UNIVERSITY OF HAWAIʻI AT MĀNOA

Department of Civil and Environmental Engineering
2540 Dole Street, Holmes Hall 383, Honolulu, Hawaiʻi 96822-2382
Telephone: (808) 956-7550, Facsimile: (808) 956-5014

May 7, 2013

Metropolitan Transportation Commission
Public Information Office
101 Eighth Street
Oakland, California 94607

Re: Comments on Model One and UrbanSim utilized in the preparation of PLAN BAY AREA DRAFT ENVIRONMENTAL IMPACT REPORT—April 2013

Dear Sir/Madam:

This letter provides my comments on the models used in the Draft EIR referenced above.

My comments are summarized starting on page 2 and detailed justification is appended. My qualifications, in brief, are provided below.

Dr. Panos Prevedouros, author of this submission, is professor of transportation engineering at the University of Hawaii at Manoa. Dr. Prevedouros earned his PhD in 1990 and his M.S. in 1987, both in Civil Engineering from Northwestern University, Evanston, IL (1987), and his Diploma in Engineering from Aristotle University, Greece (1986.) He is a registered Professional Engineer in the European Union.

Dr. Prevedouros is subcommittee chair of TRB in the area of traffic simulation (freeway operations) since 2006. Dr. Prevedouros was member of Oahu MPO Technical Advisory Committee in the late-1990s and is the principal investigator of several transportation research projects funded by Hawaii DOT, US DOT, OMPO and DOI.

Dr. Prevedouros has expertise in urban planning, traffic flow analysis and optimization, ITS, demand forecasting and evaluation of transportation alternatives, and sustainable infrastructure with emphasis on energy and impacts.

Dr. Prevedouros has published over 100 technical articles and reports, and co-authored the 2nd and 3rd editions of internationally adopted textbook Transportation Engineering and Planning (Prentice Hall, 1993 and 2001.)

Dr. Prevedouros has received several awards including Best Paper award on transportation noise, TRB, 1995 • Outstanding Faculty award, ASCE-Hawaii, 1996 • Van Wagoner award, ITE, 2005 • Freeway Operations Service award, TRB in 2009. • Honolulu Star Bulletin's one of the "10 People Who Made a Difference in Hawaii in 2008" • 2011 Sustainability Paper award, World Road Association • 2012 Honor Certificate for Public Service, Council of the City and County of Honolulu.

Summary of comments

The state of the art in modeling in urban planning is lagging the state of the art in traffic engineering. The lesson learned from traffic simulation is that high-fidelity traffic simulation models are wonderful at the local level but ungainly and impractical for regional scenario analysis. Worse yet, their errors become intractable and the uncertainty (confidence intervals) of mean estimates are too large. As a result, since the turn of the millennium there has been a stronger emphasis on mesoscopic models that preserve critical micro-level mechanisms and simplify the processing of transportation flows on large and complex networks.

MPOs need to learn from this experience from traffic engineering and apply microsimulation for useful case studies such as SF-CHAMP [42]. For their long large regional plans, they need to develop more robust mesoscopic models. Very few, if any of the UrbanSim/Model One outputs for 2040 are reliable or significantly different from each other among alternatives. If properly applied, statistical tests would not allow for the identification of the locally preferred plan at a reasonable level of confidence. For example, the minutes from the Bay Area Regional Modeling Working Group meeting on October 3, 2012 reveal that "There was considerable interest in model calibration and validation issues. Chris asked about the model's margin of error, which David [Ory] indicated was large at this point."

Given that MTC and ABAG chose to base multibillion dollar public expenditures on the long range application of the microsimulation model UrbanSim, my UrbanSim-specific comments are as follows.

All my comments are based on literature published in 2010 or later that directly cites the software UrbanSim as a reference or basis of comparison of the work presented. Only recent works were reviewed to minimize old criticisms that have potentially been rectified in recent versions of the model.

UrbanSim is complex multi-component land use and transportation software that needs to be operated by a team of analysts over a period of years in order to provide estimates for a large metropolitan area. The workings of UrbanSim, as described by experts including its developers, are summarized in Appendix A. It is clear to me that each application of UrbanSim in a specific urban area requires customization and enormous data sets. UrbanSim has six main models (not counting Model One that provides transportation input.) In the words of a user: "For example, the Household Location Choice Model of the application described here has more than 50 setting options, with a similar number for other models." [22]

In their 2007 Assessment of Integrated Land Use/Transportation Models for the Southern California Association of Governments, Fehr & Peers observe that "UrbanSim integrates with a travel demand model at the input and output level. Current users of UrbanSim include the MPOs for Salt Lake City, Houston, Seattle, Detroit, and Honolulu[1]." [61]

Many published uses of UrbanSim are exploratory research, case studies or incomplete applications given that the model has been available in a comprehensive form for less than 10 years. Several sample applications of UrbanSim since 2010 are summarized in Appendix B. The limitations of UrbanSim applications and testing are clear; Many of the published works simply try to establish a base case or address one aspect of land use. Zurich is a telling case: "Within the project, the land use model UrbanSim were adapted and implemented for the Greater Zürich area. However, validation work revealed that there is more need for calibration." [17] The subject of calibration and validation is critical; it is discussed later on. "At present a first running environment that forms a very basic 'super simplified' simulation environment [of Zurich] has been realised. This includes very reduced household location choice and employment location choice models."[68]

An evaluation at the Department of Geography, University of Potsdam, Germany [34] assessed model suitability to geosimulate housing market conditions. "…45 points is the highest possible score, meaning that a simulation system is perfectly suitable for the suggested simulation framework. UrbanSim received the highest score (33)." In other words, in just one examined dimension out of six dimensions involved in urban area modeling, UrbanSim scored comparatively well, but its ability to cover this dimension is only about 73%. This is part of the positive assessments of UrbanSim summarized in Appendix C.

Appendix D lists a number of weaknesses of UrbanSim identified in recent publications. In recent years several jurisdictions and researchers evaluated UrbanSim and chose not to use it for their planning needs (e.g., [7, 16, 63]) mostly on the grounds of complexity and data requirements. However, once UrbanSim is chosen, there are several specific concerns such as:

- "The insignificance of the public transport accessibility coefficient creates a major limitation of the model." [17]
- "Even drastic accessibility changes have little impact on construction activity or population growth."[19]
- "Inertia in income distribution and prices seems to be strong, with little variation in an eight year simulation period." [22]
- "Current practice in UrbanSim modeling treats developer behavior and the emergence of land prices as independent processes. This assumes that land prices are exogenous to the interaction between buyers and sellers—an assumption hard to sustain in urban economics and real estate research." [59]
- Large models are "vulnerable to the trends contained in the historical data they use, especially recent trends." [63]

[1] Oahu MPO informed me that the Honolulu Department of Planning and Permitting is working towards some deployment of UrbanSim and when DPP is finished with its geographic representation, OMPO plans to adopt it into their TransCAD based modeling framework. OMPO does not use UrbanSim currently for its routine tasks.

