Environment and Planning B: Planning and Design 2013, volume 40, pages 846 – 864

doi:10.1068/b38182

Modeling the effects of an urban growth boundary on vehicle travel in a small metropolitan area

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Received 3 October 2011; in revised form 9 August 2012

Abstract. An integrated land-use–transportation model was used to simulate the impact that an urban growth boundary would have on vehicle miles of travel in a small metropolitan community over a forty-year modeling horizon. The results of the modeling effort indicate that even in an area with low to moderate population growth, there is the potential to reduce vehicle miles of travel per person by as much as 25% from a business-as-usual scenario over a forty-year period. The reduction would result primarily from a shift of driving alone to carpooling or walking for many trips. A scenario in which growth is concentrated in a single urban core would also benefit from shorter average trip lengths; a scenario with multiple village centers would not have shorter trip lengths, but would still have significant improvements in total vehicle miles of travel.

Keywords: integrated land-use–transportation model, urban growth boundary, vehicle miles of travel

1 Background

Vehicle miles of travel (VMT) is a measure of how much driving a person or a population does in a given period of time. VMT per capita has been described as the strongest single correlate of environmental degradation and resource consumption in the transportation sector (Cervero and Murakami, 2010). Since the dawn of the automobile age, VMT in the United States has increased steadily. In 1940 people drove an average of 2300 VMT per person per year (Federal Highway Administration, 2010). By 1980 the annual average was up to 6700 VMT per person, and by 2008 the average had soared to 9800 VMT per person (Federal Highway Administration, 2010). All of this driving has significant implications for the environment, natural resources, public health, traffic congestion and safety, and social justice.

There are many potential mechanisms for reducing VMT. Potential strategies include technical innovations, educational campaigns, and fuel or other driving-related taxes. In this paper we explore a fourth type of solution, which relates to modifying the built environment, over time, to bring people and jobs closer together. The idea is to have people living and working in spaces that make walking, biking, and public transit feasible and enticing, so that people naturally choose to drive less without suffering any loss of accessibility.

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1.1 Connection between the built environment and VMT

Many researchers have attempted to clarify the connection between descriptors of the built environment, such as density, diversity of land use, and design, and travel measures, such as VMT per person, trip counts, and vehicle hours of travel (VHT). Results are typically reported in terms of elasticity of travel behavior to different built environment characteristics. Although it is not necessarily the most important aspect of the built environment for purposes of predicting travel behavior, by far the most studied aspect is population density. One recent study found that the elasticity of VMT to increasing population density was −0.38, meaning that a 10% increase in population density was correlated with a 3.8% decrease in VMT per capita (Cervero and Murakami, 2010).

Other studies have found smaller effects. In one recent study of data it was found that the elasticity was only −0.19, meaning that a 10% increase in residential density was correlated with a decrease in VMT of 1.9% (Heres-Del-Valle and Niemeier, 2011). A metaanalysis of the data from fifty studies found an even weaker connection: the range of elasticities of VMT to density across the underlying studies was −1.05 to 0.03, and the weighted average elasticity was −0.04 (Ewing and Cervero, 2010). In this study, VMT was most sensitive to distance to downtown (also called destination accessibility), with a weighted average elasticity of −0.22, and job accessibility by automobile, with a weighted average elasticity of −0.20.

Despite the work that has been done to clarify how to measure the various aspects of the built environment that are expected to affect VMT, studies have widely varying results. Part of the problem is that overall effects are small, and other factors, such as household income or employment status, may dwarf the effect of the built environment on travel behavior. Although it is possible to control for these variables, a lot of detail is lost in the process of controlling, and thus significant distortions may affect the results. Some researchers have found that attitudinal and lifestyle variables are more important than built environment characteristics (Bagley and Mokhtarian, 2002). Another significant problem is the limitations of the available data, particularly longitudinal data that could clarify the difference between correlation and causation, not to mention the inherent difficulty in establishing causation in any complex interaction.

1.2 Scenario analysis

In this field, scenario analysis is used to predict the effect that a change in land use will have on future travel patterns. Statistical analysis quantifies the relationships between urban form and travel patterns; simulation studies then use the quantitative relationships to make predictions (Handy, 1996). A scenario is “not a forecast, but one possible future outcome” (Bartholomew, 2007, page 398). The variables most often studied in scenario analysis include the location of growth, the density of growth, land-use diversity, and transportation system elements (Bartholomew, 2007).

Scenario studies also typically report more detail on density than on other built environment attributes. A metaanalysis of twenty-three scenario studies found a linear relationship between residential density and VMT across the studies, under which a 10% increase in density would lead to a 5% reduction in VMT and a 50% increase in density would lead to a 16% reduction in VMT (Bartholomew and Ewing, 2009). Other statistically significant variables included whether or not the scenario promoted mixed land use, and whether or not it included infill or compact development (Bartholomew and Ewing, 2009).

An earlier metaanalysis of scenario studies by the same researchers similarly found that a 50% increase in residential density over a forty-three-year time frame would lead to a decrease in VMT of 18% (Ewing et al, 2007). By contrast, another study found that doubling residential density across a metropolitan area might lower household VMT by only 5%–12% (perhaps by as much as 25% if the increased density was coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures) (Transportation Research Board, 2009). The most important differences driving the differing results of these studies were the assumptions about growth rates and the rate of replacement of existing land uses.

Other metaanalyses of scenario studies have reached similar conclusions. An analysis of results from twenty-two scenario studies found that land-use changes alone led to predicted decreases in VMT with a median of 4.9% at ten years, and a decrease of almost 50% after forty years (without specifying the change in residential density) (Rodier, 2009). This study found that the largest overall effect on VMT over the forty-year time horizon was for combined strategies that included land-use changes, tax strategies, and transit policies, such as increased frequency of transit service (Rodier, 2009).

1.3 Research gaps

Existing studies typically involve relatively large geographic areas that are fairly densely populated. In part because of the size of the populations they are dealing with, the existing studies mostly use aggregate data. Many of the scenario studies use minimal computer modeling. Finally, most existing studies are set in places with relatively robust public transportation systems. It is reasonable to question whether similar effects will be observed in a place with a smaller, less densely situated population, particularly where it is more difficult to shift to public transportation because the transit options are limited. These questions make the current project a useful addition to the literature on this subject.

