A Report from the University of Vermont Transportation Research Center

UVM Transportation Research Center Signature Project 1B – Integrated Land-Use, Transportation and Environmental Modeling

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DISCLAIMER

Final Report
UVM Transportation Research Center Signature Project 1B – Integrated Land-Use, Transportation and Environmental Modeling

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Note: Sections of this report, including the Background, Project Goals and Motivation, and Summary of Previous Research, are adapted from the Phase 1 report for this project.

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Disclaimer

1. Background

Land use and transportation are inextricably linked. Models that capture the dynamics and interactions of both systems are indispensable for evaluating alternative courses of action in policy and investment. These models must be spatially disaggregated and complex enough to allow for the realistic evaluation of strategies that are of significance to policy and planning, but this comes at a cost; disaggregation and complexity require money, time and resources and often these sacrifices are not cost-effective. Unfortunately little guidance exists in the literature about these tradeoffs or the appropriate level of complexity and disaggregation needed for modeling under different applications.

The linkages between land use and transportation—and the need to account for those linkages in planning—have been well established by many researchers (Giuliano 1989; Moore, Thorsnes et al. 1996; Boarnet and Chalermpong 2001; Cervero 2003) as well as by the Federal Highway Administration (USDOT 1999). In fact, under the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the Transportation Equity Act for the Twenty First Century (TEA-21) of 1997 (to a lesser extent), state or regional transportation agencies have been required to model the effect of transportation infrastructure development on land use patterns, and to consider the consistency of transportation plans and programs with provisions of land use plans in order to receive certain types of federal transportation funds. Other federal programs have attempted to encourage integrated land use and transportation modeling, including the Travel Model Improvement Program (1992) and the Transportation and Community and System Preservation Pilot program (1999). For these reasons, Metropolitan Planning Organizations (MPOs), which already almost universally use transportation models, are increasingly integrating dynamic land-use modeling into those efforts. In particular, these integrated models are frequently used to evaluate transportation infrastructure performance, investment alternatives, and air quality impacts under alternative scenarios.

These coupled models are far more robust than stand-alone transportation models that use static estimates of land use because of their ability to simulate dynamic interactions between transportation infrastructure, travel demand, and human activities. This, in turns allows for better simulation of how proposed transportation investment might affect land use patterns, and how proposed land use policies might affect traffic patterns. Land-use modeling has emerged as a relevant tool for understanding the diverse drivers of urbanization, evolving from non-spatial mathematical specifications of linear relationships to spatially explicit dynamic simulations that allow feedbacks between model subsystems and account for a divergent set of institutional and ecological forcings.

Tradeoffs between realism and cost are poorly understood. Detail and complexity can be valuable in integrated land use-transportation models, but little guidance exists as to when that added difficulty is justified. In reality, the correct balance is likely to depend on the particular application of the model. Many new approaches to comprehensive model-integration are being unveiled in the research community. However, as noted by Hunt et al. (2001), few of these models have been conclusively shown to increase the accuracy of the model output.

Three components are used in this modeling effort: UrbanSim (Waddell 2000; Waddell 2002; Waddell and Borning 2004)for land use, TransCAD (Caliper, Inc) for travel demand modeling and traffic routing, and TRANSIMS (Nagel and Rickert 2001; Rilett 2001) for traffic routing through microsimulation.

UrbanSim is a land-use model that simulates urban growth for a region based on externally derived estimates of population and employment growth (control totals). Using a series of complex algorithms, this expected growth is spatially allocated across the landscape to simulate the pattern of future development and land use. The landscape is divided into grid cells of a user-defined size, and each simulated development event is assigned to one of those cells based on factors like accessibility, site constraints, and zoning. It has been applied to metropolitan areas in Washington, Oregon, Hawaii, and Utah. A review of land use models found UrbanSim to be an excellent choice for integrated land use and transportation modeling (Miller, Kriger et al. 1999). While almost all other urban growth models rely on aggregate cross-sectional equilibrium predictive approaches, UrbanSim is an agent-based behavioral simulation model that operates under dynamic disequilibrium, which allows for more realistic modeling of economic behavior. Agents in UrbanSim include both households and employers. UrbanSim operates in an iterative fashion, in which supply-demand imbalances are addressed incrementally in each time period but are never fully satisfied. Because of its dynamic nature, UrbanSim can endogenize factors that other models take as exogenous, such as location of employment and the price of land and buildings. Model features include the ability to simulate the mobility and location choices of households and businesses, developer choices for quantity, location and type of development, fluxes and short-term imbalances in supply and demand at explicit locations, and housing price adjustments as a function of those imbalances. All of this can be done at any user-specified minimum-mapping unit resolution. Because the model consists of compartmentalized modules, if required data are not available specific modules can be disabled to simplify the implementation. Finally, the model also allows for prediction of land market responses to policy alternatives.

For transportation demand modeling we use the Chittenden County Metropolitan Planning Organization's implementation of TransCAD v4.7, a GIS-based transportation planning software package. A calibrated model was developed for the MPO by Resource Systems Group, Inc. The model includes 335 internal traffic analysis zones (TAZs) to simulate traffic flow, and includes an additional 17 external zones to represent traffic entering (or passing through) the County from outside its borders (CCMPO, 2008). The travel model is based on household travel diaries collected for the CCMPO. Traffic assignment is based on an equilibrium model which employs an iterative procedure to reach convergence. The model was calibrated against observed AM and PM peak conditions. The model operates according to the traditional four-step process, including trip generation, trip distribution, mode split and traffic assignment. The trip generation step quantifies the number of incoming and outgoing trips for each zone based on land use and employment patterns, and classifies these trips according to their purpose (e.g., home to work, home to shopping). Trip distribution assigns the incoming and outgoing travel from the trip generation step to specific zones. The mode split step estimates the number of trips by mode of transport. Finally, the traffic assignment identifies the route for each trip.

The TRANSIMS model consists of four modules: (1) Synthetic Population Generator; (2) Activity Generator; (3) Router; and (4) Micro-simulator. TRANSIMS starts by creating a synthetic population based on census and land use data, among other data sets. The Activity Generator then creates an activity list for each synthetic traveler. The Activity Generator and the Router then compute combined route and mode trip plans to accomplish the desired activities. Finally, the Micro-simulator simulates the resulting traffic dynamics based on a cellular automata model, yielding detailed, second-by-second trajectories of every traveler in the system over a 24-hour period.

While TRANSIMS is designed to allow for using an activity-based approach to transportation demand modeling (using its Population Synthesizer and Activity Generator), the model's Router and Micro-simulator modules can still be applied using standard Origin-Destination (O-D) matrices. This provides for a cost-effective approach for regional planning organizations to take advantage of the increased resolution of the TRANSIMS micro-simulator, while primarily depending upon standard O-D matrices with which they are accustomed to dealing with. Implementing only TRANSIMS's Router and Micro-simulator, using O-D matrices, for a given area is typically referred to as a "Track 1" TRANSIMS implementation. "Track 1" TRANSIMS implementation has been the focus of the current work so far.

2. Project Goals and Motivation

The Integrated Modeling Project seeks to implement several versions of an integrated land-use / transportation model for Chittenden County, Vermont. Based on those results, we hope to evaluate the benefits of increased complexity and disaggregation in modeling of land-use, travel demand, and travel supply (route choice and traffic assignment) relative to the costs. Working collaboratively with local and regional planners, the project also seeks to develop alternative policy scenarios that can be evaluated using these different model configurations. By evaluating the sensitivities of baseline and alternative policy scenarios to different configurations and complexity levels for the integrated model, we hope to gain insight about how the appropriateness of model disaggregation and complexity may also vary with policy application. Towards this end we compare an integration of the dynamic UrbanSim land use model with a static traffic assignment (TransCAD) to a more complex integration of UrbanSim with a traffic simulation (TRANSIMS) and trip generation from TransCAD. For simplicity we refer to the former integration as the "2-way model" and the latter as the "3-way model" from here on.

Finally, the Environmental Metrics Project seeks to develop tools for generating environmental indicators from the outputs of the integrated models, which will allow for evaluation of scenarios on the basis of environmental metrics. The interaction and feedback of model components is given in Figure 1.

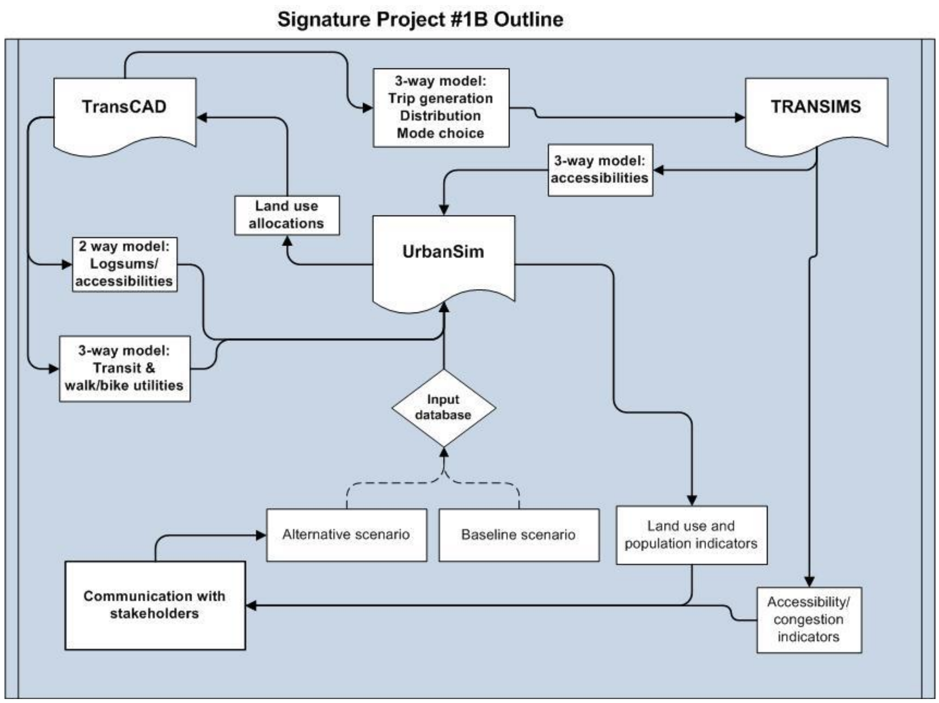

Figure 1. Interaction/ Feedback Between Integrated Model Sub-Components

3. Summary of Foundational Research by PIs Previously Funded by USDOT

Phase I activities for this project built on products from two previous research grants from the USDOT FHWA, one entitled "Dynamic Transportation and Land Use Modeling" (PI: Austin Troy) and one entitled "Implementing the TRANSIMS model in Chittenden County" (Co-PIs: Adel Sadek and Resource Systems Group, Inc.). The former resulted in the development of a working UrbanSim implementation for Chittenden County with a 1990 model base year, which was integrated with a pre-existing TransCAD static assignment model to form a 2-way integrated model. The latter resulted in the development of a functioning TRANSIMS model for the same county, using static land-use inputs.

3.1 Development of the 2-Way Model: UrbanSim and TransCAD

Most of the work on the development of 1990 base year UrbanSim model implementation was conducted under the previous USDOT grant (DTFH61-06-H-00022). Details on this process can be found in the Final Report to the funder (http://www.uvm.edu/envnr/countymodel/TROY_DOTfinal_report.pdf).