- "As there are multiple secondary reasons that might obfuscate the model estimation process, it is recommended that UrbanSim model estimation results are compared against standard econometric software to make sure that the data and underlying assumptions made by UrbanSim are indeed understood correctly." [26]

It should be made clear that the concerns above are mostly out of case study or research applications. These substantial weaknesses are not based on model outputs that are subsequently used to approve hundreds of billions of dollars in public expenditures.

Calibration of UrbanSim is a difficult process. Some have deployed "response surfaces and metamodels to mathematically approximate intractable, simulation-based processes." [03] The uncertainty involved in these processes notwithstanding, there is no good reason why the parameters calibrated to match 2005 or 2010 conditions are applicable in 2035 or 2040.

Dr. Paul Waddell, chief modeler of UrbanSim stated that "Computational performance and inability to validate integrated microsimulation models due to stochastic variation and instability, were raised as very legitimate concerns. We need to take uncertainty in models seriously." [37] Yet the application of UrbanSim in this EIR clearly did not involve a validation and uncertainly analysis effort commensurate to the public policy implications of the model's results.

Critical assumptions in the model's logic are violated, such as this major conclusion from a Purdue University study for the Indiana DOT: "Based on a review of the research literature, **transportation infrastructure appears to be a necessary, but not sufficient, condition for generating economic development**." [63] Plan Bay Area heavily relies on the false hypothesis that the development of PDAs and TODs bestowed with good transit access generates economic development.

Furthermore, "MTC and ABAG also have a large body of detailed published documentation regarding the integrated travel demand and land use model. This data and other documents can be obtained from the Plan Bay Area website at www.onebayarea.org." [EIR, Page 1.2-18]

However, searching for UrbanSim finds the chapters and appendices of the EIR but no detailed documents that address the integration of UrbanSim and Model One. MTC's David Ory responded to an inquiry by Peter Singleton as follows: **The integration is straightforward: UrbanSim passes TAZ data[2] to the travel model and the travel model passes accessibility data to UrbanSim (see \accessibility in the scenario folders). This is discussed on page 9 of the Predicted Land Use Appendix[3]**. In fact Mr. Ory is pointing to one half page of "explanations" titled Travel Model Interaction on "page 9":

[2] http://analytics.mtc.ca.gov/foswiki/Main/TazData
[3] http://onebayarea.org/pdf/Draft_Plan_Bay_Area/Draft_PBA_Summary_of_Predicted_Land_Use_Responses.pdf

> "Bay Area UrbanSim and the Travel Model work as a system to capture the interaction between transportation and land use. **Accessibility to a variety of urban features is a <u>key driver</u> in both household and business location choice**. For instance, households often prefer locations near employment, retail, and similar households but avoid other features such as industrial land use. Business preferences vary by sector with some firms looking for locations popular with similar firms (e.g. Silicon Valley) while others desire locations near an airport or university. In all cases, the accessibility between a given location in the region (defined as a Transportation Analysis Zone or TAZ) and all other locations/TAZs is provided to UrbanSim by the Travel Model. These files represent overall regional accessibility for future years considering changing infrastructure. Updated skims were provided to UrbanSim in the projection years 2018 and 2025 based on projects expected to be in place in 2020 and 2035, respectively.
>
> Moving in the other direction, UrbanSim provides the Travel Model with a projected land use pattern and spatial distribution of activities for each year into the future. This pattern includes the location of housing, jobs, and other activities that serve as the start and end locations for trips predicted by the Travel Model. This information was provided to the Travel Model at a TAZ level aggregation for each future year examined. Overall, the linkages between the two models allow land use patterns to evolve in relation to changes in the transportation system and for future travel patterns to reflect dynamic shifts in land use."

The skimpy information above reveals that a major assumption in the model does not hold water: "A general critique of integrated land use and transport simulations is that often the notion of integration is reduced to the principle that the calculated accessibility or travel time measures serve as one of the explanatory variables of the residential choice module. Timmermans states that "**the literature on residential location choice behavior has <u>systematically shown that accessibility plays a marginal role</u> in the residential choice decision**. According to him, structural attributes of the house and physical and social characteristics of the neighborhood are more important." [17]

Another likely weakness on Model One affects UrbanSim and is not addressed in the EIR: "Travel models, including activity-based travel models developed in recent years, still generally use traffic analysis zones and ignore local streets in their network representation. In short, they ignore walking scale access and movements. This is a well-known and very problematic limitation in current travel models, and by extension, in integrated land use and transportation models, even if the land use models are at a parcel level." [04]

UrbanSim's intended use, assumptions and limitations in its application for this EIR are described by the model's developer and consultant to MTC and ABAG in Appendix E. A basic critique of these assumptions is as follows. Numbering corresponds to the list in the EIR which is also copied in Appendix E:

1. "**Interactions with adjacent areas are ignored**." It is unclear how this limitation affects Alternative 4 which has interactions with the counties surrounding the 9-county area of the Plan.
2. "**A project that is inconsistent with current land use regulations cannot get a waiver**." This assumption is both impractical and unsupportable over 30 years.
3. "…**needs to be determined by a combination of sensitivity testing, experience from use, and common sense**." However, none of these are applicable to a 30 year horizon given that the model is barely 10 years old. There are barely any sensitivity and uncertainty studies available, let alone proof that sensitivity and uncertainty ranges are small.
4. "…**there was not sufficient time or resources to thoroughly address all data problems encountered, including some extreme values, missing values, and inconsistencies within and among data sources.**" Indeed this appears to be a rushed application on a very large area. The amount of built-in errors is likely substantial.
5. "**One of the most common assumptions in models, and one rarely acknowledged, is that behavioral patterns will not change dramatically over time**." A look in the 30 years between 1980 and 2010 suggests that this assumption will certainly be violated. For instance HOT lanes, cordon pricing, and telecommuting (now accounting for more trips than all forms of rail in the US) were basically unknown in 1980. (Starting at 2010 and looking back 30 years takes us to 1980; looking forward takes us to 2040.) Assuming technological and behavioral stagnation between 2010 and 2040 is necessary and convenient for the modelers, but it is not defensible.

My conclusion below is in accord with experts in the field, as highlighted by the excerpts in Appendix F. It should be clear that the activity and land use modeling frameworks are far from being mature and are not reliable for long range forecasts. The result of all this modeling sophistication applied over huge dimensions such as a time horizon of 30 years, a geographic area of nine counties and covering the activities of seven to nine million people is sky-high uncertainty that is never revealed but renders all 2040 results practically useless.

