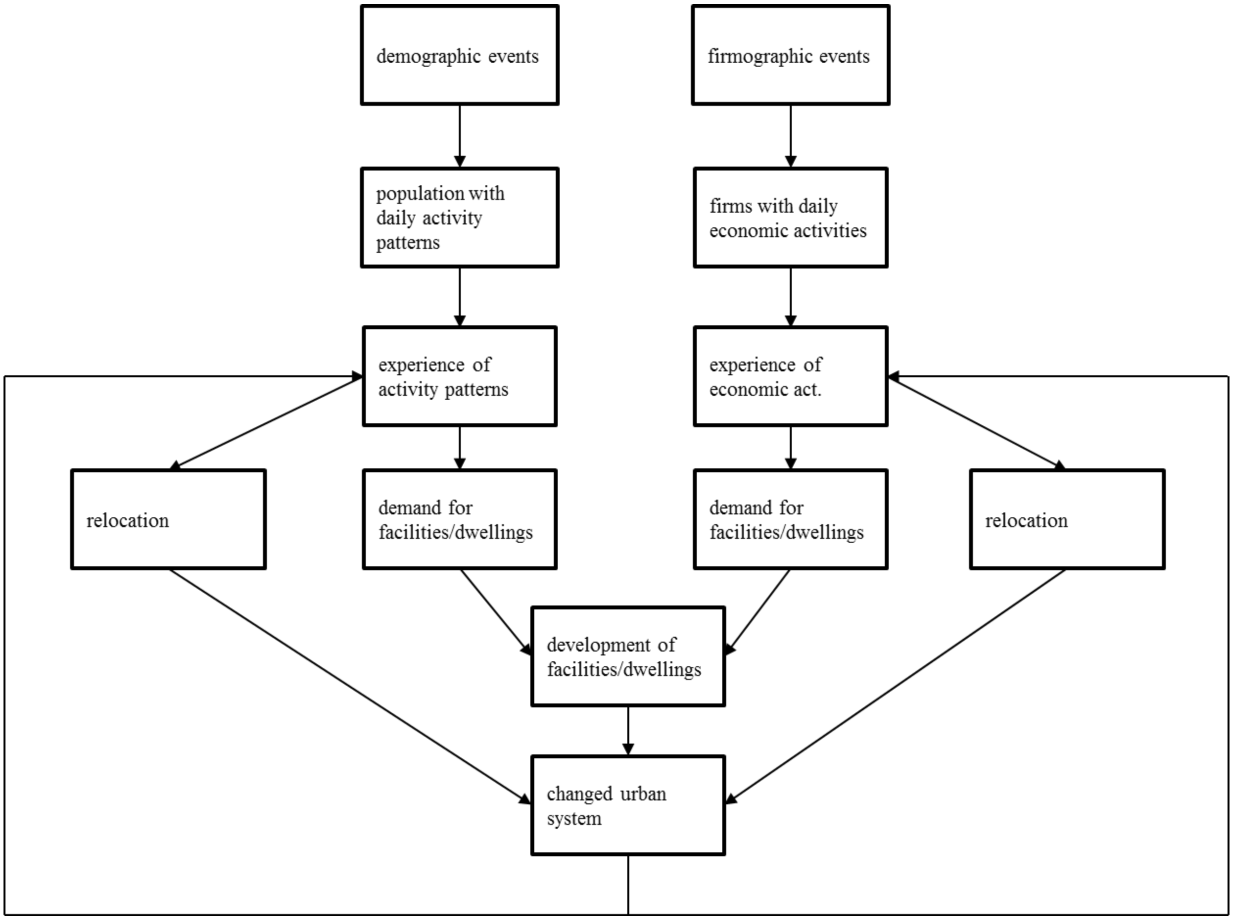


Figure 23: PUMA – Interaction of System Components (Adapted from: Ettema et al., 2007)

3.3.10 ILUMASS

ILUMASS (Integrated Land-Use Modeling and Transportation System Simulation) developed in Dortmunt, Germany (Moeckel et al., 2003) is a disaggregate microsimulation model for analyzing the effects of future transportation and land use policies. It also analyzes the agent behavior and characteristics (households, persons, etc.). The land use component of ILUMASS shares common characteristics with the IRUPD model (Wegener, 1999). ILUMASS is a GIS compatible application and both raster and vector data can be analyzed. GIS tools are also applied for results representation. Microsimulation in ILUMASS is based on a set of different modules that consider housing, traffic networks, households, market, logistics and environmental parameters. ILUMASS framework is presented in Figure 24.

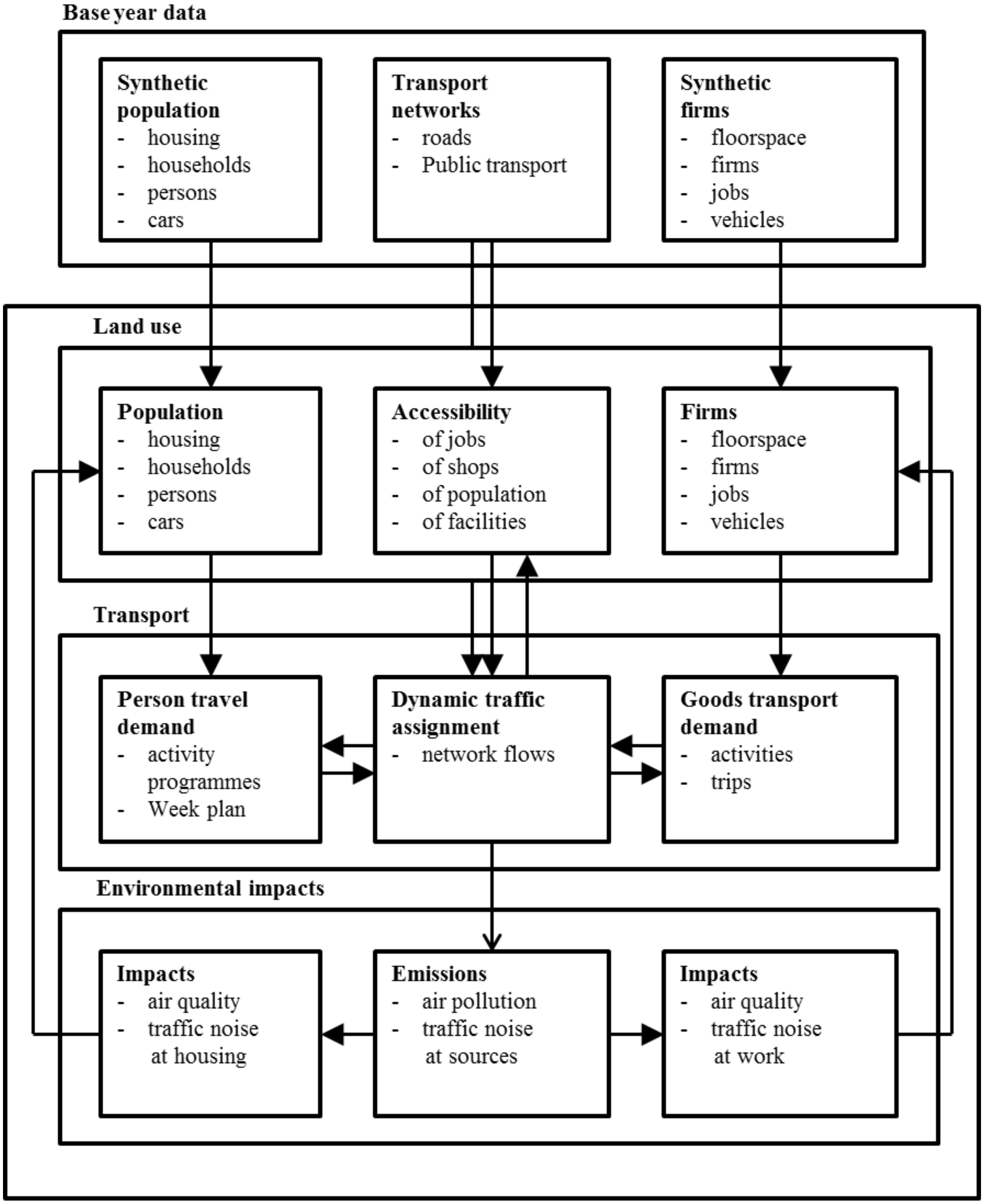


Figure 24: ILUMASS Framework (Adapted from: Moeckel et al., 2003)

3.3.11 The Land Use Scenario DevelopeR (LUSDR)

LUSDR is an agent based, microsimulation land use model developed for application by different MPOs at the greater Oregon area (Gregor, 2007). LUSDR was built to interact with regional transportation models for evaluating the land use impact on transport planning. Model development was accomplished using the R programming language and was based on Monte Carlo modeling techniques. Analysis in LUSDDR starts with the creation of household population synthesis. People are classified in different age groups. Household characteristics such as income, number of workers, etc. are specified. Employment forecasts are based on the total number of household workers and the ratio of employment to workers in the study area. Employment and property data are used to determine business developments. Residential and business developments are located in each Transportation Analysis Zone (TAZ) considering different land, environmental and regulatory constraints. Model outputs such as population and employment information and residential/business developments can serve as significant input data for transportation planning models.

3.3.12 LandSys Model

LandSys is a land use model developed to interact with the Florida Standard Urban Transportation Modeling Structure (FSUMTS) (Peng et al., 2011). LandSys was developed using Matlab software, based on a combination of Cellular Automata (CA) and agent-based modeling techniques. The CA model uses a multinomial logit model to predict land use changes considering various parameters such as adjacent land uses, accessibility, proximity to airports or central business districts, etc. Multi agent models estimate the household and employment location choices using a bid- rent function that identifies the price and demand variations of real estate over distance. Additional agents are utilized to describe the owner willingness for land development using Monte Carlo Simulation, to evaluate the impact of government policies on land use and identify the land price changes. Model structure includes three basic modules. The basic module focuses on land use categorization, data processing and storage. The Parameter module determines the set of parameters for the CA and the Agent models. Finally, the application module is used for simulating land use changes and producing household and employment data. LandSys framework is presented in Figure 25.

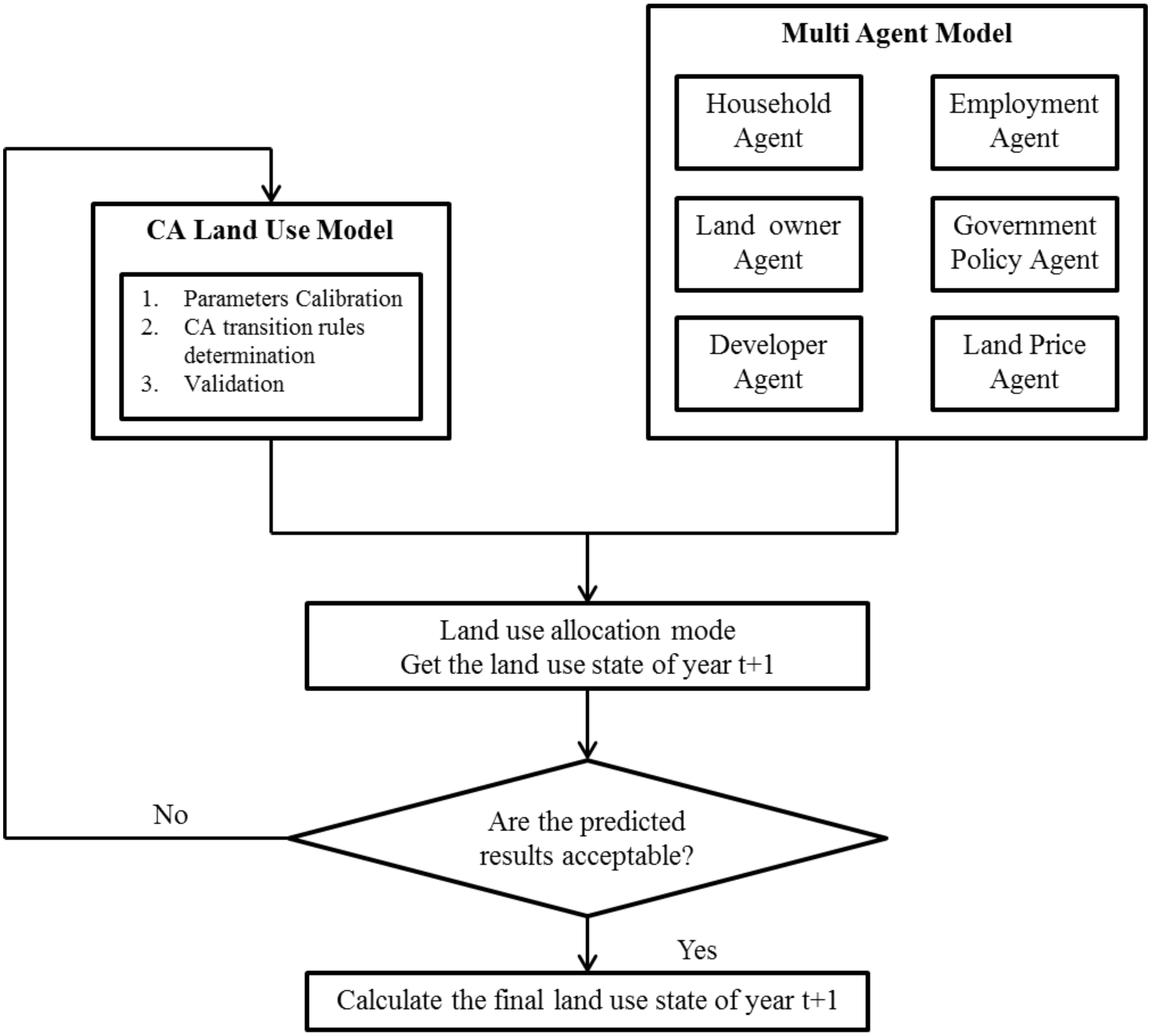


Figure 25: LandSys Model (Adapted from: Peng et al., 2011)

3.4 Integrated Land Use-Transport Models with U.S. Agencies

3.4.1 OREGON TLUMIP Model

TLUMIP (Transportation Land Use Model Improvement Program) is an integrated transport and land use system developed for the Oregon Department of Transportation (Weidner et al., 2007). System development started in the late 1990s with Oegon1 model that was a statewide economic and activity based model for forecasting land use and transport changes. The system structure was based on TRANUS and URBANSIM models and was applied for accomplishing various projects in the statewide, the regional and the urban level.

The Oregon2TM microsimulation model was the result of the continuous effort to upgrade the capabilities of the Oregon model. Analysis in Oregon2TM initiates with the application of an economic model and then continues with the zonal allocation of construction and industry activities, considering economic data, market prices and travel costs. A synthetic population is generated, based on employment data and home/work locations. These data serve as an input into the transport system that includes sub-models for analyzing freight and personal travel flows. Transportation flows are determined using equilibrium traffic assignment. Figure 26 shows the structure of TLUMIP.

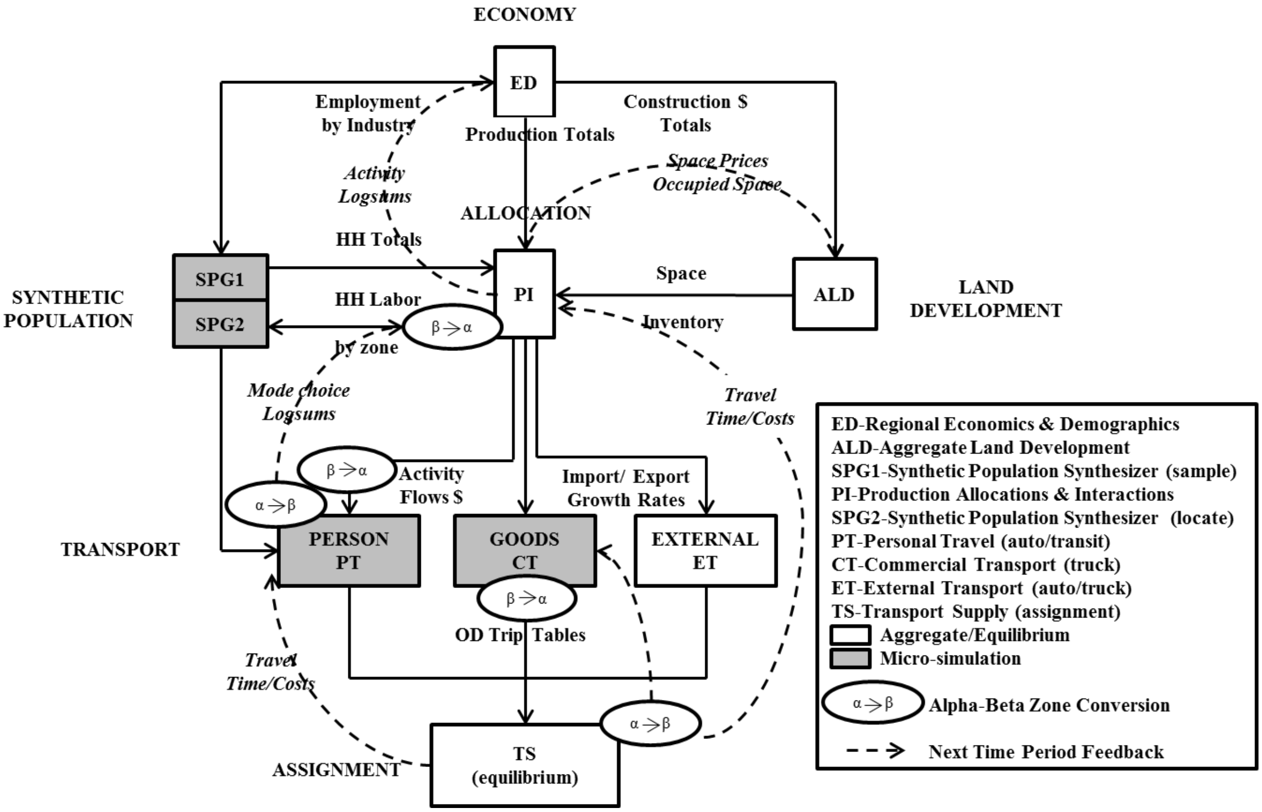


Figure 26: OREGON TLUMIP Framework (Adapted from: Weidner et al., 2007)

3.4.2 SACOG-The Sacramento Activity-Based Travel Demand Model

One of the latest versions of the integrated land use and transport system for the Sacramento (California) Area council of Governments (SACOG) was based on the interaction of PECAS model with SacSim model (Bowman et al., 2006; Bradley et al., 2009). SACSIM is an activity based transportation planning and land use model. Activity based forecasts from SACISM are used as inputs into the PECAS model for more efficient macro-level forecasts. Modeling process starts with the utilization of land use data and demographics to produce the synthesized population. Work and school locations and auto ownership are then determined using simulation. Trip scheduling (tours, number of trips) is identified with the use of DaySim (Person-Day Travel Simulator). Trip scheduling is based on the application of multinomial logit and nested logit models. The outputs from DaySim simulator along with additional trip data (e.g. external trips, commercial vehicle trips, etc.) are used for trip generation and the production of the corresponding Origin-Destination Matrices. An equilibrium traffic assignment then follows. Details are provided in Figure 27.

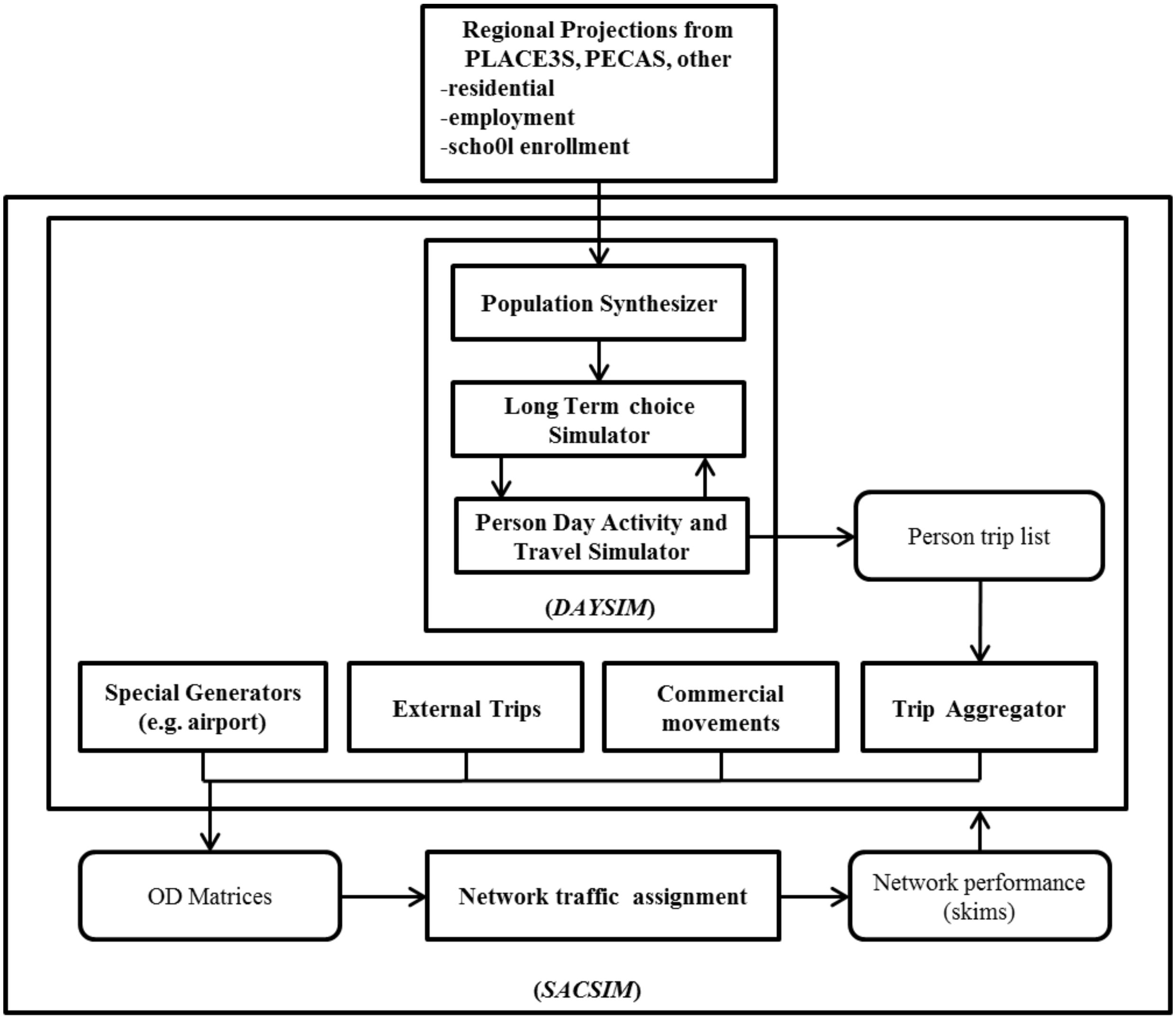


Figure 27: SACOG Model (Adapted from: Bowman et al., 2006)

3.4.3 LUCI Model (Indiana Department of Transportation)

The Land Use Central Indiana (LUCI) model focuses on simulating household and employment development. An updated version, LUCI2 statewide model operates as part of INTRLUDE (**In**tegrated **Tr**ansportation **L**and-**U**se **D**emand **E**stimation) an integrated land use and transport model, operated by the Indiana Department of Transportation (Jin and Fricker, 2008; Ottensmann, 2009). LUCI2 and the Indiana State Travel Demand Model (ISTDM) are the major components of INTRLUDE. LUCI2 is based on an aggregated logit model to predict land use change for 5-year simulation periods. Simulation with LUCI2 model starts with utilizing population growth data to predict employment change for each traffic analysis zone of the study area. Then, the model determines the land consumption for employment development. The allocation of residential development follows using probability theory. At the end of each simulation period the employment, population and land use data are updated. Simulation with INTRLUDE starts with LUCI2 model that predicts urban change, utilizing data from the transport model. The outputs from LUCI2 model (population and employment) are the major inputs into the transport model to predict travel time change. The outputs from the transport model become inputs into the land use model and this iterative process is terminated until the target year is reached. Figure 28 shows the simulation process in LUCI2.

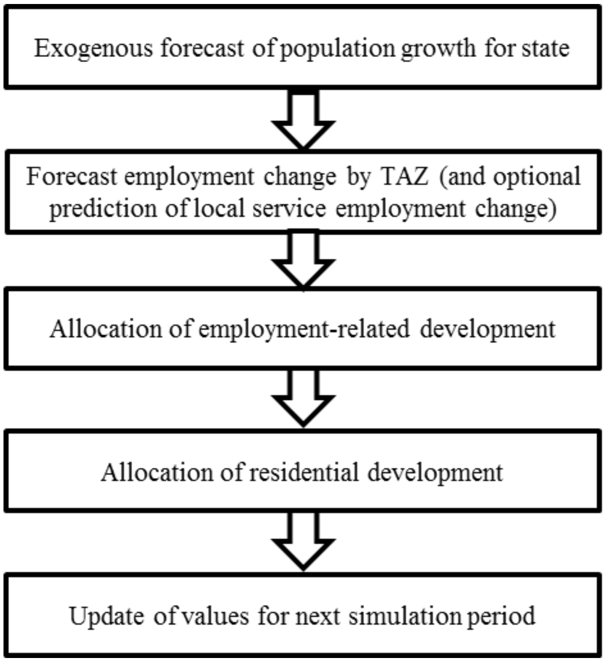


Figure 28: LUCI2-Simulation Process (Adapted from: Ottensmann et al., 2009)

3.4.4 PSRC Model

The new Puget Sound Regional Council land use model is based on UrbanSIM and operates as part of an integrated land use/transport model, replacing DRAM/EMPAL

(PSRC, 2012). The PSRC UrbanSim application is a parcel and market based model that simulates the interaction of households, firms and governments with the real estate, the labor and the services market. The major objective of PSRC land use model is to forecast demographics and land use changes and produce relevant data that can serve as significant inputs into transportation planning models and vice versa. The model can also be used to evaluate different land and transportation policies and scenarios. PSRC land use model utilizes input data such as number of households, persons and jobs, taken from a regional economic model. The major limitations of the PSRC model include the model complexity and the requirement of large amount of data. The agent interaction is described in Figure 29.

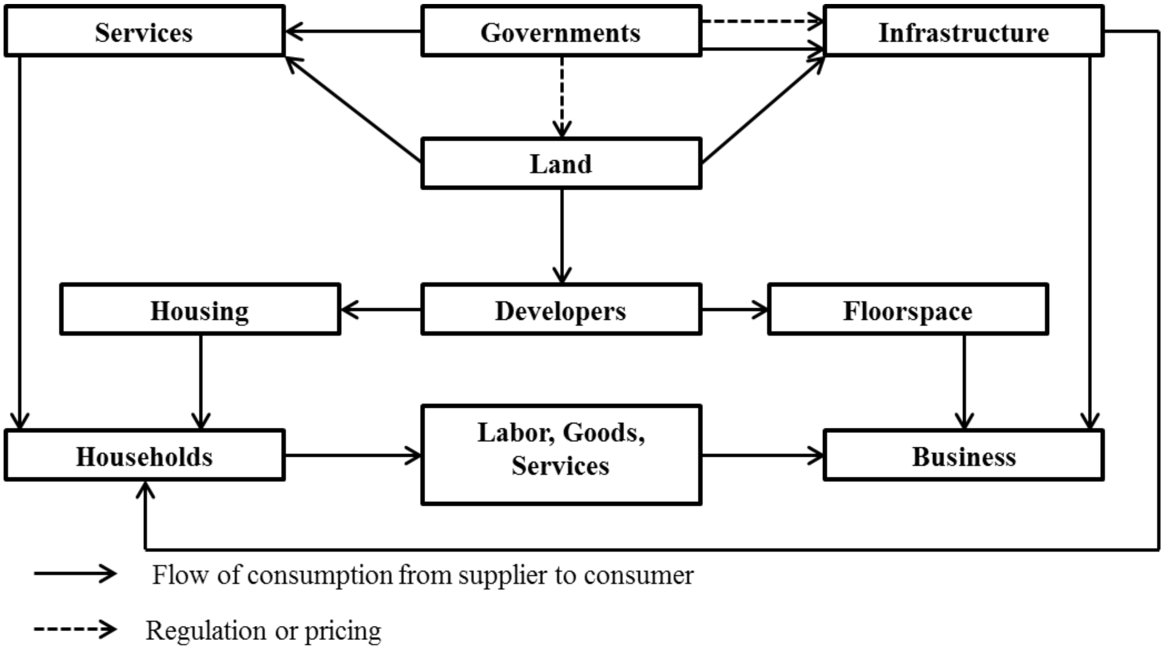


Figure 29: PSRC-Agents Interaction (Adapted from: PSRC, 2012)

3.4.5 California Statewide Integrated Model (CalSIM)

CalSIM is a land use and transport model developed for the California Department of Transportation (Caltrans) aiming to integrate PECAS land use model with a travel demand forecasting model (UC Davis website; Shengyi et al., 2009). The California PECAS statewide model objectives include: modeling the impact of land use change on the economy and the environment, evaluate the effects of transportation policies and investments and analyze the interrelationship of land use and transport. Data quality and availability and model calibration were the major problems to be resolved.