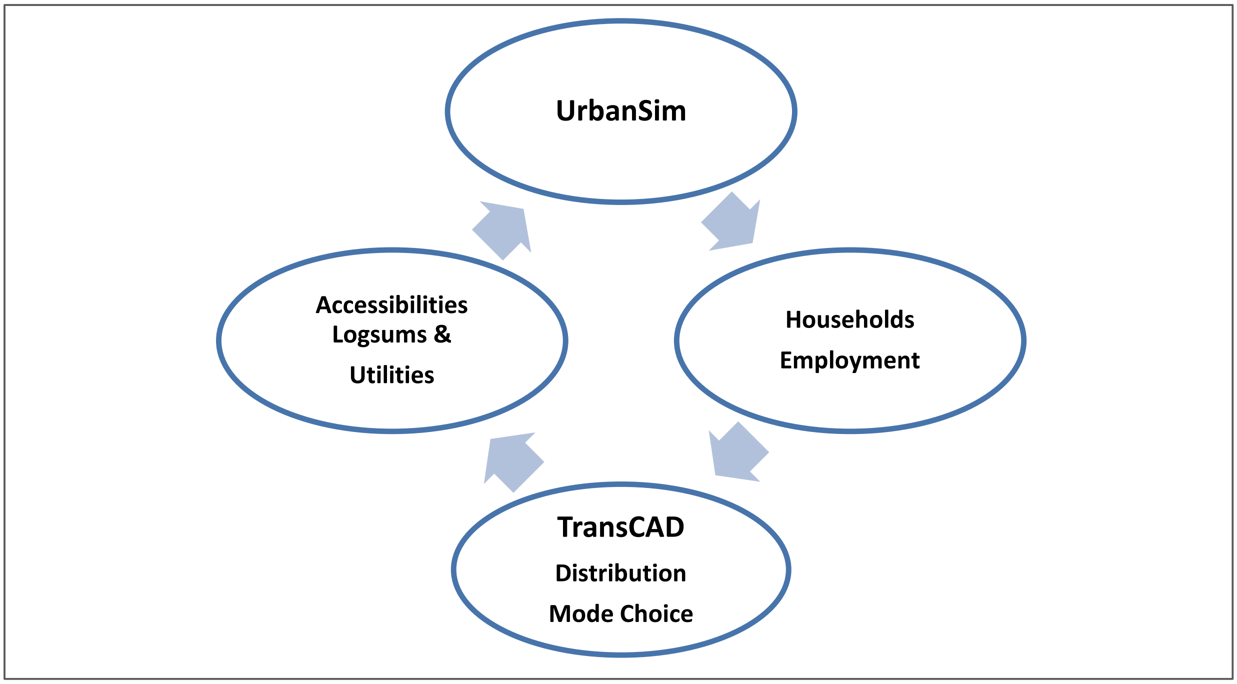

Figure 2. Two-way model process

The result of this process was a successful integrated two-way model that could be run from the 1990 base year through 2030, yielding reasonable and internally consistent outputs. A diagram of this two-way model is given in Figure 2.

3.2 Comparison of 2-Way Model with the UrbanSim Stand-Alone Model

An important element of this research is the assumption that inclusion of a travel-demand model as an endogenous integrated-model component affects predicted land use. This assumption is based on the results of the model runs with and without the endogenous travel-demand model using the 1990 base year model. This effort was jointly supported by the US DOT and TRC projects. When the travel model is not endogenous, accessibilities are only calculated once, before UrbanSim is run and no further updates of accessibilities are performed as development patterns change. This means that the accessibilities at the TAZ scale are not updated as the construction of new employment and housing are simulated.

We found that there was a significant different between the models with and without feedback between TransCAD and UrbanSim. Output maps showed that differences in predicted housing unit construction between the 1- and 2-way models were small in the more central areas around Burlington and adjacent to Interstate 89, while bigger differences were found in the more peripheral areas. Certain areas in the less developed eastern part of the county appear to display the largest differences in predicted development between the with- and without-travel model versions. This difference makes sense. As UrbanSim is predicting the development of new employment and service locations in the less developed eastern part of the county, the overall accessibility of these formerly remote areas becomes higher. This higher accessibility in turn induces higher demand for residential space in increasingly peripheral areas, triggering development. This analysis is described in detail in the US DOT Final Report and in Voigt, Troy, et al. (In press). It is included in this report to contextualize the 3-way model comparison that follows.

3.3 Completion of TRANSIMS Model

The FHWA-sponsored efforts of developing and testing the TRANSIMS over the course of the last 10 or 15 years, have resulted in the development of several utility programs or tools that can facilitate the deployment of TRANSIMS. Among those programs are routines for translating multi-modal link-node databases for use in TRANSIMS and for estimating traffic control characteristics, called TRANSIMSNet. The approach taken to build the Chittenden County TRANSIMS network, therefore, was to start with the four-step network, apply TRANSIMSNet, and then enhance the network integrity manually during calibration.

To develop the required trip tables for TRANSIMS, the first step was to extract the following PM vehicle trip tables from the CCMPO PM model, after the mode choice step: (1) Home origin; (2) Work to Home; (3) Non-work to Home; (4) Work to non-home; (5) Non-work to non-home; (6) Medium truck trips; (7) Heavy truck trips; and (8) External to external trips. The extracted PM trip tables were then expanded to the full day using time-of-day distribution factors determined from the CCMPO household trip diary survey performed in 1998. The results were also checked against NHTS data and permanent vehicle count data. For external-to-external trips, given that the primary external-to-external flow through the region is on Interstate 89, the permanent traffic counters on I-89 were used to generate diurnal patterns for these trips. Finally, the diurnal distribution for non-home-based trips was used to generate daily truck traffic.

The study's implementation of the TRANSIMS Router and Microsimulator involved running the following three steps: (1) router stabilization; (2) micro-simulator stabilization; and (3) user equilibrium.

The model was validated against a mid weekday (Tuesday, Wednesday, or Thursday) in September for the year 2000 (the same period and year of calibration as the CCMPO four-step model). This was done by comparing the model results to actual field AM and PM counts that covered an extensive portion of the model boundary. The validation exercise focused on the following items: (1) system-wide calibration comparisons to ground counts; (2) use of three directional screen lines throughout the county; (3) diurnal volume distribution for several critical links in the county; (4) limited turn-movement comparisons; and (5) scenario testing. Table 1 shows the system-wide validation statistics, categorized by facility type.

Table 1. TRANSIMS validation statistics

Facility Type	No. of Observations	Estimated Volume	Observed Volume	Percent Difference	Avg. Absolute % Error
Freeway	28	147585	143217	3.0%	7.9%
Major Arterial	262	120211	134270	-10.5%	29.1%
Minor Arterial	170	87890	89765	-2.1%	31.3%
Collector	376	119513	110136	8.5%	45.9%
Ramp	36	8310	7744	7.3%	26.8%

Two types of preliminary sensitivity analyses were performed. The first focused on assessing the sensitivity of the model results to changes in the seed number. The second analysis involved assessing the impact of replacing a set of pre-timed signals with actuated controllers. For the full results of these sensitivity tests and validation, the reader is directed to Lawe et al (2009).

Calibrating TRANSIMS with GA's – Preliminary Investigation

Genetic Algorithms (GAs) are stochastic algorithms whose search methods are based on the principle of survival of the fittest.

The use of GA in conjunction with micro-simulation model calibration offers several advantages. GAs do not require gradient information, are rather robust, and can overcome the combinatorial explosion of the simulation model calibration problem.

On the other hand, their use for calibrating or adjusting travel demand in a model like TRANSIMS is a challenging problem both computationally and analytically. Challenges include: (1) the computational requirements of running TRANSIMS; (2) memory usage; and (3) the very large search space of the problem. In this study, methods were developed to address those challenges. For a more detailed discussion of the challenges and the methods developed to overcome them, see Huang et al.(2009).

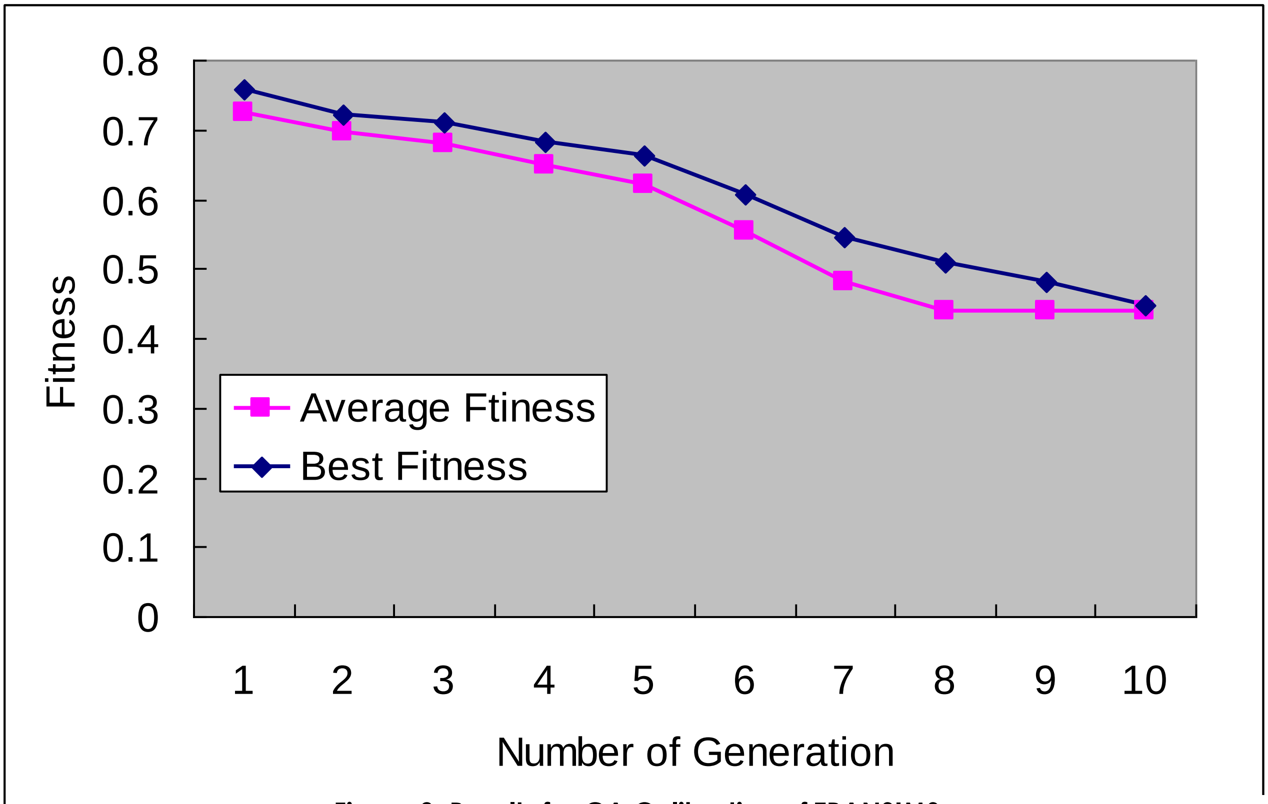

Figure 3. Results for GA Calibration of TRANSIMS

The study considered three case studies: (1) a synthetic network; (2) a small sized real-world network; and (3) the Chittenden County network. The synthetic network was used to: (1) first study the feasibility of using GA for travel demand calibration in TRANSIMS; (2) conduct some sensitivity analysis tests aimed at understanding the problem characteristics; and (3) determine empirically the best settings for the GA parameters, which include population size and the number of generations, or iterations for running the GA (as explained in the background section each cycle of evaluation, selection and alteration is called generation).The network has a total of 9 trip zones, 82 nodes and 141 links. Out of the 9 zones, 8 zones are regarded as external (all zones except zone 4), and one is regarded as internal (zone 4). The small sized real-world network was a TRANSIMS developed for the north campus of the University at Buffalo, which required significantly less time to run compared to the Chittenden County model, and hence allowed for more extensive experimentation. In all these cases, the focus was on calibrating or adjusting the demand (i.e. the Origin-Destination matrix) to bring the simulated link volumes closer to field observations.

