Integrating Land Use, Transportation and Air Quality Modeling

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EPA STAR Project Objectives

From the RFA:

“How might models that project changes in land-use and activity locations be improved to better reflect and integrate lifestyle, economic production, and public policy factors that drive vehicle miles traveled? How might spatial redistribution of activities and changes in land-use influence investments in transportation infrastructure and technology? Conversely, how might investment choices in transportation infrastructure and technology influence changes in spatial distribution of activities and land-use change?”

Premises of this Project

1) Obtaining realistic predictions of travel and air quality outcomes from integrating models will require more than loosely coupling existing land use and transportation models. It will require fundamental integration at a behavioral level – otherwise, important patterns of behavioral substitution will be missed.

Premises of this Project

2) Behavioral integration can be most effectively pursued using a disaggregate approach that combines household long-term choices regarding residential location, workplace, and auto-ownership, with short-term choices of daily activity pattern, scheduling, mode and destination in an activity-based framework.

Behavioral and Operational Components

Behavioral

- Latent lifestyle choices
- Substitution across long and short-term choices
- Endogeneity and self-selection issues
- Econometric estimation methods

Operational

- Integration of activity-based models with urban simulation models of land use
- Integration with traffic assignment models
- Integration with current and emerging emissions models
- Testing of integrated platform on alternative scenarios

Key Behavioral Hypotheses

- Household residence location choices are interdependent with the workplace choices of household workers.

- Household residence location choices are interdependent with vehicle ownership.

- Expectations of daily travel patterns influence longer-term choices of residence, workplace and auto-ownership, and these longer-term choices condition daily activity scheduling and travel.

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Key Behavioral Hypotheses

- Treating long-term household choices and short-term activity and travel behavior in an integrated way can be facilitated by representing these choices as dimensions of a latent lifestyle choice.

- An integrated approach to modeling household lifestyle choices (residence, workplace, auto ownership, and daily activity and travel patterns) can produce more realistic substitution patterns, and ultimately better predictions of VMT and other factors that directly influence emissions.

Key Behavioral Hypotheses

- An accurate knowledge of spatial cognitive maps of decision makers in residential choice models will allow for a more realistic representation of perceived neighborhoods and the appropriate consideration of the spatial extent of choice factors impacting residential location choice.

- Careful representation of the endogeneity produced by interactions or aggregation of individual choices is critical to the ability of disaggregate behavioral models to produce plausible aggregate sensitivity and substitution patterns.

Selected Research Publications
(all of the publications on the following slides site the EPA Grant)

Behavioral Integration and Econometric Methods

Waddell, P., C. Bhat, N. Eluru, L. Wang, R. Pendyala (2007) Modeling the Interdependence in Household Residence and Workplace Choices. *Transportation Research Record* Vol. 2003 (84-92).

de Palma, A., N. Picard, P. Waddell (2007) Discrete Choice Models with Capacity Constraints: An Empirical Analysis of the Housing Market of the Greater Paris Region. *Journal of Urban Economics Vol.* 62 (204-230).

Kim, H., Waddell, P., V. Shankar and G.F. Ulfarsson, (2008) Modeling Micro-Spatial Employment Location Patterns: A Comparison of Count and Choice Approaches. *Geographical Analysis* 40, (123-151).

Pinjari, A.R., R.M. Pendyala, C.R. Bhat, and P.A. Waddell, "Modeling the Choice Continuum: An Integrated Model of Residential Location, Auto Ownership, Bicycle Ownership, and Commute Tour Mode Choice Decisions," Technical paper, Department of Civil, Architectural & Environmental Engineering, The University of Texas at Austin, August 2007.

Selected Research Publications

Behavioral Integration and Econometric Methods

Pinjari, A.R., C.R. Bhat, and D.A. Hensher, "Residential Self-Selection Effects in an Activity Time-use Behavior Model," Technical paper, Department of Civil, Architectural & Environmental Engineering, The University of Texas at Austin, August 2007.

Bhat, C.R., and N. Eluru, "A Copula-Based Approach to Accommodate Residential Self-Selection Effects in Travel Behavior Modeling," Technical Paper, Department of Civil, Architectural & Environmental Engineering, The University of Texas at Austin, June 2008.

Bhat, C.R., and I.N. Sener, "A Copula-Based Closed-Form Binary Logit Choice Model for Accommodating Spatial Correlation Across Observational Units," Technical paper, Department of Civil, Architectural & Environmental Engineering, The University of Texas at Austin, June 2008.

Selected Research Publications

Behavioral Integration and Econometric Methods

Sener, I.N., R.M. Pendyala, and C.R. Bhat, "Accommodating Spatial Correlation Across Choice Alternatives in Discrete Choice Models: An Application to Modeling Residential Location Choice Behavior ," Technical paper, Department of Civil, Architectural & Environmental Engineering, The University of Texas at Austin, July 2008.

Eluru, N., I.N. Sener, C.R. Bhat, R.M. Pendyala, and K.W. Axhausen, "Understanding Residential Mobility: A Joint Model of the Reason for Residential Relocation and Stay Duration," Technical paper, Department of Civil, Architectural & Environmental Engineering, The University of Texas at Austin, August 2008.

Pinjari, A.R., N. Eluru, C.R. Bhat, R.M. Pendyala, and E. Spissu, "A Joint Model of Residential Neighborhood Type Choice and Bicycle Ownership: Accounting for Self-Selection and Unobserved Heterogeneity," forthcoming, *Transportation Research Record*.

Selected Research Publications

Behavioral Integration and Econometric Methods

Pinjari, Abdul, Ram Pendyala, Chandra Bhat, P. Waddell (2007) Modeling Residential Sorting Effects to Understand the Impact of the Built Environment on Commute Mode Choice. *Transportation* Vol 34, No. 5 (557-573).

Assessing Uncertainty

Sevcikova, H., A. Raftery and P. Waddell (2007) Assessing Uncertainty in Urban Simulations Using Bayesian Melding. *Transportation Research Part B: Methodology* Vol. 41, No. 6 (652-659).

Selected Research Publications

Integrated Land Use and Transportation Model Applications

San Francisco, Salt Lake City, Paris, Detroit

Waddell, P., L. Wang and B. Charlton (2007) Integration of a Parcel-Level Land Use Model and an Activity-Based Travel Model. *World Conference on Transport Research*, Berkeley, CA. , June 2007.

Waddell, P., G.F. Ulfarsson, J. Franklin and J. Lobb, (2007) Incorporating Land Use in Metropolitan Transportation Planning, *Transportation Research Part A: Policy and Practice* Vol. 41 (382-410).

de Palma, A., K. Motamedi, N. Picard, P. Waddell (2007) Accessibility and Environmental Quality: Inequality in the Paris Housing Market. *European Transport* No. 36, (47-64).

Waddell, Paul, Liming Wang and Xuan Liu (forthcoming) UrbanSim: An Evolving Planning Support System for Evolving Communities. Richard Brail, Editor. Lincoln Institute for Land Policy.

Selected Research Publications

Public Participation

Borning, Alan, Paul Waddell and Ruth Förster (forthcoming) UrbanSim: Using Simulation to Inform Public Deliberation and Decision-Making. In *Digital Government: Advanced Research and Case Studies*. Hsinchun Chen, Lawrence Brandt, Sharon Dawes, Valerie Gregg, Eduard Hovy, Ann Macintosh, Roland Traunmüller, and Catherine A. Larson, Eds. Springer.

Visualization

Aliaga, Daniel, Carlos Vanegas, Bedrich Benes, Paul Waddell. (forthcoming) Inferring Aerial Views for the Visualization of Simulated Urban Spaces. *IEEE Transactions on Visualization & Computer Graphics*.

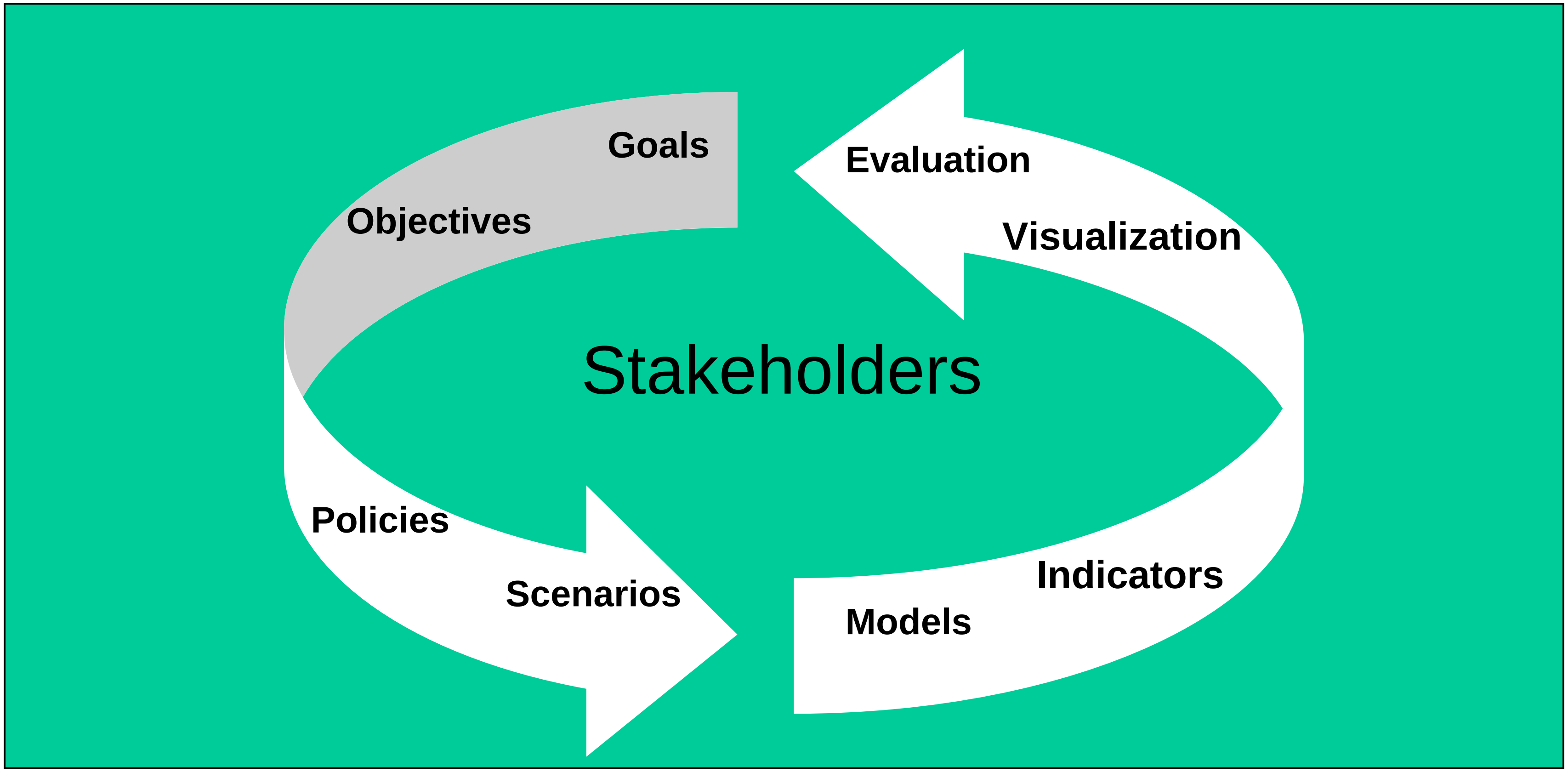
Moving the Research into Practice in the Puget Sound Region

Puget Sound Regional Council

A special acknowledgement to

Maren Outwater and others at the PSRC for their close collaboration on this work

Proposed Role of Models in Planning



Why do we need integrated disaggregate models?