3.5 Land Use Planning Tools

3.5.1 CommunityViz

CommunityViz is a GIS based land use planning tool introduced by Fritzinger and Orton, in the late 1990s (Placeways LLC, 2014). It was developed to assist agencies in planning decisions regarding land use and transportation changes. The initial version of CommunityViz comprised of three separate modules: Scenario Constructor for scenario analysis, SiteBuilder 3D for 3D visualization, and Policy Simulator for evaluating the future impact of current policies. The later versions consist of two major modules: the Scenario 360 that replaced the Scenario Constructor and an updated version of SiteBuilder 3D. Scenario 360 is a modeling framework that allows the development of user defined tools and formulations depending on the characteristics of each different case study. CommunityViz has been used from different U.S. agencies, including the Nashville area Metropolitan Planning Organization (MPO) that used this tool to build the MPO's regional land use model. CommunityViz is presented in Figure 30.

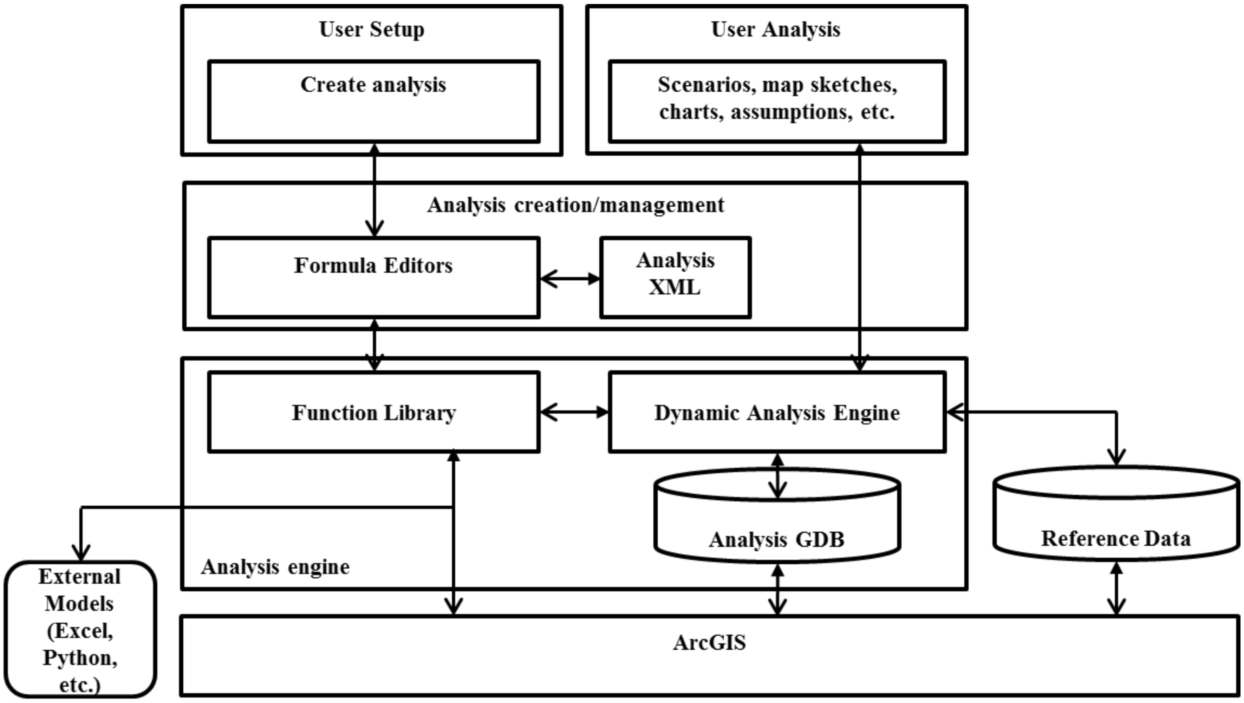


Figure 30: CommunityViz-Scenario 360 (Adapted from: Placeways LLC, 2014)

3.5.2 INDEX

INDEX is a static GIS based tool for scenario evaluation and planning in a neighborhood, community or region, developed in 1994 (Allen, 2008). It can be described as a rule based model for assisting agencies in planning decisions regarding land use, transportation and environmental issues. Two software versions: a parcel level and a zone level have been developed. Modeling process starts with identifying the existing conditions of the study area that will serve as the input data for the model. Then, the development and the evaluation of the future scenarios follow. In cases of multiple scenarios, the efficiency of each scenario can be evaluated and ranked. When a scenario application is determined, the implementation process can be monitored. INDEX has mainly been used by agencies in Illinois, Florida and California. In total, INDEX has been implemented in approximately seven hundred case studies in U.S. and has also been used by agencies in Australia, China, Japan and Spain. An overview of INDEX is provided in Figure 31.

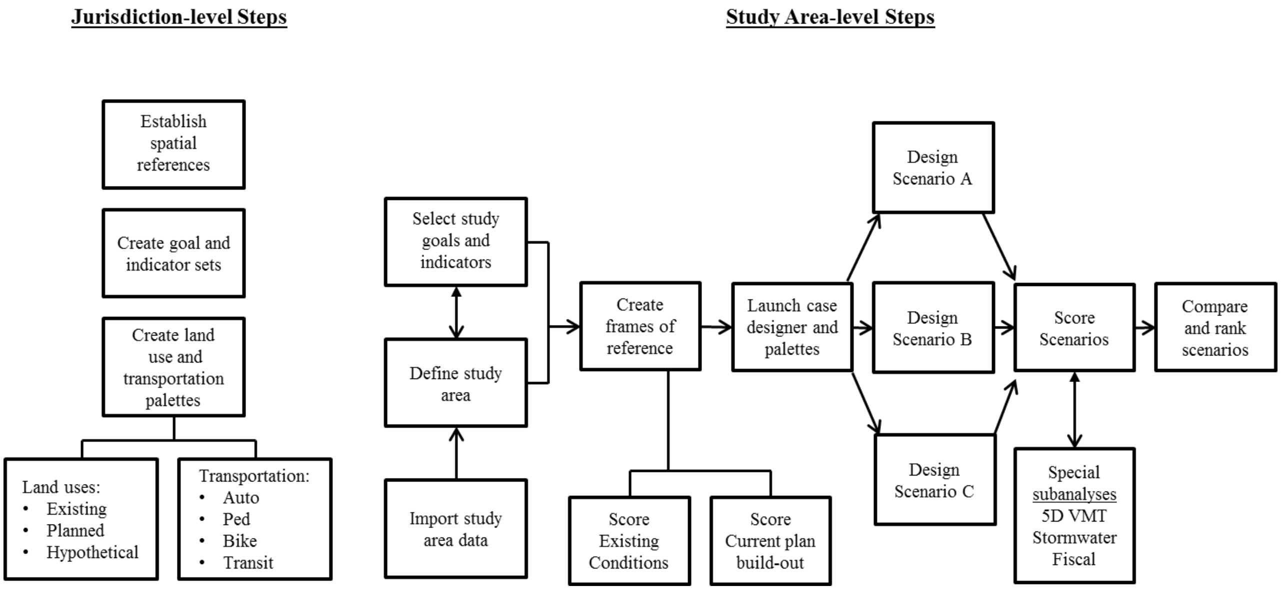


Figure 31: INDEX Overview (Adapted from: Allen, 2008)

3.5.3 LUCAS

LUCAS (Land-Use Change Analysis System) was introduced in 1994 (Berry et al., 1996). to evaluate land use changes impact and the effects of human decisions on landscape and nature. It was first applied to evaluate the regional impact of land use change in the Little Tennessee River Basin area, North Carolina and the Olympic Peninsula in Washington State. LUCAS structure is based on three major modules: Socioeconomic, Landscape and Impacts module. The socioeconomic module produces the probabilities of land use change (Transition probability matrix) considering different factors such as transportation accessibility and costs, land use potential, land ownership, land cover and population. Multinomial logit models are used to produce the corresponding transition probabilities. The outputs from the Socioeconomic module serve as inputs into the Landscape module which determines the landscape changes according to human decisions that are reflected in the Transition probability matrix. Landscape changes are represented through maps. The impacts module utilizes the maps with the landscape change to predict the potential environmental impact of these changes. A GIS tool, GRASS (Geographic Resources Analysis Support System) is used for data storage and processing and information display through maps. Figure 32 describes LUCAS model.

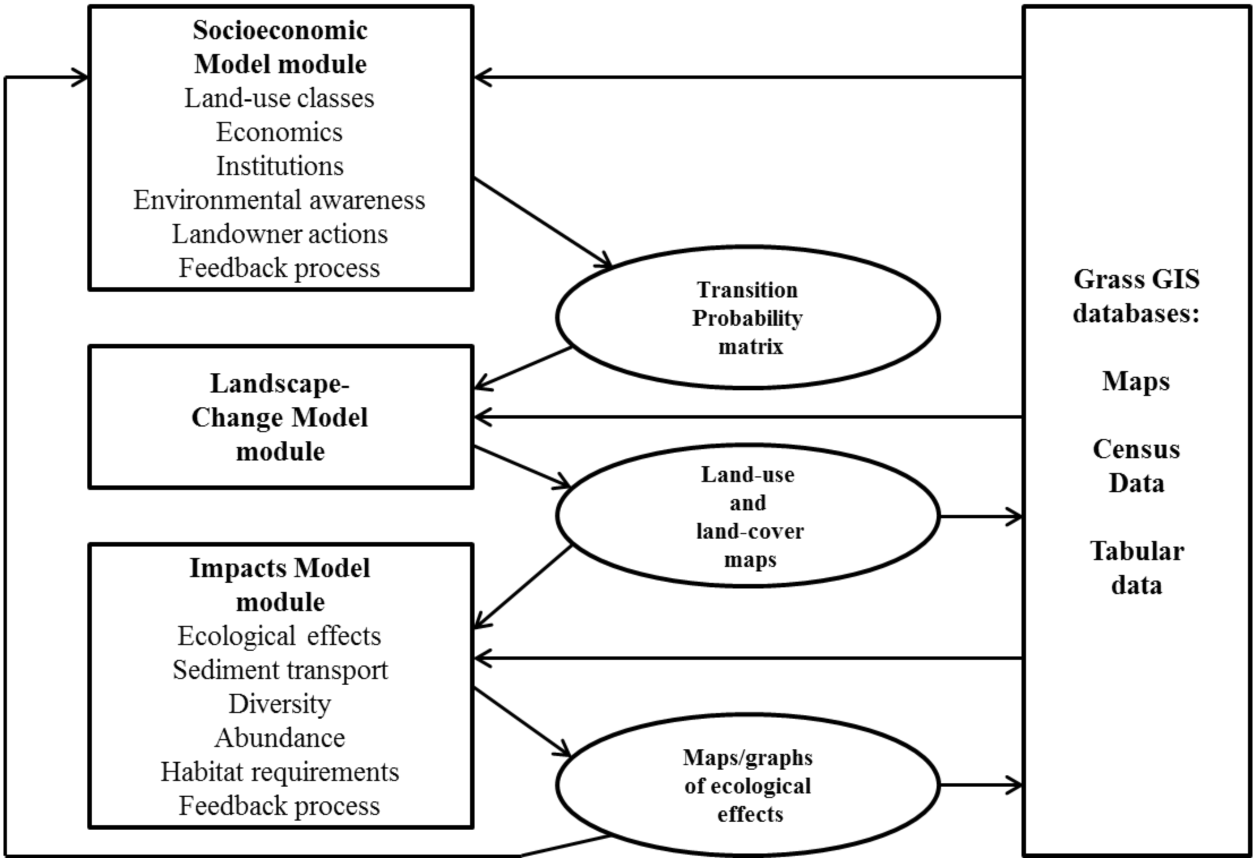


Figure 32: LUCAS Model (Adapted from: Berry et al., 1996)

3.5.4 Smart Places

Smart Places is a GIS based land use planning tool developed by the Consortium for International Earth Science Information Network (Croteau et al., 1997). It was designed to assist planners in decision making by evaluating alternative land use scenarios considering various parameters such as transportation costs, water use, energy consumption, etc. This tool was first applied in the greater area of Denver, CO. The system interface has two major components: a Scenario Builder for creating alternative land use scenarios and a Radix Evaluation Selection for evaluating the different land use scenarios. Smart Places advanced characteristics include: automatic calculation of attributes, automatic constraints checking, option for user defined attributes, data storage and retrieve options, multiple scenarios analysis, results display options and report generation.

3.5.5 TRESIS

The TRansportation and Environment Strategy Impact Simulator (TRESIS) is a tool designed to assist agencies and stakeholders in land use, transportation and environmental decision planning (Hensher and Ton, 2002). It was introduced in 2002 by the Institute of Transport Studies, University of Sydney. TRESIS is a user friendly online system in GIS interface for evaluating and predicting the impact of future transport, land use and environmental plans. It can be applied for a variety of research topics such as congestion pricing, fuel consumption and emission policies, new infrastructure development, land use change impact and existing public transport changes. The system structure includes a set of integrated models such as location, travel and vehicle choice models. Analysis at the household level focuses on applying models to determine residential/dwelling type and location. At the worker level, different submodels identify work location, mode choice and departure time. The option of traffic assignment is also available. Network files, vehicle demand functions, GIS maps and household profiles can be imported into the system. TRESIS has been applied for policy evaluation projects at the Sydney Metropolitan Area. Details are presented in Figure 33.

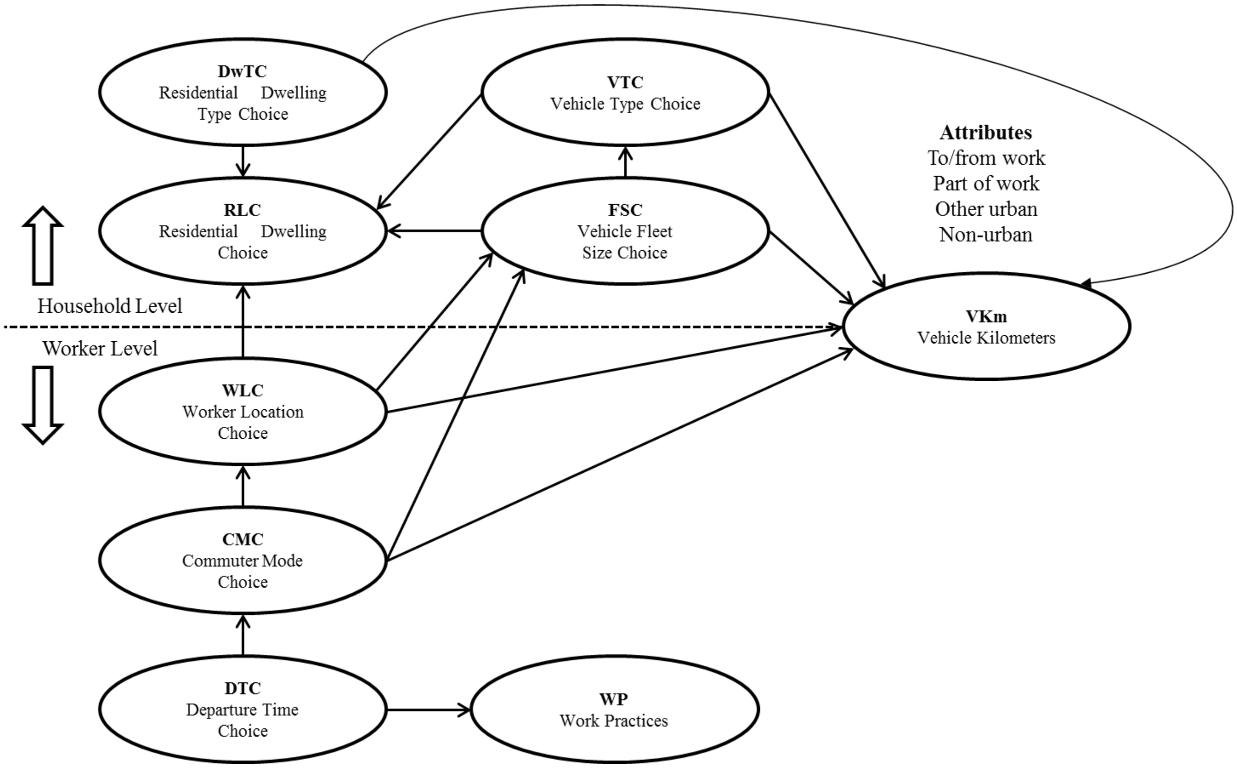


Figure 33: TRESIS Structure (Adapted from: Hensher and Ton, 2002)

3.5.6 I-PLACE3S

I-PLACE3S is the internet based version of the **PLA**nning for **C**ommunity **E**nergy, **E**conomic and **E**nvironmental **S**ustainability (PLACE3S) software, introduced in 2002 (PLACE^{3}S, 2010). The original version of PLACE3S was developed by the California, Oregon, and Washington State Energy Departments. I-PLACE3S is a scenario planning tool for evaluating land use development decisions and their impact on a study area. It evaluates the impact of planning decisions on land use, redevelopment potential, housing, employment and transportation (SLOCOG, 2010). Model outputs include population, household and employment estimates. I-PLACE3S allows growth allocation and has been designed to interact with separate travel models using a scripting language. GIS tools are used for data analysis and display. I-PLACE3S has been used by many U.S. agencies such as the Sacramento Area Council of Governments (SACOG), the San Luis Obispo Council of Governments (SLOCOG) and others.

3.5.7 Envision Tomorrow

Envision Tomorrow is a planning tool built to assist in developing and evaluating land use plans and decisions. It was first designed by Fregonese Associates of Portland, Oregon (Envisiontommorow, 2014). Data processing and analysis is based on Excel spreadsheets linked to a GIS add-on. The three major spreadsheets include: the building-level Prototype Builder spreadsheets, the scenario-level Scenario Builder spreadsheet, and individual modular models. Planning with Envision Tomorrow involves four major steps; develop Prototype Buildings, identify Development Types, create scenarios and finally evaluate these scenarios. Scenarios can be related to land use, housing, demographics, economic growth, fiscal impacts, transportation, environmental factors, etc. Envision Tomorrow includes a set of different models such as housing model, travel model, fiscal impact model and green infrastructure model. A later version of this tool, Envision Tomorrow Plus was developed by the Metropolitan Research Center (MRC) and the Fregonese Associates with advanced capabilities and characteristics. The users list includes among others the Southern California Association of Governments, the City of Portland, the Metro Regional Government, the City of Tulsa, the Chicago Metropolitan Agency for Planning, the City of Long Beach and others.

3.5.8 UrbanFootprint

UrbanFootprint is a land use scenario planning and data organization tool, developed by Calthorpe Associates (Calthorpe Associates, 2012). This tool can be used to evaluate the impact (environmental, fiscal, transportation, etc.) of planning decisions and policies. It’s a parcel based model that can be applied at the regional or state level. Scenario development is based on base year data that describe the existing land use conditions, demographics and environmental features. Planning process includes four major steps: data organization, translation of existing plans, scenario development and finally scenario analysis. The outputs from the model include: land consumption, emissions, household costs, infrastructure and operations costs, etc. The travel model of UrbanFootprint can produce information such as vehicle miles travelled (VMT), number of trips and mode choice. UrbanFootprint was validated by comparing the model outputs with other MPO models (SACOG, SCAG, SANDAG, etc.). The validity of the model results was confirmed. Many U.S. agencies are interested to integrate UrbanFootprint into their systems such as the Sacramento Area Council of Governments (SACOG) that is at the process of moving from I-PLACE^{3}S to UrbanFootprint. An Overview is presented in Figure 34.

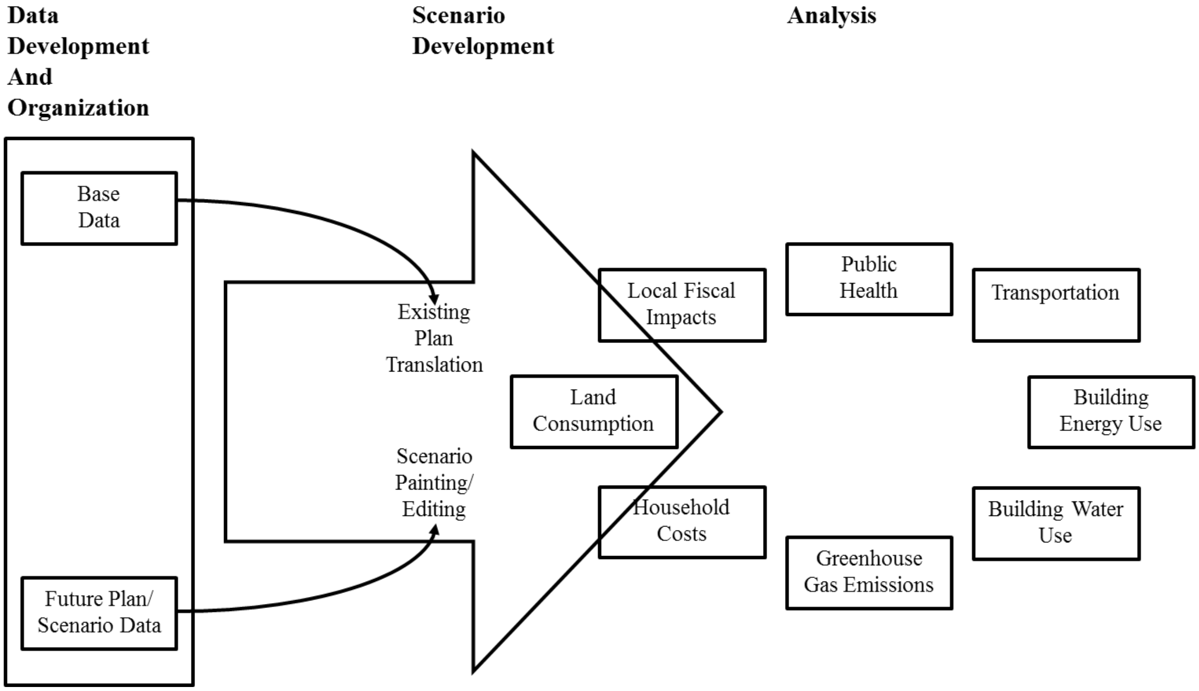


Figure 34 UrbanFootPrint Overview (Adapted from: Calthorpe Associates, 2012)

3.6 Other Models

3.6.1 LUTRIM

The Land Use-Transportation Interaction Model (LUTRIM) was developed in 1995 by William Mann (Zhao et al., 2006). LUTRIM is an integrated land use-transport model that introduced land use as the 5th step after the standard four step transportation planning process. The key factors of the modeling process are job and household accessibilities that are determined based on the gravity parameters of the corresponding trip distribution. Model inputs include previous land use forecasts, friction factors, socioeconomics factors and travel time matrix. These data inputs are utilized to produce household and employment forecasts considering accessibility changes.

3.6.2 ULAM

The Urban Land Use Allocation Model (ULAM) was first developed by Transportation Planning Services, Inc in 1996 (Transportation Planning Services, 2014). ULAM is a land use tool for allocating future growth and comparing alternative land use development patterns. The model focuses on allocating the population and employment changes from the county level to traffic analysis zones considering among others the available vacant area, the developable land and historical development/market trends (Zhao and Chung, 2006).The comparison of the alternative development scenarios is based on the changes of the land use density and the vacant acres. The ULAM Real Estate Market Index can be used to evaluate the impact of land use changes on transportation. The evaluation is carried out by ranking each traffic analysis zone for different types of land development based on the travel time and the accessibility to major activity destinations and the socio-economic characteristics of the study area. ULAM can also operate as part of an integrated land use-transport system. The model outputs can serve as major inputs into transportation systems. ULAM has been used by U.S. agencies, mainly in Florida and Tennessee, for research projects. The Nashville Area Metropolitan Planning Organization and the Knoxville Regional Transportation Planning Organization (TPO) in Tennessee used ULAM as one of the tools for developing and updating their 2030 Long Range Transportation Plan, respectively. ULAM has also been used by the Martin County MPO, the St. Lucie County TPO and the Okaloosa-Walton Transportation Planning Organization (TPO) in Florida.

3.6.3 SAM/SAM-IM

SAM (**S**ubarea **A**llocation **M**odel) was originally implemented in 1996 by the Maricopa Association of Governments (MAG) in the greater Phoenix area (Walton et al., 2000) as a land use model to forecast residences, employment and special population groups by TAZ. The release of more advanced GIS tools resulted in the development of the Subarea Allocation Model – Information Manager (SAM-IM), an updated version of SAM model. SAM-IM is a rule-based growth model, fully compatible with ArcView GIS, that was developed for land use allocation and forecasting. MAG has applied a three stage land use modeling process. At the first stage, a demographic model is utilized to create data at the county level. At the second stage, DRAM/EMPAL model is used to allocate county level population and employment data to the study region. At the final stage of land use analysis, SAM-IM is used to allocate the population and employment data from the regional level to specific Traffic Analysis Zones. SAM-IM and DRAM/EMPAL are designed to operate in an integrated environment with EMME/2 transportation model. Modeling process with SAM-IM starts with forecasting the expected growth for the target year. Then, the potential areas to facilitate the forecasted development are determined. The evaluation of the candidate areas follows and finally growth is allocated based on the evaluation ranking. One of the advanced characteristics of SAM-IM is the trip generation module that allows the generation of trip data based on land use modeling. An overview is provided in Figure 35.

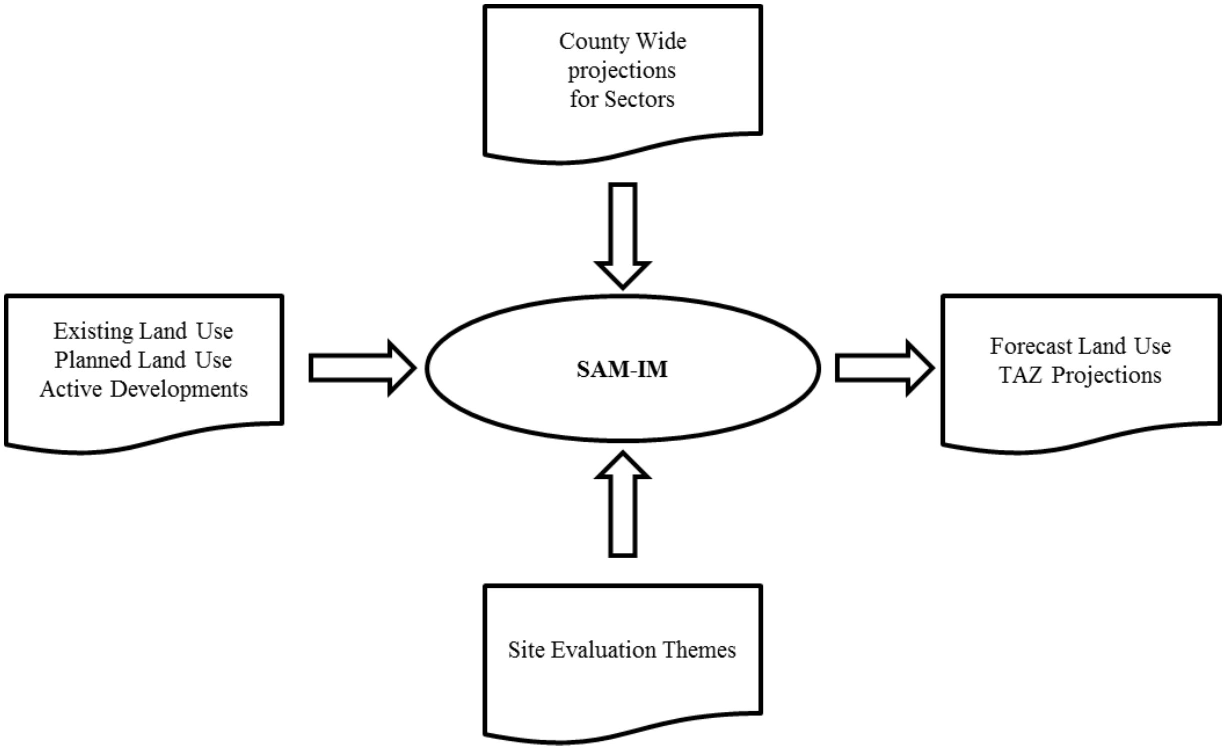


Figure 35: SAM-IM Model (Adapted from: Walton et al., 2000)

3.6.4 LUAM Model

The Land Use Allocation Model (LUAM) was developed by the North Front Range Metropolitan Planning Organization (NFRMPO) and AECOM in 2004 (NFRPMO, 2011). LUAM is a parcel based growth model for predicting population and employment future changes. Model development was based on the use of GIS platform and CommunityViz software. Model forecasts can assist planning organizations to determine future policies regarding transportation and economic development. A later version of LUAM model was developed by AECOM in 2009. This new version introduced three separate employment types: basic industry, retail and service. The new model also included attractiveness weights for different type of facilities, a Historic Trend Submodel for precisely distributing households to communities and a web based application, Crosswalk^{TM}, for joining data into a single dataset. Crosswalk^{TM} outputs include shapefiles with regional land use and facilities attractiveness and tables with employment and housing densities. These outputs are utilized as inputs for CommunityViz software to evaluate different planning scenarios. Housing and employment growth is estimated by multiplying households per acre and employees per acre by total parcel acreage for each developable parcel. Further research is now being carried out to integrate LUAM with the Florida Department of Transportation (FDOT) statewide model.

