Spatial Models for the Statewide Evaluation of Transit-Supportive Zones

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Submission Date: November 15th, 2009
Word Count: 7500 (6000 + 6 x 250)

ABSTRACT

The importance of sustainable transportation systems has been increasing in light of volatile fuel prices, congestion and augmented awareness of environmental and equity consequences resulting from our collective transportation choices. Developing sustainable and effective public transit systems in rural settings is particularly challenging – attributable to spatial constraints (e.g. long travel distances and low densities). This research uses spatial analysis in GIS to develop an objective process for determining the level and spatial arrangement of transit demand potential in the rural State of Vermont. Available GIS data for building structure and public gathering locations from the E911 system were used to classify trip potential on a statewide acre-grid level and identify Transit-Supportive Zones. The spatial transit-demand-potential and reduction in automobile trips and vehicle-miles traveled by automobile as a result of transit substitution was extracted from the statewide origin-destination trip table and estimated to be 831,007 new person-trips by transit, a daily reduction of 532,844 automobile trips and 2,594,499 vehicle-miles traveled. The next step in analysis would be using the demand potential as input to design efficient systems to service these trips.

INTRODUCTION

With traffic congestion, fuel prices, equity and environmental consequences of travel at the forefront of transportation issues, it is impertive that practical and reliable strategies be implemented to provide travel alternatives in all (including rural) areas. Public transit has the potential to serve as a mitigation technique to not only address these concerns, but also decrease vehicle-miles traveled (VMT) by single-occupancy vehicles (SOV), reduce transportation infrastructure costs, and ensure that individuals are provided with equitable and affordable transportation alternatives. The spatial constraints (e.g. long travel distances and low densities) inherent to rural settings creates a formidable environment for the development of sustainable and efficient public transit systems. Moreover, the planning data, staff and systems available in urban areas are often less available in rural areas – further challening the design of innovative and feasible public transit systems.

An important component of developing sustainable transit networks (both fixed route and non-fixed route) is first defining areas that are transit-ready (e.g. areas where population density is high enough to lend sufficient ridership). Limitations exist in previous studies regarding spatial model development to determine public transit demand and transport coverage (especially for applications to rural areas) - only examining demand on the zonal level (i.e. Traffic Analysis Zones (TAZs), Census tracts and Census blocks). The assumption of homogeneity across a zone becomes more unrealistic as the size of the TAZ increases and consequently affects the accuracy of travel forecasts and land-use patterns *(1)*. Transit demand modeling has been conducted on the parcel-level *(2, 3)* but is generally constrained to individual cities or geographic areas with limited extent, smaller analysis zones and of urban focus.

This study presents an objective process to determine the statewide spatial transit-demand-potential for the rural State of Vermont. Using E911 GIS data (a database of building structure and public gathering locations) available from the Vermont Center for Geographic Information, *Transit-Supportive Zones* (TSZs) were defined using employment statistics from the Vermont Department of Labor and trip rates from the Institute of Transportation Engineers (ITE) Trip Generation Manual. The TSZs were used to determine the proportion of trips within each Traffic Analysis Zone (TAZ) of the statewide planning model that could be made by transit. The level of demand was then estimated by applying these proportions to the Vermont State 2000 base-year origin-destination (OD) model - resulting in the total number of potential new transit trips and the potential reduction in automobile trips and VMT between each origin-destination (OD) pair.

LITERATURE REVIEW

There is continued interest in creating transit networks that not only serve the maximum number of travelers but also ensure efficiency and cost-effectiveness. Attempts have been made to evaluate the role that density *(4-8)* and land use type *(9, 10)* play in the success of transit, how access and coverage affect ridership *(7, 8)* and the quality of transit service *(3)*.

Density and Land Use

Residential and employment densities play an important role in the viability of transit. As residential densities increase, so does potential ridership in the immediate areas of transit facilities. Similarly, high employment densities generate more potential trip destinations. An analysis of transit in the Portland, Oregon region *(8)* suggests that 93 percent of the variance in transit demand can be predicted by the overall housing and employment density per acre. However, other studies indicate that high residential densities alone have little effect on transit usage if there is a lack of accessible destinations for the riders - implying a higher importance be placed on employment and other land use densities *(5)*.