New Policies in VISION 2040

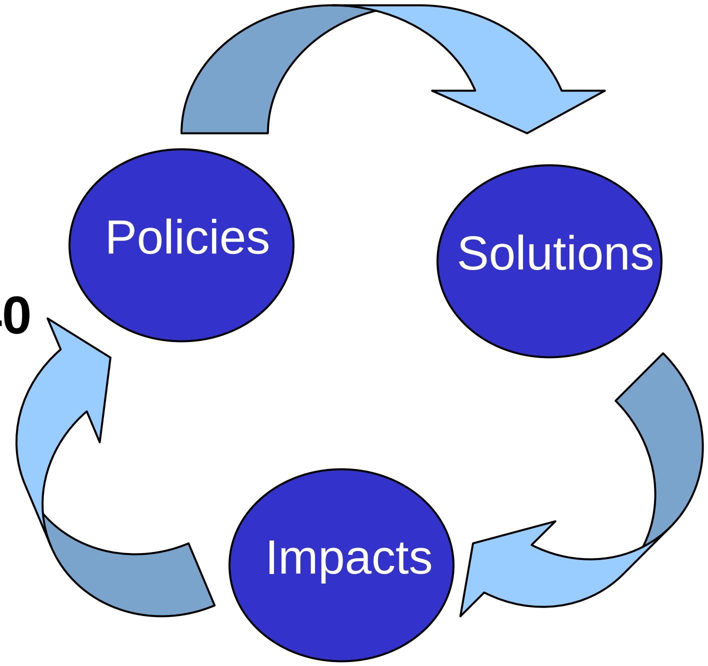
- Environment
- Economy
- Development Patterns
- Public Services
- Transportation
- Housing

New Solutions in Transportation 2040

- Demand Management
- Operational Solutions
- Tolling/pricing

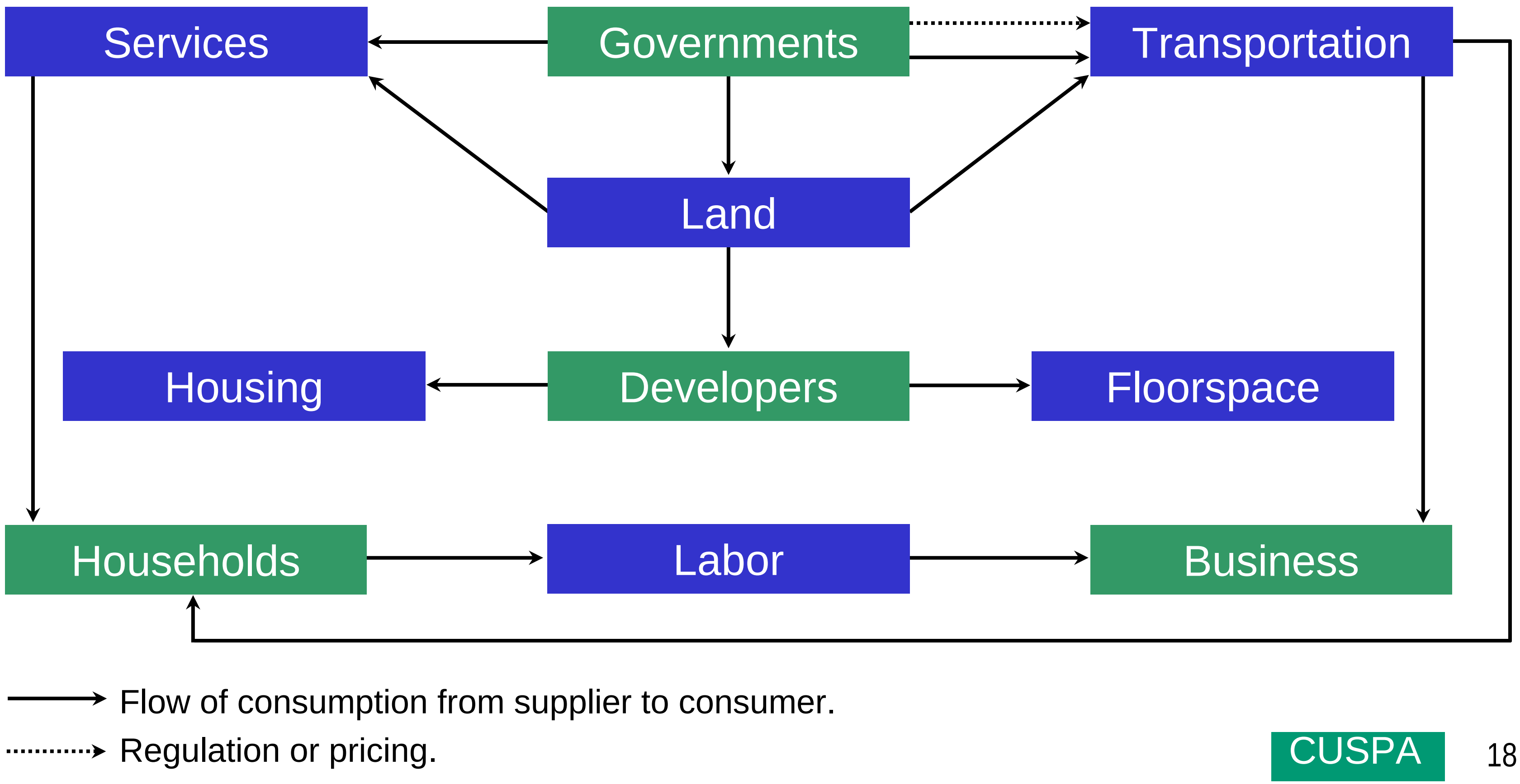
New Impacts to be Measured

- Transportation Efficiency
- Growth Management
- Economic Prosperity
- Environmental Stewardship
- Quality of Life
- Equity



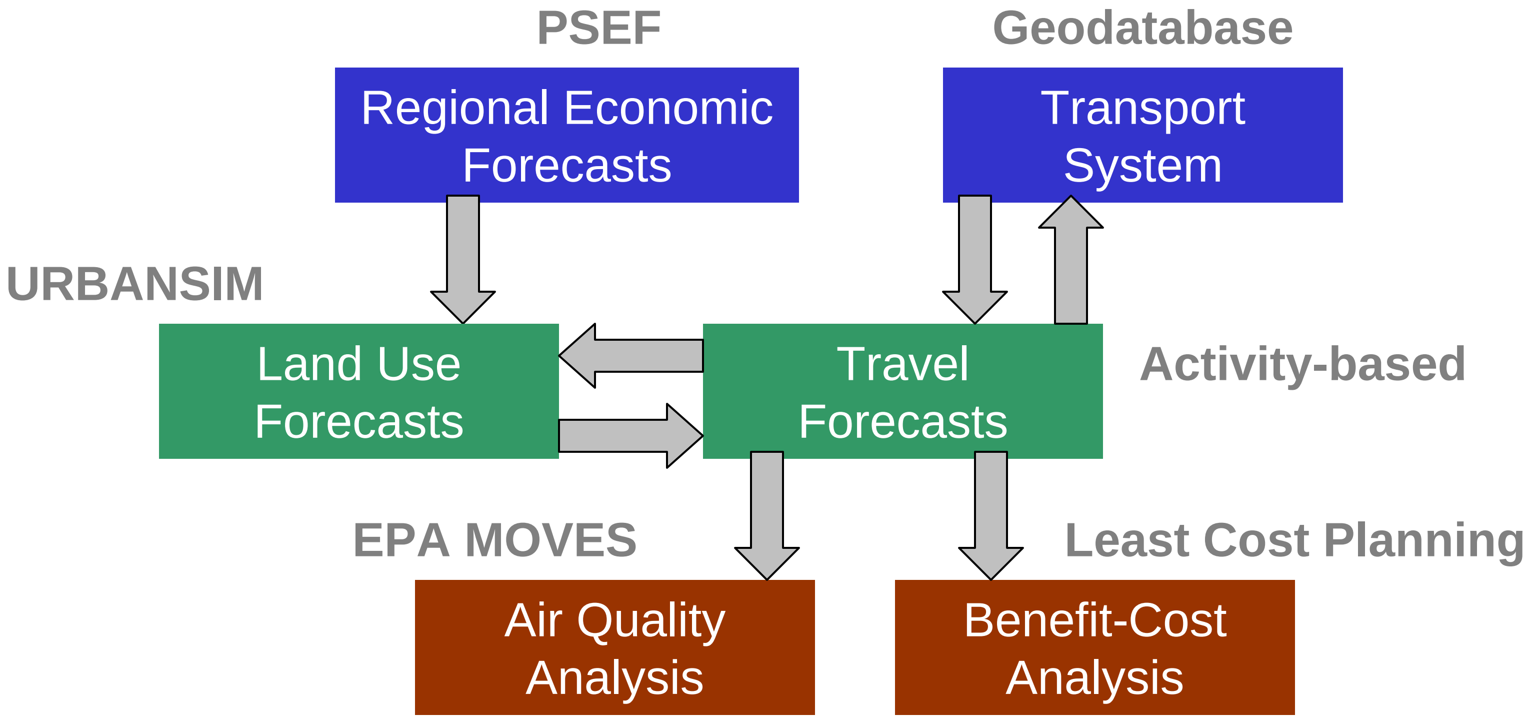
What Is UrbanSim?

Urbansim is an integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy.



