Integrating UrbanSim with a traffic router and micro-simulator for transportation and land use change analysis

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Abstract

This paper introduces and summarizes a first-of-its-kind integration of a dynamic, second-by-second traffic router/micro-simulator (TRANSIMS) with the UrbanSim land use model, implemented in Chittenden County, VT. It first describes how and why these components were integrated. It next describes a preliminary comparison of the land use outputs of this highly complex and time-intensive model integration to a more standard integration of UrbanSim with a traditional four-step transportation demand model using TransCAD. Statistical tests found only slight differences in the land use predictions between the two model integrations for 2030. Although these differences were slight, their spatial patterns shed light on how transportation models influence the outcome of land use models. In particular, differences in land use predictions appear to relate to TRANSIMS' predictions of emergent traffic bottlenecks along routes that serve peripheral areas where there is poor redundancy in route choice. These results suggest that land use models are at least somewhat sensitive to the type of transportation model that is used to generate accessibility measures. Nonetheless it is impossible to say with the data at hand which is more accurate for long term predictions. It is unlikely that the benefits of adding TRANSIMS or similar micro-simulators to a land use model outweigh the high costs of implementation. However, this assessment may vary with context. Our study site is a small metropolitan area with only modest population pressures and limited traffic congestion. Our results indicate that differences in predictions between model integrations grow as population forecasts are artificially increased, so integration of TRANSIMS may be of greater use in more congested areas.

Introduction

The linkages between land use and transportation and the need to incorporate those linkages in planning have been well established (1-4). 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), in order to receive certain types of federal transportation funds, state or regional transportation agencies are required to model the effect of transportation infrastructure development on land use patterns and to consider whether transportation plans and programs are consistent with land use plans. Metropolitan Planning Organizations (MPOs), which already frequently use transportation models, are increasingly integrating dynamic land-use modeling into those efforts, to help evaluate transportation infrastructure performance, investment alternatives, and air quality impacts.

Dynamic coupled models are distinct from stand-alone models in that they simulate the dynamic interactions between transportation and human activities. Because accessibility largely drives land use, dynamic land use models have long been integrated with 4-step travel demand models (5). However, as dynamic components are added, model integrations become increasingly complex and difficult to implement. Moreover, these models are generally simplistic and spatially aggregated in their characterizations of traffic and accessibility. Little guidance exists about what levels of complexity or disaggregation is needed or appropriate for modeling land use and transportation and how that changes for different planning applications. Tradeoffs between realism and cost are poorly understood. The correct balance likely depends 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. (6), few of these models have been conclusively shown to increase the accuracy of the model output.

This paper presents one of the first known attempts to integrate a traffic router/micro-simulator operations model with a highly disaggregated and dynamic land use model. Three components are used in this modeling effort: UrbanSim for land use (7-9), TransCAD (Caliper, Inc) for travel demand modeling and traffic routing and assignment, and TRANSIMS for traffic routing through microsimulation (10-11). We compare the more commonly-used integration of the land use model with the static traffic assignment (TransCAD) to the novel integration of the land use model with the dynamic router/micro-simulator (TRANSIMS). The latter integration also requires use of TransCAD for trip generation, so we refer to the simpler integration as the "2-way model" and the more complex one as the "3-way model."

UrbanSim is a land-use allocation model that simulates urban growth for a region based on externally derived estimates of population and employment growth (control totals). Expected growth is spatially allocated across the landscape to simulate the pattern of future development and land use. Agents in UrbanSim include both households and employers. The landscape is divided into grid cells of a user-defined size (geographic units like parcels can also be used). Each simulated development event is assigned to one of those cells based on factors like accessibility, site constraints, and zoning. 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; 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. Because accessibility is such a core determinant of land use, UrbanSim is generally integrated with some type of transportation model. The assumption is that accessibility changes over time so transportation must be made endogenous. The degree to which accessibility affects land use depends on the way that the various statistical models in UrbanSim are parameterized and the extent to which the data reveals a relationship. In our version of UrbanSim, we estimated a number of models, several of which include coefficients for accessibility.

TransCAD is a traditional four-step travel demand model, 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. Traffic assignment is based on an equilibrium model which employs an iterative procedure to reach convergence.

TRANSIMS is a detailed, data-intensive operations model that is designed to simulate traffic behavior with great spatial and temporal disaggregation. It consists of four modules: (1) synthetic population generator; (2) activity generator; (3) router; and (4) micro-simulator, although in this case we use only the third and fourth components. In standalone implementations, 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. The micro-simulator allows for a highly detailed characterization of traffic flows and is able to take into account factors like cueing, car-following, and lane changing behavior. As an operations model, it is designed to help optimize microscopic factors such as signal timing and actuation.