The Institute of Transportation Engineers estimate thresholds of residential densitites (dwelling units per acre) that can support different levels of transit service - local and intermediate bus service having a threshold of four and seven dwelling units per acre, respectively *(5)*. These findings are similar to those of Ewing *(13)* where basic and premium bus services have a threshold of seven and fifteen dwelling units per acre, respectively. Several studies have been conducted that corroborate these values. Levinson and Kumar *(14)* determined that a minimum of 7,500 persons per square mile (approximately four to eight households per zonal acre) needs to be present in order to see a relationship between density and mode choice. The results of a travel behavior study in the Seattle metropolitan area indicated that the number of transit work trips began to increase at nine to 13 persons per gross acre *(15)*. It should be noted that most of these thresholds are guidelines and when considering residential density thresholds for transit, they should be used in conjunction with the cost and efficiency of service in order to be completely meaningful *(8)*.

The Georgia Regional Transportation Authority *(16)* defines transit-supportive areas as those having either three household units or four jobs per acre (with preferred levels at 10 household units per acre and 20 jobs per acre). Other literature regarding employment densities that can support transit generally suggest similar values; 50 to 75 employees per acre *(15)*, 50 to 60 employees per acre *(4)* and 20 to 50 employees per acre inducing substantive modal shifts to transit *(6)*.

Access

Access to public transportation is another critical factor in the level of use (e.g. the farther/longer someone is required to “travel” in order to access the transit system the less likely they are to make use of it). Many studies suggest users are only willing to walk a maximum of about 400 meters (1/4 mile) to reach a transit stop – representing a comfortable walk under normal conditions *(1-3, 7, 11, 12)*. However, other studies have discussed the underestimation of existing walking access standards *(14)* and that the walk impact zone of a particular station often extends out to one-half mile or more - being increased further by the presence of pleasant urban spaces and corridors *(18)*. This is consistent with a distance of 2,460 feet at which a considerable drop-off in the number of people walking to transit is experienced *(8)*. This access distance and conditions are especially important for rural areas where lower densities will result in fewer people within the access area.

Demand Modeling

Potential demand for transit has been defined as the proportion of people who may use public transportation as a primary transportation mode where the spatial unit of measure is homogenous (e.g. size or non-travel characteristics such as demographics) and heterogeneous with respect to travel choices and factors. Land-use and socioeconomic characteristics for each TAZ of the Atlanta, Georgia area were used to calculate the relative magnitude of potential demand *(19)*.

Potential demand has also been based on urban and spatial criteria – more specifically through the use of density and walking distance parameters *(20)*. Fu and Xin *(3)* proposed a Transit Service Indicator which measures the quality of service for individuals, corridors, activity areas and service areas using weighted travel times. Furth and Mekuria *(2)* identified the need for disaggregate models that would accurately reflect the demand distributions within zones – applying parcel-level models to transit stop relocation in Boston, Massachusetts and Albany, New York. The authors also noted that despite the slightly crude method of using the ITE rates for determining trip-generation coefficients, they are still adequate for transit planning applications by appropriately assigning demand to the most developed portion of a service area.

All of the study efforts described above relate to primarily urban areas. However, with the continual growth of aging population in rural areas and increasing costs of fuel, there is a need to adapt these methods for the data and landscape found in rural areas to enable better planning for either fixed-route or demand-responsive systems to be expanded or optimized. One must note that the concept of *demand* used here (as applied to economic theory but adopted for a transportation environment) expresses a present need resulting from spatial interaction of activities *(21)*. Previous work on rural transit identifies demand as being the number of passenger trips given the availability of service *(22)*. Demand (in its entirety) should be considered as both revealed demand (i.e. ridership levels and volumes) and latent demand (a desire or need that is unsatisfied by the current system but would become revealed under an idealized system). This is to say that observed ridership is not a clear indication of full potential demand and that these should not be used synonymously.