3.6.5 FLUAM

The METROPLAN ORLANDO's Future Land Use Allocation Model (FLUAM) was introduced in 2006 (Data Transfer Solution, LLC, 2006). FLUAM is a GIS, parcel based tool for predicting population and employment changes and distributing forecasted data to Traffic Analysis Zones (TAZ). Forecasts are initially distributed at the parcel level based on historical land use data and development trends and then are aggregated at the TAZ level. The aggregation at the TAZ level allows for developing transportation policies and plans to facilitate forecasted growth. A combination of Top-down and Bottom-up approaches are applied for distributing and aggregating the forecasted data. The major inputs into the model include existing and future land use data, land use development factors/growth forecasts, etc. FLUAM structure is described in Figure 36.

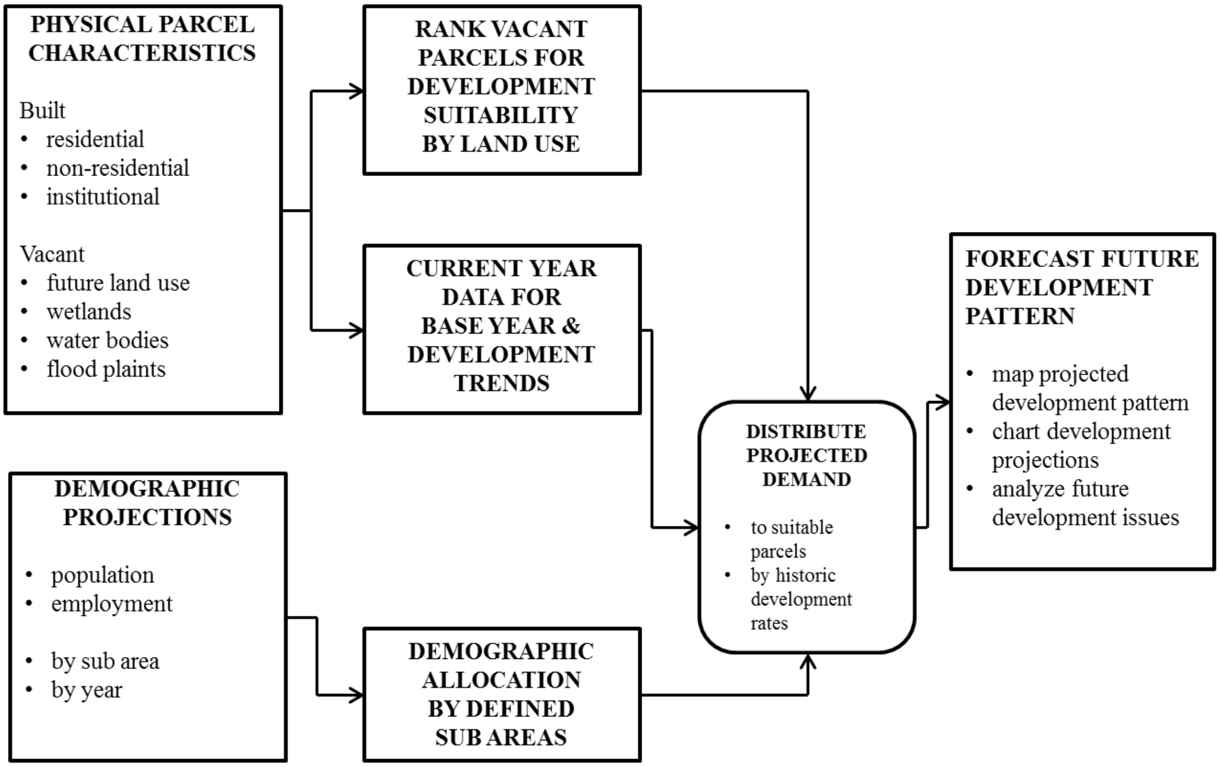


Figure 36: FLUAM Overview (Adapted from: Data Transfer Solution, LLC, 2006)

3.6.6 TELUM

TELUM is an integrated land use and transport model developed to evaluate the effects of land use on transportation planning (Spasovic, accessed 2013). It is part of the TELUS system, a computer based system developed to assist transportation agencies in decision management. TELUM was introduced in 2006, focusing to assist small and medium size MPOs to forecast the impact of future population and employment changes on land use. TELUM development was based on DRAM/EMPAL model and it's integrated with GIS tools. Model structure consists of five modules: i) IDEU module for initial data entry, ii) DOPU for data organization and preparation, iii) TIPU for travel impedance data processing, iv) MCPU for model calibration, and v) MFCU module for model forecasting. The software outputs include employment and household density, land consumption and density gradient. Different agencies such as the Missoula Area Council of Governments, the Des Moines (IA) and the Little Rock (AR) MPOs have used this model. The modeling process in TELUM is described in Figure 37.

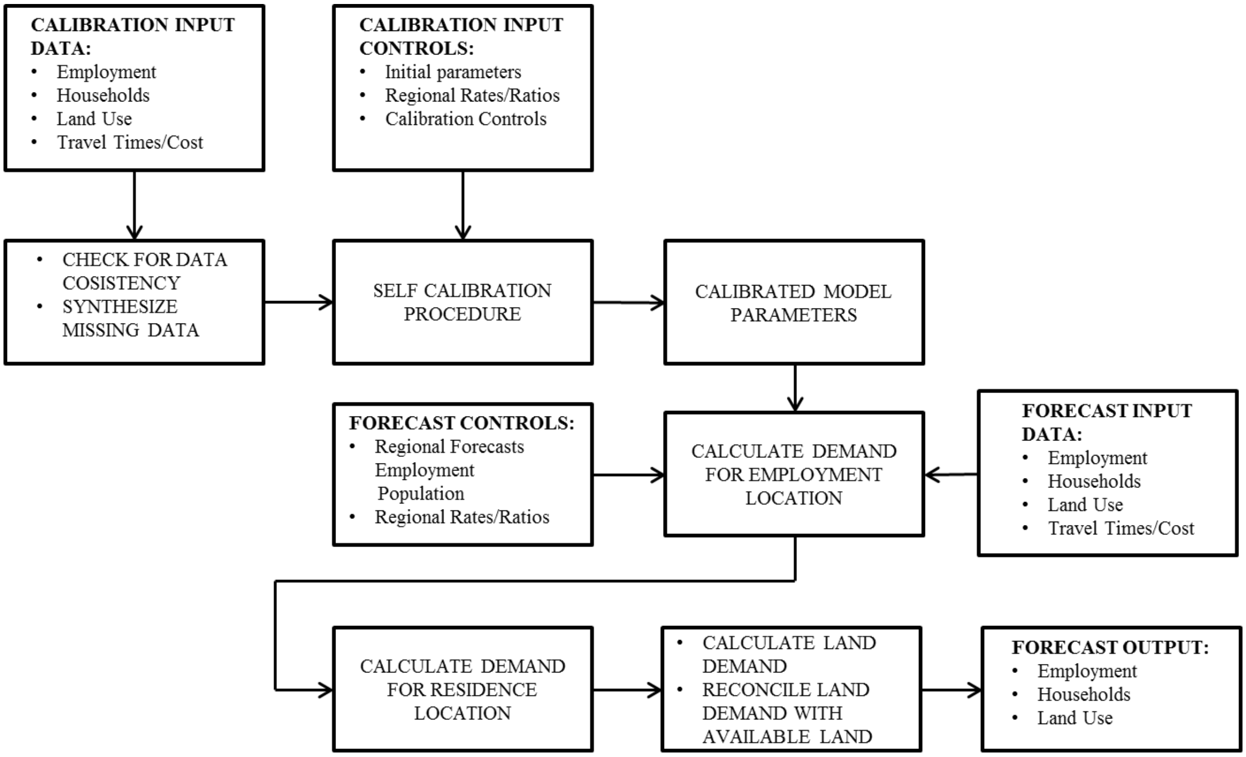


Figure 37: TELUM Modeling Process (Adapted from: Spasovic, accessed 2013)

3.6.7 G-LUM

Gravity Land Use Model (G-LUM) is a land use model developed by Professor Kara Kockelman and associates at the University of Texas at Austin (Valsaraj et al., 2007; Kakaraparthi et al., 2012). G-LUM was used to validate the outputs of TELUM. Model structure is based on the formulation of ITLUP package (Putnam, 1983) and includes three major sub-models for predicting changes on employment location, residential location and land consumption. G-LUM was developed in Matlab software and a GUI user interface is also available. Model calibration is based on the comparison of lag with base year data.

3.6.8 Land Use Allocation Model for Florida Turnpike

The Land Use Allocation Model (LUAM) was applied as part of the TSM (Turnpike State Model) integrated land use and transport model for the Florida Department of Transportation (FDOT) Turnpike Enterprise (Adler et al., 2007; Lawe et al., 2007). LUAM is a parcel based growth model, developed in C++. Processing time usually requires 2-4 minutes. LUAM focuses on the allocation of the forecasted population and employment. Land allocation at the zonal level is based on four major parameters: household and employment density, developable land and transportation accessibility.

Land consumption is estimated using a logit model that produces the probability of land development in specific traffic analysis zones. Housing and employment developments (density) are determined using a linear model. The model overview is presented in Figure 38.

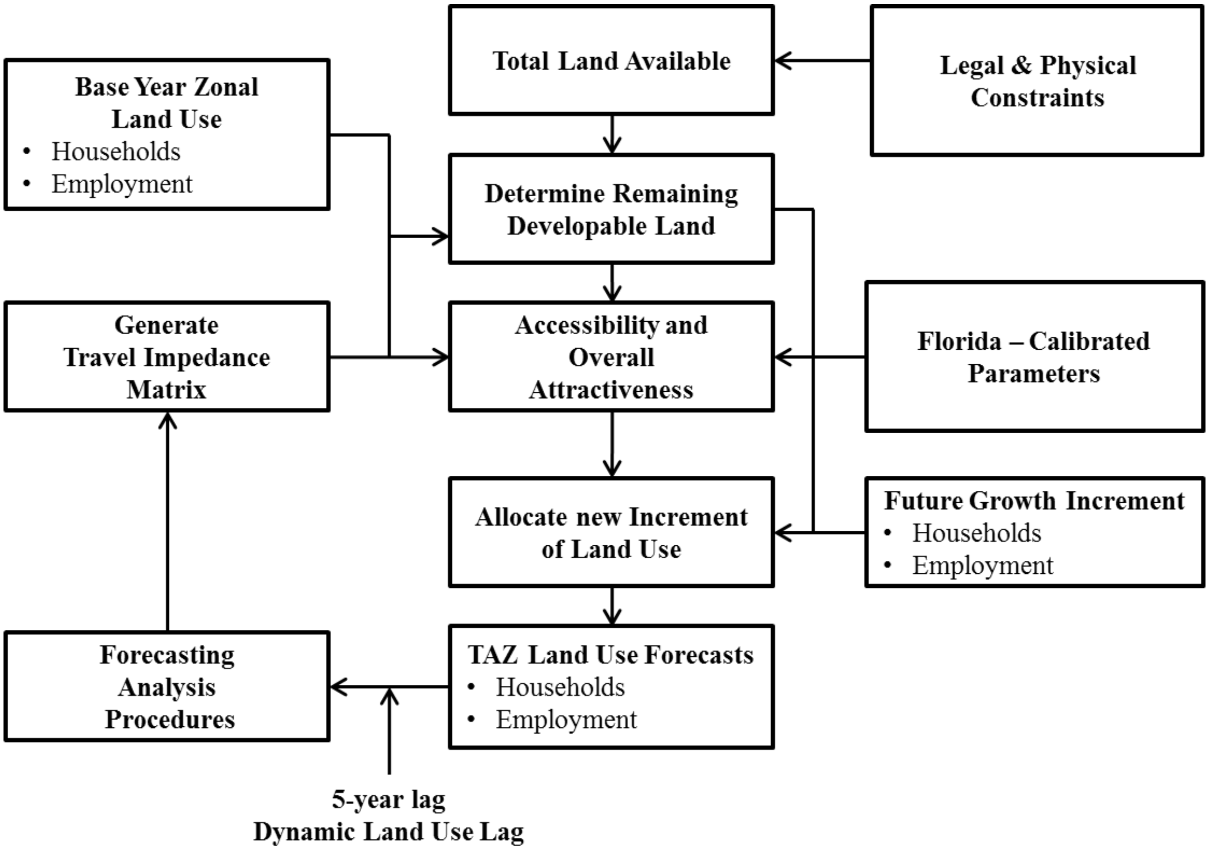


Figure 38: Model for Florida Turnpike-Modeling Approach (Adapted from: Lawe et al., 2007)

3.6.9 MARS

The Metropolitan Activity Relocation Simulator (MARS) was the result of a European project, PROSPECTS that stands for Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems (Pfaffenbichler et al., 2008). MARS is implemented in Vensim®, a dynamic programming environment. MARS is an integrated land use and transport system that provides a set of tools for evaluating the impact of land use/transport policies and planning decisions. The system comprises of different submodels such as a transport submodel, housing development and location choice submodels, workplace development and location choice submodels and an emissions/fuel consumption submodel. The outputs from the transport model such as accessibility serve as inputs into the land use model and the outputs from the land use model such as population and workplace data can be used as inputs into the transport model. This shows that the two models are completely interdependent. The transport model is used for analyzing the travel behavior of people related to the study area however the model does not provide the option of traffic assignment. The simulation period is thirty years however the data processing and total run time usually takes less than one minute. MARS has mainly been used in Europe and has also been implemented in three case studies in ASIA. Details are provided in Figure 39.

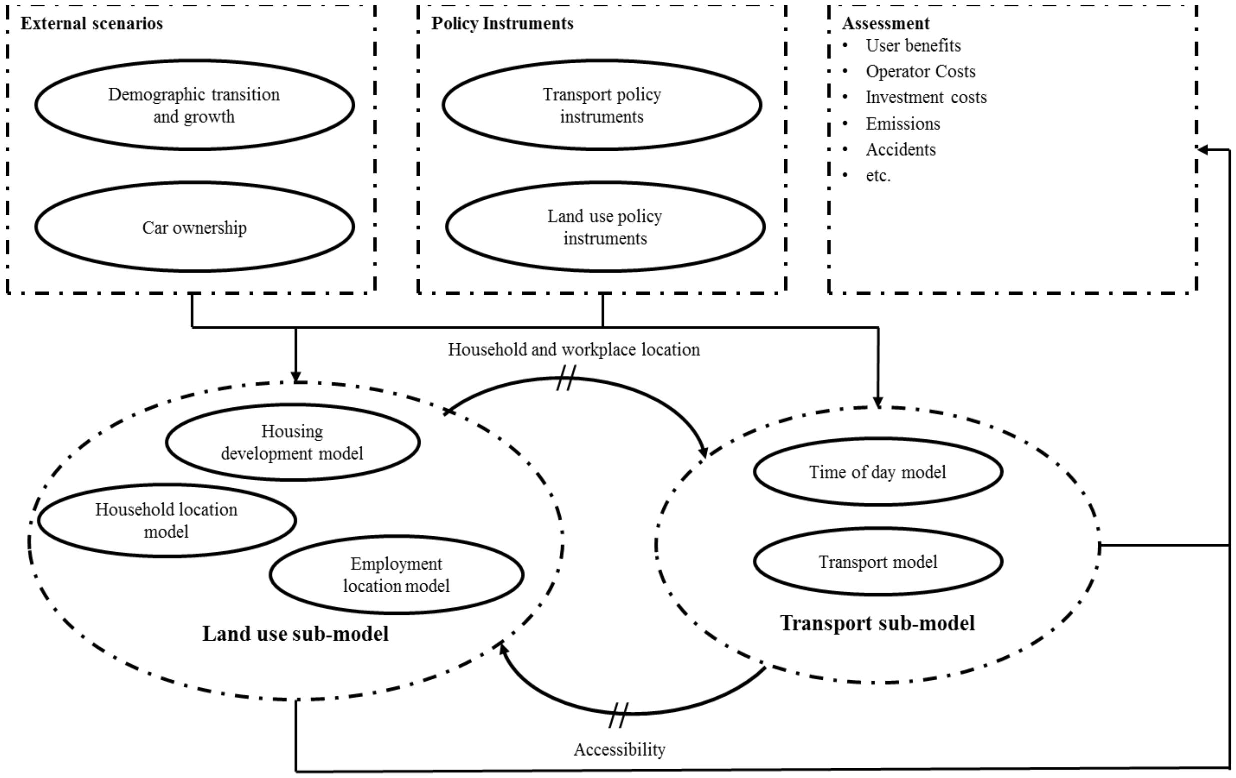


Figure 39: MARS-Model Overview (Adapted from: Pfaffenbichler et al., 2008)

3.6.10 LUTSAM

LUTSAM (**L**and **U**se and **T**ransportation **S**cenario **A**nalysis and **M**icrosimulation) was developed by two major partners; the Delaware Department of Transportation and the State Smart Transportation Initiative at the University of Wisconsin-Madison (Thompson-Graves et al., 2012; WR&A, 2013). LUTSAM is an evaluation tool of land use and transportation alternatives that integrates GIS, land use and travel demand modeling and microsimulation. LUTSAM is a GIS and parcel based model for evaluating smart growth policies, land use developments and investments such as bicycle and pedestrian facilities. Modeling inputs include road networks, layer information and traffic analysis zones and base maps. The scenario analysis and evaluation starts with the identification of the study area and the location of new developments. The study area is divided into sub-regions and then the land use type and the density of each sub-area are determined. The road network and the sidewalks are also specified. Home location and the connectivity with the sidewalks and the roadway are then identified. The last part of the modeling process focuses on merging the new roadways and sidewalks with the existing networks. LUTSAM has been designed to operate in an integrated environment and the corresponding outputs can be utilized as inputs for travel demand models and simulation software. The modeling process in LUTSAM is summarized in Figure 40.

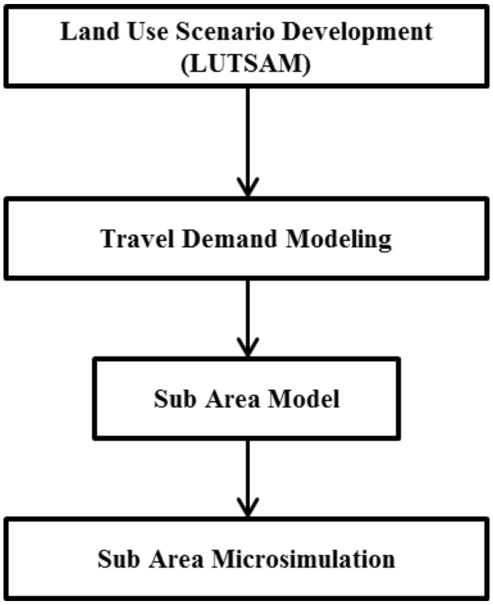


Figure 40: LUTSAM – Modeling Process (Adapted from: WR&A, 2013)

3.7 Models Short List

After carrying out a comprehensive literature review, the research team came up with a short list of operational land use/transport modeling systems. This short list includes URBANSIM, PECAS and G-LUM models. A comprehensive description is provided below:

3.7.1 URBANSIM

Overview

UrbanSim is a software based land use/transport system, developed by Paul Waddell at the University of Washington (Waddell, 2000; Waddell, Waddell, 2002). The rationale for developing UrbanSim was three fold: first to provide MPOs an efficient land use planning tool for growth management and policy evaluation, provide MPOS with a tool that can be integrated with existing travel models and finally develop a system that can be applied in multiple case studies with different characteristics (size, complexity, etc.). UrbanSim can primary be applied for evaluating the impact of alternative transportation, land use, and environmental policies. UrbanSim is open source accessed software that allows data analysis and processing on the grid, parcel or zone level. The software platform, called OPUS (Open Platform for Urban Simulation) was developed by the Center for Urban Simulation and Policy Analysis (CUSPA) at the University of Washington (Waddell et al., 2008). The option of integrating UrbanSim with travel demand models is available to users. Urbansim can be described as a microsimulation model that its modular structure is based on utility theory. Household and employment location choices, real estate development and prices can be modeled. A disaggregate classification of households is carried out, considering the number of individuals, workers, children and the income of each household. Employment is also classified in a disaggregate way, including 10-20 separate sectors. Twenty-four different types of real estate developments can be modeled. The model can also simulate disequilibrium market conditions in cases of unbalanced supply and demand.

Structure/Models

A set of different sub-models are included into the UrbanSim structure to capture the interaction of agent (households, businesses, developers, individuals, governments) choices (Waddell, 2002). The list of these models/modules includes:

- **Local and Regional Accessibility Model**: Determines the accessibility value of each zone of the study area, considering the accessibility of residents and employees to their destinations (shopping, employment, central business districts, etc.)
- **Economic and Demographic Transition Models**: The Economic model determines the number of jobs created or lost and the Demographic Transition model simulates the impact of births and deaths on the number of households created or lost.
- **Household and Employment Mobility Models**: The household and Employment mobility models identify the probability of a household and a job to move to a new location, respectively.
- **Household and Employment Location Models**: The household and Employment location models determine the location among a set of candidates for a new established household and job, respectively, based on land use patterns and prices, accessibility, real estate and market parameters.
- **Real Estate Development Model**: Multinomial land use models are applied to predict the probability of new structures development or redevelopment of existing ones. Different parameters that are considered include land use

patterns, policies, accessibility to population and major infrastructure such as arterials, highways, etc.

- **Land Price Model**: Simulates land price for each cell using economic theory. The model is calibrated based on historical data.

Figure 41 shows how the previously described sub-models interact as parts of the UrbanSim system.

Data Inputs

A large amount of data is required to develop model databases called the data store. Data inputs include census data, business establishment information and GIS maps with environmental, political and planning boundaries information (Waddell, 2002). Additional inputs for the model include: base-year land use patterns and plans, household, population and employment data, transportation plans and economic forecasts. Information for land-development policies and the related density and environmental constraints should be provided. Information for traffic analysis zones and development costs are also required (Waddell, 2008). The user can specify input scenarios that can be imported in UrbanSim and return forecasts of employment, housing and land use change for the target year.

Model Outputs

UrbanSim can provide a set of different outputs for each separate traffic analysis zone (Waddell, 2008). These outputs include: number of dwelling units, households classified by income, age, size, and number of children and business/employment information by industry. Different information for land use patterns such as land use acreage or land use value can be provided. The outputs from the travel model mainly include travel utility and travel time by mode. GIS tools are available for data visualization.

Model Applications

UrbanSim is one of the most widely used systems. Some of the major applications in U.S. agencies (UrbanSim Community Web, 2013) include: the Southeast Michigan Council of Governments in Detroit, the DCHC Metropolitan Planning Organization in North Carolina, the Lane Council of Governments in Springfield, Oregon, the Maricopa Association of Governments in Phoenix, Arizona, the Wasatch Front Regional Council in Salt Lake City, Utah the San Francisco County Transportation Authority and the County of San Francisco, the Puget Sound Regional Council in Seattle, Washington, the Houston-Galveston Area Council and the Alamo Area Council of Governments in San Antonio, Texas. UrbanSim has also been used for different case studies around the world including Amsterdam, Brussels, Burlington, Rome and Paris, Seoul, Taipei and Tel Aviv (Waddell, 2008).

Documentation

UrbanSim full documentation, including user manuals, research papers and publications is available at: http://www.urbansim.org/.

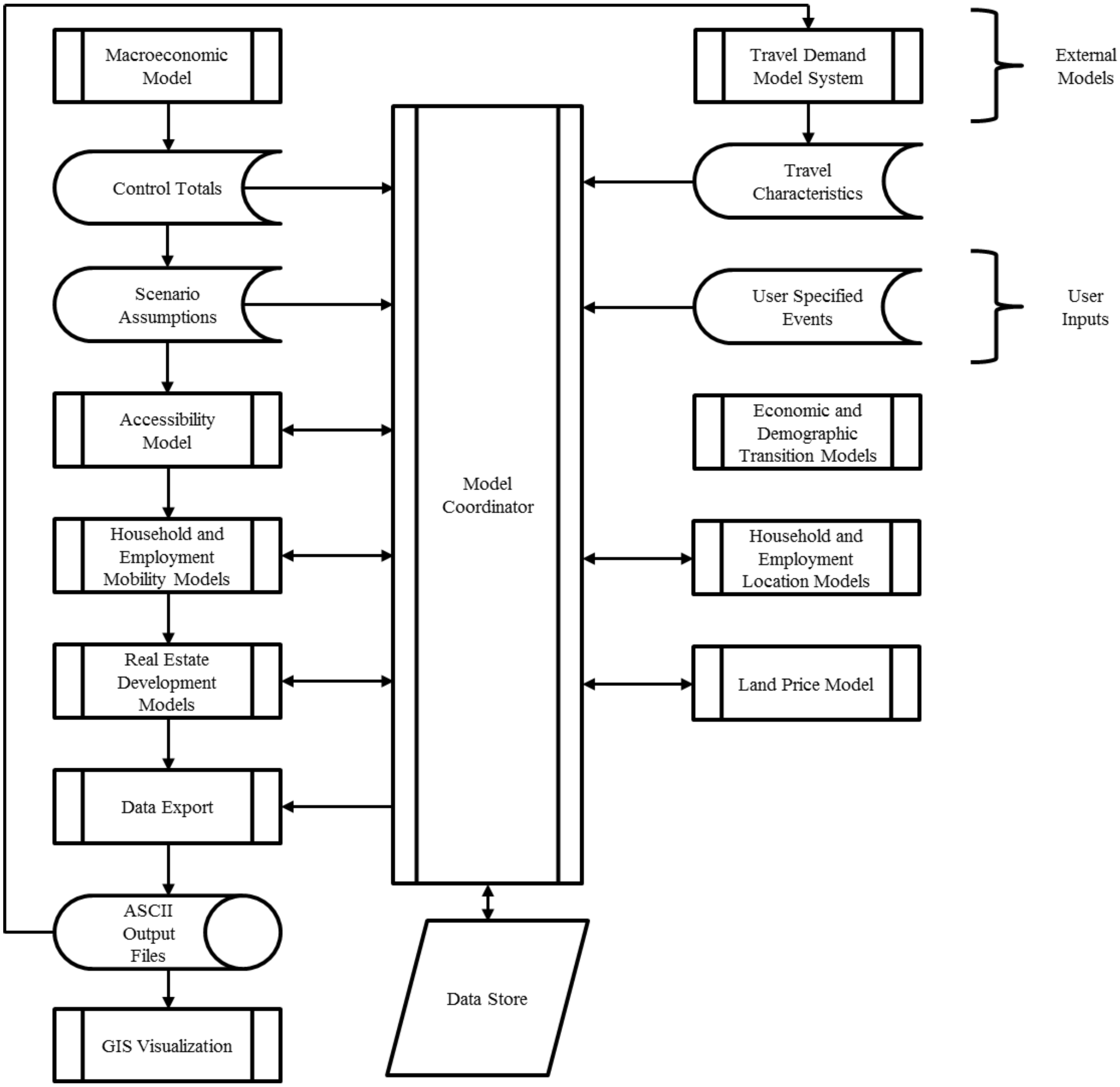


Figure 41: URBANSIM Structure (Adapted from: Waddell, 2002)

3.7.2 PECAS

Overview

PECAS (Production, Exchange and Consumption Allocation System) is a land use modeling tool designed to operate as part of integrated land use-transport systems (Waddell, 2011). The model was developed by Dr. Doug Hunt and Dr. John Abraham, at the University of Calgary to replace TRANUS land use model for the Oregon Department of Transportation. In contrast with similar models such as MEPLAN, PECAS can be considered as a microsimulation model that models the decisions of the agents (Industry, Government, Households). PECAS is a spatial input-output, econometric model for allocating flows of exchanges such as goods, services, labor and space from production to consumption points (Hunt et al., 2009). Land use consumption due to job and household growth can be simulated using Social Accounting Matrix (SAM). Nested Logit Models are applied to allocate flows based on exchange prices and market conditions. The exchange flows are then translated into transport demand for transportation networks. Unlike UrbanSim, PECAS model operates until the equilibrium between supply and demand is reached. PECAS has been applied for developing land use-transport interaction models in different case studies around the U.S.

Structure/Models

PECAS model consists of two PECAS and two non-PECAS modules that operate into an integrated environment (Hunt et al., 2009). The PECAS modules include:

- **Space Development (SD) module**: This module utilizes logit allocation models to identify the land and floor space changes due to developers actions (new developments, demolitions, etc.).
- **Activity Allocation (AA) module**: Logit models are also applied to allocate activities in space and model the interaction of activities through flows of commodities.