Sincerely,

Panos D. Prevedouros, PhD
Professor of Civil Engineering

APPENDIX A. URBANSIM BASICS

- "UrbanSim was developed as Land Use and Transport Interaction (LUTI) model in order to respond to a variety of needs to assessing the possible consequences of alternative transportation, land use, and environmental policies, trying to better inform deliberation on public choices with long-term, significant effects. It can be used by cities, counties, non-governmental organizations, researchers and students interested in exploring the effects of infrastructure and policy choices on community outcomes." [36]
- "UrbanSim is published under the GNU General Public License (Free Software Foundation, 1991). Therefore, the software code is available for free and can be adjusted by any user. Since summer 2006, UrbanSim is available in a new version with improved program design, simplified user and programming interfaces and implemented in the script language Python. Additionally, UrbanSim was put into the larger context of the newly created framework OPUS (Open Platform for Urban Simulation). OPUS follows a modular approach with the aim to encourage the testing and linking of various model approaches for land use simulations. UrbanSim is currently applied by a range of user groups. "[17]
- According to the developer of the model, "UrbanSim has been widely adopted for use by Metropolitan Planning Organizations in the United States for operational use in regional transportation planning, in spite of numerous technical and political challenges in integrating land use and transportation planning and modeling (Waddell, 2011). [29]
- A prerequisite is the availability of an external transport model, since UrbanSim only provides models of land use processes. The transport model provides information on transport supply among TAZ (foremost average travel times). UrbanSim uses such information as input data to calculate accessibility measures. Conversely, the calculated distribution of land uses by UrbanSim can be used as input for a transport model. [17]
- Unlike ABAG that opted for a wholesale deployment of UrbanSim, Fehr & Peers did not recommend "the use of particular model software (either PECAS or UrbanSim) at this time. Their implementation plan recommended a phased approach for the model. This implementation covers the development of the initial model, which would reflect a zone system of approximately 200-300 zones." [61]
- "Agent-based microsimulation models for land use (e.g., UrbanSim (2010)) or transportation planning (e.g., MATSim-T (2010)) become more and more widespread. These models simulate agents' decisions over time in order to predict future states of the system. They allow for more detailed and accurate simulation and prediction of, e.g., land pricing and travel demand than traditional aggregate models. However, they also require disaggregate input data. When implementing such a model, the initial step is the definition of agents and their relationships. Most frequently, in this context, the agents of the microsimulation represent the individual people living in the study area, grouped by households." [51]
- "UrbanSim's main variables and functional relationships consist of critical exogenous inputs of **macroeconomics** (population, employment) and **travel demand** (travel conditions), and **six models**: (1) accessibility (output: access to workplaces and shops for each cell), (2) transition (output: number of new jobs and new households per year), (3) mobility [output: number of moving (existing) jobs or households], (4) location (output: location of new or

moving jobs ± households), (5) real-estate development (output: land-use change), (6) land price (output: land prices). [47]

- “Despite its rather simple structure of independent sub-models, UrbanSim is complex to implement because, basically, it deals with a complex problem. Many details in the way models are estimated and simulations are run can be taken into consideration: sample size, involved agents and datasets, model dependency, definition and sampling of alternatives, data filters, agent group clustering and data storage options, just to name a few, can be defined by the user. For example, the Household Location Choice Model of the application described here has more than 50 setting options, with a similar number for other sub-models. Modifying the settings of a model can easily generate errors that are hard to solve without help from the developers team.” [22]
- “The most recent review includes a discussion of 18 operational tools and suggests that **no tool is sufficient for supporting all of the necessary decisions associated with the metropolitan planning process** because of the complex nature of the decision-making process (Iacono, Levinson, and El-Geneidy 2008). Parker et al. and Sussman et al. support this argument and note that the complexity of the systems being modeled coupled with the decisions that need to be made warrant the development and use of a wide range of models rather than a specific few (Parker et al. 2003; Sussman, Sgouridis, and Ward 2005).” [55]

APPENDIX B. SAMPLE URBANSIM APPLICATIONS, 2010 to present

- S. Korea: UrbanSim application in Seoul: "Need better estimation methods for households in multi-story buildings." This was a limited exploratory application. RESEARCH [05]
- Canton of Zurich, Switzerland: Extensive application of UrbanSim but not with the travel model yet: "…following the case study delimitation, for which the land use transport interaction model finally will be applied. In the case study the land use model UrbanSim and the transport model MATSim will be implemented. INCOMPLETE [02]
- Arizona: "The prototype has been enhanced to incorporate additional feedback between the model systems, and update the travel time matrices used in the simulation process. The land-use model in SimTRAVEL is UrbanSim (Waddell et al 2008). The travel demand model employed is OpenAMOS (Pendyala et al 2011). The traffic microsimulation model system used in SimTRAVEL is MALTA -Multi-Resolution Assignment and Loading of Traffic Activities (Chiu and Villalabos 2008)." RESEARCH [11]
- "The simulation software UrbanSim was chosen for various reasons. Functionality and disaggregation of the simulation software as well as its implementation can be considered advanced. Moreover, there are various applications worldwide and an extended documentation, which is available online (CUSPA, 2006). UrbanSim is not a proprietary software package and therefore available for free." RESEARCH [17]
- "Within the project, the land use model UrbanSim were adapted and implemented for the Greater Zürich area. However, validation work revealed that there is more need for calibration. This remains to be done in future projects, in which UrbanSim can be applied in case studies within the Greater Zürich area for the comparison of development scenarios." INCOMPLETE [17]
- Waddell: "Draft versions of a data imputation toolkit for use in preparing UrbanSim data at a parcel level are currently in field testing by planning agencies in Seattle and Detroit, both of which have reported very positive results compared to previous data cleaning methods available to them." INCOMPLETE [37]
- UrbanSim is part of a system with DynusT based on Puget Sound Regional Council model; in development. INCOMPLETE [38]
- At the moment, UrbanSim is adapted to a European context (see the according research project SustainCity, www.sustaincity.eu)." INCOMPLETE [43]
- Three components are used in this modeling effort: UrbanSim (Waddell 2000; Waddell 2002; Waddell and Borning 2004) for land use, TransCAD (Caliper, Inc.) for travel demand modeling and traffic routing, and TRANSIMS (Nagel and Rickert 2001; Rilett 2001) for traffic routing through micro simulation. RESEARCH [49]
- Simulating household location choice in Lyon using UrbanSim. RESEARCH [56]
- Simulating housing prices in Lyon with UrbanSim: predictive capacity and sensitivity analysis. RESEARCH [57]
- Simulating the Impact of increasing oil prices on land use and mobility in Hamburg. RESEARCH [58]
- Simultaneous Modeling of Developer Behavior and Land Prices in UrbanSim. RESEARCH [59]
- Application of UrbanSim and technical issues in the Real Estate module. RESEARCH [65]

