A Report from the University of Vermont Transportation Research Center

Efficient Transportation for Vermont
Optimal Statewide Transit Networks

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1. Introduction

Public transit systems are receiving increased attention as viable solutions to problems with transportation system robustness, energy-efficiency and equity. The over-reliance on a single mode, the automobile, is a threat to system robustness. Increasingly, policy-makers and planners are espousing transportation systems with more options where robustness and equity gains come from the redundancy of alternative modes. For public transit, equity considerations range from ensuring that the network is fully "connected" (avoiding the "you can't get there from here" problem), to providing access to critical destinations (e.g., grocery stores or health care facilities) for people without cars (Alam, 2009). Energy-efficiency gains in transit systems result when there are higher vehicle-occupancy rates which lower energy use per passenger-mile (Davis et al. 2009).

This is one of two reports stemming from a project that sought to improve our understanding of the ways in which the Vermont statewide transportation system efficiency can be improved. In this report, we envision a series of "optimal" idealized transit-networks for the state of Vermont, based on the competing motivations of efficiency and equity, and compare those idealized networks to the existing one. The main objective is to measure the potential levels of efficiency and equity, as well as the potential gains that could result from re-designing the statewide fixed-route bus service. Finally, the location of existing park and ride facilities are considered relative to the existing and idealized transit networks.

1.1 Background

In December 2008, the UVM Transportation Research Center (TRC) presented, "Transportation System Efficiency in Vermont: An Initial Evaluation" to the Vermont Agency of Transportation (VTrans). The study conducted a review of transportation system efficiency measures related to rural areas, trends in Vermont, and policy and education strategies that might encourage increased transportation system efficiencies. The report focused on strategies to reduce the energy used in individual vehicles (through increased vehicle efficiency standards and purchases of vehicles with higher fuel efficiency) and to switch travelers to different travel modes (e.g. carpooling, ridesharing, and targeted investment in public transit). Additionally, the report identified topics related to transportation system-efficiency that merit further research, including the development of an optimal transit system to coordinate between Vermont's public transit providers.

In rural areas, the challenges to implementing a successful public transit system are greater than those in urban areas (VCCC, 2009). Providing transit services in rural areas is inherently challenging, since robustness, energy-efficiency and equity are misaligned in these dispersed communities which require longer passenger trips:

1. A **robust transportation system or network** has redundant components such that overall service can be effectively maintained when one or more system components

are lost. For example, if a link such as a bridge is closed, there are other reasonable ways for trips to be completed. Or if a person is without a personal vehicle they can walk or use transit to reach their destination.

2. An **energy-efficient system or network** is one in which passenger miles or trips are served with minimum energy input. For example, a system with shorter trips, all else being equal, would be more efficient than a system with longer trips. A system with higher vehicle occupancy (i.e. full buses) would be more energy efficient than a system with lower vehicle occupancy. A system with smaller more fuel efficient vehicles would be more efficient.

3. An **equitable transportation system or network** is one in which all persons or locations have service or access through mobility to needed or desired destinations. In many cases, equitable service is considered as all people or locations having access to critical services such as medical needs or food.

Provision of an equitable transportation network requires access to the network for all. Transit service may be the only option for mobility for some in rural populations, like seniors, disabled citizens, and low-income non-drivers, so it is an important component of an equitable rural-transportation system. To address energy-efficiency concerns in rural areas where large vehicle or fixed route services are infeasible, many states and municipalities have turned to ridesharing programs, like *GoVermont* and *Hinesburg Rides*. The goals of ridesharing programs are to promote increased energy-efficiency through smaller vehicles and increased vehicle occupancy. Robustness was not until recently explicitly considered in planning and it is also harder to achieve in rural areas.

Residential and employment densities play an important role in the viability of public transit. As residential densities increase, so does potential transit ridership. Similarly, high employment densities provide better transit destinations. The relative location of denser origins and destinations guides the selection of links or roadways which form the overall network system. However, without density, the selection of routes, especially fixed routes, becomes challenging. An analysis of transit ridership in the Portland, Oregon region (TCRP, 1996) suggests that 93 percent of the variance in transit demand can be predicted by the overall housing and employment density per acre. Therefore, density and patterns of development in rural areas compromise the efficiency of the overall system.

Other studies attempt to understand additional factors which influence transit ridership by analyzing characteristics of existing riders and existing systems, especially those with high ridership (Taylor et al. 2008). These studies find that service-quality factors are important, but that socio-economic characteristics of the population served are more significant. One limitation of these types of studies is that, in focusing on existing riders and areas with high ridership, unsatisfied transit demand and non-riders are excluded. The result of this type of focus will usually be strategies which are well-suited to increase ridership by increasing route coverage to areas where demographics are expected to be consistent with current riders. While there is acknowledgement of the possibility that unsatisfied demand and potential new riders may be different and in different locations than existing demand, limited studies have data on these factors. Moreover, few studies attempt to measure the potential for ridership increases from improvements to the quality of the transit service in high-density areas where additional demand is theoretically present.

In its 2007 Public Transportation Policy Plan (PTPP), the state of Vermont expresses an interest in reducing vehicle-miles traveled per capita and increasing public transportation ridership, with the intent of having a positive impact on energy usage and environmental impacts. It is suggested that reducing auto dependency “ensures that the state can reduce vehicle emissions and meet greenhouse gas targets” (TranSystems, 2007). However, other figures demonstrate that public transit use is not necessarily associated with improved energy use and environmental impacts (VCCC, 2009). It is only through achievement of strict goals for ridership levels that transit-use begins to have a net positive environmental impact. Current ridership levels for many transit services, especially rural services, fall short of these targets (Davis et al. 2009). Therefore, in this study of hypothetical new networks, we estimate ridership levels based on actual density levels and for the energy efficient network only allow routes which will promote net environmental and energy benefits.

1.2 Objectives

This report is one of two from a study entitled *Efficient Transport for Vermont*. The overall project has four objectives:

1) Develop alternative network designs for an optimal state-wide transit system network and evaluate the state’s network of park n’ ride locations to see how it matches;
2) Survey and identify community-based transportation efficiency activities;
3) Identify obstacles and incentives to increasing work carpools with a focus on the Vermont RideShare program; and,
4) Document the existing rideshare locations and the locations of RideShare callers to the state program.