The two non-PECAS modules include:

- **Transport Model (TR) module**: An external transportation planning model is used to represent the transport network and the corresponding demands. The land use model and the transport model are integrated through the translation of commodity flows into travel demand.
- **Economic Demographic Aggregate Forecasting Model (ED) module**: ED module includes a set of different models to forecast household, population and employment future changes.

The integration of the different modules in the PECAS environment is described in Figure 42.

Data Inputs

PECAS model has extensive data requirements including parcel boundaries, land prices etc., that may not be available for the study region. In more details, the inputs for the Activity Allocation module include: economic flows, household and employment data, floorspace, transport costs, rents and commodity imports/exports. The Space Development module requires accessibility data (distance to infrastructure, highways, shopping centers, schools, etc.), existing land use types and plans (Waddell, 2011).

Model Outputs

The major outputs of PECAS model include commodity flows that can be translated into transport demands. Additional outputs include predictions of floorspace for a target year, residential/non-residential floorspace, activities allocation, rent change, household and job forecasts (HBA Specto Incorporated, 2010).

Model Applications

PECAS model has been involved in different projects for case studies mainly in the U.S. and Canada. Many U.S. Transportation agencies have integrated PECAS in their systems for land use planning and allocation. PECAS has been used by transportation agencies in the states of OHIO (Ohio Department of Transportation), Oregon (Oregon Department of Transportation) and California, in the Sacramento (Sacramento Council of Governments) and San Diego regions, the greater Atlanta area and the Baltimore region (HBA Specto Incorporated website, 2014). The model has also been applied at the greater areas of Calgary and Edmonton in Canada (Waddell, 2011).

Documentation

PECAS documentation, including user manuals and additional information is available at: http://www.hbaspecto.com/.

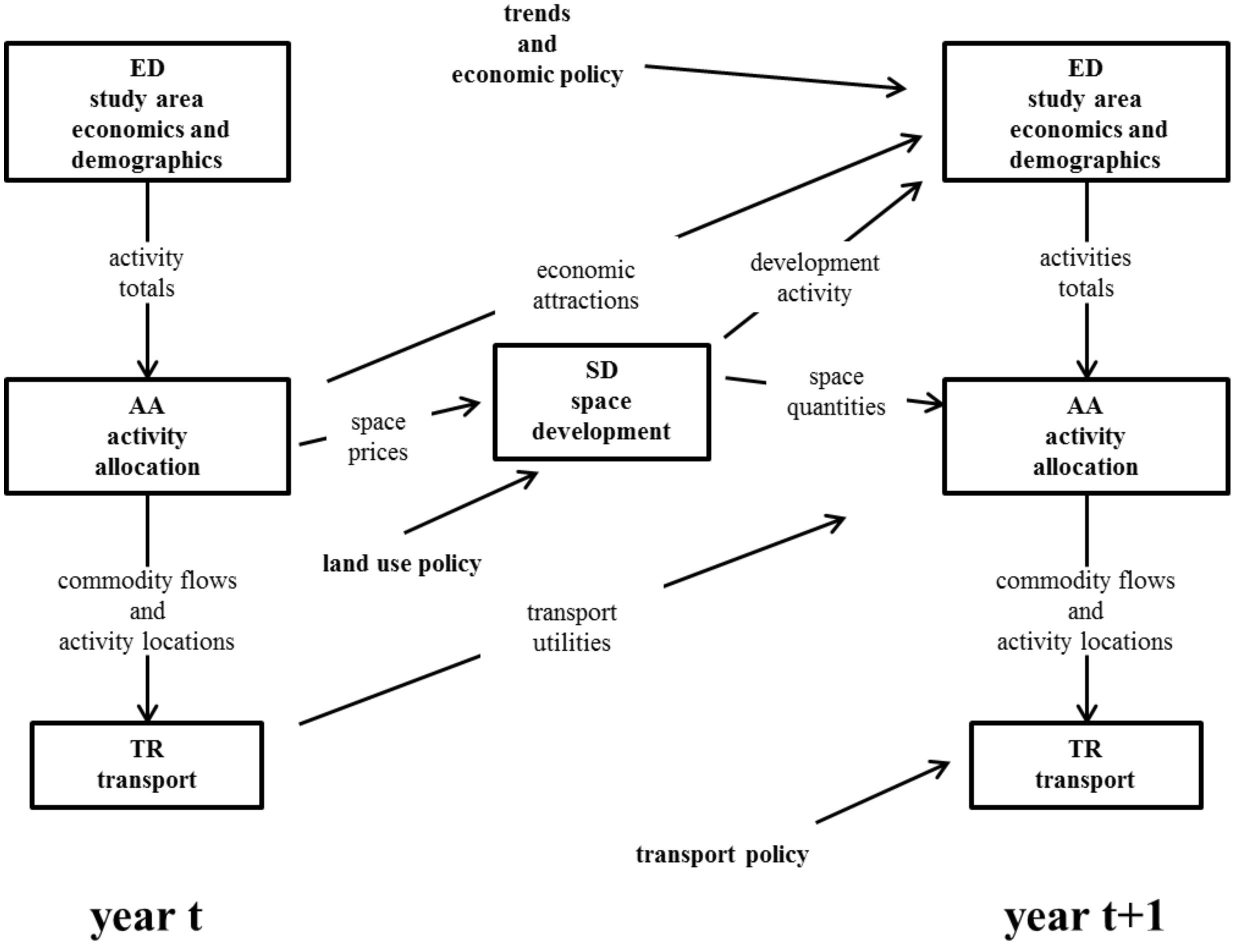


Figure 42: PECAS Structure (Adapted from: HBA Specto Incorporated, 2007)

3.7.3 G-LUM

Overview

G-LUM is a gravity and zone based land use model developed by Professor Kara Kockelman and her research team at the University of Texas at Austin (Valsaraj et al., 2007; Kakaraparthi et al., 2012). Model structure is based on the formulation of ITLUP package (Putnam, 1983) and includes three major sub-models for predicting changes on employment location, residential location and land consumption. G-LUM is freely available software and can be accessed by running either the GUI interface that has been developed or the corresponding Matlab code that is provided by the model developers. This model was primarily developed to overcome some restrictions related to TELUM model (zone size, land use density predictions) and also to validate the accuracy of TELUM outcomes. Model calibration is based on the comparison of lag with base year input data. G-LUM was selected for further consideration due to its simplicity and the relatively straightforward process for model application.

Structure/Models

As mentioned earlier, G-LUM consists of 3 major sub-models that are based on the equations that were introduced by Putman (1983) as part of the ITLUP/DRAM-EMPAL package. These sub-models are:

- **EMPLOC** (based on EMPAL model): for predicting the changes of employment location
- **RESOLC** (based on DRAM model) for determining future change of residential location
- **LUDENSITY**: for calculating land consumption based on the employment and residential changes.

The modeling process with G-LUM is described in Figure 43.

Data Inputs

Modeling process requires different input data for model calibration and prediction of future employment, residential and land consumption changes. The major input data required for calibration purposes include employment and household data for both lag and base years, and land use data (land consumed for basic employment, land consumed for non-basic employment, land consumed for residential use, land available for further development, unusable land and land consumed for streets and highways) for the base year. The size of each zone and inter-zonal travel times/costs are also required. The additional data needed for prediction purposes include forecasts with control totals of employment and household changes over the prediction time periods.

Model Outputs

Model outputs mainly include forecasts of employment and household distribution for the target year. Results can be provided for different employment categories (Basic, Services, Retail, etc.) and household types (Low Income, Medium Income, High Income, etc.) Forecasts of Land consumption change (land for basic, non-basic employment and residential use) are also available.

Model Applications

G-LUM has been applied in different case studies including Austin, San Antonio and Wago metropolitan regions.

Documentation

G-LUM documentation, including installation instructions, model description, case studies and additional information is available at: http://www.caee.utexas.edu/prof/kockelman/G-LUM_Website/homepage.htm. The GUI interface for G-LUM and the corresponding Matlab code are also available at the same webpage.

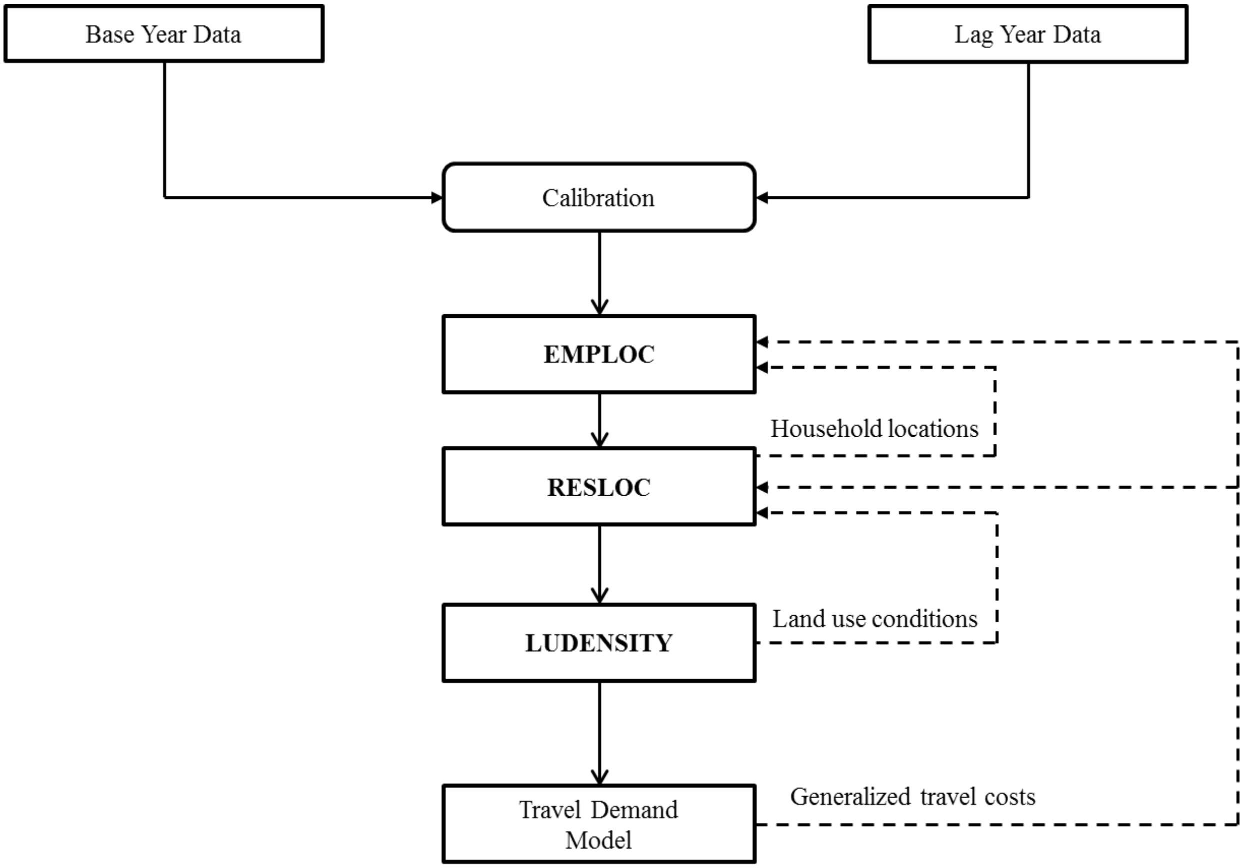


Figure 43: G-LUM Model (Adapted from: Kakaraparthi et al., 2012)

4. EVALUATION OF SELECTED MODELS

In this section some of the latest and more advanced models were selected for further evaluation. Twenty two land use models and planning tools were compared in terms of:

- Efficient Geographical Coverage
- Spatial Detail
- Incorporation of Freight Transportation
- Integration with Travel Demand Models
- Consideration of Multimodalilty
- Visualization capabilities

Regarding the Geographical Coverage, most of the model developers claim that land use models can be efficiently applied at the regional level. However, validation results that prove the accuracy of the outputs from land use models have been provided only in few case studies.

The new land use micro-simulation models such as UrbanSim, ILUTE, etc. provide multiple options for developing cell, parcel and zone based models. Similarly, since the majority of land use planning tools are GIS based, these tools also provide different options of spatial detail levels of analysis (cell, parcel and zone).

Freight movement is a significant aspect of both the transportation planning and economic success of a region. Therefore, the consideration of freight transportation in integrated land use-transport modeling becomes crucial. However, after carefully reviewing the characteristics of existing models, it was concluded that the importance of freight is not efficiently represented.

Significant progress has been made in the field of integrating land use with travel demand models. The integration of latest land use models (e.g. UrbanSim, PECAS, ILUTE, etc.) with activity-based travel models has been efficiently accomplished in many cases. The option of integrating land use with trip based demand models is also available. Also, trip based demand models are moderately integrated with some of the available land use planning tools.

The majority of the existing models allow the consideration of different transportation modes in transportation analysis. Also, different visualization tools (tables, graphs, etc.) for output representation are available. The conclusions that were extracted after comparing the different model characteristics are summarized in Table 1.

Table 1: Land Use Models' Comparison

	Land Use Model	Efficient Geographical Coverage	Spatial Detail			Freight Transport	Travel Demand Model Integration		Multi-modality	Visualization
			Zone	Parcel	Cell		Trip Based	Activity Based		
1	*UrbanSIM*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
2	*PECAS*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
5	*ILUTE*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
6	*What if*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
8	*U-Plan*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
9	*PUMA*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
10	*LEAM*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
11	*SLEUTH*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
12	*ILUMASS*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
13	*LUSDR*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
14	*LandSys*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
15	*CommunityViz*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
16	*INDEX*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
18	*Smart Places*	Regional level	☐	☐☐	☐	☐	☐	☐	☐	☐
19	*TRESIS*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
20	*I-PLACE3S*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
21	*Envision Tomorrow*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐
22	*UrbanFootprint*	Regional level	☐	☐	☐	☐	☐	☐	☐	☐

✓	Well represented
⊘	Moderately represented

5. CHALLENGES FOR THE RESEARCH COMMUNITY

The evolution of land use models is significant considering the introduction of advanced micro-simulation models and the first spatial interaction models. However, after the evaluation of selected models it was found that even these advanced models face a number of limitations that create the need for further research in the area of land use modeling. Next these limitations are briefly discussed.

Accuracy of Land Use Models at Finer Geographic Level

Researchers have focused on the development of land use models at finer geographies such as grid cell level (e.g., 30 m x 30 m) and utilization of precise development patterns. Evolution of CA based models allowed the vision to obtain grid cell level land use developments. However, three challenges have not been addressed: (1) availability of microscopic level data (building level data, parcel level land growth, detailed transportation network, etc.) to achieve higher precision of land use (2) computational requirement to analyze such models is quite large, that makes it very difficult to analyze multiple scenarios, (3) difficulty to accurately validate the models at ground level. Despite these challenges opportunities exist for land use models to capture finer geographic scales.

Computational Resources Requirement

With evolution of micro-simulation and agent based models, computational performance has become demanding. Newer generation of land use models require over a day (in simulation time) to simulate one year land patterns for small/moderate metropolitan areas. Such computational times are the result of behavioral patterns and complexity of land use and socioeconomic interactions embedded in land use models. Often empirical based land use models may not require high computational time, but this comes at a cost of accuracy of forecasts. With advancement of network cluster based computing it remains a challenge for land use models to utilize the new technology and reduce computational time while maintaining high levels of accuracy.

Visual Demonstrations versus Computational and Data Requirement Complexity

The visualization of the outputs from land use models has always been an issue. Current models provide different options for presenting output including: tabular form, graphs and animation. However, detailed and efficient results representation created the need for more advanced visualization methods. To accommodate these needs, land use software keep evolving. Few examples include the development of GeoCanvas (tool for 3D map visualization) and UrbanCanvas (tool for 3D data visualization and data editing) to integrate with UrbanSim for additional and more detailed visual demonstration of results. A major drawback to the development of such tools is the extensive data requirements. The data required for such applications should be provided separately for each building (type, value, land area, dimensions, stories, year built, etc.), household (number of persons, income, workers, cars, etc.), person (age, sex, employment status, education, etc.) and geographic area (dimensions, land value, land use per parcel/zone). For large case studies, the amount of information and data needed to be collected and processed become extremely difficult to handle. Reducing the amount of data required and the corresponding processing time can be two challenging tasks for further research to address.

Evolving Indicators and their Linkages to Transportation Models

A number of land use models (e.g., UrbanSim, PECAS, MEPLAN) are well integrated with a travel demand model, while others require additional integration efforts. Transportation model indicators have changed from the era of TEA, ISTEA, SAFETEA-LU, and MAP-21. New measures such as connectivity, accessibility and reliability are attracting more attention both in research and practice. While connectivity and accessibility are embedded in land use models to some degree, reliability is not. Other evolution of transportation indicators such as resilience, and vulnerability are hard to capture in land use models and should be addressed.

Land Use Methodology to Address Commodity Flows and Freight Movement Patterns

Forecasting of freight demand has become essential in land use and transportation planning to systematically plan for future infrastructure needs. One of the critical factors in freight and land use is commodity flows. Other factors include location factors, physical factors, operational factors, dynamic factors such as seasonal variations in demand and changes in customers' preferences, and pricing. Modeling commodity flows with land use is one possible first step; however, it has some limitations as land use data lacks detailed information on economic activities, in particular land use. The commodity flow survey conducted by census every five years captures only three to five percent of observations of the total population and cannot provide the amount and accuracy level required by these models. Further, the propriety nature of freight data makes it difficult to obtain information on commodity type, value, geographic information etc. It will remain as a challenge how to integrate land use models with freight commodity flows and capture economic growth patterns.

Uncertainty in Future Policy and Growth

Risk assessment of alternative policy choices or infrastructure investments have been widely studied in the transportation research area and are introduced in the gamut of land use modeling as well. Few examples include (1) the potential residential and commercial land use for the greater Life Science Center (LSC) proposed in Montgomery County and (2) the potential replacement of the Alaskan Way Viaduct in Seattle, Washington (Waddell, 2011). The former study found that, based on existing, approved, and proposed development, LSC could yield a maximum of 9,012 additional dwelling units to complement a projected total of 52,500 jobs. The resulting ratio of 5.8 jobs per dwelling unit is based on the existing housing in the greater LSC area and is often not accounted in the mixed land use development. This is an example of the differences between the vision of the county planners and the state planners for future of Montgomery County. The latter study evaluated risks (from the damaged of the viaduct by an earthquake) that the elevated waterfront freeway will collapse in the next earthquake (Waddell, 2011). The risk of catastrophic failure is a very tangible one, and the timing of this is inherently uncertain. Analyzing such events remains a challenge in the context of land use modeling.

Location Choice and Evolution of Freight Facilities

Freight demand is anticipated to increase significantly in the future, growing, nationally, by over sixty percent over the next twenty-five years. It is imperative to plan prudently to accommodate freight-generating industries as freight drives a larger share of employment and their location choices. The freight industry, at large, is quite dynamic as the evolving policies such as off-peak hour delivery, same day deliveries, dynamics of international supply chains (e.g., expansion of Panama Canal, reshoring to Mexico from China), can have a significant impact on location of distribution centers, intermodal facilities, etc. Evolution of such factors is quite challenging to capture in the modeling context. It remains to be seen how land use models can be better coordinated to accommodate freight and reduce its impacts by adopting “Freight as a Good Neighbor” strategies, adopting sustainable freight land use policies and practices, and accounting for freight physical and operational needs and impact mitigation through zoning.

6. A SYNTHETIC EXAMPLE FOR DEMONSTRATION PURPOSES

This chapter provides an overview of a synthetic example developed for demonstrating the forecasting capabilities of land use models and the potential outputs that can be produced. A case study area of approximately 161,310 acres was analyzed. The study area consists of seventy-five zones (Figure 44).

Figure 44: Case Study Area

A scenario was developed that considered 2005 as the lag year and 2010 as the base year of analysis. Forecasts of employment, household and land use change were provided for five year prediction periods up to 2035.

6.1 Model Selection

G-LUM model was applied for demonstration purposes. G-LUM was selected as it provides a faster and relatively straightforward model implementation. As described before, G-LUM is a land use model developed by Kara Kockelman and associated investigators at the University of Texas at Austin. The model includes three major sub-models (Valsaraj et al., 2007):

***EMPLOC*:** sub-model that focuses on employment change. The formulation for EMPLOC calibration is presented in equations 1 through 3 (Kakaraparthi et al., 2012):

$$E_{j,t}^{k} = \lambda^{k} \sum\nolimits_{i} N_{T,i,t-1} A_{i,t-1}^{k} M_{j,t-1}^{k} c_{i,j,t}^{\omega^{k}} \exp\left(p^{k} c_{i,j,t}\right) + (1-\lambda^{k}) E_{j,t-1}^{k} \tag{1}$$

$$A_{i,t-1}^{k} = \left[\sum_{l} (E_{l,t-1}^{k})^{a^{k}} (L_{l})^{b^{k}} c_{i,l,t}^{\omega^{k}} \exp\left(\beta^{k} c_{i,l,t}\right)\right]^{-1} \tag{2}$$

$$M_{j,t-1}^{k} = (E_{j,t-1}^{k})^{a^{k}} (L_{j})^{b^{k}} \tag{3}$$

where:

$E_{j,t}^{k}$: is employment of type k in zone j at time t

$\lambda^{k}, \omega^{k}, p^{k}, a^{k}, b^{k}, \beta^{k}$: are parameters considered in model calibration

$N_{T,i,t-1}$: is the total number of households in zone i at time $t-1$

L_{j}: is the total area of zone j

$M_{j,t-1}^{k}$: is the attractiveness of zone j for employment of type k at time $t-1$

***RESOLC*:** sub-model that focuses on residential location change. The formulation for RESLOC calibration is presented in equations 4 through 7 (Kakaraparthi et al., 2012):

$$N_{i}^{n} = n^{n} \sum_{j} Q_{i}^{n} B_{j}^{n} W_{i}^{n} c_{i,j,t}^{a^{n}} \exp\left(\beta^{n} c_{i,j,t}\right) + (1-n^{n}) N_{i,t-1}^{n} \tag{4}$$

$$Q_{j}^{n} = \sum_{k} a_{k,n} E_{j,t}^{k} \tag{5}$$

$$B_{j}^{n} = \left[\sum_{i} W_{i}^{n} c_{i,j,t}^{a^{n}} \exp\left(\beta^{n} c_{i,j,t}\right)\right]^{-1} \tag{6}$$

$$W_{i,t-1}^{n} = (L_{i,t}^{v})^{q^n} (x_{i,t})^{r^n} (L_{i,t}^{r})^{s^n} \prod_{n'} \left[\left(1 + \frac{N_{i,t-1}^{n'}}{\sum_n N_{t,t-1}^{n}} \right)^{b_{n'}^{n}} \right] \qquad (7)$$

where:

N_i^n: is the number of households of type n in zone i at time t

$n^n, a^n, \beta^n, q^n, r^n, s^n, b_{n'}^n$: are parameters considered in model calibration

$c_{i,j,t}$: is the impedance between zones i and j at time t

$a_{k,n}$: is the number of type n households per type k employee

$E_{j,t-1}^k$: is employment of type k in zone j at time t

$L_{i,t}^v$: is the developable land in zone i at time $t-1$

L_j^r: is the residential land in zone i at time $t-1$

x_i: is the proportion of developable land already developed in zone i at time t

$Q_{j,t}^n$: converts employment to households

W_i^n: is the attractiveness of zone i for household of type n at time $t-1$

***LUDENSITY*:** sub-model that focuses on estimating land consumption based on employment and residential changes. The formulation related to LUDENISY sub-model is presented in equations 8 through 10 (Kakaraparthi et al., 2012):

Residential Land Use

$$\frac{L_{r,i,t}}{N_{T,i,t}} = K_0 L_{D,i,t}^{k_1} \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{k_2} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{k_3} \left(\frac{E_{c,i,t}}{L_{T,i,t}}\right)^{k_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{k_5} \left(\frac{N_{2,i,t}}{L_{T,i,t}}\right)^{k_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{k_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{k_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{k_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{k_{10}} \qquad (8)$$

Basic Land Use

$$\frac{L_{b,i,t}}{E_{b,i,t}} = g_0\left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{g_1}\left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{g_3}\left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{g_4}\left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{g_5}\left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{g_6}\left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{g_7}\left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{g_8}\left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{g_9}\left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{g_{10}} \quad (9)$$

Commercial Land Use

$$\frac{L_{c,i,t}}{E_{c,i,t}} = p_0\left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{p_1}\left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{p_3}\left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{p_4}\left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{p_5}\left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{p_6}\left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{p_7}\left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{p_8}\left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{p_9}\left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{p_{10}} \quad (10)$$

where:

L_b: is the amount of land for basic employment

L_c: is the amount of land for commercial employment

$L_{d,}$: is the amount of developed land

E: is the employment by type (b: for basic and c: for commercial including both services and retail employment)

N: is number of households by type

k, g, p: are estimated parameters

A complete dataset with employment, household and land use information for the study area should be developed before the model implementation. Data preparation and inputs are described in the following section.

6.2 Data Preparation

Five major data categories (employment data, household data, land use data, zone data and inter-zonal travel times) are required for model implementation. G-LUM requires fourteen files with input data for model calibration and forecasting. Employment and household data need to be provided for both the lag and base years for model calibration. Employment information by zone was classified into three categories (Basic, Non-basic/services and retail) and was provided for both the lag (2005) and base (2010) years. Employment inputs are presented in Table 2 and Table 3.

Table 2: Employment Inputs for Lag Year

Employment Data_Lag Year (2005)			
Zone ID	**Basic**	**Non-Basic**	**Retail**
525	80	262	101
526	11	73	164
527	153	724	35
528	138	386	77
529	42	196	54
530	61	226	73
531	172	387	13
532	39	457	10
533	158	343	123
534	146	1398	185
535	27	367	2
536	58	699	92
537	65	897	959
538	126	918	239
539	211	3412	939
540	40	399	814
541	1095	8710	665
542	17	303	7
543	49	541	109
544	200	3142	725
545	62	523	36
546	133	997	347
547	183	2160	668
548	51	331	241
549	6	74	0
550	107	6449	167
551	204	2159	61
552	122	340	33
553	94	459	720
554	197	467	35
555	11	184	27
556	614	11438	3318
557	43	904	269
558	28	374	40
559	17	417	28
560	6	127	6
561	16	691	29
562	275	4647	477

Employment Data_Lag Year (2005) (Table 2 Cont.)			
Zone ID	**Basic**	**Non-Basic**	**Retail**
563	58	791	340
564	96	2334	54
565	38	434	227
566	26	1208	73
567	94	1562	199
568	1338	10271	1843
569	1238	5645	396
570	1061	5875	1641
571	30	473	413
572	59	492	1128
573	270	1281	328
574	45	471	24
575	163	3179	171
576	42	776	325
577	89	1184	445
578	496	4017	274
579	233	1628	37
580	70	859	28
581	101	442	24
582	34	1060	53
583	62	1007	20
584	58	597	185
585	746	2218	464
586	272	537	308
587	920	2151	315
588	907	4046	358
589	107	553	87
590	13	420	106
591	20	102	20
592	1867	5385	853
593	197	846	390
594	159	1639	197
595	290	985	184
596	83	494	149
597	2854	7642	731
598	27	369	112
599	39	698	78

Table 3: Employment Inputs for Base year

Employment Data_Base Year (2010)			
Zone ID	**Basic**	**Non-Basic**	**Retail**
525	160	633	31
526	54	353	119
527	94	688	3
528	129	896	35
529	16	372	21
530	74	526	95
531	104	753	2
532	34	138	4
533	131	768	121
534	69	958	5
535	23	2145	3
536	45	903	7
537	106	1389	844
538	96	1237	37
539	253	3500	363
540	60	566	814
541	832	6565	779
542	7	98	2
543	48	507	43
544	229	3351	254
545	55	614	9
546	80	958	211
547	80	1550	684
548	32	628	159
549	1	14	1
550	258	7883	11
551	157	2302	197
552	166	671	9
553	92	1076	680
554	52	384	75
555	5	388	1
556	500	8296	3147
557	64	881	193
558	10	344	26
559	7	272	2
560	13	202	5
561	25	807	2
562	134	6946	89

Employment Data_Base Year (2010) (Table 3 Cont.)			
Zone ID	**Basic**	**Non-Basic**	**Retail**
563	41	917	166
564	60	1414	64
565	16	470	27
566	12	400	5
567	119	1718	97
568	1355	14391	1067
569	1062	7045	272
570	881	6253	890
571	115	1427	819
572	118	1569	692
573	78	1654	299
574	21	380	10
575	292	3660	50
576	42	923	217
577	54	1630	40
578	405	3332	372
579	200	1844	1
580	57	1025	157
581	102	797	2
582	113	1470	25
583	24	1058	2
584	40	546	108
585	624	2428	244
586	233	1266	144
587	920	3165	45
588	987	5984	131
589	56	518	93
590	73	501	0
591	7	11	0
592	2210	5008	278
593	124	596	724
594	57	477	256
595	141	671	92
596	107	308	13
597	2943	8921	830
598	30	571	31
599	83	931	97

Household data were also provided for both the lag and base years. Households were classified in four separate categories based on the corresponding income (Low, Medium, Medium-High, High). Table 4 and Table 5 present the household input data for the lag and the base year, respectively.