DATA

This section describes the data used to determine TSZs and level of demand. The focus area for this study was the entire state of Vermont; which included 246 towns and cities - only 21 of which have a population greater than 5,000 *(23)*. There is only one Metropolitan Planning Organization (MPO) in the state - which is located in Chittenden County (CCMPO) and adjacent only to one out-of-state small metropolitan area: Hanover, New Hampshire. As a reference, the State of Vermont has an average of 65.8 persons per square mile (in comparison to the national average of 79.6 persons per square mile) and a total population of 621,270 *(24)*. Furthermore, 62% of the Vermont population lives in rural areas *(25)* as compared to 21% for the entire United States *(26)*. Similarly, only 28% of the Vermont polulation *(25)* lives within a metropolitan area *(26)*.

E911 Database

The E911 database is a point layer in GIS that represents all residence locations (i.e. single family homes, multi-family homes, seasonal homes, mobile homes, etc.) and non-residence locations (i.e. commercial, industrial, education, government, health care and public gathering locations) in Vermont. Locations not pertinent to the study (i.e. fire hydrants) were removed. The database was updated in February, 2008 and has five-meter accuracy for each point – obtained either through 45-second GPS readings or from orthophotos. The primary use of the database is for emergency responders to accurately identify the location of distress calls. Vermont is unique in that the database is publicly available through the Vermont Center for Geographic Information. Only two other states have complete statewide E911 databases –

Rhode Island (also publicly available) and New Hampshire (which is not publicly available). Several other states have E911 databases but only for select counties within the state.

Housing Characteristics

The Profile of Housing Characteristics was needed to associate trip making potential to the residences coded in the E911 dataset. The Housing Characteristics were obtained from the 2000 US Census Bureau Summary File 3 (SF-3) on the American FactFinder website *(27)* which lists the number of structures present with a given number of housing units (ranging from two units to 20+ units). This information was used as a supplement to the E911 database in order to determine the average number of units in a multi-family structure for the geographic region of interest.

Employment Statistics

The employment statistics needed to estimate trip producing potential for non-residential land uses in the E911 database were obtained from the Vermont Department of Labor which reports the employment rates by town and specific business type. Because the values were only available as an average for each town, points of a specific type were all assigned the same value for that given town.

Trip Generation Rates

Trip generation rates were extracted by land use category from the 7th Edition of the ITE Trip Generation Manual for each location type represented in the E911 database. An average of the AM and PM weekday peak hour of generator for each land use category was used (see Table 1 for values).

TABLE 1 Trip Generation Rates for Non-Residential Land Use

Land Use Category	Trip Generation Rate – Avg. Peak Hour of Generator *(trips per employee)*
Educational Services	3.05
Government	2.77
Health Care and Social Assistance	0.74
Industrial (Goods Producing)	0.46
Commercial (Retail and Services)	5.21

Vermont Statewide Travel Demand Model

The 2000 base-year Vermont Statewide Travel Demand Model (VSTDM) was developed by the Vermont Department of Transportation in conjunction with Vanasse Hangen Brustlin, Inc. The result of the model is an OD matrix depicting the number of daily person-trips by five trip purposes (home-based work, home-based shopping, home-based school, home-based other and non-home-based) between each TAZ state-wide (628 internal zones and 70 external zones). Auto-occupancy rates were applied based on a household survey conducted in 1994. In addition to the classic four-stage transport model, the Vermont model also includes a transit network that assigns transit ridership on each leg of the transit system. The model assumes that transit will only be used for home-based work, home-based shopping and home-based other trips. The GIS polygon file of the TAZs was also provided for use in the study.

Hourly Distribution of Trips

An hourly distribution of travel was determined from the Federal Highway Administration (FHWA) Highway Statistics website *(28)*. This information was used to estimate percentage of trips that occur outside the normal operating hours of transit service so that they could be appropriately removed and not overestimate potential transit demand. In this case, we assume transit would not be provided between 9pm and 6am, and appropriately decrease daily demand in the state model OD by 7.6%.

METHODS

The methodology to identify rural TSZs and estimate demand potential required, in addition to the datasets described above, use of two GIS-based software programs: ArcGIS (ESRI) and TransCAD (Caliper Corporation). The first task was to determine the criteria for and identify the areas in Vermont that are transit-supportive so trips to and from those areas could be extracted from the model OD. Once the TSZ areas were identified, an estimation was made of the transit demand and the automobile trip and VMT reduction that would result if this demand were served.

