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ASSESSMENT OF INTEGRATED TRANSPORTATION/ LAND USE MODELS

FINAL REPORT

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Acronym Key

AACOG Alamo Area Council of Governments

ABAG Association of Bay Area Governments

ASCII American Standard Code for Information Interchange

Caltrans California Department of Transportation

CEQA California Environmental Quality Act

CERES California Environmental Resources Evaluation System

COG Council of Governments

DOT Department of Transportation

DRAM/EMPAL Disaggregated Residential Allocation Model–Employment Allocation Model

EGPR Environmental Goals and Policies Report

EO Executive Order

FHWA Federal Highways Administration

FTE Full Time Equivalent

GIS Geographic Information System

HLFM Highway Land Use Forecasting Model

I- 90 Interstate 90 *(northernmost east-to-west, coast-to-coast interstate. Western terminus Seattle)*

I-O Input-Output

ISTEA Intermodal Surface Transportation Efficiency Act

ITLUP	Integrated Transportation and Land Use Package
MCAG	Merced County Association of Governments
MEPLAN	Marciel Echenique and Partners Planning Model
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
NEPA	National Environmental Policy Act
NSF	National Science Foundation
ODOT	Oregon Department of Transportation
PECAS	Production, Exchange, and Consumption Allocation System
PLACE^{3}S	Planning for Community Energy, Economic and Environmental Sustainability
PLU	Planned Land Use
PSRC	Puget Sound Regional Council
RPC	Regional Planning Commission
RTPA	Regional Transportation Planning Agency
SACMET 96	Sacramento Metropolitan Travel Demand Model of 1996
SACOG	Sacramento Area Council of Governments
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SAI	Systems Analysis Incorporated
SANDAG	San Diego Association of Governments

SCAG	Southern California Association of Governments
SLOCOG	San Luis Obispo Council of Governments
TAC	Technical Advisory Committee
TAZ	Transportation Analysis Zone
TDM	Travel Demand Management
TLUMIP	Transportation and Land Use Model Improvement Program
TMIP	Transportation Model Improvement Program
TRANUS	Modelo por Transportacion y Uso de Suelo
TRB	Transportation Research Board
UPlan	You Plan Model
US 395	United States Route 395 *(north/south route from Mojave Desert, CA though eastern WA State)*
US 97	United States Route 97 *(north/south highway from Weed, CA to Canadian Border)*
US DOT	United States Department of Transportation
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VMT	Vehicle-Miles Traveled
WFRC	Wasatch Front Regional Council

ABSTRACT

Use of integrated transportation/land use models is increasing worldwide as practical applications demonstrate the value of these sophisticated planning tools. Such models continue evolving from simple GIS-based forecasting models to extremely complex microeconomics-based integrated land use and transportation models.

Modeling is not a "one size fits all" proposition. Each Metropolitan Planning Organization or Department of Transportation is a different size, has different needs, is growing and changing in different ways, and has differing data, budget and staff available for modeling.

As part of this research, a system of information exchange involving the UC Davis research team, model developers, and modeling staff from Caltrans and selected California MPOs was created to eliminate knowledge barriers and provide feedback and criteria for model evaluation. The practical information gained through this process is related in this report, which will become a time -and money-saving resource to agencies considering selecting and implementing an integrated model to evaluate land use policies, test transportation investment scenarios, and evaluate compliance with various legal mandates.

This study focuses on four different models, including two which are considered state-of-the-art, UrbanSim and PECAS. In addition to detailed descriptions of the four models, the study identifies agencies currently using or developing various models, and provides examples of the costs and other challenges they faced in selecting and developing integrated models. The study also describes greater benefits, some of them unanticipated, which resulted from knowledge gained by use of these tools.

ASSESSMENT OF INTEGRATED TRANSPORTATION/LAND USE MODELS

INTRODUCTION

This report presents an overview and evaluation of integrated land use/economic/transportation models, including their unfolding benefits, potential applications, and implementation challenges. The project is timely because: (1) use of these types of models by metropolitan planning organizations (MPOs) and state departments of transportation is expanding, and (2) the major benefits of using these kinds of models are being revealed. Information contained in this study could improve planning and save valuable resources for jurisdictions considering adoption of integrated transportation/land use models. As an example, the state of Oregon alone redirected approximately $10 billion as a result of information gained using the integrated modeling process.

In particular, this study examines two state-of-the-art microeconomics-based integrated land use and transportation models, UrbanSim and PECAS; the MEPLAN model, which might be considered as a partial evolutionary step toward PECAS; and one less-robust land use forecasting model, UPlan.

The UC Davis research team conducting this study is headed by the project's principal investigator, Mike McCoy, co-director of the Information Center for the Environment. For more than 20 years, he has conducted research and directed outreach programs focusing on land use and transportation planning. McCoy brought together the expertise of Professor (now Emeritus) Robert Johnston with the Department of Environmental Science and Policy, whose research centers on transportation and land use modeling, and regional planning support systems.

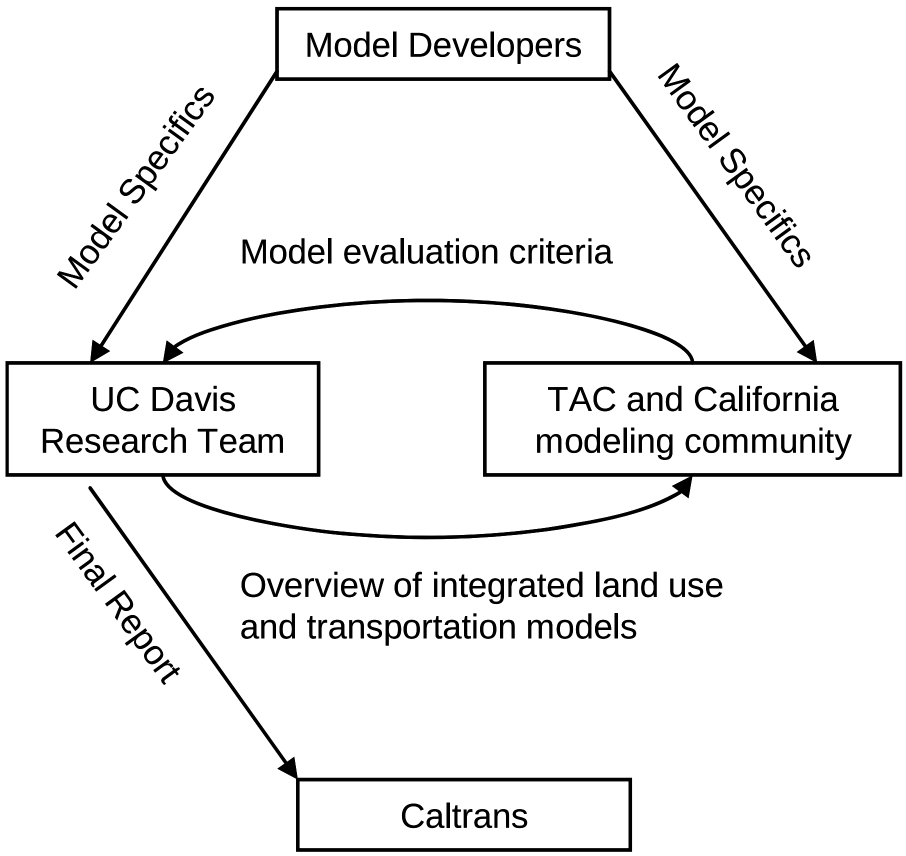
Professor Johnston was assisted by two of his Ph.D. students, Shengyi Gao and Michael Clay (now an Assistant Professor at Auburn University). Elizabeth Grassi, a Land Use Analyst with the Information Center for the Environment, provided additional management, support and outreach for this project.

A key component of this research was assembling a technical advisory committee (TAC) comprised of modeling staff from Caltrans Headquarters, District Offices and selected California MPOs to give advice and assistance on a full range of issues being considered in the evaluation of these models. (Please see Appendix A for a list of TAC members and their affiliations.)

The main goal of this committee and this project was to facilitate a system of information exchange and evaluation. This began with the UC Davis research team presenting general information on integrated land use and transportation models to the TAC and the modeling community. In turn, the TAC and modeling community provided the research team with consistent feedback and criteria against which the models should be evaluated. The exchange loop between the TAC and the research team was maintained throughout this process.

Specific details on the models themselves were presented by the model developers—Doug Hunt (the developer of PECAS) from the University of Calgary, and Paul Waddell (the developer of UrbanSim) from the University of Washington—to the TAC, modeling community, and the research team during a series of workshops conducted in Northern California, Southern California, and the Central Valley. The research team then applied the model evaluation criteria that was developed in coordination with the TAC and modeling community, and compiled this final report (This system of information exchange is presented in Figure 1).

Figure 1. *System of Information Exchange*



Over the past ten years, integrated land use and transportation modeling has received considerable attention in the scholarly literature (see Clay and Johnston, 2005; Waddell, 2002, Hunt, et al., 2005, and literature cited therein, for example). This academic interest is yielding practical applications.

The integrated land use and transportation models that are the focus of this project are of interest to California modelers and policy analysts for a variety of reasons described in this report. The

***Table 1**: Recent Implementations of Market Based, Integrated Models in the United States*

Land use models by type	Areas using
UrbanSim—a disaggregate land use model with explicit floorspace developer designed by Paul Waddell at the University of Washington	Eugene, Oregon; Honolulu, Hawaii; Salt Lake City, Utah; Houston, Texas; and currently being developed for MPOs in Seattle, Washington; San Antonio, Texas; and Detroit, Michigan.
PECAS—a disaggregate land use model with explicit economic interchanges developed by Doug Hunt and John Abraham at the University of Calgary	State of Oregon; currently being developed for the State of Ohio, and for the Sacramento, California MPO (SACOG)

project is timely because use of these types of models by MPOs and state Departments of Transportation is beginning to expand (See Table 1).

For the first time, many MPOs and state departments of transportation are beginning to implement these types of models. These agencies are responding both to local needs, expressed by their constituent cities and counties, and to external legal requirements, such as the National Environmental Policy Act (NEPA) and the Clean Air Act air quality conformity modeling rule.

This study is timely because several of the modeling exercises listed in Table 1 are yielding significant results. These models are being used to evaluate a broad range of policies, from the economic implications of different bridge construction sequencing scenarios in the state of Oregon to analysis of region-wide growth scenarios in Sacramento, California and Salt Lake City, Utah (Weidner, et al., 2005; Johnston, et al., 2005; and Waddell, et al., 2003 respectively). As the number of model implementations increases, the uncertainties inherent in model development are slowly becoming known quantities.

In California, the Sacramento Area Council of Governments (SACOG) has been a leader in integrated modeling and has implemented a variety of these models, including: DRAM/EMPAL, TRANUS, and MEPLAN. SACOG is currently calibrating a PECAS model. The SACOG experience is instructive for other MPOs seeking to develop similar models. Gordon Garry, Director of Research and Analysis at SACOG, gave one of the initial presentations to the TAC outlining how SACOG assessed user needs for the agency's integrated model. His experience, participation, and availability to the TAC and MPO staff were extremely valuable throughout this study. A brief description of the SACOG model development process can be found in Appendix E3 of this report beginning on page 91, as well as a longer description with tasks and budget.

The TAC was established at the onset of this project to help guide the process and help develop model evaluation criteria that would represent the various needs and expectations of California MPOs. The TAC was comprised of selected Caltrans staff and modeling staff from selected MPOs within California. The members of the TAC and their affiliations are presented in Appendix A (page 75). It was anticipated that the criteria arrived at through meetings with the TAC and other California modelers would represent the issues and concerns that are specifically relevant to modeling practice in California. Appendix B (page 77) outlines the roles and responsibilities of the TAC. The authors of this report are indebted to the members of the TAC for their generous contributions to this study.

BACKGROUND

The 1962 Federal-Aid Highway Act led to the institutionalization of the four-step travel demand model. The four-step model simulates the demand for travel as a function of households and employment. Once the demand model is calibrated based upon survey data and contemporaneous network characteristics, these models can be applied to forecasting by changing the inputs based upon other models or expert judgment. These models enable policymakers to directly compare the transportation system-wide effects of different road construction and transit projects (for additional information on these models, see Ortuzar, 2001).

The four-step model has been continuously updated and improved since its creation. Discrete choice models of mode and route choice, full feedback loops, capacity constraint, dynamic user equilibrium, and many other improvements have increased the conceptual validity and robustness of these models. Current work is aimed at microsimulating every household and every trip (which will be represented in tours of linked trips) to provide greater spatial detail and allow for the expanded use of discrete choice representations of behavior.

Urban land use, transportation, and urban economic systems are complex. Representing only one part of these systems (i.e. travel) limits the usability of the four-step travel demand model and the robustness of any policy analysis performed with four-step models alone. In other words, *the structure of the model determines its usefulness in policy analysis* (See Table 2). The literature is replete with attempts to use travel models to forecast policy implications where the major policy implications are land development trends and not traffic flows (Cervero, 2003; and Goodwin and Noland, forthcoming). These attempts fall short in their efforts to test policy effects on land use because a travel demand model that takes land use/development as exogenous *cannot represent land development changes resulting from improvements in traffic flow.* Many of the travel-forecasting models currently employed in the United States are inadequate to study the induced travel and induced growth effects of transportation improvements (Transportation Research Board, 1995). A model must be able to capture both short-term behavior shifts (i.e. travel changes) as well as long-term land use shifts produced by road improvements (Cervero, 2003). Citing Hunt (2002), Cervero, referring to early steps toward the integration of land use and travel models, said,

> Indeed, the general consensus of attendees at a recent conference convened by the Eno Transportation Foundation Policy Forum on induced demand was that the greatest value added of research in this area is to inform the calibration of long-range travel forecasting and urban simulation models, such as MEPLAN, TRANUS, and TRANSIMS. (*APA Journal*, Spring 2003, Vol. 69, No. 2, “Road Expansion, Urban Growth, and Induced Travel, A Path Analysis”, pg. 160.)

UrbanSim and PECAS are similar to MEPLAN, but more complex. UrbanSim, with a detailed representation of the floorspace developer, gives useful economic measures like those listed for MEPLAN. PECAS is nearly completed for ODOT and will simulate households and firms in more detail. All of these models can be run with travel models that are tour based or activity based. In general, the trend in travel models and in land use models is toward more spatial, temporal, and functional disaggregation. This means the most-advanced models run some sub-models on a daily basis, some on a monthly basis, and some on an annual basis. Households and firms will be represented by full microsimulation, meaning a 100% sample is enumerated and carried through all model steps. This permits very detailed equity analysis at the tail end, as all household and firm characteristics are in the final output tables.

Table 2. *Comparison of Analyses Capabilities of Stand-Alone Travel Demand Models vs. "Integrated" Land Use/Economic/Travel Models*

What Types of Analyses and Functions Does each Type of Model Perform?	Travel Models (Alone)	***Integrated Models***
Policies, Plans, Programs, Evaluation:		
Planning: Assist practitioners arrive at optimal planning and engineering decisions re: land use, economic, and transportation plans, programs, policies & projects.	**No**	**YES**
Strategy Assessment: *Evaluate what strategies may be most effective in achieving various objectives, and identify intervening actions necessary to reach goals.*	**No**	**YES**
Scenario planning: Provide visual and quantitative feedback regarding effects of various "what if" land use and transportation strategies and scenarios to staff, the public, stakeholders, and decision-makers.	**No**	**YES**
Economic Development: Evaluate the comparative economic development costs and benefits of various policies, programs, projects, and strategies to particular locations, industries, and populations.	**No**	**YES**
Environmental Justice: Assess potential impacts and benefits of various transportation, land use, and economic policies, programs, plans, and projects on specific populations and economic groups.	**No**	**YES**
Performance Measures: Provide the analysis capabilities to establish "non-traditional" performance measures to assess various plans, programs, and policies, re: "outcomes" of various options over long time periods.	**No**	**YES**
Transportation Analysis:		
Goods Movement: Assess baseline and future activity regarding Goods Movement (enhanced by use of actual economic data).	**Poorly**	**YES**
Market-based Measures: Estimate effects of market-based programs and projects (e.g., HOT lanes, bridge tolls, gasoline-related fees, transit fare changes, etc.)	**Poorly**	**YES**
Cumulative Impacts: Assess potential cumulative impacts of transportation project EIRs for improved project delivery (e.g., "induced demand")	**No**	**YES**
TSM: Estimate traveler responses to traffic management strategies, including route diversion, departure time choice, mode shift, destination choice, and induced or foregone demand.	**Poorly**	**YES**

What Types of Analyses and Functions **Does each Type of Model Perform?**	Travel Models (Alone)[1]	***Integrated Models*** [2]
Traffic Congestion: Assess the potential effects of transportation plans, programs & projects on highways and arterials, based on set local General Plans (but not interactively with land uses over time).	**Yes**	**YES**
Multi-modal Analysis: Compare effects of various facility types, such as freeways, high-occupancy vehicle (HOV) lanes, transit, ramps, arterials, etc. (but not interactively with land use and economic conditions).	**Yes - if it has modal component(s)**	**YES**
Land Use Analysis:		
Land use/transportation interactions: Assess the interactive effects of transportation system(s) on land uses, and vice-versa over time - either "constrained" by land use plans, &/or "free-market" regarding land uses.	**No**	**YES**
Land Uses: Predict amount and locations of various types of land uses (residential, commercial, industrial, and employment) in relation to transportation networks.	**No**	**YES**
Smart Growth: Analyze the effects and benefits of Smart Growth strategies on transportation, and vice-versa (e.g., infill and higher-density development in coordination with walk/bike facilities, transit, etc.)	**Poorly**	**YES**
Jobs/Housing Balance: Quantify Jobs/Housing Balance based on incomes of residents and employees in relation to existing and future housing prices (not just total numbers of houses and jobs).	**No**	**YES**
Planning strategies: Assess traffic-related effects/benefits of urban growth boundaries, growth management strategies, development impact fees, etc.	**No**	**YES**
Housing affordability: Analyze the linkage of travel and residential choices regarding housing affordability and resulting impacts on transportation.	**No**	**YES**
TSM: Estimate effects of land uses regarding traffic management strategies, and help set priorities among competing projects. Provide a consistent approach for comparing potential improvements or alternatives	**No**	**YES**

By: Terry Parker, DOTP, Ayalew Adamu, TSI, and Robert Johnston, UC Davis. July 25, 2005.

[1] Including: Standard four-step travel demand models, and also new activity-based and tour-based travel models.
[2] E.g., PECAS, MEPLAN.

UrbanSim and PECAS represent the next generation of integrated models evolving from models such as MEPLAN and TRANUS. The ability of integrated land use and transportation forecasting models to model the dynamics of land development and travel demand in an integrated fashion makes them conceptually well suited for use in many urban and regional policy-testing applications. Land use policies affect travel, and transportation policies affect land development patterns. For this reason, integrated land use and transportation models are superior -- for policy analysis purposes -- to traditional travel-forecasting models. This point is demonstrated by several comparative modeling studies.

The Sacramento Model Test Bed Study brought together many of the best minds in integrated modeling. This study was a side-by-side comparison of the Sacramento Area Council of Governments' (SACOG's) travel model (SACMET 96), DRAM/EMPAL (run with SACMET 96 as its travel model), TRANUS, and MEPLAN. The purpose of the study was to test and compare each model's policy analysis ability (Hunt et al., 2001). Each model was given identical data from the Sacramento region for model calibration. A trend scenario was run as well as three policy scenarios. The outputs produced by the various models were quite dispersed.

One of the more obvious findings of the Sacramento Model Test Bed Study was that when a land use model is used, such as DRAM/EMPAL, MEPLAN, and TRANUS, households and firms shift location (over time) in response to policy. As a result, the travel model (SACMET 96) alone (without the use of a land use model) predicted higher VMT across all scenarios than did the integrated models MEPLAN and TRANUS. The higher VMT is a direct result of the travel model's inability to predict land use and economic activity location changes across time in response to higher travel costs (generalized costs, including time). While this study did not explicitly recommend one model over another, the findings of this study led to MEPLAN being adopted by SACOG for regional policy analysis. SACOG has since evolved its MEPLAN model to the next generation of MEPLAN, the PECAS model, which SACOG is currently implementing.

Portland Metro staff conducted a study that further demonstrates the superiority of integrated models over traditional travel demand models. This study compared results from Portland's travel model with results from its integrated model, Metroscope. They write,

> Comparing our Metroscope results to our previous forecast reveals that Integrated Transportation and Land Use Models may produce different results in regard to Trip Length, [vehicle miles of travel], traffic congestion levels, mode and route choice, employment and household locations. Compared to trend models, integrated models robustly respond to alternative land regulation and transportation investment policy options allowing planners and officials an opportunity to evaluate the differences in land use and transportation arising from different policy choices. Moreover, the integrated models produce far more data on such factors as real estate prices, tenure choice, residential and nonresidential real estate output, land consumption, redevelopment and density.
> (Condor and Lawton, 2002.)

Similar to the Sacramento Model Test Bed Study and other model comparison studies (Rodier, et al., 2002), this study demonstrates the value added from using an integrated model for policy analysis purposes. For further review of this literature see the annotated bibliography in Appendix C (page 78).