Table 4: Household Inputs for Lag Year

Household Data_Lag Year (2005)				
Zone ID	**Low Income**	**Med Income**	**Med-High Income**	**High Income**
525	295	325	413	443
526	124	136	174	186
527	196	216	275	294
528	188	206	263	282
529	113	125	159	170
530	98	108	137	147
531	179	196	250	268
532	91	100	127	136
533	257	283	360	386
534	365	401	511	547
535	60	67	85	91
536	504	555	706	756
537	383	421	536	575
538	230	253	322	345
539	408	449	572	613
540	240	264	336	360
541	269	296	377	404
542	254	279	356	381
543	310	341	434	465
544	432	476	605	648
545	279	307	390	418
546	359	395	503	539
547	534	587	747	801
548	244	269	342	367
549	72	80	101	108
550	127	140	178	191
551	304	334	425	456
552	260	286	364	390
553	104	114	145	155
554	187	206	262	281
555	44	49	62	66
556	718	790	1006	1077
557	476	524	667	714
558	505	556	707	758
559	487	536	682	731
560	152	168	213	229
561	312	343	437	468
562	366	402	512	548

Household Data_Lag Year (2005) (Table 4 Cont.)				
Zone ID	**Low Income**	**Med Income**	**Med-High Income**	**High Income**
563	229	252	320	343
564	644	709	902	966
565	343	377	480	514
566	216	238	303	325
567	640	704	896	960
568	107	118	150	161
569	192	212	269	289
570	0	0	0	0
571	271	298	379	406
572	74	82	104	111
573	367	403	513	550
574	148	163	208	222
575	196	216	275	294
576	534	587	748	801
577	150	165	210	225
578	478	526	669	717
579	265	292	371	398
580	374	411	523	560
581	313	344	438	469
582	317	349	444	476
583	647	711	905	970
584	323	356	452	485
585	389	428	544	583
586	231	254	323	346
587	98	107	137	147
588	40	44	56	60
589	493	543	691	740
590	208	229	291	312
591	195	215	273	293
592	7	8	10	11
593	522	574	731	783
594	570	627	798	855
595	35	39	49	53
596	73	81	102	110
597	73	80	102	109
598	271	298	379	406
599	267	294	374	401

Table 5: Household Inputs for Base year

Household Data_Base Year (2010)				
Zone ID	**Low Income**	**Med Income**	**Med-High Income**	**High Income**
525	288	317	403	432
526	117	129	164	176
527	198	218	277	297
528	180	198	252	270
529	111	122	155	166
530	101	111	142	152
531	172	189	241	258
532	86	95	120	129
533	314	345	439	471
534	349	384	488	523
535	60	66	85	91
536	502	552	702	752
537	383	421	536	574
538	214	235	299	320
539	433	476	606	649
540	249	274	348	373
541	241	265	337	362
542	249	274	349	374
543	313	345	439	470
544	416	457	582	624
545	347	382	486	521
546	350	385	491	526
547	563	619	788	844
548	244	268	341	365
549	69	76	97	104
550	68	75	95	102
551	238	262	333	357
552	265	292	372	398
553	97	106	136	145
554	186	205	261	280
555	50	55	70	75
556	714	785	1000	1071
557	488	537	683	732
558	476	524	666	714
559	472	520	661	709
560	148	163	207	222
561	337	371	472	506
562	379	417	530	568

Household Data_Base Year (2010) (Table 5 Cont.)				
Zone ID	**Low Income**	**Med Income**	**Med-High Income**	**High Income**
563	220	242	308	330
564	588	647	824	883
565	313	345	438	470
566	209	230	293	314
567	709	780	992	1063
568	102	112	143	153
569	187	206	262	281
570	1	1	1	1
571	307	338	430	461
572	71	79	100	107
573	369	406	517	554
574	154	169	216	231
575	188	206	263	281
576	540	594	756	810
577	164	180	229	245
578	474	522	664	711
579	256	281	358	383
580	402	443	563	604
581	336	369	470	503
582	321	353	449	482
583	634	698	888	952
584	339	372	474	508
585	395	434	552	592
586	229	252	321	344
587	149	164	209	224
588	37	40	52	55
589	486	534	680	728
590	204	224	285	305
591	192	211	268	287
592	0	0	0	0
593	478	525	669	716
594	581	640	814	872
595	44	49	62	66
596	60	66	84	90
597	75	82	105	112
598	265	292	371	398
599	404	444	565	605

Land use data inputs need to be provided only for the base year. Six separate categories with land pattern information are required:

- **Land_b**: amount of land (acres) used for basic employment
- **Land_c**: amount of land (acres) used for non-basic or commercial employment
- **Land_d**: amount of undeveloped land (acres) that is available for future development
- **Land_r**: amount of land (acres) used for residential purposes
- **Land_s**: amount of land (acres) used for the road network
- **Land_u**: amount of land (acres) that cannot be further developed

Land use inputs are summarized in Table 6 below:

Table 6: Land Use Inputs

Land Use Data (Acres)_Base Year (2010)						
Zone ID	**Land_b**	**Land_c**	**Land_d**	**Land_r**	**Land_s**	**Land_u**
525	13	27	11619	144	500	1600
526	4	19	4990	59	150	300
527	8	28	8304	99	400	1800
528	10	37	6411	90	52	250
529	1	16	3437	55	68	50
530	6	25	3742	51	103	60
531	8	30	6563	86	381	50
532	3	6	4065	43	159	60
533	10	36	944	157	111	500
534	6	39	7432	174	78	400
535	2	86	2325	30	400	40
536	4	36	2966	251	102	70
537	8	89	1129	191	53	30
538	8	51	373	107	25	600
539	20	155	729	216	195	20
540	5	55	610	124	100	20
541	67	294	279	121	50	22
542	1	4	407	125	130	300
543	4	22	517	157	76	800
544	18	144	967	208	102	28
545	4	25	1417	174	53	30
546	6	47	669	175	58	36
547	6	89	863	281	48	32
548	3	31	2601	122	69	25
549	0	1	259	35	75	27
550	21	316	963	34	112	250
551	13	100	6792	119	200	50
552	13	27	6801	133	300	150
553	7	70	3803	48	323	62
554	4	18	3753	93	350	60
555	0	16	1405	25	248	40
556	40	458	12	357	60	38
557	5	43	275	244	169	41
558	1	15	80	238	200	250
559	1	11	258	236	146	39
560	1	8	153	74	142	320
561	2	32	173	169	103	22
562	11	281	173	189	242	28

Land Use Data (Acres)_Base Year (2010) (Table 6 Cont.)						
Zone ID	**Land_b**	**Land_c**	**Land_d**	**Land_r**	**Land_s**	**Land_u**
563	3	43	547	110	170	31
564	5	59	500	294	258	28
565	1	20	193	157	135	27
566	1	16	567	105	122	35
567	10	73	356	354	272	41
568	108	618	249	51	168	24
569	85	293	301	94	203	28
570	70	249	0	0	30	27
571	9	90	310	154	159	31
572	9	90	33	36	10	35
573	6	78	1656	185	215	22
574	2	16	349	77	60	24
575	23	148	438	94	169	36
576	3	46	0	270	345	37
577	4	67	29	82	146	35
578	32	148	662	237	42	29
579	16	74	404	128	103	41
580	5	47	161	201	242	500
581	8	32	2041	168	200	1500
582	9	60	317	161	210	37
583	2	42	427	317	150	31
584	3	26	275	169	100	200
585	50	107	944	197	150	28
586	19	56	788	115	103	21
587	74	128	820	75	50	33
588	79	245	801	18	128	32
589	4	24	1896	243	195	20
590	6	20	1722	102	39	40
591	1	0	398	96	50	38
592	177	211	374	0	130	35
593	10	53	236	239	202	320
594	5	29	590	291	102	38
595	11	31	67	22	53	35
596	9	13	629	30	145	23
597	235	390	1152	37	89	20
598	2	24	292	133	50	300
599	7	41	179	202	125	400

A matrix sample with travel times (seconds) between the zones of the study area that were used for calibrating RESLOC and EMPLOC sub-models are presented in Table 7 .

Table 7: Inter-zonal Travel Time

Zone ID	525	526	527	528	529	530	531	532	533	534	535	536	537
525	254	508	520	748	892	1011	1034	1256	1142	1079	1598	…	…
526	508	160	571	433	796	670	692	915	801	737	1257	…	…
527	520	571	260	542	681	893	1013	1235	1121	1058	1334	…	…
528	748	434	542	217	470	458	578	801	686	623	1123	…	…
529	892	797	681	470	235	821	941	1061	946	580	826	…	…
530	1030	672	893	458	821	229	463	731	617	464	1017	…	…
531	1041	639	1024	589	952	463	223	515	471	446	1000	…	…
532	1309	907	1292	858	1061	731	515	98	197	567	859	…	…
533	1202	800	1186	751	946	668	471	197	98	453	745	…	…
534	1133	731	1088	677	580	464	446	567	453	223	502	…	…
535	1614	1256	1334	1123	826	1017	1000	859	745	502	155	…	…
536	1355	953	1339	904	1238	821	713	572	458	745	998	…	…
537	1486	1084	1469	1034	1199	932	843	650	572	706	904	…	…
538	1302	900	1285	850	1016	748	659	502	388	523	720	…	…
539	1614	1212	1597	1163	1427	1079	971	831	716	988	795	…	…
540	1661	1259	1644	1209	1471	1126	1018	877	763	1050	839	…	…
541	1701	1299	1684	1249	1384	1166	1058	917	803	1061	752	…	…
542	1521	1119	1504	1070	1235	967	878	722	608	742	799	…	…
543	1495	1093	1478	1044	1209	941	853	696	582	716	643	…	…
544	1709	1307	1692	1258	1559	1174	1066	925	811	1067	928	…	…
545	1910	1508	1894	1459	1684	1375	1267	1127	1013	1190	1129	…	…
546	1619	1217	1603	1168	1447	1084	976	836	722	954	1030	…	…
547	1472	1070	1456	1021	1355	938	830	689	575	862	969	…	…
548	1445	1043	1428	994	1103	835	802	646	532	610	599	…	…
549	1817	1528	1537	1326	992	1138	1243	1229	1115	943	813	…	…
550	1884	1595	1604	1394	1060	1205	1311	1367	1252	1010	880	…	…
551	1932	1663	1653	1442	1108	1273	1379	1414	1300	1057	935	…	…
552	1391	1228	1111	901	566	930	1036	1161	1047	680	926	…	…
553	1448	1185	1168	958	623	795	901	888	774	532	428	…	…
554	1667	1405	1388	1177	844	1015	1121	1358	1244	957	879	…	…
555	1595	1238	1316	1105	808	999	982	841	727	484	380	…	…
556	1917	1515	1762	1466	1254	1381	1274	1133	1019	931	646	…	…
557	1857	1455	1588	1377	1079	1271	1214	1058	944	756	472	…	…
558	1778	1376	1738	1326	1229	1223	1135	978	864	905	597	…	…
559	1948	1591	1668	1457	1160	1351	1333	1193	1079	836	552	…	…
560	1707	1349	1427	1217	919	1110	1093	952	838	595	311	…	…
561	1883	1595	1604	1393	1059	1204	1310	1210	1096	854	569	…	…
562	…	…	…	…	…	…	…	…	…	…	…	…	…
563	…	…	…	…	…	…	…	…	…	…	…	…	…

The size (acres) of each zone is also required by G-LUM. This information is presented in Table 8 below:

Table 8: Zone Size

Zone ID	Size (Acres)		Zone ID	Size (Acres)
525	13901.99		**563**	904.56
526	5521.68		**564**	1143.76
527	10638.4		**565**	532.77
528	6850.9		**566**	845.97
529	3627.04		**567**	1105.42
530	3986.11		**568**	1218.78
531	7118.95		**569**	1002.89
532	4334.79		**570**	376.89
533	1758.43		**571**	752.17
534	8128.5		**572**	214.05
535	2882.63		**573**	2161.9
536	3428.8		**574**	527.6
537	1500.85		**575**	908.33
538	1163.22		**576**	700.69
539	1335.9		**577**	363.3
540	914.87		**578**	1150.66
541	831.9		**579**	765.71
542	965.92		**580**	1156.15
543	1575.91		**581**	3949.36
544	1466.67		**582**	793.34
545	1702.39		**583**	969.92
546	990.9		**584**	773.22
547	1320.54		**585**	1476.23
548	2850.37		**586**	1101.36
549	396.09		**587**	1179.32
550	1695.16		**588**	1303.17
551	7273.59		**589**	2382.77
552	7424.31		**590**	1929.22
553	4313.72		**591**	582.38
554	4278.23		**592**	926.95
555	1733.96		**593**	1059.69
556	964.83		**594**	1054.14
557	776.59		**595**	218.82
558	783.61		**596**	847.9
559	690.49		**597**	1924.37
560	697.88		**598**	801.33
561	501.08		**599**	954.01
562	924.33			

Finally, control totals of employment and households change over the prediction period were provided. Forecast data of control totals were developed assuming a ten percent increase between the subsequent prediction periods (Table 9 and Table 10).

Table 9: Control Totals of Employment Change

Prediction Year	Basic	Non-Basic	Retail
2015	19907	160425	19187
2020	21897	176468	21106
2025	24087	194114	23217
2030	26496	213526	25538
2035	29145	234878	28092

Table 10: Control Totals of Households Change

Prediction Year	Low Income	Med Income	Med-High Income	High Income
2015	23045	25349	32263	34567
2020	25349	27884	35489	38024
2025	27884	30673	39038	41826
2030	30673	33740	42942	46009
2035	33740	37114	47236	50610

6.3 Model Application and Results

Model developers provide two options for implementing G-LUM, a GUI interface and a Matlab version.

The Matlab code is freely provided by the model developers (Kara Kockelman and associated investigators) and can be accessed at: http://www.caee.utexas.edu/prof/kockelman/G-LUM_Website/homepage.htm.

Some steps that will allow the faster model implementation using Matlab code are:

1. Extract three separate folders: a. Code, b. Data and c. G-LUM Finale from the download folder
2. Save each folder separately at “C: drive”
3. Open “GUI_code.m” file and save it as “GUI_brenda.m” into “C:\Code”
4. Add the following paths in Matlab software:
    a. addpath c:\Code\
    b. addpath c:\Data\
    c. addpath c:\G-LUM' Finale'\
5. Run “GUI_code.m” file in Matlab

G-LUM implementation starts with calibrating the parameters of EMPLOC and RESLOC submodels using Entropy-maximization. Then, LUDENSITY model parameters are calibrated based on the Non-Linear Least Square methodology (Kakaraparthi et al., 2012). The prediction of employment, household and land use changes follow based on the input data for the lag and base years.

As mentioned earlier, five-year prediction periods were identified up to 2035 for this case study. A complete list of G-LUM outputs for each prediction period is provided in Appendix B. A snapshot of the forecast outputs from G-LUM that shows the predicted changes for the future years of 2020 and 2030 compared to the base year (2010), is presented in the following figures.

Figure 45 shows the forecasted changes comparing the employment (number of employees) of the base year to the predicted employment for the years 2020 and 2030. Employment is expected to increase in approximately seventy percent of the zones that are included in the study area until 2020 and an increase of approximately 15 percent is expected to occur between 2020 and 2030. G-LUM also provides the option of predicting employment change by type (Basic, Commercial and Retail).

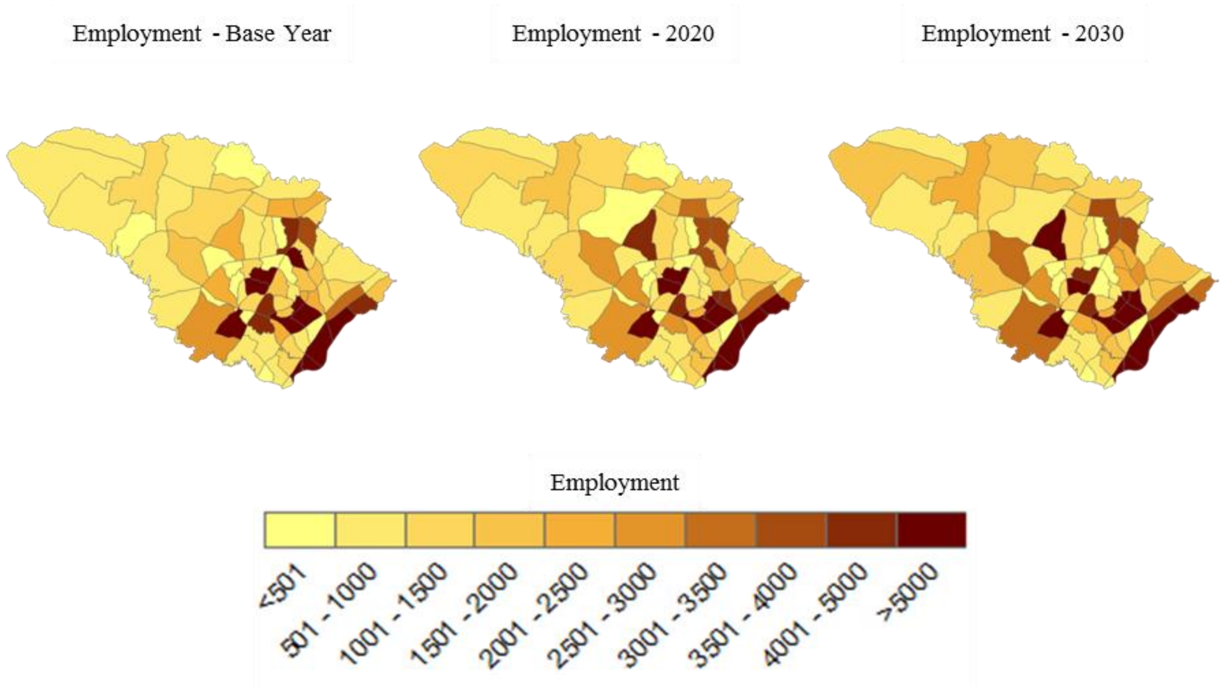


Figure 45: Forecast of Employment Change

Figure 46 focuses on the potential changes of household distribution (number of households). A household increase is expected to occur in fifty-five percent of the zones between the base year and 2020. A more significant increase is predicted for the years between 2020 and 2030 as approximately seventy-five percent of the zones of the study area are expected to accommodate more households. Forecasts of household change can also be provided by household income (Low, Medium, Medium-High and High).

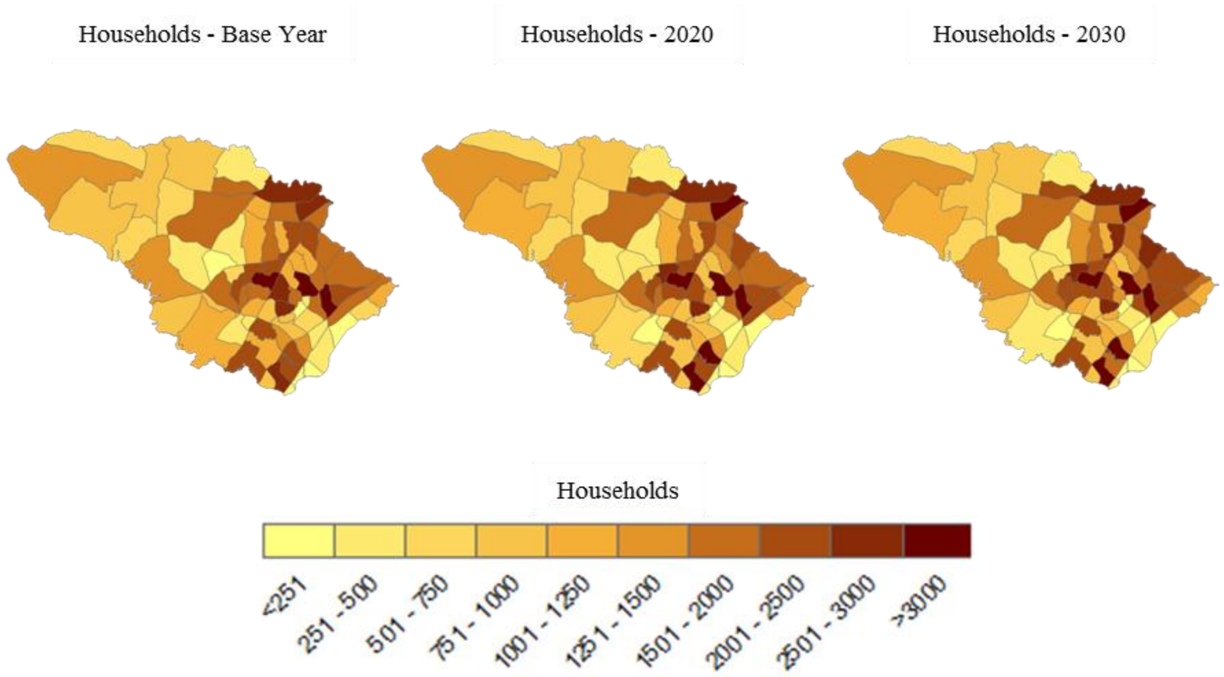


Figure 46: Forecast of Household Change

Forecasts of land use change can also be produced using G-LUM. Figure 47 shows the expected change of the land (acres) dedicated for Basic employment. Not significant changes are expected to occur between the base year and 2020 since the control total at the county level was not high as well. The land consumption for basic employment is expected to significantly increase at the suburbs of the study area between 2020 and 2030.

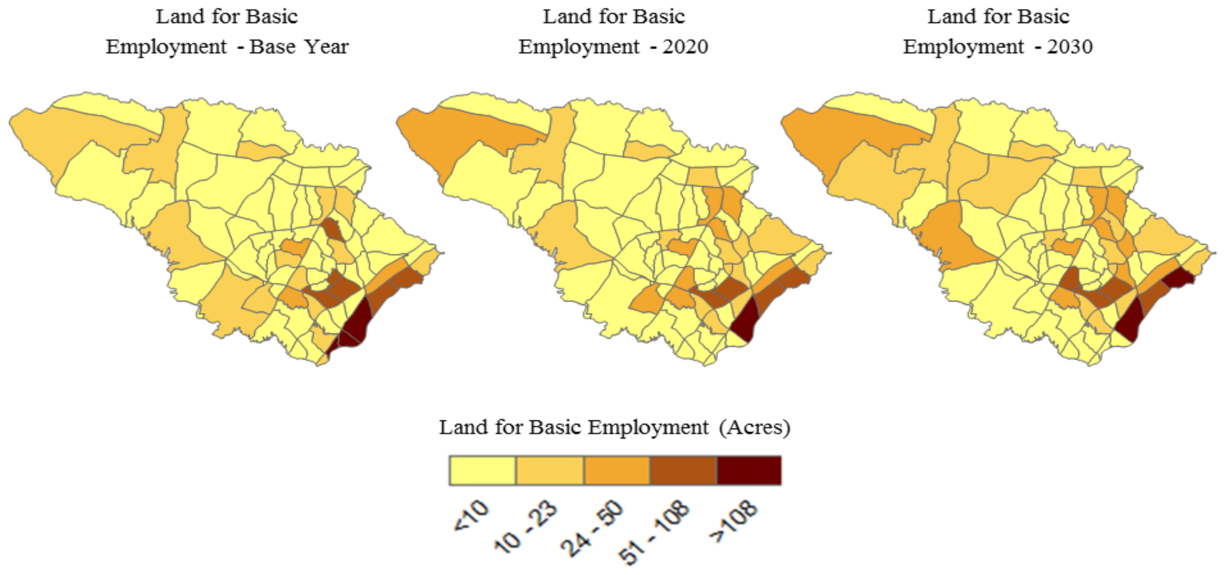
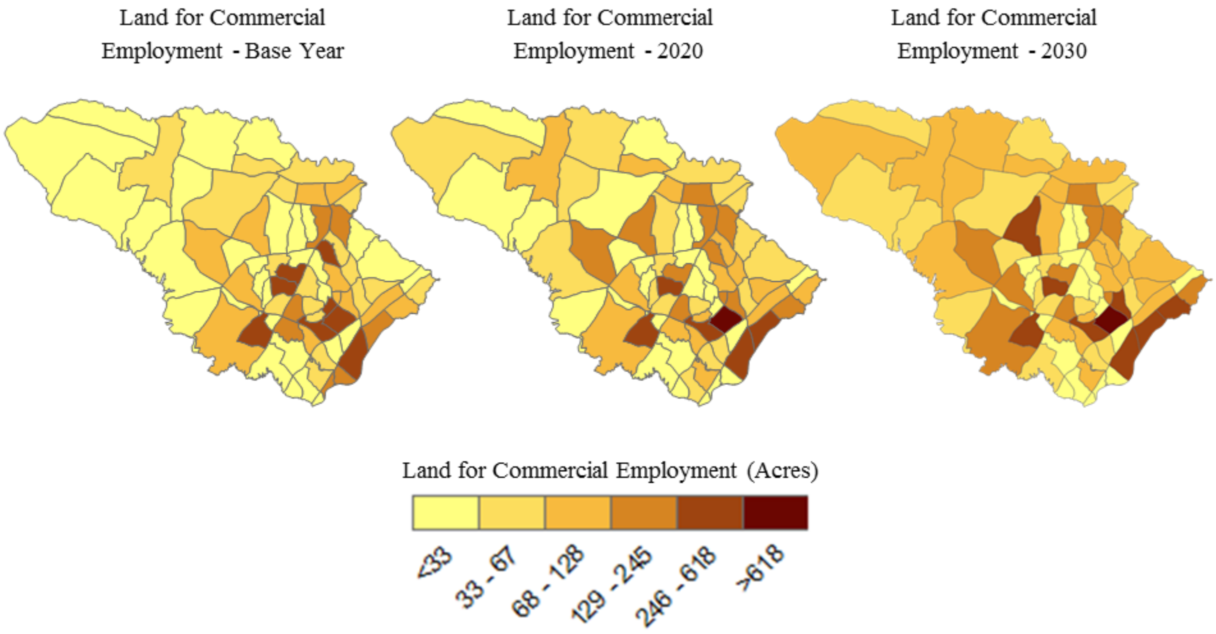


Figure 47: Land for Basic Employment-Forecast of Change

Figure 48 shows that the land (acres) dedicated for Commercial employment/Services is expected to grow significantly during the prediction period from 2010 to 2030. An increase for approximately eighty percent of the zones included in the study is predicted to occur between the base year and 2020. An additional increase in ninety percent of the zones is expected for the period between 2020 and 2030. The suburbs of the study area are predicted to accommodate the upward trend of consumption for land dedicated for Non-basic employment.


Land for Commercial Employment - Base Year

Land for Commercial Employment - 2020

Land for Commercial Employment - 2030

Figure 48: Land for Commercial Employment-Forecast of Change

An increasing trend regarding the land (acres) dedicated for residential use is predicted to occur as presented in Figure 49. G-LUM forecasts indicate that a significant increase in the land consumption for residential purposes will occur in the majority of the zones that are included in the study area for both the time periods between the base year and 2020 and from 2020 to 2030.