Transit-Supportive Zones

In order to determine which areas of Vermont were transit-supportive, ArcGIS was used to interpret the E911 database. The E911 database was first filtered so that only locations where either a trip production or attraction would be present (i.e. fire hydrants and other utility structures were excluded). Employment statistics and trip generation rates were applied to each remaining point based on its location type. The *Demand Potential* (DP) of a given residential point (*i*) or non-residential point (*j*) was determined such that:

$$DP\ (i) = f(DU(i), T(i)) \quad (1)$$

$$DP\ (j,t) = f(E(j,t), T(j)) \quad (2)$$

where:

$DU(i)$ is the type of dwelling structure represented by point *i*

$E(j,t)$ is the average employment level for the type of location represented by point *j* and the town *t* in which the point resides

$T(i)$ is the trip generation rate for residential location *i*

$T(j)$ is the trip generation rate for non-residential location *j*

For the residence structures, factors were assigned to represent the typical number of family units present. Multi-family residential points were assigned a factor of 6.52 (a result of the weighted average of units per structure obtained from the US Census Bureau housing characteristics for Vermont). All other residential point locations were given a factor of one - where only one family unit is present in them (i.e. single-family homes).

Employment statistics were applied to each non-residential point based on the type of location that the point represented and the town in which it resides. For instance, the average employment for a commercial location in city of Burlington is approximately 75 employees whereas the average commercial employment in the town of Montpelier is approximately 60. The number of trips generated by each non-residence location was then calculated based on the ITE Trip Generation Manual. The trip generation rates for non-residential locations (except for public gathering) were based on the average number of employees present at that particular location. Since adequate data were not available, public gathering locations were assigned the same factor as a single-family home in order to remain conservative. For residential locations, the number of trips generated per dwelling unit was determined and applied in addition to the aforementioned residential weight factors for number of units. These values for each residential and non-residential location then represent the respective DP generated by that point.

In order to assess the overall transit serviceability of a given area, it was necessary to combine all DP to common units. In this case, the DP for each point was converted into a single housing unit *Equivalent Demand Potential* (EDP) by dividing the DP for a given location (*i* or j) by the DP for a single-family housing unit. In doing so ensures that intensity, land use balance and land use interaction are accounted for as suggested in previous research *(29)*. This also allows the transit-supportive thresholds reported in previous studies to be considered with the densities calculated from the E911 database. The EDP is equated back to an “equivalent” dwelling unit – dwelling units are the units that most transit-supportive criteria were based on. All areas within the State of Vermont for which the EDP per acre was greater than seven (the threshold generally accepted for fixed-route bus service at 30-minute intervals) *(5, 13)* were identified.

As an example, assume that all the E911 data points shown in Figure 1a are single family homes with an EDP of one with the grid representing one-acre parcels that serves as the unit of analysis. Also assume for this example that the cells surrounding the grids depicted in Figure 1 are void of E911 data points. Figure 1b would then represent the demand density (e.g. the sum of EDPs on a one-acre level). The Neighborhood Measure (N_z) for a three-acre by three-acre (neighborhood$_a$) area is depicted in Figure 1c (where the value for a given cell is the sum of that particular cell and all surrounding cells included in that area). The Neighborhood Maximum (N_{max}) (Figure 1d) is determined by assigning the maximum value within nine-acre by nine-acre (neighborhood$_b$) area to the central cell. N_{max} serves as reference to determine the locations of local maximums by dividing N_{max} by N_z. The local maximums (Z_p) within these identified areas were extracted by applying the following criteria:

$$Z_p \equiv \frac{N_z}{N_{max}} = 1 \; and \; \sum EDP \; per \; acre \geq 7 \quad (3)$$

Once the local maximum points were identified, TSZs were identified by creating a half-mile service area (based on the literature described above regarding access) around each center point or maximum point of the TSZ. The sum of all EDP values within that catchment area (even those below the seven equivalent dwelling units per acre) was considered the total TSZ demand potential. In order for an area to be deemed a TSZ, the centroid must meet the criteria in Equation 3 as well as the sum of EDP for the entire service area being greater than or equal to 3520 EDP units. The transit service area is defined as the area of a circle with a half-mile radius which represents the accepted walking distance to access transit services. The value of 3520 represents the same density of EDPs over the half-mile radius area as is experienced with seven EDPs on the one-acre level (meaning that the average density of the entire service area has to be as sufficient as the threshold criteria suggested for a single acre).

