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# Phase I Report: Integrated Land Use, Transportation and Environmental Modeling

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A Report from the University of Vermont Transportation Research Center

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# Phase I Report
# UVM Transportation Research Center Signature Project 1B – Integrated Land Use, Transportation and Environmental Modeling

July 2010

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## Disclaimer

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# 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 realistic evaluation of strategies that are significant to policy and planning. But this comes at a cost. Disaggregation and complexity require money, time and resources that often 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 the Federal Highway Administration (USDOT 1999) and many researchers (Giuliano 1989; Moore, Thorsnes et al. 1996; Boarnet and Chalermpong 2001; Cervero 2003), In fact, under the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and, to a lesser extent, the Transportation Equity Act for the Twenty First Century (TEA-21) of 1997, 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 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 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, which has evolved from non-spatial mathematical specifications of linear relationships to spatially explicit dynamic simulations that allow feedback between model subsystems and account for a divergent set of institutional and ecological forcing.

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 micro simulation.

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) and is found an excellent choice for integrated land use and transportation modeling (Miller, Kriger et al. 1999). 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. This model has been applied to metropolitan areas in Washington, Oregon, Hawaii, and Utah.

While almost all other urban growth models rely on aggregate cross-sectional equilibrium predictive approaches, UrbanSim is an agent-based behavioral simulation model that includes both households and employers and operates under dynamic disequilibrium, which allows for more realistic modeling of economic behavior. . UrbanSim also 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, a GIS-based transportation planning software package, the Chittenden County Metropolitan Planning Organization's (CCMPO) implementation of TransCAD v4.7 was used.. A calibrated model was developed for the CCMPO 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. The travel model is based on household travel diaries that were collected for the CCMPO. Traffic assignment is based on an equilibrium model that 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 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. 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

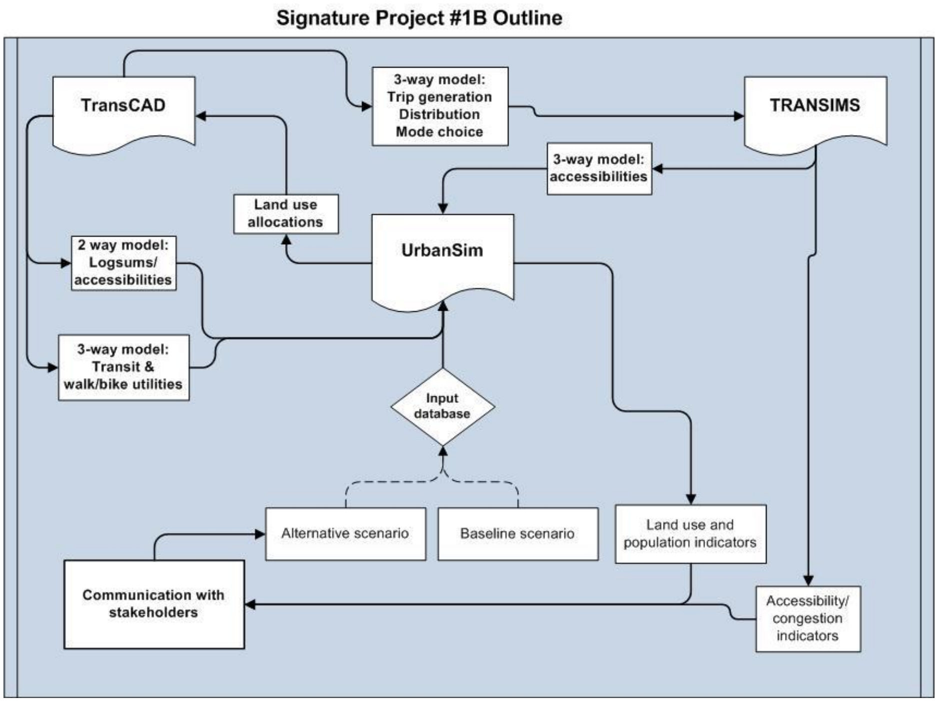
As of September 2009, the TRC Signature Project No. 1 is treated as two separate components under the Land Use and Transportation Modeling focus area:

- The Integrated Modeling Project
- The Environmental Metrics Project

The Integrated Modeling Project seeks to implement several versions of an integrated land use/transportation model for Chittenden County, Vermont. Based on those results, the TRC project team hopes 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, the aim of the project is to gain insight about how the appropriateness of model disaggregation and complexity may also vary with policy application. Towards this end the project team will 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, from here on, the former integration will be referred to as the "2-way model" and the latter as the "3-way model".

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**



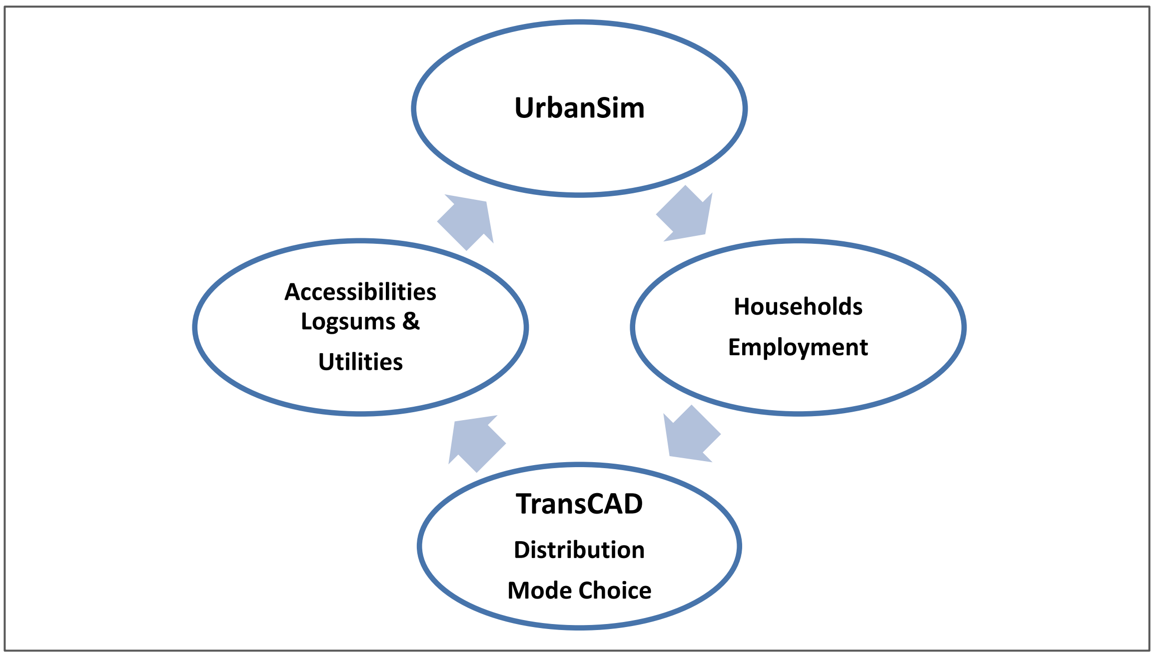

## 3. Summary of Previous Research

Phase I activities for this project are built on products from two previous research grants from the USDOT FHWA: "Dynamic Transportation and Land Use Modeling" (PI: Austin Troy); and "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 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 at http://www.uvm.edu/envnr/countymodel/TROY_DOTfinal_report.pdf. The result of this process yielded reasonable and internally consistent outputs and successfully integrated a two-way model that could be run from the 1990 base year through 2030, A diagram of this two-way model is given in Figure 2.