Federal and State Laws Relating to Land Use Models

The Federal Clean Air Act requires that MPOs and counties be able to project mobile emissions accurately, in absolute amounts, in order to meet emissions budgets. This means that travel modeling must represent all trips and get vehicle speeds right. Past modeling practice is inadequate in these regards, as it was formulated simply to indicate which roads were relatively more congested. *This statute requires that travel modeling represent all modes and all trip purposes, in detail*. This law then necessitates that agencies represent the effects of changes in accessibility on trip making, trip lengths, and on land development patterns. This last function is particularly out of reach for traditional travel models. *The advantage of integrated models in addressing the Clean Air mandate is that they include land use zoning while testing market behavior*.

The Air Quality Conformity rule adopted by US DOT and US EPA requires that *all model steps represent the effects of changes in accessibility on trip lengths* (40 CFR 93.122(b)(1)). The rule also requires these MPOs to have "consistent" land use and facility scenarios, that is, to use different activity patterns (land uses) in the "Proposed Plan," "No Build," and other alternative plans. This means MPOs need some method of assessing the effects of changes in accessibility on land development. Travel must be modeled for at least peak and non-peak time periods and vehicle speeds must be based on measured speeds. The Federal Clean Air Act also requires the consideration of Travel Demand Management (TDM) measures and so *models now must be able to evaluate parking pricing, road tolls, and fuel taxes, among other TDM strategies*. Many regions also wish to evaluate land use measures, such as increased density, mixing land use types, jobs/housing balance, flextime, para-transit, park-and-ride lots, and increasing sidewalks and bicycle paths. This complex mix of factors, especially those involving land use, are generally beyond the scope of single purpose travel models.

The Intermodal Surface Transportation Efficiency Act (ISTEA), signed in 1991, *requires that all modes of travel be considered in planning*. Transportation planning must now include much stronger consultation with other agencies and with citizens than in the past, and MPOs with populations over 200,000 are recertified every three years by US DOT, based on these and other issues.

The Civil Rights Act of 1965 has been interpreted by some courts as requiring equitable provision of transit services. The Environmental Justice Presidential Executive Order, signed in 1994, requires that all federal agencies evaluate the effects of their actions on minority and poor households, evaluated at the finest level of spatial detail possible. The US EPA has issued a guideline for these analyses. *Travel models, to fulfill these mandates, must be able to evaluate the economic effects of land use and facility plans on households by income class and, if possible, by minority status.* Our study has found that it would also be desirable to be able to evaluate the effects of plans on firms by type and location. The only agency in California that does this with adequate methods is the South Coast Air Quality Management District, which uses an input-output model to evaluate the effects of air quality regulations on poor and minority households and on small firms.

On September 18, 2002, President George W. Bush signed Executive Order (EO) 13274, Environmental Stewardship and Transportation Infrastructure Project Reviews. This EO established an Interagency Task Force to advance current US DOT and interagency environmental stewardship and streamlining efforts, to coordinate expedited decision-making related to transportation projects across federal agencies, and to bring high-level officials to the table to address priority projects. The Task Force established an interagency Work Group on Integrated Planning, which recognized the continuing need to more effectively "link" short and long-range transportation planning and corridor level planning studies performed by state and local governments with resource agency and land use planning processes, and with project-specific environmental reviews, approvals, and permitting processes. Integrated transportation planning is about a collaborative, well-coordinated decision-making process that solves the mobility and accessibility needs of communities in a manner that optimizes across multiple community goals—from economic development and community livability to environmental protection and equity. It is about providing users of transportation systems with choices, and about providing information on the performance of transportation networks and facilities that reflects what customers value most.

An integrated planning framework is characterized by the following elements, including: *integration with land use planning and across transportation modes and capacity enhancement options.* Looking at transportation as a system requires a more careful and robust assessment of the various options available to planners and decision-makers for addressing accessibility, safety, and mobility needs. To do that, transportation professionals need a process that integrates transportation and land use…" (http://www.fhwa.dot.gov/stewardshipeo/planning.htm Integrated Planning Work Group, Baseline Report and Preliminary Gap Analysis .Deliberative Draft)

Table 3. *Summary of federal legal requirements affecting travel modeling*

Summary of Federal Legal Requirements Affecting Travel Modeling:

Clean Air Act of 1990

Serious and Worse Air Quality Regions:

MPO must show attainment by deadlines
Run network-based regional travel demand model
Run model to equilibrium (to show induced travel)
Land development patterns must be consistent with facility plans
Peak and off-peak time periods
Travel costs must be included in all model steps

All Other Areas:

Must use any of the above methods, if the MPO has them available

Surface Transportation Act of 1991

Agencies must plan for all travel modes
MPOs must consult with other agencies and interest groups on scenarios, modeling methods, and indicators
Planning process must be recertified every 3 years

Civil Rights Act of 1964

Agencies cannot discriminate against minorities in transit services
Agencies must consider the effects of all projects and plans on minorities and on lower-income households (Exec. Order on Environmental Justice)

National Environmental Policy Act

MPOs must consider the growth-inducing impacts of projects (including the land development effects of major projects).

The National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) both require the assessment of growth-inducing impacts of all major projects. Transportation plans and projects normally affect land development patterns in regions. Consequently, land use models provide significant advantages when employed by agencies for transportation planning and for evaluating those plans. Also, both statutes require assessment of the cumulative impacts of transportation projects. Cumulative impact analysis is normally done by evaluating the secondary impacts of existing regional transportation plans on land development and the impacts of proposed land development on the environment. However, the feedback loop to land development is not present in stand-alone travel models, which are not effective tools for understanding growth inducement or cumulative impacts.

California Assembly Bill 857 (Wiggins, 2002) requires the governor to submit a five-year statewide infrastructure plan every year and to update the State Environmental Goals and Policies Report (EGPR) regularly. Both plans must include objectives for infrastructure development patterns that:

1. “promote” infill development
2. “encourage” new development that is contiguous to existing urban areas, and
3. “protect” open space, forestry, and agriculture.

State agency infrastructure plans must be consistent with these objectives. For models to be able to provide the kinds of data needed in evaluating whether plans, programs and projects comply with these policies, the models need to have the capability to calculate the effects of infrastructure projects on land use location, density and mix on travel, and vice-versa.

Perhaps the most basic argument for using an integrated model is that it replaces the judgmental process now used by many agencies to forecast future economic activity with a replicable and theoretically defensible method. The current process is much less related to local general (land use) plans than most people appreciate. First, most general plans are several years old and do not contain enough land zoned for development to meet the needs for a 20-year regional transportation plan. So, the MPO or Regional Transportation Planning Agency (RTPA) staff must add areas for development, in consultation with local planning staffs. These areas are never mapped and submitted to public scrutiny, as such information can be very politically sensitive.

Second, many cities and counties are overzoned for employment and underzoned for apartments and even for residential in general. So, this means the MPO or RTPA staff must project where new employment will locate in the many areas zoned for it. This is a very difficult process, as it involves considerations of accessibility, conglomeration economies among economic sectors, land prices, and neighborhood characteristics. Generally, the MPO or RTPA staff drafts the growth maps and takes them out to the member cities and counties for their responses. Some jurisdictions say they want more jobs or people and some say they want less. This process of political accommodation is finally resolved. The agencies never document this process, as is required by the surface transportation act, because it is not scientifically defensible. It is not based on urban economics theory and it is not replicable by other professionals.

SUMMARY OF MEETINGS

Numerous meetings were conducted as part of this project. Initial meetings were held between the research team and Caltrans staff to determine whom to invite to be a part of the TAC. It was determined that the TAC would be made up primarily of modelers from Caltrans Headquarters, Caltrans Districts associated with large MPOs, and modelers from several larger MPOs (see Appendix A, page 75). Once the members of the TAC were invited and the TAC was formed, an initial meeting with the TAC was held in Davis. The purpose of this meeting was to present an overview of integrated modeling and to have Gordon Garry present the model development program that he heads at SACOG. Many questions were asked during the course of this meeting and in subsequent meetings that led to the development of the evaluation criteria that will be presented in the next section.

Modeling staff from the San Diego Association of Governments (SANDAG) were not able to attend the initial TAC meeting, so members of the research team traveled to SANDAG and presented the information and handouts to them in order to keep everyone together.

We provided a series of workshops showcasing three of the models considered in this study. The developers of these models, Doug Hunt (PECAS), Paul Waddell (UrbanSim), and Bob Johnston (UPlan), presented their respective models to MPO and Caltrans staff at six (6) separate workshops in San Diego, Los Angeles, Bakersfield, Oakland, Stockton and Sacramento. UrbanSim was presented once, at the Southern California Association of Governments (SCAG) offices, and we coordinated with appropriate agencies to enable all interested and relevant personnel (Caltrans and SANDAG staff) to attend. PECAS was presented at San Francisco Bay

Area's Association of Bay Area Governments (ABAG) and Metropolitan Transportation Commission (MTC), SCAG, SANDAG, and at Caltrans Headquarters in Sacramento. Presentations of these two models engaged 102 attendees within the San Diego, Los Angeles and Bay Area regions and included participants from the Central Valley.

UPlan was presented twice, by Bob Johnston at Stockton and Bakersfield. These cities were selected because of their location in the San Joaquin Valley, a region of great interest due to listed species, loss of farmlands, and high growth rates. We also invited directors of medium-sized MPOs and RTPAs outside of the Valley to attend. Forty-three individuals attended the meeting representing a broad array of agencies, including: Caltrans Districts 5, 6, and 10; the counties of Kern, Fresno, Tulare, Merced, San Joaquin, Tuolumne, Monterey, San Luis Obispo and Santa Barbara; the cities of Modesto, Stockton, and Escalon; as well as the California Department of Fish and Game, Region 4.

Attending multiple workshops enabled staff at the selected MPOs to gain an understanding of how the various models worked and what the data needs are like for each model. Each workshop also included a lengthy question-and-answer session with the model developers in which the attendees were able to ask direct questions regarding the feasibility of implementing these models in their respective agencies/regions. Careful notes were taken at these meetings by the research team as the questions asked by the modeling community inform us as to the real-world constraints and requirements faced by MPOs when seeking to implement new models.

In addition to the face-to-face meetings discussed here, the TAC and the UC Davis research team conducted monthly conference calls to update the TAC on the study's progress, upcoming meetings and schedule changes, and to respond to TAC questions and requests for information. Information gained from these conference calls was the catalyst that generated the survey of current users discussed in the previous section. A website developed for this project was used to collect and disseminate information (website: http://www.ice.ucdavis.edu/um/). This website will remain active until June 30, 2006.

What Was Gained from These Meetings

The purpose of this project was to transfer information among several sources: general information on integrated modeling from the research team to modeling professionals, modeling evaluation criteria from the modeling community to the research team, and specific information on each model from the model developers to the modeling community and the research team. It became evident from the various meetings held in conjunction with this project that MPO staff are interested in integrated modeling. Following is a "snapshot" of current interest by modeling staff at major metropolitan MPOs in California:

SACOG has been working with these models for some time and continues to pursue the development of cutting-edge models. We have put into the Appendix a brief description of SACOG's model development program, as well as a longer description and list of tasks and budget.

Modelers at SCAG expressed an interest in this type of model development. SCAG had previously worked with Doug Hunt (the developer of the PECAS model) to help them evaluate SCAG's model development program and make recommendations. From that work it was determined that SCAG would benefit from the additional modeling capacities available in the PECAS model. Due to inadequate funding, SCAG did not pursue the development of PECAS at that time.

SANDAG has expressed interest in pursuing an entry strategy for the implementation of PECAS.

ABAG/MTC staff expressed doubt about the practicality of developing an integrated model due to local and regional political and institutional constraints.

TYPES OF URBAN MODELS

The following section is from Johnston et al. (2003).

A. Federal Highway Administration FHWA Typology

The FHWA has a Web site, called the "Toolbox for Regional Policy Analysis", that outlines a variety of analysis methods useful in transportation planning and in evaluating transportation plans and projects (http://www.fhwa.dot.gov/planning/toolbox/land_develop_forecasting.htm). Their typology of methods for forecasting land development patterns is:

1. ***Proximity-Based Forecasting***. These are regression models that project development based on the proximity of past development to transport facilities and other urban infrastructure.

2. ***Delphi/Expert Panel***. Several case studies of these methods are given. The Delphi method has also been documented in a Transportation Research Board TRB report (Land Use, 1999).

3. ***Accessibility-Based Forecasting***. Accessibility, derived from a travel model, is used to forecast development.

4. ***Simple Land Use Models***. These are zone-based models based on a small set of equations defining relationships with accessibility and past development rates. HLFM II+ is a FHWA-supported model for use by small MPOs.

5. ***Complex Land Use Models***. These can be a land use model that interfaces with an existing travel model, or an integrated urban model with land development and travel models together. These models generally use land prices, and sometimes floorspace lease values, to

represent demand for space. They also use accessibility and other factors to represent site attributes. DRAM/EMPAL has been widely used in the U.S. and does not use land value or floorspace lease value data and so is the easiest to implement. TRANUS and MEPLAN have been applied to many regions all over the world and do rely on land market data. A review of complex land use models can be found at Wegener (1993).

B. Miller, Kriger, and Hunt Typology

Another way to categorize land use models is to examine those in use in regional transportation planning agencies. The following table (Table 4) derived from Miller, Kriger, and Hunt (1998) and updated to 2001 by Hunt and by us, shows the combinations of land use models and travel models in use or in development in the U.S.

It is important to note that most MPOs use the judgment method of land use forecasting and *then use this single forecast for all transportation investment scenarios*. This is an inaccurate method, in that improvements in radial accessibility will generally increase the spread of land development. Significant additions to road capacity, especially on the edges of congested urban regions, will increase land development in those areas, according to the official study in the U.S. (Expanding, 1995). If these land use impacts in the outer areas are not assessed, the National Environmental Policy Act (NEPA) documents will be inaccurate in that the studies will likely bias the projections of travel and emissions downward for highway improvement plans and projects. The secondary effects of land development on habitats, water quality, farmlands, and other systems will also be under-projected.

The advantage of taking an overview of these models is so MPOs can see that they can start with a simple rule-based model, such as UPlan, and then advance to a more complex model type as they gain expertise and gather more data. Table 4 also shows that agencies can move to the right, improving their travel models, or they can move downward, improving their land use modeling, first. Because the errors from not forecasting land development changes can be substantial (Rodier, et al., 2002), it seems that MPOs should advance their land use modeling, at least to the rule-based level or the equilibrium allocation level, before improving their travel models to account for trip tours or household activity allocation.

Table 4: *Travel Model/Land Use Model Integration Matrix*

<table>
<tr><th colspan="2"></th><th colspan="7">Travel Models</th></tr>
<tr><th colspan="2" rowspan="2">Land Use Models</th><th colspan="3">Trip-Based Models</th><th colspan="2">Tour</th><th colspan="2">Activity</th></tr>
<tr><th>Standard</th><th>Enhanced</th><th>Complex</th><th>Aggregate</th><th>Simulation</th><th>Aggregate</th><th>Simulation</th></tr>
<tr><td rowspan="3">Stand Alone</td><td>Factored</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Judgment</td><td>Fresno Co.
San Joaquin Co.</td><td></td><td></td><td>Boise
New Hampshire</td><td></td><td></td><td>San Francisco County</td></tr>
<tr><td>Policy + Trends Allocation</td><td></td><td></td><td>Edmonton</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Connected</td><td>Rule-Based Allocation</td><td></td><td>Sacramento Travel model 2000</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Equilibrium Allocation (e.g. DRAM)</td><td>San Diego
Puget Sound</td><td>San Francisco Bay Area
Atlanta</td><td>Santiago</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Market-Based Allocation</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Portland, Oregon</td></tr>
<tr><td rowspan="2">Integrated</td><td>Aggregate Economic (Input/Output)</td><td>Sacramento 2003</td><td rowspan="2">Eugene/ Springfield, Oregon
Honolulu
Salt Lake City</td><td>London</td><td></td><td></td><td>Sacramento 2004</td><td rowspan="2">Oregon Statewide 2004</td></tr>
<tr><td>Disaggregate Economic Micro-simulation</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

An agency, after deciding which general type of model to develop, can use criteria suggested by the U.S. Environmental Protection Agency (US EPA) to select a specific land use model. These criteria include: policy relevance, cost, data requirements, and accuracy (Projecting, 2000).

C. New Models Coming Into Use

Urban modeling has a long history in the U.S. Department of Housing and Urban Development, which funded the early models by Alonso and Lowry. Then, the ITLUP model (also called DRAM/EMPAL) was funded by the U.S. Department of Transportation (DOT) and is now in use by about a fifteen MPOs. Later, DOT also funded the development of the MEPLAN model, the first model of the spatial competition type, with floorspace bidding by locators and full travel networks. MEPLAN has been used in several dozen applications around the world. *This project will examine the most recent models, which are UrbanSim and PECAS.* They represent floorspace developers explicitly and are compatible with the new generation of activity-based travel models.

Many MPOs have been using land use models of various sorts for many years, but not in iteration with their travel model. That is, they use the models for their base case demographic forecasts, which are then used for all transportation scenarios (Porter et al., 1995; SAI International, 1997). A more recent survey shows a few MPOs using land use models for projecting different scenarios (MAG, 2000). Full microeconomic urban models (UrbanSim, PECAS) were recently developed for Honolulu, Salt Lake City, Eugene (Oregon), Sacramento, New York City, and the state of Oregon. Similar models are being developed for Calgary,

Edmonton, the state of Ohio, and the Seattle and Chicago regions. The San Diego, Atlanta, and San Francisco regions have had zonally aggregate urban models for many years.
MEPLAN and TRANUS have been applied in dozens of regions outside of the U.S. and the earlier model, DRAM/EMPAL, which has been used in about 15 regions in the U.S., is now seen as obsolete. Prof. Johnston of the research team has implemented MEPLAN with SACOG, the Sacramento region MPO. With others, Johnston has also done a paper comparing MEPLAN, TRANUS, DRAM/EMPAL, and the SACOG travel model, where teams modeled the same scenarios. Most small MPOs, however, will need to implement a less-complex model, such as one of the various GIS-based models. Of these, PLACES is being used for scenario-generation by SACOG and UPlan is being used by the Merced County Association of Governments (MCAG) in a Caltrans-funded demonstration. This latter project is now being extended to all of the San Joaquin Valley counties. Fresno COG is using the WhatIf? model, which is similar to UPlan, but is proprietary.

To make the situation even more complex, a newer type of model has recently come into use, where developer behavior is more explicit and smaller zones are used. The US DOT Travel Model Improvement Program held a conference on urban models in 1995 and published a report with recommended improvements for such models. The National Science Foundation (NSF) started funding urban model development in 1996, resulting in creation of several model development programs. The first such model to be completed was UrbanSim by Paul Waddell. It is an open-code public license model and has been implemented on the Eugene-Springfield, Oregon region. UrbanSim has also been applied to Honolulu and the Salt Lake City region. It is underway for the Seattle region.

Miller, Kriger, and Hunt did a report for US DOT in 2000 that reviewed urban models and recommended additional advanced improvements. Out of this effort came the PECAS model, which is being applied to the State of Oregon. The State of Ohio, Calgary, Edmonton, and SACOG are also implementing PECAS. This model has an improved representation of economic exchanges and so will give a theoretically proper measure of producer surplus, useful in economic analysis.

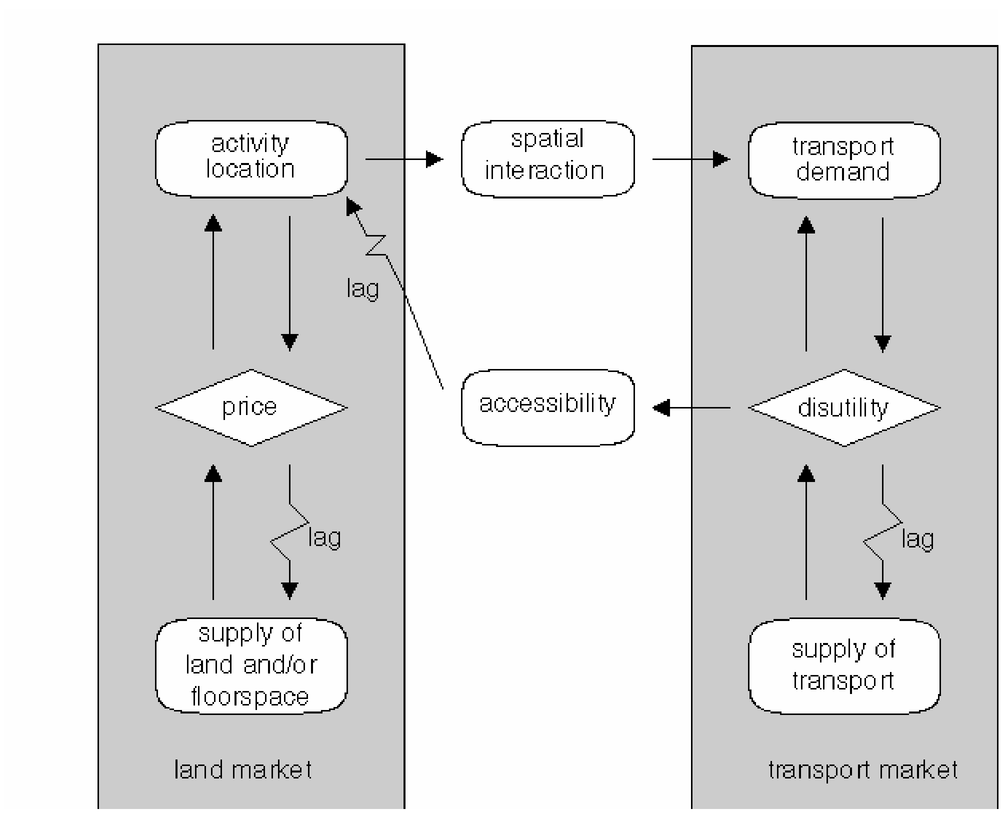
THE MEPLAN MODEL

Here, we briefly describe MEPLAN to illustrate how market-based urban economic models work. MEPLAN may be useful for medium-sized MPOs, after they have used a GIS-based model. UrbanSim and PECAS, which are described in sections III and IV, are similar to MEPLAN, but more complex. The following information came from Johnston et al. (2001).