PSRC Integrated Model System Design

Simulates persons and households at a parcel level



Why the move to UrbanSim

Current models (DRAM/EMPAL) restricted in using plans as inputs

- Plans need detailed measures of land
- Requires density limitations in Urban Growth Area
- Limited feedback with the travel models

Expanded and more flexible forecast output

- Can fit forecasts to different geographies
- Annual forecasts instead of 10-year increments
- Greater forecast detail (households, jobs, built data, market values)

Micro-simulation supports next generation of travel demand models

- Modeling individual households and persons, activities instead of trips

Open-source, collaborative approach

- Created at UW, other MPOs implementing and researching improvements

Why the move to Activity Models

Current models (trip-based) do not represent transportation strategies well

- Demand management strategies need linked activities (tours)
- System management strategies need vehicle simulations
- Tolilng strategies require distributed values of time

Expanded and more flexible forecast output

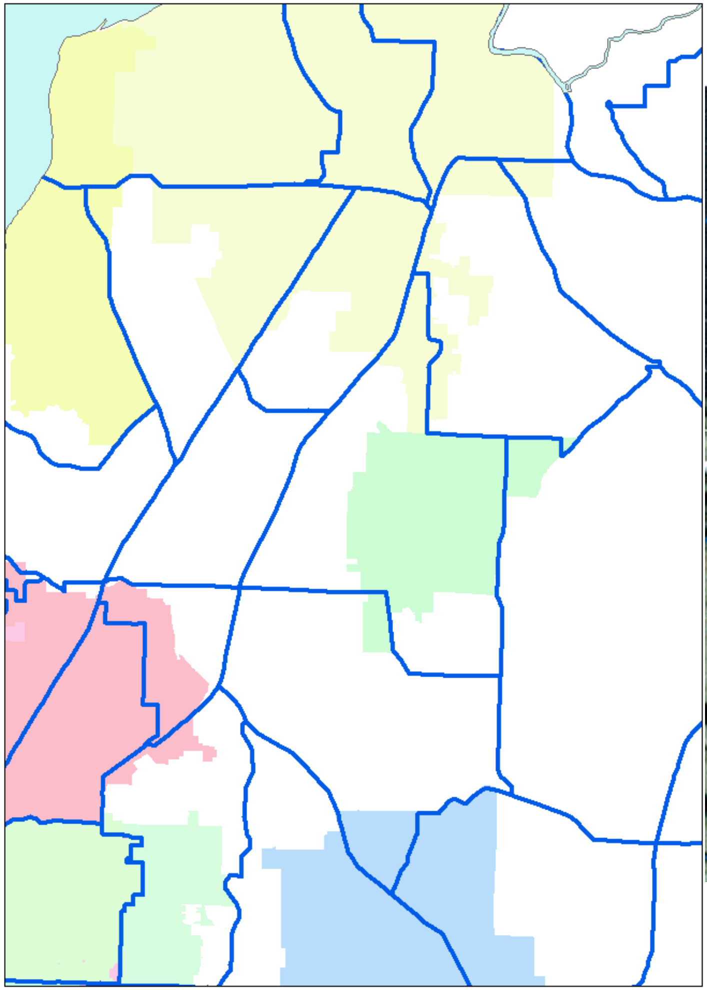
- Can distribute benefits and costs for equity analysis
- Greater forecast detail (trips, tours, stops, temporal and spatial detail)

Micro-simulation supports next generation of operational models

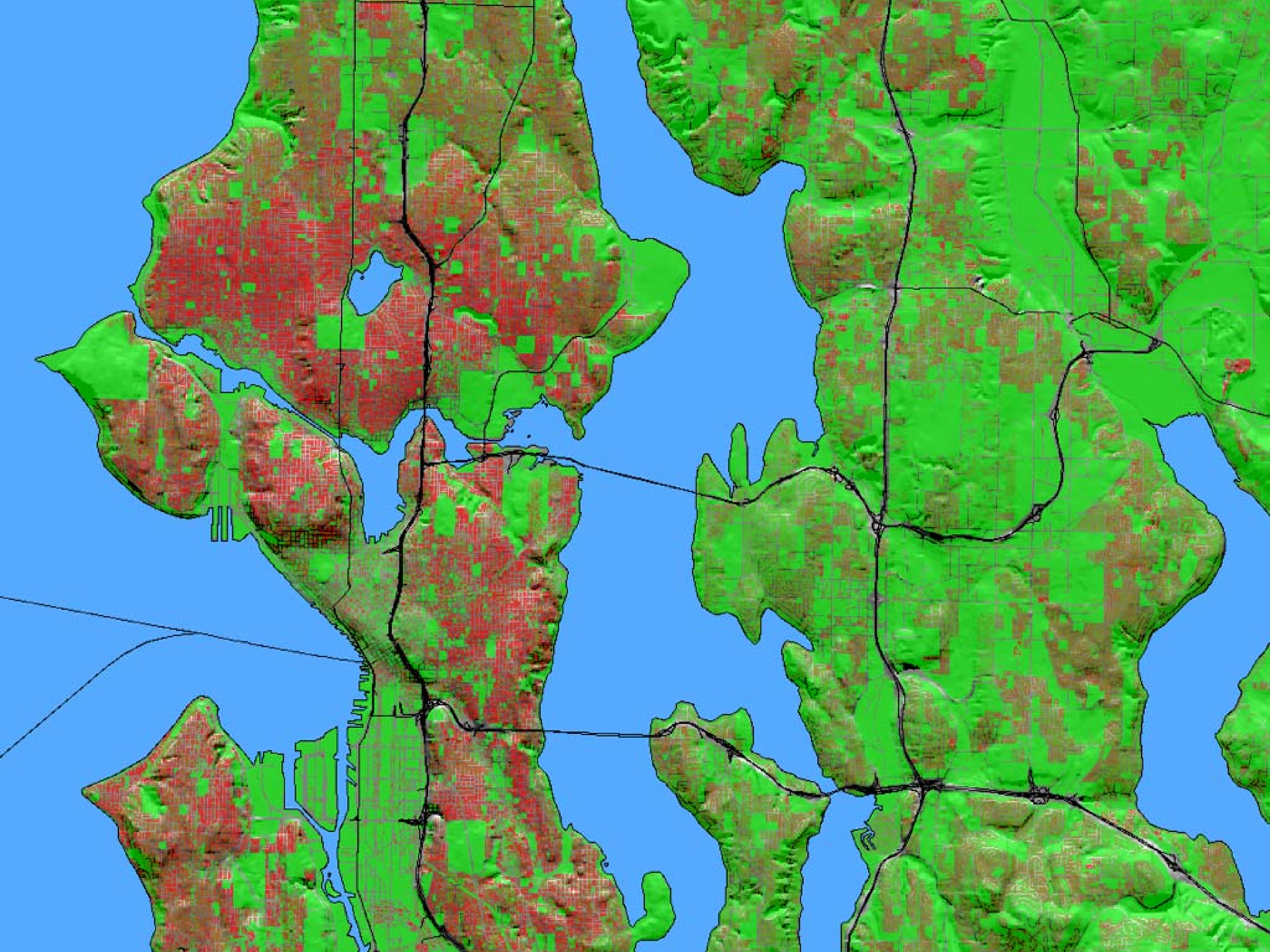
- Modeling individual vehicles for operational and air quality analysis

UrbanSim Geography

DRAM / EMPAL: Forecast Zones

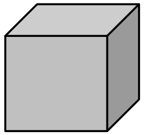
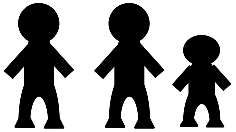
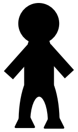


UrbanSim: Individual Parcels or Gridcells



Primary UrbanSim Databases

Five primary inputs and outputs

Parcels	Buildings	Households	Persons	Jobs
				
Parcel id	Building id	Household id	Person id	Job id
Zones, cities, zip code, etc.	Parcel id	Building id	Household id / Job id (if worker)	Building id
1.18 million parcels	1.0 million buildings	1.28 million households	3.2 million people	1.85 million jobs

UrbanSim Models

Land Development Models

- Process Pipeline Events
- Real Estate Price Model
- Expected Sale Price Model
- Development Proposal Choice Model
- Building Construction Model

Household Location Models

- Household Transition Model
- Household Relocation Model
- Household Location Choice Model

Employment Location Models

- Employment Transition Model
- Employment Relocation Model
- Employment Location Choice Model

Workplace Location Models

- Economic Transition Model
- Home-based Job Choice Model
- Workplace Location Choice Model
- Job Change Model

Scenario and Alternative Analysis

Land use plan assumptions:

- Type of development (residential, commercial,…) and density

Transportation system:

- Accessibility measures from zone to zone, jobs 10-30 minute travel times

Critical area buffers:

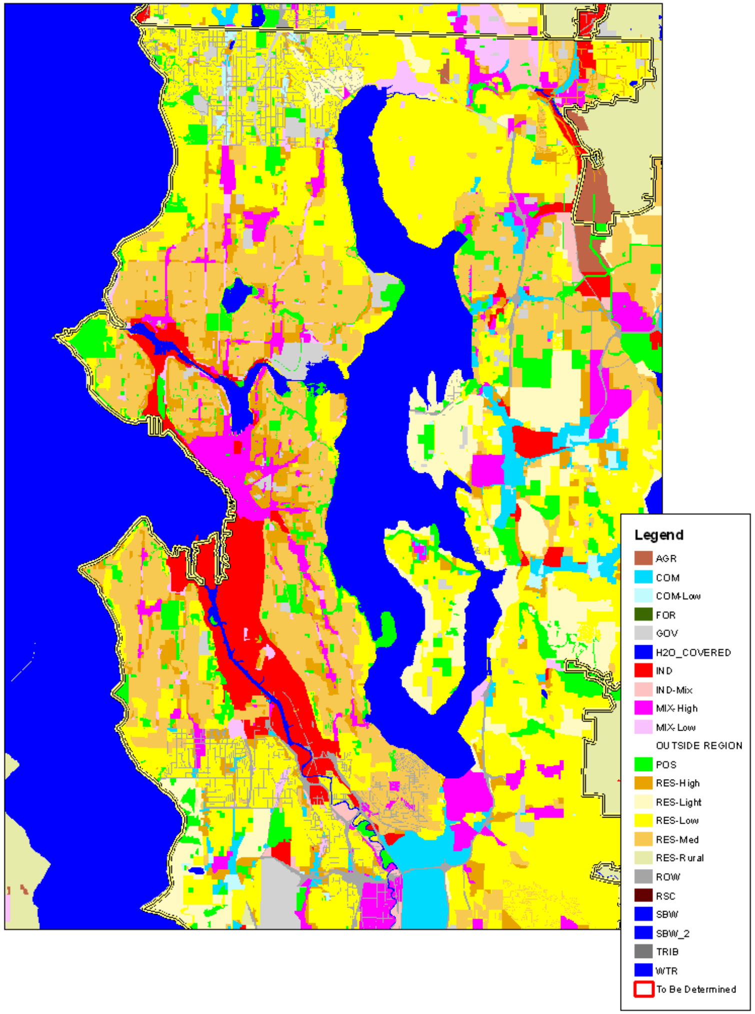
- Restrictions on parcels near streams, wetlands, slopes, shorelines, floodplains, etc.