**Figure 2. 2-Way Model Diagram**




### 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 USDOT 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.

A significant different was seen 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 and triggers development. This analysis is described in detail in the USDOT Final Report and in Voigt, Troy, et al. (In press) and 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 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) 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 2 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 | 147,585 | 143,217 | 3.0% | 7.9% |
| Major Arterial | 262 | 120,211 | 134,270 | -10.5% | 29.1% |
| Minor Arterial | 170 | 87,890 | 89,765 | -2.1% | 31.3% |
| Collector | 376 | 119,513 | 110,136 | 8.5% | 45.9% |
| Ramp | 36 | 8,310 | 7,744 | 7.3% | 26.8% |

Two types of preliminary sensitivity analyses were performed: assessing the sensitivity of the model results to changes in the seed number; assessing the impact of replacing a set of pre-timed signals with actuated controllers. Full results of these sensitivity tests and validation have been documented (Lawe et al, 2009).

**Calibrating TRANSIMS with GA's – Preliminary Investigation**

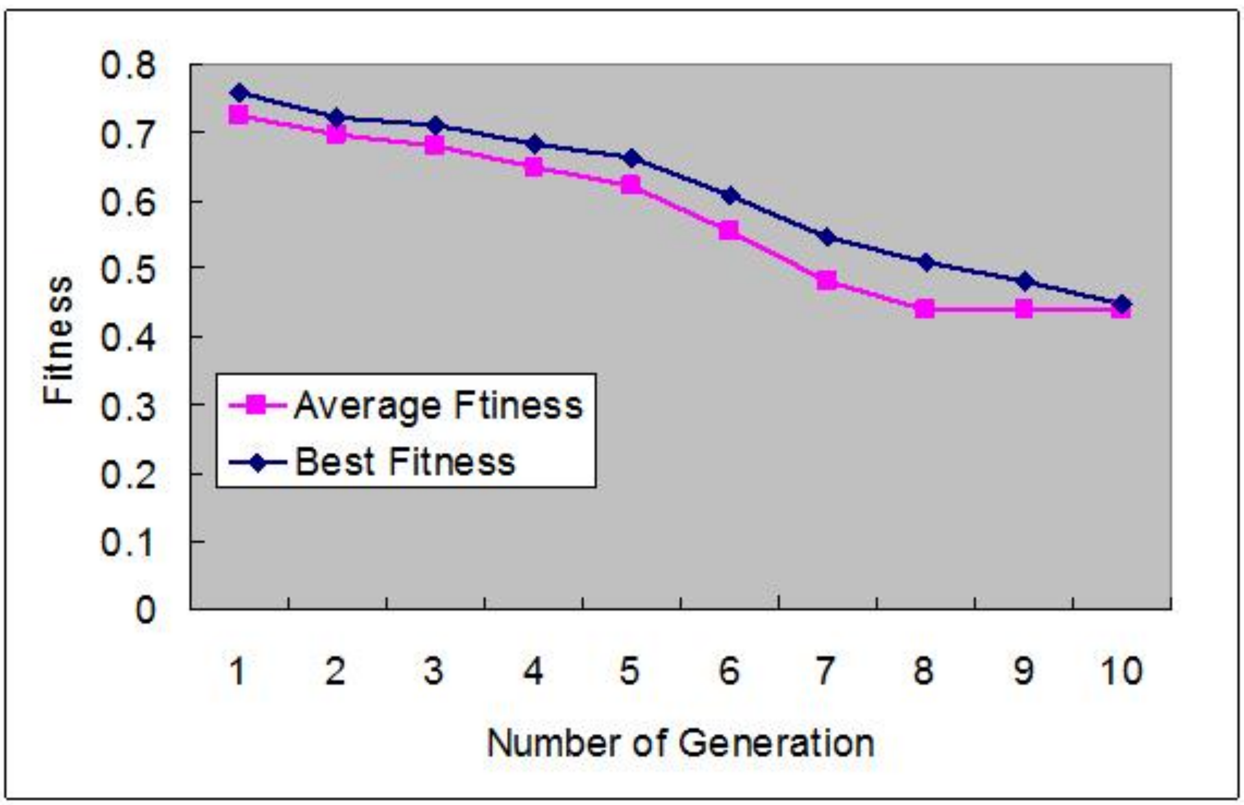
Genetic Algorithms (GAs) are stochastic algorithms whose search methods are based on the principle of survival of the fittest. The use of GA in conjunction with micro-simulation model calibration offers several advantages. GAs do not require gradient information, are rather robust, and can overcome the 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: the computational requirements of running TRANSIMS; memory usage; and 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).

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: study the feasibility of using GA for travel demand calibration in TRANSIMS; conduct some sensitivity analysis tests aimed at understanding the problem characteristics; and determine empirically the best settings for the GA parameters, which included 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 (ie, the O-D 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 (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 seen from Figure 3, 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.

**Figure 3. Preliminary Results for GA Calibration of TRANSIMS**



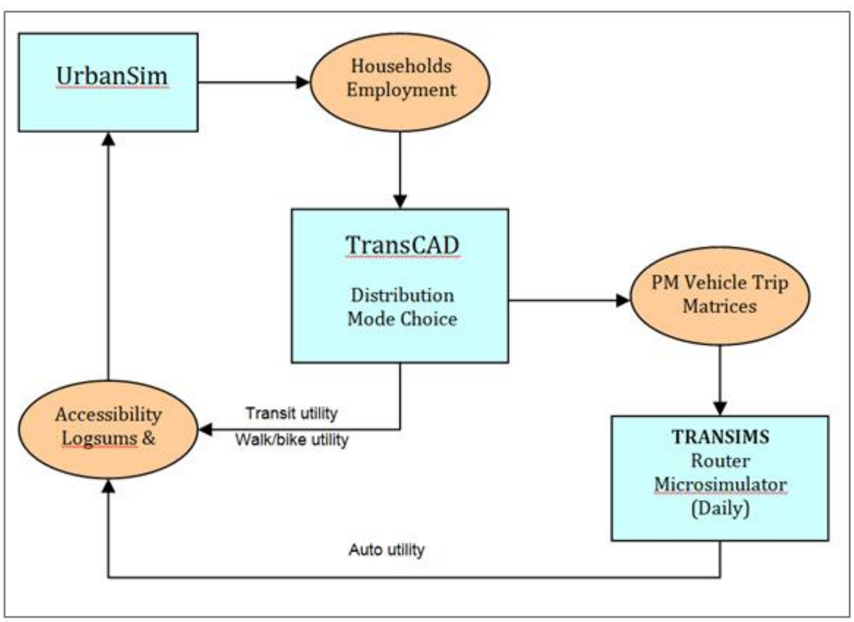
# 4. Summary of Phase I Integrated Modeling Activities

## 4.1 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 Resource Systems Group, Inc., with the exception of the estimation of the regression equation for translation of auto utilities to travel times.