> The basis of the framework is the interaction between two parallel markets, the land market and the transportation market. This interaction is illustrated in Figure 1. Behavior in these two markets is a response to price signals that arise from market mechanisms. In the land markets, price and generalized cost (disutility) affect production, consumption, and location decisions by activities. In the transportation markets, money and time costs of travel affect both mode and route selection decisions.
>
> The cornerstone of the land market model is a spatially-disaggregated social accounting matrix or input-output table that is expanded to include variable technical coefficients and uses different categories of space (e.g., different types of building and/or land). Logit models of location choice are used to allocate volumes of activities in the different sectors of the table to geographic zones. The attractiveness or utility of zones is

based on the cost of inputs (which include transportation costs) to the producing activity, location-specific disutilities, and the costs of transporting the resulting production to consumption activities. The resulting patterns of economic interactions among activities in different zones are used to generate origin-destination matrices of different types of trips. These matrices are loaded to a multi-modal network representation that includes nested logit forms for the mode choice models and stochastic user equilibrium for the traffic assignment model (with capacity restraint). The resulting network times and costs affect transportation costs, which then affect the attractiveness of zones and the location of activities, and thus the feedback from transportation to land use is accomplished.

Figure 2. *The Interaction of Land Use and Transportation Markets in MEPLAN*



The framework is moved through time in steps from one time period to the next, making it "quasi-dynamic." In a given time period, the land market model is run first, followed by the transportation market model, and then an incremental model simulates changes in the next time period. The transportation costs arising in one period are fed into the land market model in the next time period, thereby introducing lags in the location response to transport conditions.

The Sacramento MEPLAN model [as implemented by us] uses eleven industry and service factors that are based on the input-output table and aggregated to match employment and location data. Households are divided into three income categories (high, medium, and low) based on the table and on residential location data. The consumption of households by businesses represents the purchase and supply of labor. The consumption of business activities by households represents the purchase of goods and services by consumers. Industry and households consume space at different rates and have different price elasticities, and thus there are seven land use factors in the model. Constraints are placed on the amount of manufacturing land use to represent zoning regulations that restrict the location of heavy industry. Each of these land uses (except agricultural land use) locates on developed land represented by the factor URBAN LAND. Two factors are used to keep track of the amount of vacant land available for different purposes in future time periods (MANUF VAC LAND and TOTAL VAC LAND), and the development process converts these two factors to URBAN LAND. The MONEY factor is a calibration parameter that allows differential rents to be paid by different users of the same category of land.

The MEPLAN model may be updated by increasing external demand for goods and services produced in the region, or by increasing employment or population. With all methods, the model starts in a Lowry fashion by increasing basic sector demand for goods and services. Basic sector jobs

> are located, generally near to existing ones, due to economies of consolidation. Then, these employees choose affordable rental housing near their jobs. Then, the non-basic sector jobs are located, generally near to the basic sector employees. Finally, those non-basic employees locate their residences. MEPLAN can produce many useful measures for policy analysis, such as number of employees by type by zone, number of households by income by zone, rents paid by firm or household by zone, producer surplus and consumer surplus for both households and firms, and the accompanying travel model measures travel, mode share, travel time, congestion, and emissions.

The UrbanSim Model

The following information comes from Waddell, 2002.

> UrbanSim includes model components reflecting the key choices of households, businesses, developers, and governments (as policy inputs) and their interactions in the real estate market. By focusing on the principal agents in urban markets and the choices they make about location and development, the model deals directly with behavior that planners, policy makers, and the public can readily understand and analyze. This behavioral approach provides a theoretical structure more transparent than 'black-box' models that do not clearly identify the agents and actions being modeled. The structure allows users to incorporate policies explicitly and to evaluate their effects.
>
> UrbanSim is not a single model. It might be better described as an urban simulation system, consisting of a software architecture for implementing models and a family of models implemented and interacting within this environment. The models that are currently implemented employ a range of techniques and approaches. Some of the models, such as the economic and demographic transition models, are

aggregate, non-spatial models that deal with the interface to external macro-economic changes. Other components such as location choice are discrete choice models of an agent (a household, for example) making choices about alternative locations, taking a top-down, or birds-eye view of the metropolitan area. The developer model, by contrast, takes a mostly bottom-up (wormseye?) view, from the vantage point of a developer or land-owner at a single location (grid cell) making choices about whether to develop, and into what type of real estate. The bottom-up view in the developer model is tempered by market information that reflects the state of the market as a whole, such as vacancy rates.

The structure and processing sequence of UrbanSim are shown in Figure 3. Inputs to the model include the base year data store, control totals derived from external regional economic forecasts, travel access indicators derived from external transportation models, and scenario policy assumptions regarding development constraints arising from land use plans and environmental constraints. The individual model components predict the pattern of accessibility by auto ownership level (access model), the creation or loss of households and jobs by type (demographic and economic transition), the movement of households or jobs within the region (household and employment mobility models), the location choices of households and jobs from the available vacant real estate (household and employment location models); the location, type, and quantity of new construction and redevelopment by developers (developer model); and the price of land at each location (land price model). One special component, the model coordinator, manages the individual model components and handles the scheduling and implementation of events such as reads and writes to the data store. Taken together as a system, these components maintain the data store and simulate its evolution from one year to the next. For simplicity, the household and employment counterpart models for transition, mobility, and location are represented jointly in the diagram and described together in Table 5, since they are parallel and almost identical.

The model system runs on events generated by the model components. A number of choices by households, businesses, and developers are simulated on an annual basis, and their outcomes are implemented as scheduled events. Large-scale development projects may be scheduled with multiyear timetables, defined using a template that describes the characteristics of different types of development events. In addition to model-generated events, the system accommodates information that planners have about pending development, corporate relocations, or policy changes. We have developed a capacity to introduce user-specified events such as these into the model, both to allow planners to use available information about developments that are 'in the pipeline', and also to provide a capacity for testing the potential effects of a major project on further development and on traffic.

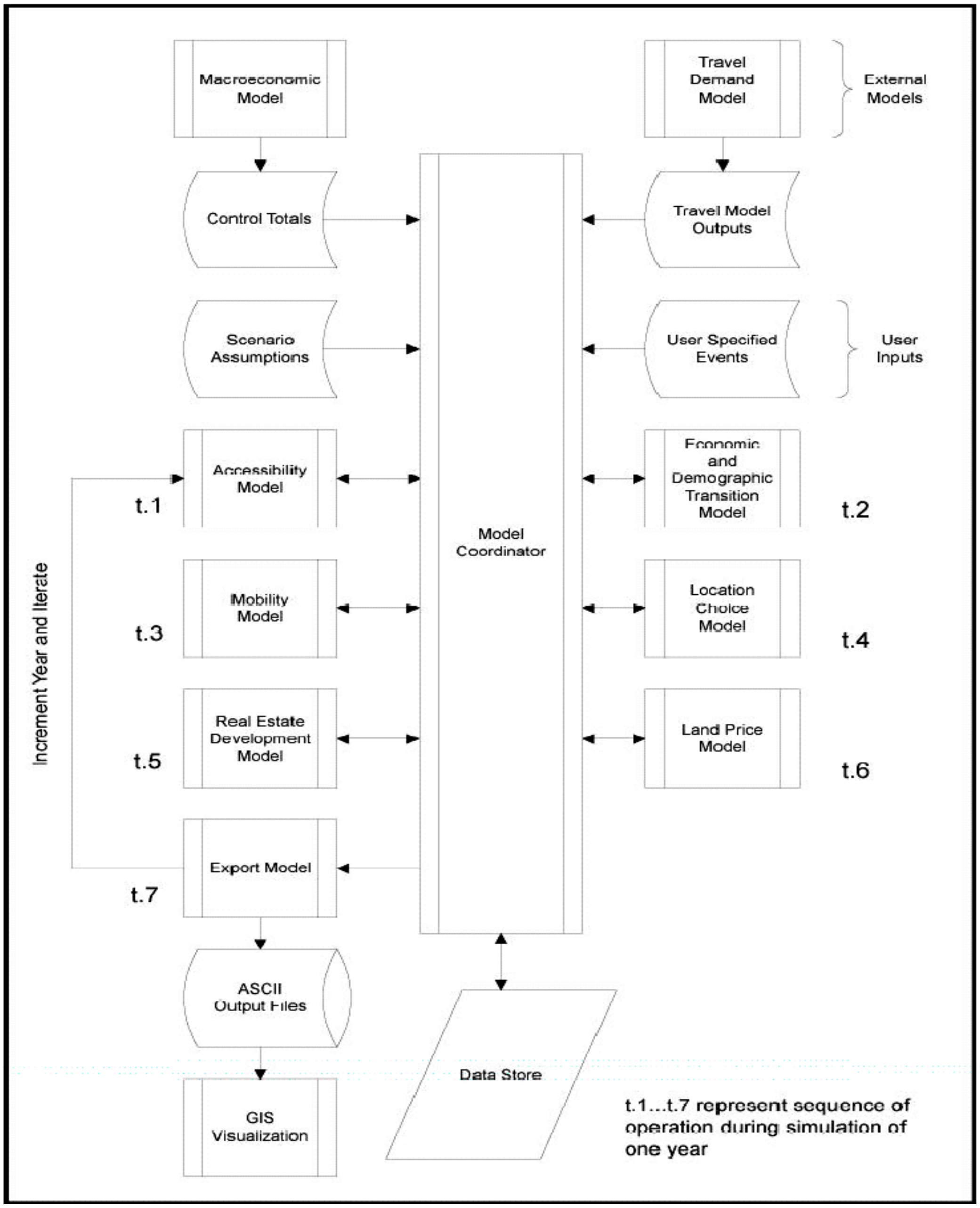
UrbanSim allows users to specify policy inputs and assumptions, generate and compare scenarios, compute evaluation measures, and query the database of results. The user interface of the model is focused on the interaction of the user with the inputs to each scenario. Scenarios consist of a combination of development policies, represented by appropriate input data such as comprehensive plans, infrastructure plans, urban growth boundaries, and development restrictions on environmentally sensitive lands. These policies are linked to locations at a grid cell, zonal, municipal, county, or metropolitan scale. Broadly speaking, government agencies influence the land development process through a combination of land use regulations and infrastructure provision. These are frequently combined into packages that attempt to foster a development pattern in ways that promote planning objectives, for example by pursuing one or a combination of the following community visions:

- Containing development within an Urban Growth Boundary
- Focusing development along primary transportation corridors
- Focusing development within centers connected by multi-modal transportation
- Diverting development into new or existing satellite communities
- Encouraging development in parts of the region with underutilized infrastructure
- Promoting development of impoverished areas

The use of the term “scenario” differs in the UrbanSim context from its potential use to describe a particular “vision” such as those listed above. An UrbanSim scenario is a collection of policy assumptions that can be input to the model to examine their potential consequences on outcomes such as urban form, land use mix, density, and travel patterns. In other words, the system allows interactive testing of how different policy strategies fare in achieving a particular vision or set of community objectives. It does not assume that a particular vision can be realized, but facilitates exploration of the trade-offs that may be involved in attempting to achieve it, given the range of policies available and their costs and consequences. The model does not attempt to “optimize” policy inputs, but is intended to facilitate interactive use to support an iterative, participatory planning process.

The translation of these scenarios into inputs to UrbanSim involves interpreting policies and creating input files for the model that represent these policy interpretations. Interpreting the comprehensive land use plan is a key part of constructing a policy scenario in UrbanSim. Each land use plan designation (Planned Land Use or PLU) may be described as a set of restrictions on development options. For example, the plan

***Figure 3**. UrbanSim Model Structure and Processing*



designation of "agricultural" may not allow conversion to any developed urban category under restrictive interpretation of the land use plan, or may allow conversion to rural density single-family residential under a less restrictive interpretation. The adopted comprehensive plan guidelines for a local area should spell out the intended interpretation of these plan designations, but the user of the model may wish to assess the impact of altering these constraints as a matter of policy testing.

Development regulations may be coded for an entire metropolitan area, for individual counties, cities, or special overlays such as environmentally sensitive lands or urban growth boundaries. Overlays such as wetlands, floodways, steep slopes, or other environmental features may be used to specify environmental regulations that impose development constraints. The model interprets the cumulative impact of the policies by reflecting the most restrictive policies that apply to a given grid cell. For example, a general county plan might allow substantial development for a particular land use plan designation, but a more restrictive regulation that applies to wetlands would overrule this for any grid cell that was in a wetland.

In addition to development constraints, the scenario inputs include regional control totals from the external macroeconomic models, and assumptions about the space utilization rates (such as square feet per employee for different development types). Transportation policy assumptions are incorporated in the external transportation model, and are embedded in the travel time and utility outputs from the travel model that UrbanSim uses to calculate accessibility.

The Accessibility Model is responsible for maintaining accessibility values for occupants within each traffic analysis zone, including accessibility by residents and employees to shopping and other amenities, to employment, and to the central business district. The accessibility value for a zone to a specific type of activity is defined as the sum of the quantity of the activity (jobs, for example) at each possible destination, discounted by a weight between 0 and 1 reflecting the multimodal travel utility to the destination1. Handy (1993) and others have referred to this kind of measure as representing "regional accessibility", in that it is regional in scope and uses the transportation network on a zone to zone basis to represent travel access. It is contrasted with "local accessibility", which measures access to opportunities within a walkable neighborhood.

The link between land use and the travel model is two-way, since different accessibility values from the travel model will influence the decisions of developers, employers, and residents, giving rise to different travel demands, which then feed back into the travel model. The external travel model provides travel times and utilities to the Accessibility Model. The travel model is typically run only once every five simulated years or when there is a major change to the transportation system, since running it is relatively cumbersome and since its outputs generally change more slowly than other values in the simulation. However, UrbanSim is run annually, updating the accessibility values based on the evolving spatial pattern of activities.

Table 5. *Description of Core Models*

Demographic and Economic Transition Models

The Demographic Transition Model simulates births and deaths in the population of households. Externally imposed population control totals determine overall target population values, and can be specified in more detail by distribution of income groups, age, size, and presence or absence of children. This enables the modeling of a shifting population distribution over time. Iterative proportional fitting (Beckman *et al*, 1995) is used to determine how many households of each type are to be created or deleted. Newly created households are added to the household list but without an assignment to a specific housing unit (placed in limbo), to be placed in housing later by the Household Location Choice Model. Households to be deleted to meet the control totals are selected at random, drawn preferentially from households in limbo. The Economic Transition Model is responsible for modeling job creation and loss. Employment control totals are determine employment targets, and can be specified by distribution of business sector.

Household and Employment Mobility Models

The Household Mobility Model simulates households deciding whether to move. Movement probabilities are based on historical data. Once a household has chosen to move, it is placed in limbo to indicate it has no current location, and the space it formerly occupied is made available. The Employment Mobility Model determines which jobs will move from their current locations during a particular year using a similar approach to the Household Mobility Model.

Household and Employment Location Models

The Household Location Choice Model chooses a location for each household that has no current location. For each such household, a sample of locations with vacant housing units is randomly selected from the set of all vacant housing. Each alternative in the sample is evaluated for its desirability to the household, through a multinomial logit model calibrated to observed data. The household is assigned to its most desired location among those available. The Employment Location Choice Model is responsible for determining a location for each job that has no location. For each such job, a sample of locations with empty square feet, or space in housing units for home-based jobs, is randomly selected from the set of all possible alternatives. The variables used in the household location model include attributes of the housing in the grid cell (price, density, age), neighborhood characteristics (land use mix, density, average property values, local accessibility to retail), and regional accessibility to jobs. Variables in the employment location model include real estate characteristics in the grid cell (price, type of space, density, age), neighborhood characteristics (average land values, land use mix, employment in each other sector), and regional accessibility to population.

Real Estate Development Model

The Real Estate Development Model simulates developer choices about what kind of construction to undertake and where, including both new development and redevelopment of existing structures. Each year, the model iterates over all grid cells on which development is allowed and creates a list of possible transition alternatives (representing different development types), including the alternative of not developing. The probability for each alternative being chosen is calculated in a multinomial logit model. Variables included in the developer model include characteristics of the grid cell (current development, policy constraints, land and improvement value), characteristics of the site location (proximity to highways, arterials, existing development, and recent development), and regional accessibility to population.

Land Price Model

The Land Price Model simulates land prices of each grid cell as the characteristics of locations change over time. It is based on urban economic theory, which states that the value of location is capitalized into the price of land. The model is calibrated from historical data using a hedonic regression to include the effect of site, neighborhood, accessibility, and policy effects on land prices. It also allows incorporating the effects of short-term fluctuations in local and regional vacancy rates on overall land prices. Similar variables are used as in the Development Model.

UrbanSim also incorporates local accessibility measures, corresponding to the activities that can be reached by walking, over a distance of 600 meters (approximately 1/3 mile), using spatial queries of the grid cells in the data store. Achieving this scale of analysis makes UrbanSim the first operational urban model system to support analysis of location and travel behavior at a level that can effectively represent pedestrian and bicycle scales of travel. Given the ongoing debate over the potential influence of neo-traditional urban design on travel behavior, this innovation should provide a basis for making more systematic assessments of the effects of urban design-scale policies on both location and travel behavior. Traditional zone-based travel models are severely limited by poor performance on intra-zonal travel and insufficient representation of non-motorized travel modes. By creating a more detailed basis for the land use model, the main barrier to the improvement of transportation planning to address non-motorized modes and the integration of urban design policies has been effectively removed.

The data export process is responsible for gathering, aggregating, and exporting data from the object store to a set of external files for subsequent analysis and graphical display. The user interface allows specification of desired output files and designation of specific simulation years for which to generate the outputs. Outputs are created at the grid cell level, and also summarized by traffic zone and for the region as a whole. The data are written in a standard format for ease of loading into ArcView, Excel, or other common desktop tools.

THE PECAS MODEL

The following information comes from Abraham, Gary, and Hunt, 2005 and Hunt and Abraham, 2003.

> The PECAS modeling framework consists of two sub-models. The first sub-model, called the "spatial input-output model", is an aggregate allocation system using a nested logit representation of three types of choice. The first choice, at the highest level of the logit system, is the choice of location for activities. The middle relationship is the choice of production or consumption options given location, that is the choice of how much of which "commodities" to produce ("make") or consume ("use") per unit of activity. Commodities in PECAS include categories of goods, services, labor and floorspace. The third relationship is the choice of where to exchange (purchase or sell) the commodities given location and the quantities produced and consumed. It is the choice of exchange zone, or local market, in which to participate. This third level choice implies a choice to travel or to have goods or services shipped, and the utility of these lowest level alternatives includes a calculation of transport costs or disutility using the attributes of travel calculated by the transport model. The levels are connected in both directions, from the top down through the conditional nature of the lower levels, and from the bottom up through the calculation of the expected maximum utilities of choosing from amongst the lower level options; so production, consumption and location are all influenced by prices and transportation conditions. Prices are established at each exchange zone to clear the local market for each commodity in each zone, with higher prices acting to suppress demand and increase supply. The spatial IO model produces, among other things, a landscape of prices by commodity, flow matrices by commodity and the locations of activities.
>
> The second sub-model, called the "land development model", is a representation of longer-term development processes. The prices for

floorspace types established in the spatial IO model are used, together with an inventory of land characteristics, to calculate expected profits for developers by development type for each unit of land. These expected profits are used as utility functions in a logit model of the choice to develop. Aggregate (zone based allocation systems) and disaggregate (grid cell or parcel based microsimulations) development models are available; the Sacramento model uses the disaggregate formulation.