When TRANSIMS was initially run using the original O-D matrices extracted from the CCMPO planning model (i.e. before using the GA to adjust the O-D matrix), the resulting absolute percent error was about 74%, a relatively high value.

Figure 3 shows the extent to which the GA was able to improve on the results after only 10 generations. The figure plots the average absolute percent error of the best individual from each generation, as well as the average of the average absolute percent error for each generation. As can be seen from the figure, the GA appears to have had a significant impact on improving the quality of the solutions. Specifically, the best average absolute percent error obtained after 10 generations was about 44%. This represents a significant improvement over the original average absolute percent error of 74%. As mentioned above, the "parameters" being calibrated are the values of the O-D demand matrix.

4. Summary of Results from Phase 1

4.1 Stakeholder workshops

A large stakeholder workshop was co-sponsored between this project and the US DOT-funded project to solicit input from the planning, business, and environmental communities about the development of alternative scenarios. Scenarios are defined as an alternative to the 'business as usual' baseline condition by representing shifts in policy (e.g. zoning or tax policy), investment (e.g. transportation or utility infrastructure construction), or external conditions (e.g. loss of a major employer, changes in energy prices, etc.). Scenarios are meaningful only inasmuch as they represent realistic and relevant policy alternatives that are actually under consideration. Towards the end of creating a set of meaningful scenario themes, we conducted a stakeholder workshop, organized in conjunction with the Chittenden County Metropolitan Planning Organization and Regional Planning Commission.

The workshop was held on March 26, 2008. Approximately 70 people attended, including most of the planners from Chittenden County Regional Planning Commission (RPC) and Metropolitan Planning Organization (MPO) and top planners from most of the county's major towns and cities. The workshop involved a presentation (http://www.uvm.edu/envnr/countymodel/Workshop08bv3.ppt). Following the presentation, breakout groups worked to give detail to each one of the five general scenarios. The five scenarios included the following.

Transportation corridor-oriented development for the county. Focusing on two major corridors (routes 15 and 2), this scenario involved a range of potential changes, such as redefining zoning district boundaries, changing allowable densities and uses, upgrading roadways, implementing new public transportation lines, deploying intelligent transportation systems, and investing in capital projects, like schools, parks, and government buildings within the zones of influence of these corridors

County-wide growth center implementation. Growth centers are intended to be compact planning areas within established town cores that concentrate mixed-use development in relatively high densities around existing infrastructure. They are intended to combat sprawl by helping take pressure off more rural lands. In return for meeting the planning criteria, growth centers are eligible for a number of incentives, including tax increment financing, a more predictable and faster permitting process, and priority consideration for state buildings, municipal grants, transportation investments, wastewater funding, affordable housing funds, etc. This scenario was designed to imagine what the county would look like if growth centers, recently enabled as a planning tool by the Vermont legislature, were implemented to their full extent.

Investment in roadways for increased regional connectivity. Chittenden County has several major road corridors that generally parallel each other but have very poor connectivity between them. It was hypothesized that if some new, strategically placed connections were made between these corridors, it would dramatically increase connectivity and reduce bottlenecks. Participants were asked to work off the MPO's list of potential projects (identified through their Transportation Improvement Program (TIP)) and then add their own as necessary. The types of upgrades could include new road links, new interstate exits/onramps, adding through access to planned unit developments, etc.

Population and employment boom. This scenario changes the control totals, which set the total population and employment growth forecasts used by the model. Such changes have a very large impact on outputs. Participants were asked to revise those forecasts to higher levels and to break down employment growth by sector. They were also asked to simulate probably future changes to zoning that would be required to accommodate that additional growth.

Natural areas protection/ green scenario. Participants in this scenario were asked to implement regulations that minimize the county's environmental footprint. In particular, they were asked to focus on conservation of important natural areas.

The output of each breakout session was recorded and presented at the end of the meeting. The details of each scenario are included on the project website (www.uvm.edu/envnr/countymodel). Further, a Wiki was created at http://landusemodel.pbwiki.com where scenarios were summarized in detail and participants could comment online and offer suggestions about the scenarios. Finally, a set of four smaller workshops were held with a sub-group of approximately 12 planners over the next several months to help in further defining scenario details, the indicators that would be used to evaluate scenarios, and the criteria for determining the desirability of outcomes.

4.2. Analysis of transportation network improvement scenario

As part of phase 1, and extending into phase 2, we ran the Investment in Roadways scenario, based on information presented at the stakeholder workshop and subsequent followup with the Chittenden County MPO and RPC. The results of this analysis was published as a journal article (Voigt et al. accepted with minor revisions)

It was evaluated under both baseline population but later evaluation in conjunction with a high-population scenario (#4). Developing this scenario involved making numerous edits to the transportation network in TransCAD as well as changing control totals. Some examples of those network edits are given in Figure 8 below.

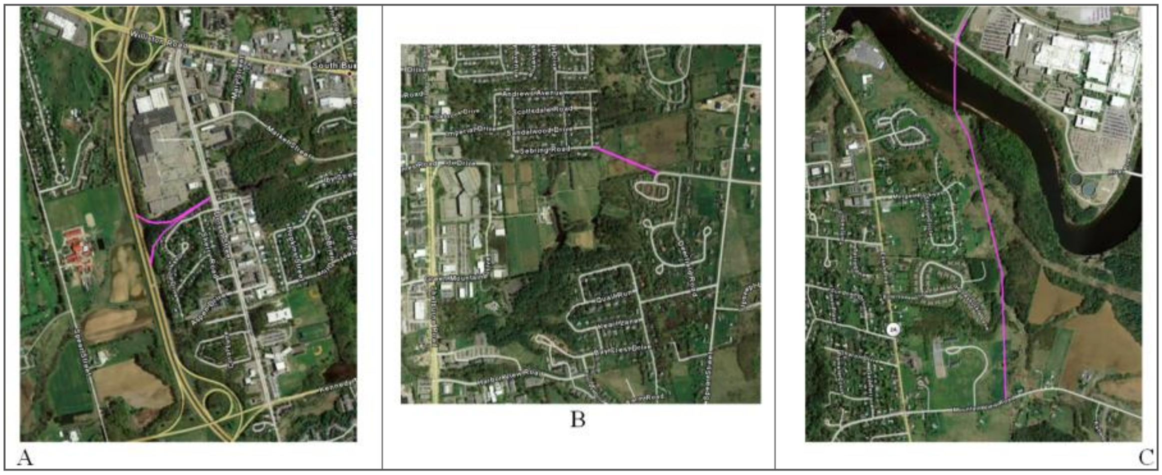

Figure 4 Examples of Three Proposed Network Changes Resulting from the Alternative Scenarios

Three versions of the transportation network were evaluated, including business as usual (“baseline”), only changes from the Metropolitan Transportation Plan (“MTP scenario”), and the more comprehensive changes recommended by the stakeholder workshop (“stakeholder scenario”). Each model configuration was run under two different control total scenarios: the forecast populations/ employment counts and an assumed 50% increase over the forecast. This resulted in six scenario permutations (baseline, baseline+50%, MTP, MTP+50% , stakeholder, and stakeholder +50%). Modeled outputs from the alternative scenarios were then compared against those from the baseline run and each other at multiple spatial scales, ranging from the full set of TAZs to grid cells within a specified distance of road projects.

Our analysis found significant differences between the baseline and stakeholder scenarios. Not only did the improvements suggested by the stakeholders reduce average vehicle hours travelled, but they also resulted in changes to land use. While these changes were not statistically evident when looking at the entire county, they became significant when analyzing just the subset of Traffic Analysis Zones containing these projects or the gridcells located near the projects.

Regional results, presented in Table 2, indicate that both the stakeholder and MTP scenarios are expected to yield slight increases in daily travel distance while reducing daily travel time by more than 6%. Differences in VMT by TAZ are shown graphically in the maps in Figure 5. Here, negative numbers (red, orange, yellow) mean the baseline exceeds the alternative scenario and positive numbers (greens) mean the scenario values exceed the baseline. Both figures use the same legend. The stakeholder scenario appears to yield differences between the baseline and the stakeholder for peripheral TAZs and those located along Interstate 89 in the center of the county.

Table 2 Vehicle-Miles Traveled and Vehicle-Hours Traveled in Chittenden County Under Alternative Transportation Scenarios

	Baseline	MTP	Stakeholder
Daily VMT	455,563	459,470	462,891
% change		0.86%	1.61%
Daily VHT	19,076	17,864	17,755
% change		-6.35%	-6.93%

Statistically significant differences in VMT were also found at the TAZ scale between scenarios using forecast control totals. Table 3 shows the p-values from statistical tests of difference, with all those significant at the 95% confidence level given in bold. We found that differences were much greater for the stakeholder than MTP scenario comparison against the baseline. Also, there were differences depending on whether only TAZs containing proposed projects ("Stake" and "MTP") were being analyzed versus those TAZs plus their adjacent neighbors ("Stake+N" and "MTP+N").