The 3-way model integrates three distinct planning software platforms: the UrbanSim land use allocation model; the CCMPO TransCAD regional travel demand model; and 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 and 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.

**Figure 4. 3-Way Integrated Model Diagram**



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 4 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, the project team first needed to convert the PM peak hour vehicle trip matrices that 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 non-home and; non-home-based, non-work to non-home. There is also a single post distribution trip table that includes commercial truck trips. Finally, there is a single post distribution trip table that includes the external-to-external trips.

Using diurnal distribution data that were collected and prepared during the development of the daily CCMPO TRANSIMS model, the amount of daily traffic volume which occurs in the peak PM hour were known (defined as 5:00 pm to 6:00 pm in the TransCAD model). Therefore, it was possible to derive a PM peak hour to daily adjustment factor for each trip type using the diurnal distribution data. The diurnal distribution data are presented in Figure 5. The calculated PM peak hour to daily adjustment factors are listed in Table 2.

**Figure 5. CCMPO TRANSIMS Model Diurnal Distributions**

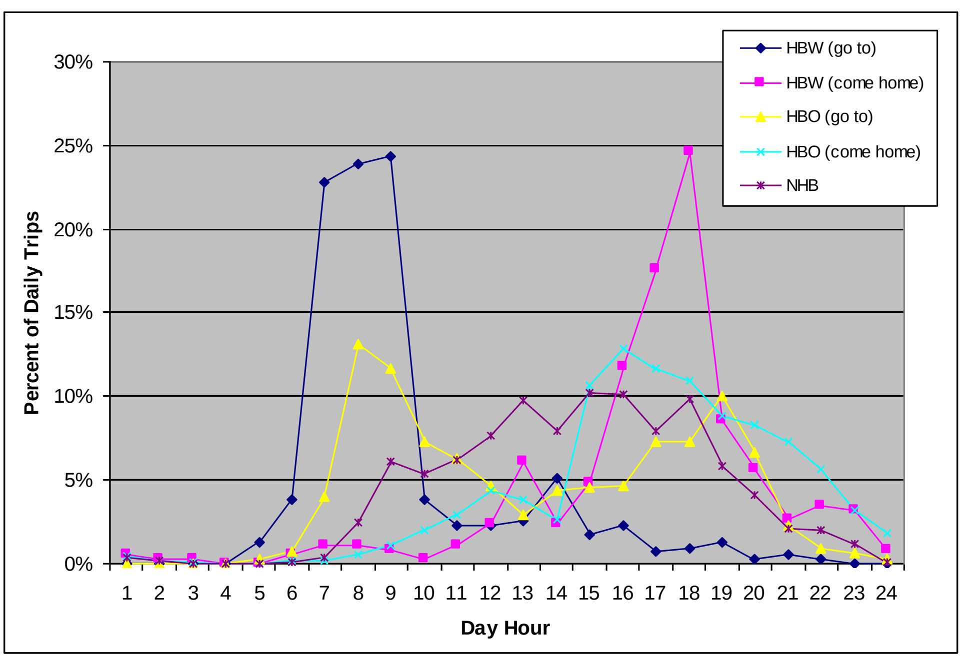


**Table 2. PM-Peak Hour to Daily Adjustment Factors**

| 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 (VB) 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 creates 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, the auto utilities are now replaced 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 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 5:00 pm to 6:00 pm 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.

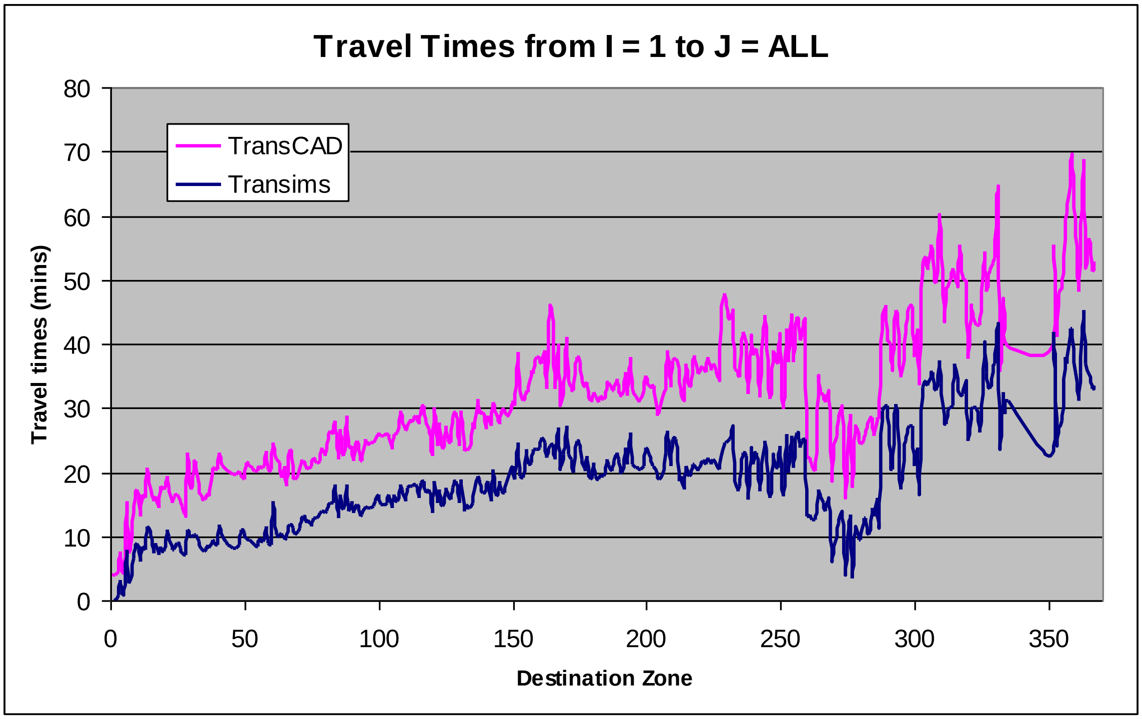
## 4.2 Preliminary Comparison of 3-Way and 2-Way Models

With the completion of the 3-way model integration in early November 2009, preliminary comparisons were conducted of outputs between that and the 2-way model. All of the outputs discussed in this section are for the forecast year 2030. These are preliminary results only - considerable work remains to be done in this area.