While TRANSIMS allows 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 a cost-effective approach for regional planning organizations, which can take advantage of the increased resolution of the TRANSIMS micro-simulator, while continuing to depend upon familiar O-D matrices. Implementing only TRANSIMS's router and micro-simulator is typically referred to as a "Track 1" TRANSIMS implementation. "Track 1" TRANSIMS implementation has been the focus of the current work so far.

The primary difference between TransCAD and TRANSIMS is the way each one characterizes traffic and resulting accessibilities (which are an input into UrbanSim). TransCAD uses a volume-delay function, where the congested travel time on the link is equal to the ratio of the number of vehicles on the link divided by the total capacity of the link. It assumes that inflow equals outflow for all individual links in the network. TRANSIMS, on the other hand, calculates congested travel times based on a simulated interaction of vehicles on the roadway that takes into account factors like weaving, merging, queuing, traffic signals, and intersection spill-back. TRANSIMS is designed to replicate the real-world phenomenon that lead to increased travel time and congestion that cannot be explained by just a simple volume-to-capacity ratio. This means that failure can occur at some intersections where inflow no longer equals outflow. As a result, TRANSIMS is likely to predict more localized bottlenecks.

Objectives

The first purpose of this paper is to introduce and describe the first-of-its-kind integration of the TRANSIMS router/micro-simulator with the UrbanSim land use model. The second purpose is to determine whether the two model integrations lead to different land use predictions. To the extent the land use predictions differ, we analyze the pattern of outputs to better understand how the two approaches to calculating accessibilities in each transportation model contributes to these differences. By characterizing and analyzing these differences we hope to shed light on the role that transportation and accessibility modeling play in long-term land use predictions and the tradeoffs to added complexity in such modeling efforts.

Methods

<u>Modeling Site</u>

Our models are run for Chittenden County, VT (Figure 1), the most populous county in the state and the home to its largest city, Burlington. Chittenden County is among the smallest metropolitan areas where UrbanSim has been implemented, with an estimated 2009 population of 152,000. It is an excellent location for modeling for two reasons: first, its small size makes highly disaggregate and data-intensive modeling tractable; second, its isolation from other cities (the nearest metropolitan area is Montreal, more than 90 miles away), means it approximates “closed city” modeling conditions (although we do use 17 external TAZs to account for inter-county traffic, this is a small component of the county’s overall transportation). Despite its small size, Chittenden County has its own Metropolitan Planning Organization, which conducts extensive modeling.

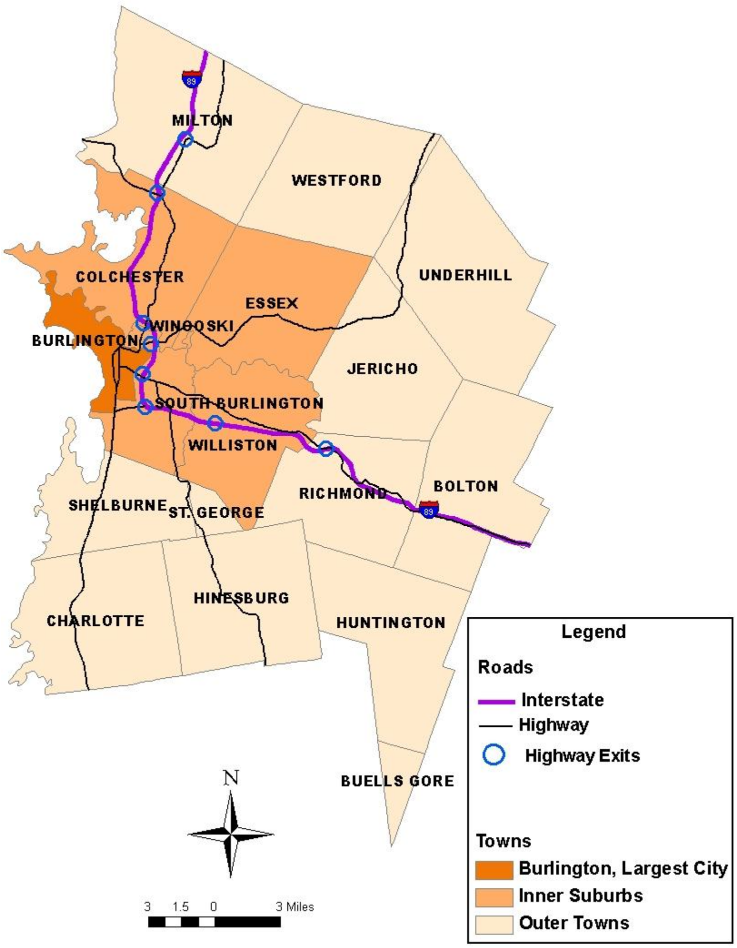

FIGURE 1 Map of Chittenden County.