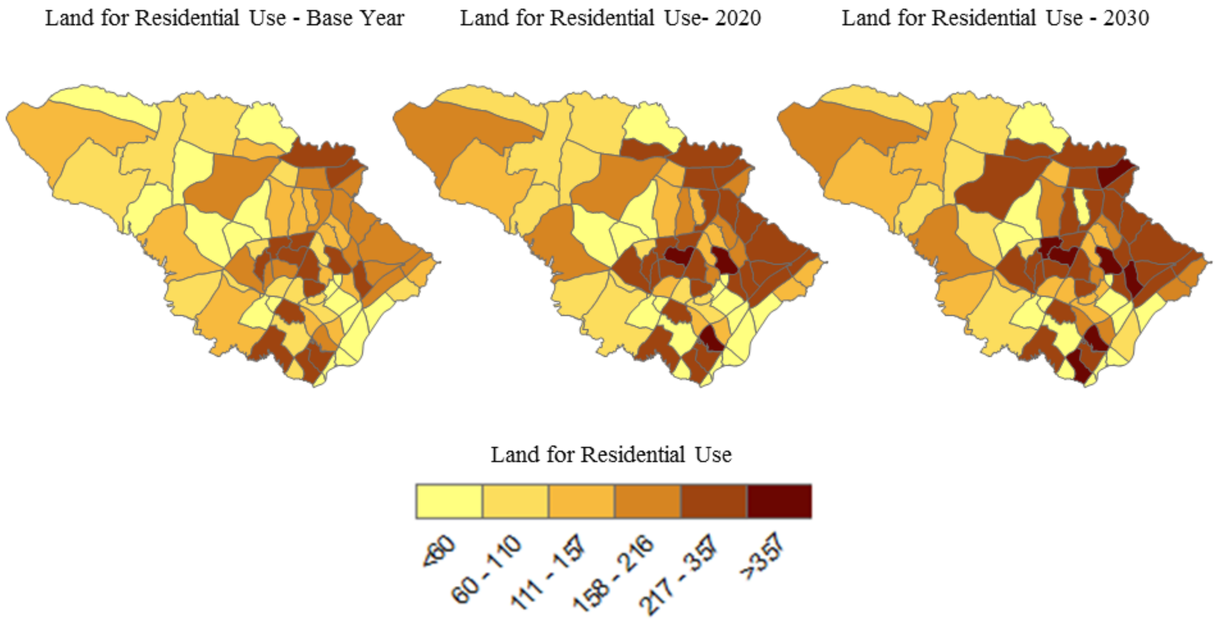


Figure 49: Land for Residential Use-Forecast of Change

7. APPLYING A MORE ADVANCED LAND USE-TRANSPORT MODEL

After carefully examining and evaluating (in Section 4) the available land use-transport models, it was concluded that UrbanSim is one of the most efficient integrated land use-transport models for application in a regional case study. UrbanSim is a micro-simulation model for land use, transportation and environmental planning with advanced capabilities for evaluating transportation policies and regulations. The model is now fully operational and has been implemented by different transportation agencies and organizations (for a list with some of the major UrbanSim users, refer to section 3.7.1) due to its advanced characteristics that are summarized below:

- Efficient Geographical Coverage at the regional level
- Spatial Detail Options that include Grid, Parcel and Zone versions of UrbanSim
- Integration with Travel Demand Models (including both trip based and activity based)
- Consideration of Multimodalilty
- Visualization capabilities for output representation that include tables, graphs, animation and lately 3-D representation options

In general, UrbanSim provides the option to develop extremely detailed models at the micro level that allow users to carry out complicated and efficient land use-transportation analysis and research. However, data requirements are quite extensive. In some case studies, approximately seventy-five percent of the effort for developing a new model application was spent to produce the required input data (Waddell, 2011).

If the obstacle of collecting extensive and quality data has been overcome, UrbanSim can provide a set of different forecast outputs that are summarized as follows:

- Buildings by type, price, etc.
- Size of land, open space, etc.
- Households by income, size, etc.
- Employment by sector and building type
- Transportation Accessibility, Mode Choice, Delay, etc.
- Greenhouse Gas Emissions, Energy Use, etc.

The major datasets needed for all levels of analysis (grid, parcel and zone) include (Waddell, 2011):

- Building data per **Building id**

- Household data per **Household id**
- Person data per **Person id**
- Job data per **Job id**

Additional data required for a detailed analysis that need to be collected are described below (**Source: http://www.urbansim.org/Documentation/WebHome):**

- **Data for grid cells, parcels or zones** (coordinates, related city/county, major activities, land use type, land value, tax information, etc.)
- **Travel data** (travel time to work, walking time for transit access, travel time between zones, etc.)
- **Scheduled events** (new buildings, demolitions, land use change plans, new employment facilities, new residential units, etc.)
- **Validation data from surveys** (data for household characteristics, persons, jobs, etc.)

To prepare that kind of detailed and extensive datasets is a challenging task that requires the utilization of both open source and classified databases. Transportation agencies and organizations (e.g. MPOs, DOTs, etc.) have been some of the major providers of classified data that were required for developing accurate UrbanSim models in different case studies. Some freely accessible databases that can provide significant employment, household and economic data are described below:

- **Census data** (census.gov database): Household/population data, American Community Survey (ACS)
- **Longitudinal Employer-Household Dynamics** (LEHD database): Employment data, Local Employment Dynamics (LED)
- **U.S. Bureau of Labor Statistics** (BLS database): Labor data
- **Bureau of Economic Analysis** (BEA database): Economic data
- **Real Estate Assessment Data** (assessment.state.tn.us): Parcel data

As described earlier, UrbanSim includes a set of submodels (Local and Regional Accessibility Model, Economic and Demographic Transition Models, Household and Employment Mobility Models, Household Employment Location Models, Real Estate Development Model and a Land Price Model). The data required to apply each one of these sub-models are described in Table 11 and

Table 12 for the Parcel and the Zone versions of UrbanSim, respectively.

Table 13 focuses on the data requirements of some simple Demographic Evolution sub-models that are included in UrbanSim.

Table 11: Data Requirements per Model for the Parcel Version of UrbanSim

(Source: http://www.urbansim.org/Documentation/WebHome)

`	**Model Name**	**Description**	**Data Requirements**
1	*Scheduled Development Events Model*	Focuses on Scheduled Development Events	year, action, attribute, amount, building id, zone id, building type
2	*Scheduled Employment Events Model*	Focuses on Scheduled Employment Events	year, action, attribute, amount, building id, zone id, building type
3	*Real Estate Price Model*	Forecasts price per unit for each building	buildings, zones, travel data, households, jobs
4	*Expected Sales Price Model*	Forecasts sale prices for proposed development projects	buildings, zones, travel data, households, jobs
5	*Development Proposal Choice Model*	Forecasts which development proposals will be constructed	building sqft per job, constraints, demolition cost, development proposal/templates, target vacancies, velocity functions
6	*Building Construction Model*	Constructs selected development projects, using a schedule	buildings, velocity functions,
7	*HouseholdTransitionModel*	Adds New Households or Removes Households to Match Control Totals	annual household control totals, households
8	*EmploymentTransitionModel*	Adds New Jobs or Removes Jobs to Match Control Totals	annual household control totals, jobs
9	*HouseholdRelocationModel*	Forecasts Households Decision to Relocate Within Region	annual household relocation rates, households
10	*HouseholdLocationChoiceModel*	Forecasts Location Choices for New or Moving Households	households, buildings, zones, travel data
11	*EmploymentRelocationModel*	Forecasts Job (Employer) Decision to Relocate Within Region	annual job relocation rates, jobs
12	*EmploymentLocationChoiceModel*	Forecasts Location Choices for New or Moving Jobs	jobs, employment sectors, buildings, zones, travel data
13	*Distribute Unplaced Jobs Model*	Allocates sectors of employment (e.g. Military) proportionally	jobs, employment sectors, buildings
14	*Refinement Model*	Refine simulation results according to user specified conditions	refinement id, year, transaction id, action, amount, agent dataset, agent expression, location expression

Table 12: Data Requirements per Model for the Zone Version of UrbanSim

(Source: http://www.urbansim.org/Documentation/WebHome)

	Model Name	Description	Data Requirements
1	*Scheduled Development Events Model*	Focuses on Scheduled Development Events	year, action, attribute, amount, building id, zone id, building type
2	*Scheduled Employment Events Model*	Focuses on Scheduled Employment Events	year, action, attribute, amount, building id, zone id, building type
3	*Real Estate Price Model*	Forecasts Price per Unit for Each Building	buildings, zones, travel data, households, jobs
4	*DevelopmentProjectTransitionModel*	Forecasts New Development Projects to be Located	buildings, zones, travel data, households, jobs
5	*Residential Development Project Location Choice Model*	Forecasts Locations for New Residential Development Projects	building sqft per job, constraints, demolition cost, development proposal/templates, target vacancies, velocity functions
6	*Non Residential Development Project Location Choice Model*	Forecasts Locations for New Non-Residential Development Projects	buildings, velocity functions,
7	*HouseholdTransitionModel*	Adds New Households or Removes Households to Match Control Totals	annual household control totals, households
8	*EmploymentTransitionModel*	Adds New Jobs or Removes Jobs to Match Control Totals	annual employment control totals, jobs
9	*HouseholdRelocationModel*	Forecasts Households Decision to Relocate Within Region	annual household relocation rates, households
10	*HouseholdLocationChoiceModel*	Forecasts Location Choices for New or Moving Households	households, buildings, zones, travel data
11	*EmploymentRelocationModel*	Forecasts Job (Employer) Decision to Relocate Within Region	annual job relocation rates, jobs
12	*EmploymentLocationChoiceModel*	Forecasts Location Choices for New or Moving Jobs	jobs, employment sectors, buildings, zones, travel data
13	*Distribute Unplaced Jobs Model*	Allocates sectors of employment (e.g. Military) proportionally	jobs, employment sectors, buildings
14	*Refinement Model*	Refine simulation results according to user specified conditions	refinement id, year, transaction id, action, amount, agent dataset, agent expression, location expression

Table 13: Demographic Evolution Models in UrbanSim

(Source: http://www.urbansim.org/Documentation/WebHome)

	Model Name	**Description**	**Data Requirements**
1	*AgingModel*	Adds one to the age of each person at the beginning of the year	-
2	*FertilityModel*	Forecasts the birth of persons	Annual birth rates for eligible women, persons, households
3	*MortalityModel*	Forecasts the death of persons	Annual death rates for persons, persons, households
4	*EducationModel*	Updates the educational status of students and predicts when they will end their schooling career	Annual education exit rates for persons, persons
5	*MarriageModel*	Forecasts household formation through male/female marriages	Annual marriage rates for persons, persons, households
6	*CohabitationModel*	Forecasts household formation through male/female cohabitation	Annual cohabitation rates for persons, persons, households
7	*DivorceModel*	Forecasts household dissolution by the divorce of married couples	Annual divorce rates for persons, persons, households
8	*BreakupModel*	Forecasts household dissolution by the breakup of cohabitating couples	Annual breakup rates for persons, persons, households
9	*ChildLeavingHomeModel*	Forecasts the event of a child leaving home	Annual child leaving home rates for 'children', persons, Households formed for each child leaving home
10	*RoommateModel*	Forecasts the formation of non-family households	Persons, household formed for each set of roommates
11	*HouseholdWorkersInitializationModel*	Forecasts household workers for households with a newly assigned household id	Households, person-level variables aggregated at the household-level to use as predictors
12	*HouseholdWorkersModel*	Forecasts year to year changes in the number of household workers	Households, persons, household workers model coefficients, household workers model specification
13	*IncomeRegressionModel*	Forecasts household income	Households, persons, income regression model coefficients, income regression model specification
14	*ZeroworkerRegressionModel*	Forecasts household income for zero-worker households	-

8. CONCLUSIONS

The major objectives of this project were to develop a guidebook for the available models on integrated land use-transport modeling and suggest the application of a similar model in a regional case study. The research team focused on reviewing the evolution of land use models and evaluating variations in model structure and characteristics. The evolution of land use modeling saw spatial interaction models being replaced by advanced micro-simulation models due to the need for more accurate land use forecasts, introduction of activity based travel demand models and the necessity to integrate land use with travel demand modeling. The progress on the development of efficient land use models has been significant and new models allow researchers to analyze land use patterns at the micro level and produce high quality forecasts of land use, employment and household changes. The efficient integration with more advanced travel models is on track and different visualization options are available. The outputs from the new land use models are more accurate and an increasing number of public agencies and organizations in U.S. are interested in implementing similar models.

However, limitations still occur and include the huge amount of data required for producing detailed forecasts; the extended processing times; difficulties in using new models; validation of results, etc. These limitations create new challenges for the research community to pursue and endeavor further advancement in development of land use models. Future, research could focus on exploring efficient procedures for data preparation, reduce processing times, incorporate freight transportation, create more user friendly models, improve the model accuracy and develop better output representation tools.

At the second part of this study, the application of a land use model using G-LUM was suggested. A synthetic case study was used for demonstrating modeling and forecasting capabilities of land use models. G-LUM was selected as it is open source and provides a faster and relatively straightforward model implementation. A modified version of G-LUM was able to model and forecast employment, household and land use change in a 161,310 acres study area for a prediction period from 2010 to 2035. For a more advanced and detail study the research team concluded that UrbanSim is one of the most efficient available models for a regional case study application. UrbanSim is a micro-simulation model for land use, transportation and environmental planning with advanced capabilities for evaluating transportation policies and regulations. UrbanSim was selected as it promises to ensure efficient geographical coverage at the regional level, different spatial detail options (Grid, Parcel and Zone), efficient integration with Travel Demand Models (including both trip based and activity based), consideration of Multimodalilty and different visualization options for output representation (tables, graphs, animation and lately 3-D representation). Model efficiency has been tested in different case studies. However, data requirements are quite extensive. The data collection and preparation process is one of the most challenging and consuming tasks for using advanced microsimulation models. The application of UrbanSim at a regional case study at the greater Tennessee area and the development of a detailed and efficient model at the micro level can be considered as future research.

REFERENCES

Adler, T., Dehghani, Y., and Doherty, M. (2007). Design of Florida's Turnpike's State Integrated Land-Use Travel Demand Model

Allen, E. (2008). Clicking Toward Better Outcomes: Experience with INDEX 1994 to 2006. Planning Support Systems for Cities and Regions. Cambridge, MA: Lincoln Institute of Land Policy.

Anas, A. & Associates. (2002), THE NYMTC-LAND USE MODEL, Final Report, Prepared for the New York Metropolitan Transportation Council and Parsons, Brinckerhoff, Douglas and Quade.

Anas, A. and Duann, L. S. (1983), Dynamic Forecasting of Travel Demand, Residential Location and Land Development. IIASA Seminar on July 20, 1983

Anderson, R. S. (2006). Development of Mid- Ohio Regional Planning Commission Tour- Based Model. Commission Tour- Based Model. Innovations in Travel Demand Modeling, Summary of a Conference, Vol. 2: Papers, May 21–23, 2006, Austin, Texas

Arentze, T.A., Hofman, F., Mourik, H. Van and Timmermans, H.J.P. (2000). Albatross: multi-agent rule based model of activity pattern decisions. Transportation Research Record, 1706, 136-144.

Atlanta Regional Commission (2012). Activity-Based Travel Model Specifications: Coordinated Travel – Regional Activity Based Modeling Platform (CT-RAMP) for the Atlanta Region.

Berry, M. W., Flamm, R. O., Hazen, B. C., and MacIntyre, R. L. (1996). LUCAS: a system for modeling land-use change. Computing in Science and Engineering, 3(1), 24-35.

Bhat, C. R., Guo, J., Srinivasan, S., and Sivakumar, A. (2003). Guidebook on activity-based travel demand modeling for planners. Prepared for the Texas Department of Transportation

Borning, A., P. Waddell, and R. Förster. forthcoming. Using simulation to inform public deliberation and decision-making. In *Digital government: Advanced research and case studies*, ed. Hsinchun Chen et al. Springer-Verlag. http://www.urbansim.org/papers/borning-urbansim-case-study-2006.pdf

Bowman, J. L. (1995). Activity based travel demand model system with daily activity schedules. Master of Science Thesis in Transportation, Massachusetts Institute of Technology

Bowman, J. L. (1998). The day activity schedule approach to travel demand analysis. Ph.D. Dissertation, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Bowman, J., L and Bradley, M. (2012). DAYSIM: Activity and Travel Schedule Simulator. Technical Documentation

Bowman, J., L., Bradley, M. A. and Gibb, J. (2006). The Sacramento Activity-Based Travel Demand Model: Estimation and Validation Results. Presented at the European Transport Conference, September 18-20, 2006, Strasbourg, France

Bradley, M., Bowman J. L. and Griesenbeck, B. (2009). Activity-Based model for a medium sized city: Sacramento**.** Traffic Engineering and Control, Vol. 50 No. 2: 73-79.

Calthorpe Associates (2012). UrbanFootprint. Technical Summary. Model Version 1.0

Cambridge Systematics, Inc. (1991). Making the Land Use, Transportation, Air Quality Connection, Modeling Practices, Volume 1, Cambridge Systematics, Inc. with Hague Consulting Group

Cambridge Systematics, Inc. (2002). San Francisco Travel Demand Forecasting Model Development. Final Report, Prepared for the San Francisco County Transportation Authority

Cambridge Systematics, Inc. (2010). Focus Model Overview. Prepared for the Denver Regional Council of Governments

Chakraborty, A., Mishra, S., Kim, Y. W. (2012). Extending the application of urban models in plan making. Journal of the Urban and Regional Information Systems Association, vol. 24(1), pp. 53-62.

Clarke, K. C., and Gaydos, L. G. (1998). Loose-coupling a cellular automaton model and gis: long-term urban growth prediction for San Francisco and Washington/Baltimore. *International Journal of Geographic Information Science* 12(7): 699-714

Conder, S. (2000). METROSCOPE: The Metro residential and nonresidential real estate models-general description and technical appendix. In Conference on Land Market Monitoring for Smart Urban Growth.

Croteau, K. G., Faber, B. G., and Vernon, L. T. (1997). SMART PLACES: A tool for design and evaluation of land use scenarios. In Proceedings of the 1997 ESRI User Conference (CDROM), ref. artículo (Vol. 121).

Crecine, J.P. (1968). A Dynamic Model of Urban Structure, Rand Corporation, Santa Monica.

Davidson, W., Vovsha, P., Freedman, J., and Donnelly, R. (2010). CT-RAMP family of activity-based models. In Proceedings of the 33rd Australasian Transport Research Forum (ATRF).

De la Barra, T. (1989), *Integrated Land Use and Transport Modeling*, Cambridge, Cambridge University Press.

De La Barra, T., Pérez, B. and Vera, N. (1984). TRANUS-J: putting large models into small computers. Environment and Planning B: Planning and Design, 11(1), 87-101

Data Transfer Solution, LLC. (2006). METROPLAN ORLANDO Future Land Use Allocation Model, Manual, Prepared for METROPLAN ORLANDO, Orlando Florida

Deal, B. M., and D. Schunk. (2004). Spatial dynamic modeling and urban land use transformation: A simulation approach to assessing the costs of urban sprawl. *Ecological Economics* 51(1): 79-95.

Dowling, R. G., Ireson, R., Skabardonis, A., Gillen, D., and Stopher, P. (2005). Predicting air quality effects of traffic-flow improvements: final report and user's guide. Vol. 535. Transportation Research Board,

Envision Tomorrow (2014). A Suite of Urban and Regional Planning Tools. http://www.envisiontomorrow.org/, Accessed January, 2014

Echenique, M., A.D.J Flowerdew, J.D. Hunt, T.R. Mayo, I. J. Skidmore, and D.C. Simmonds. (1990). The MEPLAN models of Bilbao, Leeds and Dortmund. *Transport Reviews* 10(4): 309-322.

Ettema, D., (1996), Activity based Travel Demand Modeling. P.h.D. Thesis at the Eindhoven Technical University, Holland

Ettema, D., de Jong, K., Timmermans, H. and Bakema, A. (2007). PUMA: multi-agent modeling of urban systems. In Modeling land-use change (pp. 237-258). Springer Netherlands.

Fosgerau, M. (2001) PETRA- An Activity Based Approach to Travel Demand Analysis. Chapter 11 of the book “National Transport Models-Recent Developments and Prospects”, Springer Publishing Company, Germany

Goldner, W. (1968). A Model for the Spatial Allocation of Activities and Land Uses in a Metropolitan Region, BATSC Technical Report 219, Berkley: Bay Area Transportation Study Commission

Goldner, W. (1971). The Lowry model heritage. *Journal of the American Institute of Planners*, *37*(2), 100-110.

Gregor, B. (2007). Land use scenario developer: Practical land use model using a stochastic microsimulation framework. *Transportation Research Record: Journal of the Transportation Research Board* 2003.1 (2007): 93-102.

HBA Specto Incorporated. (2010). PECAS-for Spatial Economic Modeling. SCAG modeling status and next steps. System Documentation Technical Note. Working Draft. Calgary, Alberta

Hensher, D. A., and Ton, T. (2002). TRESIS: A transportation, land use and environmental strategy impact simulator for urban areas. Transportation, 29(4), 439-457.

Hunt, J. D., and Abraham, J. E. (2003). Design and Application of the PECAS Land Use Modeling System

Hunt, J. D., and J. E. Abraham. (2007). Pecas - for spatial economic modeling. System Documentation Technical Memorandum 1 WORKING DRAFT, HBA Specto Inc.

Hunt, J. D., J. E. Abraham and Silva, D. DE. (2009). Pecas - for spatial economic modeling. System Documentation Technical Memorandum 2 WORKING DRAFT, HBA Specto Inc.

Iacono, M., Levinson, D., and El-Geneidy, A. (2008). Models of transportation and land use change: a guide to the territory. Journal of Planning Literature, 22(4), 323-340.

Jin, L., and Fricker, J. D. (2008). Univariate Sensitivity and Uncertainty Analysis of Statewide Travel Demand and Land Use Models for Indiana. In Transportation Research Board 87th Annual Meeting (No. 08-1947)

Jovicic, G. (2001). Activity based travel demand modeling – a literature study. Danmarks TransportForskning, Note 8

Kakaraparthi, S., Tirumalachetty, S., Kockelman, K., Duthie, J., Paul, B., Valsaraj, V. and Zhou, B. (2012). “DOCUMENTATION FOR USE OF THE GRAVITY-BASED LAND USE MODEL (G-LUM): WITH AND WITHOUT IN-BUILT TRAVEL DEMAND MODEL ASSUMPTIONS”

Kain, J. F., and Apgar Jr, W. C. (1985). The Harvard Urban Development Simulation Model. In Microeconomic Models of Housing Markets (pp. 27-71). Springer Berlin Heidelberg.

Kitamura, R., Pas, E. I., Lula, C. V., Lawton, T., K. and Benson, P. E. (1996), The sequenced activity mobility simulator (SAMS): an integrated approach to modeling transportation, land use and air quality. Transportation, Vol. 23, pp.267-291

Klosterman, R. (1999). The what if? collaborative planning support system. *Environment & Planning B: Planning & Design* 26: 393-408

Landis, J. (1994), The California urban futures model: a new generation of metropolitan simulation models, Environment and Planning B, **21**, 399-420.

Lowry, I. S. (1964). A model of metropolis. Tech. Rep. RM-4035-RC, Rand Corporation, Santa Monica, CA.

Lawe, S., Lobb, J., and Hathaway, K. (2007). Statewide Land-Use Allocation Model for Florida, 11th TRB National Transportation Planning Applications Conference, Daytona Beach, Florida

Martinez, F.J. (1997b), MUSSA: A land Use Model for Santiago City, *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1552, pp. 126-134

Mackett, R. L. (1990). Comparative analysis of modeling land-use transport interaction at the micro and macro levels." Environment and Planning A 22:459-475

McNally, M.G. (1997). An activity-based microsimulation model of travel demand forecasting. In Ettema, D.F. and H.J.P. Timmermans (eds.), Activity-Based Approaches to Travel Demand Forecasting, Pergamon Press

Miller, E. J. and Roorda M. J. (2003), A Prototype Model of Household Activity/Travel Scheduling. A Paper Submitted to the Transportation Research Board (TRB) for Presentation at the TRB 2003 Annual Meeting

Miller, E.J. and Savini, P. (1998). The Integrated Land Use, Transportation, Environment (ILUTE) Modeling System: A Framework, Proceedings 77th Annual Meeting of the Transportation Research Board, Washington, D.C.

Mishra, S., Ye, X., Ducca, F., and Knaap, G. (2011). A Functional Integrated Land Use-Transportation Model for Analyzing Transportation Impacts in the Maryland-Washington D.C. Region, in Journal of Sustainability Science Policy and Practice, vol.7(2), pp. 1-10.

Miyamoto, K., Vichiensan, V., Sugiki, N., and Kitazume, K. (2007). Applications of RURBAN integrated with a transport model in detailed zone system. In Proceedings of the 11th world conference on transport research, CD-ROM.

Moeckel, R., Schurmann, C. and Wegener, M. (2002), Microsimulation of urban land use, Paper presented at the 42nd European Congress of the Regional Science Association, Dordmund, August 27-31, 2002

North Front Range Metropolitan Planning Organization and AECOM. (2011). Land Use Allocation Model Update. Final Report

Ottensmann, J. R., Brown, L., Fricker, J., and Jin, L. (2009). Incorporating a land consumption model with a statewide travel model. In Proceedings of the 12th TRB National Transportation Planning Applications Conference, Transportation Research Board, http://www. trb-appcon. org/. Accessed (Vol. 12).

Outwater, M. L. and Charlton, B. (2006). The San Francisco Model in Practice. Validation, Testing, and Application. Innovations in Travel Demand Modeling, Summary of a Conference, Vol. 2: Papers, May 21–23, 2006, Austin, Texas

Parsons Brinckerhoff Quade and Douglas, Inc. (1998). Land Use Impacts of Transportation: A Guidebook. Prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council

Parsons Brinckerhoff Quade & Douglas, Inc. (2005). New York Best Practice Model (NYBPM). General Final Report, Transportation Models and Data Initiative, New York Metropolitan Transportation Council

Peng, Z. R., Liyuan Z. and Fei Y (2011). Development of a Prototype Land Use Model for Statewide Transportation Planning Activities.

PLACE^{3}S (2010). The I- PLACE3S User Guide. Version 1.1

Placeways LLC. (2014), CommunityViz History; CommunityViz in Transportation Planning and Modeling, www.placewasys.com, Accessed March 2014

Pfaffenbichler, P. (2003). The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator). Institut für Verkehrsplanung und Verkehrstechnik der Technischen Universität Wien.

Prastacos, P. (1986). An integrated land-use-transportation model for the San Francisco Region: 1. Design and mathematical structure. Environment and Planning A, 18(3), 307-322.

Putman, S.H. (1983), *Integrated Urban Models*, Pion Limited, London. England.

Recker, W.W., M.G. McNally and G.S. Root (1986a). A Model of Complex Travel Behavior: Part I-Theoretical Development. Transportation Research A 20A(4): 307-318.

Recker, W.W., M.G. McNally and G.S. Root (1986b). A Model of Complex Travel Behavior: Part II-An Operational Model. Transportation Research A 20A(4): 319-330.

San Luis Obispo Council of Governments San Luis Obispo Council of Governments (2010). Integration of I-PLACE^{3}S into Land Use and Travel Modeling at SLOCOG.

Savini, P. and Miller, E.J. (2005). ILUTE: An Operational Prototype of a Comprehensive Microsimulation Model of Urban Systems. Networks and Spatial Economics, Vol. 5, No. 2, Page 217

Shengyi, G., Lehmer, E., Wang, Y., McCoy, M., Johnston, R. A., Abraham, J., and Hunt, J. D. (2009). "Developing California Integrated Land Use/Transportation Model." For Presentation and Publication at the Transportation Research Board’s 89th Annual Meeting Washington, D.C., January, 2010

Simmonds, D.C. (1999). The design of the DELTA land-use modeling package, *Environment and Planning B*, **26**, 665-684

Sivakumar, A. (2007). MODELING TRANSPORT: A Synthesis of Transport Modeling Methodologies. Imperial College, London

Southworth, F. (1995). A Technical Review of Urban Land Use--Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies.

Spasovic, L. N. (accessed 2013). TELUM-interactive Software for Integrated Land Use and Transportation Modeling. New Jersey Institute of Technology, http://www.telus-national.org/, accessed January, 2013

Srinivasan, S. (2012). Comparing Operational Activity-Based Models (ABMs): What is Different and What is Not?, FSUTMS Users Group Meeting, Ft. Lauderdale

Stopher, P. D., Hartgen, D. and Li, Y. (1996). SMART-Simulation Model for Activities, Resources and Travel. Transportation, Vol. 23, pp. 293-312

Svalgard, S. (1994). The implementation of an integrated transport and land-use model, using new features of EMME/2 Release 7.0. In 3rd European EMME/2 Users Meeting, Stockholm.

Tahoe Metropolitan Planning Organization in collaboration with the Tahoe Regional Planning Agency. (2009). Proposition 84 Funding Application for Transportation Model Development and Data Gathering. Prepared for Strategic Growth Council

Thompson-Graves, S., DuRoss, M., Subhani, R., Holloway, B., and Sundquist, E. (2012). "Development of the State Smart Transportation Initiative's DelDOT 3-D Micro Model Process—A scenario planning tool to evaluate urban form, land use, and multimodal investment impacts on mobility." State Smart Transportation Initiative. Retrieved 02/28/2014 from http://www.ssti.us/2012/06/lutsam/

Timmermans, H. (2003). The Saga of Integrated Land Use-Transport Modeling: How Many More Dreams Before We Wake Up? Conference keynote paper, 10th International Conference on Travel Behaviour Research, Lucerne, 10-15. August 2003

Transportation Planning Service, Inc. (2014). Urban Land Use Allocation Model. www.ulam.org, Accessed March 2014

Pfaffenbichler, P., Emberger, G., and Shepherd, S. (2008). The integrated dynamic land use and transport model MARS. Networks and Spatial Economics, 8(2-3), 183-200.

Puget Sound Regional Council (2012), 2012 Land Forecast. Analysis and Forecasting at PSRC, Seatle, WA

Putman, S. H. (1991). DRAM/EMPAL-ITLUP. Integrated Transportation Land-Use Activity Allocation Models: General Description. S.H. Putman Associates

Valsaraj, V., Kockelman, K., Duthie, J., & Zhou, B. (2007). FORECASTING EMPLOYMENT & POPULATION IN TEXAS: An Investigation on TELUM Requirements, Assumptions, and Results, including a Study of Zone Size Effects, for the Austin and Waco Regions.