This report includes the findings of this study which relate to the first objective; the development of alternative network designs for an optimal state-wide transit network. The findings related to objectives 2 through 4 are documented in a separate report. The work is being co-funded by the USDOT under the UVM Transportation Research Center (TRC) UTC Focus Area *Transportation Energy and System Efficiency.*

This analysis includes consideration of the spatial “total network length” of the idealized public transit networks. By “total network length”, we mean the footprint of the transit network – how much physical length it takes to reach the origins and destinations defined for each case throughout the state. The logistics behind the service or operation of the transit networks are not considered. It is assumed that the logistics can be “tuned” to increase ridership by increasing service quality once the optimal total network length has been secured. This exclusion is not intended to diminish the importance of service design as this “tuning” will be critical, since studies have found that a considerable portion of the variation in transit use can be correlated to service frequency and fare levels (Taylor et al. 2008). Therefore, only estimates for daily travel are used – peak hours are not considered – and the directional routes, frequency of service, types of vehicles, locations of stops, and fares are not determined. This macro-level approach is consistent with the approach typically used for large-scale, statewide travel-demand models and is intended in this case only to estimate the potential for improvements to the state-wide public transit network.

Three new hypothetical networks and the existing network for fixed-route service are compared in this report using three existing straightforward metrics: total network length in miles; the number of the 255 Vermont towns reached or serviced by the network; and the percentage of the population with access (within ½ mile) to the network. An additional new measure, the coincidence ratio (CR) is used to compare the relative spatial location and overlap between pairs of networks.

2. Alternative State-wide Transit Network Designs

2.1 The Existing Transit Network

Vermont is currently served with fixed-route, flexible fixed-route, and demand-response transit bus service provided by 12 different agencies, each representing a geographical region of the state, as shown in Table 2.1.

Table 2-1 Existing Transit Service Agencies in Vermont

Agency	Service Area
Advance Transit	Upper Valley (Northern Windsor and Orange Counties) including Hanover and Lebanon, New Hampshire
Addison County Transit Resources (ACTR)	Middlebury Area
Town of Brattleboro Bus Line	Brattleboro Area
Chittenden County Transportation Authority (CCTA)	Chittenden County
Connecticut River Transit	Windham and Southern Windsor Counties Along the Connecticut River and Up into Rutland County
Deerfield Valley Transit Association	Towns of Wardsboro, Wilmington, Whitingham, Halifax, Dover and Readsboro (Western Windham County)
Green Mountain Community Network (GMCN)	Bennington
Green Mountain Transit Agency (GMTA)	Central Vermont (Washington and Lamoille Counties)
Marble Valley Regional Transit District	Rutland County and Manchester (Northern Bennington County)
Rural Community Transportation (RCT)	Northeast Kingdom (Caledonia and Orleans Counties)
Stagecoach Transportation Services (STSI)	26 towns in Northern Windsor and Orange Counties

The merged route network for all agencies is shown in Figure 2.1, with total network lengths ranging from 8 miles to 122 miles, with an average of 74 miles (not including Greyhound). This existing network of fixed-route service includes over 1,300 total miles of road coverage, reaches 112 of the 255 Vermont towns, and is accessible (within ½ mile) to over 77% of Vermonters.