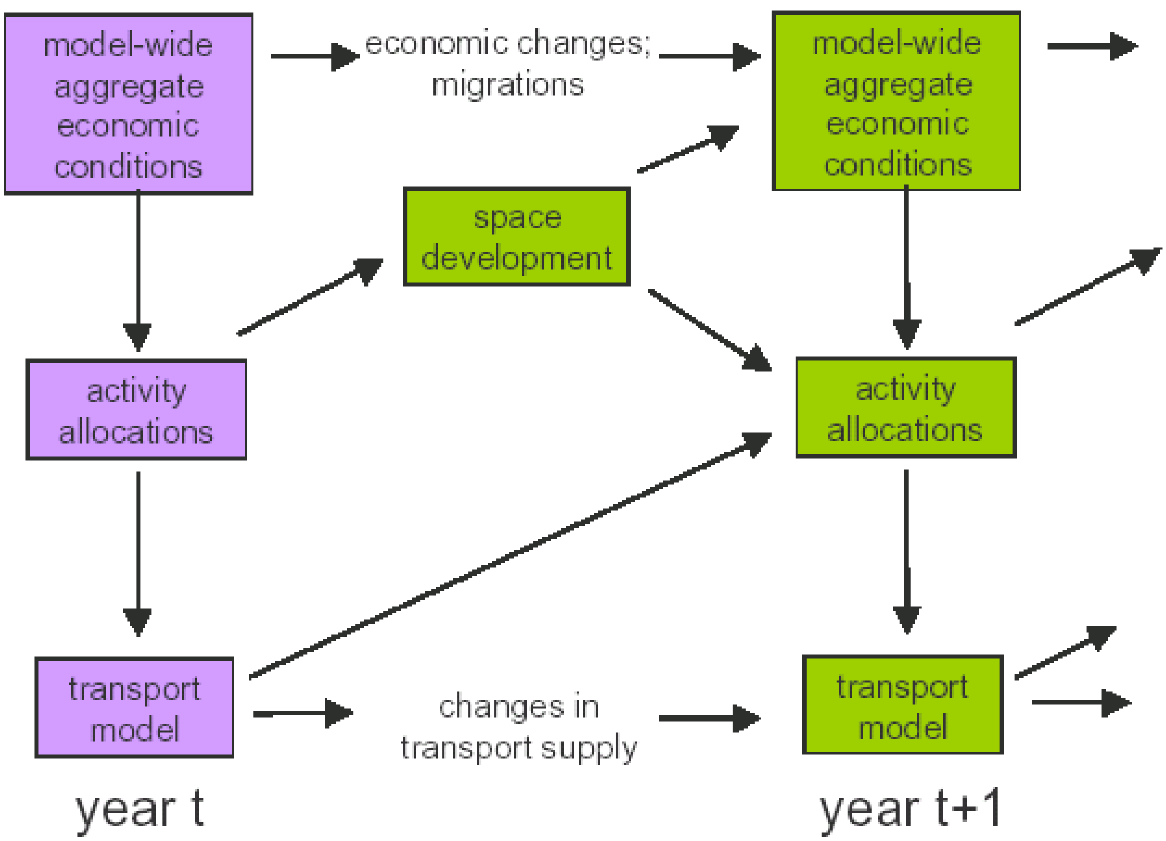
The area covered by PECAS is organized into a set of land use zones. Activities locate in these zones and interact between them. Ideally these zones are the same as the transport zones used in the transport model being run with PECAS, or at least are aggregations of whole numbers of adjacent transport zones. The connectivity among the land use zones is then based on the representation provided by the transport model, where the transport model uses its networks to establish congested network times and costs and associated interchange (dis)utilities that PECAS uses in its consideration of the interactions between land use zones.

Currently it is recommended that a maximum of about 750 such land use zones be used because of the two-gigabyte memory address space limitations of most current operating systems.

PECAS works through time in a series of discrete, fixed steps from one point in time to the next, with the activity allocation module running at each point in time and the space development module considering the period from each point in time to the next. The steps can be of any fixed duration, but one-year time steps are recommended since they allow an appropriately quick response of land developers in the land development module to the prices established in the activity allocation module.

Figure 4 illustrates the interactions among the modules and with other models when the two PECAS modules are run as part of an integrated land use transport modeling system. The transport model used to calculate the congested travel times and disutilities is normally run for each year (after PECAS completes its run for that year) or, if travel conditions are relatively stable, the transport model can be run less often to save computation time.

***Figure 4**. Interactions among modules simulating temporal dynamics*



The mathematics behind the PECAS framework are described in Hunt and Abraham ("Design and Application of the PECAS Land Use Modelling System", 8th Computers in Urban Planning and Urban Management Conference, Sendai, Japan, May 2003). The software implementing PECAS has been developed in Java with many individuals and agencies contributing. Consistent with the philosophy of Open Source Code, the software is available to other agencies with the understanding that improvements will also be made available (see http://creativecommons.org/).

THE UPLAN MODEL

UPlan is the simplest model considered in this study. Unlike the MEPLAN, UrbanSim and PECAS models -- complex land use models which interface with an existing travel model or an integrated land development and travel model -- UPlan is a simple GIS-based model. UPlan output can be used in a travel model, but it's not linked in an iterative fashion yet.

U-Plan is a rule-based model, applicable to counties, metropolitan regions, watersheds, and bioregions. The model was designed as an inexpensive and easy-to-use tool for long-range scenario testing using fine-grained grid data representing existing urban, local land use plans and other natural and built features that define the model. UPlan projects urban growth disaggregated into seven land uses: at least four residential densities, industrial density and two densities of commercial development.

The UPlan model works based on the following assumptions:

- Population growth can be converted into demand for land use by applying conversion factors to employment and households.
- New urban expansion will conform to city and county general plans.

- Cells have different attraction weights because of accessibility to transportation and infrastructure.
- Some cells, such as lakes and streams, will not be developed. Other cells, such as sensitive habitats and floodplains, will discourage development.

UPlan consists of three model types. The one used most often is the UPlan County Sub-area Model, a share-shift model designed to project spatial allocation of residential and employment uses at a county sub-area level. The future population total for each sub-area is determined by its share of the total population growth of the county. Each sub-area is allowed to have its own input parameters. The share of population growth for each sub-area is pre-determined outside of UPlan, before the model is run. The employment growth share for each county sub-area is independent of its population growth share, allowing different growth rates for each share type in any sub-area. The UPlan County Sub-area Model is particularly useful for evaluating conventional county transportation plans, general plan updates, and other typical county and city policies.

A second model type is the Single-County UPlan Model, which is designed for evaluating new highways or highway widenings, new freeway interchanges, and new city or county general plans, where growth trends within a county are likely to change. The third type is the Cluster UPlan Model, useful only when evaluating new freeways, high speed rail, and state and regional land use policies likely to affect regional growth patterns.

CURRENT PRACTICE

As part of this study, we conducted a survey was conducted of current integrated modeling practice among all California MPOs. The purpose of the survey was to gain an understanding of current land use modeling practice. Our survey showed that several MPOs had at least some experience with land use models. However, this experience was typically limited to DRAM/EMPAL or other non-behaviorally based, statistical or linear programming land development models. None of the MPOs surveyed who had used DRAM/EMPAL reported having a positive experience with it, stating, among other issues, that they had to "force" the model -- by repeatedly manually adjusting its calibration -- to produce reasonable forecasts. As mentioned earlier, SACOG has developed and tested a variety of models, including: DRAM/EMPAL, TRANUS, MEPLAN, and is currently implementing a PECAS model. Each model represents an improvement over the last. Facilitating a transfer of knowledge from SACOG to the other MPOs was one of the goals of the early meetings held with the TAC.

Through these surveys, we learned that there is a good deal of interest in integrated modeling here in California, particularly with respect to the new generation of these models, UrbanSim and PECAS. However, agencies cited a variety of reasons and barriers preventing them from moving forward in selecting and developing an integrated model. These include: lack of political will, budgetary constraints, lack of knowledge or understanding of the models, lack of recognized need among administrators, and pursuit of more pressing priorities. To address the knowledge-based barriers, our aim was to introduce ABAG/MTC, SCAG, and SANDAG to the developers of UrbanSim and PECAS. This interaction was an opportunity for the developers to present their work and answer the agencies' questions about integrated models, including: their data requirements, costs of development (in time, money, and staff commitment), and usefulness in policy and alternatives analysis.

Survey of Current Users of Integrated Models

A request repeatedly made by the TAC was for the research team to conduct a brief survey of agencies within and outside California that are currently developing, or that have developed, integrated models. This was not in the original research proposal, but we added it because TAC members agreed that understanding the experience of other agencies in developing an integrated model would be beneficial to agencies considering a similar process. Few agencies have developed an operational integrated land use and transportation model. However, there are a number of MPOs and two state departments of transportation (Oregon and Ohio) that are currently developing integrated models. In addition to those listed in Table 6 (below), representatives from the Denver Regional Council of Government and the Maricopa Council of Governments (Phoenix, Arizona) were contacted.

The Oregon DOT (ODOT) has an extensive model development program (what they call TLUMIP -- Transportation Land Use Model Improvement Program) and a great deal of experience developing and using integrated models. In the past eight years ODOT has developed a “proof of concept” UrbanSim model together with the Lane Council of Governments (Eugene/Springfield, Oregon) and developed and used the TRANUS model and what they call the Oregon Statewide Generation II model of which PECAS is a portion. The PECAS model currently being developed for SACOG and the Ohio Department of Transportation was created as part of ODOT’s TLUMIP. The Lane COG UrbanSim model was never used for policy analysis purposes and is no longer being maintained by Lane COG. The costs given for ODOT do not represent the total costs of TLUMIP. Bill Upton, who heads this program for ODOT, stated that a great deal of cost sharing has taken place between ODOT and MPOs in Oregon. This cost sharing is what has allowed them to develop their second-generation statewide model. Data is also readily shared between agencies, further facilitating model development. ODOT has been actively using its integrated models to test and analyze different planning and facilities alternatives.

Table 6: *Results from survey of current users developing an integrated model (April, 2005)*

JURISDICTION	INTEGRATED MODEL	TIME TO DEVELOP	COST IN DOLLARS	COST IN FTE	OTHER MODELS CONSIDERED
Wasatch Front Regional Council	UrbanSim	3 years	$500,000 to date	3.5	N/A
Puget Sound Regional Council	UrbanSim	2.5 year	$300,000/year	1.0	Previously used DRAM/EMPAL
Alamo Area Council of Governments	UrbanSim	3 years	$150,000/year	2.0	Topaz, MEPLAN, TRANUS, Transtep, Previously using DRAM/EMPAL
Houston-Galveston Area Council	UrbanSim	3-years	$200,000/year to develop, an addition $400,000 for subsequent updates	3 during model development, 4 for subsequent	Previously used DRAM/EMPAL
Oahu Metropolitan Planning Organization	UrbanSim	3 years so far	$200,000 total	0	UrbanSim was recommended by consulting firm
South East Michigan Council of Governments	UrbanSim	3 years	500,000/year	6.0	Previously used DRAM/EMPAL
Oregon (ODOT) TLUMIP	PECAS	8 years total for TRANUS and Gen. II models	$750,000/year	2.0	MEPLAN, TRANUS, Delta, Dortmund, others.
Sacramento Area Council of Governments	PECAS	5 years	$240,000/year	0.3	UrbanSim
Ohio Department of Transportation	PECAS	3 years	$200,000/yr.	0.2	N/A

Similar to Lane COG, the Oahu, Hawaii, MPO got involved very early on with the UrbanSim model. The project manager overseeing the Oahu MPO UrbanSim project said the expectation that UrbanSim would be a relatively inexpensive and easy-to-use tool had proven incorrect and the Oahu MPO's experience was plagued by insufficient budget. The project manager said Paul Waddell continues to work with them (even in the absence of funding), but progress is slow. The Oahu MPO plans to dedicate sufficient funding to finish development of the model in the near future, according to the project manager.

The Wasatch Front Regional Council, Houston-Galveston Council of Governments, and Puget Sound Regional Council have each nearly completed the development of their UrbanSim models and are investing additional funds to further develop and maintain these models and the associated data. Each indicated that UrbanSim represents an improvement over previously-used land use forecasting methods. In a resolution on the suitability of UrbanSim, the Wasatch Front Regional Council (WFRC) stated:

> WFRC staff anticipates that UrbanSim will eventually be useful in developing more realistic and accurate forecasts of both land use and transportation system performance than current forecasting methods. In addition, UrbanSim will allow for more accurate reflections of local master plans into the regional transportation plan. Further, UrbanSim will afford the ability to analyze further the complex policy interactions that affect urban systems. (Quote taken from the WFRC Resolution on the Suitability of UrbanSim, available at: http://www.urbansim.org/projects/utah/WFRC%20resolution%20on%20UrbanSim.pdf and accessed on 7/19/2005.)

Mark Simonson of Puget Sound Regional Council (PSRC) stated that the local Growth Management Act, environmental concerns, and the ability to model "what if?" scenarios -- together with local interest in being able to model land use changes resulting from changes in local comprehensive plans -- were major contributors to PSRC adopting and developing an UrbanSim model. PSRC anticipates completion of a usable UrbanSim model for its region by the end of 2005.

Table 6 presents a summary of the survey findings. The indicators requested by the TAC include:

- the amount of time was required to develop the agency's integrated model,
- the amount of money did the agency spend on model development and data gathering,
- the amount of staff commitment was required (FTE), and
- the list of other models considered during the agency's model selection process.

For agencies that had not yet completed model development, the amounts in Table 6 represent estimated amounts. Table 6 shows amounts of time and money spent varied by agency and to some extent reflected whether data and model calibration were done in-house or outsourced to consultants. WFRC and AACOG did much of their work in-house while Oregon DOT, SACOG, and PSRC contracted most of the model development and data collection out to consulting firms.

In most cases, no other model was considered; the agencies were aware of the UrbanSim model and decided to use it with little to no evaluation against other models. This is not surprising, as UrbanSim and PECAS represent what the agencies consider to be the state-of-the-art integrated land use and transportation modeling practice. Many of those which are developing UrbanSim models were not aware of the PECAS model or were not aware that it is available for implementation outside of Oregon.

DRAM/EMPAL was the most common previously-used model. Survey respondents, like California users, had few positive experiences with the model. They complained that it lacks the ability to represent current land use plans, changes in land use over time, or other vital indicators. PSRC users, like those in California, said they had to make many manual adjustments to the model to get it to produce reasonable forecasts.

This survey was intended only to gather some basic data on the costs of model development from agencies that are developing or have developed an integrated model. Table 6 presents a reasonable picture of what the agencies surveyed have spent and committed to spend on model development. Our survey was conducted over the phone and numbers gathered represent agency-derived approximations.

Model Evaluation

A major purpose for this study was to evaluate current integrated land use and transportation models against a set of criteria derived from the modeling community here in California. We anticipate that this will lead to a more relevant set of standards to benchmark the models. Throughout this process, the research team gathered information during meetings and conference calls to determine which issues and model characteristics were of particular importance. This information was compiled into a set of criteria. While the majority of the criteria came from the modeling community, the research team reviewed criteria used by other organizations, in other studies, and also borrowed germane criteria from that literature. We will treat each of the criteria listed in Table 7 in this section.

Credibility

Questions regarding the credibility of each model were raised often. The credibility issue centered on the believability of the outputs produced by the model and the validity of the process used by the model to arrive at those outputs. Modelers said that believability is critical in gaining support and establishing credibility with citizens and elected officials. Furthermore, they said the validity of the modeling methodology is of critical importance for more technically oriented individuals. Finally, credibility and validity are critical in making the model results more defensible in the event of litigation.

Table 7. *Criteria obtained from meetings with the TAC and MPO modeling staff.*

Credibility:	
	Believability
	Validity
Usability:	
	Level of Geography
	Temporal Detail
	Model Runtime
	Expertise Required
	Policy Relevance
	Link-Ability
	Open Code
	Free Software
	Accessible to Public
	Output Presentation
Feasibility:	
	Costs ($)
	Costs (FTE-staff)
	Time to develop
	Data needs

Believability can be correlated to breadth of model output. Each model considered in this study, at least conceptually, has the ability to produce believable outputs. PECAS and UrbanSim outperform UPlan simply by producing a greater number of interpretable outputs that would likely tell a consistent story. In other words, having a larger number of logically related outputs enhances the believability of those outputs because a consistent story is told by the model. For example, being able to explain the land use outputs as a function of the floorspace price outputs, which are in turn a function of the supply of and demand for land (as in UrbanSim and PECAS) is more believable than simply outputting regional land uses (as in UPlan).

The validity of outputs is demonstrated by the use of objective measures. We know conceptually and from empirical research that certain conditions result in urban development. At the most basic level, urban development/growth is a direct result of increases in population and employment within the region and should be allocated to available land according to zoning constraints. All three models represent at least this level of spatial accounting.

In addition to these basic relationships, a more explicit representation of urban development should include: household location choice, several types of households (size, number of workers, income, auto ownership, etc.), employment location choice, several types of employment (e.g. industrial/manufacturing, office, retail, managerial, etc.), and a host of other regulatory, demographic, and economic processes. Of the models considered in this study, PECAS endogenously represents the largest share of urban processes. UrbanSim is a close second. Both of these two models use discrete choice representations of location choice and floor-space construction. Within these choice models, an agency can put all of the relevant variables for its region and estimate these models on local data. For UPlan, no explicit representations of choice or economic influences are modeled. Location of land use is determined by proximity to desirable facilities and amenities within the boundaries of zoning constraints.

Table 8. *Criteria Matrix of Models Studied*

	UPlan	MEPLAN	UrbanSim	PECAS
Credibility:				
Believability	Moderate	High	High	High
Validity	Low	High	High	High
Usability:				
Level of Geography	Grid Cells	Zones	Grid Cells & Zones	Grid Cells & Zones
Temporal Detail	All years	All Years	All Years	All Years
Model Runtime	Short	Long	Long	Long
Level of Expertise Required	Minimal	High	High	High
Policy Relevance	Low	Good	Good	High
Link ability	Yes	Yes	Yes	Yes
Open Code	Yes	No	Yes	Yes
Free Software	Yes	No	Yes	Yes
Accessible to Public	Good	Fair	Fair	Fair
Output Presentation	Good	Poor	Good	Fair
Feasibility:				
Costs ($)	Low	High	High	High
Costs (FTE-staff)	Low	Moderate	High	High
Time to develop	Low	High	High	High
Data needs	Low	High	High	High

Usability

The usability of any particular model must be determined on an agency-by-agency basis, as it is difficult to generalize the internal capacities and requirements of any particular agency for any particular set of policy analyses. In general, we judge PECAS and UrbanSim capable of a wide variety of policy analysis satisfying many of the legal requirements described earlier.

Geographic detail is an important model choice variable. A question that was raised early on in this process by the TAC was whether or not these models could be used to evaluate policies and scenarios at different levels of geography, ranging from subregions to corridors. Each of the models considered in this study produces outputs at a fine enough level of geography that aggregations to differing levels of geography would be fairly straightforward. The concern was that with aggregate zonal models disaggregating down to the level of interest can be difficult and interpretations of disaggregated outputs challenging.

Temporal detail relates to the time step in models such as UrbanSim and PECAS. Each can be run with a single year time step. Further, UrbanSim and PECAS build their way to the horizon year so outputs for intermediate years are available. UPlan produces outputs for a single year. If intermediate years are needed, UPlan can be run to those intermediate years, by treating them as the out-year.

Model runtime is a concern for MPO modeling staff because current travel demand models require a great deal of time to run and adding an integrated land use model to that process could yield a significant increase in runtime. While UrbanSim and PECAS run every year, the model developers for both models stated during their presentations that the travel models would only need to be run every fifth model year. The land use model would then utilize the accessibilities obtained from those model runs across a five model year period before obtaining new accessibilities. This is not ideal but is a sufficient compromise in order to reduce the overall runtime of these models. UPlan typically runs independent of a travel model and only models the horizon year, therefore, UPlan requires significantly less runtime to produce horizon year outputs.

Another concern, particularly for smaller MPOs, is the amount of expertise needed by the modeling staff to develop and operate an integrated model. UPlan is a fairly simple, GIS based model that requires minimal modeling knowledge. In contrast, UrbanSim and PECAS require similar levels of modeling expertise to a fairly sophisticated travel demand model.

The desire to model a broader range of policies and alternatives than is presently available in travel demand models is a key component of the attractiveness of integrated models. As stated earlier, PECAS endogenously models more of the urban system than does UrbanSim, including land use and various economic stocks and exchanges within the system. For this reason, PECAS can model a greater variety of policies or alternatives. UrbanSim is primarily designed to represent the impacts of travel on land use and conversely. The non-behavioral nature of UPlan limits its ability to represent the effects of many types of policies, particularly those that rely upon behavioral shifts in location (or other) choices, which are a key component of many land use policies.

PECAS and UrbanSim have already been successfully linked to travel models, either internally (Oregon Statewide Generation II model—PECAS) or externally (UrbanSim). As more agencies develop these models, our understanding of their "linkability" to travel and other models will increase. UPlan has been linked to a travel model in Merced County, and work is underway at the Delaware Valley Regional Planning Commission (RPC) to also do this.

One reason for selecting the four models evaluated in this study is that they were developed by academics and are open code (users have access to the programming codes and can make changes, additions, or deletions to the programs) and free (no license purchase required). This aspect of these models was critical to the TAC and to MPO modelers because it allows them to customize the software and eliminates the "black box" effect of closed code models (i.e. not being able to verify all relationships in the model set).

The final criterion under the "usability" heading deals with the quality of the model's data output presentation. Currently PECAS and UrbanSim produce all outputs in a series of data tables. The user must determine how that data will be presented (e.g. graphs, charts, tables, GIS, etc.); the model itself does not create any type of output report. This can create the need for post model data processing in order to present the data in a format that is readily interpretable or understandable by non-technical participants. Because UPlan is GIS-based, its outputs are already in GIS format and can be presented with little manipulation.

Feasibility

For the feasibility section of the evaluation criteria, perhaps the best information was obtained from the survey of current users (see Table 6.). In this survey, efforts were made to obtain a realistic view of the costs in time, money, and staff that are required to develop an integrated model. While UPlan was not included in the survey, it is clear that UPlan is by far the least expensive, least data hungry, and least time intensive model of the three considered in this study. UrbanSim requires slightly less data than PECAS, but the majority of the data needs are similar for both models.