### Preliminary Comparison of Travel Times

Figure 6 compares the PM-peak hour zone-to-zone travel times produced for forecast year 2005 by the TransCAD model (2-way model) and the TRANSIMS model (3-way model). The plots show the travel times for origin zone 1 to all other destination zones. It should be noted that a comprehensive review and comparison of the TRANSIMS travel time skim data against the TransCAD travel time skim data for all zone pairs has not been prepared yet. However, if differences similar to those shown in Figure 5 were observed, rescaling the auto utility equation accordingly would be suggested. The causes for why travel times are consistently lower in the TRANSIMS simulation than in the TransCAD assignment in the figure below has not yet been fully investigated, but it may simply be due to the fact that travel times from one zone only have been analyzed. There may be other zones where the opposite is true. Currently, data are lacking to adequately determine which characterization of travel times is more accurate at this point. Both of these questions will be investigated in subsequent research.

**Figure 6. PM – Peak Hour Travel Times Comparison for Static Assignment (TransCAD) and Simulation (TRANSIMS)**




## Preliminary Comparisons of UrbanSim Indicators

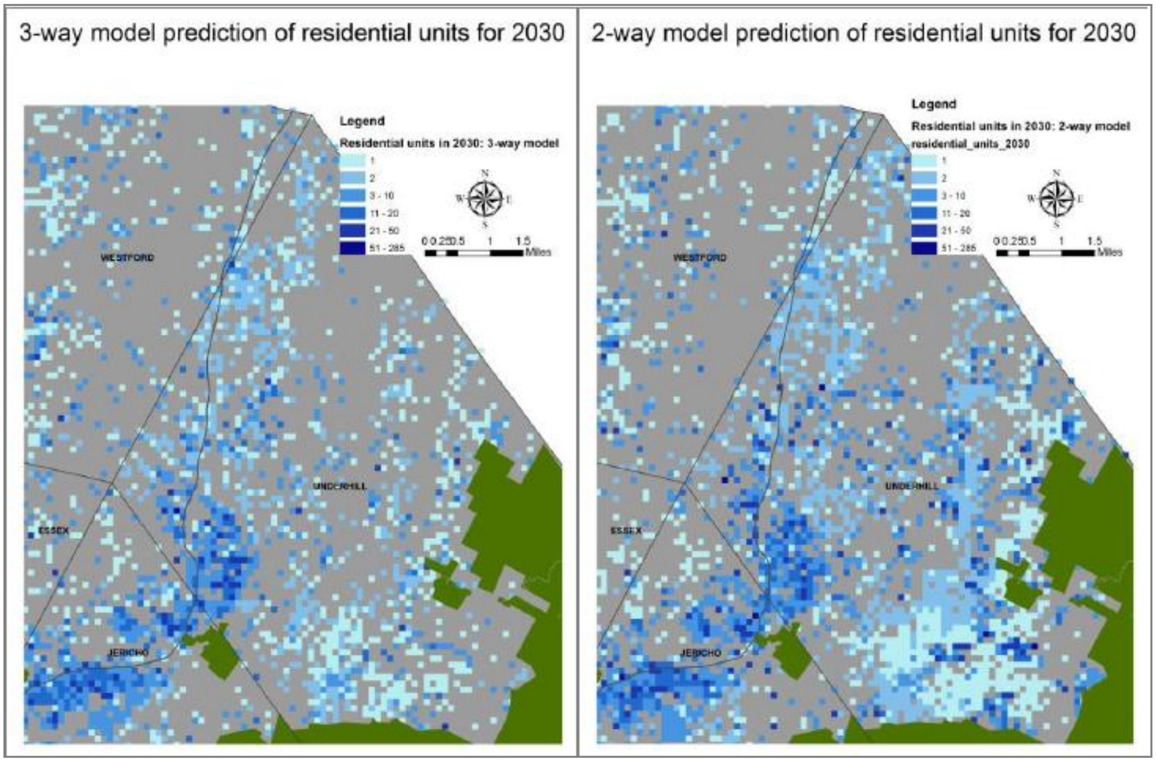
Preliminary comparisons between the 2-way (using traffic assignment) and 3-way (using traffic microsimulation) models suggest significant differences in predicted residential units and commercial square footage by town, as shown in Table 3.

**Table 3. Comparison of Land Use Indicators Summarized at the Town Level**

| | Residential units | | | Commercial square footage | | |
|---|---|---|---|---|---|---|
| | 2030-3way | 2030-2way | % diff | 2030-3way | 2030-2way | % diff |
| Bolton | 1324 | 1350 | 2% | 675,832 | 611,539 | -11% |
| Buels | 20 | 26 | 23% | 264,625 | 324,336 | 18% |
| Burlington | 16435 | 16365 | 0% | 10,621,194 | 10,622,922 | 0% |
| Charlotte | 3101 | 2816 | -10% | 3,552,133 | 4,242,071 | 16% |
| Colchester | 9911 | 9418 | -5% | 2,726,101 | 3,462,653 | 21% |
| Essex | 8488 | 8418 | -1% | 4,057,979 | 5,088,850 | 20% |
| Hinesburg | 2981 | 3397 | 12% | 310,207 | 352,759 | 12% |
| Huntington | 1530 | 1499 | -2% | 1,476,543 | 1,422,927 | -4% |
| Jericho | 4199 | 5290 | 21% | 427,880 | 759,246 | 44% |
| Milton | 8989 | 4689 | -92% | 13,032,393 | 5,977,818 | -118% |
| Richmond | 5173 | 5638 | 8% | 2,797,301 | 5,359,473 | 48% |
| Shelburne | 3101 | 2886 | -7% | 1,262,605 | 1,351,397 | 7% |
| South Burlington | 5511 | 5478 | -1% | 4,141,137 | 4,120,148 | -1% |
| St. George | 355 | 364 | 2% | 65,540 | 49,584 | -32% |
| Underhill | 4292 | 8764 | 51% | 972,988 | 2,000,071 | 51% |
| Westford | 4891 | 3935 | -24% | 996,665 | 1,594,096 | 37% |
| Williston | 2866 | 2838 | -1% | 3,434,804 | 3,685,083 | 7% |
| Winooski | 2934 | 2934 | 0% | 507,938 | 507,938 | 0% |
| Total | 86101 | 86105 | | 51,323,865 | 51,532,911 | |