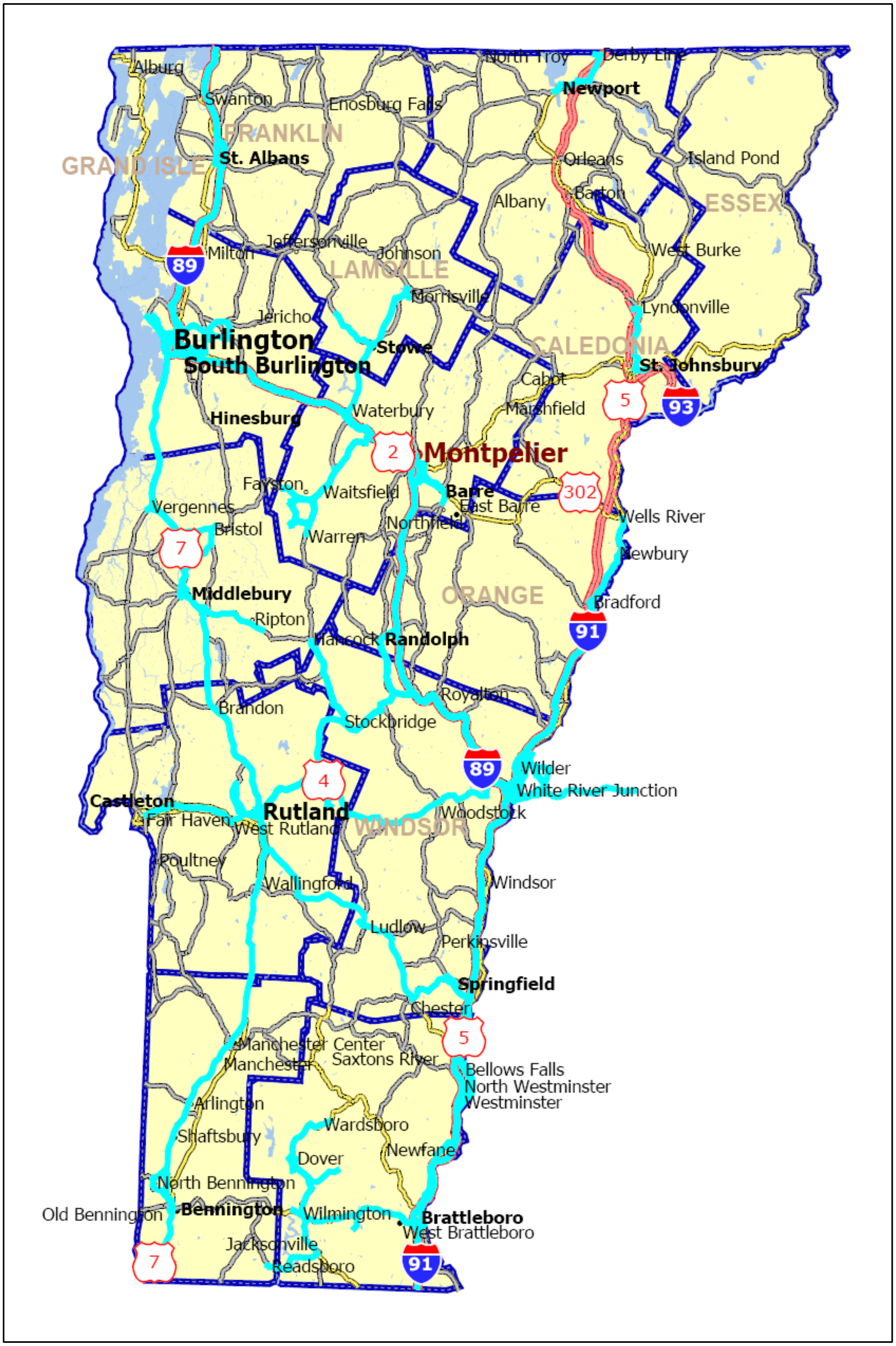

Figure 2-1 Existing Transit Network in Vermont

2.2 The Energy-Efficient Transit Network

The development of the three hypothetical networks requires spatial analysis. One reasonable process for developing optimal transit networks begins with a spatial assessment of inhabitable structures within the area of study. Spatial density of residences and employment locations provides a foundation for the development of a matrix of potential transit demand. Implicit in the consideration of building density is the consideration of walking distances. Transit trips typically begin and end with a walking trip, either to a destination such as a building, or to another mode of transport. Therefore, just as important as the building density is the assessment of maximum acceptable walking-distances in the development of a transit network. This study uses the end-to-end walking link in every transit trip to "anchor" the transit network to all inhabitable structures in the state.

For studies like this one, of a region which is primarily rural with some small urban sub-regions, spatial factors are likely to be particularly important, since it is the spatially dispersed nature of rural areas, including village clusters, which creates the need for increased efficiency. In rural areas, maximum acceptable walking distances may significantly limit access, and alternative paths for fixed routes through areas may not exist. Therefore, an analysis of transit potential in a rural region must start with a focus on the spatial factors associated with fixed-route transit.

Energy-Efficient Transit-Supportive Demand

Potential demand for optimal transit has been estimated spatially through the use of density and walking distance (Jerby and Ceder, 2006). In this project, demand for an energy-efficient, fixed-route state-wide transit system was developed using point locations from the Vermont E911 database. E911 emergency location information, obtained from Vermont Center for Geographic Information, consists of the locations and descriptions of every structure in the state. This demand is identified as the transit-supportive demand potential (TSDP), and provides the basis for the development of the energy-efficient transit network. This represents a significant improvement for network design over use of average population and population densities at the town level.

Background Data

Residential and employment densities play an important role in the viability of transit. As residential densities increase, so does potential transit ridership. Similarly, high employment densities generate more potential trip destinations. The Institute of Transportation Engineers (ITE) estimate thresholds of residential densities (dwelling units per acre) that can support different levels of transit service - local and intermediate bus service having a threshold of four to five and seven dwelling units per acre, respectively (ITE, 1989). The Georgia Regional Transportation Authority (GRTA, 2003) 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 (Frank and Pivo, 1994), 50 to 60 employees per acre (Chang, 2005) and 20 to 50 employees per acre inducing substantive modal shifts to transit (BCBSM, 2008). In this study we assume 7 equivalent housing units per acres is transit supportive and convert non-residential units to equivalent housing units based on relative trip generation rates.

Access to public transportation is another critical factor in the level of use. The farther 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 that some users are only willing to walk a maximum of about 400 meters to reach a transit stop – which represents a comfortable walk under normal conditions (Furth and Mekuria, 2007; Fu and Xin, 2007; VHB, 2007a). However, other studies have noted that in many cases the walk-impact zone of a particular station can extend out to ½-mile or more depending on the presence of pleasant urban spaces and corridors (Levinson and Kumar, 1997; Bernick and Cervero, 1997). A TCRP study on transit and urban form showed a distance of 2,460 feet at which a considerable drop-off in the number of people walking to transit is experienced (TCRP, 1996). In this study we assume accessible walking distance between the route network and the destination is ½ mile.

The Vermont E911 database is a point layer of latitude and longitude in GIS that represents all residence locations (single locations family homes, multi-family homes, seasonal homes, and mobile homes) and non- residence locations (commercial, industrial, education, government, health care and public gathering) in Vermont. The database is a tool for emergency responders to identify the location of people calling in distress. Therefore, some locations not pertinent to potential transit ridership, like fire hydrants, had to be removed. Vermont is unique in that the database is publicly available through the Vermont Center for Geographic Information.

The Profile of Housing Characteristics was needed to associate trip making potential to the residences coded in the E911 dataset (USCB, 2000). 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 were extracted by land use category from 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 (ITE, 1989).

Delineation of Transit-Supportive Zones

The methodology to identify demand potential and transit-supportive zones (TSZs) required, in addition to the data described above, the ArcGIS software by ESRI. ArcGIS was used to interpret the E911 database. The Demand Potential (DP) of a given point was determined as a function of the type of dwelling structure (for residential points) or the average employment level (for non-residential points). For the residence structures, factors were assigned to represent the typical number of family units present. Multi-family residential points were assigned 6.5 households, the weighted average of units per structure obtained from the US Census Bureau housing characteristics for Vermont. All other residential point locations assumed to represent only one household. Employment statistics were applied to each of the non-residential points based on the type of location that the point represented and the town that it is located in. 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 from trip generation rates for non-residential locations based on the average number of employees present at that particular location. Since adequate data for public gathering locations was not available, these points 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. The trip 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 convert all DPs into common units. The DP for each point was converted into an Equivalent Demand Potential (EDP) by dividing the DP for a given location by the DP for a single-family housing unit. In this way, the DP is equated back to an “equivalent” single dwelling unit, since most transit-supportive criteria are based on dwelling units.

TSZs, or the areas where transit might be viable, were identified by creating a half-mile service area around each point. 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. This approach has also been used in previous studies (Murray, 2001; Ramirez and Seneviratne, 1996).

Estimation of the Transit-Supportive Demand Matrix

The demand potential in the state was similarly determined by summing all EDPs within each of the 628 traffic analysis zones (TAZs) in the Vermont Statewide Travel Demand Model (VHB, 2007b). The proportion of the EDP served by each TSZ in relation to the total EDP for a TAZ which the respective TSZ falls within was then calculated such that Transit-Supportive Demand Proportion (TSDP) for TAZ *n* is:

$$TSDP_n = \sum a \; EDP_{TSZ} \,/\, \sum a \; EDP_{TAZ} \qquad (5)$$

Where:

$\sum a \; EDP_{TSZ}$ is the sum of *a* EDPs in the TSZs in TAZ *n*

$\sum a \; EDP_{TAZ}$ is the sum of *a* EDPs in TAZ *n*

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. A bi-proportional gravity model update was conducted using the TSDP for each zone as though it were an updated estimate of the zone production or attraction. To maintain this study’s focus on potential demand, it was assumed here that transit trips can occur for any of the trip purposes, including school, work, and leisure. Implicit in this method is the constraint that in order for a trip to be served by transit it must both start and end in a transit serviceable zone.