Description of the Models

This analysis was conducted by integrating previously developed implementations of three models. We used the implementation of TRANSIMS developed by Resource Systems Group and Adel Sadek (12, 13). We use an implementation of UrbanSim developed for the same area by Austin Troy and Brian Voigt (6, 14, 15). We used the Chittenden County Metropolitan Planning Organization's (CCMPO) implementation of TransCAD, which 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 (14). The travel model is based on household travel diaries collected for the CCMPO. Customized scripts were developed that automated the integrated models.

The 2-way configuration consists of UrbanSim, which generates the socio-economic land use data like total number of households and employment in each traffic analysis zone, and TransCAD, which derives accessibilities using travel times from the static vehicle assignment. These travel times are then sent as input to UrbanSim. After every five years of model time TransCAD is rerun using updated land use data from UrbanSim, and in turn updating UrbanSim's accessibilities for that model component (6, 14, 15).

The 3-way configuration adds a third component: the TRANSIMS router/micro-simulator. In this configuration (Figure 2), TransCAD performs trip generation, trip distribution, and mode choice, and exports a PM peak vehicle trip matrix to TRANSIMS. TransCAD's static vehicle assignment is replaced by TRANSIMS' regional vehicle micro-simulation. The amount and distribution of regional auto travel demand is identical in the two models, but in the 3-way model the auto travel times are derived from the regional micro-simulation. Finally, accessibilities are derived using the simulation-based auto travel times and sent as input to UrbanSim.

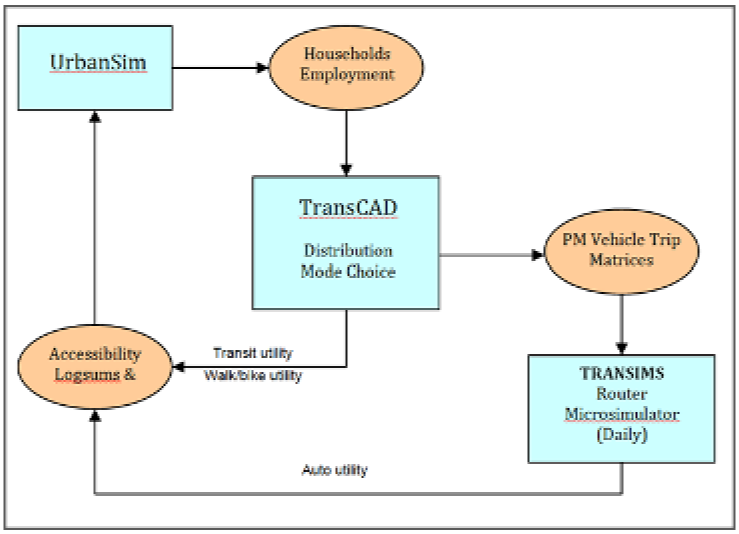

FIGURE 2 Three-way model configuration.

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 produced by TransCAD to daily vehicle trips.

There are five post-mode-choice vehicle trip matrices for three trip purposes: (1) home-based-other, leaving home; (2) home-based-work, coming home; (3) home-based-other, coming home; (4) home-based-work, work to nonhome; and (5) non-home-based, nonwork to nonhome. There is also a single post-distribution trip table which includes commercial truck trips. Finally, there is a single post-distribution trip table which includes external-to-external trips.

We had diurnal distribution data that was collected during the development of the daily CCMPO TRANSIMS model, and daily peak PM hour traffic volume (defined as 5:00 pm to 6:00 pm in the TransCAD model). From this, we derived 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 3 below. The calculated PM peak hour to daily adjustment factors are set forth in Troy, et al. (14).

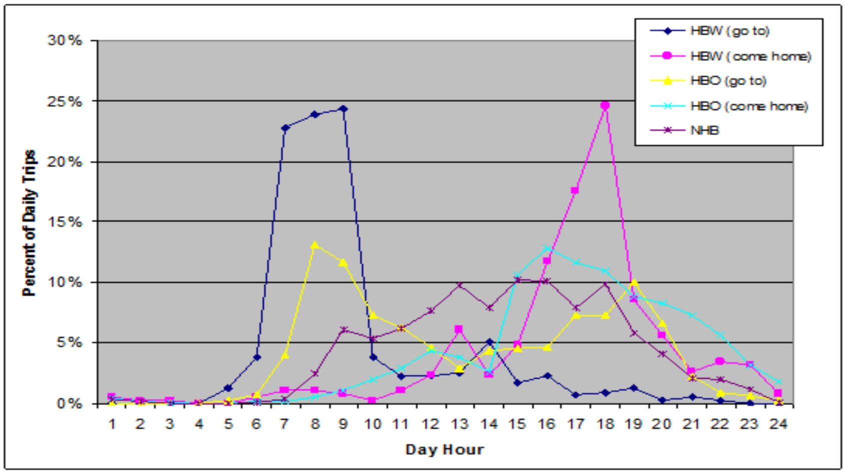

FIGURE 3 CCMPO TRANSIMS model diurnal distributions.