APPENDIX C. URBANSIM POSITIVE ASSESSMENTS AND PUBLISHED RESULTS, 2010 to present

- Analysis of tolling strategies: "The conclusion is that the static and the dynamic urban modeling frameworks [UrbanSim], despite their fundamental differences, can generate, in most cases, comparable empirical results, which are intuitively logical and can be used for policy scenarios evaluations." [01]
- Projections of changes in Seattle's built environment and demographics between 2000 and 2030 were obtained from an urban simulation model (UrbanSim) for water curtailments during drought. [14]
- "Integrated land use and transport simulations have achieved a level of technical maturation, which enables in principle their use in practice. But, the best simulation system is dependent on the underlying data used for the model estimations and the base year data of the initial state." [17]
- UrbanSim received the highest score (33) but the training time that has to be calculated to set up a basic model and the enormous amounts of high scale geodata (e.g. socioeconomic data at household level) that has to be acquired to set up a basic model disqualifies UrbanSim for prototype development for one single person." "…45 points is the highest possible score, meaning that a simulation system is perfectly suitable for the suggested simulation framework." [34]
- "UrbanSim is a much more complex model. It can be edited to create scenarios and add agent-based modeling, but takes years to set up for a city. This modeling has already been set up for the City of Phoenix, so we could use Phoenix [to investigate] Water, Energy, Land Use, Transportation and Socioeconomic Nexus: A Blue Print for More Sustainable Urban Systems." [74]
- Waddell: "UrbanSim land use model in San Francisco, using individual land ownership parcels as the basic geographic unit for real estate development and individual buildings on parcels as the locational unit for households and businesses. We link this model system to the San Francisco activity-based travel model system (SF-CHAMP) using a loose coupling approach." [42] This application was limited to rather small corridors. "One noteworthy methodological result is that the extreme level of disaggregation of the model, using individual business establishments, households, buildings, and parcels for the whole of San Francisco, generated remarkably robust estimation results. The goodness of fit on the estimated models was generally higher than has been the case with previous applications using grid cells or zones as units of analysis, in spite of considerable noise in the data." [42]
- "There is also an increasing number of applications implemented by researchers, urban planning offices or public authorities outside the UrbanSim core developers team. These include, among others, the case studies of Paris, France (De Palma et al., 2005); Phoenix, Arizona (Joshi et al., 2006); Volusia County, Florida (Zhao and Chung, 2006); Zurich, Switzerland (Buergle et al., 2005; Loechl et al., 2007); Lausanne, Switzerland (Patterson and Hurtubia, 2008; Patterson and Bierlaire, 2010); Lyon, France (Kryvobokov et al., 2008); Brussels, Belgium(Patterson et al., 2010); Rome, Italy (Zio et al., 2010) and Seoul, Korea (Joo et al., 2011; Hassan and Jun, 2011). Many of the applications are prototype

or proof-of-concept models with simplified datasets and assumptions. Some of the applications report an intensive use of human resources, in some cases excessive considering the quality of the obtained results (Nguyen-Luong, 2008). [22]

- Sprawl indicators were calculated and forecasted for Maricopa County, AZ, for 2000 to 2030. The study area is subdivided into one square mile grid cells. The analysis is based on the demographic projection data from a software-based simulation model called UrbanSim." [53]
- Both the PECAS and UrbanSim model provide data and analysis suitable for many of the duties which SCAG performs. These models would be particularly useful in the development of demographic forecasts, which is a key task performed by SCAG." [61] "These models integrate well with regional travel demand models, another key analysis tool utilized by SCAG." [61]
- UrbanSim was used to project the urban land-cover growth of Houston, Texas from 1992 to 2025. An important feature of UrbanSim is that it accounts for key actors in the urban development processes: (1) household and business actors reflecting consumer preferences for place or location; and (2) developer actors reflecting where and which type of construction is built. Government, political and environmental constraints are inputs designed to restrict development activity. Urban development is treated as an interaction between market behavior and governmental projections. This feature makes it very useful for assessing the impacts of alternative governmental plans and policies related to land use. [67]
- The Zurich Case Study of UrbanSim: At present a first running environment that forms a very basic "super simplified" simulation environment has been realised. This includes very reduced household location choice and employment location choice models. The first phase of the Zurich Case Study within the SustainCity project including data conditioning and implementing the first model in UrbanSim is therefore mostly finished. [68]

APPENDIX D. URBANSIM DIFFICULTIES AND WEAKNESSES

Highlights of critiques (verbatim) are included below with clarification added in [brackets]. All pertain to very recent sources published between 2010 and 2012 to avoid stating weaknesses potentially applicable to earlier versions only.

- Calibration of UrbanSim is a difficult process. "The parameter estimation problem for an integrated urban microsimulation problem was investigated. The operational difficulty of jointly estimating all parameters of the urban model was met with two different approaches: the decoupling through estimated process interactions and the deployment of response surfaces and metamodels to mathematically approximate intractable, simulation-based processes." [03] There is no good reason why the parameters calibrated to match 2005 or 2010 data are applicable in 2035 or 2040.
- UrbanSim requires an extensive amount of data at disaggregated levels spatially. Very few regions or metropolitan areas routinely collect all the data needed by UrbanSim, not to mention smaller urban areas. [13]
- A recent urban simulation evaluation in Australia chose TransCad and ArcGIS. They **did not choose UrbanSim**. "More recently, Klosterman and Pettit (2005) suggested that the most notable off-the-shelf planning support systems are CommunityViz, SLEUTH, INDEX®, UrbanSim and What if?™. From this set of Planning Support Systems (PSS) only CommunityViz and INDEX provide comprehensive impact assessment tools. [07]
- Recent evaluation of land use models that included but **did not choose UrbanSim** include the States of Florida [20] and Indiana: "The Regional Economic Models, Inc. (REMI), model is the fundamental tool employed by Indiana Department of Transportation to provide long-range socioeconomic forecasts that are used as inputs to the Indiana Statewide Travel Demand Model." [63]
- "Urban modeling has revived since the 1980s. Many new urban growth models have been developed, such as CUF, GSM, LUCAS, SLEUTH, UrbanSim, What if?, etc." They conducted an evaluation and **did not choose UrbanSim**; SLEUTH was chosen. [16]
- "In UrbanSim, the insignificance of the public transport accessibility coefficient creates a major limitation of the model." [17]
- "Housing policies are harder to implement in a modeling platform. [UrbanSim in this application.] For example, rent control should affect somehow the Real Estate Price Model but it is not clear how the rent thresholds affect the prices in general in the real-estate market. Social housing can be included as forced developments of a particular type of housing unit in the Development Project Transition Model; however this must be exogenously defined by the analyst." [18]
- Working with UrbanSim requires good programming skills preferable with Python programming language. The program cannot yet be mastered via the graphical user interface only. [68]
- "The story that seems to emerge is that for the PSRC implementation of UrbanSim, even drastic accessibility changes have little impact on construction activity or population growth."[19]