A user-equilibrium assignment on the new energy-efficient origin-destination matrix was performed for persons, not vehicles. Ridership is the critical variable in the analysis of transit systems and the extent to which the energy efficiency of the system is improved. A transit system's "success" is often determined by its ridership, but ridership itself is also dependent on many other factors. So lack of ridership on a transit route may simply be a factor of the variables related to service quality – safety, convenience, reliability, travel time, fee and comfort. Therefore, in this analysis, ridership was maintained as a variable with the energy-efficient potential representing its maximum, and controlled by service quality.

Hourly capacities in the road layer were converted to daily capacities by multiplying by 15 to reflect that there are 15 hours during which people might use transit (6:00am to 9:00pm). The total flow levels for each link, then, represent the maximum potential persons per day who would use transit service, if the quality met their desires.

The energy intensity of a transit bus is estimated to be approximately 9.1 times that of a private car (Davis et al. 2009). This means that, excluding passengers, it takes 9.1 times more energy to run a transit bus that it does to run a private car. Therefore, the minimum goal for an efficient transit system should be ridership of 9 passengers or more. In fact, average ridership of transit buses in the United States is estimated at about 9 passengers. However, when the average occupancy of a private car (1.6 persons) is factored in, the result is that for energy efficiency a vehicle occupancy of 11.2 passengers per transit vehicle is needed (Davis et al. 2009). A critical factor in this comparison is that a bus passenger does not include the driver, but car occupancy does. Typically, the driver of a car needs to make the trip as much as the passenger(s). However, it is assumed that the driver of a transit vehicle does not personally need to make the trip, but is doing it for employment.

The traffic assignment performed for the transit OD and the Vermont state-wide network resulted in some very low levels of flow which cannot possibly sustain transit, due simply to the lower energy efficiency of a transit vehicle when compared to a private vehicle. It was assumed that transit demand of fewer than 11.2 persons per trip is better suited to automotive travel, since a private motor vehicle can be operated more efficiently for this number of people. Coupled with this figure is the assumption that the lowest frequency for transit service being considered in this study is one bus trip per hour, with increasing frequencies associated with increased ridership. Based on these assumptions, only links which had at least one direction of flow of more than 168 persons per day were included in the network.

Once the network had been selected, a check was performed to ensure that all of the buildings within TSZs in the state are within walking distance of a fixed-route link in the network. Where maximum acceptable walking-distances (1/2 mile) were exceeded, links were added to the optimal transit network to ensure walkability for all 54,000 buildings within TSZs in the state. When a group of fewer than 3 buildings fell outside the walking distance of the optimal transit network, it was assumed that these buildings did not effectively contribute to the building-density required to support transit in the first place, and this process was skipped. As a result, a total of only 29 transit-supported buildings in 14 separate towns in Vermont were left outside the network.

The energy-efficient (E-E) transit network which results after the TSDP is assigned to the state road network, and the rules concerning energy efficiency and walkability are enforced, is shown in Figure 2.2. Clusters of buildings which fall within TSZs are also shown. The E-E network includes 153 miles less road length than the existing transit network, reaches 13 fewer towns, and is accessible to 75% of Vermonters.