A Euclidean distance was used for the transit service area radius and is assumed to be sufficient for this analysis – having been used in previous studies by Murray *(11)* and Ramirez and Seneviratne *(1)*. Because the state-wide traffic model demand is based on the TAZ level, it was necessary to relate the demand potential of the TAZ to the TSZs that may be contained partially or completely within each TAZ. The demand potential for each TAZ was similarly determined by summing all EDPs within each of the 628 internal zones (external zones were not included since only transit within Vermont was being studied). The proportion of the EDP served by each TSZ in relation to the total EDP for a TAZ which the respective TSZ falls within can then be calculated such that the *Transit-Supportive Demand Proportion* (TSDP) is:

$$TSDP = \frac{EDP_{TSZ}\ (n)}{EDP_{TAZ}\ (n)} \tag{5}$$

where:

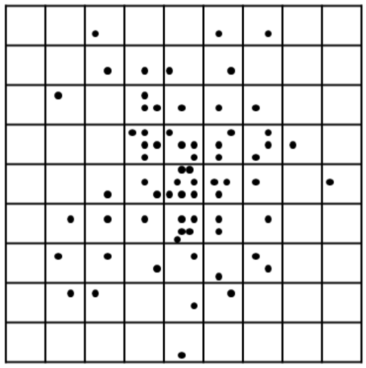
$EDP_{TSZ}\ (n)$ is the sum of EDP in the portion of each TSZ falling within the n^{th} TAZ

$EDP_{TAZ}\ (n)$ is the sum of EDP in the n^{th} TAZ

This TSDP represents the proportion of trips within a TAZ that could theoretically be served by transit if service were in place for all areas meeting or exceeding the density threshold criteria. To further explain this concept, a TAZ having a TSDP value of 0.75 would mean that 75-percent of the trip demand for the entire TAZ falls within the TSZ. The portion of demand that falls within the TSZ is assumed to be supportable by transit. This may correspond to 75% of the residences in the town being within a small village center at relatively high density. Note that we do not know at this point whether a feasible service routing or service schedule could be provided for these spatial areas, hence the use of the term potential.

Estimation of Transit Demand

The VSTDM was used to extract the number of daily person-trips by trip purpose (to later account for vehicle occupancy) between each TAZ – which includes trips that are currently being made by transit. The truck trips present in the model were excluded. The VSTDM also has the number of trips by trip purpose. In order to later determine the modal trip proportion for each OD pair, a weight factor was calculated by dividing the each trip purpose matrix by the total trip matrix. A bi-proportional



(a)

0	0	1	0	0	1	1	0	0
0	0	1	1	1	1	0	0	0
0	1	0	3	1	1	1	0	0
0	0	0	5	4	3	3	1	0
0	0	1	2	7	3	1	0	1
0	1	1	1	5	2	1	0	0
0	1	1	1	1	1	2	0	0
0	1	1	0	1	1	0	0	0
0	0	0	0	1	0	0	0	0

(b)

0	2	3	4	4	4	3	1	0
1	2	7	8	9	6	5	2	0
1	2	10	16	20	15	10	5	1
1	2	12	21	29	27	13	7	2
1	3	11	26	32	29	14	7	2
2	6	9	20	23	23	10	5	1
3	6	8	12	13	14	7	3	0
2	4	5	6	6	7	4	2	0
1	2	2	3	3	3	1	0	0

(c)

32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32
32	32	32	32	32	32	32	32	32

(d)

FIGURE 1 Process for determination of local maximums from E911 data.

gravity update was conducted using the TSDP for each zone as though it were an updated estimate of the total zone production or attraction. This matrix was reduced by 7.6% in order to take into account hourly distribution of travel and remove trips that are likely taking place outside of transit operation hours (typically before 6am and after 9pm).