- “The model, implemented in the urban simulation platform UrbanSim and the traffic microsimulator MATSim, is estimated and applied to the city of Brussels…. Results obtained with UrbanSim seem reasonable, although inertia in income distribution and prices seems to be strong, with little variation in an eight year simulation period.” [22]
- ”As there are multiple secondary reasons that might obfuscate the model estimation process, it is recommended that UrbanSim model estimation results are compared against standard econometric software to make sure that the data and underlying assumptions made by UrbanSim are indeed understood correctly.” [26]
- “One of the key components of UrbanSim is the use of land or real estate price data. These are applied in the model system as an indicator of the relative market valuations for attributes of housing, non-residential space, and location (Waddell et al., 2003). However, finding suitable data sources of real estate transaction prices and rents might be a challenge while setting up an UrbanSim application when transaction and rent price data from data suppliers are unavailable.” [27]
- Waddell: “The first challenge is that in any spatial choice model, the assumption of IIA may be difficult to fully support. In most spatial choice situations, there is likely to be correlation in unobserved attributes that are correlated with preferences, and which would violate IIA assumption. ... Recent work by Guevara and Ben-Akiva (2009) has begun to clarify the path to extending sampling to other non IIA-based models, which offer considerable potential for enriching location choice models using parcel-level detail.” [37]
- Waddell: “The second remaining challenge is how to deal with the massive choices sets in the application of the models in predictive, or simulation mode. Unfortunately, for models such as parcel level location choice models, the universal choice set is potentially a million or more in size, for a moderate sized metropolitan area. This would be both behaviorally implausible as an approach (since people cannot actually make this kind of assessment), and is likely to run into problems from a flattening of the probability distribution predicted by the model, since each of the alternatives receives a non-zero probability. ” [37]
- Waddell: “Computational performance and inability to validate integrated microsimulation models due to stochastic variation and instability, were raised as very legitimate concerns. We need to take uncertainty in models seriously. If our models have high levels of embedded uncertainty arising from uncertainty in input data, in model parameters, and even in model specifications and structures, then we should be able to analyze and even calibrate the uncertainty in the models.” [37]
- The main purpose of this review was to ascertain the potential and the challenges of future simulation efforts and the applicability of these simulation models to phenomena such as urban shrinkage. UrbanSim is an Agent Based Model that is applied with the opposite view point... expansion.” [47]
- A lack of data necessary for calibrating and validating simulation models was identified, especially with respect to decisions made by households rather than individuals. [47]
- The Census is collected every 10 years which restricts the choice of the base year for the microsimulation model.”[51]

- "In addition to the study of the TRANSIMS model, preliminary scenario analysis of UrbanSim for Chittenden County has been conducted. UrbanSim simulations have been run for many scenarios. The simulation results show a job number increase in the main region of Charlotte when the parameter **near-arterial-threshold** is **doubled**; a household number increase in the northwest of Milton when the parameter **mid-income-fraction** is **reduced to half**; and a job number increase in main region of Charlotte together with a household number increase in the northwest of Milton when the **parameter near-arterial-threshold** is **doubled** and **mid-income-fraction** is **reduced to half**." [54] This demonstrates the sensitivity to parameter settings, for just one county. These are just two out of 50 plus parameters with a wide range of settings, not just doubling or halving the base value.
- We conclude that the calibrated residential Real Estate Price Model from the UrbanSim application in Lyon is sensitive to changes in accessibility and provides good predictive capacity in the city centre, but underestimates prices in other areas. [57]
- "A strong inter-dependence exists between the decision to develop land and the expected returns to be gained from that development. Current practice in UrbanSim modeling treats developer behavior and the emergence of land prices as independent processes. This assumes that land prices are exogenous to the interaction between buyers and sellers—**an assumption hard to sustain in urban economics and real estate research**." [59]
- The Regional Economic Models, Inc. (REMI) model, like its competitors, is vulnerable to the trends contained in the historical data it uses, especially recent trends. After the most recent periodic update in data, the performance of the REMI PI+ model improved, that is, it produced long-term forecasts that were more credible. Based on a review of the research literature, **transportation infrastructure appears to be a necessary, but not sufficient, condition for generating economic development**. [63]

APPENDIX E. ABAG / MTC USE OF URBANSIM FOR PLAN BAY AREA

With respect to Plan Bay Area, UrbanSim's intended use and limitations are described by the model's developer and consultant to MTC and ABAG as follows.

Intended Uses of the Model System [24]: UrbanSim has been developed to support land use, transportation and environmental planning, with particular attention to the regional transportation planning process. The kinds of tasks for which UrbanSim has been designed include the following:

• Predicting land use information for input to the travel model, for periods of 10 to 40 years into the future, as needed for regional transportation planning.
• Predicting the effects on land use patterns from alternative investments in roads and transit infrastructure, or in alternative transit levels of service, or roadway or transit pricing, over long-term forecasting horizons. Scenarios can be compared using different transportation network assumptions, to evaluate the relative effects on development from a single project or a more wide-reaching change in the transportation system, such as extensive congestion pricing.
• Predicting the effects of changes in land use regulations on land use, including the effects of policies to relax or increase regulatory constraints on development of different types, such as an increase in the allowed Floor Area Ratios (FAR) on specific sites, or allowing mixed-use development in an area previously zoned only for one use.
• Predicting land use development patterns in high-capacity transit corridors.
• Predicting the effects of environmental policies that impose constraints on development, such as protection of wetlands, floodplains, riparian buffers, steep slopes, or seismically unstable areas.
• Predicting the effects of changes in the macroeconomic structure or growth rates on land use. Periods of more rapid or slower growth, or even decline in some sectors, can lead to changes in the spatial structure of the city, and the model system is designed to analyze these kinds of shifts.
• Predicting the possible effects of changes in demographic structure and composition of the city on land use, and on the spatial patterns of clustering of residents of different social characteristics, such as age, household size and income.
• Examining the potential impacts on land use and transportation of major development projects, whether actual or hypothetical. This could be used to explore the impacts of a corporate relocation, or to compare alternative sites for a major development project.

Assumptions and Limitations of the Model System [24]: UrbanSim is a model system, and models are abstractions, or simplifications, of reality. Only a small subset of the real world is reflected in the model system, as needed to address the kinds of uses outlined above. Like any model, or analytical method, that attempts to examine the potential effects of an action on one or more outcomes, there are limitations to be aware of. Some of the assumptions made in developing the model system also imply limitations for its use. Some of the more important of the assumptions and limitations are:

1. Boundary effects are ignored. Interactions with adjacent metropolitan areas are ignored.
2. The land use regulations are assumed to be binding constraints on the actions of developers. This is equivalent to assuming that developers who wish to construct a project that is inconsistent with current land use regulations **cannot get a waiver** or modification of the regulations in order to accommodate the project. This assumption is more reflective of reality in some places than others, depending on how rigorously enforced land policies are in that location**. Clearly there are cities in which developer requests for a variance from existing policies meets with little or no resistance.** For the purposes the model system is intended, however, this assumption, and the limitation that it does not completely realistically simulate the way developers influence changes in local land use policies, may be the most appropriate. It allows examination of the effects of policies, under the expectation that they are enforced, which allows more straightforward comparisons of policies to be made.
3. Large scale and microscopic events cannot be accurately predicted. While this limitation applies to any and every model, not just UrbanSim, it bears repeating since the microscopic level of detail of UrbanSim leads to more temptation to over-invest confidence in the micro-level predictions. Though the model as implemented in the Bay Area predicts the location choices of individual jobs, households, and developers, the intent of the model is to predict patterns rather than discrete individual events. No individual prediction made by the model, such as the development of a specific development project on a single parcel in a particular year 20 years from now, is likely to be correct. But the tendencies for parcels in that area to have patterns or tendencies for development is what the model is intended to represent. Model users should therefore not expect to accurately predict large scale, idiosyncratic events such as the development of a specific high-rise office building on a specific parcel. It would be advisable to aggregate results, and/or to generate multiple runs to provide a distribution of results. A related implication is that the lower level of sensitivity and appropriate use of the model system needs to be determined by a combination of sensitivity testing, experience from use, and common sense. It would not be likely, for example, that changing traffic signalization on a particular collector street intersection would be a large enough event to cause significant changes in model results.
4. Errors in input data will limit the model to some extent. Efforts were made to find obvious errors in the data, and to prevent these from affecting the results, **but there was not sufficient time or resources to thoroughly address all data problems encountered, including some extreme values, missing values, and inconsistencies within and among data sources.** The noise in the input data limits to some extent the accuracy of the model, though the statistical estimation of the parameters should help considerably in developing unbiased parameters even in the presence of missing data and other data errors. Over a longer period of time, it would be well worth investigating how much difference errors in input data make in model results, and to fine-tune a strategy to invest in data where it makes the most effective use of scarce resources.
5. **Behavioral patterns are assumed to be relatively stable over time**. One of the most common assumptions in models, and one rarely acknowledged, is that behavioral