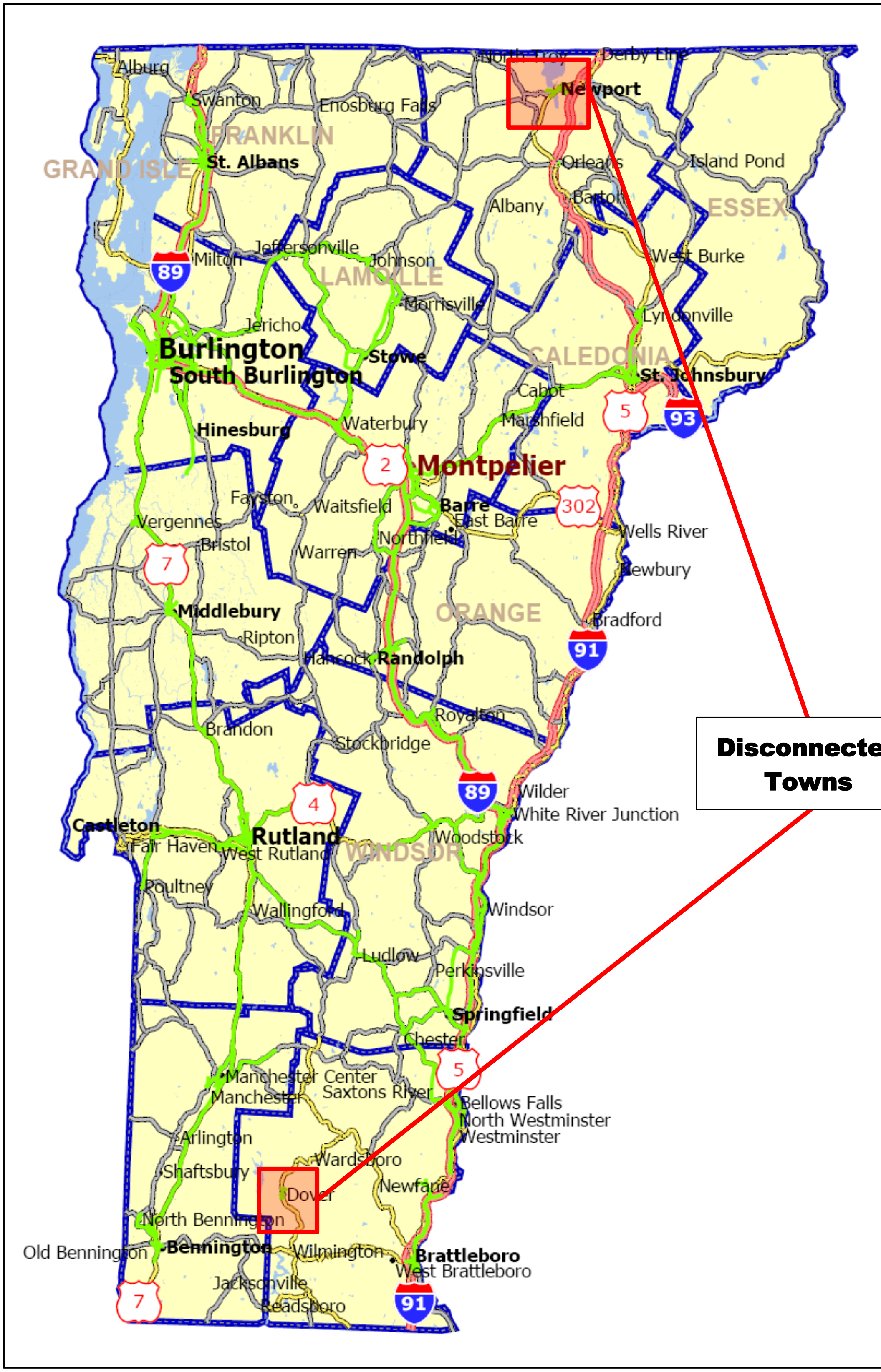

Figure 2-2 The Energy-Efficient Transit Network (Green)

2.3 Equitable Transit Networks

Design of transportation networks often must balance the competing interests of efficiency and social equity. In the United States, the layout of our transportation networks are motivated by both. Within the notion of equity come the ideas of uniformity and "fairness". Equitable transportation networks provide more uniform connectivity throughout a region and come at an efficiency cost.

The E-E network in Figure 2.2 considers only efficiency but real-world transit services often attempt to satisfy interests of both efficiency and equity. The procedure used to select the energy-efficient transit network was based on assuming that links where transit demand could not be satisfied more efficiently by bus than by car were excluded from the network. However, in the primarily rural state of Vermont, older drivers will progressively reach an age when their driving ceases. At this point, it becomes increasingly important that alternatives to driving be available even when energy efficiency is lost. Other residents who are in position to benefit from an alternative to driving are those without a driver's license or without a car, like school-age children and low-income adults. Equitable transit networks address the needs of non-driving demographic groups and include uniform connectivity, without regard to vehicle occupancy.

Two adjustments are made to the E-E network in this study: one for connectivity and one to ensure access to critical locations.

A Connectivity-Fairness Transit Network

Two limitations related to equitable access are immediately evident in the E-E network:

- The towns of Newport and Dover (in the vicinity of Mt. Snow) have transit networks serving transit supportive zones but are disconnected from the rest of the state-wide transit network (Figure 2-2), and
- The town of Bradford, although dense enough to support transit, is too small (population of 815) to support energy-efficient transit (see Figure 2.2).

The rest of the statewide network is connected, allowing travelers to access any place in the transit network from any other. Several towns with populations lower than Newport are within the continuous statewide network, including Springfield, Vergennes, and White River Junction. These smaller towns remain connected primarily due to their proximity to larger towns, or their position between larger towns. Some populated regions are connected to the larger network whereas others are not. A connectivity-fairness (C-F) transit network, then, can be envisioned which resolves these fairness problems, enforcing full connectivity. The network shown in Figure 2.3 includes the fixed-route network created by connecting the shortest paths from Newport, Dover, and Bradford to the E-E network. The following specific equity-based connections are added to the E-E transit network:

- Newport – St. Johnsbury
- St. Johnsbury – Bradford
- Bradford – White River Junction

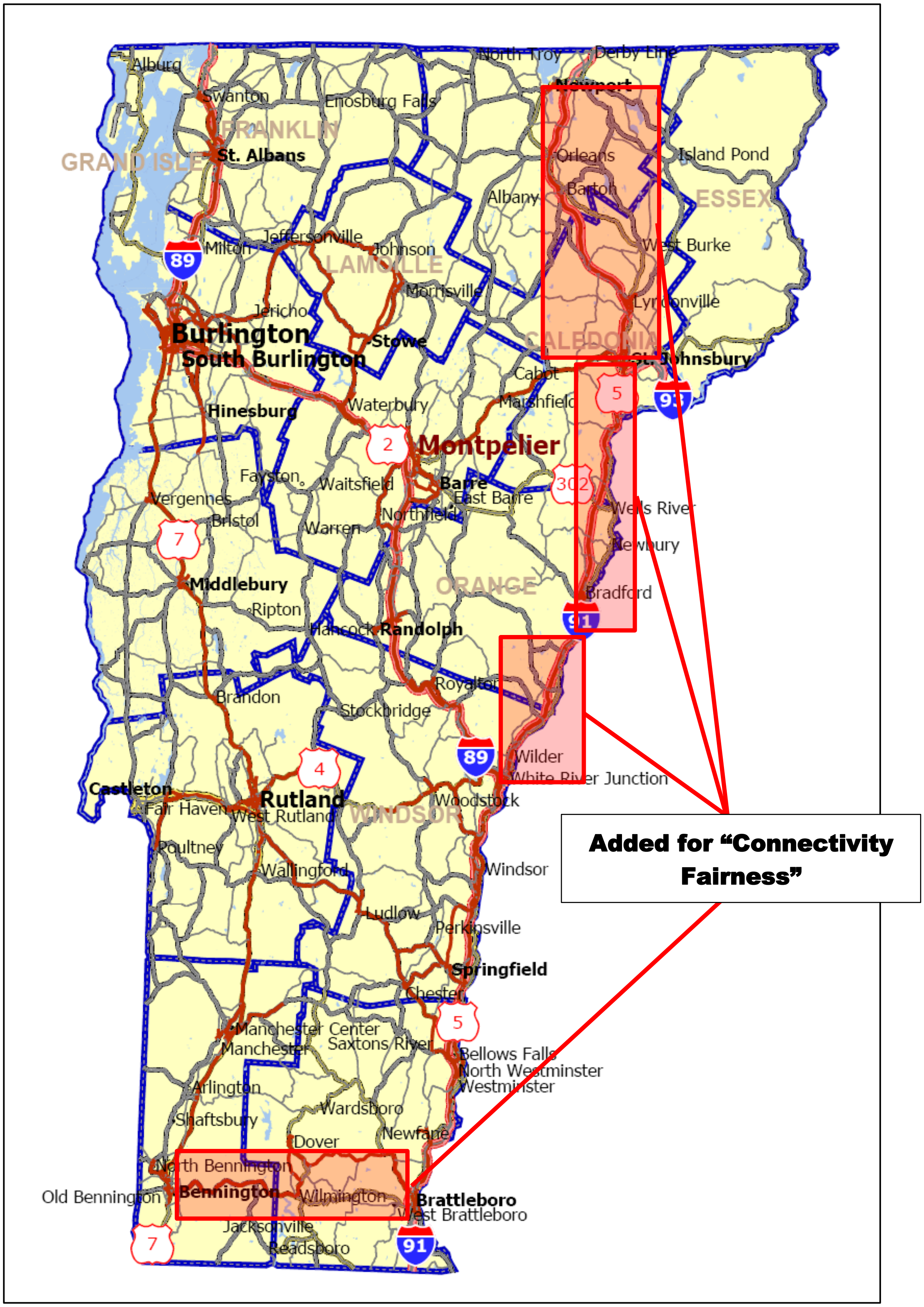

Figure 2-3 The C-F Transit Network (Brown)