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 in integer form for input to 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.

<u>Updating the Accessibility File with TRANSIMS Times</u>

For the 2-way model, TransCAD generates a file that contains the auto, walk/bike, and transit utilities as well as the logsum (composite measure of accessibility across modes) for each zone-to-zone pair. This file is fed back to UrbanSim for the next iteration. By incorporating TRANSIMS into the model chain in the 3-way model, we replace the auto utilities in this file with auto utilities based on zone-to-zone travel times calculated by the TRANSIMS micro-simulator instead of the TransCAD model assignment module.

TRANSIMS-based auto utilities are calculated using the following regression equation:

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

Logsum value for each zone-to-zone pair are calculated based on the new auto utilities.

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

TRANSIMS has built-in utilities that 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 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 micro-simulator, since the 2-way model also utilized PM peak hour travel times from the static vehicle assignment.

A python script reads the existing logsum file 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 micro-simulator.

Model Runs and Analysis

We ran forty year simulations of both the 2-way and 3-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. Each model integration uses the same UrbanSim model coefficients.

Two versions of each model were run, one using population and employment forecasts obtained from the MPO as control totals, known as the “baseline scenario,” and another using controls totals artificially increased by 50%, known as the “increased control total scenario.” This was done to help determine whether differences in the models may relate to population development pressures.

Finally, we analyzed the outputs. While a large number of indicators are produced by these model integrations, we focus this analysis on three: 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). We found no statistically significant differences in prediction accuracies for the two model integrations. For that reason, we do not present the results here. Nevertheless, we ran statistical analyses to look for differences in the 2030 outputs of the two models and analyzed geographic patterns in those differences.

Results

Statistical differences in models

Variance ratio tests for the whole population of TAZs revealed no significant difference in variance across the whole population of TAZs between models for both sets of indicators for 2030.Using paired t-tests, slight significant differences were found in predicted commercial square footage for 2030 at the TAZ level when grouped by town. For the baseline population scenario, significant differences in commercial square footage were found at the 95% confidence level for the town of Williston ($t=2.654$, $p=0.011$), which has the third largest number of TAZs in the county. Westford had significant differences at the 90% confidence level ($t=-2.366$, $p=0.099$). With the increased control total scenario, differences were fewer: there were no significant differences in commercial square footage at the 95% confidence level, although Burlington ($t=-1.825$, $p=0.072$) and Shelburne ($t=-1.867$, $p= 0.92$) were different at the 90% level. A significant difference in residential units was found for Milton at the 95% confidence level in the baseline scenario ($t=-2.487$, $p=.03$). In the increased control total scenario, significant differences at the 95% level were found in residential units for Jericho ($t=-3.61$, $p=.037$) and at the 90% level for Milton ($t= -2.12$, $p=.058$). A spatial statistical analysis was also conducted using Moran's I (Moran (1950) to see if measures of spatial autocorrelation differed between the outputs of the two models, but no difference was found.

Preliminary Comparison of Travel Times

Figure 4 shows the difference in predicted logsum accessibilities between TRANSIMS and TransCAD for the year 2030 under a scenario with baseline population forecast control totals. Because accessibility is one of the core driving factors in the land use predictions, the fact that there are clear differences in the spatial pattern of accessibility served as an indication that differences in land use outputs were a distinct possibility and that further analysis was warranted.