Veldhuisen, K., Timmermans, H.J.P. and Kapoen, L.L. (2000), Ramblas: A regional planning model based on the micro-simulation of daily activity travel patterns, Environment and Planning A, **32**, 427-443

Vovsha, P. and Chiao, K-A. (2006). Development of New York Metropolitan Transportation Council Tour- Based Model. Innovations in Travel Demand Modeling, Summary of a Conference, Vol. 2: Papers, May 21–23, 2006, Austin, Texas

Waddell, P. (2000). A behavioral simulation model for metropolitan policy analysis and planning: residential location and housing market components of UrbanSim. Environment and Planning B, 27(2), 247-264

Waddell, P. (2011). Integrated land use and transportation planning and modeling: addressing challenges in research and practice. Transport Reviews, 31(2), 209-229.

Waddell, P. (2011). Spatial Input-Output models: PECAS. Webinar 4 of an 8-part TMIP Webinar series on land use forecasting methods.

Waddell, P. (2002). Urbansim: Modeling urban development for land use, transportation and environmental planning. *Journal of the American Planning Association* 68(3): 297-314.

Waddell, P., Wang, L. and Liu, X. (2008). UrbanSim: an evolving planning support system for evolving communities. *Planning support systems for cities and regions*, 103-138.

Walton, R., Corlett, M., Arthur, C. and Bagley, A. (2000). Land Use and Transportation Modeling with the ArcView Spatial Analyst. The MAG Subarea Allocation Model. Maricopa Association of Governments.

Wegener, M. (1998). The IRPUD Model: Overview, 1998 Michael Wegener, IRPUD

Weidner, T.J., Donnelly, R., Freedman, J., Abraham, J.E., and Hunt, J. D. (2007). A Summary of the Oregon TLUMIP Model Microsimulation Modules, presented at the 86th Annual Meeting of the Transportation Research Board, Washington D.C

Wen, C. H. and Koppelman, F. (2000), A Conceptual and Methodological Framework for the Generation of Activity-Travel Patterns, Transportation, Vol. 27, pp. 5-23

White, W., L. (2010). FSUTMS/Land Use Model Integration. Status Update. Presented to the Florida Model Task Force

Whitman, Requardt & Associates. (2013). Land Use and Transportation Scenario Analysis and Microsimulation. 14th TRB National Planning Applications Conference, Columbus, OH

Zhao, Fang, and Soon Chung. (2006). A study of alternative land use forecasting models. No. BD015-10. Final Report

APPENDIX A_ REQUIRED DATA FOR URBANSIM MODELS

UrbanSim has quite excessive data requirements. The data for developing a full scale model at the Parcel and the Zone level in UrbanSim (Source: http://www.urbansim.org/Documentation/WebHome) are described in

Table 14 and Table 15, respectively.

Table 14: Data Required for the Parcel Version of UrbanSim

(Source: http://www.urbansim.org/Documentation/WebHome)

	Dataset	Description	Data
1	*annual_employment_control_totals*	Control totals containing the aggregate targets for employment by sector	year, sector id, home based status, number of jobs
2	*annual_household_control_totals*	Control totals containing the aggregate targets for households by type	year, age of head, persons, income, total number of households
3	*annual_household_relocation_rates*	Annual relocation rates for households by category	age of head min, age of head max, income min, income max, probability of relocating
4	*annual_job_relocation_rates*	Annual relocation rates for jobs by employment sector	sector id, job relocation probability
5	*buildings*	Individual buildings on a parcel	building id, building type, improvement value, land area, non residential sqft, year built, residential units, sqft per unit, stories, tax exempt, parcel id
6	*building_sqft_per_job*	Non-residential sqft used by each job	zone_id, building type, building sqft per job
7	*building_types*	Building types as classified by the user, usually at least 2 residential types and several non-residential types	building type id, is residential, building type name/description, unit name
8	*cities*	List of cities within the region, primarily for indicators	city id, city name
9	*counties*	List of counties within the region, primarily for indicators	county id, county name
10	*demolition_cost_per_sqft*	Demolition cost per square foot, for redevelopment of existing structures	building id, building name, demolition cost per sqft
11	*development_constraints*	Regulatory constraints on development, from comprehensive plans or other sources	constraint id, constraint type, land use type, plan type id, min/ max density allowed by constraints
12	*development_event_history*	Development projects that have been built over a historical period of (for example) 10 years. Not used in Development Proposal Choice Model	parcel id, building type, change type, residential units, non residential sqft, scheduled year, change type

	Dataset	Description	Data
13	*development_template_components*	Descriptions of components of development templates	component id, building sqft per unit, building type, percent building sqft, construction cost per unit, template id
14	*employment_adhoc_sector_groups*	Aggregations of employment sectors into groups such as basic, retail, service	group id, name
15	*employment_adhoc_sector_group_definitions*	Definitions (textual) of ad-hoc sector groups	sector id, group id,
16	*employment_sectors*	Employment sectors, defined by the user as aggregations of an industrial classification, e.g. NAICS or SIC	sector id, name
17	*fazes*	Optional geographic table that provides a zone aggregation, used mainly for indicators	faz id, large area id
18	*generic_land_use_types*	Broad classifications of land uses	generic land use type id, generic description
19	*home_based_status*	Indicator table for jobs that are home-based	home based status, name
20	*household_characteristics_for_ht*	Household characteristics used in the Household Transition Model	characteristic, min/max value of user defined attribute
21	*households*	Household data, for socioeconomic and density variables	household id, cars, persons, income, age of head, race, workers, children, building id
22	*households_for_estimation*	Households table used in estimation, from a household survey with recent movers, if available	household id, cars, persons, income, age of head, race, workers, children, building id
23	*jobs*	Employment data, for accessibility and density variables	job id, building id, sector id, home based status
24	*jobs_for_estimation*	Jobs table used in estimation, from sample of newly locating jobs, if available	job id, building id, sector id, home based status

	Dataset	**Description**	**Data**
25	*parcels*	Parcels, usually based on property ownership, which may contain 0, 1 or more buildings	parcel id, land use type, land value, parcel sqft, plan type id, centroid x/y, tax exempt flag, city id, county id, zone id, census block id
26	*persons*	Optional persons table, used for workplace choice model and activity-based travel model integration	person, household id, member id, relate, age, sex, race, student, worker, hours, work at home, education, earning, job
27	*plan_types*	Plan types are a composite of development regulations, represented as polygons in a GIS layer	plan type, name
28	*race_names*	Optional names for race groups defined in the synthetic population	race id, minority, name
29	*target_vacancies*	Structural or target vacancies - trigger development when vacancies fall below this	target type, target vacancy rate, year
30	*travel_data*	Zone-to-zone skims from the travel model, for accessibility variables	from zone id, to zone id, am single vehicle to work travel time
31	*velocity_functions*	Velocity functions describe the schedule for development of development projects spanning multiple years	velocity function, annual construction schedule, building type id, min/max units
32	*zones*	Zones used in the travel model, for accessibility and density variables	zone id, city id, county id, faz id
33	*development_project_proposals*	Proposals for development projects, either user-specified or simulated	proposal id, parcel id, template id, status id, start year, is redevelopment
34	*development_templates*	User-provided templates describing different types of development projects	template id, density type, density, land use type id, development type, is active, land sqft min/max, percent land overhead (land required for purposes other than buildings)
35	*large_areas*	Optional higher level geography, aggregations of FAZ geography (user-determined), for indicators	large area id, large area name, county id
36	*land_use_types*	Land use types, classification of land use	land use type, description, land use name, unit name

Table 15: Data Required for the Zone Version of UrbanSim

(Source: http://www.urbansim.org/Documentation/WebHome)

	Dataset	Description	Data
1	*annual_employment_control_totals*	Control totals containing the aggregate targets for employment by sector	year, sector id, home based status, number of jobs
2	*annual_household_control_totals*	Control totals containing the aggregate targets for households by type	year, age of head min/max, race, total number of households
3	*annual_household_relocation_rates*	Annual relocation rates for households by category	age min/max, income min/max, probability of relocating
4	*annual_job_relocation_rates*	Annual relocation rates for jobs by employment sector	sector id, job relocation probability
5	*buildings*	Aggregated buildings, by building type and zone	building id, building type, improvement value, land area, non residential sqft/capacity, year built, residential units/capacity, sqft per unit, zone id, value per unit
6	*building_sqft_per_job*	Non-residential sqft used by each job	zone_id, building type, building sqft per job
7	*building_types*	Building types as classified by the user, usually at least 2 residential types and several non-residential types	building type id, is residential, building type name
8	*cities*	List of cities within the region, primarily for indicators	city id, city name
9	*counties*	List of counties within the region, primarily for indicators	county id, county name
10	*development_event_history*	Development projects that have been built over a historical period of (for example) 10 years.	zone id, building type, change type, residential units, non residential sqft, scheduled year, change type
11	*employment_adhoc_sector_groups*	Aggregations of employment sectors into groups such as basic, retail, service	group id, name
12	*employment_adhoc_sector_group_definitions*	Definitions (textual) of ad-hoc sector groups	sector id, group id,
13	*employment_sectors*	Employment sectors, defined by the user as aggregations of an industrial classification, e.g. NAICS or SIC	sector id, name

	Dataset	**Description**	**Data**
14	*fazes*	Optional geographic table that provides a zone aggregation, used mainly for indicators	faz id, large area id
15	*home_based_status*	Indicator table for jobs that are home-based	home based status, name
16	*household_characteristics_for_ht*	Categories used in control totals	characteristic, min/max value of user defined attribute
17	*households*	Household data, for socioeconomic and density variables	household id, cars, persons, income, age of head, race, workers, children, building id
18	*households_for_estimation*	Households table used in estimation, from a household survey with recent movers, if available	household id, cars, persons, income, age of head, race, workers, children, building id
19	*jobs*	Employment data, for accessibility and density variables	job id, building id, sector id, home based status
20	*jobs_for_estimation*	Jobs table used in estimation, from sample of newly locating jobs, if available	job id, building id, sector id, home based status
21	*large_areas*	Optional higher level geography, aggregations of FAZ geography (user-determined), for indicators	large area id, large area name, county id
22	*race_names (Optional)*	Optional names for race groups defined in the synthetic population	race id, minority, name
23	*target_vacancies*	Structural or target vacancies - trigger development when vacancies fall below this	building type, is residential, target vacancy rate, year
24	*travel_data*	Zone-to-zone skims from the travel model, for accessibility variables	from zone id, to zone id, am single vehicle to work travel time
25	*zones*	Zones used in the travel model, for accessibility and density variables	zone id, city id, county id, faz id

APPENDIX B_ OUTPUT FFROM G-LUM MODEL

Appendix B includes the outputs from G-LUM model. Results are provided per 5-year prediction periods and include forecasts of Employment (number of employees), households (number of households) and Land Use (in acres) change. Land use forecasts include Land (acres) dedicated for Basic Employment, Land (acres) dedicated for Non-Basic-Commercial Employment and Land (acres) dedicated for residential use. The corresponding outputs from G-LUM are presented in the figure 50 through 81.

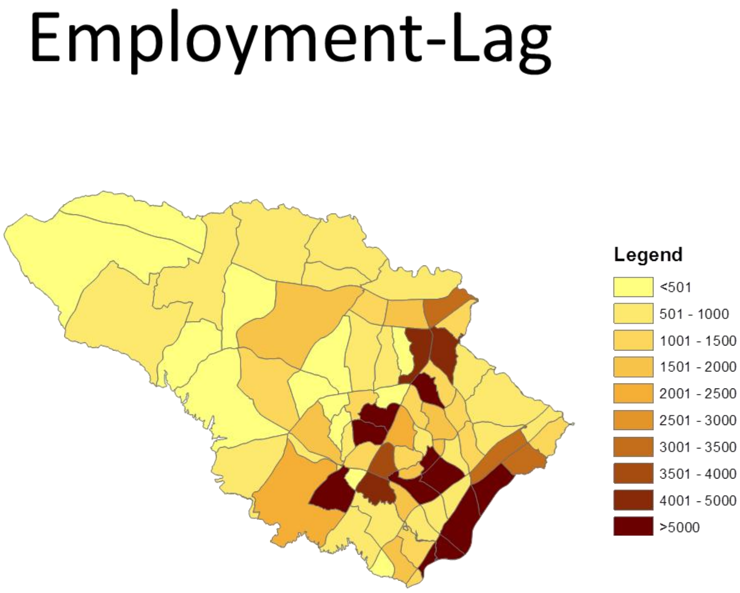


Figure 50: Employment - Lag Year (2005)

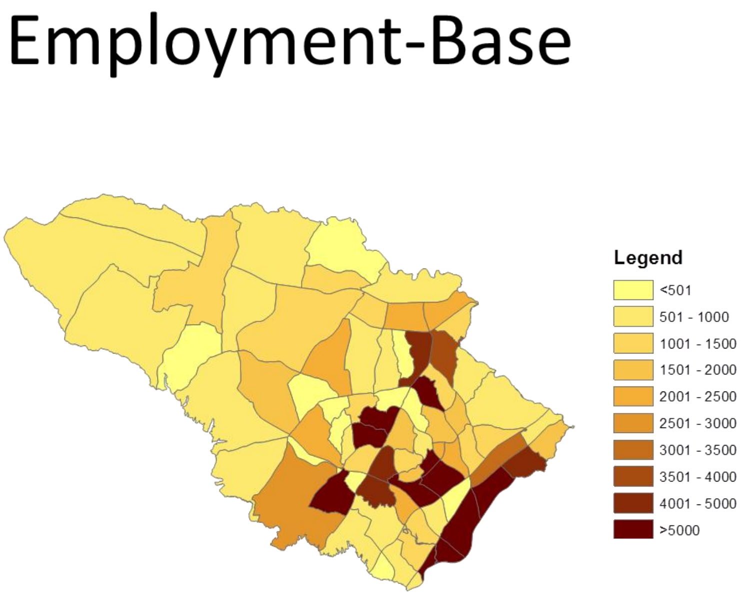


Figure 51: Employment - Base Year (2010)

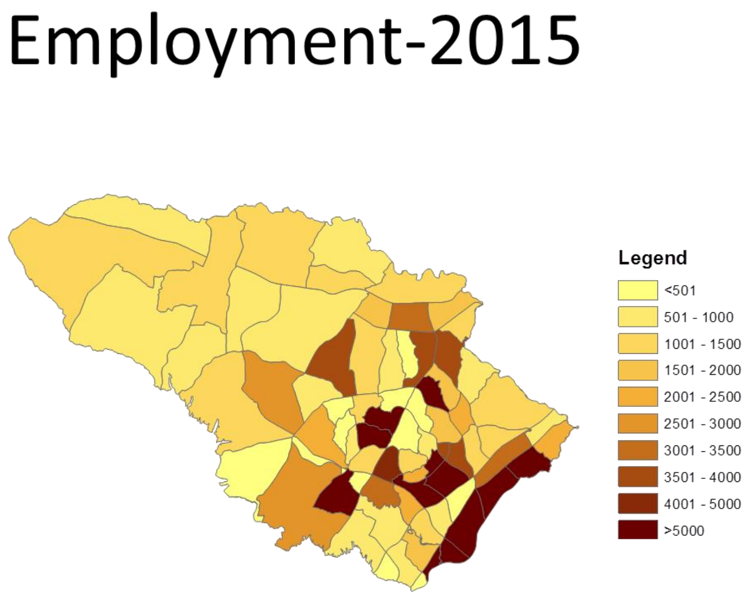


Figure 52: Employment – Predicted Year (2015)

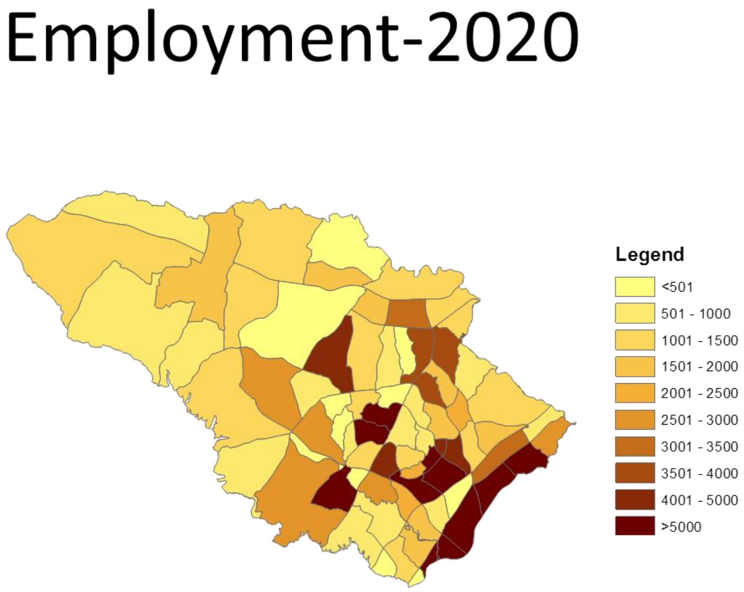


Figure 53: Employment – Predicted Year (2020)

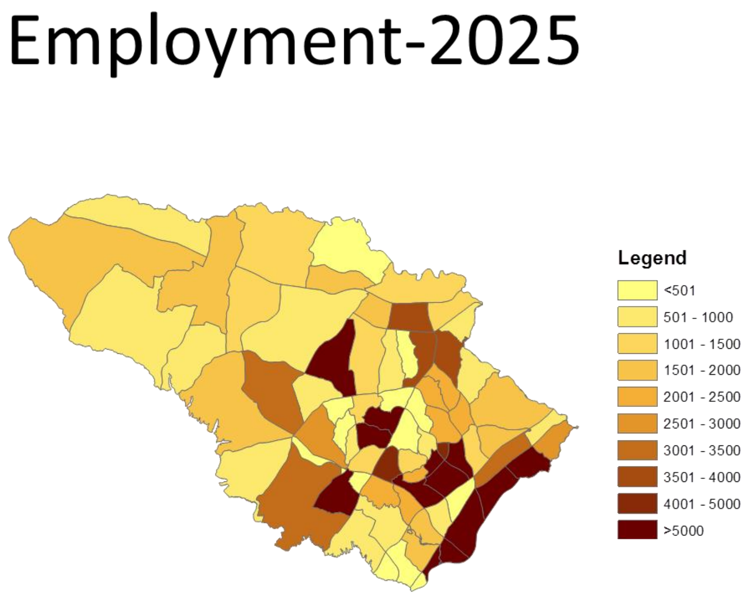


Figure 54: Employment – Predicted Year (2025)

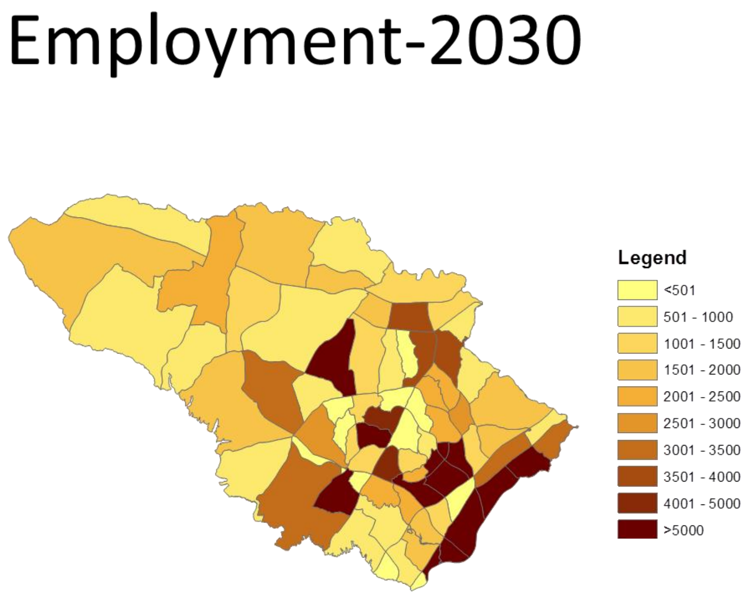


Figure 55: Employment – Predicted Year (2030)

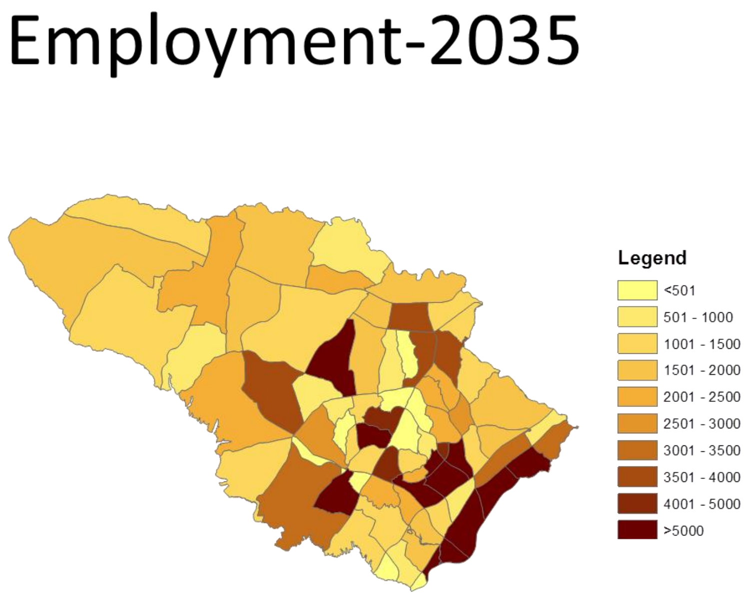


Figure 56: Employment – Predicted Year (2035)

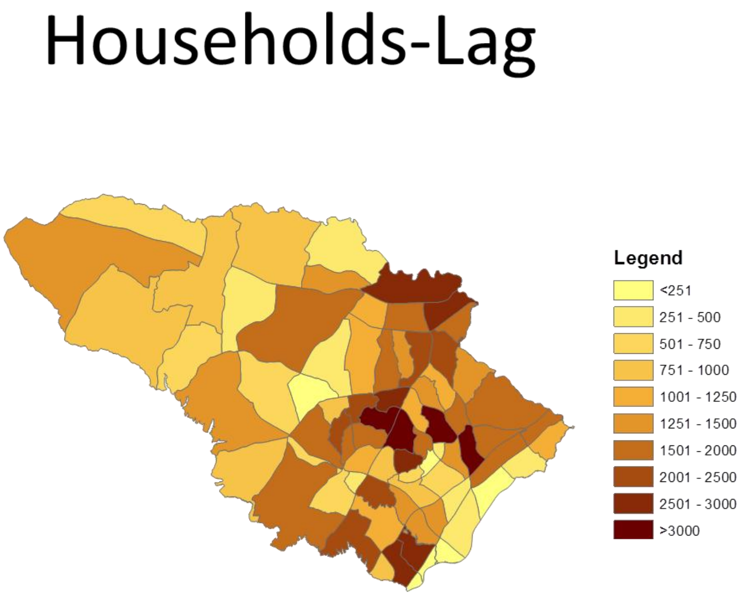


Figure 57: Households – Lag Year (2005)

Households-Base

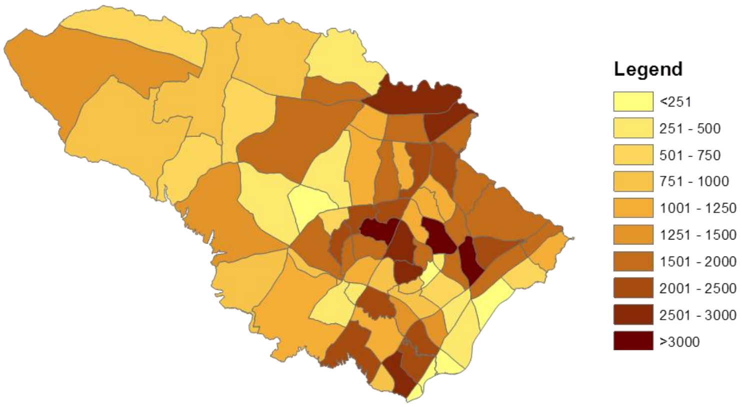


Figure 58: Households – Base Year (2010)

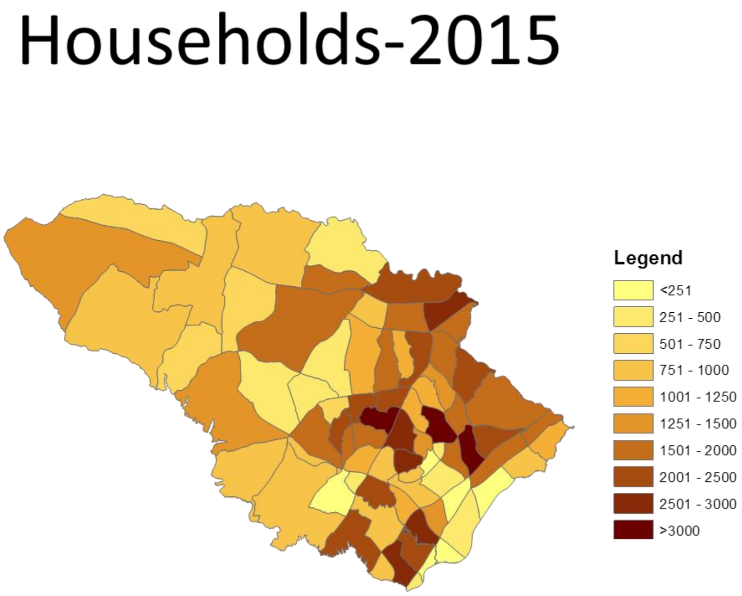


Figure 59: Households – Predicted Year (2015)

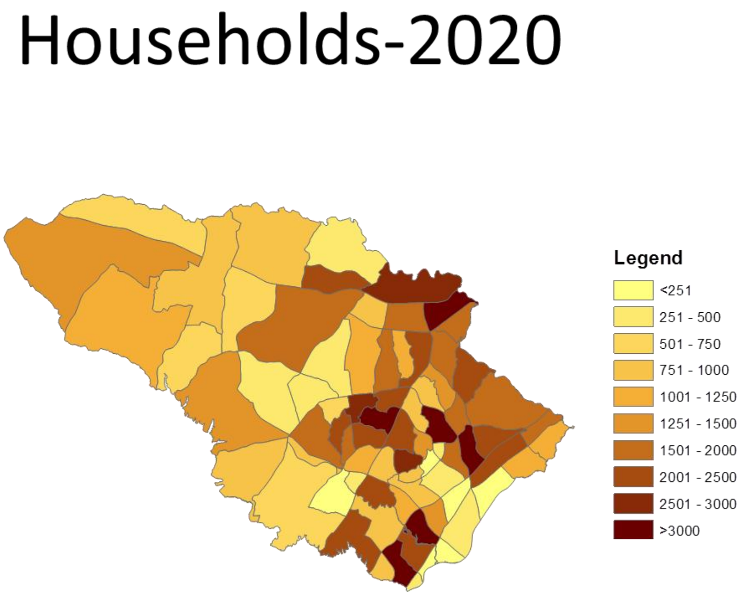


Figure 60: Households – Predicted Year (2020)

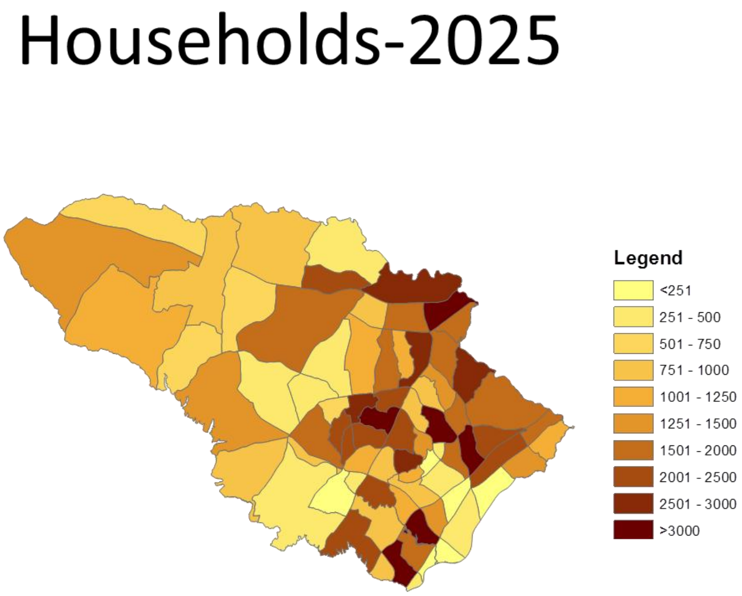


Figure 61: Households – Predicted Year (2025)