- Brattleboro – Dover
- Dover – Bennington

These connections are shaded in Figure 2.3. Dover and Bradford are linked to two nearby population centers in the energy-efficient network and Newport, due to its unique position near the Canadian border, is linked to one.

The C-F network includes 70 miles more of road length than the existing transit network, reaches 6 additional towns, and is accessible to over 79% of Vermonters.

An "Access to Critical Locations" Transit Network

Vermont state policy supports the "aging-in-place" concept. One definition of Aging in Place is "to remain in a residence despite physical or mental decline that might occur with aging or with disability" (VOC, 2006). Currently, with the "baby boomers" growing older, the number of older adults using the transportation system in the United States is expected to double in the next thirty years (Collia et al. 2003). The number of older licensed drivers is expected to nearly double by 2029 when the last of the boomer generation reaches age 65 (Granda and Thompson, 2006). In the primarily rural state of Vermont, these drivers will be progressively reaching the age when their driving becomes restricted, or ceases altogether. In addition, school-age children and low-income adults may stand to gain the greatest advantage from fixed-route transit, if school-bus transport is considered a component of this system (TCRP, 1999). An "Access to Critical Locations" transit network provides access between all "critical" or "important" places in the state and all transit supportive areas for the non-driving community. Note however, this assumes access to critical locations only from transit supportive areas or zones not all areas.

One way of defining an "important place" in the context of equity is one which has a hospital or a health care facility. Within the E911 database, a subset of buildings in the state is identified as "Health Care" facilities. This category includes all buildings which house, in whole or in part, a hospital, a health clinic, a medical practice, or a physician's office. Using these 322 locations, the walkability rule was enforced on a merged network of existing transit routes, the E-E transit routes, and the C-F transit routes. In this case, though, a stricter walkability standard of ¼- mile was enforced in order to increase the equity value of the network for youth, the elderly and disabled persons. Where health-care buildings were found to be greater than ¼-mile from the nearest link in this merged network, links were added until the buildings could be accessed by a comfortable walking distance.

The "Access-to-Critical Locations" (ACL) fixed-route transit network resulting from this step is shown in Figure 2.4. The ACL network includes over 700 miles of road coverage more than the existing transit network, reaches 49 additional towns, and is accessible to 90% of Vermonters.

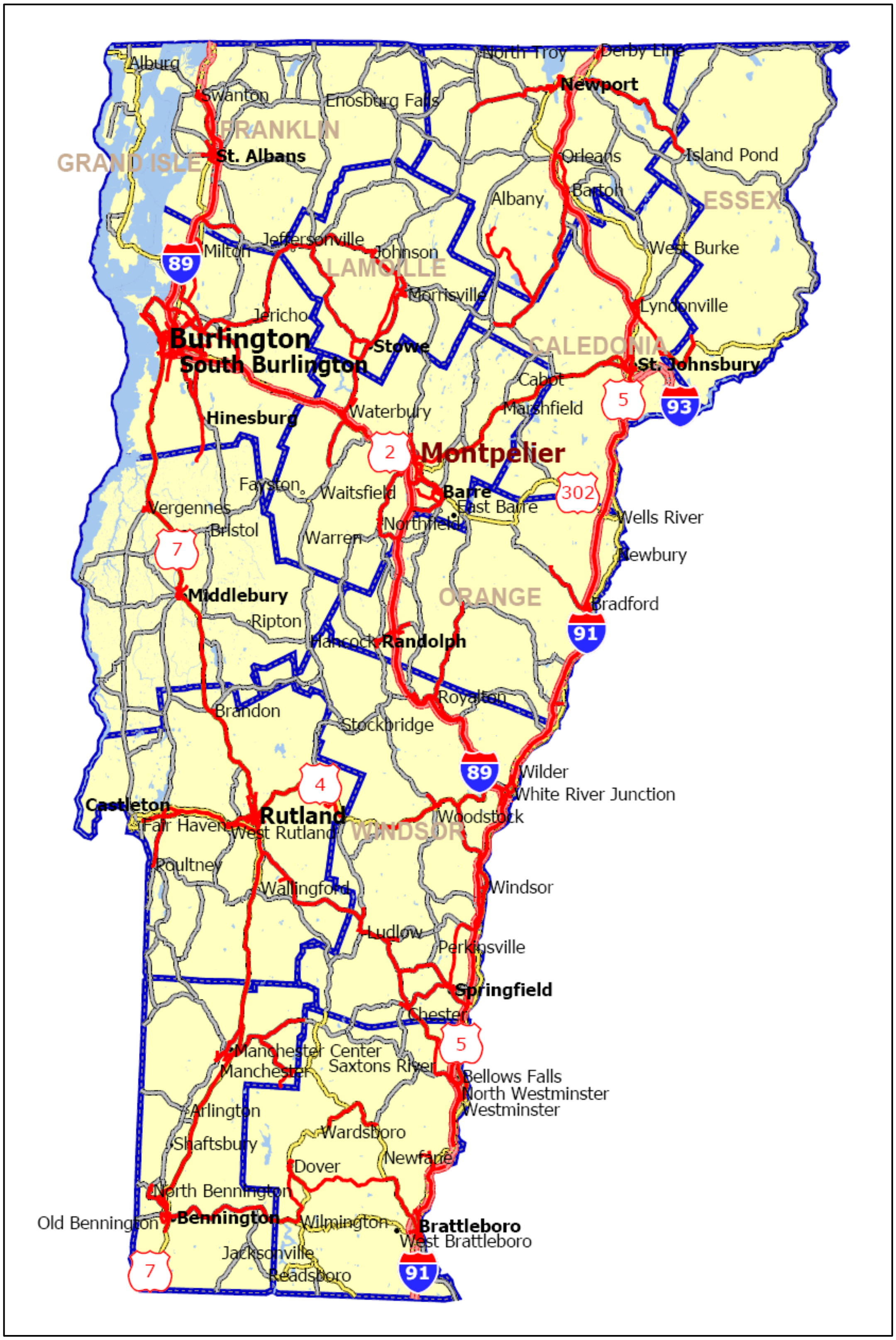
Alburg
North Troy
Derby Line
Newport
Swanton
Enosburg Falls
FRANKLIN
GRAND ISLE
St. Albans
Orleans
Island Pond
Barton
Albany
ESSEX
Jeffersonville
Johnson
West Burke
Milton
LAMOILLE
89
Morrisville
Jericho
Lyndonville
Burlington
Stowe
CALEDONIA
South Burlington
St. Johnsbury
Cabot
5
93
Hinesburg
Marshfield
Waterbury
2
Montpelier
Fayston
Waitsfield
Barre
302
Vergennes
East Barre
Wells River
Bristol
Northfield
Warren
7
Newbury
Middlebury
ORANGE
Bradford
Ripton
Hancock
Randolph
91
Royalton
Brandon
Stockbridge
89
4
Wilder
White River Junction
Castleton
Rutland
Fair Haven
West Rutland
WINDSOR
Woodstock
Poultney
Windsor
Wallingford
Ludlow
Perkinsville
Springfield
Chester
5
Manchester Center
Saxtons River
Manchester
Bellows Falls
North Westminster
Westminster
Arlington
Wardsboro
Shaftsbury
Newfane
Dover
North Bennington
Old Bennington
Bennington
Wilmington
Brattleboro
West Brattleboro
Jacksonville
Readsboro
7
91