In order to calculate the number of new transit trips that could be introduced to the system between each OD pair, the number of existing transit trips (also available from the VSTDM) were subtracted from the updated matrix. The resulting number of automobile trips (AT_{ij}) was then calculated by dividing each person transit trip by the auto occupancy rate for each respective trip purpose that is assumed in the VSTDM. Despite the assumptions of the VSTDM, it is assumed here that transit trips can occur for any trip purpose (e.g. all trips calculated for home-based shopping and non-home-based trips would be new transit trips). A potential reduction in VMT (R_{VMT}) by automobile for the State of Vermont can be determined by estimating the reduction of trips and the shortest path distance between OD pair centroids. To further illustrate this process, the method to obtain AT_{ij} is expressed in Equation 5 and the method to obtain R_{VMT} is expressed in Equation 6.

$$AT_{ij} = \sum_p [\sum_{ijp} \frac{TT_{ij}{}^{(p)}}{AO_p}] \quad (5)$$

$$R_{VMT} = \sum_{ij} (AT_{ij} * Min[DN_{ij}]) \quad (6)$$

where:

$TT_{ij}^{(p)}$ is the number of new trips originating in TAZ_i and destined for TAZ_j for each trip purpose p

AO_p is the auto occupancy rate for trip purpose p

$Min[DN_{ij}]$ is the network distance from TAZ_i to TAZ_j determined from a shortest path algorithm in TransCAD

This procedure assumes that users are currently minimizing their travel distance, which is common for modeling travel in large-scale urban areas and that TAZ centroids are of close proximity to TSZ centroids such that the shortest-path distance difference between travel starting at the TAZ and TSZ can be disregarded. At this point, this assumption is appropriate because the exact locations of transit stops have yet to be determined – so a precise analysis of the difference was not warranted or possible. The distances for intrazonal trips for each TAZ were approximated by using the radius of a circle whose area is equivalent to that of the TAZ *(30, 31)*. Average intrazonal travel in heavily urbanized areas may be shorter than a radius, but this assumption is assumed to be stronger for travel within primarily rural TAZs.

RESULTS

Examining spatial potential for transit service is the necessary first step in any analysis of transit-demand potential, particularly in large geographical areas which are predominantly rural. In this study, comprehensive transit-demand potential can be considered in terms of the spatial location of TSZs but also in terms of potential person transit trips, reduction in automobile trips and VMT. Call to mind that the term *potential* is being used to emphasize that the inherent structure of demand is doubly-faceted: revealed and latent demand. The results of the study indicate, that even when very disaggregate analysis is conducted using more refined data than town or census tract, there are limited locations within Vermont that can be considered "transit-supportive" (Figure 2). As one would expect, zones that *are* transit-supportive tend to be areas which are most dense (with respect to residence and non-residence locations) on a local scale and as such, tend to be the areas with the most trip productions and attractions. Figure 2 depicts the resulting TSZs of Vermont (note that these are mapped as areas *not* as points). These TSZs are spread throughout the state – making it hard to implement a comprehensive transit system that would serve both daily-local and intertown travel needs. In general, these zones also fall within larger towns (i.e. the places where greater residential and employment densities are likely to occur).

Table 2 summarizes the percentage of land area, residences and employment points that fall within an area defined as a TSZ. Only 5.7% of the area within the MPO is transit-supportive but is less than 1% elsewhere in the state. The percentage of residences and employment points that are within TSZs is high both inside and outside the MPO. A large portion of the employment points (40%) fall within TSZs throughout the state. For the CCMPO, over a third of the residences fall within TSZs (only 12% are within TSZs for the rest of the state – although this percentage is higher than expected, it further emphasizes the very rural nature of Vermont).

The gravity model-based update used to extract the portion of the OD by trip purpose that could be substituted by transit assumes that TSZs (the areas determined to have characteristics that are supportive of transit) were served with both intrazonal (service within the TSZ) and interzonal service (service between TSZs). Recall at this point that the current travel demand model for Vermont assumes transit will not occur for home-based other and non-home-based trips and as such, all transit trips resulting from the process discussed here are considered "new." The extracted TSZ OD would result in a maximum potential of 831,007 new daily person-trips by transit, a 43% reduction of trips made by automobile and a 21% statewide reduction in VMT by automobile (assuming that all users originating in a TSZ and destined for a TSZ utilized the service). The potential automobile trip and VMT reduction by trip purpose are shown in Table 2. These values are appreciably larger than the physical areas portrayed in Table 1. Of particular note is the significant potential estimated for non-home-based trips (a trip type usually considered to occur after home-based service and to have more variable temporal patterns). Despite the fact that only a small portion of the land area in Vermont is transit-supportive, potential reduction in automobile trips and VMT is quite substantial. Table 3 shows the spatial interaction characteristics of the potential automobile trip and VMT reduction (e.g. percentage of intrazonal trips versus interzonal trips and percentage of trips within the CCMPO versus trips destined outside of the CCMPO). In spite of 14% of auto trips being intratown travel, the reduction in VMT for those trips is only 3% - attributable to the short travel distance of those trips. These values also suggest that the nature of transit-supportive travel in Vermont is predominantly long intertown trips.