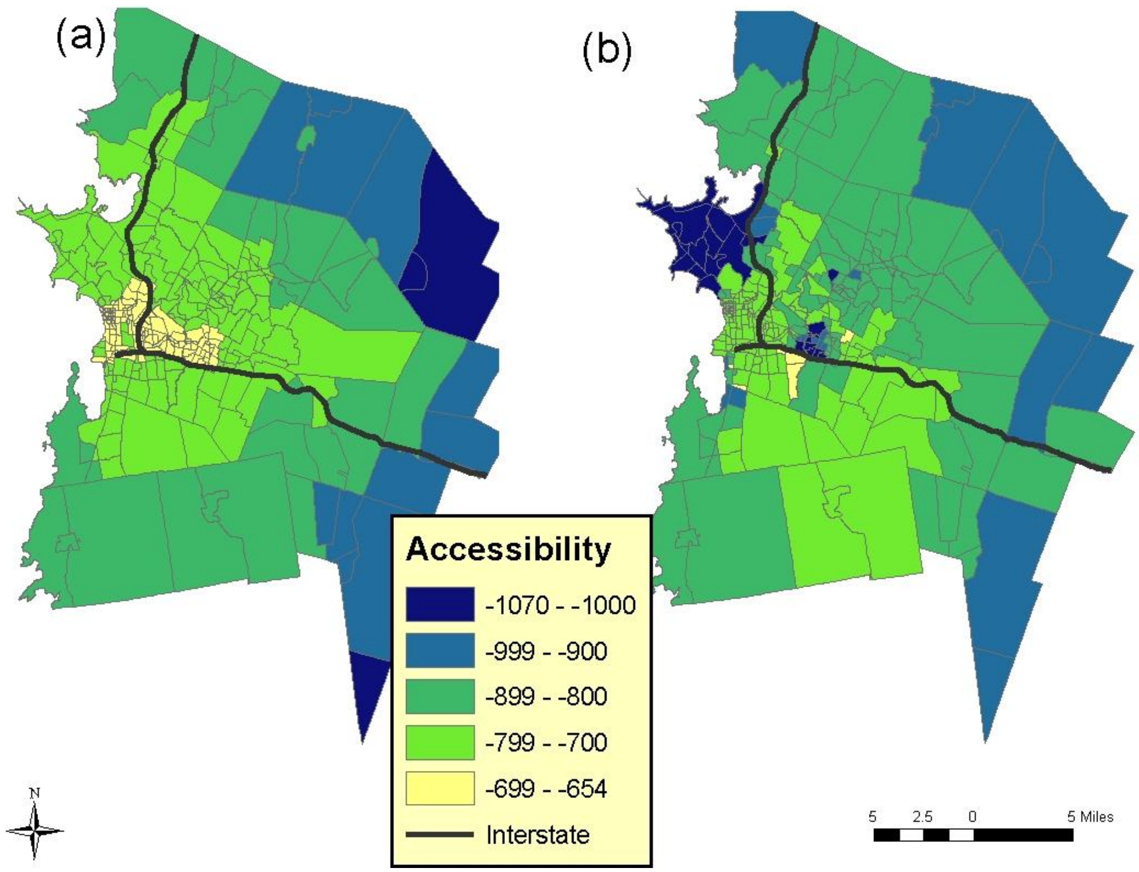

FIGURE 4 Comparison of accessibilities characterized as logsums by TAZ for 2-way (a) and 3-way (b) models. Logsums are unitless measures of relative accessibility. Yellow indicates TAZs with better accessibility, blue indicates worse.

<u>Long-term trends</u>

We looked at graphs of key indicators to see when large discrepancies emerge between the models, if at all. Figure 5 shows the percent difference in predicted housing units between the two models for a sample of eight towns from 1990 to 2030. It indicates a continuously growing difference for the outlying towns of Milton and Underhill. Milton has higher predictions for the 2-way model, while Underhill has the opposite. Other towns, like Bolton, show divergence between the models in early years and then return to smaller differences later. Several towns start to show patterns of divergence between models and then return to small differences in later years, such as South Burlington, Richmond and Colchester. Others are in close agreement throughout all forty years of model time, such as Charlotte and Burlington. Commercial square footage prediction graphs (not shown here) show a somewhat similar pattern with Milton also having increasingly positive 2-way prediction differences over time, several outlying towns with the opposite pattern and a number of towns in the middle, with relatively little difference.

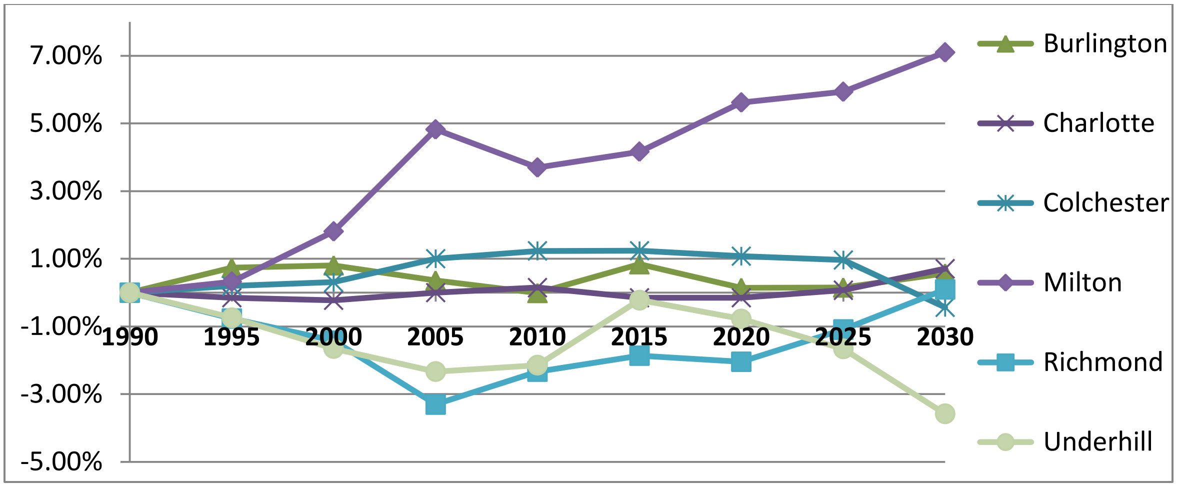

FIGURE 4 Percent difference in predicted residential units between models (2-way minus 3-way divided by total units) for a sample of 6 towns.