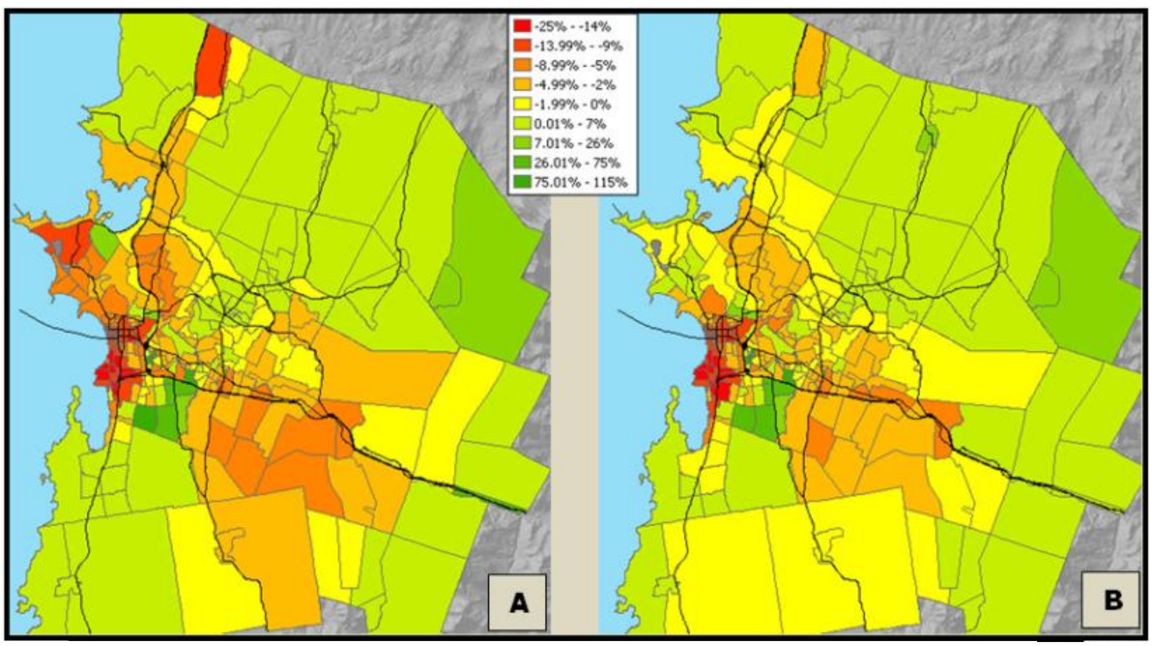

Figure 5 Percent Difference in Vehicle-Miles Traveled Between Baseline and MTP (A) and Between Baseline and Stakeholder (B)

Table 3 P-Values of T-tests Comparing MTP and Stakeholder Scenario Outputs Against the Baseline Model, Under Standard Control Totals

	Forecast Control Totals		Increased Control Totals			
Attribute	Stake	Stake+N	Stake	Stake+N	MTP	MTP+N
COM SQFT					0.0206	
IND SQFT						
COM JOBS					0.0252	
IND JOBS						
RES UNITS					0.0934	
VAC COM SQFT						
VAC IND SQFT						
VAC RES UNITS						
COM SQFT	0.0080	0.0628		0.0113		
IND SQFT			0.0440			
COM JOBS	0.0085	0.0565		0.0125		
IND JOBS						
RES UNITS	0.0513	0.0154	0.0078	0.0042		
VAC COM SQFT						
VAC IND SQFT				0.0814		
VAC RES UNITS	0.0508		0.0623	0.0390		

The analysis was also conducted at the grid cell level to evaluate how predicted land use outputs differed between scenarios at different spatial lags. We evaluated the outputs of grid cell outputs at 500, 1000, 1500, 2000, and 2500 meter distances from the proposed projects under both the MTP and stakeholder scenarios, using both forecast and inflated control totals. For the stakeholder scenario using forecast control totals, we found significant differences in almost all land use outputs at the 500 m scale and differences in vacancy variables at greater lags, given in Table 4.

Table 4 P-Values of T-tests Comparing MTP and Stakeholder Scenario Outputs Against the Baseline Model Results at the Gridcell-Level, for Selected Buffers Around Proposed Projects, Under Standard Control Totals

	STAKEHOLDER SCENARIO BUFFER DISTANCE (meters)				
	500	**1000**	**1500**	**2000**	**2500**
COM SQFT					
IND SQFT	0.0317	0.0547			
COM JOBS	0.0449				
IND JOBS	0.0176				
RES UNITS	0.0353				
VAC COM SQFT	0.0494	0.0436	0.0881	0.0896	
VAC IND SQFT	0.0458			0.0385	0.0527
VAC RES UNITS		0.0412			

Results were found to differ considerably for grid-cell level analyses when the higher (+50%) control totals were used. Interestingly, there was no longer a difference in land use outputs at the 500 m level (except for vacant residential units), but there now was significant differences in several variables—particularly commercial jobs and commercial square footage—at the 1000, 1500, and 2000 m scales for the MTP scenario and at the 1500, 2000, and 2500 m scales for the stakeholder scenario. This is consistent with our expectation that under higher population projections, alternative scenarios would see greater variation from the baseline at intermediate distances from the network improvements because available areas in locations closer to the road are likely to be at or near development capacity, regardless of scenario. In this case there would be no expected difference at the 500 m scale because all land near improvements would be fully developed regardless. At the lower population project levels, we would expect to see greater variation at the nearby scale (i.e. 500 m) because the areas near those improvements do not reach capacity.

The existence of these statistically significant differences tells us that our model predicts different outcomes under alternative versus baseline scenarios. In terms of transportation, we find that increased miles traveled would go up while time spent traveling going down under the alternative scenarios, indicating improved travel conditions. As for land use, we find that particularly the stakeholder scenario would result in additional development in the area immediately around network improvements, but that impacts would be negligible beyond one kilometer, except in the case of higher control totals.

4.3 Development of the 3-Way Integrated Model

The 2-way model served as a foundation for building the 3-way integrated model. This task was performed mainly by RSG, with the exception of the estimation of the regression equation for translation of auto utilities to travel times. A summary of the process of integrating these models and its usability was given in Troy et al. (2012)

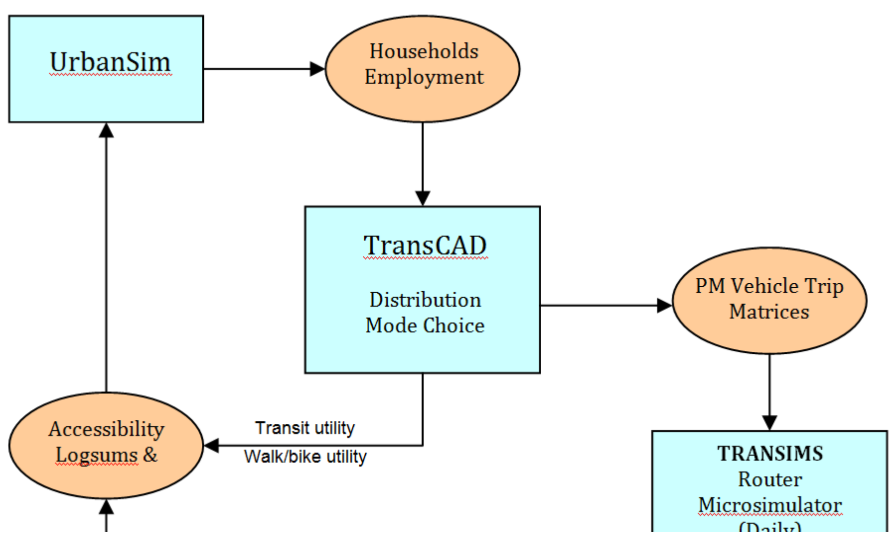

Figure 6. Three-way model process

The 3-way model integrates three distinct planning software platforms: 1) the UrbanSim land use allocation model, 2) the CCMPO TransCAD regional travel demand model, and 3) the CCMPO TRANSIMS regional microsimulation model. The UrbanSim software is used to generate the socio-economic land use data, specifically the total number of households and employment in each traffic analysis zone. The TransCAD-based regional travel demand model is a traditional aggregate 4-step travel demand model. The TransCAD software performs trip generation, trip distribution, mode choice and finally a static vehicle assignment. In the 2-way model, accessibilities are derived using travel times from the static vehicle assignment which are then used as input to UrbanSim. In the 3-way model, the final component of the TransCAD regional travel demand model, namely the static vehicle assignment is removed. It is replaced by a regional vehicle microsimulation that is performed using the TRANSIMS software. In this case, the amount and distribution of the regional auto travel demand is identical to the 2-way model. However, in the 3-way model the auto travel times are derived from a regional microsimulation instead of a static vehicle assignment. Finally, accessibilities are then derived using the simulation-based auto travel times which are then used as input to UrbanSim.

To incorporate the daily CCMPO TRANSIMS model daily trip lists were generated for input to the TRANSIMS Router using the PM peak hour vehicle trip matrices output from the PM peak hour CCMPO TransCAD model. The second step was to update the accessibility measures that are read as input to UrbanSim using auto travel times generated by the TRANSIMS microsimulator in order to finalize the feedback process. The final step to complete the integration was the development of a script that would call and execute each process in the model chain. Figure 6 shows a graphical representation of the integrated 3-way model.

Conversion of PM Vehicle Trip Matrices

To integrate the CCMPO PM-peak hour TransCAD model and the daily CCMPO TRANSIMS model we first needed to convert the PM peak hour vehicle trip matrices which are produced by the TransCAD model to daily vehicle trips.

There are 5 post mode choice vehicle trip matrices for the 3 trip purposes: home-based-other, leaving home; home-based-work, coming home; home-based-other, coming home; home-based-work, work to nonhome and; non-home-based, nonwork to nonhome. There is also a single post distribution trip table which includes the commercial truck trips. Finally, there is a single post distribution trip table which includes the external-to-external trips.

Using diurnal distribution data that was collected and prepared during the development of the daily CCMPO TRANSIMS model, we know the amount of daily traffic volume which occurs in the peak PM hour (defined as 5:00 pm to 6:00 pm in the TransCAD model). We are therefore able to derive a PM peak hour to daily adjustment factor for each trip type using the diurnal distribution data. The diurnal distribution data is presented in Figure 7 below. The calculated PM peak hour to daily adjustment

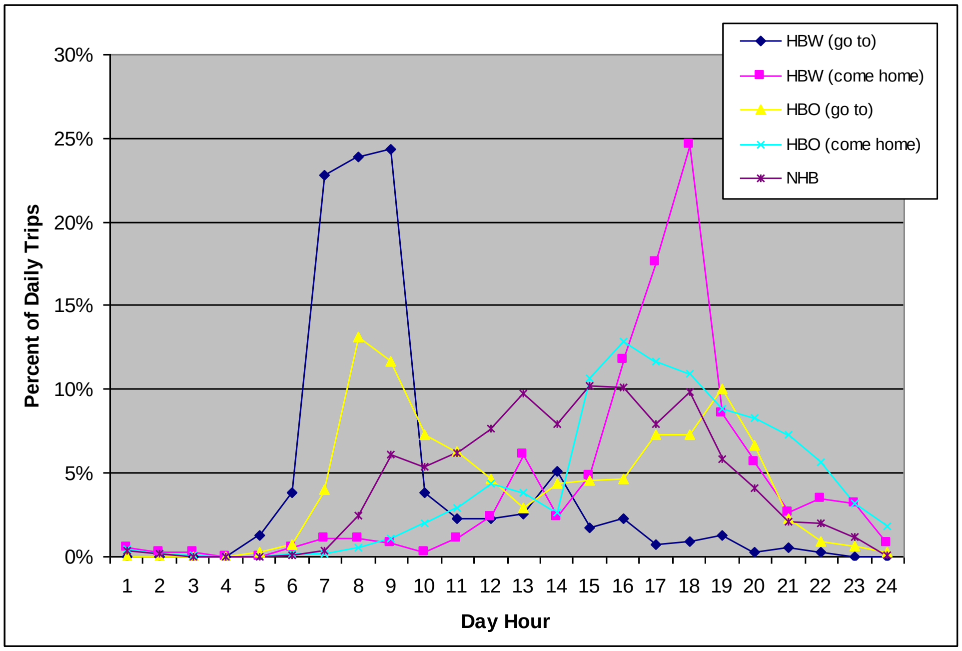

Figure 7 CCMPO TRANSIMS Model Diurnal Distributions

factors are listed in Table 5.