Figure 2-4 The "Access to Critical Locations" Network (Red)

3. Transit Network Comparisons

The three hypothetical networks were compared to the set of roads currently covered by the 12 transit agencies throughout the state. The "merged network" of the existing agencies was created by geographically merging the service networks of each agency as if the state provided transit service through one centralized agency. Using this merge, it was possible to compare the actual and the idealized networks. A new performance measure is proposed, which utilizes the spatial layout of two or more sub-networks on a larger network. The new measure is well suited to comparisons like the ones proposed here, since it provides a quantification of the extent to which two separate sub-networks coincide in terms of location or physical space. The Coincidence Ratio (CR), is a ratio of the relationship between sub-networks n and m:

$CR_{n,m} = L_{n,m}/L_m$

Where $L_{n,m}$ is the length on the larger network shared by sub-networks *n* and *m*, and L_m is the total length of sub-network *m* on the larger network. The CR can be used to evaluate the overlap between an idealized transit network and a real-world existing transit network when they both utilize the same road network. The transit networks effectively constitute sub-networks of the larger road network. A value of 1.0 indicates that the two sub-networks coincide perfectly, whereas a value of 0.0 indicates that the two sub-networks do not share any links in common.

Table 3.1 presents some useful figures for comparison of the four fixed-route transit networks examined in the previous section.

Table 3-1 Fixed-Route Network Comparison

Transit Network	Total Miles of Road Network	Number of Vermont Towns Reached (of 255)	Population Reached (of 609,000 in 2000)	Population Reached Per Mile of Network	CR
Existing	1,318	112	471,777	358	--
Energy-Efficient (EE)	1,153	99	455,111	395	0.58
Connectivity-Fairness (C-F)	1,388	118	483,850	349	0.58
Access to Critical Locations (ACL)	2,039	161	548,382	269	0.64

The overall interpretation of Table 3.1 suggests that:

1. Based on total miles of network, the existing network is strong in terms of energy-efficiency which suggests relatively good efficiency.
2. The metrics for the C-F network suggests that the connection of the Northeast Kingdom to the rest of Vermont is a challenging task.
3. Connecting all population in transit serviceable densities to medical facilities (the ACL network) comes at a substantial cost in terms of network length but has the positive side effect of connecting many more Vermonters within the system
4. Based on the CR there is limited physical overlap between the existing network and the hypothetical networks suggesting that a state-wide network design might result in a spatial reconfiguration compared to the existing service area-based route design.

In addition to these general conclusions, this section includes four subsections which contain detailed discussions of the differences between the hypothetical networks and existing network including suggestions of possible under-service and over-service as well as possible path discrepancies where the networks take different parallel routes along adjacent corridors.

3.1 Total Network Length Discrepancies

As summarized in column 2 of Table 3-1, there are differences in the "total network length" between the existing transit network (Figure 3.1) and the three theoretical transit networks (Figures 3.2, 3.3, and 3.4). These total network length discrepancies suggest possible over-service by the existing transit network and potential under-service.

Places Over-Served by the Existing Transit Network

Places of possible over-service are suggested when laying the E-E network over the existing network, as in Figure 3.1. In the figure, portions of the existing network which are shaded represent potential over-service. These situations exist in (1) central portions of the state, with service to Bristol, Ripton, Fayston, Waitsfield, Warren, Stockbridge, and Hancock, (2) the eastern Connecticut River Valley with service to Wells River, Newbury, and Bradford, and (3) the southern part of the state, with service to Wardsboro, Wilmington, Whitingham, Dover, Jacksonville, and Marlboro. The density of origins and destinations from our analysis of the E-911 data and travel demand from the state-wide model suggest none of these areas demonstrate demand at a level sufficient for energy-efficient public transit.

A possible explanation for this total network length discrepancy between the E-E network and the existing network is that the existing network is responding to out-of-state demand, which is not considered in this study. Services near the state borders with New Hampshire and Canada, including the towns of Alburg, Enosburg Falls, Wilder, Wells River, Newbury, and Bradford may fall into this category. Services through Alburg and Enosburg Falls may be connected to transit demand in Montreal, and services through Wilder, Wells River, Newbury, and Bradford may be connected to transit demand in Hanover, New Hampshire.

No recommendation for service changes can be made based on this analysis, however, we recommend these areas for evaluation of service changes.