What can an integrated land-use–transportation model tell us about the potential for decreasing VMT in a small metropolitan area by changing the permissible land use? Specifically, if an urban growth boundary (UGB) strategy were implemented, in which new developments were proscribed outside the central core, does the model predict that VMT would be reduced compared with a business-as-usual scenario and, if so, by how much? And, what would the resulting land-use patterns be like, in terms of residential density and commercial–residential mix? Alternatively, if new development were permitted in traditional village centers scattered throughout the region in addition to the urban core, what does the model predict the impact would be on VMT and on land use? Using an integrated land-use–transportation model to simulate the changes in land-use regulations will inform the debate on whether changing the land-use regulations is a worthwhile tool for reducing VMT.

2 Methods

2.1 Study area

Chittenden County is located in the northwestern part of the state of Vermont. It is the most populous county in the state, and home to its largest city, Burlington. It is approximately 100 miles from Montreal and 150 miles from Albany, the two closest major cities. It is bounded to the west by Lake Champlain, and by farming communities on all other sides. Its total area is 620 square miles, but its total land area is only 539 square miles. The main roads in Chittenden County are Interstate 89, and US Routes 7 and 2.

Chittenden County consists of eighteen municipalities (figure 1), ranging in size from Buell's Gore, with a population of less than twenty, to Burlington, with a population of 42 417 as of the 2010 Census. The total population of the county was approximately 130 000 in 1990, 160 000 in 2010, and is projected by the local regional planning commission to be over 230 000 in 2030 (Economic and Policy Resources, 2000; 2001).

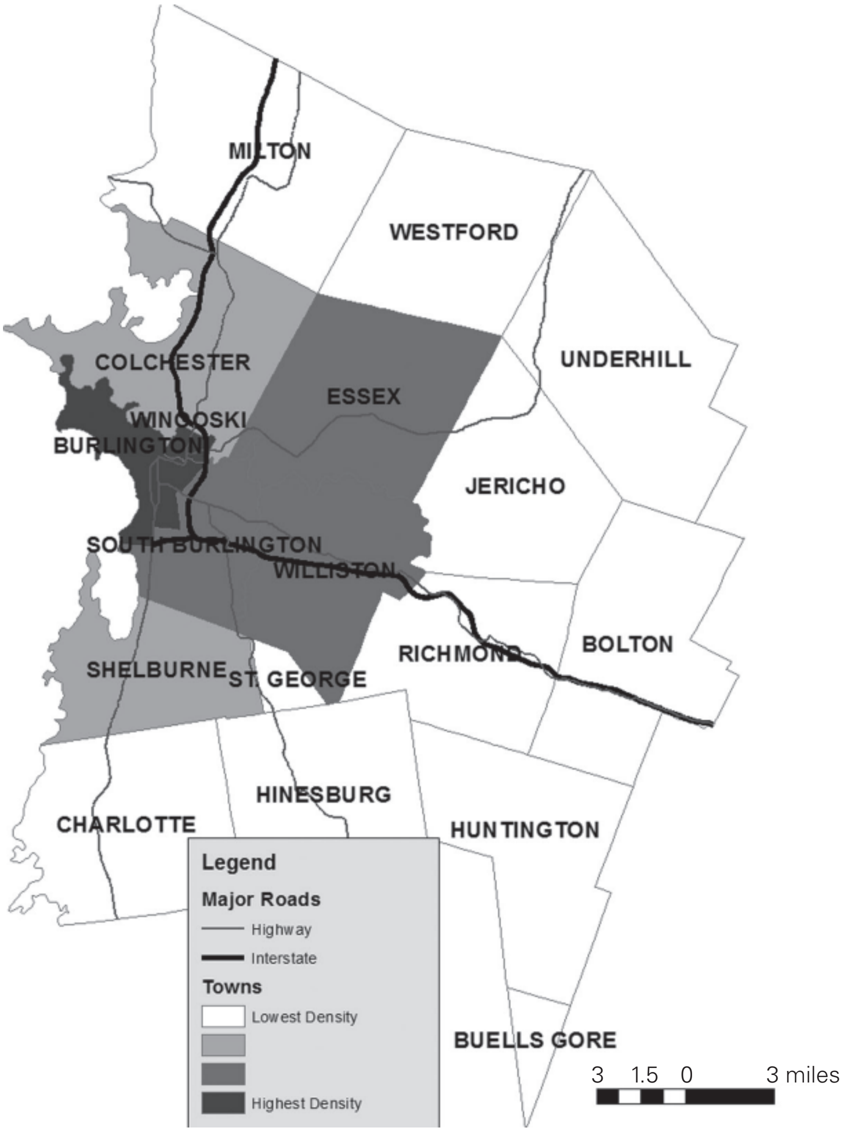


Figure 1. Study area.

2.2 UrbanSim and TransCAD

UrbanSim is a land-use-allocation model that is designed to be integrated with a travel model (Hunt et al, 2005; Waddell, 2002). It spatially allocates the development of real estate and the movement of households and businesses for a region on the basis of externally derived forecasts of population and employment change, using a series of discrete choice submodels developed and estimated for the area using a base year and historical data (Voigt et al, 2009). Agents in UrbanSim include households, employers, and real-estate developers. UrbanSim takes as inputs existing land use, suitability for development, zoning restrictions, demographic data about residents and businesses, as well as population and employment forecasts. A complete description of the base-year data assembly process, model development, and coefficient calculation can be found in Voigt (2010).

UrbanSim as implemented for Chittenden County has been integrated with the county's travel-demand model, which was developed using TransCAD version 4.9 (Caliper Corporation) (Voigt et al, 2009). The travel demand model is a four-step model, based on a road network that covers the entire county and 335 traffic analysis zones (TAZs) within the county plus seventeen external TAZs that reflect traffic entering or leaving the county on major roads (Resource Systems Group, 2008). Using land-use data regarding population, jobs, commercial space, and density, the model determines the number of incoming and outgoing trips generated by each TAZ, connects the start and end points of each trip, determines which mode (drive alone, carpool, walk or bike, or transit) will be used for each trip, and assigns each trip to a particular route on the network. The transit option consists of a small network of bus routes centered in Burlington.

In the integration of the travel demand model with UrbanSim, the land-use portion of the model runs for every year of the simulation. Within the land-use model, the land price submodel runs first, and then the residential land share submodel, which takes land price as an input. Following the residential land share submodel, the household and employment transition submodels are run. These submodels rely on the control totals. The combination of new households and new employers plus the households and employers flagged as 'movers' define the set of agents that are passed to their respective location choice submodels. Once the set of movers has been determined, the submodels compute the available capacity to accommodate both new and relocating agents. If the capacity is too low, that triggers residential, commercial, and industrial development, each of which is each addressed in a separate location choice submodel. Finally, the location choice submodels for selecting new sites for the individual households and employers are run. After all the submodels have run, new population and commercial densities and other indicators can be calculated.