patterns will not change dramatically over time. Models are estimated using observed data, and the parameters reflect a certain range of conditions observed in the data. **If conditions were to change dramatically, such as massive innovation in currently unforeseen fuel technology, it is probably the case that fundamental changes in consumption behavior, such as vehicle ownership and use, would result**.

APPENDIX F. GENERIC CRITICISM OF PLANNING MODELS

"Nearly twenty years after the passage of ISTEA and the ruling against the MTC, there appears to be a revival in the development and adoption of using large-scale urban models as changes in society, technological advances, and improvements in data collection have all but forgiven Lees' seven deadly sins (Rabino 2007). Proponents of using large-scale regional models point to how these models have improved over time in forecasting ridership." [55]

"The application of large-scale modeling tools such as TRANSIMS and UrbanSim brings up a historical debate on their use as part of the decision-making process. In 1973, Lee professed the eventual disappearance of large-scale urban models because of 'seven deadly sins' including hyper-comprehensiveness, grossness, data hungriness, wrongheadedness, complicatedness, mechanicalness, and expensiveness (Lee, Jr. 1973). Today, much of the debate surrounding the use of large-scale regional models centers on criticizing the overall usefulness of such tools that are so complex in nature that they are expensive to run (expensiveness), difficult to use (complicatedness), and unable to represent reality (wrongheadedness) (Rabino 2007)." [55]

"Critics of large-scale regional models point to the historic mis-use of these tools during the 1970s and 1980s as part of the planning for rail systems in U.S. cities and the manipulation of the models in such a way as to provide erroneous results that only catered to political needs (Kain 1990). Pickrell provides a succinct analysis of this phenomenon in showing how regional planning models significantly overestimated ridership forecasts and underestimated capital costs (Pickrell 1992). The results of these large-scale urban models were used to justify spending billions of dollars on heavy- and light-rail transit systems in the U.S. for the purpose of economic development." [55]

"In developing discrete choice models, McFadden demonstrated the inaccuracies of the regional demand models used for the planning of the Bay Area Rapid Transit (BART) system in the San Francisco Bay Area. The regional demand model forecasted 15% demand in the transit system while McFadden predicted 6.3%. In an analysis of actual demand, the real number was 6.2% (McFadden 1974)." [55]

"A number of models like UrbanSim, Sleuth, Clue-s or what-if, developed for both laboratory and commercial purpose facilitate the spread of Planning Support Systems (PSS) and improve the cognition of this concept to urban planners in particular. **Comparing to the academic success, the application in the professional world is rather disappointing**." [39]

Waddell: "...and **integrated land use and transportation models** based on a dynamic microsimulation formulation (Salvini and Miller 2005; Waddell 2000, 2002). Although there has been some crossover in these research areas**, little has made its way into practical application in the field**." [42]

"For the acceptance of such complex simulation systems in planning practice, not only a moderate implementation effort is necessary but also a **certain degree of trust** of the potential users. The base for that trust is built by well-founded analysis of the reliability of land use and transport simulation results that go beyond the model fit values of single model estimations." [17]

"The study findings suggest that improved models derived from the academy may not translate into better practice in the field, unless the procedural dimension of modeling activities is improved. …Workshop participants were asked to rate the importance of dealing with these challenges on a scale from 1 (unimportant) to 5 (critical importance)." The top five choices of planners and modelers were: Data preparation (4.8), **Planners do not understand models and the modeling process** (4.6), Modelers do not understand the policy development and decision making process (4.4), Changing models (4.4), and Flexibility of models (4.4)" [16]

"Modeling of socio-economic and environmental interactions: The modeling of the considered phenomena must take into account many factors of different nature which interact via various functional relationships. These heterogeneous dynamics are a priori nonlinear and complex: they may have saturation mechanisms, threshold effects, and may be density dependent. The difficulties are compounded by the strong interconnections of the system (presence of important feedback loops) and multi-scale spatial interactions. ... **At this stage, it is crucial to understand that the scientific fields considered here are far from being mature**." [44]

"The relocation decision of a household is a major subject in the reviewed literature. Land use models usually focus more in the location choice process than in the elements that trigger relocation. The relevance (and complexity) of modeling the relocation decision process should be addressed carefully, maybe accounting more explicitly for the changes in the household's life cycle or identifying relocation triggers (like changes in land price or neighborhood quality of the current location of a household)."[18]

"Most projects utilizing large planning models seem to be in a permanent experimental status within an academic domain, few operational models exist. The learning curve for all the systems is steep and all the evaluated systems lack a satisfying visualization of simulation results." [34]

"UrbanSim takes a micro-simulation approach, modeling and simulating choices made at the level of individual households, businesses, and jobs, for instance, and it operates on a finer geographic scale than TRANUS. Now, let us focus on key challenges more directly related to modeling issues. <u>Model calibration and validation</u>: the above models consist of several interacting modules. Currently, these modules are typically calibrated independently; this is clearly sub-optimal as results will differ from those obtained after a global calibration of the interaction system, which is the actual final objective of a calibration procedure. <u>Sensitivity analysis</u> consists, in a nutshell, in studying how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model inputs. It is complementary to an uncertainty analysis, which focuses on quantifying uncertainty in model output. **Model calibration and validation, as well as sensitivity analysis have largely been ignored until now,** when they are really critical in this context. **They are also extremely arduous and complex."** [44]

"There is very little on evaluation of model performance: Conduct ex post evaluations of model forecasting and scenario allocation results: In hindsight, **did they get the locations right?** Why or why not?" [45]

"Although performance measures encourage agreement in other disciplines, measures for state transportation and land use may engender disagreement among stakeholders. A literature review and a survey of 25 states and three metropolitan planning organizations identified 41 such measures." [23]