Table 5 PM-Peak Hour to Daily Adjustment Factors

Trip Type	Adjustment Factor
HBW (come home)	4.48
HBO (go to)	13.92
HBO (come home)	8.00
NHB	9.50
Trucks	9.90
Externals	20.00

A new macro was added to the PM-peak hour CCMPO TransCAD model that applies the adjustment factors to the PM vehicle trip matrices to generate daily vehicle matrices. The macro then exports the vehicle trip matrices for each trip type as comma-delimited text files. A custom Visual Basic program then applies a bucket rounding so row totals are maintained since the number of trips for each origin-destination pair must be integerized for input to TRANSIMS. The VB program also converts the format from comma-delimited to tab-delimited required by TRANSIMS. The trip lists for each trip type are now ready for input into the ConvertTrips batch which is the first module of the TRANSIMS model.

Updating the Accessibility File with TRANSIMS Times

For the integrated UrbanSim -> TransCAD model, a file called UtilsLogsum.txt was generated that contains the auto, walk/bike, and transit utilities as well as the logsum for each zone-to-zone pair. This file is then fed back to UrbanSim for the next iteration. By incorporating TRANSIMS into the model chain, we now replace the auto utilities in this file with auto utilities based on zone-to-zone travel times calculated by the TRANSIMS microsimulator instead of the TransCAD model assignment module.

New TRANSIMS based auto utilities are calculated using the following regression equation.

Utility (Auto) = -1.09438 - 0.020795 * TRANSIMS Time

A new logsum value for each zone-to-zone pair must now also be calculated since the auto utilities have changed.

Logsum = LN(EXP[Utility(Walk-Bike)] + EXP[Utility(Transit)] + EXP[Utility(Auto)])

TRANSIMS has built-in utilities that can aggregate the temporally and spatially detailed travel time information produced by the vehicle microsimulation to produce zone-to-zone congested travel time skim matrices for selected time periods and increments. A new module was added to the existing CCMPO TRANSIMS model to produce and save these zone-to-zone travel time skim matrices. The skim file output contains the zone-to-zone congested travel time for the 5:00pm to 6:00pm hour, calculated by the microsimulator since the 2-way model also utilized PM peak hour travel times from the static vehicle assignment.

We have written a python script that reads the existing UtilsLogsum.txt generated by the TransCAD model as well as a TRANSIMS zone-to-zone travel time skim file. The program updates the UtilsLogsum.txt by calculating a new auto utility and then recalculating the logsum for each zone pair using the equations presented above. The revised logsum and utility file can then be used as input to UrbanSim to complete the feedback process.

A new module was added to the CCMPO TRANSIMS model that writes out a zone-to-zone travel time skim matrix. The skim file output contains the zone-to-zone congested travel time for the 5:00pm to 6:00pm hour calculated by the microsimulator.

4.4 Environmental indicators toolbar

During phase 1 and into phase 2 the project team also worked on the development of an ArcObjects-based toolbar for use in ArcGIS (ESRI) to allow for visualization of UrbanSim outputs and calculation of environmental indicators. An earlier and incomplete version of this toolbar was funded under the previous US DOT grant, but the latest, fully-functional version was prepared under the auspices of the TRC project.

This toolbar was designed to estimate future land cover, imperviousness, and changes to water quality due to predicted development as simulated by UrbanSim. Using the outputs of UrbanSim, the toolbar algorithms estimate future land cover and impervious surface and then, based on the pollution coefficients that are currently being estimated in Signature Project 1G, it estimates nutrient export under future conditions. Although those coefficients are not yet available, we created a framework that will allow for easy input of those coefficients when they are, and that also allows for use of "placeholder" coefficients in the interim. The toolbar was mostly developed in phase 1, but testing and correction of bugs continued throughout phase 2.

The toolbar uses the following steps:

1) Tabulating current land cover data by UrbanSim grid cell, yielding a table that gives the percentage of each land cover type for each cell.

2) "Updating" land cover by grid cell with UrbanSim's future predictions of development (which is given in terms of number of residential units and square footage of commercial space). Doing this requires setting a number of assumptions about how each residential unit and square foot of commercial space translates into actual impervious or impacted surface. In general, the amount of impervious surface created for each housing unit will vary upon housing and population density. With commercial sites, each square foot of actual built space will usually be accompanied by additional impacted space for purposes such as parking, driveways, and walkways. We predict that the factor translating built square footage to impacted area will also vary, but in this case with number of jobs. The "update interface" (see Figure 8) allows users to either set a fixed constant translating residential units and commercial square footage into impervious area (using a slider bar), or it allows them to specify variables with which those factors will vary. The output is a table giving predicted future land cover and imperviousness by grid cell.

3) Estimating nutrient export from each grid cell based on future land cover. In the nutrient export calculation interface (Figure 9), users can set a nutrient export coefficient for each land cover type. Each coefficient can be used to calculate amount of that nutrient that is expected to be exported into waterways over a given time period. Although this feature is not currently in place, we hope to eventually include buttons where default coefficient values from the Project 1G research can be easily specified by clicking a button

4) Summarizing nutrient loads by other geography. In this last step, the user specifies a meaningful geographic unit by which to summarize nutrient loads, such as watershed, for generation of maps.

5)

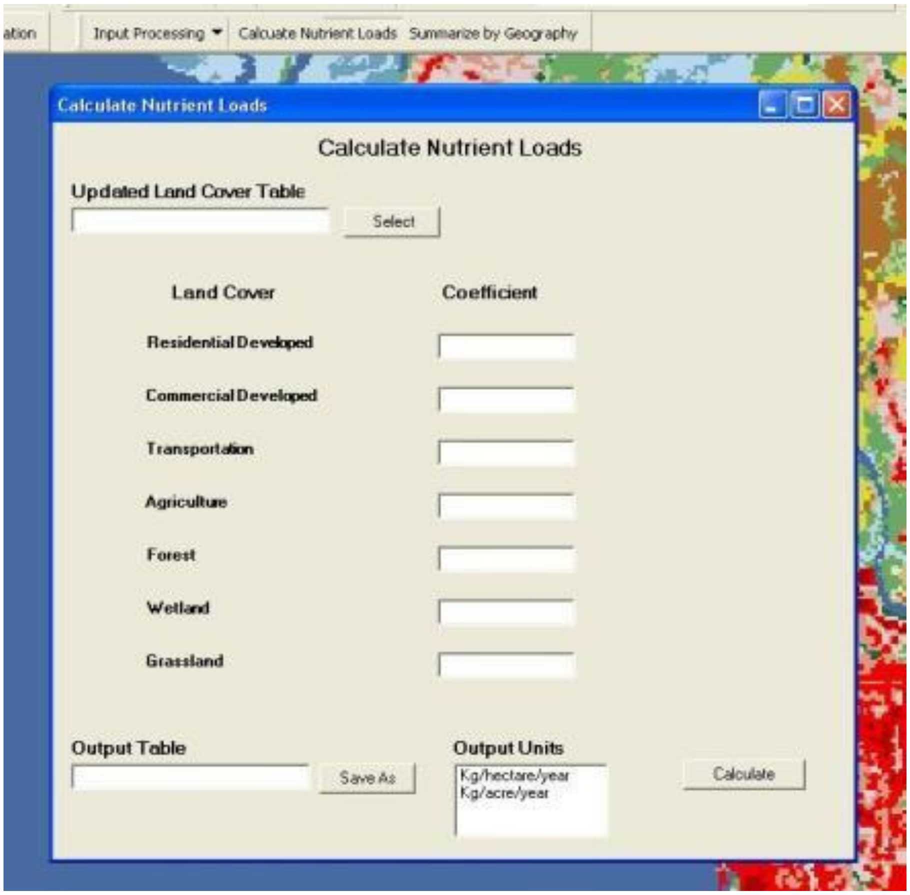

Figure 8 "Update Land Cover" Interface

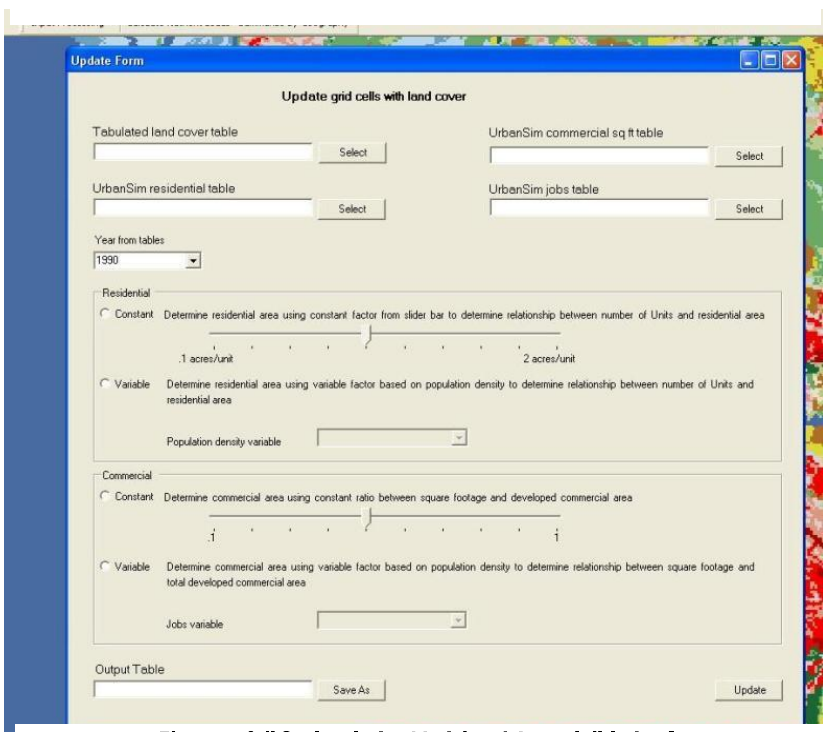

Figure 9 "Calculate Nutrient Loads" Interface

5. Summary of Results from Phase 2

5.1 Comparison of 3-Way and 2-Way Models

The 2-way and 3-way models were compared in terms of their outputs. The results of this comparison and an assessment of the added value of the 3-way model relative to the 2-way was given in Troy et al (2012).

For this comparison, we ran forty year simulations of both the two-way and three-way model integrations using the same data sets, starting in 1990 and ending in 2030. In both cases, UrbanSim iterated every year while the transportation model ran every five years. A fixed seed was used in choice-set delineation for UrbanSim to minimize stochasticity and maximize comparability between the model integrations. Both model integrations use the same UrbanSim model coefficients.

We focused this analysis on three output indicators: residential units (at the town and TAZ level), commercial square footage (at the town and TAZ level) and accessibilities, characterized as logsum values (at the TAZ level only). Because our model base year is 1990, we were able to conduct a preliminary validation of both model integrations against observed data from later years (2006 for household development and 2009 for commercial development). Variance ratio tests were run to look for differences in the statistical distributions of predicted future housing units and commercial square footage. Paired t-tests were run to compare differences between the two-way and three-way models for the same two indicators. These comparisons were broken down first by town and then by a coarser grouping variable which split towns into three categories: core, transitional and non-core. Pearson's correlation coefficients were also estimated on the relationship between absolute values of town-level t-statistics from tests of difference on model predictions for land use indicators and similar t-statistics for accessibility measures.