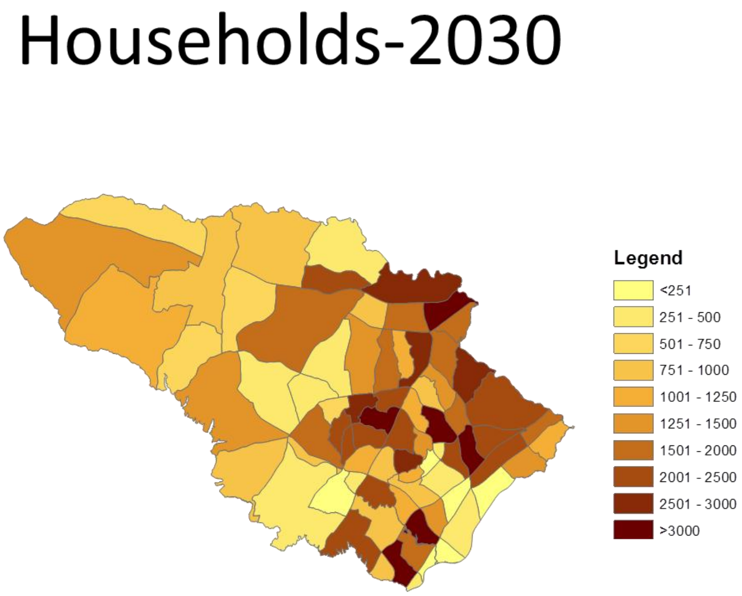


Figure 62: Households – Predicted Year (2030)

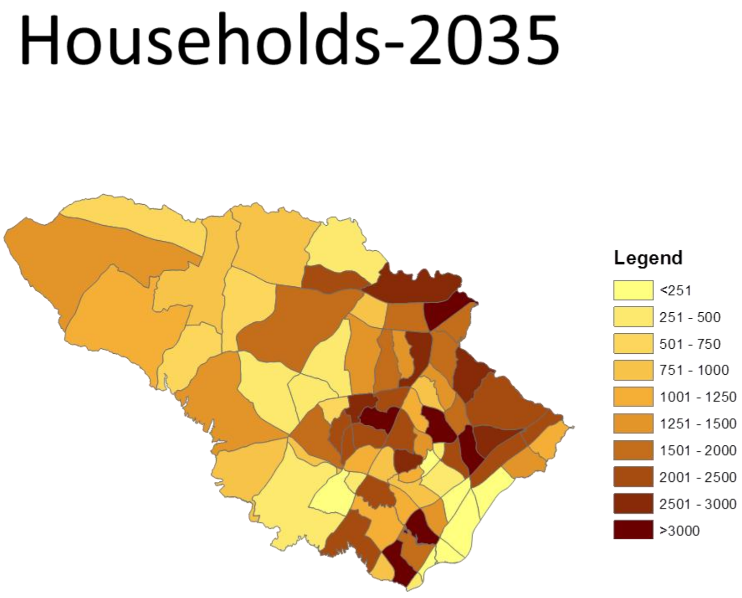


Figure 63: Households – Predicted Year (2035)

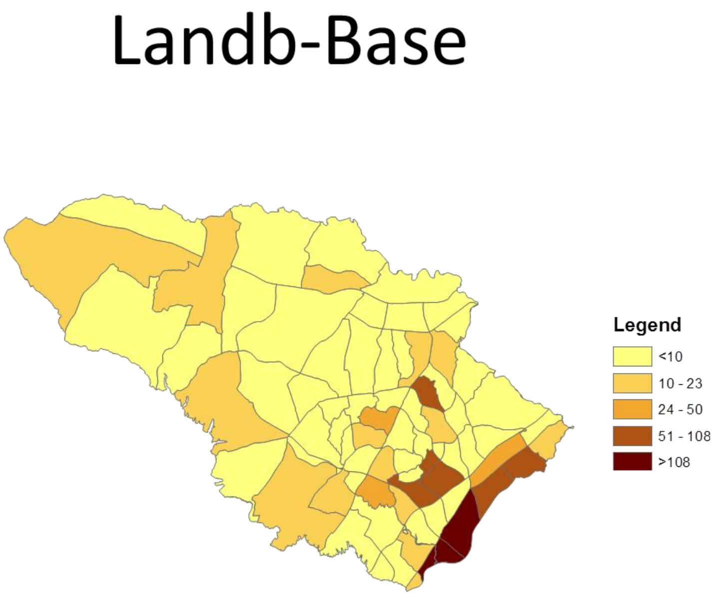


Figure 64: Land for Basic Employment – Base Year (2010)

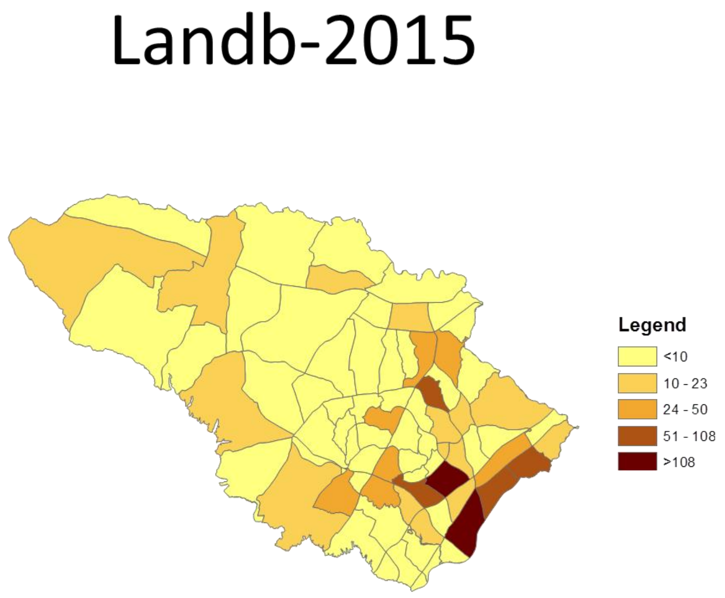


Figure 65: Land for Basic Employment – Predicted Year (2015)

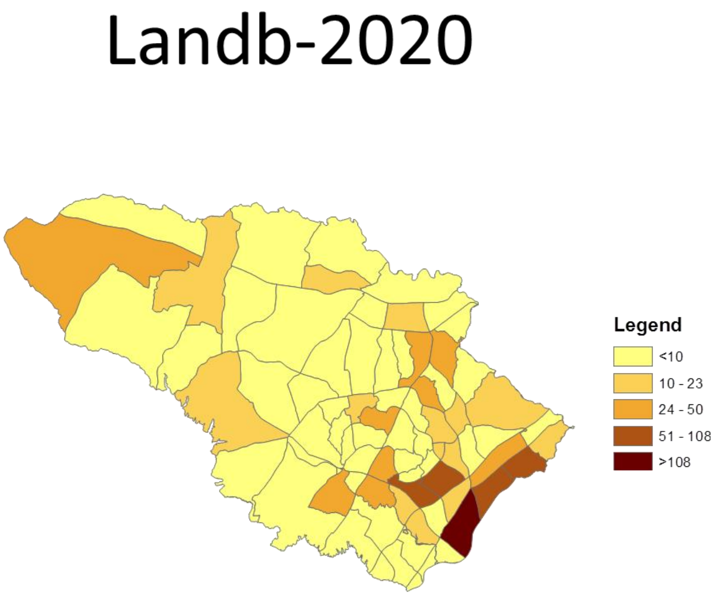


Figure 66: Land for Basic Employment – Predicted Year (2020)

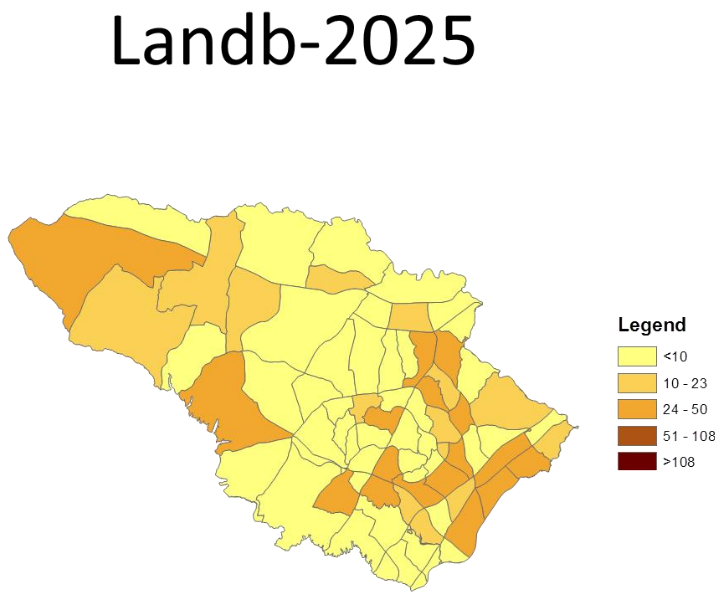


Figure 67: Land for Basic Employment – Predicted Year (2025)

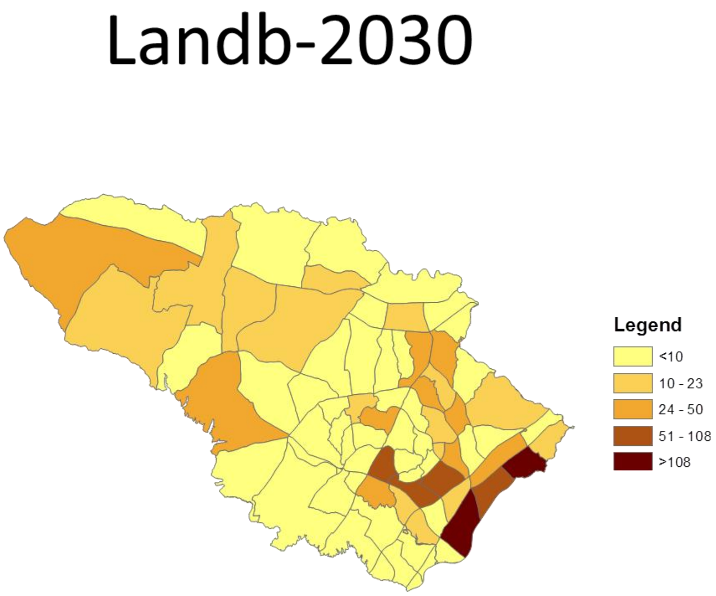


Figure 68: Land for Basic Employment – Predicted Year (2030)

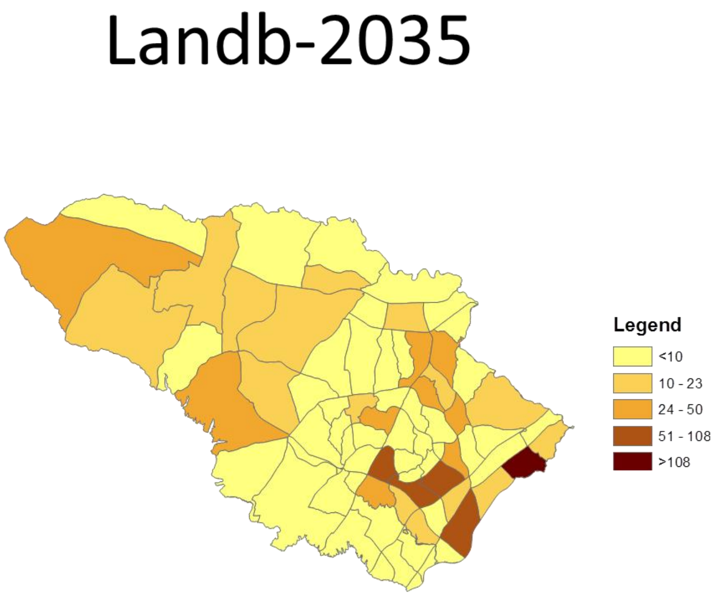


Figure 69: Land for Basic Employment – Predicted Year (2035)

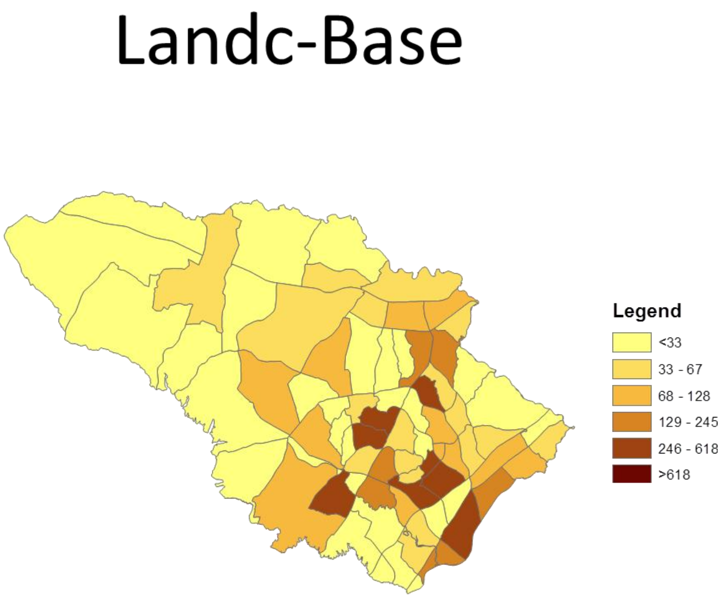


Figure 70: Land for Non-basic/Commercial Employment – Base Year (2010)

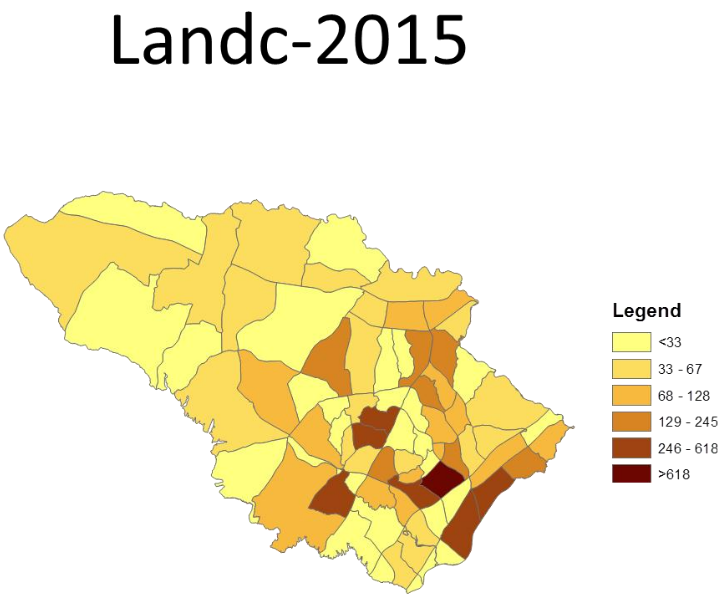


Figure 71: Land for Non-basic/Commercial Employment – Predicted Year (2015)

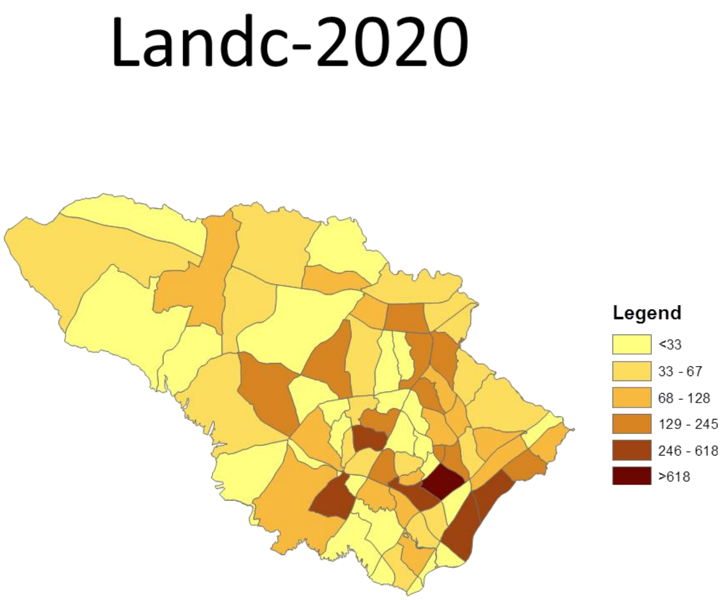


Figure 72: Land for Non-basic/Commercial Employment – Predicted Year (2020)

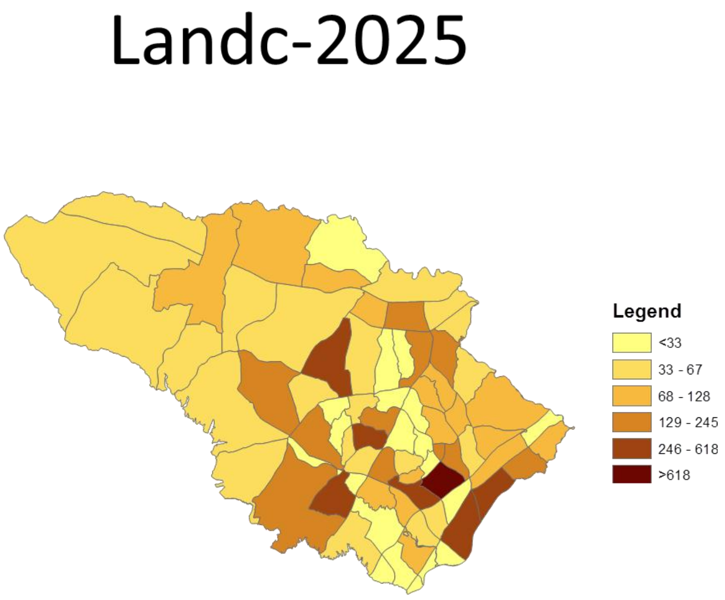
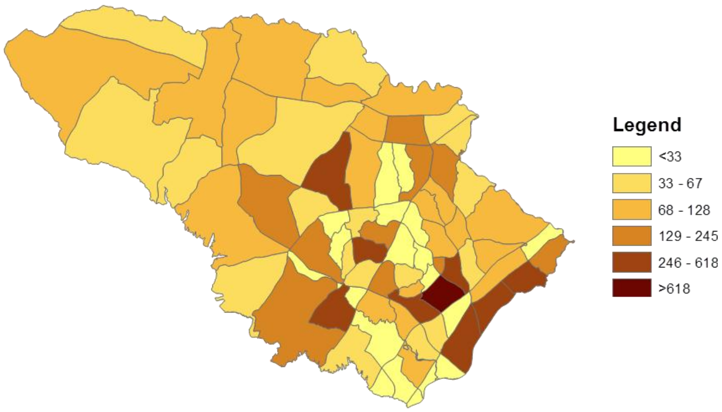


Figure 73: Land for Non-basic/Commercial Employment – Predicted Year (2025)



Landc-2030

Figure 74: Land for Non-basic/Commercial Employment – Predicted Year (2030)

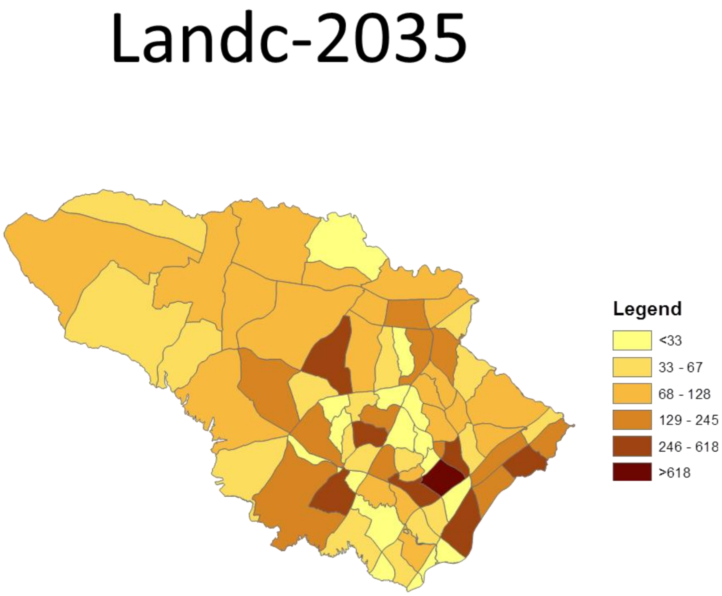


Figure 75: Land for Non-basic/Commercial Employment – Predicted Year (2035)

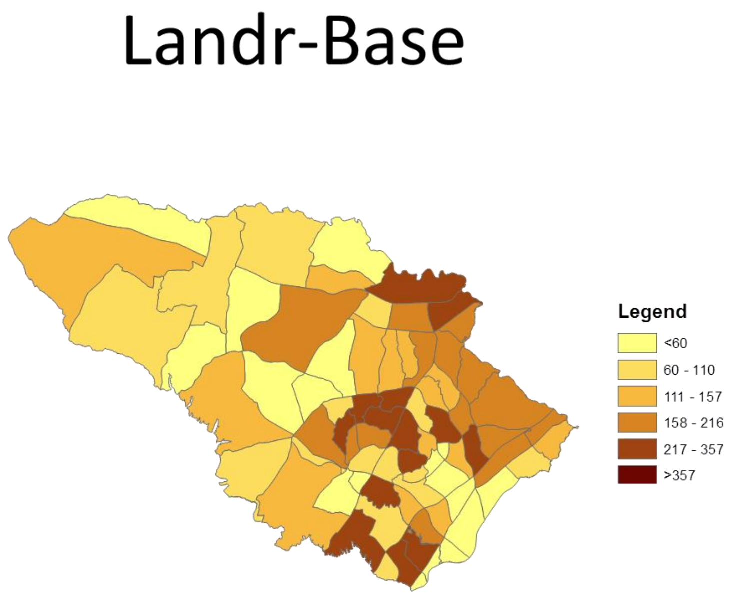


Figure 76: Land for Residential Use – Base Year (2010)

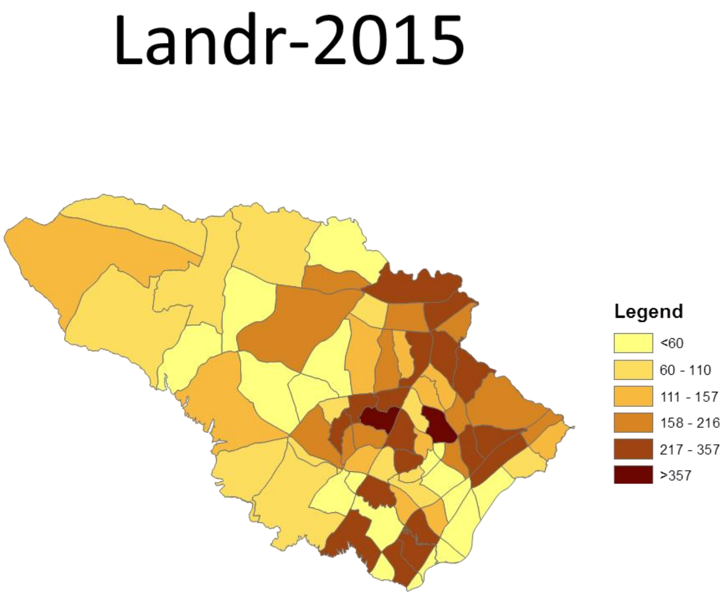

Landr-2015

Figure 77: Land for Residential Use – Predicted Year (2015)

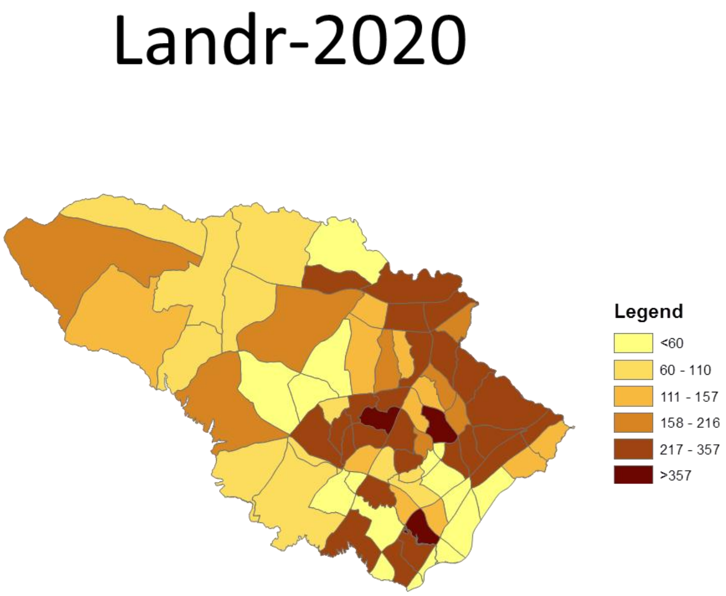


Figure 78: Land for Residential Use – Predicted Year (2020)

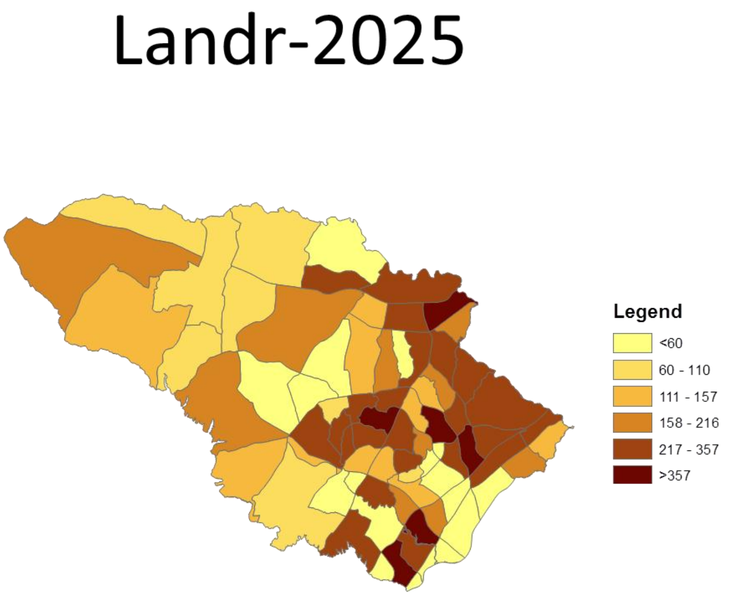


Figure 79: Land for Residential Use – Predicted Year (2025)

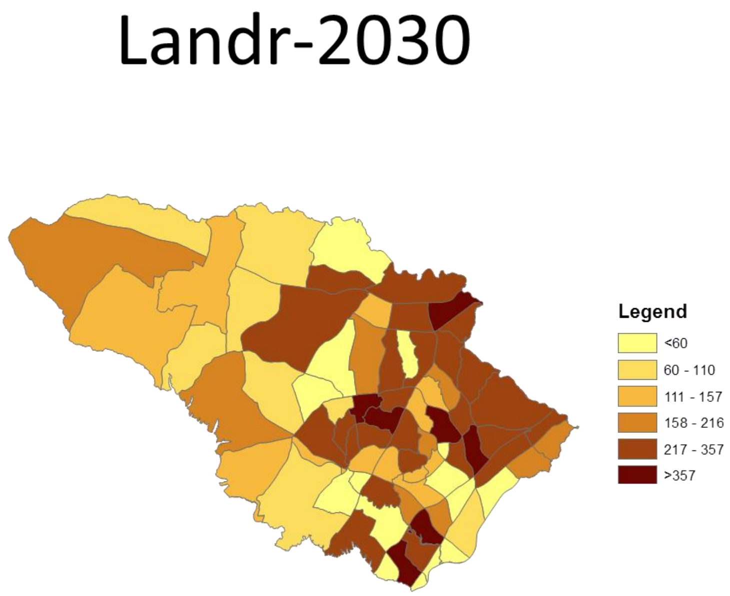


Figure 80: Land for Residential Use – Predicted Year (2030)

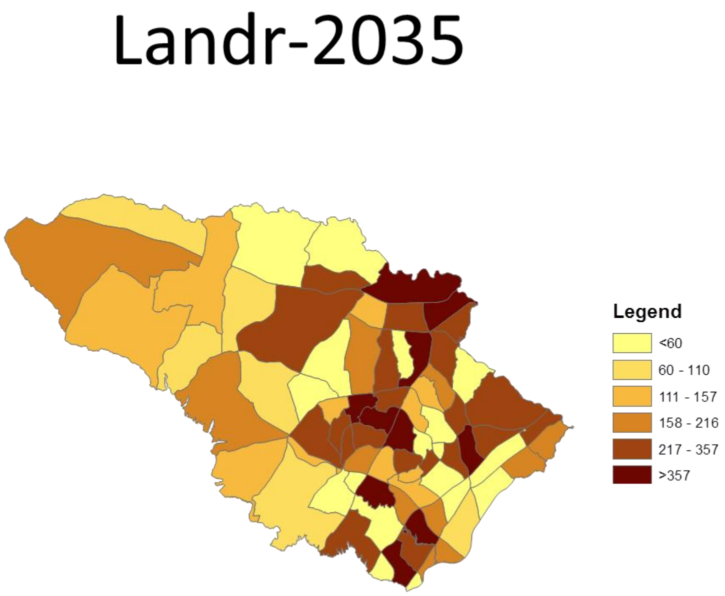


Figure 81: Land for Residential Use – Predicted Year (2035)