Because local transportation and policy concerns are numerous and complex, associated costs become the overarching feasibility issue. The experience of SACOG demonstrates the importance of maintaining support from an MPO or RTPA board by having agency staff adopt a "bottom-up" approach to capture the interest of the constituent local agencies. SACOG surveyed member agency staff in 2001 and held several public workshops to get feedback on policy concerns. The survey revealed that the following issues were hot (in order of popularity):

1. land use and smart growth;
2. pricing of parking and roads;
3. automated traveler information systems;
4. paratransit, bus rapid transit;
5. environmental justice, social equity;
6. induced land development;
7. induced and suppressed travel;
8. peak spreading, departure time choice;
9. effects of land use and design on travel;
10. sidewalks, bike lanes;
11. air quality conformity, NEPA documents, traffic impact studies, land use planning;
12. models useful for subregion and subarea studies (fine spatial detail);
13. models useable by other agencies, standard modules, GIS;
14. making all assumptions explicit;
15. inter-regional travel;
16. open space planning and habitat protection;
17. useful for sensitivity analyses of policies;
18. including lots of understandable performance measures;
19. representing all travel behaviors;
20. representing non-motorized modes and telecommuting;
21. representing land markets, not just local land use plans;
22. representing multi-modal trips in tours, by time of day; and
23. useful for broad scenario testing.

The most difficult data to acquire for advanced (market-based) integrated models are those on quantity and price of floorspace. Some counties describe building floorspace in their parcel data files, since floorspace is used to calculate permit fees and for tax appraisal in many jurisdictions.

Most often, though, these data are not available. Residential floorspace can be approximated from Census housing data, which include the number of dwellings by number of rooms, at the tract level. These data are electronic and downloadable for 1990 and 2000. The data for multifamily buildings can be checked against apartment and condominium floorspace data from leasing agents. Often these data only cover relatively new buildings, but they are still helpful. We can also get population and number of households by tract, of course. Housing monthly rents can be inferred from the Census housing mortgage and rent data. Rent data are fresh, while mortgage data are old and so have to be inflated to current costs. The owner units data can be checked against recent residential sales data from private vendors.

For quantity of nonresidential floorspace, we can “back it out” from employee data, by multiplying employees by floorspace per employee, by type of employee. Most MPOs and RTPAs have number of employees by employment type for traffic analysis zones (TAZs). You need these for two base years, preferably 1990 and 2000, to calibrate a model. Small MPOs and RTPAs have only the manufacturing, retail, and other categories, but this is good enough. Larger MPOs have five or more categories. These data can be checked and improved with a windshield survey of all nonresidential buildings and by developing databases using the electronic yellow pages. Also, Coldwell Banker and other leasing and brokerage firms can give floorspace for at least fairly new large leased buildings. InfoUSA sells employment data by street address and X-Y coordinates. Archived data, not in the current year, are inexpensive. The firm name and phone is included, as are number of employees by type, gross sales, and many other data types. The earliest year with valid addresses is 1997 for California and so only the 2000 data match the year of the other data sources. ES-202 data from the U.S. Dept. of Commerce are also available, but self-employed and some government jobs are excluded. All of these data sources can be used in a cross-checking effort. The models need number of employees by type and so none of this effort is wasted. Another data source is oblique air photos, interpreted for building volumes.

Land use data are not available from most MPOs and RTPAs, as they are not used for travel modeling. Satellite data, such as from the USGS, are not very reliable categorically, although they can be used as a broad check. They are available for two or more years in most places and are digital and downloadable off of the California CERES site. Local general plans can be used to define broadly what land uses occur where, although preexisting nonconforming uses are common in older areas. These plans are now available as digital information which can be accessed over the Internet in most jurisdictions. The preferred data are parcel data for defining land uses in each zone. Most counties have some sort of land use code in the data table, but, mysteriously, some do not. Parcel data are difficult to get from some county assessors, although the recent attorney general's \opinion that they are public data should help solve this problem. A recent study done for Caltrans used a private statewide real estate dataset with street addresses for all parcels. Even though this dataset does not include parcel boundary files to locate the parcels, the street addresses can be geocoded (to X-Y coordinates) with Census crosswalk tables.

The only problem is that the Census assigns the addresses evenly along each block face and so many parcels get located inaccurately, although they are on the correct block face. So, parcel data with boundary files are preferable, followed by parcel data without boundaries, followed by the other methods. If a windshield survey is done to estimate floorspace, the land use type can also be coded.

In Sum

PECAS endogenously includes more of the urban system than does UrbanSim and therefore should be able to model a broader range of policy alternatives. The inclusion of explicit economic exchanges within the model should produce more consistent and defensible forecasts. UrbanSim is also a viable alternative as it adequately represents micro-economic and behavioral theory in the decision processes of locators and developers and requires slightly less data than does PECAS. PECAS has the most consistent use of accessibility measures within the whole model set. It also has the greatest potential for theoretically valid economic welfare measures. UPlan is the simplest of the models considered in this study. It is a good alternative for MPOs without sufficient expertise or budgets to develop sophisticated, labor-intensive models such as PECAS or UrbanSim.

***Table 9**. Summary of Good Modeling Practice*

Summary of Good Modeling Practice for Medium-Sized and Large MPO

Time Representation
Peak and off-peak periods

Data Gathering
Household travel survey every decade with tours
Vehicle speed surveys
Data for urban model

Activity Forecasts
GIS land use model or economic urban model

Auto Ownership
Discrete choice model, dependent on land use, parking costs, and accessibility by mode

Trip Generation
Walk and bike modes
More trip purposes
Dependent on auto ownership
Three or more time periods

Trip Distribution
Full model equilibration
Composite costs used (all modes, all costs)
All-day trip tours represented

Mode Choice
Discrete choice models used
Land use variables in transit, walk, and bike models

Goods Movement
Fixed trip tables

Assignment
Capacity-restrained
Cleaned-up link capacities
Speeds calibrated
Three or more time periods

RESULTS AND CONCLUSIONS

The purpose of this project was to facilitate a system of information exchange. The goal was to provide the California modeling community with pertinent information on the current state-of-the-art in integrated land use and transportation modeling, the state-of-the-practice (in California), and the experiences of other modeling entities as they have developed and used integrated models. This information exchange led to development of evaluation criteria against which the models were judged. These criteria were largely derived from the various meetings held throughout this study, but fit well with those used in previous studies.

Integrated land use and transportation modeling has progressed a great deal in the past decade. The problems experienced by California and other modelers regarding the use of the DRAM/EMPAL model will likely not hinder the behaviorally based microeconomic spatial competition models, such as UrbanSim and PECAS, that are the focus of this study. UrbanSim and PECAS represent a complex system of relationships between households, employment, and travel. These relationships are represented in a conceptually consistent and valid manner. Both of these advanced models are used along with an MPO's travel demand model.

In our analysis, we concluded that PECAS is superior to UrbanSim in its basic structure. While UrbanSim represents locator behavior as determined by accessibility and other local factors, PECAS is an economic transactions model. PECAS derives both location demand and travel demand from economic transactions, which means it has a more complete spatial competition theory underlying it. These exchanges of workers and goods are derived from input-output tables for regions and states. So, the full version of PECAS does not use the existing travel model for trip generation or distribution, only for mode choice and assignment. Instead, trip generation is derived from the exchanges of workers, goods purchased while shopping, and the consumption of other services, such as medical or education. Trip distribution is then directly derived from the spatial exchanges in input-output tables. Goods movements are also derived in this fashion, directly from the aggregate spatial I-O data. All shipments by water, air, rail, and trucks are represented in the input-output tables. So, using other data on goods volumes by carriers, these shipments are assigned to the various modes. This strong theoretical underpinning means that PECAS will produce more realistic locator and traveler behavior in situations where data are incomplete or erroneous. PECAS will also produce performance measures concerning the economic effects of transportation or land use policies, by sector and region, as all consumer and producer choices are based on utility maximization.

The second reason why we prefer PECAS is that it has the most consistent use of accessibility measures among all submodels. This means that it is consistent, conceptually, and therefore more valid. Related to this is the fact that PECAS also uses utility measures consistently throughout the travel submodels and the locator model, all represented as a nest of logit (discrete choice) statistical models. This mathematical consistency permits the derivation of a measure of economic output called producer locator surplus, which encompasses traveler surplus. In urban economics, this is generally acknowledged as the most complete aggregate measure of effects on the economy, due to changes in transportation systems or land use policies. Related to this economic calculation is the fact that PECAS represents economic exchanges as occurring in the producer zone, the consumer zone, or somewhere in between. This permits the travel and goods movements costs to be accurately attributed to the two parties, which results in more accurate pricing, demand, and travel and goods flows. PECAS is the only model anywhere that has this accurate portrayal of travel and shipping costs.

PECAS has other advantages, due to its ability to simulate economic activities. As regional travel models in California progress to tour-based simulations and then to activity-based tours, the microsimulation of households, travelers, and employment will require the microsimulation of economic activities. Another motivation for MPOs to utilize integrated models is the necessity for upzoning and infill development in the many cities in the State that are running out of land. Integrated models can show how rents will rise and where redevelopment is most likely to take place first.

Finally, we note that PECAS is an open-code model, meaning that the code is given out for free. This is essential, since the users can verify how the model works, in detail. UrbanSim, on the other hand, is an open-source model, meaning that the code is given out for free and the writers of the code encourage other programmers to modify the code. As a result, UrbanSim has several versions created by numerous authors. Eventually, there may be many versions with many add-on modules. While this is appealing to programmers, it can be frustrating to modelers who want firm versions of the model code to work with and compare with the experience of other users.

The predecessor model to PECAS, used in Oregon for statewide analyses, TRANUS, is similar in concept to PECAS, as is MEPLAN. They are all spatial interaction models, with input-output tables at their cores. With this family of models, then, there is some experience gained in Oregon that helps us to see the benefits of such a model. The Oregon DOT Economic and Bridge Options Study (2003) found that fixing the worst bridges first, as originally proposed, had higher economic costs to the State than did a phased approach that upgraded bridges on bypass routes first, then fixed I-84, and then fixed I-5 in the last three phases. So, only the use of such an economic model could have forecast the economic effects of the various options.

An earlier study done with TRANUS, a precursor to MEPLAN, was the Eastern Oregon Freeway Study (2001) that looked at upgrading either US 395 or US 97, both N-S routes in eastern Oregon, in order to increase the growth rate in that part of the State. The study concluded that neither plan would perform as desired in Western Oregon, due to factors which would have been unforeseen without using modeling. A large investment, possibly several billion dollars, in highway improvements was avoided as a result of knowledge gained via the study. Another successful Oregon study was done on broad transportation and land use scenarios for 2050 for the Willamette Valley. A study of the economic effects of a bypass around two towns was also completed. In Washington State an E-W corridor study of I-90 was done with the MEPLAN model in 2003.

Because of these successful applications of an integrated spatial competition model in Oregon, the TAC recommends the development of a Statewide PECAS model for California. This model would be especially useful for the evaluation of high speed rail, conventional passenger rail, and goods movement. The existing Caltrans Statewide Travel Model is being upgraded by consultants to improve the accuracy of the representation of the high speed rail, conventional passenger rail, and air travel modes. This work will be completed in 2006. (This travel model, then, could be used with a Statewide PECAS model. Goods movement could be added without having to add to the networks. The Statewide PECAS model would be useful to the State Economic Development Department and to the Department of Housing and Community Development in evaluating the economic impacts of transportation, housing, land use, and employment policies in California. The model would also be useful to the California Energy Commission in their mandated work on cost-effective transportation scenarios for the State. The statewide model would help Caltrans districts, as well as MPOs and RTPAs, in evaluating regional and interregional projects. Assessing environmental mitigation on a regional or statewide basis would help in gaining regional or statewide permits from State and Federal environmental agencies. This has been the experience in Oregon: statewide modeling and mitigation resulted in statewide permits. This is permit streamlining of the highest order.

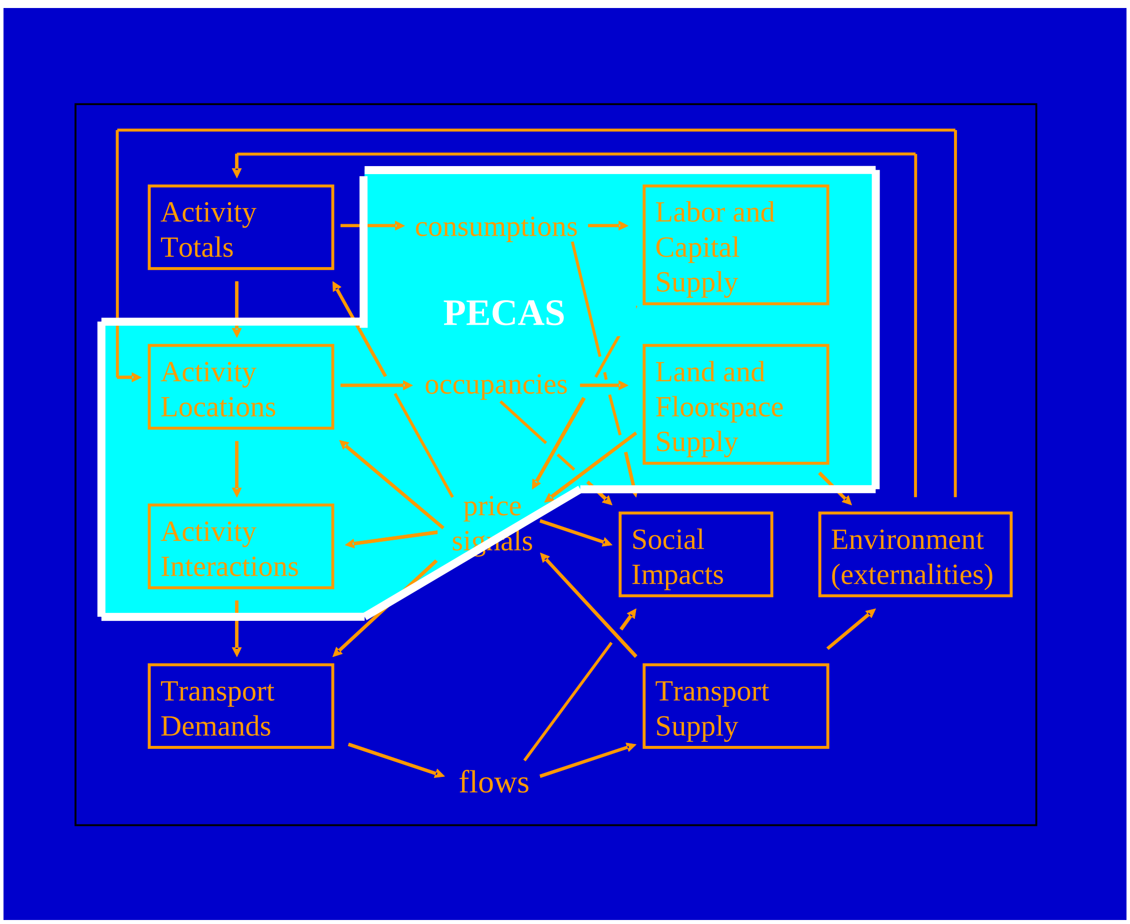
We also note that the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) amendments to the surface transportation act identify four objectives for both regional and state transportation plans: reduce air pollution and fuel use and increase mobility and economic development. The act also requires that regional and state transportation plans "accomplish the objectives." This seems to require that these plans be developed using models that can forecast these four objectives. (Traditional travel models can forecast on-road emissions, vehicular fuel use, and mobility fairly well. Of special interest is that travel models cannot measure changes in the economy very well. A three-step travel model can give changes in travel costs, based on time and distance traveled. A four-step travel model with a logit mode choice submodel can give a better measure of traveler welfare, consumer surplus. These measures are inaccurate, however, since the unmeasured changes in locator surplus may be larger and in the opposite direction. For example, if a household moves farther from the city center, the travelers' costs may go up, but they are commuting farther to a home that gives them a much higher utility. The travel model method would say that they experienced a loss in welfare, whereas the urban model could show that they experienced an overall gain in economic welfare. This is a good illustration of why urban models are needed. The PECAS model will give change in locator surplus, inclusive of changes in travel costs. It will also give changes in locator surplus for firms, and so cover about half of the urban economy and virtually all parts that can be affected with transportation and land use policy. Also, the model is accounting for changes in wages, consumption of other goods and services, and the rest of the urban economy. Intended or not, this requirement in SAFETEA seems to argue for the adoption of integrated models by MPOs and state DOTs.

Perhaps the most important reason for implementing integrated modeling for regions and for the State is simply improved accuracy in travel forecasts. Accuracy in travel projections is essential to forecasting mobile emissions, which are of great policy importance in this state. Also, accuracy in demand forecasting is necessary to useful land use, transportation, and economic analysis. A recent paper by Flyvbjerg, Holm, and Buhl (J. of Am. Plng. Assoc., Sp., 2005) reviews 210 transportation project evaluations in 14 nations and shows that forecasts are quite inaccurate and that accuracy has not increased in the last 30 years. It is incorrect to assume that a more complex integrated model system will be more inaccurate than a typical travel demand model. The more complex model set has its component submodels all calibrated separately, at first, and then all together. So, error does not propagate across submodels. Also, the submodels feed back to each other, correcting for unreasonable data and for divergent paths of behavior over time. Market-based models are especially good at these corrections because of the effects of prices on demand.

Last, we emphasize the importance of integrated economic models such as PECAS in performing equity evaluations, including environmental justice analysis. These models can give performance measures such as change in economic welfare for households by income and location and for employees by employment type and location. Also, the model can give aggregate measures of economic welfare for counties, regions, and the State.

The following diagram shows a complete conceptual modeling system, with the typical PECAS model set outlined. As can be seen, the travel model networks and the mode choice and assignment steps lie outside of PECAS, as do the input population, employment, or economic activity growth. Also, social and environmental impact models are external. Typically, PECAS is run with a regional or statewide travel model and any impact models desired are also linked to PECAS outputs.

Figure 5. *PECAS conceptual modeling system*



Challenges

From past modeling efforts, we can summarize the challenges encountered in large model development programs as follows:

1. Data gathering and use. Much of the effort in developing a model is spent on data gathering, cleaning, updating, and sharing. A data cooperation process must be devised and agreed on by all parties.

2. Political support. MPOs and State DOTs have many component governments or departments that must support the model development effort, which is expensive and takes several years. It is best to have early buy-in by all parties, based on their stated needs for better modeling. That is, a bottom-up approach will work better than a top-down one.

3. Detail. The model must provide outputs that make sense to the users, in terms of detail. This means not only that many categories of outputs are needed but that they also must be spatially disaggregated.

4. Governing body support. The MPO or State DOT must keep the support of the top-level decision makers over several years. This is best done by developing the model in stages, in order to get a working, if simple, model going in a year or two. This strategy worked well in Oregon and at SACOG.

5. Staffing. Loss of staff to higher-paying private firms is a problem in travel modeling and will be worse in integrated modeling, as there are fewer trained people at this time. The only remedy is to have higher pay scales in MPOs and State DOTs for these specialized people. Cross-training will also help. It is critical to have more than one person proficient with the model.

6. Costs. The costs associated with running a modeling program are often underestimated. As models become more complicated and data hungry, the costs connected with model development and maintenance have also increased. Also, the true costs of maintaining a modeling program include not only the cost of developing the model, but also the costs associated with creating model input data, personnel costs, model maintenance costs, training costs, and software/hardware costs. It should be noted that costs associated with modeling can be more than offset by beneficial impacts of information obtained as a result of modeling. In some cases, in may be impossible to obtain such information in any other way.

7. Time requirements. Typically models require more time to develop than first envisioned. Considerable time is required just to build the model database. Additional delay is often experienced during the model calibration/validation process. In most cases, MPOs will be building integrated models from scratch. First generation model development efforts often experience considerable delays dealing with unexpected challenges.

Recommendations:

1. ***The TAC recommends that the four large MPOs (SCAG, MTC/ABAG, SANDAG, and SACOG) strongly consider implementing an integrated model in the near future.*** Our review showed that UrbanSim and PECAS are the two most advanced models and that several MPOs across the U.S. are applying them. Indeed, SACOG has already started implementing the PECAS model. SCAG has commissioned a report comparing advanced models, including these two. Our research demonstrated that these two models are behaviorally based in microeconomics and produce useful outputs regarding land use changes over time. For those MPOs also interested in projecting the effects of transportation or land use policies on housing prices and/or commercial development or redevelopment, both models are useful. For those MPOs additionally interested in goods movements, the PECAS model seems to better represent these flows, as it uses an input-output table as an overall structure for the other model interactions.

2. ***The TAC also recommends that medium-sized MPOs and RTPAs in California consider implementing simpler urban models, such as PLACES, What If?, UPlan, and others.*** Most of these models are based in GIS and so readily produce useful maps. SACOG and SLO-COG have already successfully used PLACES, for example, for rapid scenario testing. The UPlan model was used successfully by the Merced County Association of Governments two years ago for joint land use/habitat/transportation planning, and UPlan currently is being applied by Calaveras, Alpine, and Tuolumne counties for land use planning and for transportation planning. Recently, the San Joaquin

Valley consortium of eight counties was awarded a Caltrans "Blueprint" planning grant and has selected the UPlan model for use in scenario testing over the next two years.

3. ***Data sharing should be instituted among MPOs, RTPAs, and Caltrans.*** Data types necessary for all urban modeling include: census data on households, county boundaries, roads, railroad lines, major rivers, all streams, digital elevation maps, slopes, general soil types, agricultural lands, vegetation types (plant communities), important habitats, public lands, parcels, and land use plans. Many counties have most, or all, of these data layers. The Information Center for the Environment at UC Davis has prepared a statewide general plan layer and generalized it to fifteen land use classes. Counties, RTPAs, and MPOs can use this layer or they can use the data in its native format (with all local plan categories), if they do not have their own data. Data necessary for the advanced integrated urban models include, in addition to the above data: employment by location and type, floorspace by location and type of economic activity and type of land use and type of building, floorspace lease values, floorspace consumption by households and firms by type and location, and origins/destinations for worktrips by type of employment and household type.