Side by side maps in Figure 6 and 7 show percentage differences in predicted residential units (a) and commercial square footage (b) for 2030 at the town level and the TAZ level, respectively, under the increased control total scenario. Baseline control total maps are not shown in the interests of space and because the patterns are similar but much weaker.

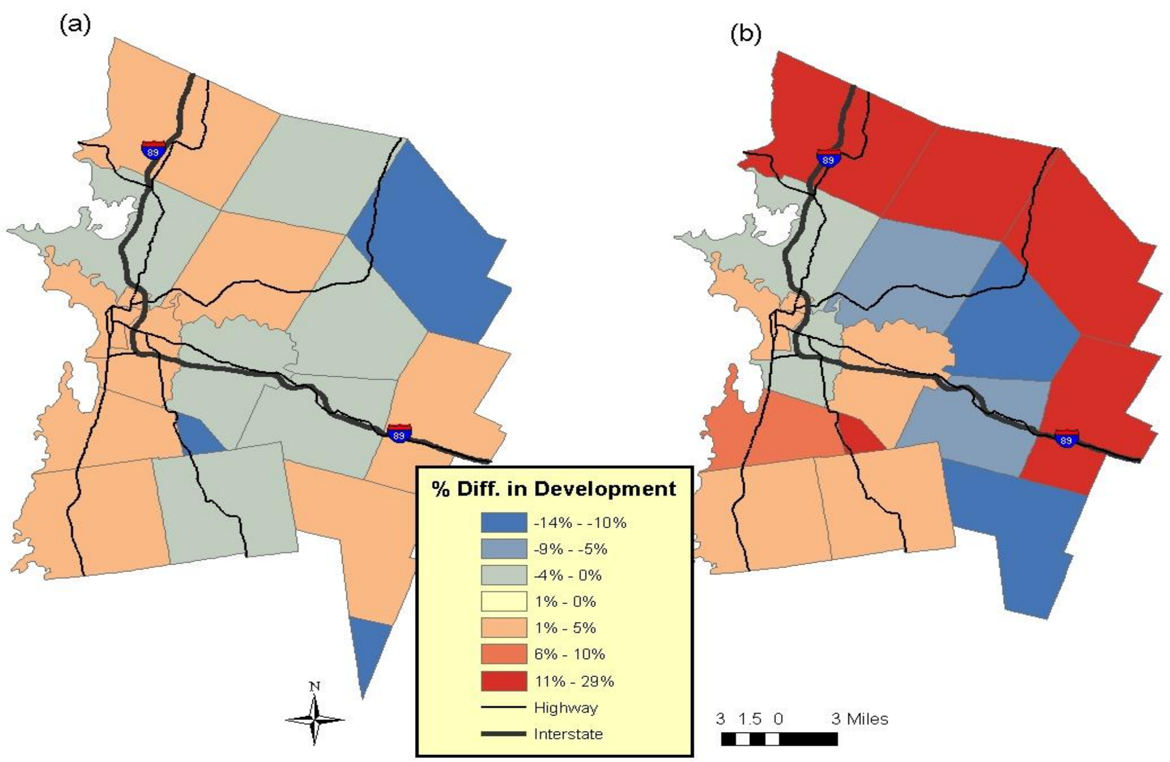

FIGURE 5 Town-level comparison under increased control totals: (a) Percent difference in residential development forecasts from the two way and three-way models for 2030 using baseline control totals. (b) Percent difference in commercial development forecasts from the two way and three-way models for 2030 using baseline control totals. Blue indicates more development predicted by the three-way model; red indicates more development predicted by the two-way model.