CONCLUSION AND DISCUSSION

It is deemed that the most important result of this work is related to data and methodology. Rural public transit systems - whether fixed route or demand responsive - are much more challenging to plan, fund and operate compared to their urban counterparts. The planning data and models available in urban areas are not typically available in rural areas or on a state-wide basis. By incorporating residence and non-residence point locations available through the publicly available Vermont E911 database, land use interactions and densities were taken into account on a disaggregate level. Using disaggregate data is important for rural settings in order to analyze areas that are often neglected by information only available on the TAZ, block group or census tract level. Despite being developed for a rural setting where it is more difficult to identify spatial patterns, the methods could have value as a data-driven decision tool in any region - illustrating both the application of a statewide E911 database and identifying the need for development and availability of similar data on a national scale.

The results of this project indicate limited areas with very specific geographic precision that may be transit serviceable in the rural state of Vermont. While only 6% of the state's area may be serviceable, this corresponds to a much larger proportion of the total statewide trips and VMT by automobile (43% and 21%, respectively). While a large number of the substitution potential was in the one MPO in Vermont, significant portions were in other towns as well. The larger than expected proportion of substitutable trips between towns suggests a potential to consider intercity transit in addition to intracity or local services. It is unlikely that *all* the potential identified in this study could be connected via viable systems, but the magnitude of travel potential motivates the use of these results (and in particular, the spatial location of potential) to consider more integrated and new state-wide transit systems.

Future work will include improving the methods used here by analyzing the effect of different threshold criteria levels on overall VMT reduction. Information available on the block level will also be used in addition to the available disaggregate data in order to