We recommend coordination between state and regional agencies for data collection, classification, and publication, so that various organizations could use the same data types and, wherever possible, the same data categories. This standardization would facilitate data sharing, make it easier to understand other agencies' models and reports, and make many modeling exercises comparable across jurisdictions. Perhaps the university or some other entity could provide a web site listing funding sources used by MPOs and RTPAs and available data sources. On such a site, brief statements regarding progress in model development could be posted by all agencies, as is done on the Federal Transportation Model Improvement Program (TMIP) web site. Minutes of the quarterly statewide modelers meetings could also be posted. Overviews of urban model developments across the U.S. should also be on the site.

4. ***Caltrans should consider implementing a statewide integrated interregional urban model.*** Such a model should be implemented in phases, and should use the Statewide Travel Model that is currently being upgraded to more accurately represent the high speed rail, conventional passenger rail, and air travel modes. Goods movement could be represented well with these networks, but this is assuming that adequate activity data can be obtained. Such data are not currently available. A statewide integrated interregional model, if successfully implemented, would be able to provide consistent traffic flow data and goods movement data across the State, and so will permit the MPO and RTPA models to also incorporate consistent external trips data. This model would also allow Caltrans districts and Statewide staff to better evaluate interstate and interregional transportation improvements, such as new freeways, new high speed rail, conventional passenger rail upgrades, freeway widenings, and airport expansions. Both UrbanSim and PECAS would allow the evaluation of the effects of such interregional projects on housing prices across the State. PECAS would allow State officials, in addition, to evaluate the effects of transportation policies on the economy in various types of business

in different areas of the state, and also to be able to assess a number of transportation and land use "scenarios" that cannot currently be evaluated using transportation models alone. These include (but are not limited to) jobs/housing proximity, economic fees and/or incentives programs, and the benefits and impacts of various proposed plans, programs, and projects on specific populations in different locations, especially those impacts effecting environmental justice considerations.

APPENDICES

APPENDIX A – TECHNICAL ADVISORY COMMITTEE/AFFILIATION

MEMBERS OF THE TECHNICAL ADVISORY COMMITTEE FOR "ASSESSMENT OF REGIONAL INTEGRATED TRANSPORTATION/LAND USE MODELS" CONDUCTED BY UC DAVIS - 2005

MPO STAFF:	CALTRANS STAFF:
SF Bay Area: **Metropolitan Transportation Commission (MTC):** • **CHARLES PURVIS,** Principal Transportation Modeler **Association of Bay Area Governments (ABAG):** • **PAUL FASSINGER,** Director of Research and Analysis, and various staff	**District 4 (SF Bay Area):** • **PHILLIP COX,** Senior Transportation Engineer, ***Advance Planning, Traffic Modeling and Forecasting***
Sacramento Area Council of Governments (SACOG): • **GORDON GARRY,** Director of Research and Analysis	**District 3 (Sacramento region):** ***Office of Travel Forecasting & Modeling*** • **DENNIS AZEVEDO,** ***Chief,*** **PHONG DUONG,** Transportation Planner
San Diego Association of Governments (SANDAG): • **ED SCHAFER,** Senior Planner/ Demographer • **MARK WOODALL,** Principal Planner	**District 11 (San Diego region):** • **MAURICE EATON,** Sr. Transportation Planner **Traffic & Travel Demand Forecasting** • **STEVE THRELKELD,** Transportation Engineer ***Traffic Forecasting and Modeling*** • **SUSIE MARTIN,** Transportation Engineer • **PAT LANDRUM,** Assoc. Trans. Planner • **RICK CURRY,** Research Analyst II (GIS)
Southern California Association of Governments (SCAG): • **MIKE AINSWORTH ,** Lead Modeling Analyst - Information Services • **HUASHA LIU ,** Interim Director of Information Services • **GUOXIONG HUANG,** modeler	**District 7 (Southern Calif.):** • **JOHNATHAN OSBORN,** Research Program Specialist, *Modeling and Forecasting*

Merced County Association of Governments: • **RICHARD GREEN,** GIS Program Manager, and Coordinator of the "Partnership for Integrated Planning"	**District 6 (Southern San Joaquin Valley):** **DAVID BERGGREN,** Assoc. Trans. Planner **District 10 (Northern San Joaquin Valley):** **CARLOS YAMZON,** ***Chief, Travel Forecasting and Metropolitan Planning***
CALTRANS HEADQUARTERS STAFF: **Division Of Transportation Planning (DOTP):** **Office of Community Planning:** • **TERRY PARKER,** Senior Trans. Planner ***(Caltrans' Project Manager of study)***	**Division of Transportation Systems Information (TSI):** • **DOUG MACIVOR,** Senior Transportation Planner • **VAHID NOWSHIRAVAN,** Research Program Specialist II
Office of Regional Planning: • **KATIE BENOUAR,** Senior Transportation Planner • **DARA WHEELER,** Senior Environmental Planner	
Office of Systems Planning: • **AL ARANA ,** Senior Trans. Engineer	

APPENDIX B - TAC ROLES AND RESPONSIBILITIES

ASSESSMENT OF REGIONAL INTEGRATED TRANSPORTATION/LAND USE MODELS

Technical Advisory Committee – Roles and Responsibilities

Initial steps in this study include:

- Conducting a thorough review of the literature of all such models.
- Inventorying land use models currently in use throughout California.
- Engaging a technical advisory committee (TAC) and a Caltrans management committee to provide oversight and guidance.

THE TAC MEMBERS WILL

- Review the UCD development of background materials on the current generation of urban integrated land use/ transportation models.
- Advise UCD on the development of workshops for each MPO.
- Help UCD focus on the modeling needs of the individual "host" MPO and its member jurisdictions.
- Provide UCD with advice and recommendations regarding the types of models that would be most advantageous for Caltrans and the MPOs and possible next steps for further testing and deployment of such models.

MEETING SCHEDULE

The TAC members will be asked to participate in a total of seven (7) meetings between January and October of 2005. A conferencing system will be available at each meeting for those individuals who are unable to attend in person.

Initial Meeting: February 3, 2005 --UC Davis Campus

Additional Meetings:

March 3, 2005 Teleconference			May 3, 2005 Oakland, CA	or	May 5th, 2005 San Diego, CA	or	June 7, 2006 Los Angeles, CA
April 7, 2005 Teleconference			June1, 2005 Stockton, CA	or	June 2, 2005 Bakersfield, CA		
April 11, 2005 UC Davis Campus	or	May 9, 2005 Los Angeles	June 6, 2005 UC Davis Campus				
April 27, 2005 UC Davis Campus			November 10, 2005 UC Davis Campus				
			March 27, 2006 Teleconference Call				

APPENDIX C – ANNOTATED BIBLIOGRAPHY

ANNOTATED BIBLIOGRAPHY OF RELEVANT LITERATURE FOR INTEGRATED LAND USE and Transportation Modeling

Robert A. Johnston
and
Michael J. Clay

UC Davis
February 3, 2005

COMPARATIVE REVIEWS OF MODELS

1. Wegener, Michael (1994) Operational Urban Models: State of the Art. Journal of the American Planning Association. Vol. 60 (1).

This paper briefly documents the current state-of-the-practice in integrated land use and transportation modeling. It also summarizes of the history of this field and enumerates current applications, worldwide, of this type of modeling. This paper demonstrates that integrated modeling in Europe has been strong for some time and has been gaining attention in the U.S. since the mid-1980s.

2. USEPA. Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns. EPA/600/R-00/098, Sept., 2000.

Description and comparison of 22 land use models, ranging from simple GIS ones to complex urban economic models. Useful comparison criteria and tables.

3. Available Methods for Land-Use/Transport Interaction Modeling. David Simmonds. David Simmonds Consultancy, Cambridge, England. Mar., 1995. Unpublished.

A useful comparison of 13 models based on their structure and purpose. Concludes that many models can synthesize missing base year data. Finds MEPLAN and TRANUS to be the best models, at that time, as they are predictive, dynamic, and based on spatial economics. He believes that the activity based models, based on microeconomic simulation, will be stronger, when better data are available from stated preference surveys and other sources.

Applied Model Comparison Projects

1. Hunt, J. D., R.A. Johnston, J.E. Abraham, C.J. Rodier, G.R. Garry, S.H. Putman, and T. de la Barra (2001) Comparisons from the Sacramento Model Test Bed. Transportation Research Record 1780, pp. 53-63.

The Sacramento Model Test Bed study was a side-by-side comparison of the SACOG travel model (SACMET 96), DRAM/EMPAL (run with SACMET 96 as its travel model), TRANUS, and MEPLAN. The purpose of the study was to test and compare each model's policy analysis ability. Each model was given identical data from the Sacramento region for model calibration. A trend scenario was run as well as three policy scenarios. The models were quite different in their base year simulations, due to alternative-specific constants for mode choice. This was mainly due to a small budget and rapid calibration of the models. They were quite similar, when the policy scenarios were compared, in terms of percent change from the base case, giving the user some confidence in this type of model.

2. ISGLUTI. Urban Land-use and Transport Interaction: Report of the International Study Group on Land-use/Transport Interaction. Ed. by F.V. Webster, P.H. Bly, and N.J. Paulley. Avebury (Brookfield, MA), 1988.

Compared 9 urban models of various types, in terms of their published simulations. Then, compared 7 of them run on 40 policy combinations intended to reduce auto travel, in different urban regions. Found many theoretical weaknesses of the models, but that they were generally useful for regional analysis of strong policies (scenarios). Found that spatial and categorical disaggregation requires a better understanding of the behaviors being simulated. In terms of policies, found that land use policies don't do much to reduce travel without pricing of travel also applied. Quite high increases in auto ownership and operation costs or quite high increases in land use density were required to reduce auto travel substantially. Home-based work trips were found to be quite unresponsive to pricing and so regions need good transit service to employment centers. Higher freeway speeds result in greater sprawl and greater social segregation, residentially. Must have walk and bike modes in models, as lower transit costs and better service tends to take riders from walk and bike. Increased transit speeds lower costs for all motorized modes. Urban growth boundaries do not increase land prices (per unit), as development densities rise, but do decrease travel. The most complete comparison study ever done.

3. Final Report on SPARTACUS: System for Planning and Research in Towns and Cities for Urban Sustainability. EC, Sept., 1998.

Applied MEPLAN with a new GIS mapping program and a user interface (USE-IT) on Helsinki, Bilbao, and Naples. Found that you need large regions, comprehensive models, and long time periods to capture most important behaviors. Examined sustainable development policies. Lots of maps, tables and graphs, and other outputs in comparative formats. Equity analyses done. http://www.ltcon.fi/spartacus

4. Wegener, Michael. A New ISGLUTI: the SPARTACUS and PROPOLIS Projects. Second Oregon Symposium on Integrated Land Use and Transport Models. Portland, July, 2000. On ODOT web site.

Review of SPARTACUS and an introduction to the follow-on PROPOLIS project, which applies three models (MEPLAN, TRANUS, and IRPUD) on 7 urban regions.

5. PROPOLIS: Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability. Final Report. EC, Feb., 2004.

Tested 20 policies on 7 urban regions, using 3 urban models. Found that improving transit, pricing auto ownership and use, and land use intensification worked best, if all done together. Evaluated a broad array of impacts including: net economic societal benefits to travelers, total rents, employment, tax revenues, exposures to noise and pollutants, traffic deaths, percent overcrowded housing units, productivity gains from land use, various justice measures, and many other conventional ones. All 3 models used GIS for impact mapping and had good user interfaces for output measures. All used 3D maps for land uses. Productivity gain from land use was calculated as size of labor market and costs of work trip access. Useful methods for aggregating output measures. Good brief discussions of urban economic theory and model representation methods. Note that these models did not produce a measure of locator producer surplus.

6. 2001. Rodier, Caroline J., John E. Abraham, and Robert A. Johnston. Anatomy of Induced Travel: Using an Integrated Land Use and Transportation Model in the Sacramento Region. Transportation Research Board Annual Meeting, Jan., Washington, D.C.

The authors compared a full urban model with a travel model, run on the same scenarios, and show that the full model produces a higher growth in VMT when comparing a No Build scenario to a typical regional transportation plan. This is due to the land use impacts, which reinforce the added radial road capacity with low-density growth.

Model Testing and Validation

1. Condor, Sonny and Keith Lawton (2002). Alternative Futures for Transportation and Land Use – Integrated Models Contrasted with "Trend-Delphi" Methods: The Portland Metro Results, presented at the 81st Annual Meeting of the Transportation Research Board, Washington, D.C.

This is an important paper that compared the forecasting abilities of an integrated land use and transportation model to those of an expert driven, Delphi, process. This paper found that the results from the integrated model were preferred. From the abstract: "Since completing a 'Trend-Delphi' based regional forecast and transportation plan in 1996, Metro has developed an integrated transportation and land use model (Metroscope). . . Comparing our Metroscope results to our previous forecast reveals that Integrated Transportation and Land Use Models may produce different results in regard to Trip Length, VKT, traffic congestion levels, mode and route choice, employment and household locations. Compared to trend models, integrated models robustly respond to alternative land regulation and transportation investment policy options allowing planners and officials an opportunity to evaluate the differences in land use and transportation arising from different policy choices. Moreover, the integrated models produce far more data on such factors as real estate prices, tenure choice, residential and nonresidential real estate output, land consumption, redevelopment and density." Practically speaking, the urban model resulted in lower traffic volumes, as firms moved around to avoid congestion.

2. Rodier, Caroline J., John E. Abraham, Robert A. Johnston, and Doug Hunt (2002) A Comparison of Highway and Travel Demand Management Alternatives Using An Integrated Land Use and Transportation Model in the Sacramento Region. Presented at the Transportation Research Board, Annual Meeting, Washington, D.C.

This paper ran an early version of the Sacramento MEPLAN model on a variety of transportation and land use policies and had five major conclusions: "First, transportation investment in both highway and light rail may allow for greater decentralization of regional development. Second, new highway capacity projects, even if they include HOV lanes, may increase VMT and emissions. Third, transit investment with supportive land use policies or pricing policies may be very effective in reducing VMT and emissions. Fourth, transit investment with supportive land use or pricing policies may provide congestion reduction that is as great, if not greater, than highway investment policies. Fifth, transit investment combined with land use policies may provide greater benefits (i.e., change in travel time and cost) than highway investment." In addition to these findings, this paper demonstrates the abilities of this model to forecast both travel and land policies.

3. Pradhan, Anant and Kara Kockelman (2002) Uncertainty Propagation in an Integrated Land Use-Transportation Modeling Framework: Output variation via UrbanSim. Transportation Research Record, 1805, pp. 128-135.

This paper examines error in the UrbanSim model. It demonstrates that for UrbanSim, errors in the population and employment forecasts are cumulative and "overshadow all other differences." The ability of the actors within the model to respond to uncertain conditions, produced a non-linear effect of input error on output values. Errors increased in the initial model years but then decreased as the model worked forward to the final model year.

4. Clay, Michael J. and Robert Johnston (2004) Univariate Uncertainty Analysis of a Fully Integrated Land Use and Transportation Forecasting Model. Presented at the Annual Meeting of the Association of Collegiate Schools of Planning, Portland, OR.

This paper analyzed uncertainty in the Sacramento MEPLAN model and found that errors in the commercial trip generation rates and exogenous production forecasts (population and employment forecasts) have the largest impact on model outputs.

5. Abraham, John and J.D. Hunt (1999) Policy Analysis Using the Sacramento MEPLAN Land Use-Transportation Interaction Model. Transportation Research Record: No. 1685, TRB, National Research Council, Washington, D.C.

UrbanSim

The model's website, http://www.urbansim.org/, contains a wealth of information, including numerous research articles and reports documenting this model. This website, in the past, has been updated regularly and is a good source for up-to-date information regarding this model. Below are the two best overview papers for this model.

1. Paul Waddell, UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning. Journal of the American Planning Association, Vol. 68 No. 3, **Summer 2002, pages 297-314.**

This paper provides a good overview of the UrbanSim model. It is less technical and covers the basic model structure, at the conceptual level. This paper is a good starting point for those interested in UrbanSim.

2. Paul Waddell, Alan Borning, Michael Noth, Nathan Freier, Michael Becke and Gudmundur Ulfarsson, Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim. Preprint of an article that appeared in Networks and Spatial Economics, **Vol. 3 No. 1**, ***2003, pages 43--67.***

This is more of a technical review of the UrbanSim model and presents the structure of the model, including the submodels, submodel interactions, data requirements (not fully developed), and the model's "data store".

PECAS

The website of the firm that created PECAS, http://hbaspecto.com/, contains numerous research papers that document this model. Interested parties are encouraged to check this site regularly for updated documentation. Below are two of the documents that summarized the PECAS model.

1. Abraham, John, Gordon Gary, and Doug Hunt. The Sacramento PECAS model. Presented at the annual meeting of the Transportation Research Board, 2005.

2. Hunt, J.D. and J.E. Abraham, Design and Application of the PECAS Land Use Modelling System, presented at the 8th Computers in Urban Planning and Urban Management Conference, Sendai, Japan, May 2003

METROSIM

1. MetroSim. Alex Anas. Anas and Associates, Williamsville, NY. 1994.

2. Application of MetroSim to New York. 1998. Unpublished.

3. Transportation Model Improvement Program (1998) Land Use Compendium. Washington, D.C.

The first paper in this compendium summarizes several models, one of which being MetroSim.

POLIS

1. Poulicos Prastacos. Urban Development Models for the San Francisco Region: From PLUM to POLIS. Transp. Res. Rec. 1046. c. 1985, pp. 37-44.

Describes the author's programming model of job location, housing selection, and trip making. POLIS is based on utility maximization, in locator surplus. Includes economies of agglomeration. Can handle zoning and other planning constraints on zones. Applied to 9 counties in 107 zones with two travel modes, auto and transit. His model reduces the traditional reliance on basic industry as a drive of location choice in Lowry-type models.

APPENDIX D -- MODEL ASSESSMENT DOCUMENT

ASSESSMENT OF REGIONAL INTEGRATED TRANSPORTATION/LAND USE MODELS

Caltrans Contract 65A0186, FY 2004-05
Michael McCoy, Principal Investigator, UC Davis
Terry Parker, Contract Technical Supervisor, Caltrans

Report for Task 2a: Literature Review and Bibliography, and Report for Task 2b: Survey of MPO Use of Urban Models Final Version.

January 24, 2005

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Distributed at the Technical Advisory Committee Meeting of February 3, 2005 at UC Davis

APPENDIX E – INITIAL TECHNICAL ADVISORY COMMITTEE MEETING HANDOUTS

ASSESSMENT OF REGIONAL INTEGRATED TRNASPORTATION/LAND USE MODELS

HANDOUTS

INITIAL TECHNICAL ADVISORY COMMITTEE MEETING

FEBRUARY 3, 2005

E-1 TCRP PROJECT H-12 FINAL REPORT, 1998
Basic list of good model structures. Basic list of model evaluation criteria

E-2 USEPA, PROJECTING LAND USE CHANGE, 2000
Model evaluation criteria…

E-3 SACOG FINAL MODEL DEVELOPMENT REPORT, 2001
Good example of phased model development program. Good user needs analysis.

APPENDIX E1 – TCRP PROJECT H-12 – INTEGRATED URBAN MODELS FOR SIMULATION OF TRANSIT AND LAND-USE POLICIES

that have been identified in the modeling, academic and practitioner communities.

The main requirements for integrated transportation - land-use models are summarized below:

1. *The economics of land markets and rents must be incorporated in the models.* This reflects the need for a broader treatment of the decision-making on the demand side (i.e., individuals and households) as well as the supply side (i.e., developers and land owners).

2. *A more dynamic feedback* between the travel demand modeling component and the land-use modeling component is required. This reflects technical modeling requirements, but also may require different approaches to transportation - land-use planning -- i.e., that transportation and land-use plans should be developed in tandem with each, rather than one reacting to the other. Ultimately, there is a further need to link land-use, transportation and air quality.

3. *Integrated models must be capable of addressing macro issues* (for example, region-wide policy analysis) *and micro issues* (for example, the impacts of and on individual transportation facilities or developments).

4. *Integrated models must be capable of providing graphically-oriented information* to decision-makers and stakeholders at all levels: politicians, developers, the public, etc.

5. *Integrated models should provide improved information for political decision-making, rather than simulating the political decision-making process itself.* This allows the models to address the technical issues at hand, thereby allowing more informed debate and the ability to address a broader range of concerns.

6. With regards to forecasting transit impacts on land-use (and vice-versa), *there is a need for the improved simulation and assignment of transit demand on specific facilities.* These reflect the need for improved measurement of transit demand. These may be considered most appropriately in travel demand forecasting models (existing and TRANSIMS), which is beyond the scope of this project. However, there is a need to incorporate these improved capabilities in integrated models, and to better replicate both the changes in land-use that may result and ridership that is induced as a result of land-use changes.

7. *Disaggregate household information should form the basis of the integrated model.* This is consistent with the TMIP direction of microsimulation, but also with the need to simulate better the dynamics of household decision-making.

8. *Data must be compatible* -- in quality, scale, availability and replicability -- *with any improved modeling capabilities.* In particular, land market data are problematic, since relative few data exist at the required level of detail and in sufficient time points in time to support trends analysis, model development, etc. The opportunity exists to exploit the capabilities of GIS (geographic information systems), to manage and present data at the required level of detail.