Planned / Pipeline Developments:

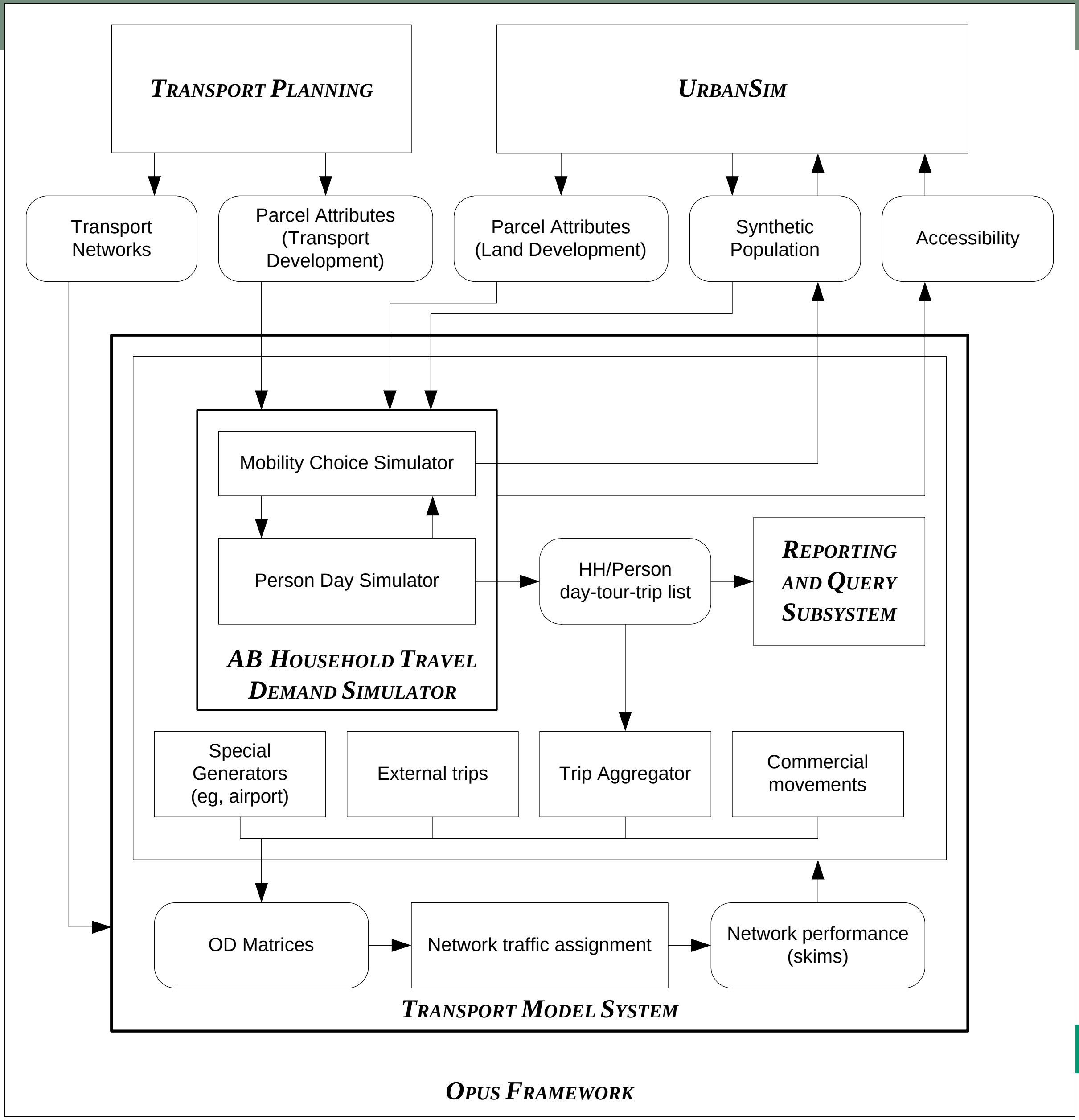
- Predetermine number of housing units, non-residential SQFT on parcels, year

Costs factors:

- Land development variables



Model Design for Integrated Activity Models



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Incremental Approach to Implementation of Activity Models

Develop activity generator

- Assess changes in trip-making from tolling and growth management strategies
- Assess impacts on climate change and transportation efficiency

Link with current trip-based models

- Necessary to use in current transportation plan update
- Validation of activity generator with current models

Complete remaining activity model components

- Destination choice
- Mode choice
- Time of day

Implementation Timeline

Rest of 2008

April	May	June	July	Aug	Sept	Oct	Nov	Dec

Urbansim Validation and Testing

Ongoing Refinements

Model Regional Growth Strategy

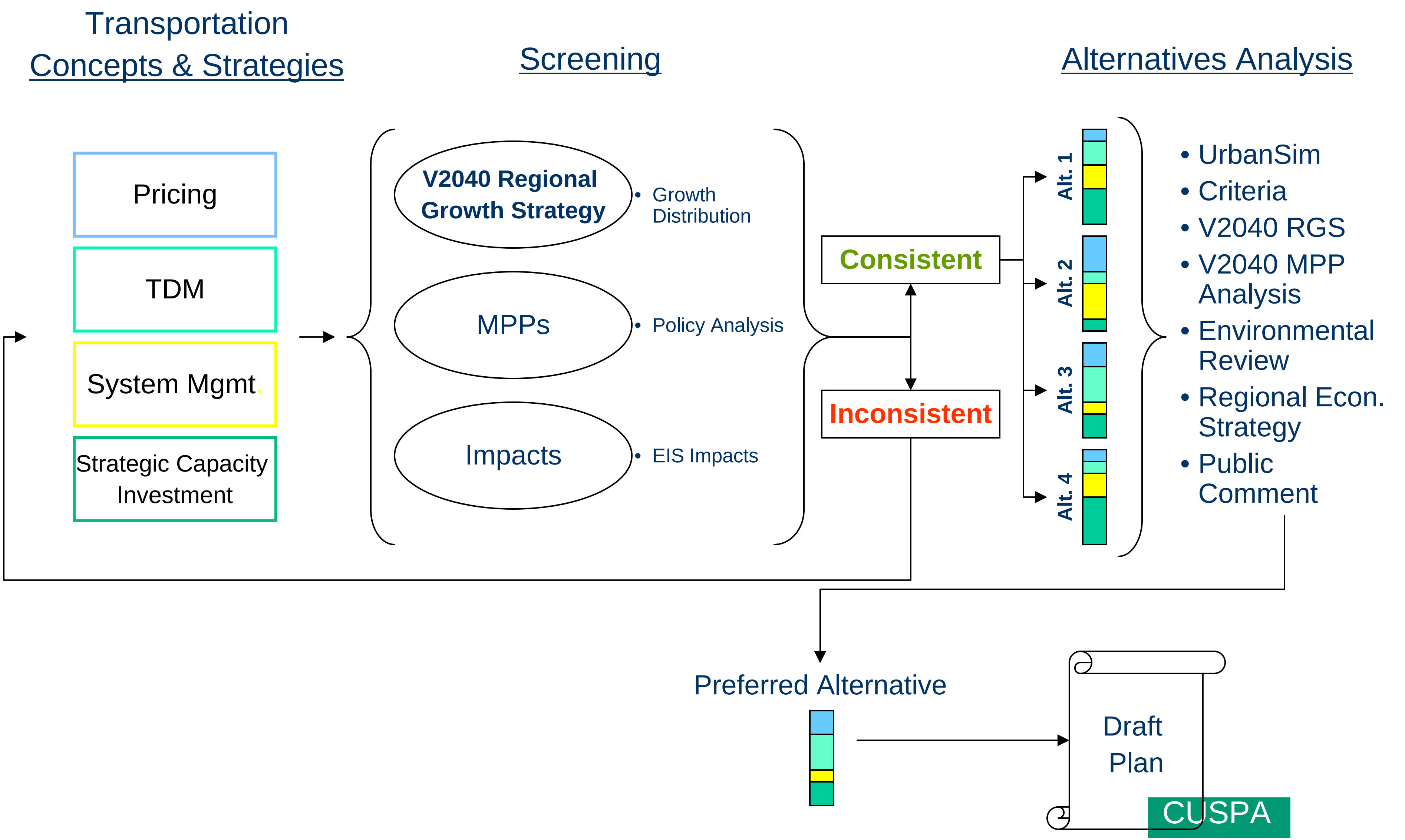
Activity Generator Development and Calibration

Apply in Transportation 2040 Analysis (into 2009)

Activity Model Design

Activity Model Development (into 2009)

Destination 2030 Update and Regional Growth Strategy



Refinements in UrbanSim and OPUS to Support Integration with Activity-based Models

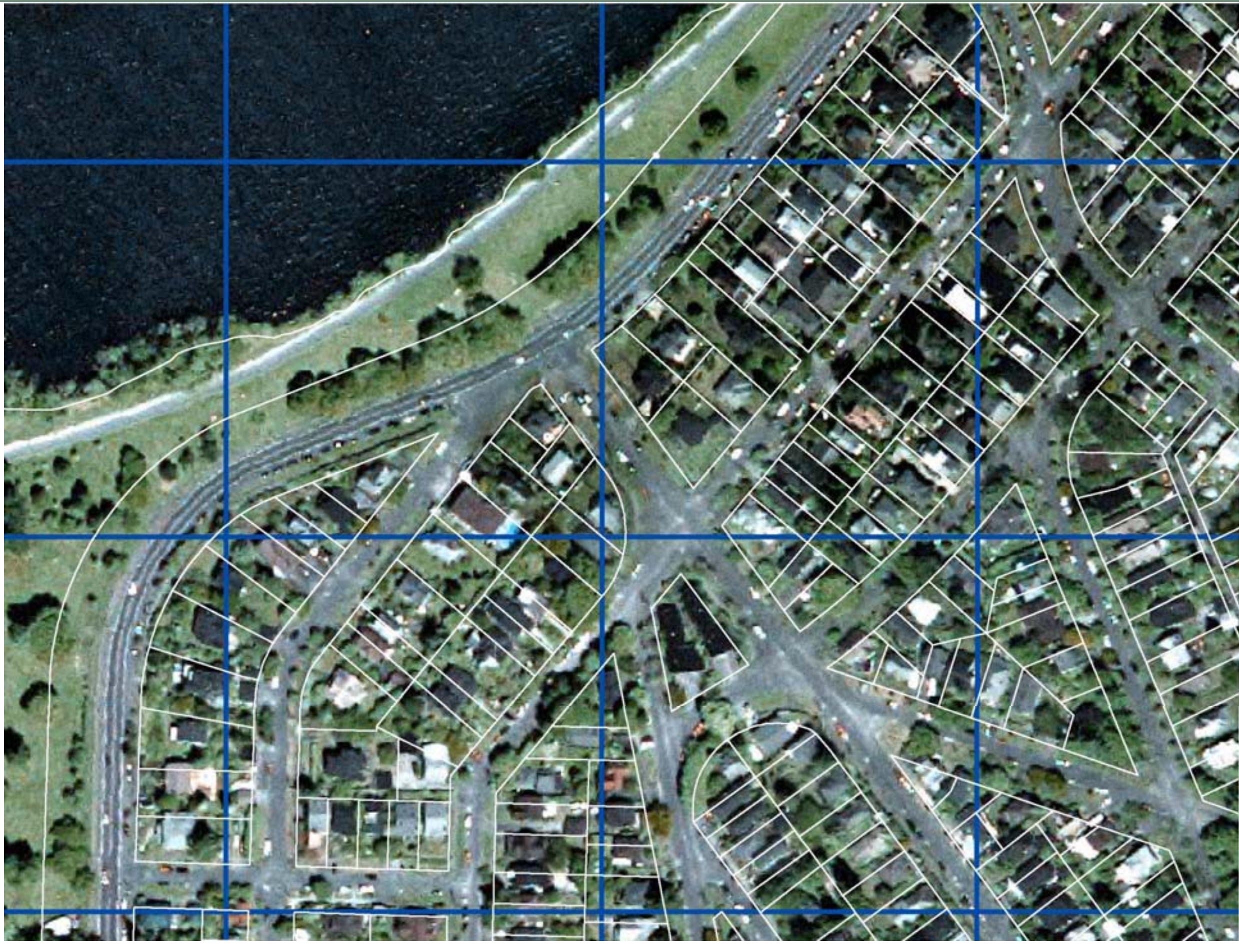
- **Flexible Geography and Data Structures**
  - Shift to parcel and building level of detail
- **New and Significantly Modified Models**
  - Residential Location
  - Workplace Choice
  - Real Estate Development
- **Assessing Uncertainty**
  - Bayesian Melding
  - Current testing on Alaskan Way Viaduct project
- **Visualization**