The maps in Figure 7 also suggest significant visual differences at the grid cell level for the northeastern part of the county. These results suggest that inclusion of TRANSIMS not only has a large impact on predicted travels times, but also on predicted long-term land use change. Towns with big predicted differences are Milton and Underhill. The 3-way model shows nearly double the residential units and more than double the commercial square footage for Milton, located in northern Chittenden County along the I-89 corridor. This result suggests that TRANSIMS is predicting far greater accessibilities for Milton than TransCAD alone for the level of accessibility, one of the primary drivers of development events. While more analysis of the model outputs is required to confirm exactly why these results differed, one possibility is that TRANSIMS, with its more realistic depiction of traffic behavior, is predicting greater congestion, and hence losses to accessibility, throughout the parts of the county primarily serviced by surface streets relative to Milton, which is primarily serviced by an uncongested stretch of Interstate. Therefore Milton becomes more desirable relative to the other parts of the county with similar amounts of developable land. Another way of thinking of this is that TRANSIMS makes those other parts of the county seem comparatively less attractive because of their lower relative accessibilities. On the other hand, the 3-way model predicts only half the residential development for Underhill (see Figure 7) than the 2-way model—the opposite result. This is consistent with Milton results. In this case, the 3-way model predicts less development for distant Underhill because getting from Underhill to any major employment center requires commuting on small highways and surface streets, not Interstates. With its more detailed characterization of accessibility from the simulation in the 3-way model, all those surface streets become more congested, leading to lower average accessibility—and lower development desirability—for areas dependent on those types of roads alone, such as Underhill.

**Figure 7. Visual Comparison of Predicted 2030 Residential Units**




Understanding why this different characterization of accessibility exists 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 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. A typical volume-delay function applied in static vehicle assignment 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.

### 4.3 Stakeholder Workshop

A large stakeholder workshop was co-sponsored between this project and the USDOT-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, a stakeholder workshop was conducted and organized in conjunction with the CCMPO and the Chittenden County Regional Planning Commission (CCRPC).

The workshop was held on March 26, 2008. Approximately 70 people attended, including most of the planners from CCRPC, CCMPO and top planners from most of the county's major towns and cities. The workshop involved a presentation, which can be seen at 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.

1. **Transportation corridor-oriented development for the county**. Focusing on two major corridors, Routes 15 and 2, this scenario involved a range of potential changes: 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, e.g., schools, parks, and government buildings within the zones of influence of these corridors.

2. **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.

3. **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.

4. **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.

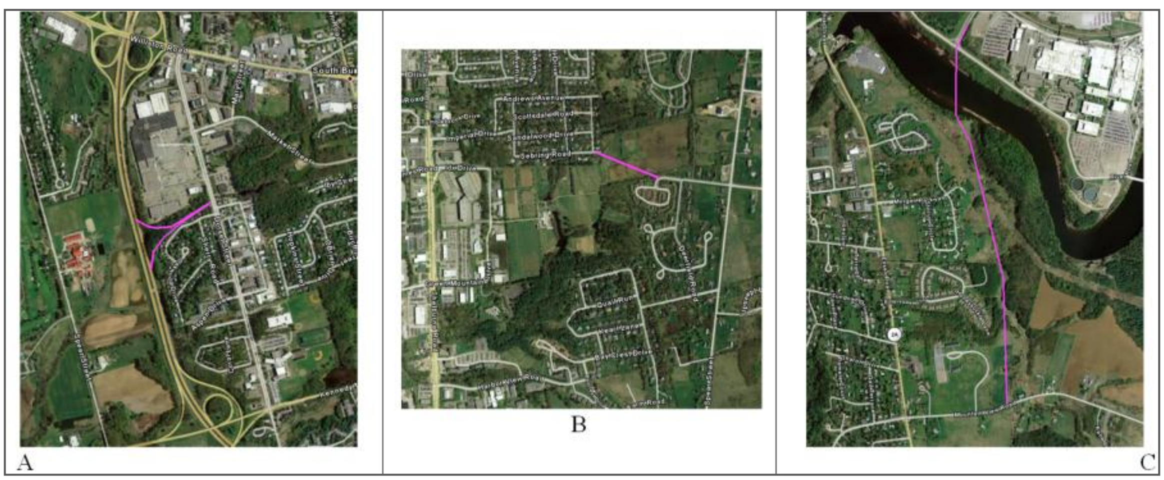
5. **Natural areas protection/ green scenario.** Participants in this scenario were asked to implement regulations that minimize the county's environmental footprint. In particular, they were asked to focus on conservation of important natural areas.

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.

### 4.4 New Alternative Scenarios Using 2-Way Model

Two of the scenarios were evaluated under the USDOT funding, Natural Areas Protection (#5) and Growth Centers (#2). Results are described in detail in the USDOT Final Report. More recently, using TRC funding, the Investment in Roadways scenario (#3) was evaluated under both baseline population and later evaluated 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.

**Figure 8. Examples of Tree 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.

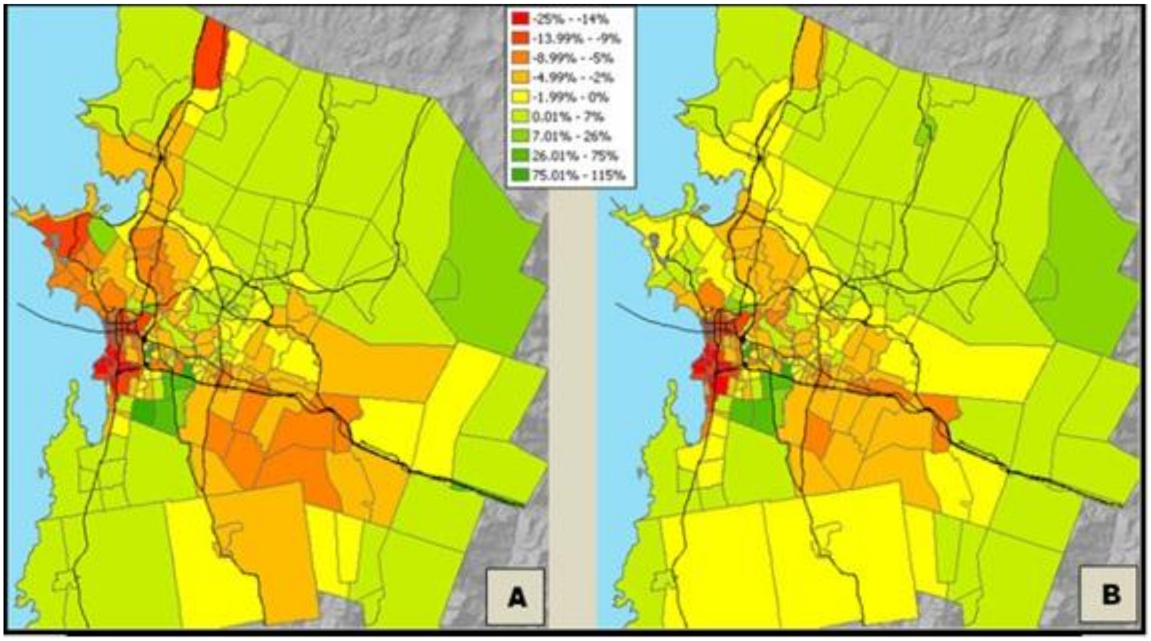
Analysis found significant differences between the baseline and stakeholder scenarios. Not only did the improvements suggested by the stakeholders reduce average vehicle hours travelled, but they also resulted in changes to land use. While these changes were not statistically evident when looking at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