After each five years of land-use simulation the land-use data are aggregated to the TAZ scale and passed to the travel model (figure 2). The land-use data that are relevant to the travel model include the number and attributes of households and employers in each TAZ (Resource Systems Group, 2008). These data directly affect the number of trips to and from each TAZ, which, in turn, affect the total amount of travel (the VMT) within the model system, as well as the congestion levels on the various routes. After the travel model runs, various accessibility measures for each TAZ are passed back to UrbanSim, where they become part of the land-use decision-making process for each future year of the simulation, as covariates in certain of the discrete choice submodels (Voigt et al, 2009). Because mode choice in Chittenden

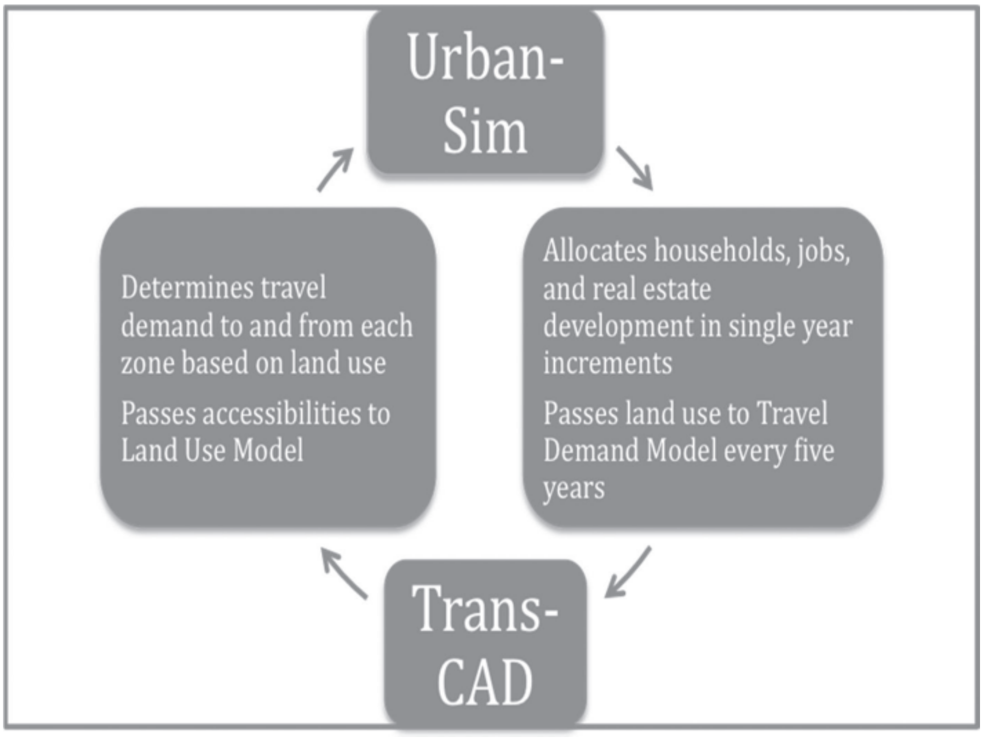


Figure 2. Interaction between land-use and transportation model.

County is heavily dominated by automobile travel, automobile accessibility is the dominant determinant of overall accessibility for each TAZ.

2.3 Scenario development

The business-as-usual scenario (table 1) reflects the model as estimated for Chittenden County using 1990 data as the base-year data (Voigt et al, 2009). It relies on population and employment forecasts from the Chittenden County Metropolitan Planning Office and Regional Planning Commission.

Table 1. Scenario summary.

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

In developing the contours of the urban core scenario, in which no new development was permitted outside a UGB, the goal was to keep the area within the UGB as compact as possible, taking into account the existing road network and development patterns [figure 3(a)]. As with the business-as-usual scenario, the urban core scenario (table 1) was run using a 1990 base year. Once the boundary had been set, all gridcells outside the boundary were modified to prohibit any new residential, commercial, or industrial development. Zoning restrictions inside the growth boundary were not modified, so that growth could occur within the boundary up to the existing limits, but would not occur outside the boundary.

The intent of the multicenter scenario (table 1) was to spread growth around, while still requiring that it be relatively compact in those places where it is permitted. To implement this scenario, one or more TAZs were selected from each town in the county. Most towns have a small TAZ in the traditional town center, and one or more additional TAZs covering the remainder of the town. For all towns with a central, compact TAZ, that TAZ was chosen for growth [figure (3b)]. The gridcells in those TAZs that were selected as the growth areas kept their existing zoning regulations; all other gridcells were modified to allow no development of any type.

The scenarios are not intended to be completely realistic, and the results are not intended to be a prediction of the future. More realistic scenarios would allow some development outside the growth boundaries. However, the complete prohibition on development outside the boundaries allows us to measure the maximum potential of this strategy. Relaxing these restrictions might give more realistic results, but would leave open the question of how much improvement is possible with this technique. As work on this concept progresses, future research might include testing the results if a limited amount of development were permitted outside the growth boundaries.