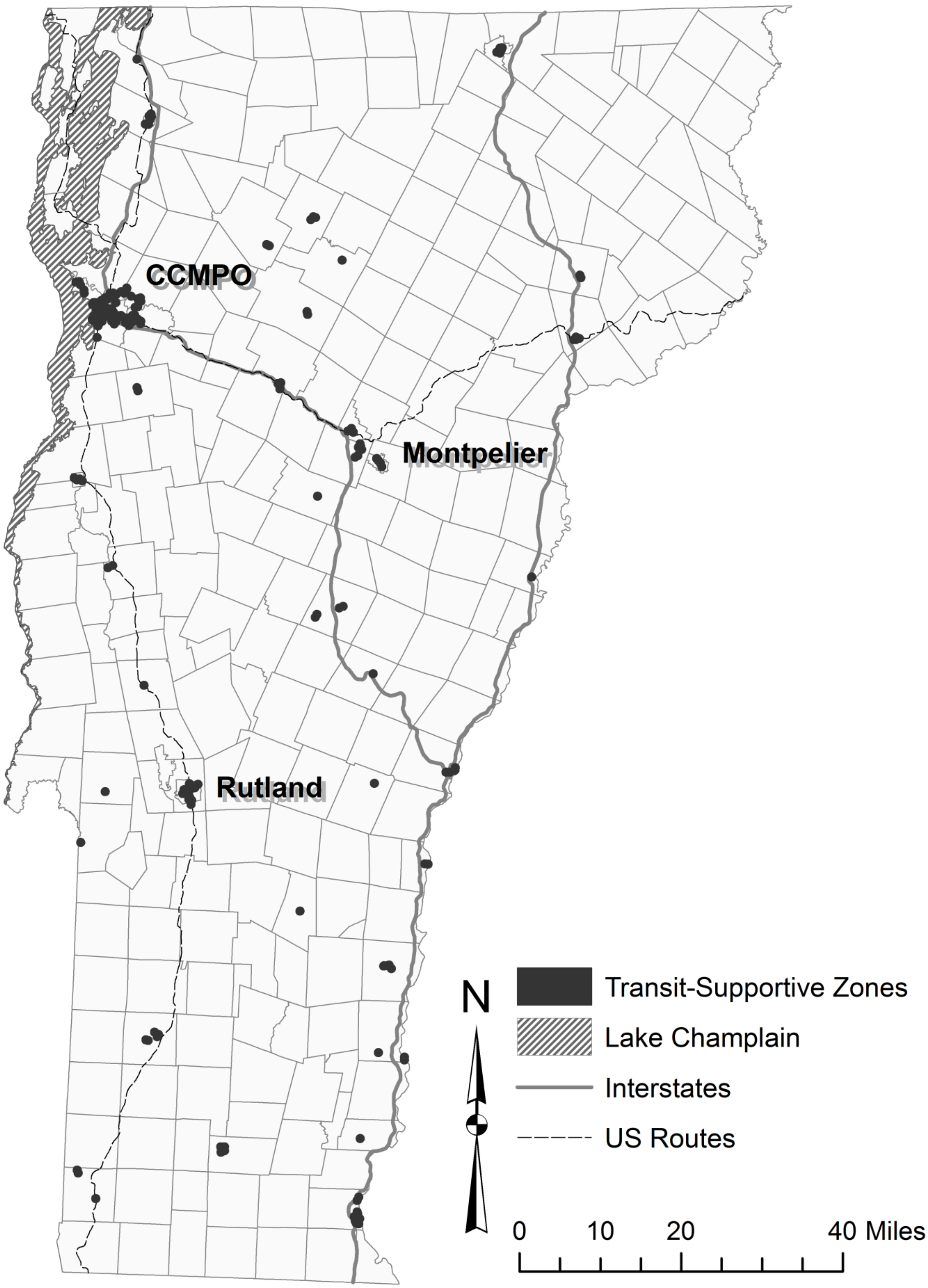


FIGURE 2 Statewide Transit-Supportive Zones in Vermont.

TABLE 2 Percent Area, Residence and Employment Points Within TSZs by Region

	% Within TSZs		
	MPO	*Non-MPO*	*Vermont (Total)*
Land Area	5.72	0.64	0.93
Residence Points	37.43	12.07	16.84
Employment Points	66.26	33.12	39.16

TABLE 3 Potential Automobile Trip and VMT Reduction by Trip Purpose

Trip Purpose	**Auto Trips**	**Auto VMT** (miles)	**% Reduction**	
			Trips	*VMT*
Home-Based Work	137,210	938,895	37	21
Home-Based Shopping	62,910	392,408	38	20
Home-Based School	4,964	25,443	38	19
Home-Based Other	133,599	601,829	34	16
Non-Home Based	194,161	635,924	64	33
TOTAL	532,844	2,594,499	43	21

TABLE 4 Spatial Interaction Characteristics of Transit Demand, Auto Trip and VMT Reduction by Region

	Itself	**Another Town**
% of Auto Trip Reduction		
Town	14.36	85.64
MPO	2.60	97.40
% Auto VMT Reduction		
Town	2.82	97.18
MPO	3.60	96.40
% Transit Demand *(person trips)*		
Town	14.70	85.30
MPO	2.59	97.41

incorporate sociodemographics into the potential demand. More work will be done to more accurately reflect the walking distance of potential users (i.e. substituting network distance for Euclidean distance and considering propensity as a function of distance from a given point). Data will be sought on the town or block level in order to more accurately reflect spatial changes in the number of units within a multi-family structure. Further research is also under way to develop an optimal statewide transit network that will serve three distinct purposes: 1) to connect Vermonters to work, 2) to connect Vermonters to services, and 3) to connect Vermonters via major hubs to the rest of the "world." The results of this paper, which provide an indication of location and level of transit demand, will be used in that study. In addition, by supplementing this spatial analysis with social equity, need, energy efficiency and network walkability factors, preliminary work has been able to identify underserved and over-served locations as well as shortest-path discrepancies.

ACKNOWLEDGEMENTS

This research was supported by funding provided by the US Department of Transportation to the University Transportation Center at the University of Vermont. The authors would like to thank Austin Troy, Andrew Weeks and Jim Sullivan for their insight.

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