9. *The travel demand component of the integrated models should be consistent with current developments*, including activity-based modeling, replication of individual traveler's choices and time-of-day variations in travel patterns; in addition to the TRANSIMS microsimulation approach.

These issues define the directions that should be followed in the development of the long-term integrated model. However, it is appropriate also to consider the role of integrated models in TMIP, for two reasons:

1. If the integrated model is to serve as a tool for policy analysis in a public forum, an important role for it will be in scenario **development** in addition to scenario **analysis**. The term "scenario" refers both to transportation network or service scenarios and to land-use scenarios.

2. The TRANSIMS activity-based travel demand module estimates individuals' activities, their characteristics and locations (where, when and why people want to travel). These estimates are based upon the characteristics of individuals, their households and vehicles, which are determined by a synthetic population generator. However, there is (or will be) a need for a more fundamental and broader ability to examine the allocation of human activities over time, before these can be input to the synthetic population generator.

As it stands now, Track E (land-use) stands separately from the other four (original) TMIP tracks. Its relationship is not fully defined, which perhaps reflects the state of our understanding of the transportation - land-use interaction (let alone how to simulate it). Likely for the same reason, TMIP's emphasis, quite naturally, has been on the other tracks, focused on the simulation of travel demand.

We note that the current project contains procedural similarities, and in many cases similarities in content, with each of the other four (original) tracks: outreach, data, near-term improvements and long-term improvements. These tracks -- A through D, respectively -- define a logical sequence of considerations.

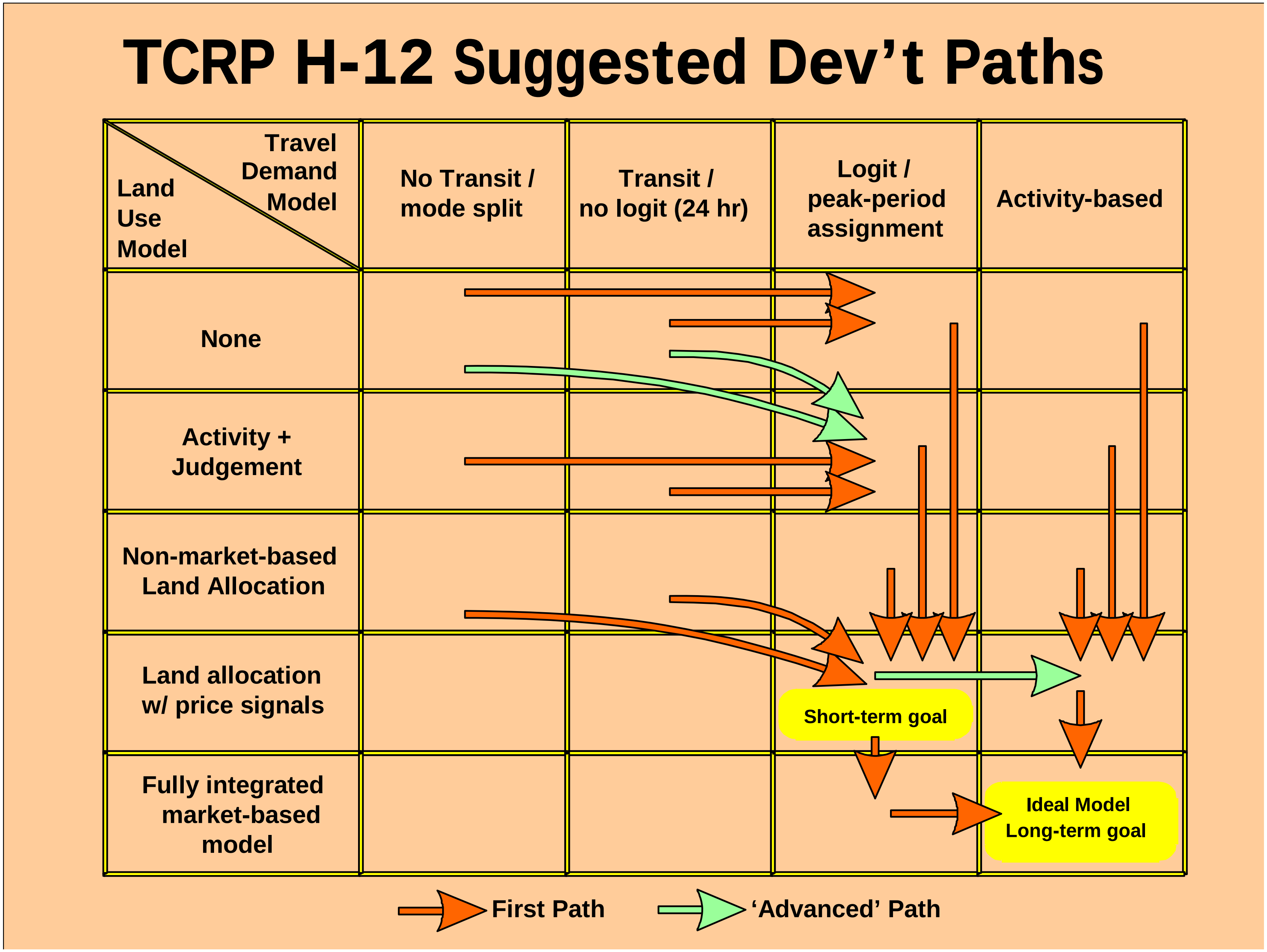
- physical attributes (number of lanes, speed limit, lane capacity, etc.);
- connections (i.e., intersection configurations, delay, control type, etc.);
- service attributes (frequency, reliability, etc.);
- travel time;
- travel cost;
- comfort, safety, personal security;
- flow;
- operating cost (i.e., cost to the service supplier as opposed to the "travel cost" -- the cost to user of the service);
- emissions generated;
- energy consumed; and
- other attributes or outputs (e.g., accidents; side friction due to parking, etc.) as required and available.

Central to the design of the transportation network representation is the nature of the network performance and route assignment model to be used. The current, dominant trend in this regard is to the development of dynamic, microsimulation network models (TRANSIMS, DYNASMART, INTEGRATION, PARAMICS, etc.)[14] which require very detailed representation of the (road) network and which generate time, cost and flow information for each link dynamically over time. Such models are generally viewed as being required to generate improved estimates of emissions and energy consumption, as well as to represent system behavior under real-time control and other ITS-related options. However, the extent to which this level of detail is required in an integrated urban model, or (if it is not required) how such detailed operational models impact and are impacted by integrated models, are questions for further research and testing.

Services. The development of land depends on the provision of many services in addition to transportation. These include:

- sewers
- water
- electricity/gas
- communications (telecommunications, fiber optic networks, etc.)
- heating/cooling
- proximity to emergency services (fire stations, hospitals, etc.)

[14] These are all road assignment software packages. However, disaggregate transit assignment packages also exist. These transit assignment procedures are comparable to the road procedures in terms of level of detail of representation of the transit network and in assigning point-to-point trips over the network. They do not, however, have the same dynamic representation of these flows through time, with both being more traditional "static" procedures. See, for example, Chapleau [1986].


TCRP H-12 Suggested Dev't Paths
Travel Demand Model
Land Use Model
No Transit / mode split
Transit / no logit (24 hr)
Logit / peak-period assignment
Activity-based
None
Activity + Judgement
Non-market-based Land Allocation
Land allocation w/ price signals
Fully integrated market-based model
Short-term goal
Ideal Model
Long-term goal
First Path
'Advanced' Path

APPENDIX E 2 – USEPA PROJECTING LAND USE CHANGE , 2000

Step 4. Assessing Internal Capabilities

The next step in selecting a model requires a clear understanding of what internal capabilities can be accessed to acquire and use the model. This includes assessing the following:

- ***Financial resources*.** How much can be afforded?
- ***Staff resources*.** What is the extent and talent of staff available to use the tool? Does additional help or consulting expertise need to be hired?
- ***Computer resources*.** Do the proper hardware, software, and computing power resources exist on-site to run models?

It is important to be realistic in this assessment since a shortage of resources could result in ineffective installation and maintenance of the modeling tool–essentially rendering it useless.

4.5 Step 5. Choosing the Right Model (Using Selection Criteria)

Once the first four "background" steps have been completed, the final step is assessing and selecting the best model to meet identified needs. Before choosing, however, each option should be thoroughly analyzed against selection criteria. Thirteen primary selection criteria are provided and explained below as guidance. They are listed in an order that follows the likely thought process of a community that is considering a range of models. This is not an all-inclusive list of selection criteria. Other criteria may be important to consider based on the particular results of steps 1 through 4. The criteria may be weighted, based on level of importance, to guide the decision-making process. See Exhibit 4-5, at the end of this section, for an example approach to weighting the criteria.

- ***Relevancy.*** Does the model provide pertinent information that meets the analytical needs of the community?

For a land-use model to be relevant and of value to a community, it must be able to model and project outcomes for scenarios that relate to the community and its needs. The first step in determining the relevancy of a model to community needs is to ask which land-use change will be evaluated by the study. Keep in mind that some models can evaluate several different types of land-use changes, while other models are limited to only one or two types.

The next step is to carefully identify the questions or issues that will be addressed by the study. Careful definition of the questions is essential in determining the boundaries of a study (e.g., topical, spatial, temporal) and the general types of information required to run the model. Every attempt should be made to break the larger questions into smaller, more quantifiable ones. Supporting documentation on the model, as well as a detailed description of the model's data output, should provide the necessary information to determine if the model can answer the questions. It may be helpful to review the data outputs and capabilities of various land-use models in order to better identify and clarify the types of questions for potential evaluation.

- ***Resources.*** Are the model and the computer requirements (hardware, software) and staff (number of people and their time) needed to support the system within the community's budget and infrastructure?

The resources required to use a model include cost of the model and associated computer requirements and the staff time to implement the model. To determine the full cost of a model, conduct an accurate accounting of the associated costs needed to acquire and maintain the model, measured in both dollars and time. Consider the purchase price of the model, as well as any additional hardware and software computer requirements needed to support the model. Also consider any long-term maintenance costs associated with the use of the model and associated computer resources.

It is important also to factor in the amount of time and labor needed to run the model. Some models require full-time attention from dedicated staff and/or consultants, while others provide more user-friendly software tools that someone with minimal experience can run from a desktop computer. If the staff involved in the project are not volunteers, then their salaries, or the appropriate percentage of their salary based on anticipated labor hours needed to perform the study, should be incorporated into the overall operating costs of the model. In addition to any staff that may be supervising or supporting the study, expert consultants may be required to run the model and interpret the results, depending on the complexity of the model chosen. If an outside consultant is required, these additional consulting fees must also be added to the cost of the model.

Finally, when considering cost, it is necessary to evaluate whether it would be more cost-efficient to hire an outside consulting firm to perform the study than to purchase the model. Government agencies may be able to save money by seeking assistance from another agency with adequate resources. In general, the more sophisticated a model is, the more expensive it is to obtain, tailor to local conditions, and operate. In any proposed project, the cost of the models used must be weighed against the level of precision necessary to meet the project's objectives. If the types of analyses desired are needed on a regular basis, it may be most worthwhile to purchase the model and its components and hire skilled operators as permanent in-house technical staff.

- ***Model Support.*** Do the model developers, or does the model itself, provide sufficient support needed to understand and implement the model (e.g., model documentation, user discussion groups, training)?

Computer models, like any other computer hardware or software products, often have varying levels of support for end-users. Typically, models offer documentation and a user's guide to help understand how to load and run the model. Other levels of service also may be offered, including the potential to join users' groups, take workshops or electronic tutorials, view an Internet web site for additional information, and contact help lines. A careful assessment of in-house capabilities is needed to determine which kind of model support would be necessary. Depending on the outcome of such an assessment, this could be an important criterion for consideration.

- ***Technical Expertise.*** Does the community have the technical expertise required to use, calibrate, and interpret the results of the model?

In general, the more sophisticated a model is, the more technical expertise will be required to operate the model and interpret the results. An expensive, complex, sophisticated model is of no value to the community if the community lacks the ability to use the model or understand its data output. Before selecting a model, a community must understand the level of technical expertise required to maintain and operate the model in order to determine if the model can be maintained in house or if the services of a consultant will be needed.

- ***Data Requirements.*** Does the community have, or can they obtain, the data necessary to run the model?

Many land-use change models are data intensive and/or require a certain scale of data to provide reliable results. For example, a model may require that land-use data be on a scale that can be provided only by aerial photography, not satellite imagery. Some models operate best with locally-based data inputs. Unfortunately, much available data are aggregated to a county, regional, or larger area. Disaggregation of such data may be impossible and/or severely compromise data quality. Collection of local data may require a significant resource commitment. In some instances, the necessary temporal scale of data is not available. It is important to conduct a realistic assessment of existing data resources (including time period, and spatial coverage and resolution) and/or a user's ability to collect new data. Always remember that the selected model will be constrained by the data available.

- ***Accuracy.*** Are the projections generated by the model reliable to a degree that is useful to the community?

The term "accuracy" can be interpreted in different ways. In general, it refers to how close the model comes to reality, and how well the model answers the questions posed. Complex models usually take into account more variables (i.e., they contain a greater level of detail) and, therefore, can provide more specific results and can more successfully simulate true conditions than simplified models that rely on many averages and assumptions. Accuracy also involves the "goodness-of-fit" of model results when compared against known outcomes of given scenarios. Some model developers have conducted accuracy analyses by "back-casting" projections through a recent historical period, and comparing the results with what actually transpired. The more important that known accuracy is to a study, the more advisable it is to use a model where goodness of fit has been evaluated.

Additional factors for consideration include the *resolution* and the *temporal capability* of the model (see below). The more accurate a model is, the more useful the results and potentially the more defensible if challenged. When a model is intended to provide the basis for key land use policies and decisions that may greatly impact citizens or businesses, the user should take accuracy into consideration to evaluate whether the model results could withstand challenges by affected community members.

- ***Resolution.*** What amount of land and what level of detail can be modeled in a single scenario?

Resolution refers to the minimum unit of land that the model recognizes in its functions. Some models can simulate land use down to the parcel level, while others may be limited to larger areas (e.g., larger than a certain number of acres, full city- or county-level). High resolution (e.g., square feet) is useful when the study area is small and generalizations or averages would render differences between land areas within the overall study with less clarity. Low resolution (e.g., acres) is useful when the study area is large, averages would provide adequate information, and collection of highly detailed data would create a volume of information so large that it would impede a thorough analysis.

- ***Temporal Capabilities.*** Can the model project outcomes for multiple time periods?

When evaluating a model, it is important to determine the level of flexibility a model provides in temporal resolution and extent. The term *temporal capabilities* refers to the time periods the model examines and the length of each of these time periods. For example, a model may project housing needs for the next 50 years, breaking the results down by 10-year increments. In some models, these time periods may be fixed. If there is a need to examine trends over different time periods and at different intervals, this type of model probably is not best.

- ***Versatility.*** Can the model project outcomes for multiple variables (i.e., land use, transportation, employment, housing, and environmental)?

The versatility of a model refers to the model's ability to evaluate, integrate, and link multiple variables such as land use, transportation, employment, and housing. Consider versatility once it is clear how complex the proposal is that is being evaluated. Generally, the more versatile a model is, the more complicated it is. As a model becomes more complex, the data requirements and technical expertise needed to operate the model increase. When selecting a model, it is necessary to be aware of the types of issues that need to be evaluated and the cost-effectiveness of investing in a model that can evaluate multiple variables. When looking at the versatility of a model, it is important to consider two fundamental selection criteria: *relevancy* and *cost*.

- ***Linkage Potential.*** Can the model be linked to other models currently in use by, or of interest to, the community?

The linkage potential of a model refers to the ability of a model to join with other tools, including geographic information systems (GISs), other models, or presentation software. A model with high linkage potential is desirable, since it allows the user to connect the data outputs to other software that could help further analyze and/or present the information in a different or more useful way. To date, no single model exists that can perform all community planning functions; it is very likely that it will be necessary to link economic, transportation, and land use models together, then visualize the results by incorporating the output into a GIS.

- ***Public Accessibility.*** Can the model be run in an interactive public environment and display the results in a manner that is comprehensible to the general public?

A model is publicly accessible if it can be approached and understood by the general public. If data output is presented in an easy-to-comprehend manner, such as a graph or bar chart, the results can reach a wider audience. Using a model in a public forum or meeting to demonstrate the outcomes of different scenarios can be a powerful way to educate the public and generate support for a proposed policy or plan.

- ***Transferability.*** Can the model be applied to locations other than the one(s) for which it was developed?

A model may have been designed for a particular location, and therefore may require intensive efforts to adapt it for use in another. Site-specific information that may require modification includes land use, environmental, and economic policies; land-use categories; available data and resources; time periods; and spatial extent (e.g., regional, local, neighborhood). The type of information that can or must be changed will depend on the model, as will the level of effort necessary to make the changes, such as having to re-calibrate underlying statistical equations, change input parameters, and modify model assumptions. Such efforts can be costly due to the time and the technical expertise required for each adaptation. If resources are minimal, it is wise to select a model that can be easily transferred. For several land use models, the technical fact sheets in Appendix B provide details on the efforts (reflected in the pre-processing, calibration, assumptions, and setting parameters information) required for adaptation to a new locale.

- ***Third-Party Use.*** How extensively has this model been used in “real-world” situations?

Some land-use change models are under development, or have been used primarily in academic settings, while others have been used more extensively in community settings. A model used in a community setting, however, does not necessarily mean that the model is better than one with more limited use; one should carefully consider all the selection criteria to select the best model. Usually, it is best to select a model with a proven track record, especially if it has been used for communities having a similar size or similar situations. Also, if a model has been used extensively, there should be documented case studies about the efficacy of the model and opportunities to consult with end-users.

APPENDIX E 3 – SACOG FINAL MODEL DEVELOPMENT REPORT, 2001

Definition of Forecasting Model Options

Element	Options	Current	Options: New Standard	Enhanced	Advanced
Land Use Model					
Base year population					
	Track housing unit completions, apply vacancy rates.	x			
	Synthesized with Beckman procedure, resample PUMS to match aggregate zonal breakdown for income, household size, etc. Rule-based allocation to parcels/blockfaces		x	x	
	Synthesized as above, "Partial Equilibrium" with travel preferences – households are in locations that are appropriate for them based on their randomly generated sensitivities and preferences				x
Base year employment					
	Track job locations by situs address and SIC code.	x			
	Aggregate model of industrial activity, in categories of occupation and industry		x		
	Individual firm simulation, with specific characteristics for shipping, labour and customers			x	
	Individual firm simulation as above, with "Partial Equilibrium" so that individual firms are in desirable locations given their randomly selected characteristics				x
Shifts in population demographics over time					
	Allocate DOF population to minorzone. Rule-based cross-classifcation to persons, workers, income	x			
	Birth rates, death rates. Household dissolution and formation		x		
	Advanced tracking of socioeconomics (race, income, occupation)			x	x
Shifts in size/structure of economy over time					
	Current development trends + land use policy, bounded by housing unit growth.	x	x	?	
	Tied to changes in labour supply and the ability of the transportation and land-use system to serve the needs of various industries			?	
	Firm formation and dissolution, firm relocation				x
Labor market -- demand and supply					
	Regional employment parallels regional housing unit growth.	x			
	Zonal aggregate -- changes in employment conditions (salary, benefits, etc.) to match demand to supply in each zone		x		
	Model of occupation transition/skills upgrading based on labour market conditions; -- tied to individual households and impacting labour migration			x	x
Home relocation					
	N/A	x			
	Aggregate allocation of household categories to zones, with floorspace prices adjusted to clear market for residential space. Based on household categories (not individual household characteristics). Rule-based assignment to individual parcels/blockfaces re-performed in each time period		x		
	"Move" or "Stay" decision for each household based on household characteristics. Zone choice with rule-based assignment to parcels/blockfaces. External impacts (e.g. school quality, crime) on location choice			x	
	As above, but triggered by changes in household composition/jobs/income				
	As above, but simulation of search procedure (in place of zone choice with rule-based assignment)				x

Definition of Forecasting Model Options (continued)

Element	Options	Current	Options		
			New Standard	Enhanced	Advanced
Firm / establishment relocation					
	N/A	x			
	Aggregate allocation to zones, with floorspace prices adjusted to clear market. Based on categories. (Micro-level effects handled in development model.)		x		
	"Move" or "Stay" decision based on firm characteristics. Zonal choice with rule-based assignment to parcels/blockfaces re-performed in each time period			x	x
	As above, but simulation of search procedure (in place of zone choice with rule-based assignment)				
Floorspace prices					
	N/A	x			
	In equilibrium with floorspace demand by firms and households		x		
	Price adjustments by land-owners simulated dynamically based on vacancy rate and cost function			x	x
Development of floorspace					
	Implied development of acreage based on jobs/acre (see attached tables)	x			
	Aggregate zonal development based on floorspace prices. Allocation to individual parcels based on simple rules. Re-development/demolition included.		x		
	Simulation of individual developer behaviour for parcels/gridcells/linkfaces; with consideration of zonal floorspace prices and vacancy rates			x	
	Simulation of individual developer behaviour as above, with consideration of neighbouring parcels and direct simulation of land assembly. Consideration of Developer Permit procedures beyond just permitted uses and development impact fees – e.g. bureaucratic delay and special relaxations.				x
Shipment logistics					
	N/A	?			
	Trip based goods movement, with intermodal assignment		x		
	Simulation of individual shipments, and allocation of shipments to trucks nearby. Time-of-day choice responsive to travel conditions. Mode choice (i.e. truck type).			x	x