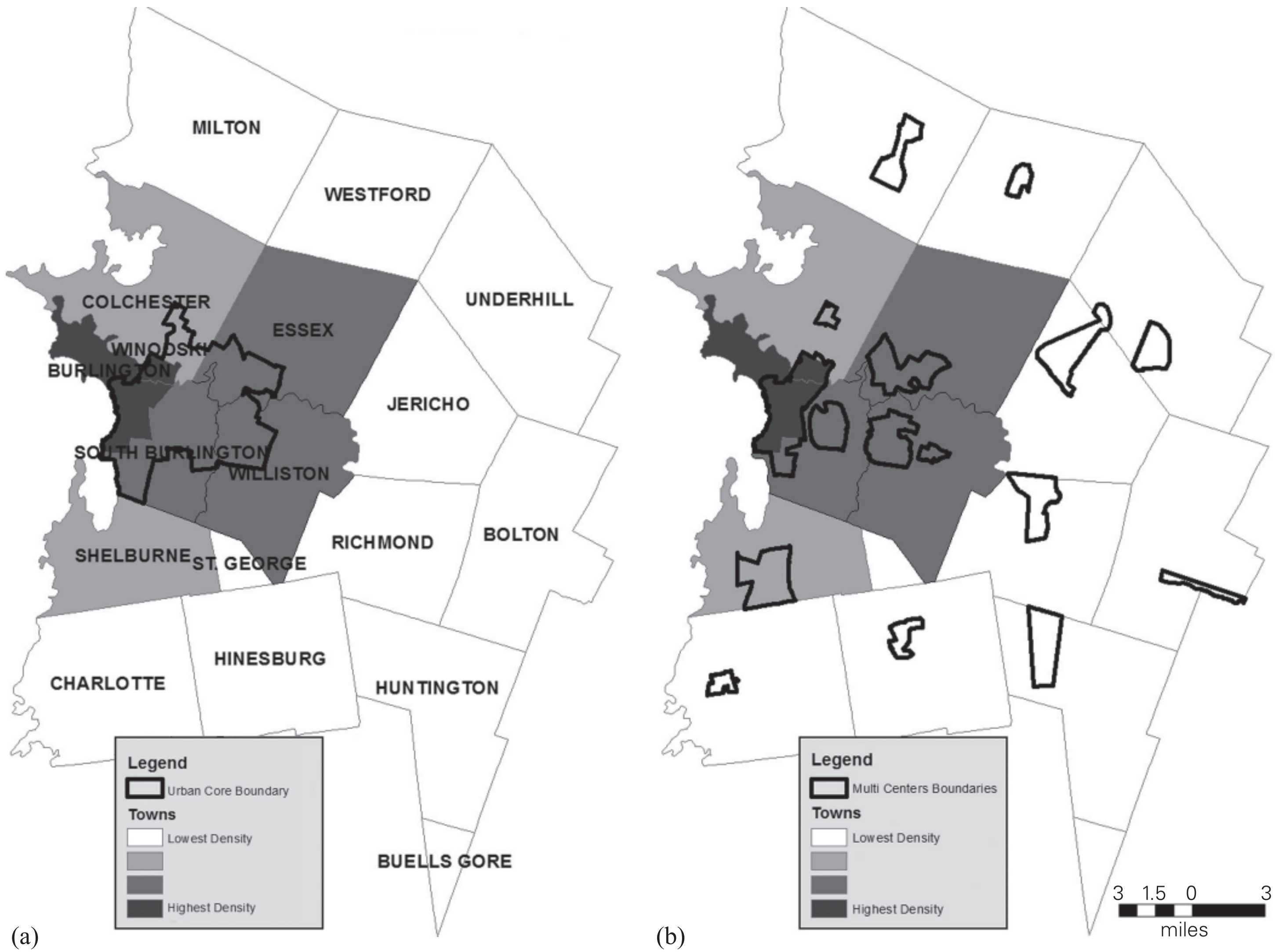


Figure 3. Borders of growth areas in (a) urban core scenario and (b) multicenter scenario. Shading indicates residential density as of 1990.

3 Results

3.1 Land-use results

Over the forty years of the model run county-wide, population density increases from 0.32 people per acre in 1990 to 0.54 people per acre in 2030 [figure 4(a)]. Under the business-as-usual scenario, Burlington, the county's largest city, is forecast to grow from 4.9 people per acre in 1990 to 6.2 people per acre in 2030. Winooski, the most densely populated town in both 1990 and 2030, is forecast to grow from 7.1 people per acre in 1990 to 8.0 people per acre in 2030.

The business-as-usual scenario yields widespread low-density growth, with most new development occurring in rural areas [figure 4(b)]. This growth pattern is particularly evident in Williston, Hinesburg, Westford, and Underhill, towns that were predominantly rural in 1990. The towns with the least increase in residential units in the business-as-usual scenario are the three towns with the highest density in 1990: South Burlington, Winooski, and Burlington (table 2).

The urban core scenario was run for the same years as the business-as-usual scenario, with the same population and job control totals. Thus, the county-wide growth and density is the same as in the business-as-usual scenario, although it is distributed differently throughout the county (figure 5). The density in the area designated as the 'urban core' is 2.8 people per acre in 1990, and it is forecast to grow to 4.7 people per acre in 2030 in the business-as-usual scenario. By contrast, in the urban core scenario the density in that area is forecast to grow to 7.2 people per acre. Burlington's density ends up at 9.3 people per acre under the urban core scenario, almost 10% higher than forecast in the business-as-usual scenario.

Turning to the multicenter scenario, density in the areas designated as town centers increases from an average of 1.0 residential units per acre in 1990 to 2.3 units per acre in 2030. In comparison, the business-as-usual scenario forecasts only 1.2 units per acre in these areas in 2030. Several town centers (eg, Charlotte) are limited in growth under this scenario by their current zoning regulations, which limit the maximum permitted density, even in the town centers.

Another way to evaluate the population density is by looking at the proportion of land that is minimally developed, the proportion that is densely developed, and the proportion of the population living in low-density or high-density areas. In the business-as-usual scenario, and measuring at the gridcell level, 14 000 more acres of land are forecast to have residential development over the forty years of the model run (table 3). Under the urban core scenario, the new growth would occupy only 4400 acres, and with the multicenter scenario it would occupy 8100 acres. Under the business-as-usual scenario, no new land is forecast to have high-density development (at least 10 units per acre). By contrast, the urban core and multicenter scenarios increase the proportion of the population living at moderate densities (at least one residential unit per acre), and increase the amount of land that is densely developed by approximately 250 acres, in order to maintain the proportion of the population that is living at high density.

Turning from residential development to commercial development (figure 6), under the business-as-usual scenario the largest portion of commercial growth is forecast to occur in the towns of Colchester, Charlotte, and Jericho, outside the urban core. In 1990 there was commercial or industrial development in only 2450 gridcells out of 64 000 in the county; by 2030, under the business-as-usual scenario, such development is forecast to be in 5868 gridcells.

Under the urban core scenario commercial and industrial growth were limited to areas within the urban core where such development is permitted under existing zoning regulations. With these restrictions in place, the number of gridcells with such development is not forecast to increase in the same way as in the business-as-usual scenario, growing from 2450 gridcells

Figure 4. (a) Total residential density in 2030 under the business-as-usual scenario, and (b) residential growth from 1990 to 2030 under the same scenario.

Table 2. Growth in residential units by town.