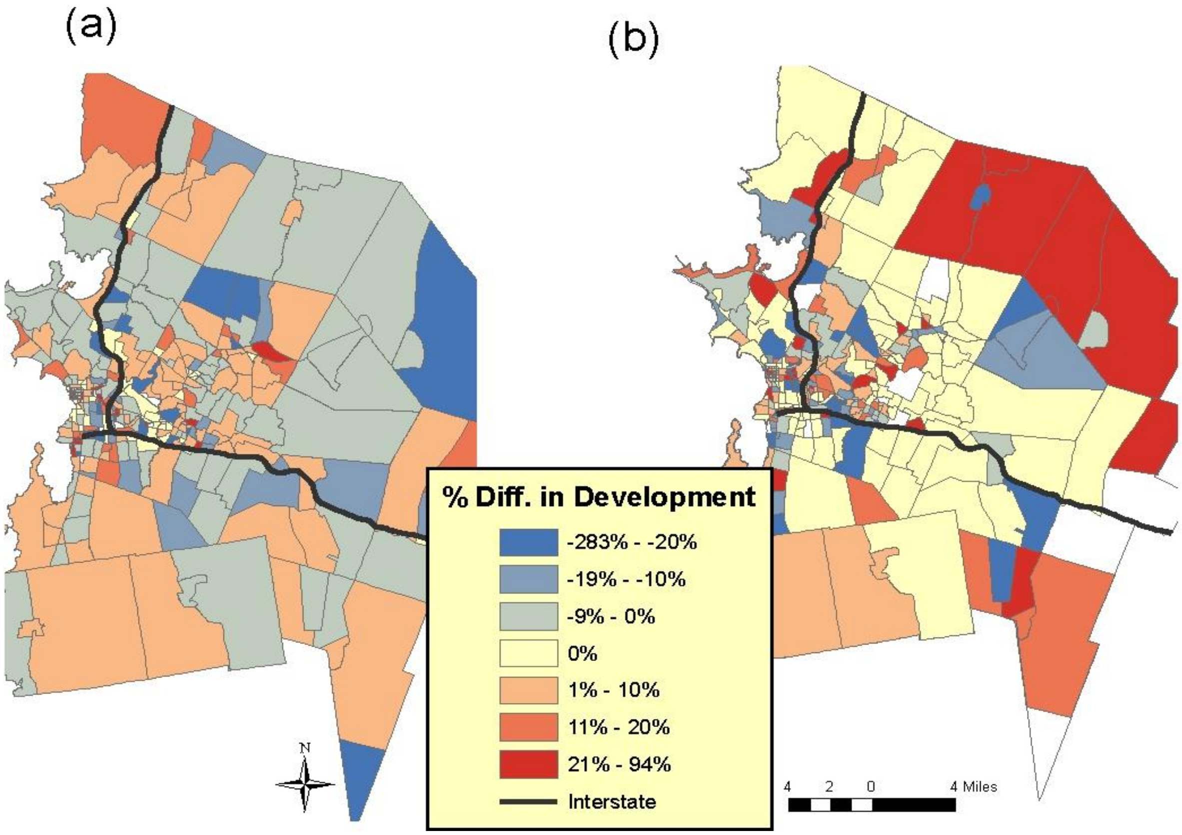

FIGURE 6 Same as Figure 6 but at the TAZ level.

Discussion

This project was the first of its kind to successfully integrate the TRANSIMS router/micro-simulator with a highly disaggregated and dynamic land use model like UrbanSim. This project is significant in showing that such an integration of highly complex models is feasible. However, questions remain about whether using this type of transportation model has significant implications for land use modeling or not and, if so, whether its benefits are worth the effort. With hundreds of gigabytes of outputs, far more analysis of the results of these models remains to be done before an answer to these questions can be made definitely. However, this analysis represents a preliminary attempt to address it.

The fact that accessibilities are far more spatially heterogeneous in the 3-way model (Figure 4), would lead us to believe that, theoretically, there could be systematic differences in the land use outputs. Our UrbanSim implementation consists of ten statistical models that drive activities like household and employment moves, land price, and development events. While many include spatial parameters such as location within the "urban core," or the amount of commercial or residential development within walking distance, only the residential and commercial development models include parameters on accessibility from the travel model. Because TRANSIMS predicted more localized areas of reduced accessibility within the interior of the county, we expected to find that some more centrally located areas might develop slightly less in the 3-way model than in the 2-way model.

While the results of our two models are different, it is not clear that these differences are important enough to matter for the purposes of land use change prediction. Our validation results (not presented here) show minimal differences between the two in predicting intermediate-year data. Statistical pairwise comparisons of TAZ-level results grouped by town suggest that differences in predicted indicators for 2030 are present for only a few towns. Tests of the whole population of TAZs found no significant difference in variance for both land use indicators.

Nonetheless, our maps of 2030 prediction differences in commercial development under increased control totals (which was use because it emphasizes the differences between models more) show some interesting patterns that suggest potential systematic spatial differences in predictions. As Figure 6 shows, all the peripheral towns along the northern and eastern boundaries of the county have more commercial development under the 2-way model than under the 3-way. The same pattern is evident at the TAZ level, although heterogeneity is slightly greater along the periphery. This result is intuitive given what we know of the models. As population grows, TRANSIMS predicts more congestion and delay and hence lesser accessibility in the outer TAZs than TransCAD. This pattern is particularly evident for TAZs that do not adjoin the Interstate (where the Interstate runs through, there are fewer red TAZs). Redundancy of routes is very poor the further out one travels in the county, so just a few high-delay links can make a big impact on accessibility in areas that require a long drive on non-Interstate routes. Our preliminary analysis of TRANSIMS's link level outputs (not presented here) shows a number of predicted traffic bottlenecks along such key arterials that connect outer suburbs to the urban core that TransCAD does not capture. Not all of these "red TAZs" are on the outer periphery. Some are more central, but require significant driving on bottleneck-prone arterials. Interestingly, as is reflected in Figure 8, most of the TAZs containing an Interstate exit appear to have higher employment predictions in the 2-way model, which is consistent with this explanation.