Definition of Forecasting Model Options (continued)

Element	Options	Current	Options		
			New Standard	Enhanced	Advanced
Travel Model					
Auto ownership					
	Zone-based	x			
	Cross-sectional vehicle holdings model. No logsum linkages		x		
	Cross-sectional vehicle holdings model with logsum linkages			x	
	Dynamic vehicle transactions and type choice models, including logsums				x
Tour/ trip generation					
	Trip-based. Limited use of accessibility variables	x			
	A simple day pattern model with a few tour purposes, no explicit household interactions, limited logsum feedback from lower level models		x		
	A more detailed day pattern model with more tour purposes and more logsum feedback from lower level models			x	
	A day pattern model with explicit interaction between choices made by various housheold members, more linkages to other models				x
Destination choice					
	Trip-based destination choice, integrated with mode choice model	x			
	Work and school locations already known (above generation models). Tour-based destination choice integrated with tour-based mode choice Separate intermediate stop location model, but with no logsums to upper levels.		x		
	Same as "basic", but with logsums from intermediate stop location up to destination and mode choice models			x	x
Mode choice					
	Trip-based, with no non-motorized modes.	x			
	Tour-based, including non-motorized modes - no mixed-mode tours (except P&R)		x		
	Both tour- and trip-based, including non-motorized modes, mixed modes			x	
	Same as "enhanced", with explicit model of parking choice				x
Time of day					
	Factoring for a few periods	x			
	Choice model for about 15 time period combinations. Limited logsum feedback from lower level models. Separate peak-spreading model within peaks		x	x	
	Use of more time time periods, and both choice and duration models. More extensive logsum feedback.				x
Level of spatial detail					
	All data at TAZ level	x	x		
	LOS at TAZ level, land use at block-face level			x	x
Network simulation/ route choice					
	Assignment in MINUTP	x			
	Assignment in TP+		x	x	x
	Network micro-simulation			x	x
	Micro-assignment respecting individual characteristics			?	x
Application framework					
	Zone-based enumeration, store by OD, mode, purpose, time of day	x			
	Person-based sample enumeration, full sample, simulate and store individual choices		x	x	x
External and special trips					
	Fixed matrices	x			
	Airport access model Inter-regional trips sensitive to growth in other areas		x	x	
	Airport access model Other regions included explicitly in location choices.				x

User Needs Evaluation of Forecasting Options

User Need	Current Tools	Forecast Model Options: New Standard	Forecast Model Options: Enhanced	Forecast Model Options: Advanced	Comments
Policy Relevant	○	◔	◒	◒	
Support the policy issues which the region is likely to face:					
Smart Growth strategies	○	◔	◒	●	Options including fine geographic detail, microsimulation of land use changes, and effects of mixed use, perform best (enhanced, advanced).
Pricing policies (e.g. toll roads, HOT lanes and parking)	◔	◒	◒	●	All options improve signifcantly, because person/household data retained in trips/tours.
ITS strategies (e.g. travel information, operations improvements, etc.)	○	◔	◔	◒	Traveler information not captured; traffic management captured with micro-simulation of assignment (advanced only). Other improvements based on better market segmentation.
"Non-traditional" transit modes (community-serving transit, BRT)	○	◔	◔	◔	Software limitations make this difficult at regional level. A "proxy" approach, at best, is possible.
Environmental justice and social equity issues	◔	◒	◒	●	Each option provides capabilities of tracking household and demographic data on trip makers to trips.
Capture important "secondary effects" of transportation projects and growth:					
Effects of transportation projects on land development	○	◒	◒	●	Land use/travel model integration necessary.
"Induced" or "suppressed" demand	◔	◒	◒	●	Time-of-travel choice, chaining of activities, land use dynamics needed to perform better.
Peak spreading or changing times of travel	○	◒	◒	●	Time-of-travel choice or duration of activity model needed to perform better than current tools.
The secondary effects of the built environment (i.e. urban design, density, mixed use, etc.) on travel behavior should be included in the model.	◔	◒	◒	●	Micro-simulation of land use and travel provides greatest capability (enhanced, advanced option).
The secondary effects of the transportation projects (i.e. roadway width, presence/absence of **sidewalks, inclusion/exclusion of bike lanes, etc.) on travel behavior should be included in the** model.	○	◔	◔	◒	Highly detailed network data and assignment needed to make more improvement.
Significant Upcoming Model Applications	◒	◒	◒	●	
Upcoming model applications using SACOG forecasting tools:					
"New Starts" applications for LRT	◔	◒	◒	●	All options include ground access to airport; advanced land use models can do a better job of land uses complementary to LRT service
MTP in 2005	◔	◒	◒	●	More advanced models are much more policy sensitive and faciliate a wider range of policy options in the MTP
SIP in 2003	◔	◒	◒	●	All options provide more time periods, with more detailed information on trips.
AQ conformity	●	●	●	●	All options will meet requirements (as do current tools).
Local agencies/other model users applications:					
EIR's/EIS's	◒	◒	●	●	All options capture joint effects of land use and travel changes. Tools/protocols for local users needed.
Traffic impact studies	◒	◒	◒	◒	Fine geographic (and network) detail provides better accuracy in representing projects. Tools/protocols for local users needed.
Specific/General Plans	◒	◒	◒	●	Full effects of land use and travel changes captured, including mixed use. Tools/protocols for local users needed.
Flexible	◒	◒	◒	◒	
Usable or adaptable for local and sub-regional studies by other agencies	◒	◒	◒	◒	Finer geographic detail, "trip diary" output provide flexibility; model complexity makes it potentially more difficult to use.
Fine level of detail, to allow for others to tailor it to their needs.	◔	◔	◒	◒	Enhanced, advanced models contain more detail on zones and networks.
Developed and maintained in a standardized, portable format.	◒	◒	◒	◒	Data in standard format or GIS makes it more portable; custom software may reduce portability and standardization.

● Fully addresses user need
◒ Partially addresses user need
◔ Minimally addresses user need
○ Does not address user need

User Needs Evaluation of Forecasting Options (cont.)

User Need	Current Tools	Forecast Model Options: New Standard	Forecast Model Options: Enhanced	Forecast Model Options: Advanced	Comments
Transparent	◔	◒	◒	◒	
Key input assumptions should be explicit, and subject to public review	◔	◒	◒	◒	Activity/tour approach more intuitive, but models themselves more complex and potentially harder to understand.
Comprehensive	○	◔	◒	◒	
Inter-regional and even international travel should be represented in some form	◔	◒	◒	◒	Basic, enhanced provide exogenous inter-regional demand; advanced provides inter-regional demand model.
Special emphasis on inter-regional rail.	○	◔	◔	◒	As above
Special emphasis on travel between region and the Bay Area.	○	◒	◒	◒	As above. Limited network expansion to Solano County assumed.
Commercial vehicle and truck travel should be represented in some form.	◔	◔	◒	◒	**Basic option as simple trip-based truck model. Enhanced, advanced include more dynamic input/output** approach.
Airport ground access should be included in the model.	○	◔	◒	◒	Required for any airport LRT extension, usable for all options.
The model should include some way of representing seasonal and recreational travel.	○	○	◔	◒	More time periods and multi-day travel in the advanced model
Model input and forecast data should include specification of significant land development information (agricultural quality, environmentally sensitive lands, etc.)	○	◔	◒	◒	More data on land variables needed. Improved developer modules do a better job of considering the impact of local physical conditions
Credible	◒	◒	◒	◒	
Validation—the model should predict known conditions	◒	◒	◒	◒	More advanced options have more flexibility, but are also more difficult to validate because of data limitations
Sensitivity tests—the model should provide reasonable results when key variables are changed	◒	◒	◒	●	More advanced options have more ways to respond to policy, and their mechanisms for responding to policy are more behavioural and believable
Are the input assumptions (fuel costs, forecasts, etc.) reasonable? Do they cross-check with other known sources?	◒	◒	◒	◒	More opportunity for inputing the "actual" numbers (rather than some composite surrogate) in the advanced models
Are known trends in demographics (aging, income, etc) reflected in forecasts?	◔	◔	◒	◒	All options provide greater detail in demographic forecasts, especially in household structure.
Key model output measures should be reasonable and understandable by non-technical persons	◔	◒	◒	◒	More detailed output for all options, but understandability depends on user familiarity and presentation.
Behaviorally Accurate	◔	◒	◒	●	
Model should correctly represent travel behavior by individuals, and include the major factors influencing travel behavior.	◔	◒	◒	●	More advanced options provide more sophistication and greater congruence with actual behavior and choices.
Model input data should include key variables affecting travel behavior (income, number of workers, number of autos, school age children, retired, etc.)	◔	◒	◒	●	All options require more detailed input data, provide more detailed forecast data.
Non-motorized modes (bike, walk) and "substitutes for travel" (work-at-home, e-commercer, telecommute) should be represented in the model	◔	◒	◒	●	Walk and bike included in basic option. Non-travel substitutes included in enhanced, advanced options.
Forecast data for the model should be market-based, and represent developer and firm behavior, in addition to general plans and public land use policy.	◔	◔	◒	●	Enhanced, advanced options include developer behaviour models.
Model should represent travel as it actually occurs (i.e. mixing modes and purposes, occurring at different times of day, etc.)	◔	◒	◒	●	All options based on tours or activities. More advanced options factor in both personal and household dynamics.
Scenario Testing	◔	◒	◒	◒	
Forecasting tools should be able to generate and test multiple scenarios built around key variables and assumptions	◔	◒	◒	◒	Key variables and assumptions are "levers" built directly into the advanced model, so they are much easier to change than in a less comprehensive framework'
Forecasting tools should take account of general trends (e.g. e-commerce, telecommuting, etc.) in reasonable ways	○	◔	◔	◒	Tricky in any model, but at least in the more advanced models we have more places to "fiddle"

● Fully addresses user need
◒ Partially addresses user need
◔ Minimally addresses user need
○ Does not address user need

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Resource Evaluation of Forecasting Options

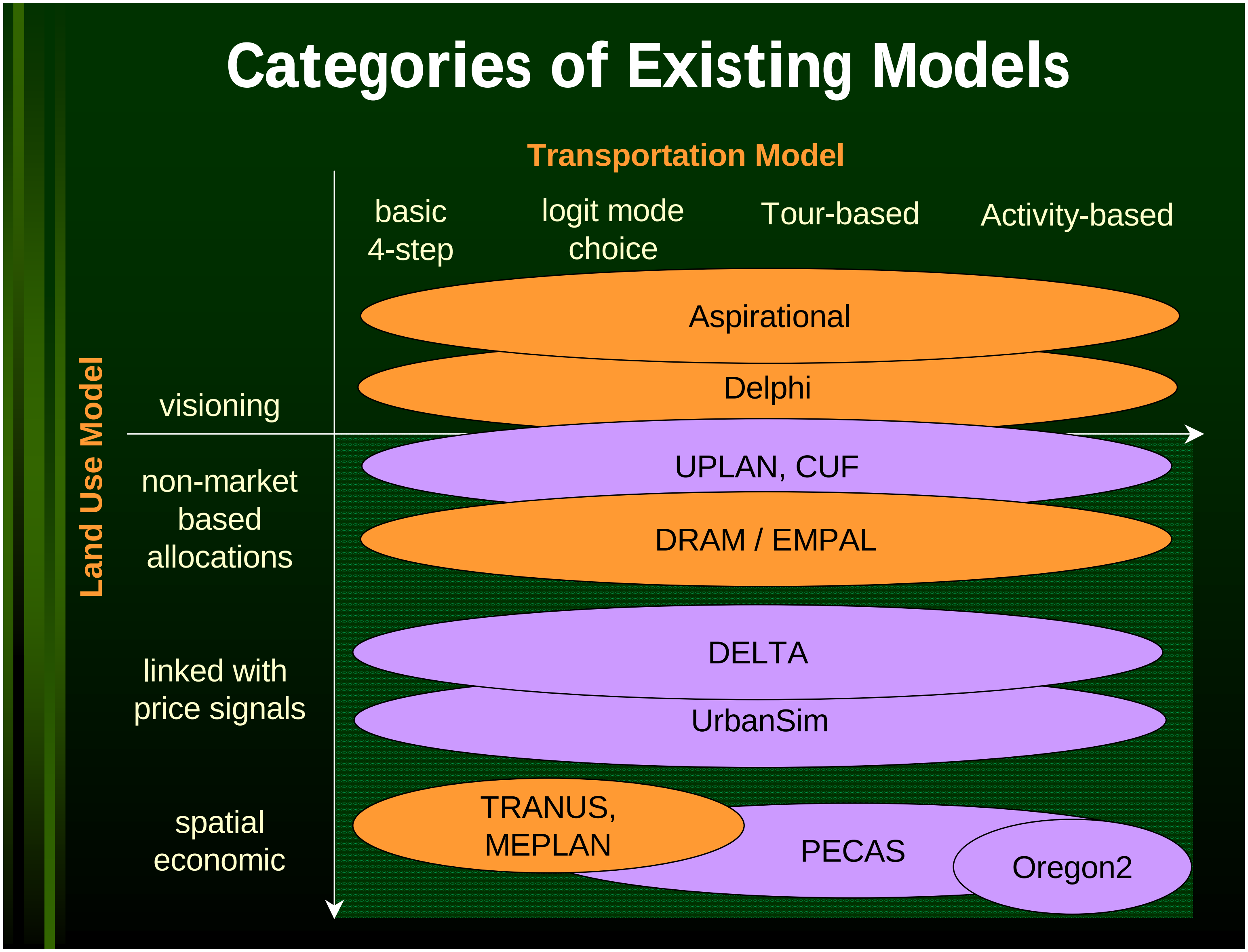
	Forecast Model Options		
Resource	**New Standard**	**Enhanced**	**Advanced**
Software Development/Acquisition			
Land Use Model	Some commercial software needed for land use/travel integration. Modification of SACOG's UPLAN for data preparation, management.	Modify software developed for ODOT statewide model.	Major enhancement of software developed for ODOT statewide model, plus develop software for some new elements.
Travel Model	Modify existing software (Portland, SF). Acquire commercial software for assignment.	Modify existing software (Portland, SF). Acquire commercial network microsimulation software.	Major enhancement of existing software (Portland, SF), and develop some new elements. Acquire commercial network microsimulation software.
Other	Link with Arcview needed	Link with arcview [4]	Link with arcview [4]
Data Requirements			
Land Use Model	Floorspace data by sector and land use zones needed.	Floorspace data same as "New Standard" but to smaller zones. Commodity price data needed. Panel survey for household change.	Need floorspace data for smaller zones (or parcels), plus commodity price data. Also, developer behavior survey
Travel Model	Airport ground access survey needed.	Same as "New Standard", but possibly finer zones.	Same as "Enhanced", but also nneed data on other issues- vehicle type choice and use, weekend travel, interregional travel. Additional stated-preference surveys.
Goods Movement	Truck cordon count, basic I/O table needed.	Same as "New Standard", but more detailed I/O data needed.	Same as enhanced, plus a shipper survey needed.
Other			
Staffing Requirements			
SACOG	Some new staff required.	Same as "New Standard", but staff will need training.	Same as "Enhanced", but staff will need training.
Other Model Users	Minimal orientation, training.	Minimal orientation, training.	Minimal orientation, training.
Development Cost			
Land Use Model	Medium	High	High, with some uncertainties
Travel Model	Medium	Medium	High, with some uncertainties
Other	Low	Low	Medim
Development Timeframe	**1-2 yrs**	**3-4 yrs**	**>4 yrs**
Land Use Model	Short	Middle	Uncertain
Travel Model	Short	Middle	Long

APPENDIX F – URBAN MODEL TYPES

Types of Urban Models

- Scenario testing GIS models with no rules (PLACES) (ArcView)
- Rule-based GIS scenario testing models (UPlan, WhatIf?)
- Statistical forecast models (regression on past data) (CLUE, SLEUTH, CUF II). Cellular automata models, included.
- Accessibility-based set of equations. “Lowry” models. Need travel model.
- Simple land use equilibration models (accessibility & past dev. rates) (DRAM/EMPAL, HLFM II+) (statistical, not economic) (need travel model)
- Aggregate (zonal) economic models (with floorspace prices) (MEPLAN) (need travel model). Many users, globally.
- Microsimulation economic models (UrbanSim, PECAS). Can be

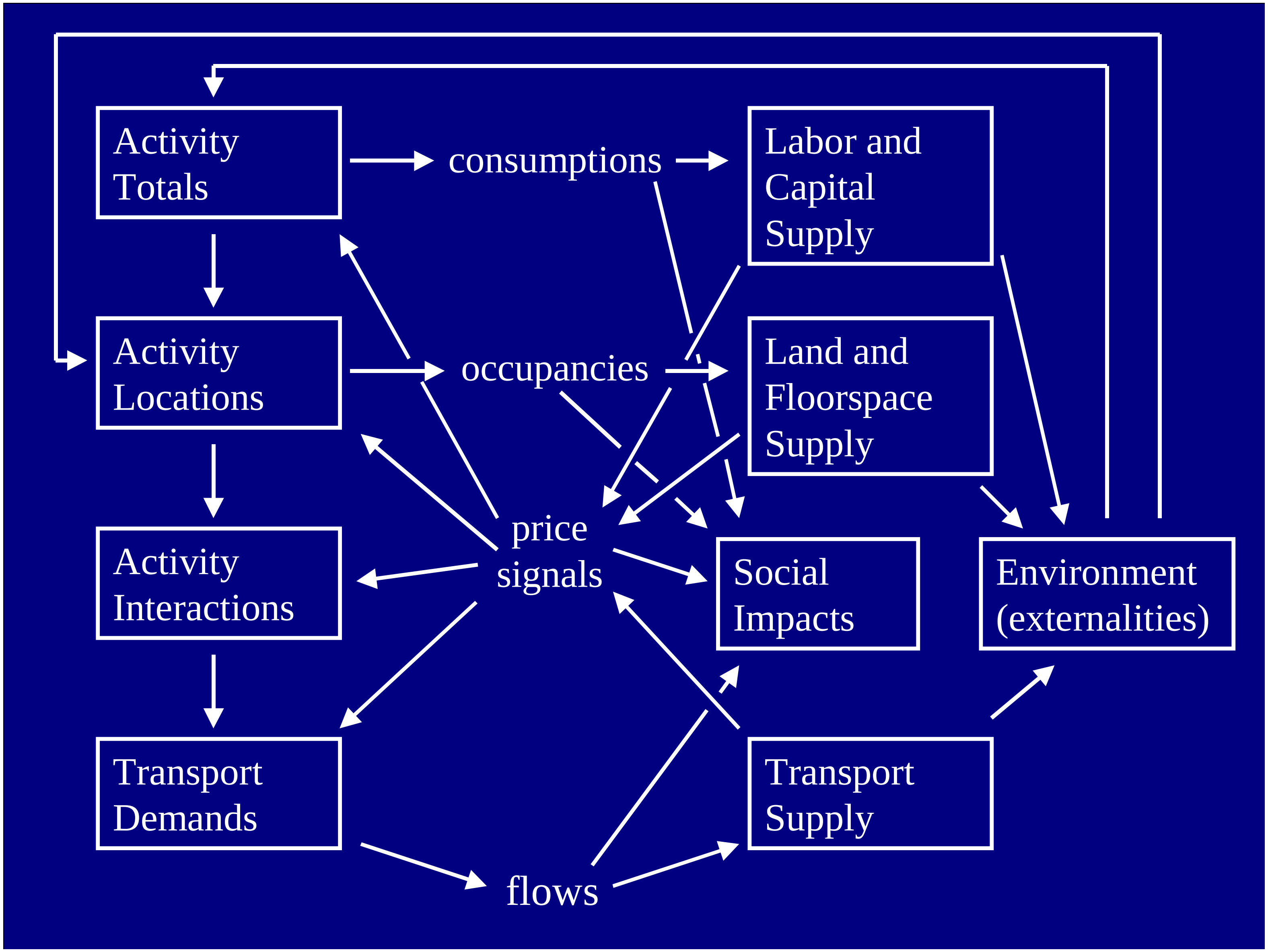
APPENDIX G – CATEGORIES OF EXISTING MODELS



APPENDIX H – PATHWAYS OF MODEL DEVELOPMENT

"SNAKES & LADDERS"		Travel Models						
Land Use Models		Trip-Based Models			Tour		Activity	
		Standard	Enhanced	Complex	Aggregate	Simulation	Aggregate	Simulation
Stand Alone	Factored							
	Judgement	Fresno San Joaquin			Boise New Hampshire			San Francisco County
	Policy+ Trends Allocation		**SACOG Travel Model 1996**	Edmonton				
Conn-ected	Rule-Based Allocation	Merced Co. UPlan	**SACOG Travel Model + PLACE S 2004**					
	Equilibrium Allocation (e.g. DRAM)	San Diego Puget Sound	Atlanta	Santiago Portland				
	Market-Based Allocation							Portland
Integ-rated	Aggregate Economic (Input/ Output)		**SACOG MEPLAN2 004**	London	**SACOG PECAS 2005**			Oregon Statewide 2004 **SACOG PECAS 2006**
	Disagg. Economic Microsim-ulation							

APPENDIX I- PECAS MODELING FUNCTIONS (FROM J. DOUGLAS HUNT)



Economic Interactions:
Production - Exchange - Consumption