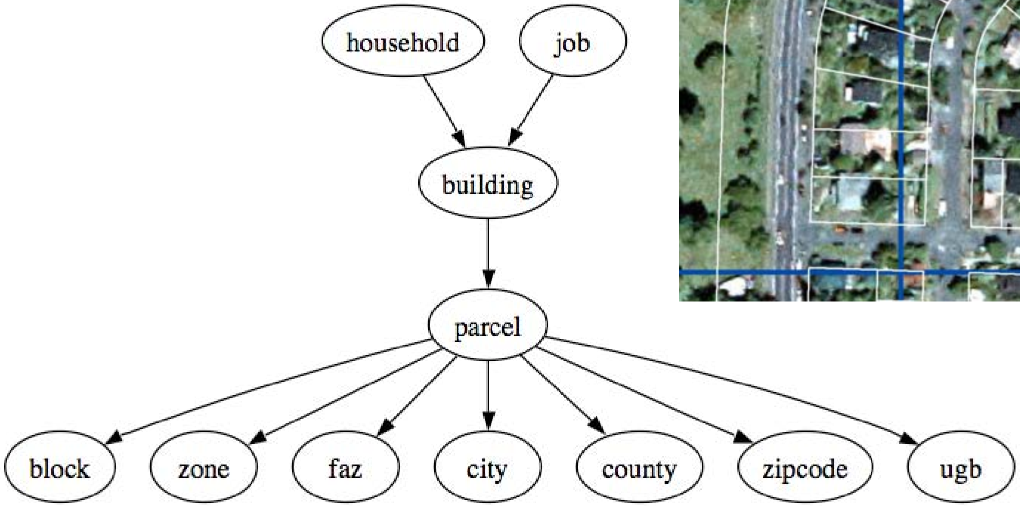
Creating New Models in OPUS

- **Models can be implemented in the new GUI**
  - Most models can be implemented from Model Templates
  - When using templates, no coding required
  - Model specification and estimation is interactive
  - Drop a new model into a model list, and run!

- **Model Templates:**
  - Simple Model
  - Allocation Model
  - Regression Model
  - Choice Model
  - Agent Location Choice Model

New Model System Based on Parcels and Buildings





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Advantages of Parcel Geography

- **Parcels are clear behavioral units**
- **Parcels reflect original data sources**
- **Buildings map to parcels directly**
- **Land use regulations apply to parcels directly**
- **Parcels aggregate cleanly to other geographies**
- **Easier to interpret and diagnose models**

Disadvantages of Parcel Geography

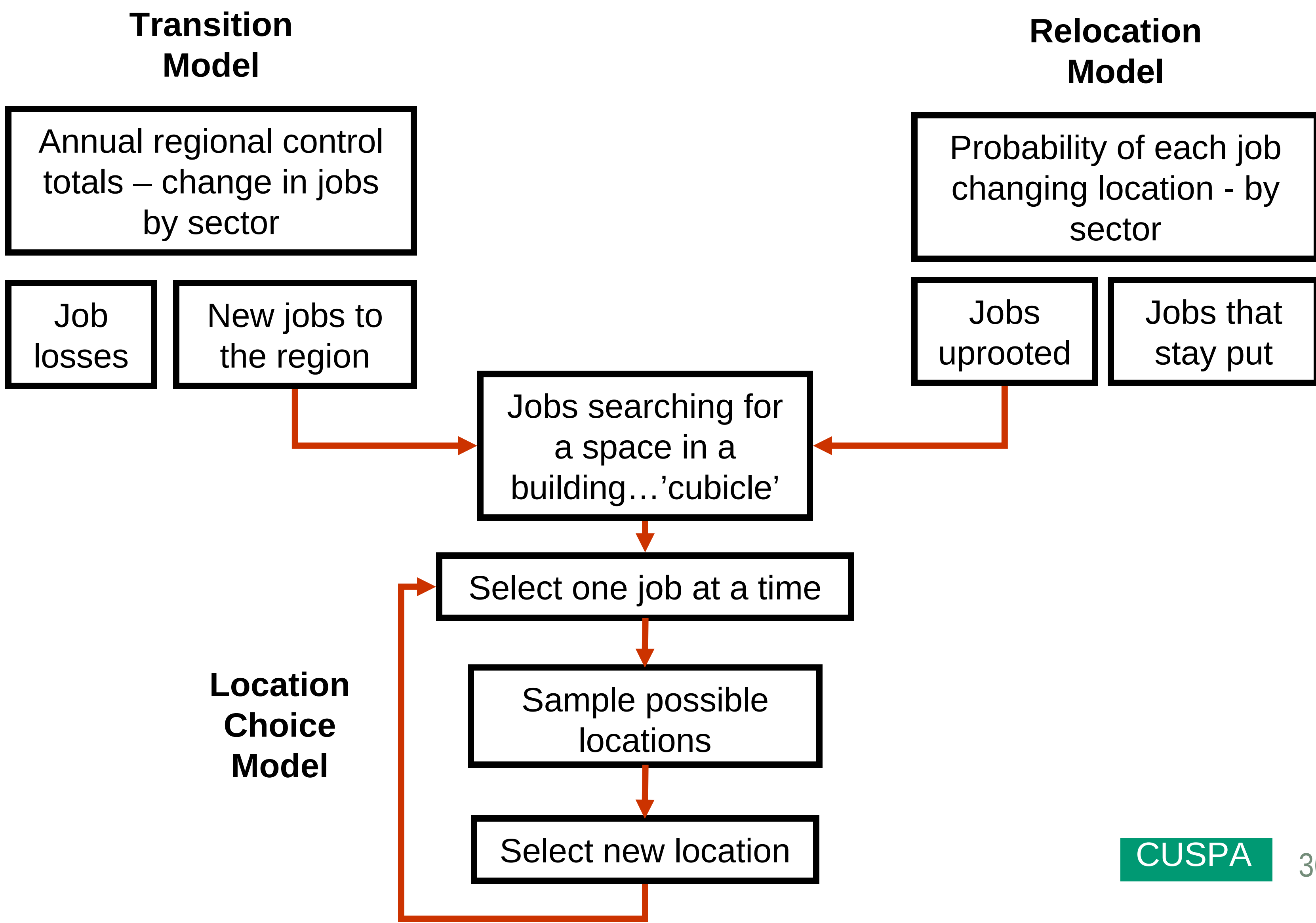
- **Variable size and shape**
  - Mitigate initially by using centroids for spatial calculations

- **Boundaries change over time**
  - Working on geometric subdivision and aggregation (demo later in presentation)

  - In the mean time, subdivide parcels but new sub-parcels share original centroid

Household and Employment Location Models

Using Employment as the example



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Advances in Household Location Choice Using Time-Space Prism Accessibility

	Base Model		Accessibility Models							
			General		Neighborhood		Workplace		Work-to-home	
Variables	coeff.	t-val.	coeff.	t-val.	coeff.	t-val.	coeff.	t-val.	coeff.	t-val.
residential_units	0.688	17.3	0.665	17.2	0.695	18.3	0.696	17.6	0.679	17.0
same_area_type	0.399	4.10	0.371	3.70	0.370	3.62	0.340	3.20	0.368	3.66
same_area	2.64	28.0	2.68	26.8	2.68	26.0	2.70	26.0	2.72	26.5
high_inc_x_size	0.981	11.4	0.829	10.1	0.972	11.5	1.03	12.3	0.935	11.2
mid_inc_x_size	-0.324	-8.30	-0.315	-8.20	-0.326	-7.89	-0.296	-7.65	-0.349	-8.22
low_inc_x_size	-0.287	-4.86	-0.224	-4.19	-0.267	-4.41	-0.315	-5.05	-0.301	-4.93
mid_inc_x_dispos_inc	0.0859	3.27	0.0822	3.16	0.0724	2.78	0.0803	3.03	0.0762	2.93
low_inc_x_dispos_inc	0.0771	2.45	0.0808	2.50	0.0728	2.23	0.0720	2.38	0.0666	2.12
inc_x_condo	0.0515	2.82	0.0582	3.17	0.0416	2.37	0.0486	2.75	0.0541	2.98
inc_x_MFR	-0.127	-6.64	-0.114	-5.81	-0.136	-7.27	-0.135	-7.12	-0.143	-7.27
inc_x_unit_price	0.00606	2.02	0.00738	2.45	0.00696	2.14	0.00727	2.28	0.00715	2.27
kids_x_SFR	0.647	3.18	0.620	3.02	0.555	2.73	0.613	3.03	0.455	2.15
kids_x_kids_HH	0.0155	3.33	0.0143	3.19	0.0201	4.09	0.0183	3.70	0.0199	3.95
one_pers_x_not_SFR	0.696	4.31	0.587	3.48	0.656	4.06	0.620	3.80	0.718	4.27
renter_x_is_MFR	2.90	14.7	2.99	14.8	2.92	15.0	3.07	15.5	3.09	14.9
young_x_young_HH	0.0233	5.73	0.0155	3.80	0.0189	4.47	0.0187	4.36	0.0200	4.58
Accessibility variables										
gen_cost_CBD			-0.0209	-7.23	-0.0215	-7.41	-0.0189	-6.43	-0.0193	-6.45
Neigh_shopping					0.0330	2.12	0.0372	2.41	0.0326	2.05
work_travel_time							-0.00949	-4.25	-0.00827	-3.62
Work_to_home_shopping									0.284	2.75
Log-likelihood	-3997.1		-3964.4		-3953.0		-3950.1		-3925.7	
Likelihood ratio	0.29922		0.30496		0.30695		0.30746		0.31174	