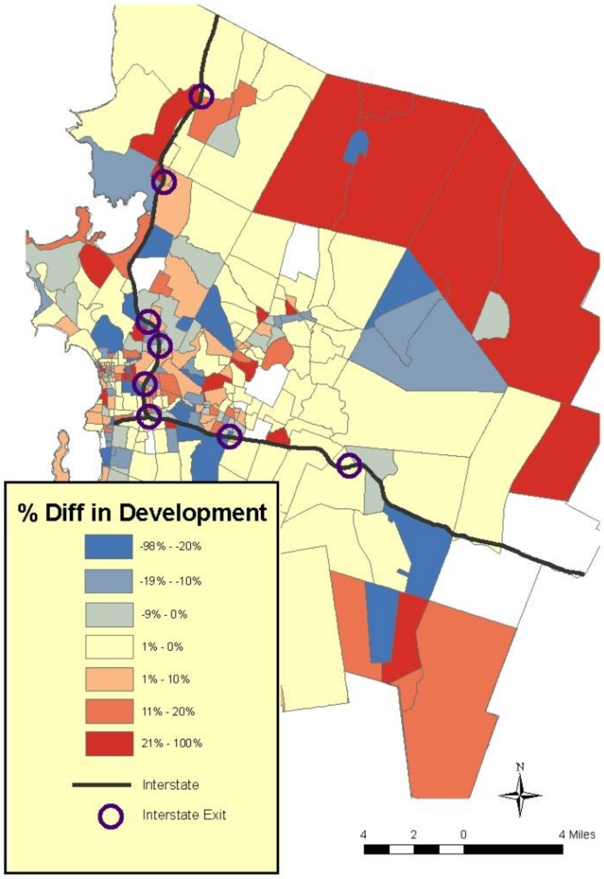

FIGURE 8 Blow-up of Figure 7(b) showing Interstate Exits.

No clear spatial pattern is evident for differences in residential predictions. Figure 6 suggests that only one of the towns included in the graph experience steadily increasing differences over time between models. Otherwise, differences oscillated within a small range over time. This difference between residential and commercial indicators is likely due to the model coefficients that relate to output from the transportation models. The residential developer model includes a parameter for home accessibility to employment while the commercial developer model includes a parameter for work accessibility to employment. Further, the commercial development coefficient is almost twice the magnitude of the residential coefficient.

Conclusion

TRANSIMS is designed as an operations model for assessing and optimizing microscopic factors in the traffic network. Some believe that models like this are inappropriate for coupling with long-term land use change models. Our land use results from the 2030 simulation look generally reasonable, but our preliminary analysis of link level data from TRANSIMS indicates that after forty years of simulation, a number of unrealistic bottlenecks and congestion points develop. This is probably because, as an operations model, TRANSIMS runs with an assumption that factors like signal timing and lane rules are to be changed over time. When they remain static over long periods like forty years, this may lead to unrealistic characterizations of accessibility. Nonetheless, these bottlenecks only had a very minor impact on development predictions. This may be because of our model coefficients, which were estimated in an area where traffic congestion is relatively minimal. Had we estimated these coefficients in a larger urban area with extensive congestions, it is possible that the impacts of these accessibility differences on development would have been greater. Hence, the impact of transportation model type on land use results is extremely sensitive to model coefficient specification. It is also possible that had we run the TRANSIMS Track 2 implementation which includes the activity model with disaggregated activity locations, differences would have been more pronounced.

Given our current results, there appears to be little justification for expending the large amount of time and money required to implement TRANSIMS for the purposes of long-term land use modeling in a context like Chittenden County. However, this approach might be more valuable in large metropolitan areas where population pressures and traffic delays are much greater. In such cases, we would expect to find delay-related (as opposed to distance-related) accessibility having a greater impact on land use. It is possible that in such cases a land use model integrated with TRANSIMS would yield a more accurate characterization of accessibility, leading to better land use predictions. However, such a model should probably only be run for short-term predictions in highly congested areas, as long-term simulations could result in unrealistic localized stoppages of traffic flow which, in real life, could be addressed through minor interventions, like re-timing signals. Further research is warranted to determine the usefulness of including a micro-simulator in land use modeling for more populous and congested regions and to determine the appropriate time frame of modeling in this context.

The integration of TRANSIMS with a land use model may also be valuable in assessing how hypothetical changes to the transportation network might influence the spatial pattern of development, potentially even in smaller metropolitan areas. We are currently in the process of running the 2-way and 3-way models on an alternative scenario involving the construction of a large number of new roads to determine if the 3-way model's land use predictions are more spatially sensitive to the new infrastructure. This and other future research will help us better understand the usefulness and cost effectiveness of complex integrated modeling tools for the planning process.

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