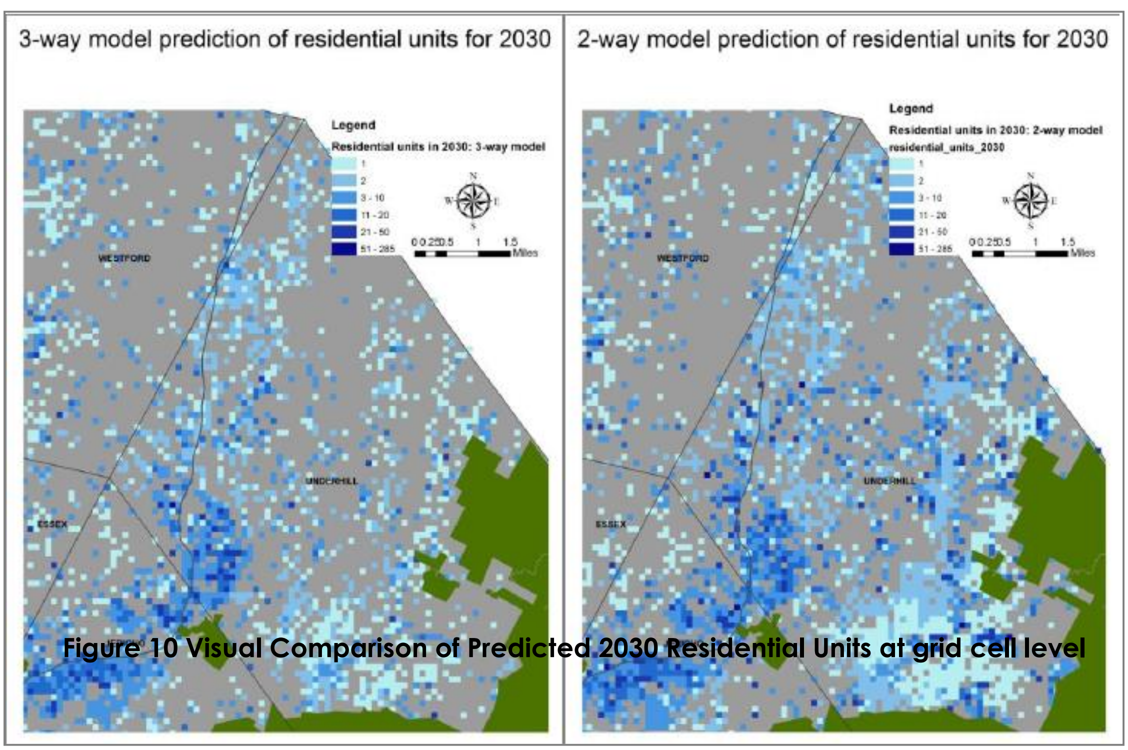

Figure 10 Visual Comparison of Predicted 2030 Residential Units at grid cell level

Comparing model output to actual data from 2006 (residential) and 2009 (commercial, for selected towns only) at both the town and TAZ level, we found no significant differences in prediction accuracy for the two vs. three way models using mean absolute error and root mean square error techniques. However, measures of accessibility for 2030 were slightly different. T-tests of mean-normalized logsum accessibility scores for the year 2030 indicated that there were statistically significant differences in nine of 17 towns in the study area. The towns with the highest two t-statistics (indicating greatest difference) were Essex and Essex Junction.

Differences in predicted accessibility caused by the differences in the transportation models used appeared to result in slight differences in land use outcomes in absolute and percentage terms (see Figure 10 for differences at the grid cell level and Figure 11 for differences at the TAZ level). Correlations between the town level t-statistics representing difference in predicted land use indicators and the difference in predicted accessibilities indicated a very strong and statistically significant relationship between residential unit differences and accessibility differences (less so for commercial development). And, the two towns with the most significant differences in terms of both commercial and residential development, Essex and Essex Junction (Figure 12), also had the biggest statistical differences in predicted accessibility. The fact that Essex Junction and Essex displayed the greatest differences is noteworthy, because these two towns include some of the most congested bottlenecks in Chittenden County and have some of the poorest route redundancy. The fact that the two transportation models predict significantly different traffic flows in these areas suggests that a microsimulator might be particularly useful for these conditions.

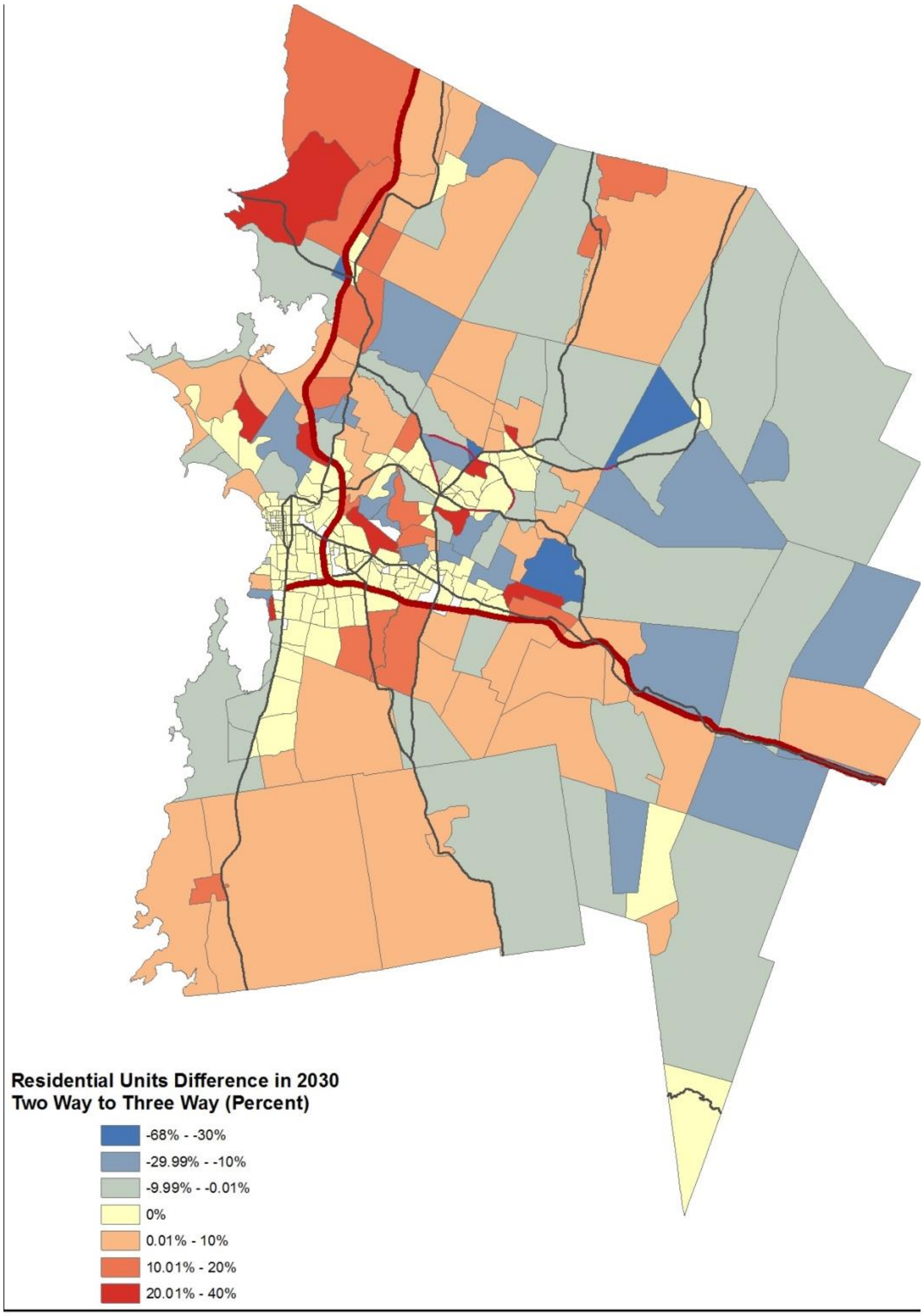

Figure 11. Percentage difference in residential units in 2030 at TAZ level

Despite these differences, we concluded that these potential predictive gains likely do not justify the tremendous added cost of implementing a traffic router and microsimulator in this type of small metropolitan environment, where a general lack of real-world congestion means that computed differences in accessibility are likely to be small. We expect that more crowded and congested metropolitan areas will exhibit more significant differences between the two model integrations.

Understanding why we get this different characterization of accessibility requires some explanation of the difference between a static assignment and simulation. In a static vehicle assignment model, the congestion properties of each roadway link are described by a volume-delay function that expresses the travel time on a link as a function of the volume of traffic on the link and its assumed capacity. The volume of traffic on the link is determined by loading an Origin-Destination (O-D) matrix onto the links via shortest-path routes. The travel times on each link that make up the route are subsequently added together to derive the total travel time for the route.

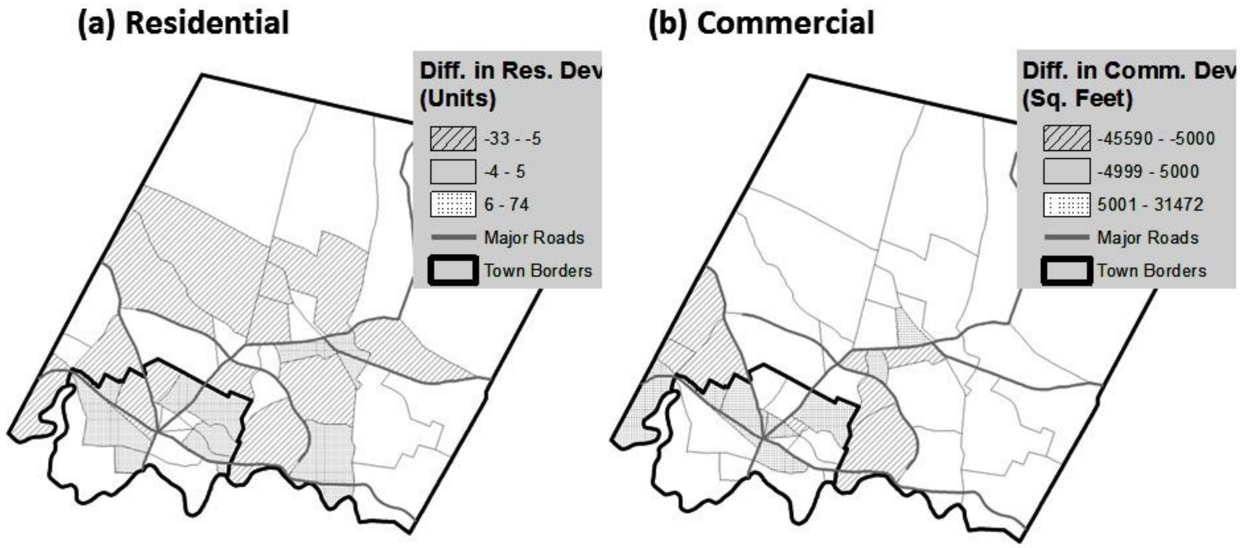

Figure 12. TAZ-level differences in residential development for Essex and Essex Junction

A typical volume-delay function applied in static vehicle ass ignment model is the Bureau of Public Roads (BPR) formula where V is the traffic volume on the link and C is capacity of the link.

$$T_{Congested} = T_{FreeFlow}[1 + 0.15(V / C)^4]$$

Volume-delay functions are limited in their ability to represent the actual processes which take place on roadways that lead to congestion and increased travel time. In static assignment models, the inflow to a link and the outflow are always equal. In addition, the volume-to-capacity ratio does not correlate with any physical measure describing congestion such as speed, density or queue.