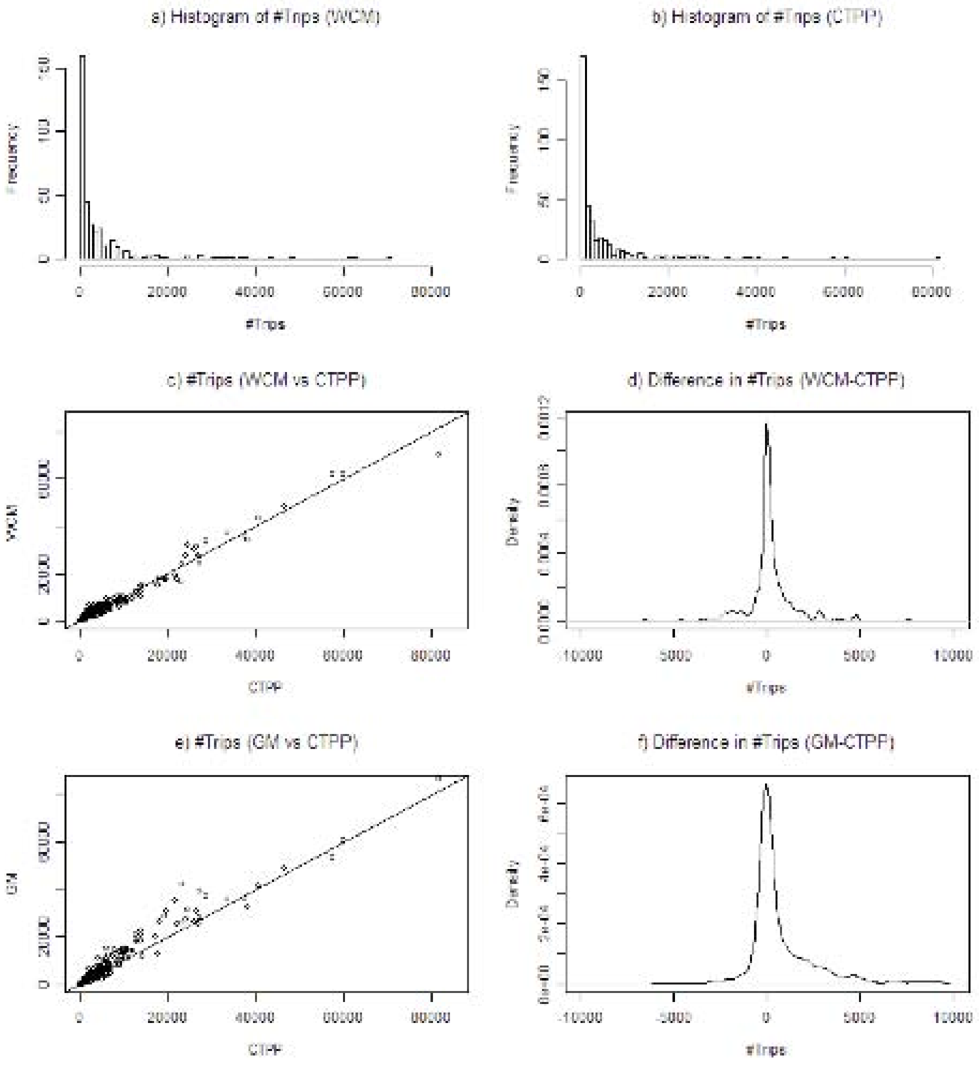
Work at Home Choice Model (individual worker)

variable	coeff	*t*-value
Constant	3.802	12.483
worker's age	0.019	4.116
worker's education	0.089	3.085
working part time	0.892	7.690
presence of children < 13yr	0.218	1.713
emp within 30 minutes' drive	0.0001	1.647

Workplace Choice Model
(individual worker matched to individual job)

	coeff	*t*-value
edu_x_emp_sector_group_basic	-0.131	-10.703
edu_x_emp_sector_group_edu	0.235	15.879
edu_x_emp_sector_group_fires	0.171	16.6547
edu_x_emp_sector_group_retail	-0.138	-10.375
logsum_hbw_am_from_home_to_work	1.418	40.050
network_distance_from_home_to_work	-0.041	-11.623
home_district_is_same_as_workplace_district	0.691	14.223
home_area_type_3_workplace_area_type_1	0.239	2.915
home_dist_19_workplace_dist_19	1.042	4.357
home_dist_1_workplace_dist_1	0.989	1.776
home_dist_6_workplace_dist_6	-0.531	-2.454

Validation of Workplace Choice Model



Individual-level New Logit model
RMSE 1440

Previous aggregate gravity model
RMSE 2558

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New Real Estate Development Models

- **Key elements**
  - Parcel-based unit of analysis
  - Development project templates
  - Development constraints
  - Return on investment calculations
  - Infill
  - Redevelopment
  - Building schedules

Example of Land Use Plan and Land Development Constraints

Example parcel

- 2.5 acres / 107,000 SQFT size
- Min Units 4.5, Max Units 8.7

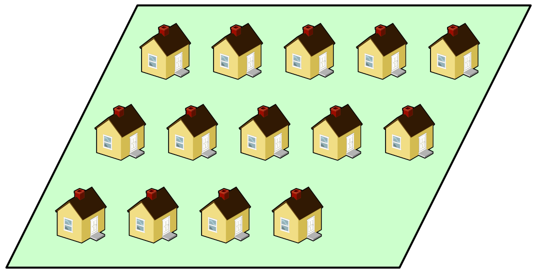
Traits of each parcel factor into its attractiveness to location, development models:

- Price
- Proximity to downtown, jobs
- Vacant or built, etc.

Development Templates:
Can represent any land use mix, density, size

How Land Development is Modeled

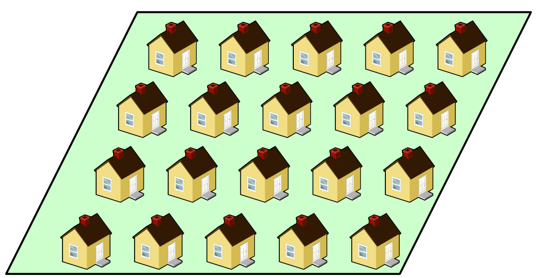
Template #1



Units Per Acre……………….. …6
Total Units……………………..14
Min Parcel size…….87,000 SQFT
Max Parcel size….350,000 SQFT
Land Use………………..SF Resid
ROI: ....………………$440,000

Vacant Parcel

Template #2



Units Per Acre……………….…8.5
Total Units……………………..20
Min Parcel size…….87,000 SQFT
Max Parcel size…..283,000 SQFT
Land Use………………...SF Resid
ROI: ...…………………..$536,000

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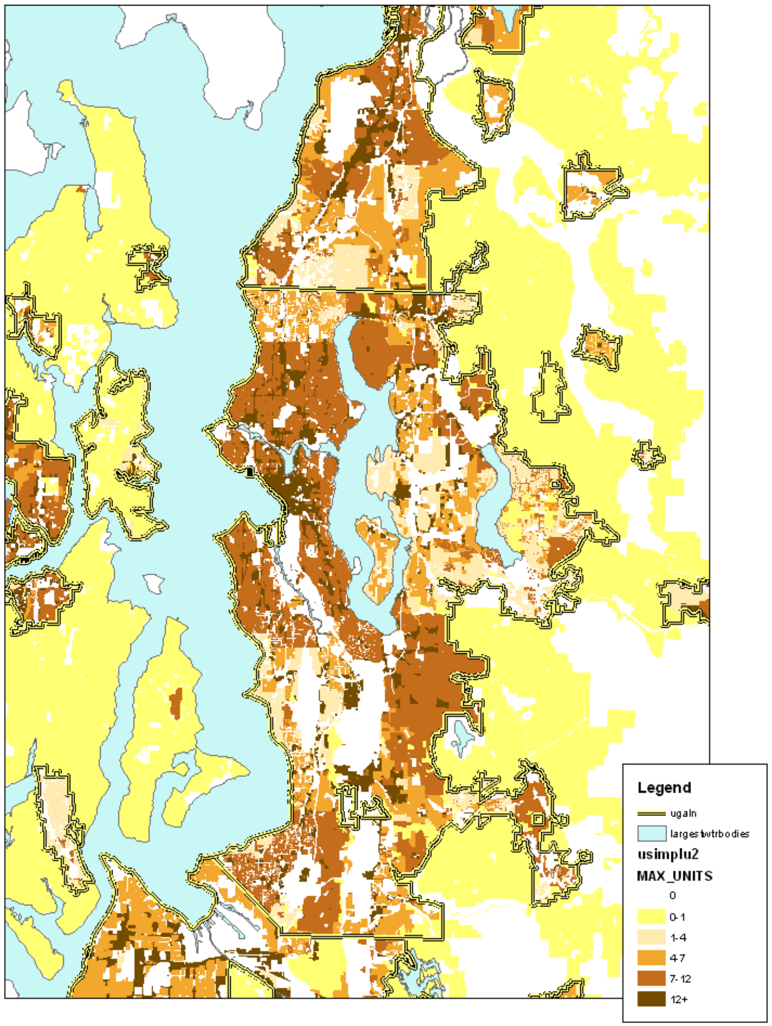
How Land Use Plans Are Modeled

Example of Max Units per Acre



Land use plans converted to an overlay in GIS containing:

- Min and Max Housing Units (per Acre)
- Min and Max Floor Area Ratio

Every parcel assigned to a specific part of the GIS overlay:

- Constraints transferred to parcels

Assessing Uncertainty: Bayesian Melding

- Developed rigorous methodology for assessment of uncertainty in integrated land use and transport models based on Bayesian Melding (published in Transportation Research A, 2007)

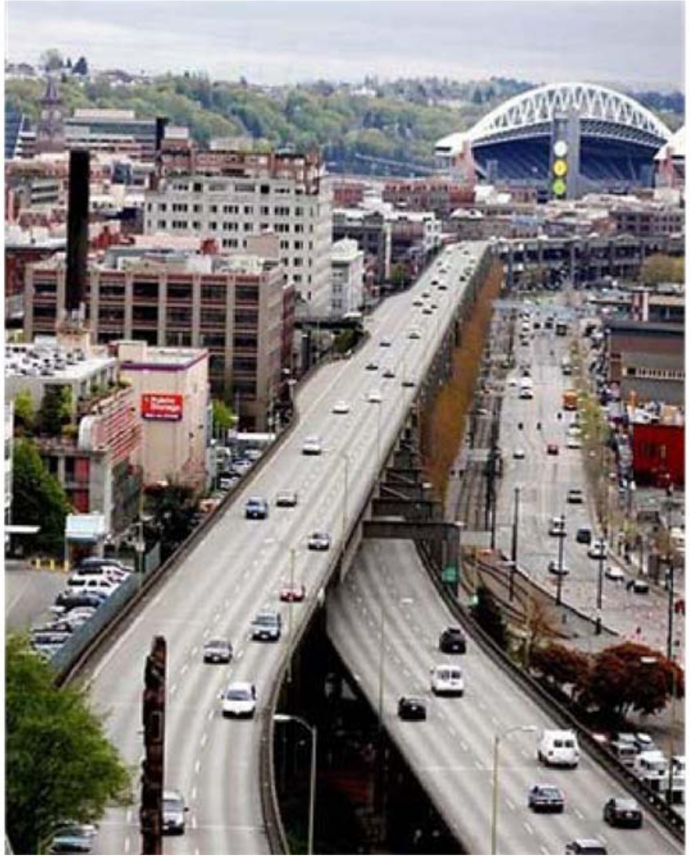
- Currently testing an application to the question: what would happen if the Alaskan Way Viaduct adjacent to the waterfront in the Seattle CBD were demolished? It is at risk of collapse in the next earthquake.

- Note: the following results are PRELIMINARY, and will self-destruct in 10 minutes.

Alaskan Way Viaduct Scheduled for Demolition in…

The next earthquake?