APPENDIX G. REFERENCES

1. Marko Kryvobokov, Jean-Baptiste Chesneau, Alain Bonnafous, Jean Delons. Comparison of the static and dynamic Land Use-Transportation Interaction models: the PIRANDELLO and UrbanSim application. TRB Annual Meeting. 2013
2. Christof Zöllig, Kay W. Axhausen. A conceptual, agent-based model of land development for UrbanSim. Land use real estate and housing markets session ERSA 51th Conference. 2011
3. Gunnar Flötteröd, Michel Bierlaire. A framework for the data-consistent deployment of urban microsimulations. 2010
4. Fletcher Foti, Paul Waddell, Dennis Luxen. A generalized computational framework for accessibility: from the pedestrian to the metropolitan scale. The 4th Transportation Research Board Conference on Innovations in Travel Modeling. 2012
5. Hyejung Kwon, Yongjin Joo, Chulmin Jun. A land price prediction model using multi-scale data and UrbanSim in Seoul. GeoSpatial World Forum. 2012
6. Mohammad Mehedy Hassan, Chulmin Jun. A microscale simulation of land prices, household and employment growth using UrbanSim in Yongsan-Gu, Seoul. International Journal of Urban Sciences. 2011
7. Arron Walker ,Douglas Baker. A planning support system for airport city development. Proceedings of the 14th Air Transport Research Society Conference.2010
8. Yiyi Wang, Kara M. Kockelman, Paul Damien. A spatial autoregressive multinomial probit model for anticipating land use change in Austin, Texes. Annals for Regional Science. 2012
9. James Westervelt, Todd BenDor, Joseph Sexton. A technique for rapidly forecasting regional urban growth. Environment and Planning B: Planning and Design. 2011
10. Fernando Fonseca, Rui Ramos. An agent-based model to simulate the development of industrial parks in an urban network. 2011
11. Ram M. Pendyala, Karthik C. Konduri, Yi-Chang Chiu, Mark Hickman, Hyunsoo Noh, Paul Waddell, Liming Wang, Daehyun You, Brian Gardner. An integrated land-use transport model application: simulating the impact of network disruption on activity-travel engagement patterns.
12. Andre Brits, Matthew Burke, Teibei Li. An urban sustainability assessment framework – role and integration of modeling activities.
13. Meiwu AN, Mei CHEN. An iterative approach to an integrated land use and transportation planning tool for small urban areas. Journal of Modern Transportation. 2012
14. Austin S. Polebitski, Richard N. Palmer. Analysis and predictive models of single-family customer response to water curtailments during drought. Journal of the American Water Resources Association. 2013
15. Yiyi Wang, Kara M. Kockelman, Xiaokun (Cara) Wang, Anticipating land use change using geographically weighted regression models for discrete response. 90th Annual Meeting of the Transportation Research Board. 2011
16. Jingnan Huang, Ling Tian, Wenwei Pan, Yong Liu. Application of SLEUTH model for planning scenarios comparison: a case study of Chongqing, China.
17. Michael Lochl. Application of spatial analysis methods for understanding geographic variation of prices, demand and market success. A dissertation submitted to ETH ZURICH. 2010
18. Ricardo Hurtubia, Olivier Gallay, Michel Bierlaire. Attributes of households, locations and real-estate markets for land use modeling. Sustaincity working paper 2.1. Lausanne. 2010
19. Thomas W. Nicolai, Liming Wangy, Kai Nagelz, Paul Waddellx. Coupling an urban simulation model with a travel model - A first sensitivity test. paper presented at the Computers in Urban Planning and Urban Management (CUPUM), Lake Louise, Canada 2011
20. Zhong ren Peng, Liyuan Zhao, Fei Yang. Development of a prototype land use model for statewide

transportation planning. Report submitted to the System Planning Office, Florida Department of Transportation. 2011
21. Zachary Patterson, Michel Bierlaire. Development of prototype UrbanSim models. Environment and Planning B: Planning and Design. 2010
22. Discrete choice and microsimulation methods for agent based land use modeling. 2012
23. John S. Miller, Linda D. Evans. Divergence of potential state-level performance measures to assess transportation and land use coordination. The Journal of Transport and Land Use. 2011
24. Paul Waddell, Draft technical documentation: San Francisco Bay Area UrbanSim application. Metropolitan Transportation Commission (MTC). 2013
25. Dalal Pamela, Chen Yali, Ravulaparthy Srinath, Goulias Konstadinos G. Dynamic opportunity-based multipurpose accessibility indicators in California. Earlier Faculty Research, University of California Transportation Center, UC Berkeley. 2011
26. Nathalie Picard, Constantinos Antoniou. Econometric guidance for developing UrbanSim models - First lessons from the SustainCity project.
27. Nathalie Picard, Constantinos Antoniou, André de Palma. Econometric Models. Université de Cergy-Pontoise. 2010
28. Noordini Che'Man1, H.J.P.Timmermans. Economic growth and urban land use modeling. Map Asia. 2010
29. David Simmonds, Paul Waddell, Michael Wegener. Equilibrium v. dynamics in urban modeling. Symposium on Applied Urban Modelling "Innovation in Urban Modelling" at the University of Cambridge. 2011
30. Marco te Brömmelstroet. Equip the warrior instead of manning the equipment - Land use and transport planning support in the Netherlands. The Journal of Transport and Land Use. 2010
31. Ulrike Wissen Hayek, Noemi Neuenschwander, Adrienne Grêt-Regamey. Facilitating well-informed trade-off decision making on land use change:Integrating rules and indicators of ecosystem service provision into procedural 3D visualization. International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet. 2012
32. Marco Te Brommelstroet, Pieter M Schrijnen. From planning support systems to mediated planning support: a structured dialogue to overcome the implementation gap. Environment and Planning B: Planning and Design. 2010
33. S. Tamilenthi, R. Baskaran. Geomatic based urban sprawl detection of Salem city, India. Recent Research in Science and Technology.2011
34. Harald Schernthanner, Hartmut Asche. Geosimulation of Urban Housing Market conditions: A Preliminary Investigation. Proceedings REAL CORP 2012 Tagungsband. 2012
35. Yuill Herbert. Greenhouse gas emissions modelling to build resilient communities: A Review of the Literature. Sustainability Solutions Group Worker's Cooperation. 2010
36. Maria Cerreta, Pasquale De Toro. Integrated spatial assessment (ISA): a multi-methodological approach for planning choices. Advances in Spatial Planning.2012
37. Paul Waddell. Parcel-level microsimulation of land use and transportation: the walking scale of urban sustainability. IATBR Workshop on Computational Algorithms and Procedures for Integrated Microsimulation Models. 2009
38. Robert Tung, Yi-Chang Chiu, Sarah Sun. Integration of dynamic traffic assignment and diurnal departure curve estimation in a four-step framework. RST International.
39. Ji Yuan Yu. Introducing large scale urban model to Sydney's metropolitan planning. OIDA International Journal of Sustainable Development. 2011
40. Morito Tsutsumia, Akira Shimadaa, Daisuke Murakamia. Land price maps of Tokyo metropolitan area. International Conference: Spatial Thinking and Geographic Information Sciences. 2011
41. Dong Cai, Manchun Li, Zhenjie Chen, Xiaohui Jiang, Yanming Chen. Land use scenario simulation