Simulation models apply traffic flow dynamics to ensure a more realistic and direct linkage between travel time and congestion by explicitly representing cases where the outflow from a link is less than the inflow. This condition occurs when two lanes merge into one, in high weaving areas near on and off-ramps, on arterial streets where traffic signals reduce capacity, and at choke points where significant queuing from one movement reduces the flow of other entering/exiting movements.

Simulation models track each individual vehicle on the roadway and use much more detailed roadway (where each lane is represented individually) and traffic signal information to reflect the complex and real-world interactions among vehicles on the network. Volume-delay functions are not utilized to derive travel time in the simulation model. The travel times are derived from the second-by-second movement of vehicles through the network using a cellular automata simulation where speeds and locations are measured as an integer number of cells per time step in the case of TRANSIMS. In the cellular automata simulation applied in TRANSIMS, each link in the roadway network is divided into a number of grid cells and vehicles move within the grid based on a complex set of rules that govern when and how a vehicle can move into a new downstream grid cell.

5.2 Growth boundary scenario analysis

This research, which resulted in a master's thesis and journal article (Azaria et al, 2013), used the two-way model to determine the impact than urban growth boundary might have on vehicle miles traveled (VMT) in Chittenden County. The outputs of the three following scenarios were compared:

Table 6. Growth boundary scenarios

Scenario Name	Description
Business as Usual	- Land use and zoning limits on development reflect actual regulations as of 1990 throughout the county
Urban Core	- Land use and zoning limits in a central core of 31 square miles, as depicted in Figure 2(a), reflect actual regulations as of 1990 - In the balance of the county, no new development is permitted - Existing properties can still be used in the "no growth" area, and people and businesses can move in and out freely
Multi Center	- Land use and zoning limits in 16 town or village centers covering a total of 41 square miles, as depicted in Figure 2(b), reflect actual regulations as of 1990 - In the balance of the county, no new development is permitted - Existing properties can still be used in the "no growth" area, and people and businesses can move in and out freely

The urban core scenario (Figure 13) was designed to keep the area within the urban core as compact as possible , taking into account the existing road network and development patterns. The intent of the multi center scenario (Figure 14) was to spread growth around, while still requiring that it be relatively compact in those places where it is permitted.

The simulation found that urban core scenario results in greater population density in the urban core (7.2 vs. 4.7 people per acre) in 2030 (Table 7). Under the town centers scenario, housing density in satellite towns is predicted to be 2.3 units per acre in 2030 as compared with 1.2 units under business as usual. As for land consumption, under the business as usual scenario, 14,000 acres are predicted to be consumed by 2030, while that figure is 4400 acres for the urban core scenario and 8100 acres for the multicenter scenario.

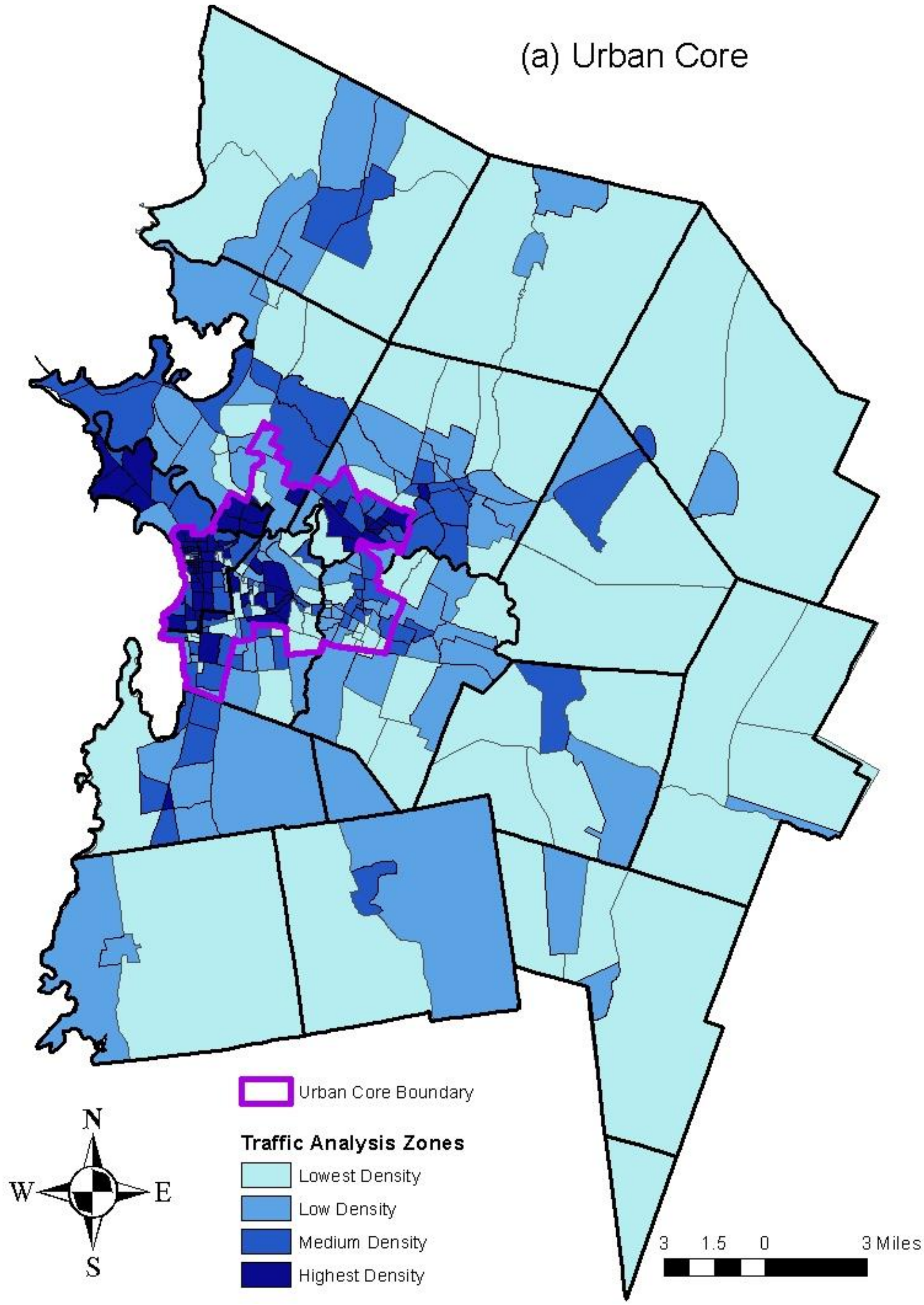

Figure 13. Urban core scenario

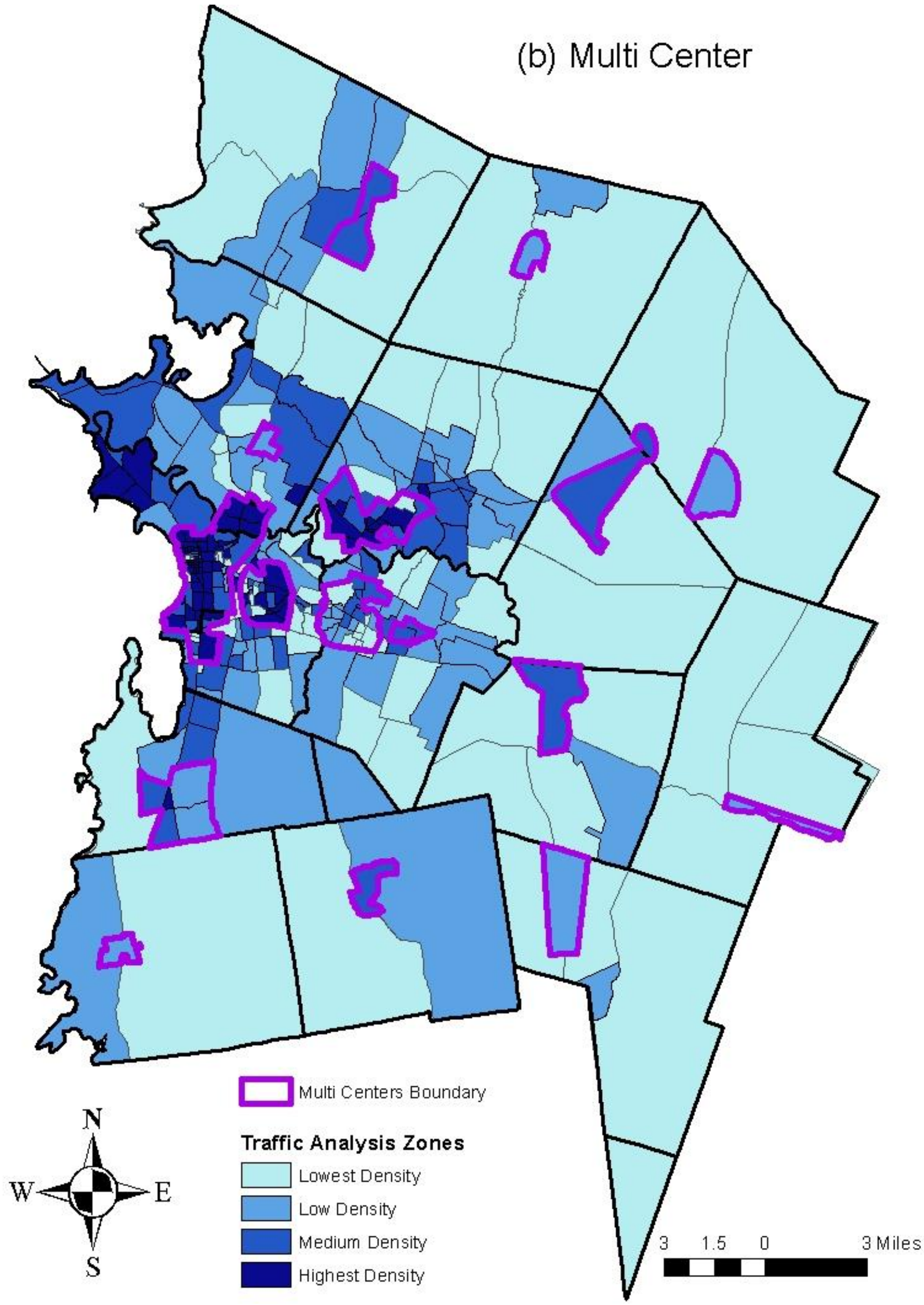

Figure 14. Multi center scenario

Table 7. Land use outcomes under scenarios

	1990	2030 business as usual	2030 urban case	2030 multicenter
Gridcells with any residential development				
gridcells	11 531	14 062	12 327	12 999
acres	64 111	78 183	68 536	72 273
residential units	52 878	86 098	86 041	86 073
Gridcells with >1 residential units/acre				
gridcells	1 939	4 402	3 008	3 126
residential units	37 306	65 936	71 102	69 090
percentage	71	77	83	80
Gridcells with >10 residential units/acre				
gridcells	128	128	172	173
residential units	12 615	12 664	20 226	20 227
percentage	24	15	24	23

Travel demand is also predicted to vary significantly based on scenario (Table 8). The urban core scenario is predicted to result in 25% less VMT in 2030 than the business as usual scenario, with 8% fewer vehicle trips and 29% more walking and biking trips and 23% more transit trips. The multicenter scenario yields results that are in between the other two scenarios, as shown in the table below. One tradeoff, however, is that the overall accessibility of the urban core go down somewhat in the urban core scenario due to increased congestion. However, accessibility is lower in the periphery under the business as usual scenario relative to the urban core scenario because of the outward spread of residential development.