Town	Baseline	Business-as-usual scenario			Urban core scenario			Multicenter scenario		
	residential units 1990	residential units 2030	growth	percentage change	residential units 2030	growth	percentage change	residential units 3030	growth	percentage change
Bolton	526	1764	1238	235	526	–	0	704	178	34
Buells Gore	8	49	41	513	8	–	0	8	–	0
Burlington	16280	16517	237	1	27214	10934	67	26581	10301	63
Charlotte	1331	4971	3640	273	1331	–	0	1352	21	2
Colchester	5901	11785	5884	100	8445	2544	43	7197	1296	22
Essex	6317	8206	1889	30	11295	4978	79	10222	3905	62
Hinesbury	1476	4780	3304	224	1476	–	0	2077	601	41
Huntingdon	616	2268	1652	268	616	–	0	1186	570	93
Jericho	1500	4463	2963	198	1500	–	0	2176	676	45
Milton	3014	5304	2290	76	3014	–	0	4602	1588	53
Richmond	1390	4326	2936	211	1390	–	0	2949	1559	112
Shellburne	2356	3683	1327	56	2356	–	0	4167	1811	77
S Burlington	5413	5568	155	3	15391	9978	184	11426	6013	111
St George	285	537	252	88	285	–	0	285	–	0
Underhill	1013	3062	2049	202	1013	–	0	1317	304	30
Westford	637	2459	1822	286	637	–	0	853	216	34
Williston	1882	3423	1541	82	5153	3271	174	4536	2654	141
Winooski	2933	2933	–	0	4391	1458	50	4435	1502	51

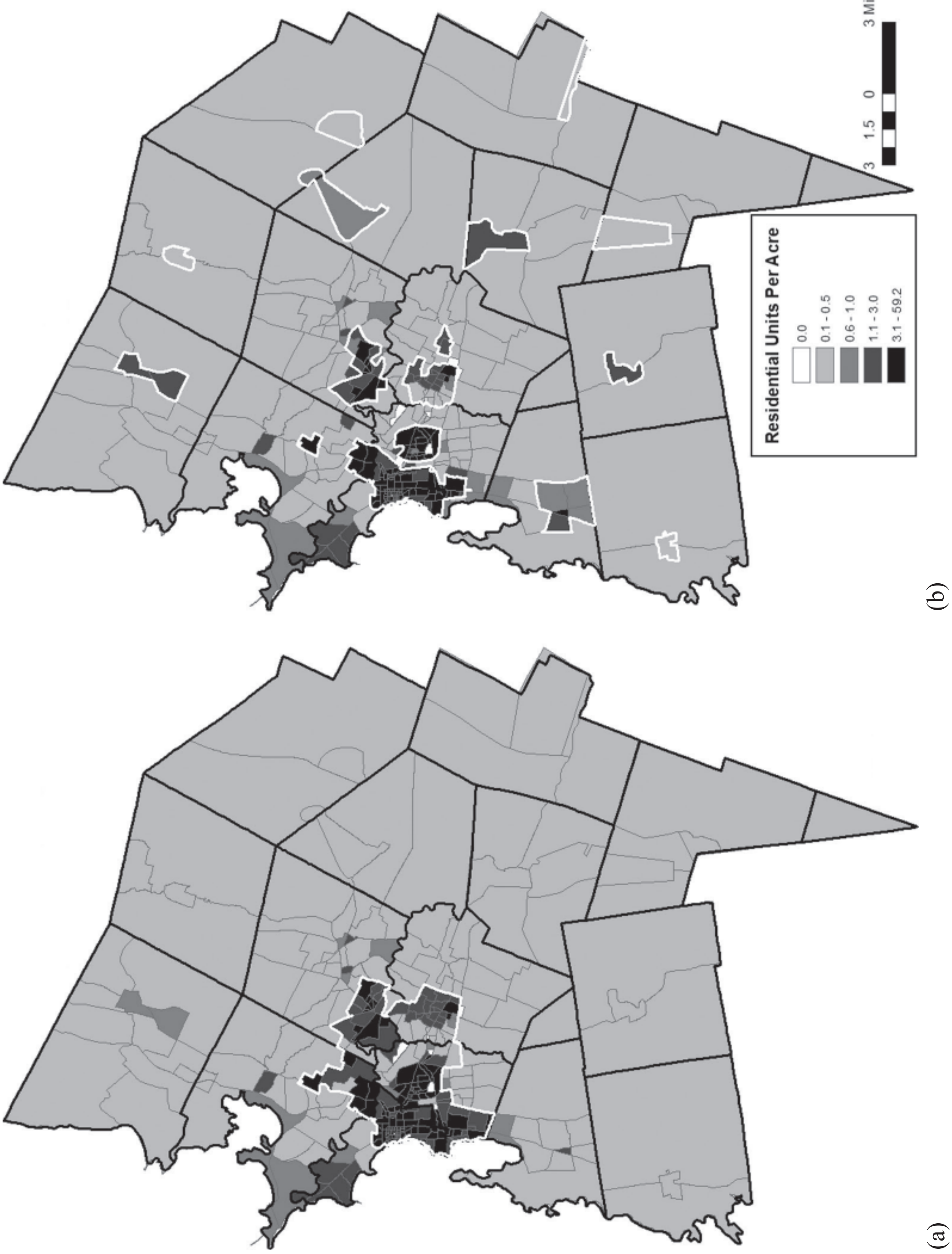


Figure 5. Residential units per acre in 2030 in (a) urban core scenario and (b) multicenter scenario.

Table 3. Areas with varying levels of residential density

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

in 1990 to 3088 in 2030, although the overall total number of gridcells in the county is the same (because it is determined by the control totals). In the multicenter scenario, commercial and industrial space spreads to 3121 gridcells. In this scenario, the commercial square footage in the areas designated as town centers almost doubles, compared with a projected 12% increase in the same areas under the business-as-usual scenario.

The mix of residential and commercial development is another important land-use indicator, and another way to evaluate scenario outcomes. In 1990, 113 344 people, or 89% of the population, lived within 400 m (approximately 0.25 miles) of a gridcell with commercial development (table 4). By 2030, under the business-as-usual scenario, that number is forecast to grow slightly, to 195 950 people, representing 91% of the population.

Under the urban core scenario, by 2030 93% of the population is forecast to live within 400 m of a gridcell with commercial development. Even though commercial development is much less dispersed under this scenario than under the business-as-usual scenario, a slightly higher proportion of the population can reach some commercial development on foot.

Table 4. Land-use mix.

	Gridcells with commercial space	Residential units in gridcells with commercial space	Residental units within 400 m of commercial space	Percentage of population within 400 m of commercial space
1990	2 427	22 172	47 839	89
2030 business as usual	5 333	33 995	76 870	91
2030 urban core	2 904	43 019	80 337	93
2030 multicenter	3 159	42 701	79 517	92

3.2 Transportation results

In terms of transportation indicators, under the business-as-usual scenario, total VMT in Chittenden County is forecast to increase by 92% from 1991 to 2030 (table 5). Part of this growth is attributable to forecast population growth. VMT per capita is also forecast to increase, although only by 18%. The total number of trips is forecast to increase by 73% overall, but only by 6% per capita. In 1991, 69% of trips are by car with a single occupant, 19% are by car with more than one occupant, 12% are by walking or biking, and public

Table 5. Transportation results.[a]

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

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

[b] VMT = vehicle miles of travel.