based on multi-agent system. 2011
42. Paul Waddell, Liming Wang, Billy Charlton, Aksel Olsen. Microsimulating parcel-level land use and activity-based travel-Development of a prototype application in San Francisco. The Journal of Transport and Land Use. 2010
43. BR Bodenmann. Modelling firm (re-)location choice in UrbanSim. 2011
44. Elise Arnaud, Pierre-Yves Longaretti, Emmanuel Prados, Peter Sturm. Modelling for local scale sustainability and decision-making support: reflections and difficulties. Proceeding of the conference on Flows modeling for urban planning. 2012
45. John D. Landis. Modeling urban land use change: approaches, state-of-the art, prospects. 2012
46. Wu, Belinda; Birkin, Mark. Moses: Planning for the Next Generation. International review for spatial planning and sustainable development. 2013
47. Nina Schwarz, Dagmar Haase, Ralf Seppelt. Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage. Environment and Planning B: Planning and Design. 2010.
48. Shan Jiang. Paradigm shifts in urban policies and land-use transport models: prospects of the activity-based approach. UIS Research Seminar. 2012
49. Austin Troy, Brian Voigt, Adel Sadek, Stephen Lawe, Jun Yu, Yi Yang, David Hershey, Brian Grady, John Broussard, John Lobb. Phase I Report UVM Transportation Research Center Signature Project 1B – Integrated Land Use, Transportation and Environmental Modeling. A Report from the University of Vermont Transportation Research Center. 2010
50. Joshua A. Auld, Abolfazl Mohammadian. Planning constrained destination choice modeling in the adapts activity-based model. 12th WCTR. 2010
51. Kirill Müller. KayW. Axhausen. Population synthesis for microsimulation: State of the art. paper presented at the 90th Annual Meeting of the Transportation Research Board, Washington, D.C 2011
52. Naleeza Ebrahim, George Sun, Mageret Ely, Foo Jong Ai. Journeys-sharing urban transport solutions. LTA Academy Land Transport Authority 1 Hampshire Road Singapore 2194282011. 2011
53. Ariane Middel, Inga Scheler, Hans Hagen. Visualization of Large and Unstructured Data Sets – Applications in Geospatial Planning, Modeling and Engineering. ISchloss Dagstuhl-Leibniz–Zentrum für Informatik gGmbH, Dagstuhl Publishing, Saarbrücken/Wadern,Germany. 2010
54. Jun Yu, Yi Yang. Scenario analyses and simulations using TRANSIMS and UrbanSim for the Chittenden County of Vermont. University of Vermont Transportation Research Center. 2010
55. Matthew H. Hardy. Simplified integrated transportation and land use modeling to support metropolitan planning decisions: an application and assessment. A dissertation submitted to the graduate faculty of George Mason University. 2011
56. Marko Kryvobokov, Dominique Bouf, Nicolas Ovtracht, Pierre-Yves Peguy. Simulating household location choice in the Lyon Urban Area.
57. Marko Kryvobokov, Aurélie Mercier, Alain Bonnafous, Dominique Bouf. Simulating housing prices in Lyon with UrbanSim: predictive capacity and sensitivity analysis. Firenze University Press. 2012
58. Max Bohnets, Carsten Gertz. Simulating the impact of increasing oil prices on land use and mobility in the Hamburg Metropolitan Region. 12th International Conference on Computers in Urban Planning and Urban Management. Proceedings CD-ROM. Lake Louise. Calgary. 2011
59. Daniel Felsenstein and Eyal Ashbel. Simultaneous Modeling of Developer Behavior and Land Prices in UrbanSim. Journal of Transportation and Land Use. 2010
60. Anita Raja, Catriona Kennedy, and Roger Hurwitz. Socially Intelligent Agents to support Ethical Decision-Making.
61. Fehr & Peers. An assessment of integrated land use/transportation models. Southern California Association of Governments-Integrated Land Use/Transportation Model. 2007
62. Michael Iacono, David Levinson, Ahmed El-Geneidy. Models of transportation and land use change: a guide to the territory. Journal of Planning Literature. 2008

63. Yingge Xiong, Jon D. Fricker, Kevin T. McNamara, Joseph W. Longley. Socioeconomic forecasting. Joint Transportation Research Program. 2012
64. Heri Sutanta. Spatial planning support system for an integrated approach to disaster risk reduction. A thesis submitted to The University of Melbourne. 2012
65. Olivier Gallay. Starting with UrbanSim: on the creation of an introductory project. Internal Seminar of Transport and Mobility Laboratory, Ecole Polytechnique Fédérale. 2010
66. Ram M. Pendyala, Yi-Chang Chiu, Paul Waddell, Mark Hickman, Karthik C. Konduri, Bhargava Sana. The design of an integrated model of the urban continuum-location choices, activity-travel behavior, and dynamic traffic patterns. 12th World Conference on Transportation Research. 2010
67. J Marshall Shepherd, Michael Carter, Michael Manyin, Dmitry Messen, Steve Burian. The impact of urbanization on current and future coastal precipitation: a case study for Houston. Environment and Planning B: Planning and Design. 2010
68. Patrick Schirmer, Christof Zöllig, Kirill Müller, Balz R. Bodenmann, Kay W. Axhausen. The Zurich case study of UrbanSim. ERSA Conference Papers ersa11p562, European Regional Science Association. 2011
69. Ram M. Pendyala, Yi-Chang Chiu, Mark Hickman, Paul Waddell, and Bria Gardner. Towards an integrated model of location choices, activity-Travel behavior, and dynamic traffic patterns. http://itm2010.fulton.asu.edu/ocs/custom/allpapers/157 paper.pdf. 2010
70. Poulicos Prastacos, Nektarios Chrysoulakis, George Kochilakis. Urban Atlas, land use modelling and spatial metric techniques.
71. A. ERATH, Kay W. Axhausen. Urban sustainability and transportation: research framework for medium and long term transport planning.
72. Harish M. Urban transport and traffic management - for sustainable transport development in Mysore city. International Journal of IT, Engineering and Applied Sciences Research (IJIEASR). 2013
73. Sebastian Petsch. Visualization methods for sustainable planning. Vom Fachbereich Informatik der Technischen Universität Kaiserslautern. 2011
74. Elizabeth A. Minne, John C. Crittenden, Arka Pandit, Hyunju Jeong, Jean-Ann James, Zhongming Lu, Ming Xu, Steve French, Muthukumar Subrahmanyam, Douglas Noonan, Lin-Han Chiang Hsieh, Marilyn Brown, Joy Wang, Reginald Desroches, Bert Bras, Jeff Yen, Miroslav Begovic, Insu Kim, Ke Li, Preethi Rao. Water, energy, land use, transportation and socioeconomic nexus: a blue print for more sustainable urban systems.
75. Sevgi Erdogan, Timothy Welch, Gerrit J. Knaap, Frederick W. Ducca. What to expect in 2030: the impacts of fuel price and fuel economy on land use and transportation. 92st Annual Meeting of the Transportation Research Board and Publication in Transportation Research Record. 2012
76. Alain PHOLO BALA. Descriptive and geographical data for European cities. Université Catholique de Louvain, Belgium. 2010