Table 8. VMT outcomes under scenarios

	1991	2030 business as usual	2030 urban core	2030 multicenter
Vehicle trips	40 715	70 409	64 586	54 263
Vehicle trips/capita	0.32	0.33	0.30	0.25
VMT[b]	324 203	622 775	465 256	492 802
VMT[b]/capita	2.60	2.90	2.20	2.30
VHT[c]	13 296	24 873	19 679	20 533
VHT[c]/capita	0.10	0.11	0.091	0.10
Walking trips	5 531	7 945	9 735	9 643
Bus trips	308	425	550	527

[a] Because the travel demand model from which these results are derived is a peak-hour model that uses only a portion of the actual road network, the results should not be considered to be predictions of actual travel levels. Rather, they should be considered as relative values, meaningful only in comparison with each other.

[b] VMT = vehicle miles of travel.

[c] VHT = vehicle hours of travel.

5.3 Correlating urban form metrics with VMT

This research, which resulted in a master's thesis (Lanute 2013), attempted to quantify the relationship between urban form metrics and VMT by creating forty urban form scenarios for Chittenden County within the 2-way model and regressing those urban form metrics against predicted VMT in each case. The forty scenarios were defined by creating varying combinations of six urban growth boundaries. Many, but not all, of the model's development constraints, are based on town zoning laws.

The first three growth boundary zones were denoted as core, middle, and satellite - with the satellite boundary being composed of six mutually exclusive, small downtowns on the periphery of the county. The next two included a boundary encompassing a two mile buffer moving outwardly from the middle boundary and a boundary encompassing a two-mile buffer moving outwardly from the satellite boundary. Any overlap between a buffer region and one of the three original regions was defaulted to the original region. Any overlap between two buffer regions was defaulted to the middle buffer region. Lastly, any area of land that was not contained within one of those five urban growth boundaries was denoted a "non-designated" area. This created a total of six designated urban growth boundaries (Figure 15) that were systematically implemented in various combinations from one scenario to the next.

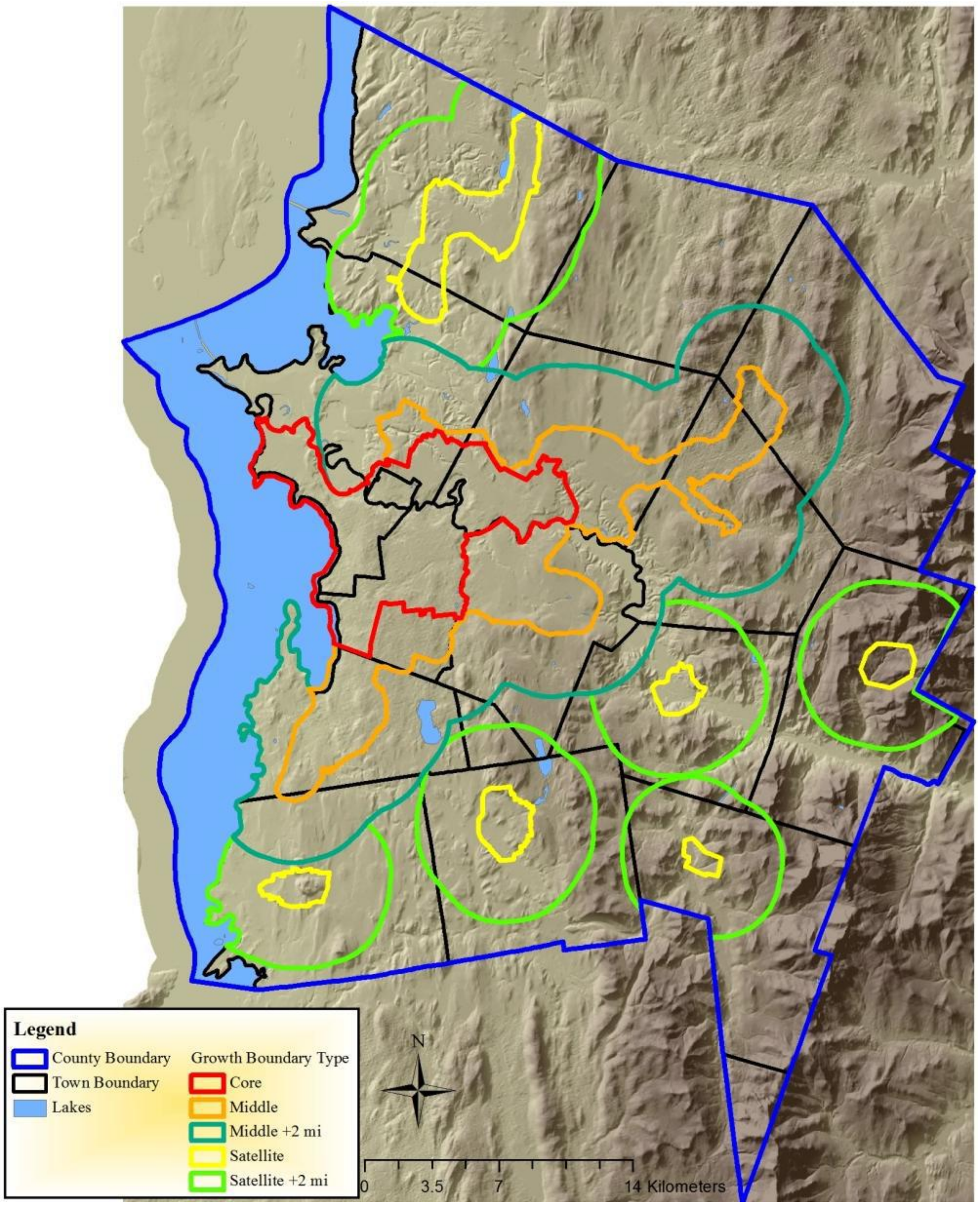

Figure 15. Growth boundary constituent elements

Three assumptions were maintained in the development of these scenarios: the same population and employment forecasts were used for each scenario; the same road network was used for each scenario and was held constant throughout each scenario; and if a particular grid cell was not designated as within an urban growth boundary for a given scenario, then the baseline zoning constraints were applied.

The urban form metrics created from these scenarios included measures of residential density gradient, centrality and fragmentation. For the first category, there were three measures: Euclidean gradient, a drive distance gradient, and a drive time gradient. Each represented a different way for estimating a residential density gradient curve. For the measures of centrality there were also three measures: one based on moncentric form, one based on polycentric centers close to the urban core and one based on polycentric centers further from the urban core. Each centrality metric was calculated based on the total number of residential units for 2030 within a given distance threshold from the areas designated as centers. Finally, there were two indicators of fragmentation, one measuring the degree of build-out (PLAND) and one measuring “contagion.”

These and other variables were regressed separately against predicted VMT with the result that fourteen predictor variables were found to yield R^2 values above .50. Among the best fitting metrics were those describing centrality (Table 9). In all cases, centrality measures had negative coefficients, showing that greater centrality leads to significantly lower VMT, and that this effect is greatest where population share is concentrated relative to a single urban center.

Table 9. Built form variables associated with VMT

	Independent Variable	Coefficient	Significance	Adjusted R^2
Residential Density Gradients				
1.	Euclidean Distance Gradient	1983.858849	0	0.589
2.	Drive Distance Gradient	2686.306018	0	0.514
3.	Drive Time Gradient	1712.867792	0	0.385
Residential Centrality Measures				
4.	Monocentric Centrality	-7.372454	0	0.917
5.	Polycentric Centrality - Inner Satellites	-7.664397	0	0.892
6.	Polycentric Centrality - Outer Satellites	-6.996163	0	0.605
Two-Class Landscape Metrics				
7.	Shannon's Diversity Index	2245.267	0	0.643
8.	Undeveloped PLAND	-10.613	0	0.78

6. Conclusions

This research project resulted in a number of valuable findings and deliverables that will directly or indirectly assist planners and policy makers in applying modeling to complex decision making at the interface of land use and transportation. Among the deliverables and findings of value are:

- An implementation of an integrated land use-transportation model for a small, isolated metropolitan area, which both demonstrates that such models are applicable to this context and can be used to help guide future modeling efforts in these contexts. This implementation and the many data sets used to created it are also of direct value to Chittenden County itself, whose MPO and RPC were partners on this.
- A determination that there is a significant difference in the predicted land use outcomes under a two-way model relative to a stand-alone land use model and that these differences largely stem

from the fact that increasing decentralization of commercial development over time changes the overall accessibility of once-peripheral locations, and that only a model integration travel demand can account for this.

- A successful integration of the three-way model, proving that a dynamic land use model like UrbanSim can be integrated with a 4-step travel demand model and a traffic router/micro-simulator, and that outputs and predictions are reasonable. We found that the 3-way model results in slight differences in predicted land use changes relative to the 2-way model, particularly where there is potential for congestion. Despite these slight differences, we concluded that the added work and expense of the 3-way model may not be warranted, particularly for smaller metropolitan areas like Chittenden County, where traffic congestion is fairly minimal.
- An ArcGIS toolbar that allows users to calculate predicted future impervious surface by any geography using the outputs of UrbanSim. This can then be used to estimate predicted nutrient fluxes by watershed or other geography. This greatly speeds up and facilitates the comparison of different scenario outputs in terms of environmental performance.
- Feedback on the types of scenarios that planners, business people and other stakeholders are interested in seeing evaluated with this type of integrated model, as gathered from our stakeholder workshops.
- A finding that this model implementation can be used successfully to evaluate and compare alternative policy scenarios. Examples include:
    - Analysis of transportation network improvements that focus on better route connectivity and redundancy and are largely consistent with Chittenden County's Metropolitan Transportation Plan. This scenario analysis found that the combined improvements result in a county-wide reduction in the vehicle hours traveled and that land use does change as a result, but only in grid cells very close to the investments.
    - Analysis of urban growth boundaries. This study found that an urban core-based growth boundary would result in far greater population concentration in the core, significantly reduced vehicle miles traveled, and less land consumption.
- A finding that urban form does have a strong correlation with predicted vehicle miles traveled, even in a small metropolitan area like Chittenden County. This analysis found particularly that measures of centrality—that is how and in what pattern buildings are concentrated—has a very strong impact on distances driven.

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