[c] VHT = vehicle hours of travel.

transit is less than 1%. Those proportions are not forecast to change significantly in the business-as-usual scenario.

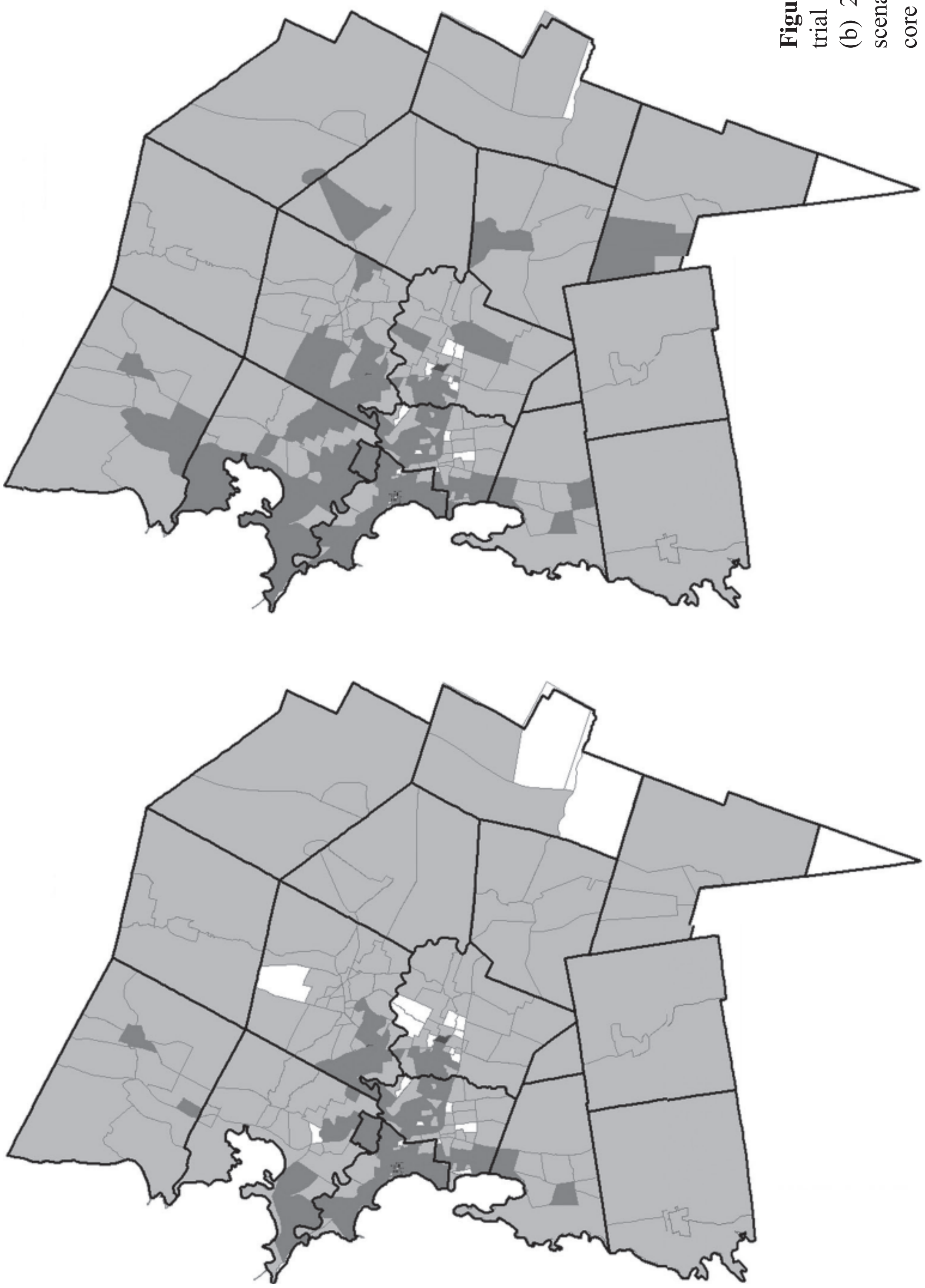
In the urban core scenario, with no changes to the transportation system or the travel demand model, VMT is forecast to be 25% lower in 2030 than in the business-as-usual scenario (table 5), and the total number of vehicle trips is forecast to be 8% lower. Walking and biking trips are 29% higher, and transit trips are 23% higher, although they still constitute less than 1% of the total number of trips.

VHT is also forecast to be lower in 2030 in the urban core scenario compared with the business-as-usual scenario, although the difference is not as great in percentage terms as the difference in VMT. The decrease is due to the decrease in trip count and in trip length, but the average travel speeds are forecast to be slightly slower in the urban core scenario (23.6 miles per hour) than in the business-as-usual scenario (25.0 miles per hour).

The results of the multicenter scenario fall in between the business-as-usual scenario and the urban core scenario on almost every indicator, but generally closer to the urban core results than to the business-as-usual results. This pattern is true for VMT, VMT per capita, and VHT.

3.3 Accessibility results

TransCAD generates travel utilities, a measure of the relative ‘cost’, for trips by automobile, transit, and walking and biking trips from each TAZ to every other TAZ. It then generates a logsum that combines the utilities for each of the three modes into a single measure of the relative accessibility for each TAZ. The logsum values are dominated by the automobile utility, reflecting the dominance of automobile trips in the Chittenden County transportation system. By 2030 the business-as-usual scenario forecasts poor accessibility in many areas on the periphery of the core, shown in light gray in figure 7. These areas fare better in the urban core scenario. By contrast, the TAZs in the heart of the urban core become congested in the urban core scenario (TAZs in darker gray in figure 7). The logsums for the multicenter scenario are very similar to the business-as-usual scenario (Pearson’s correlation coefficient > 0.99999).



(b)

(a)

Figure 6. Commercial and industrial square feet per acre in (a) 1990; (b) 2030 under the business-as-usual scenario; (c) 2030 under the urban core scenario; and (d) 2030 under the multicenter scenario.

(c) (d)

Figure 6 (continued).