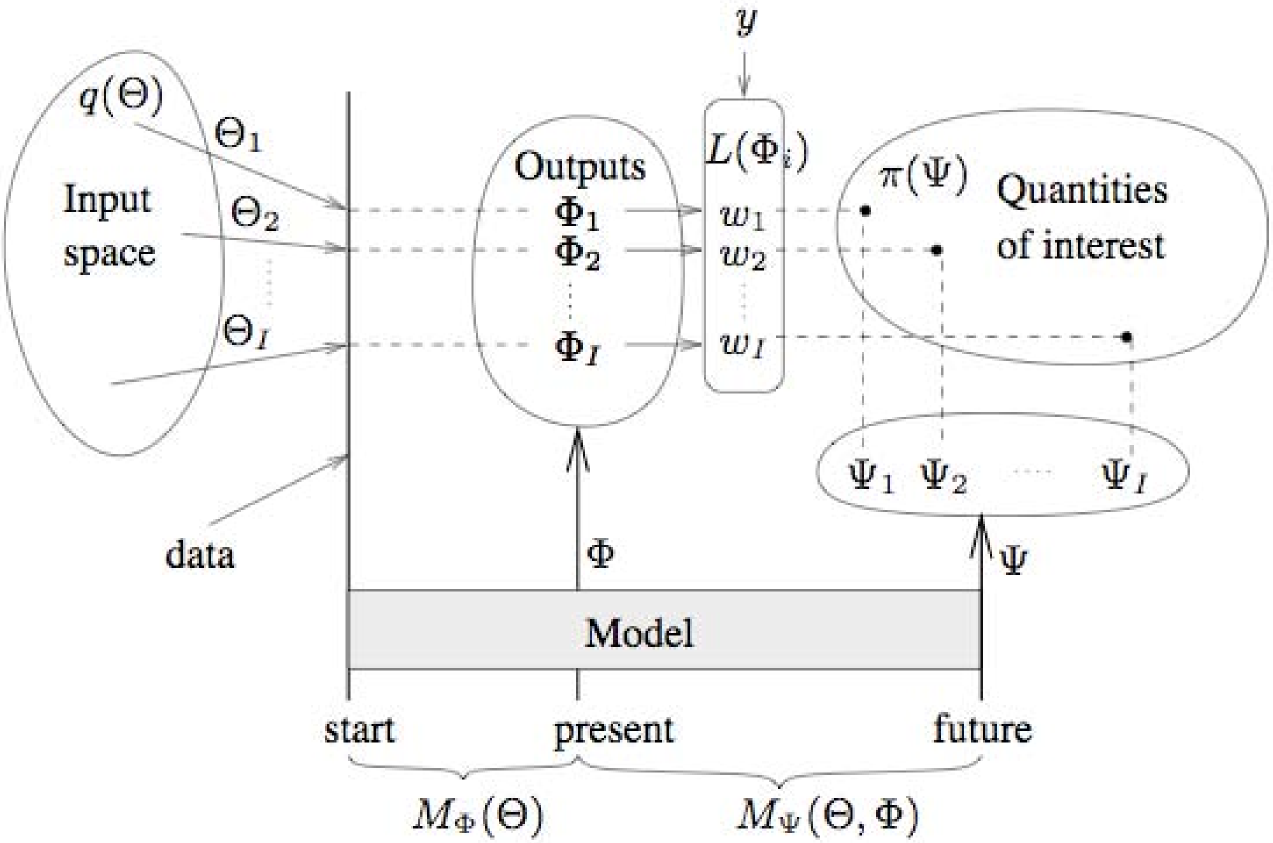
Some claim that alternatives which do not have comparable Traffic capacity will Cause massive failure of traffic in CBD and on I5.



Others claim that we should replace it with surface street and transit, and reclaim the waterfront. It won't cause much traffic impact because people adapt.

How much would a low-capacity alternative affect travel times over 10 years?

Assessing Uncertainty with Bayesian Melding



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Assessing Uncertainty with Bayesian Melding

Likelihood and posterior distribution

y_k is sqrt of observed quantity in zone k

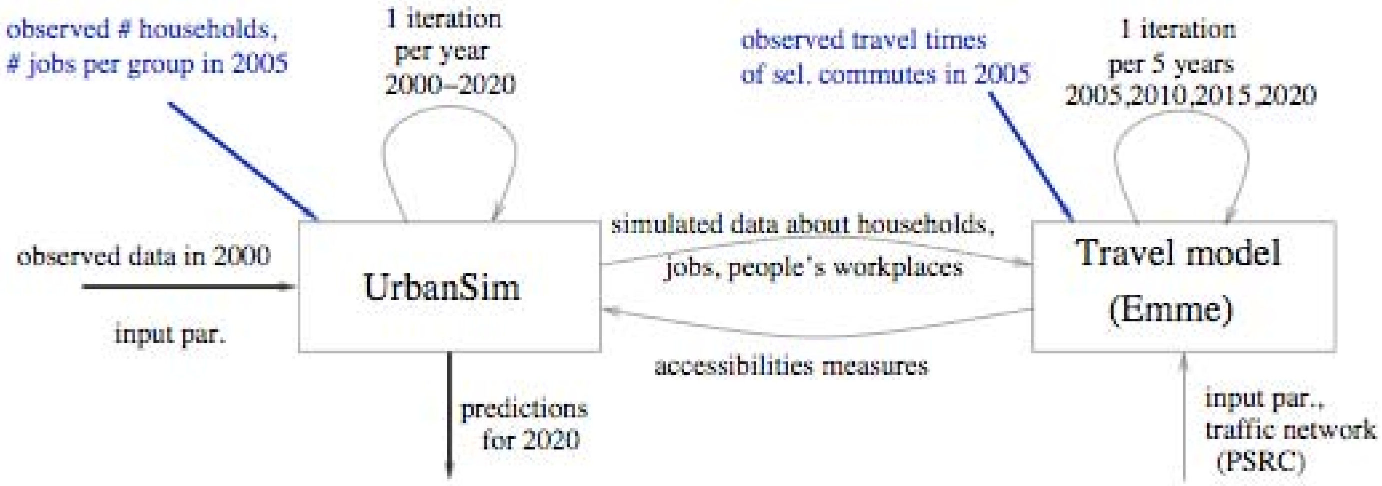
$$y_k|\Theta_i \sim N(\hat{a} + \hat{\mu}_{ik}, \hat{\sigma_i}^2)$$

$$w_i \propto p(y|\Theta_i) = \prod_{k=1}^{K} \frac{1}{\sqrt{2\pi\hat{\sigma_i}^2}} \exp\left[-\frac{1/2(y_k - \hat{a} - \hat{\mu}_{ik})^2}{\hat{\sigma_i}^2}\right]$$

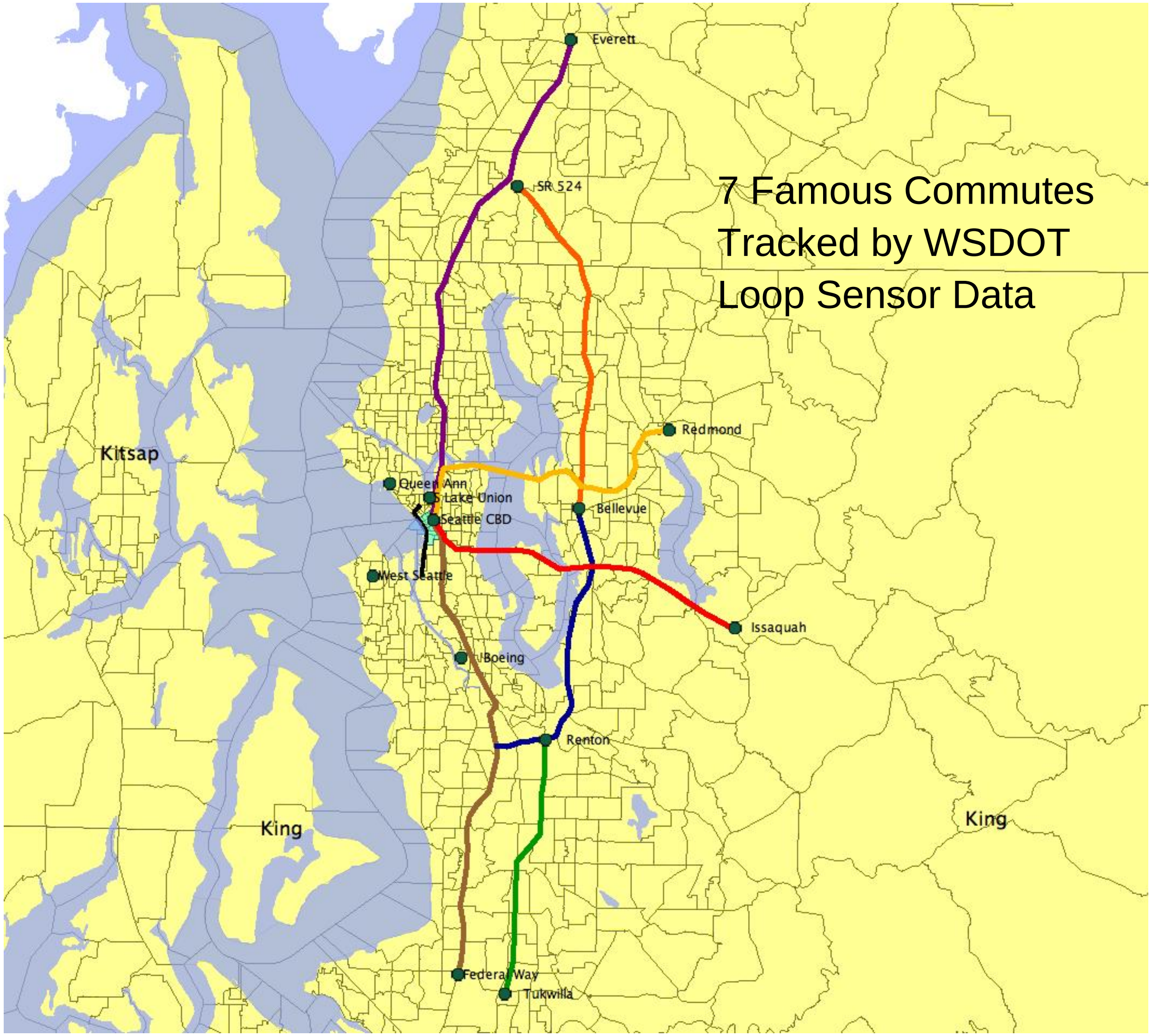
$$p(\Psi_k) = \sum_{i=1}^{I} w_i N(\hat{a}b_a + \Psi_{ik}, \hat{\sigma_i}^2), \quad k = 1, \ldots, K$$