Regional results, presented in Table 4, 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 vehicle miles traveled (VMT) by TAZ are shown graphically in the maps in Figure 9. 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 4. Vehicle-Miles Traveled and Vehicle-Hours Traveled in Chittenden County Under**

| | 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% |

**Figure 9. Percent Difference in Vehicle-Miles Traveled Between Baseline and MTP (A) and Between Baseline and Stakeholder (B)**




Statistically significant differences in VMT were also found at the TAZ scale between scenarios using forecast control totals. Table 5 shows the P-values from statistical tests of difference, with all those significant at the 95% confidence level given in bold. The 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).

**Table 5. 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. Grid cell outputs were evaluated 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, significant differences were found in almost all land use outputs at the 500 m scale and in vacancy variables at greater lags (Table 6).

**Table 6. P-Values of T-tests Comparing MTP and Stakeholder Scenario Outputs Against the Baseline Model Results at the Grid cell-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, no longer there was 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, a greater variation at the nearby scale (i.e. 500 m) was expected because the areas near those improvements do not reach capacity.

The existence of these statistically significant differences tells reveal that this model predicts different outcomes under alternative versus baseline scenarios. In terms of transportation, it was found that increased miles traveled would go up while time spent traveling would go down under the alternative scenarios, indicating improved travel conditions. As for land use, particularly the stakeholder scenario, it 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.

### 4.5 Data Development for the 2005 Base-Year Model

All the UrbanSim outputs presented up to this point are generated using a 1990 model base year. Our research team is in the process of trying to update the base year to 2005. Although some work was done under the initial USDOT grant to create a 2005 base year model for UrbanSim and a rough prototype of that model was created, after the termination of that project, extensive work remained to achieve a high-quality 2005 UrbanSim base year model. This included extensive work in data development, described below. Based on these updated data sets, preliminary synthetic household populations have been created.

**Year built:** Year built data values were updated to reflect the more recent base year. From the master list of year built data points (generated as part of the 1990 base year database development), all records less than or equal to the base year (2005) were selected into a new data set. Then, a series of spatial data overlays and database queries were required to complete the task. In grid cells where only a single development point exists, the year built value of that development was assigned to the grid cell. For grid cells with more than one development, the most recent data point within each grid cell that occurred prior to 2005 were selected and that value to the grid cell was assigned. For grid cells where there was development (based on E911, housing, or employment data locations) but no corresponding year built data points existed, the remaining data values were interpolated. A raster surface was generated from the total set of year built data points (prior to 2005). The raster surface was then used to calculate zonal statistics for the grid cell data set. Grid cell year built values were assigned based on the zonal statistics calculation. Finally, grid cells where no development existed (based on E911, housing, or employment data locations) a year built value of 0 was assigned.

**Property and improvement values:** Property and improvement values were updated following a similar set of process steps detailed in the section above, with a few exceptions. Property values were assigned to each parcel based on the data points located within their bounds. A raster surface was interpolated from the set of property value data points. Zonal statistics were calculated for the parcels with NULL property values and property values were derived based on the zonal statistics output and the size of the parcel.

Improvement values were assigned to parcels from the data points located within their bounds. In instances where development existed (based on E911, housing, or employment data locations), but there was no corresponding data point, the improvement value was calculated as a percentage of the property value (calculated in the preceding steps). Next the parcel polygon data was converted to a point data set to simplify the aggregation to the grid cell scale. Unlike property values, improvement values were not assumed to span individual grid cell boundaries (even though the parcels might do just that). The grid cell improvement value was equal then to the sum of all improvement value data points contained within its bounds.

**Employment data:** Updating the employment data consumed the bulk of time due to a number of factors including the complexity of the data set, the paucity of reliable data, and the native format of the data housed at the individual towns. With few exceptions (where digital data with a sufficient level of detail existed), each of the towns within the county was visited to convert paper records to digital files. We transcribed building square footage, year built, and property and improvement values from the town-level records. In some cases, year built and property values contradicted the records acquired for the development of the aforementioned data sets. These data points (for year built and property / improvement value) were then resolved on a case by case basis.

Proprietary employment data was acquired in 2003. This data represents employment locations, employment sector and the number of employees. Following data collection, we rectified our proprietary data with those data collected from each of the towns. The result was a data set representing employment data, employment sector, and building square footage for each parcel. These data were then aggregated to the grid cell scale based on their employment sector groupings to calculate total square footage and square foot per employee values. Finally, a new jobs table was created with a grid cell ID and an employment sector for each job.