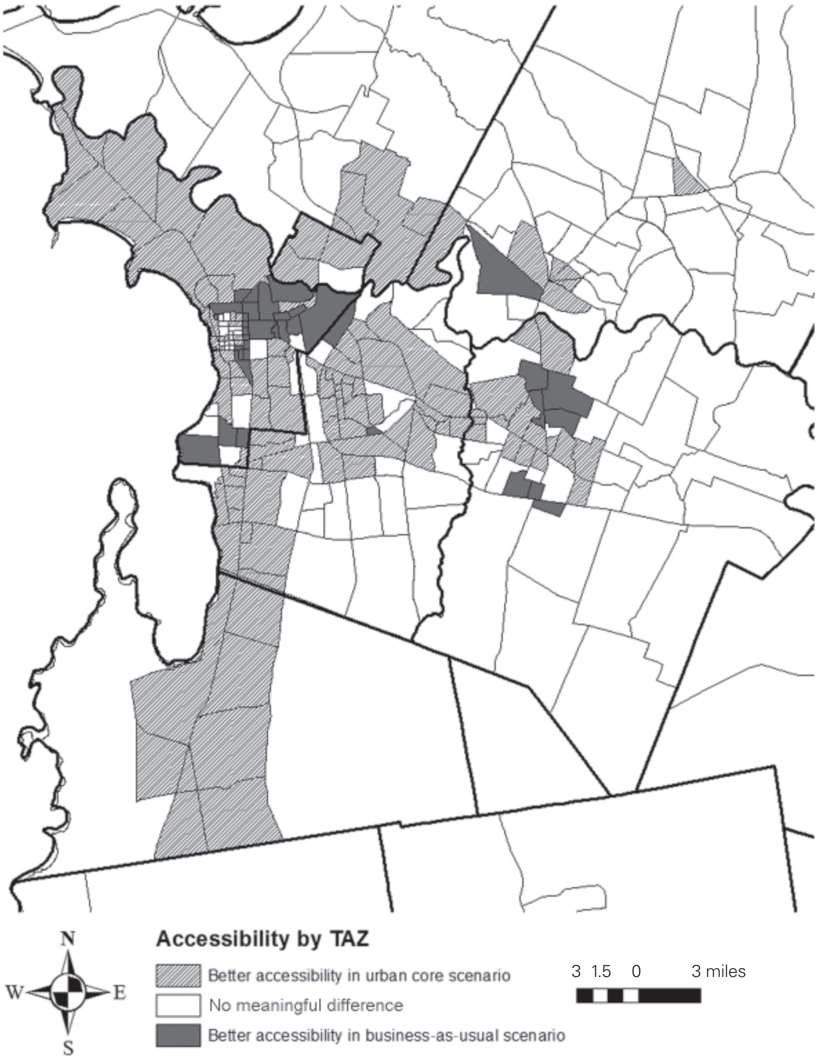


Figure 7. Difference in accessibility logsums in 2030 between the business-as-usual scenario and the urban core scenario. TAZs beyond the extent of this figure had no meaningful difference in accessibility between the two scenarios.

The primary way that accessibility features in the land-use model is via the home-access-to-employment variable, which measures how many jobs can be accessed within a limited amount of time from a home in a given TAZ, and job-access-to-employment variable, which measures how many other jobs can be accessed within a limited amount of time from a job in a given TAZ. These measures incorporate the logsum data from TransCAD with the modeled land-use results (UrbanSim Project, 2008). The home-access-to-employment variable is included in the residential development location choice model (where better accessibility makes the location more desirable for development), and the job-access-employment variable is included in the commercial development-location-choice model. Although other measures exist, these are the two that were determined to be useful predictors of residential and commercial development within Chittenden County (Voigt et al, 2009). Moreover, these are typical measures of destination accessibility, found to be the built environment variable most strongly correlated with VMT in a major 2010 metaanalysis (Ewing and Cervero, 2010).

In comparing these terms across the three scenarios, the values the model produces for each TAZ differ slightly from scenario to scenario, but in relative terms there is almost no difference between the three scenarios. When broken into deciles, out of 335 TAZs, only three change decile from one scenario to another for either variable, and those shift only a single decile. The Pearson's correlation coefficient is > 0.9999 among the three scenarios for the 2030 values for both variables.

4 Discussion

4.1 Validation

Actual growth in Chittenden County between 1990 and 2010 has been significantly lower than the modeled growth. The model inputs stated that population would be approximately 165 000 in 2010, but in fact the 2010 population was only 156 545 (US Census Bureau, 2011). While the difference between the actual and modeled population in 2010 is only 5% in absolute terms, there is a 29% difference in the amount of growth over the first twenty years of the time period modeled.

Apart from the difference in the quantity of growth, actual growth has been in different locations from the model predictions under the business-as-usual scenario. Several close-in suburbs of Burlington, including South Burlington, Williston, and Essex, have a greater share of growth in reality than the model predicts, as does Milton, an outlying town with a significant commercial core. Conversely, several of the more distant suburbs such as Hinesburg, Westford, and Charlotte received, in reality, a smaller share of growth than the model predicts (US Census Bureau, 2011). The difference in the pattern of growth indicates that the model parameters, which were developed using the baseline 1990 data, do not reflect current trends perfectly. Changes may include growing preferences for shorter commutes or other factors that favor the close-in towns over the more distant areas.

Comparing the transportation results with reality, the model predicted that VMT would grow by 11.5% per capita from 1990 to 2010 under the business-as-usual scenario. In actuality, growth in VMT per capita in Chittenden County, at approximately 6%, has been lower than the model predicts. This is likely connected, at least in part, to the different land-use patterns. In Vermont as a whole, over the same time period, VMT per capita has increased by almost 16% (Vermont Agency of Transportation, 2010).

4.2 Chittenden County results

The results of this modeling effort indicate that even with its relatively small size and slow rate of growth, Chittenden County can make significant changes to its land-use patterns that will result in significant shifts in its mobility profile, decreasing VMT and vehicle trips while maintaining or improving accessibility. Moreover, doing so will not result in undesirably dense or congested urban areas.

The densities that result from all three scenarios are within what the towns have already approved. Even the urban core scenario does not result in the densities that would make Chittenden County or its core feel like a major city. It happens with moderate population growth, and the end result is moderate density. To put the scenario results in context, consider that Manhattan's population density is more than 100 people per acre over 23 square miles, and in Boston and Chicago the density is approximately 20 people per acre over 48 square miles and 227 square miles, respectively (US Census Bureau, 2011). Burlington's actual population density in 2010 is 6 people per acre over just 11 square miles. Under the urban core scenario, the density in Burlington climbs to 9 people per acre by 2030. Almost 90% of the land area of the county is forecast to have a population density of fewer than 5 people per acre. Only 1.2% of the land area is forecast to be more densely populated than 10 people per acre, although 38% of the population would live in those areas.