Assessing Uncertainty with Bayesian Melding

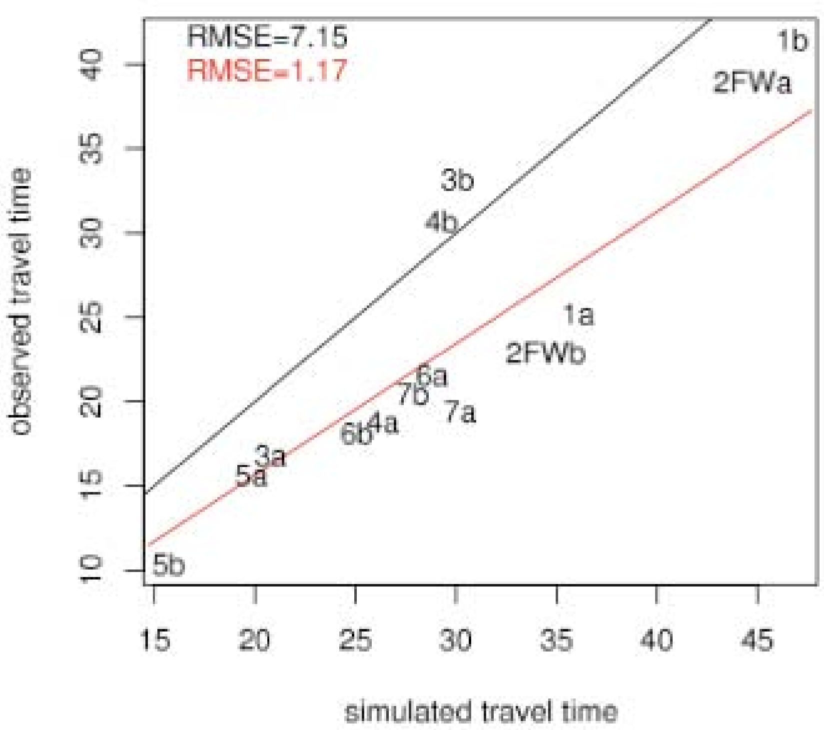
Quantity of interest: Travel times on selected routes



Assessing Uncertainty with Bayesian Melding



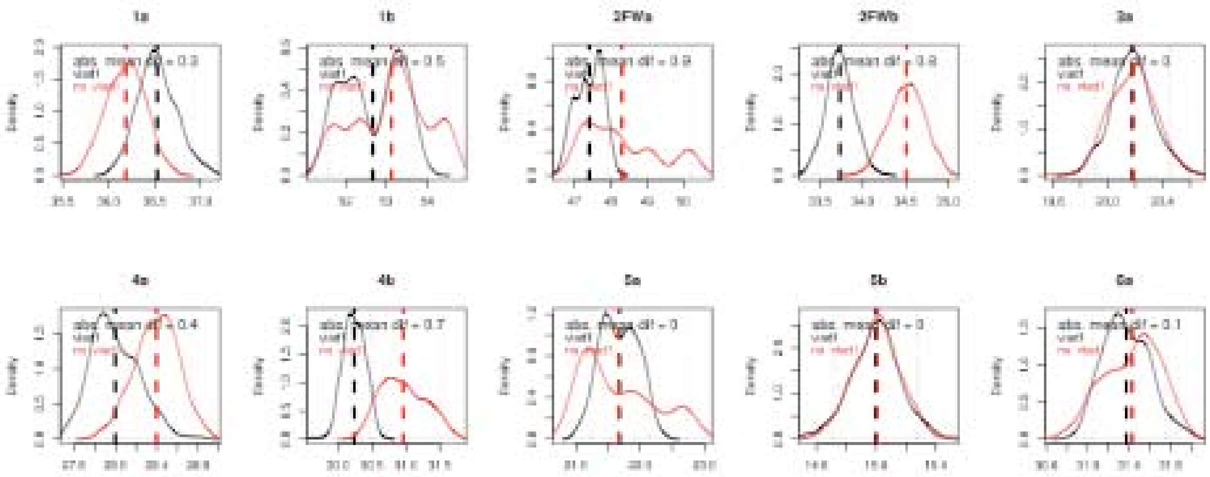
Assessing Uncertainty with Bayesian Melding



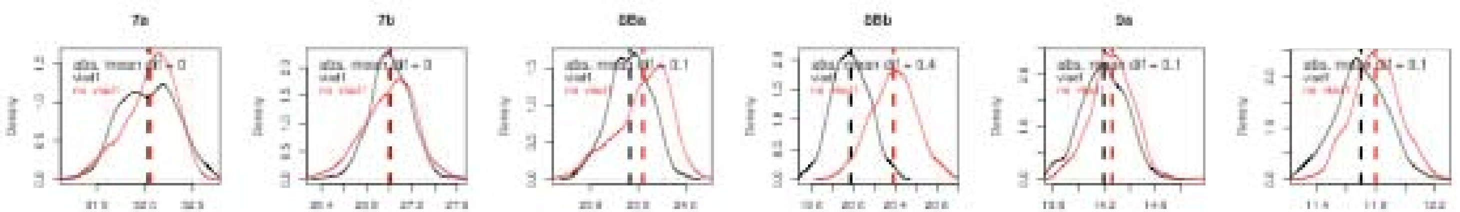
Systematic bias in travel times predicted by travel model was corrected

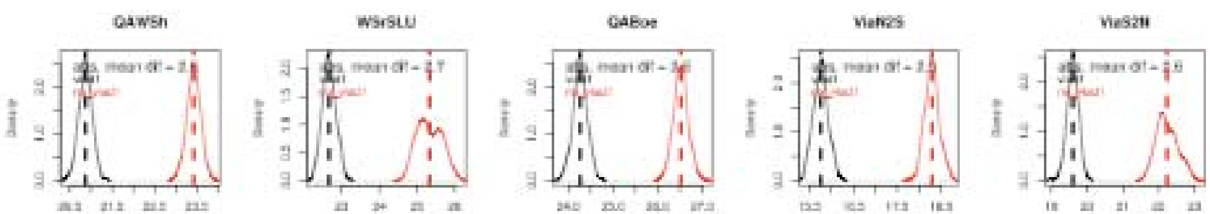
$$\log(T) \sim N(\log(T_{sim}) - 0.25, 0.16^2)$$

Assessing Uncertainty with Bayesian Melding



How much difference in travel time on those famous commutes if we remove the Viaduct in 2010 and simulate land use and transport to 2020?





On distant routes < 1 minute,
On others closer to 2-3 minutes

CUSPA

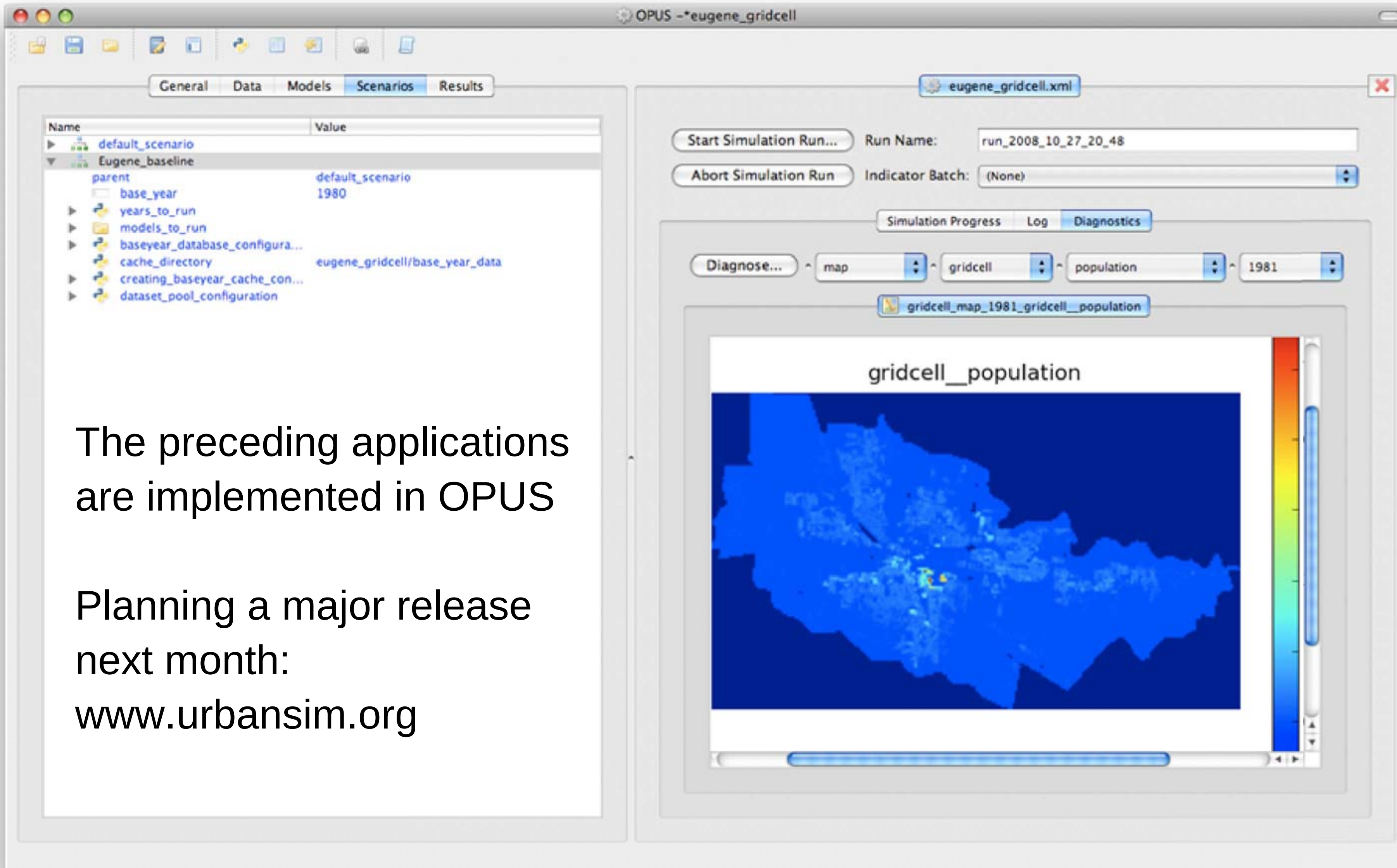
Assessing Uncertainty with Bayesian Melding

route	scen.	2000	2010	inc.	2020	inc.
QAWSh	viad	21.1	21.3		21.1	
(7.4mi)	no v.		23.4	10%	23.7	12%
WSrSLU	viad	20.9	22.1		22.8	
(7.4mi)	no v.		24.7	12%	25.5	12%
QABoe	viad	24.5	24.6		24.5	
(9.9mi)	no v.		26.7	9%	26.8	9%
ViaN2S	viad	16.0	16.1		16.0	
(5.2mi)	no v.		18.4	14%	18.5	16%
ViaS2N	viad	18.1	19.1		19.8	
(5.2mi)	no v.		21.5	13%	22.4	13%

On shorter routes close to Viaduct, these translate to 9 – 16% increases in travel time

Assessing Uncertainty with Bayesian Melding

Open Platform for Urban Simulation (open source software)



The preceding applications are implemented in OPUS

Planning a major release next month: www.urbansim.org

New Tools for Visualization

Interactive Visualization of Simulated Urban Spaces
by Using Procedurally Generated Content

Online ID: #vis-1278

Acknowledgments

EPA R831837: Integrating Land Use, Transportation, and Air Quality Modeling. Science to Achieve Results Program

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NSF EIA-0121326: Modeling Uncertainty in Land Use and Transportation Policy Impacts: Statistical Methods, Computational Algorithms, and Stakeholder Interaction. Digital Government Program.

NSF BCS-508002: Emergent Patterns of Urban Landscapes. Biocomplexity Program.

NSF EIA-0121326: Interaction and Participation in Integrated Land Use, Transportation, and Environmental Modeling. Information Technology Research Program