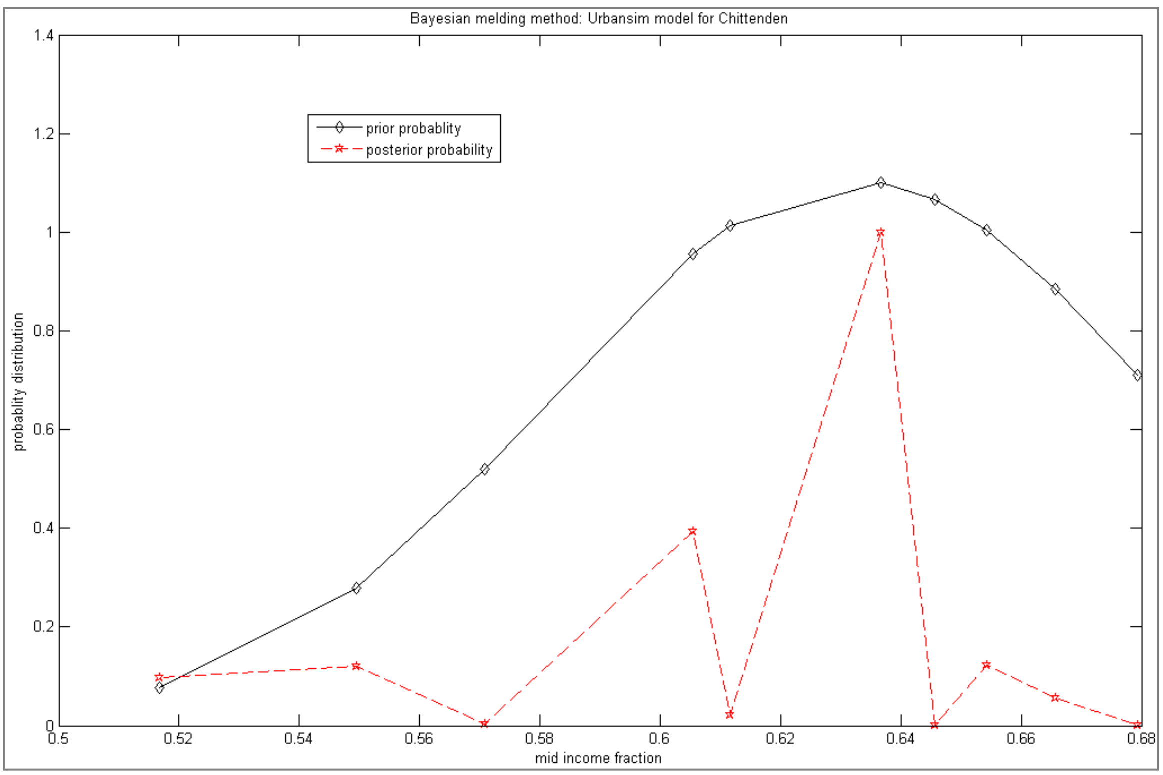
### 4.6 Bayesian Melding

The Bayesian Melding method is a technique for assessing uncertainties in simulation models. This method combines all the available evidence about model inputs and model outputs in a coherent statistical way and can be used in validation and calibration of simulation models. For example, to calibrate a parameter in a model, a prior probability distribution of the parameter may be assumed and sample values of the parameter can be chosen using Monte Carlo sampling method. Then simulations can be carried out using these parameter values. After estimation of the likelihood using observation data and the simulation results, Bayes' theorem can be used to obtain the posterior distribution of the parameter. The resulting posterior distribution can be considered as a calibrated distribution for the model parameter. Furthermore, a validation process can be carried out by comparing additional observation data with the results obtained from simulation with the calibrated parameter. Bayesian Melding is a suggested method for both calibrating and validating the model parameters in UrbanSim. While it is data intensive and requires many model runs, increases in computing power make this approach more feasible, particularly for smaller metro areas like Burlington.

For this portion of research, Jun Yu, Yi Yang, Austin Troy, and Brian Voigt have met several times to discuss and begin implementation of Bayesian Melding in validation/calibration of UrbanSim. Jun Yu and Yi Yang worked out a Matlab program to carry out Monte Carlo sampling and Yi Yang wrote a DOS batch file to implement Bayesian Melding method with UrbanSim. Realistically, only a relatively small number of model parameters can be calibrated in this way because of the large number of model runs necessary. As a test case, the mid-income-fraction parameter, defined as the fraction of the households with mid-level incomes, was chosen to demonstrate schematically how Bayesian Melding method can be used in calibration of the UrbanSim model. Prior probability distribution was assumed to be a normal distribution around the default value (0.632). Monte Carlo sampling scheme was used to choose 10 test values of the parameter. Then UrbanSim modeling of Chittenden County for the given values of parameter was carried out (10 runs), and by comparing with observation data of the households distribution in 1991, a posterior probability distribution was estimated. The prior and posterior probability distributions of the mid-income-fraction parameter are shown in Figure 10. While the expected values of the mid-income-fraction parameter are comparable, the variances of the parameter are quite different with the calibrated one considerably smaller than what was anticipated. However, that this is only a test case result with a very small sampling number (10 values), this result needs further investigation.

To apply Bayesian Melding method to general validation and calibration procedures, a large number of computer simulations (about 2000 runs) with UrbanSim for Chittenden County are needed. As a preparation, Yi Yang is currently working on improving the DOS batch file so that more automation can be incorporated for simulations with UrbanSim and for the processing of the simulation results.

**Figure 10. Prior (Solid Line) and Posterior (Dashed Line) Probability Distributions of Mid-Income Fraction Parameter**



# 5. Summary of Phase I Environmental Metrics Activities

## 5.1 Environmental Outputs Toolbar

During this period 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 USDOT 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, the project team created a framework that will allow for easy input of those coefficients when available and allows for use of placeholder coefficients in the interim.

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. It is predicted that the factor translating built square footage to impacted area will also vary, but in this case with number of jobs. The update interface (Figure 11) 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 12), 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.