Even though the population density remains moderate, VMT and vehicle trips decrease significantly, especially under the urban core scenario. In future research, if the land-use scenarios are combined with simulations of transportation changes, such as increasing the bus service or increasing the cost of driving, or both, the impact on VMT and vehicle trips will likely be even greater, and the minor congestion effect evidenced in the VHT results might be ameliorated.

It is important to bear in mind that these results are not predictions of the future, and that development is not likely to occur exactly as modeled in any of these scenarios. First, as we have seen, the business-as-usual model forecasts that growth will be more dispersed than it has been in reality, which means that the scenario analysis has likely exaggerated to some degree the transportation benefits of the modeled regulatory changes. Moreover, the urban core and multicenter boundaries were drawn for purposes of exploring these ideas, and the precise boundaries of any urban growth boundary or other growth management tools actually adopted in Chittenden County would likely differ significantly from these preliminary and rough contours. However, the results are useful for revealing an idea of the type and scale of benefits that might accrue from such a course of action.

5 Conclusion

As is the case with all models, the results reported here only provide information about those variables that are included in the model. If a variable was not statistically significant in predicting outcomes in the past, it is not included for the purposes of predicting future outcomes, even though attitudes can change over time and different variables may be of greater or lesser importance at different times. For example, the household location choice submodel focuses on variables such as the residential density, the average age of homes in the area, and the income level and family makeup of other residents of the area. It has no variables reflecting amenities, such as proximity to parks, schools, or shopping districts, that might, in reality, have a strong influence on a household's decision about where to locate. In addition, even if they might be important, variables are not included if it is impossible or impractical to develop the data needed to include them, or they may be included via proxies that may, or may not, be good reflections of the variables that really matter.

These limitations necessarily impact the model results, which must be interpreted with the included (and excluded) variables in mind. The inclusion of a variable reflecting the preference for young households to locate inside the core in the household location choice submodel, for example, without changing the coefficient on that variable over the forty-year duration of the model run, may not reflect the reality that such preferences go in and out of style over time.

The lack of meaningful differences between the scenarios on home-access-to-employment and job-access-to-employment measures suggests that the control totals do not anticipate enough growth to affect accessibility significantly, even with the extreme changes to the land use regulations reflected in the scenarios.

These limitations notwithstanding, the model and its results provide a useful way to structure our thinking about the potential of this particular VMT reduction strategy. At the very least, it gives both professionals and the public something to react to, something to stimulate discussion about the land use we want to promote (or discourage), and the transportation outcomes we think would be beneficial.

Acknowledgements. This work was funded by grants from the US Department of Transportation administered through the University of Vermont Transportation Research Center and the Federal Highway Administration. The authors also wish to thank the Chittenden County Regional Planning Commission and Resource Systems Group, Inc. for their help in developing this project.

References

Bagley M, Mokhtarian P, 2002, "The impact of residential neighborhood type on travel behavior: a structural equations modeling approach" *Annals of Regional Science* **36** 279–297

Bartholomew K, 2007, "Land use—transportation scenario planning: promise and reality" *Transportation* **34** 397–412

Bartholomew K, Ewing R, 2009, "Land use—transportation scenarios and future vehicle travel and land consumption" *Journal of the American Planning Association* **75** 13–27
Cervero R, Murakami J, 2010, "Effects of built environments on vehicle miles traveled: evidence from 370 US urbanized areas" *Environment and Planning A* **42** 400–418
Economic and Policy Resources, 2000 *Economic and Demographic Forecast: Northwest Vermont and Chittenden County 2000 to 2035 and Beyond* Canadian County Regional Planning Commission and Chittenden County Metropolitan Planning Organisation, Williston, Vermont, VT
Economic and Policy Resources, 2001 *Economic and Demographic Forecast: Demographic Forecast Update for Chittenden County 2000 to 2035* Canadian County Regional Planning Commission and Chittenden County Metropolitan Planning Organisation, Williston, Vermont, VT
Ewing R, Cervero R, 2010, "Travel and the built environment" *Journal of the American Planning Association* **76** 265–285
Ewing R, Bartholomew K, Winkelman S, Walters J, Chen D, 2007 *Growing Cooler: The Evidence on Urban Development and Climate Change* (Urban Land Institute, Chicago, IL)
Federal Highway Administration, 2010 *Our Nation's Highways* http://www.fhwa.dot.gov/ policyinformation/pubs/hf/pl10023/
Handy S, 1996, "Methodologies for exploring the link between urban form and travel behavior" *Transportation Research D* **1** 151–165
Heres-Del-Valle D, Niemeier D, 2011, "CO_2 emissions: are land-use changes enough for California to reduce VMT? Specification of a two-part model with instrumental variables" *Transportation Research Part B* **45** 150–161
Hunt J D, Kriger D S, Miller E J, 2005, "Current operation urban land-use–transport modelling frameworks: a review" *Transport Reviews* **25** 329–376
Resource Systems Group, 2008 *CCMPO Regional Transportation Model Documentation* Chittenden County Metropolitan Planning Organization, Winooski, VT
Rodier C, 2009, "A review of the international modeling literature: transit, land use, and auto pricing strategies to reduce vehicle miles traveled and greenhouse gas emissions", presentation to the 2009 Transport Research Board Annual Meeting, http://www.arb.ca.gov/planning/tsaq/docs/rodier_8_1_08_trb_paper.pdf
Transportation Research Board, 2009 *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions* (National Research Council, Washington, DC)
UrbanSim Project, 2008 *Opus:The Open Platform for Urban Simulation and UrbanSim Version 4 Reference Manual and Users Guide* (Center of Urban Simulation and Policy Analysis, Seattle, WA)
US Census Bureau, 2011 *The 2011 Statistical Abstract* http://www.census.gov/compendia/ statab/2011/
Vermont Agency of Transportation, 2010 *2009 Miles and Annual Vehicle Miles Travelled (AVMT) by County and Functional Classification* http:// www.aot.state.vt.us/planning/documents/highresearch/publications/pub.htm
Voigt B, 2010 *Models of Anthropogenic Influence on the Landscape* PhD thesis, University of Vermont, Burlington, VT
Voigt B, Troy A, Miles B, Reiss A, 2009, "Testing an integrated land use and transportation modeling framework for a small metropolitan area" *Transportation Research Record* number 2133, 83–91
Waddell P, 2002, "UrbanSim: modeling urban development for land use, transportation, and environmental planning" *Journal of the American Planning Association* **68** 297–314