**Figure 11. Update Land Cover Interface**

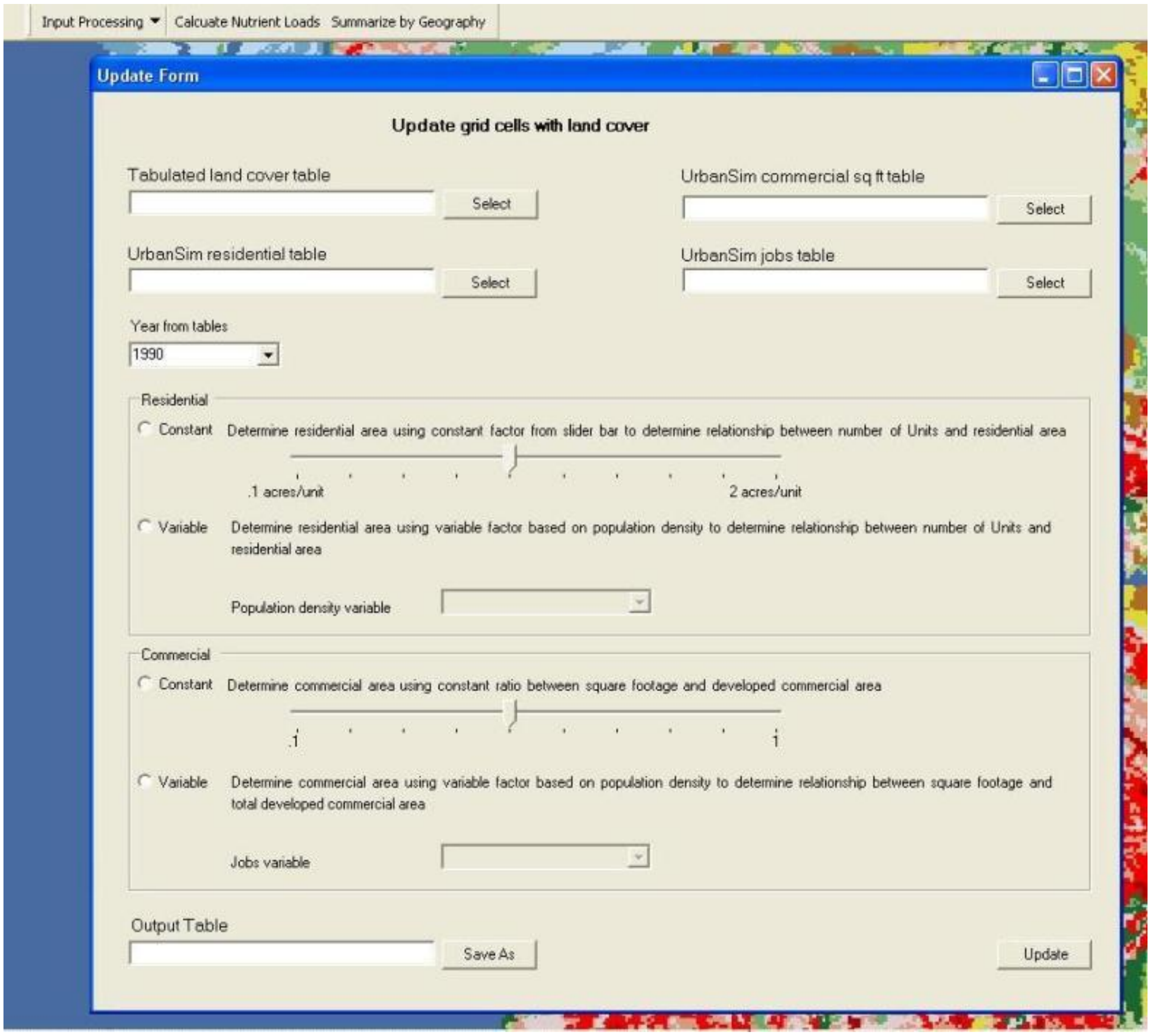
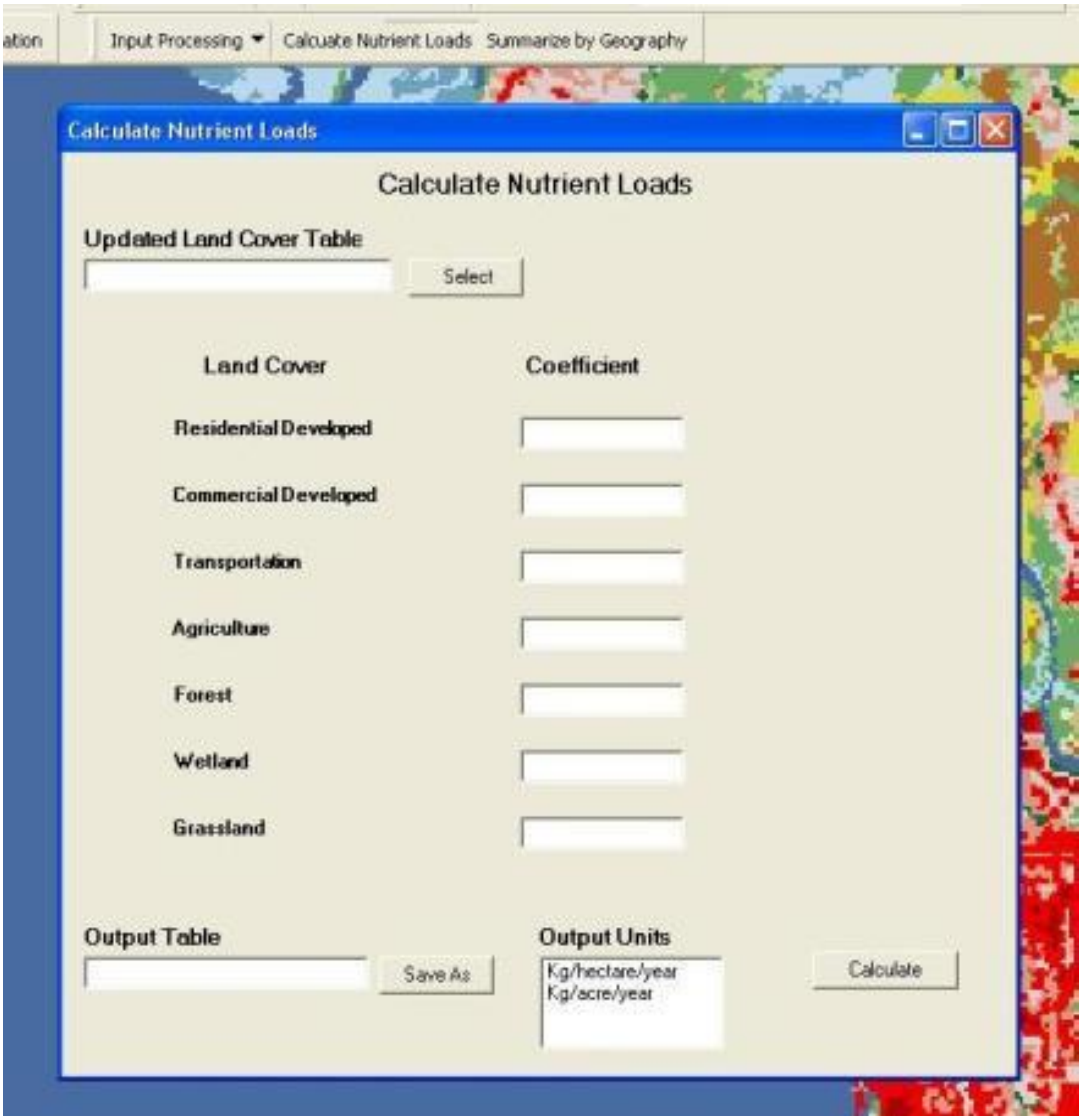


**Figure 12. Calculate Nutrient Loads**




## 6. Future Directions

A complete description of proposed activities for the coming year of research funding is described in a work plan document entitled: "Integrated land use, Transportation and Environmental Modeling Project: Phase II Work Plan," available from the UVM Transportation Research Center.

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## 8. Appendix: Naming conventions for trip matrices

1) tt1_nlm_app.mtx – home-based-other, leaving home
2) tt2_nlm_app.mtx – home-based-work, coming home
3) tt3_nlm_app.mtx – home-based-other, coming home
4) tt4_nlm_app.mtx – home-based-work, work to nonhome
5) tt5_nlm_app.mtx – non-home-based, nonwork to nonhome
6) DistOUTS.mtx : post distribution table for medium and heavy trucks.
7) PM00TTI.mtx post distribution trip table which includes the external-to-external trips