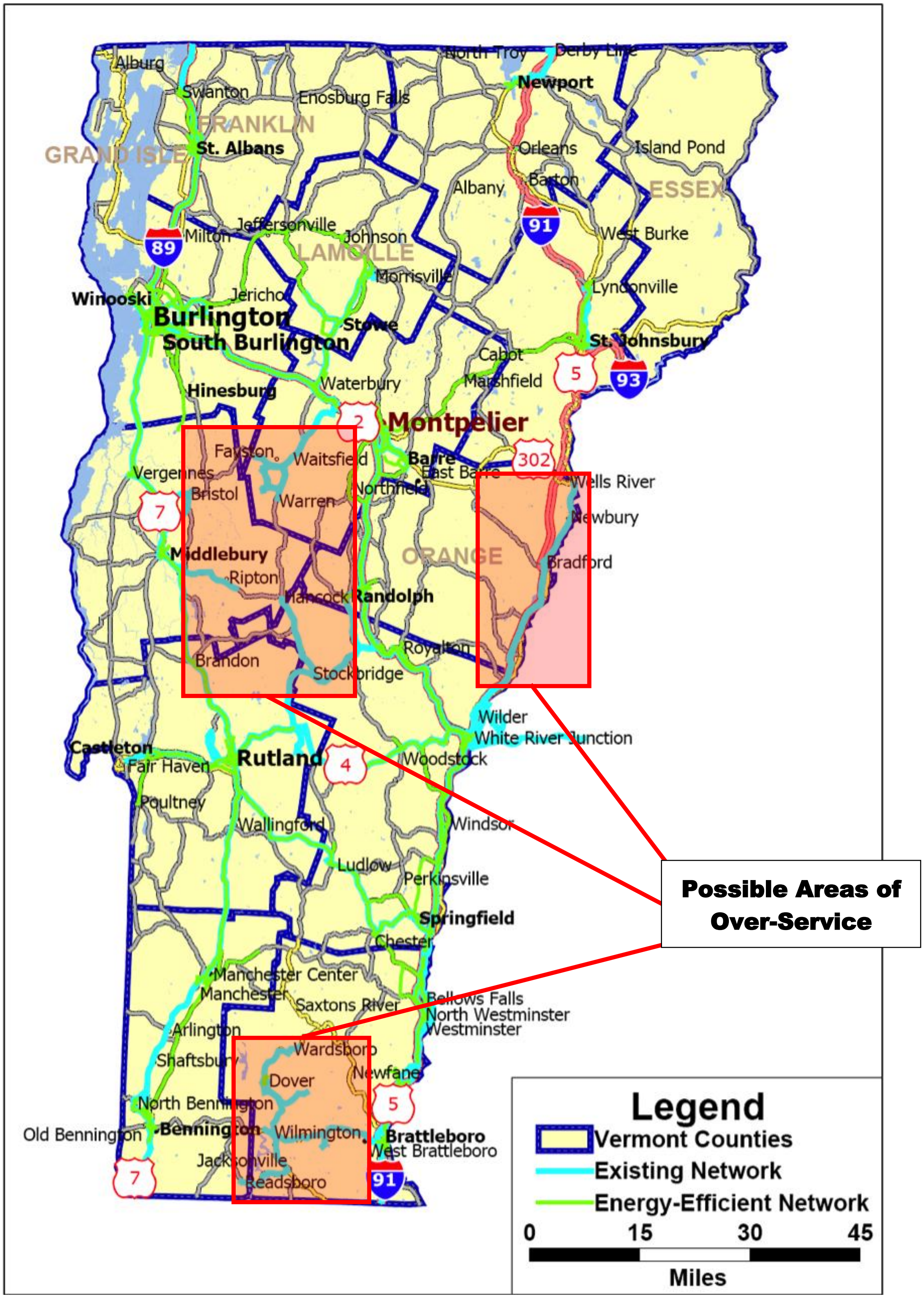

Figure 3-1 Transit Over-Service Analysis

Places Potentially Under-Served by the Existing Transit Network Relative to the Energy-Efficient Transit Network

Evidence of potential under-service by the existing fixed-route transit network can be found throughout the state, as shown in the shaded areas in Figure 3.2, which is the existing network over the E-E network. The E-E transit study identifies the towns of Hinesburg and Johnson, and the residential community of Morses Mill (on Route 108), as transit-supportive zones (see Figure 3.3). In addition, the towns of Poultney (Figure 3.4), Northfield (Figure 3.5), Saxton's River, and the Putney School (see Figure 3.6) are areas with transit supportive land use patterns which are not served by existing fixed-route transit. These locations represent towns or clusters of buildings which have potential to be served by transit, due to the volume of travel demand and the density of origins and destinations. These locations do not need to constitute new routes, but could be explored as extensions to existing routes. Finally, a critical connection between St. Johnsbury and Montpelier is omitted from the existing transit network, but is included in the E-E network. Without this link, potential demand to/from St. Johnsbury cannot be served.

There are various reasons why the existing transit network has not responded to potential transit demand in these communities and towns. The primary reason may be that the E-E transit network includes school transport, but the existing transit network does not. Studies have shown that integration of public transit and public school transit is feasible and can result in significant efficiency gains (TCRP, 1999). Demand to/from locations like the Putney School is likely due to this methodological discrepancy. However, demand to/from other locations in Figure 3.2 may also be affected by the tendency of the existing transit network to focus on commuters. The E-E transit network optimizes all potential transit trips – work, school, shopping, and non-home-based. Travel trends in the last decade have begun to shift away from commuting travel, which now accounts for less than 25% of all travel (Davis et al. 2009). Focusing on commuter travel may limit other travelers, and may prevent the system from reaching its potential demand levels.

Other evidence of possible under-service of the existing transit network exists in areas where the E-E transit network has reached farther into neighborhoods to support walking to transit. Many areas of the existing transit network do not penetrate transit supportive areas far enough to allow all potential users to walk. Consider the region shown in Figure 3.2 near Poultney. The E-E transit network comes off Route 4 on the smaller Route 4A before it reaches the denser area of Castleton. This departure from the existing transit network allows the E-E network to satisfy demand from the buildings in Castleton which would otherwise be beyond a comfortable walking distance to the existing transit network along Route 4. These examples, suggest that spatial analysis as well as state-wide coordination of the network could improve overall service.

Relative to the Connectivity-Fairness Transit Network

Figure 3.7 provides an overlay of the existing transit network on the C-F transit network. Most of the new connections in the C-F network are not included in the existing transit network. This observation demonstrates that, although the existing transit network appears to be more equity-based than the E-E network, its extra services may need re-alignment if providing fair access and full connectivity to the entire state is a policy goal. The C-F

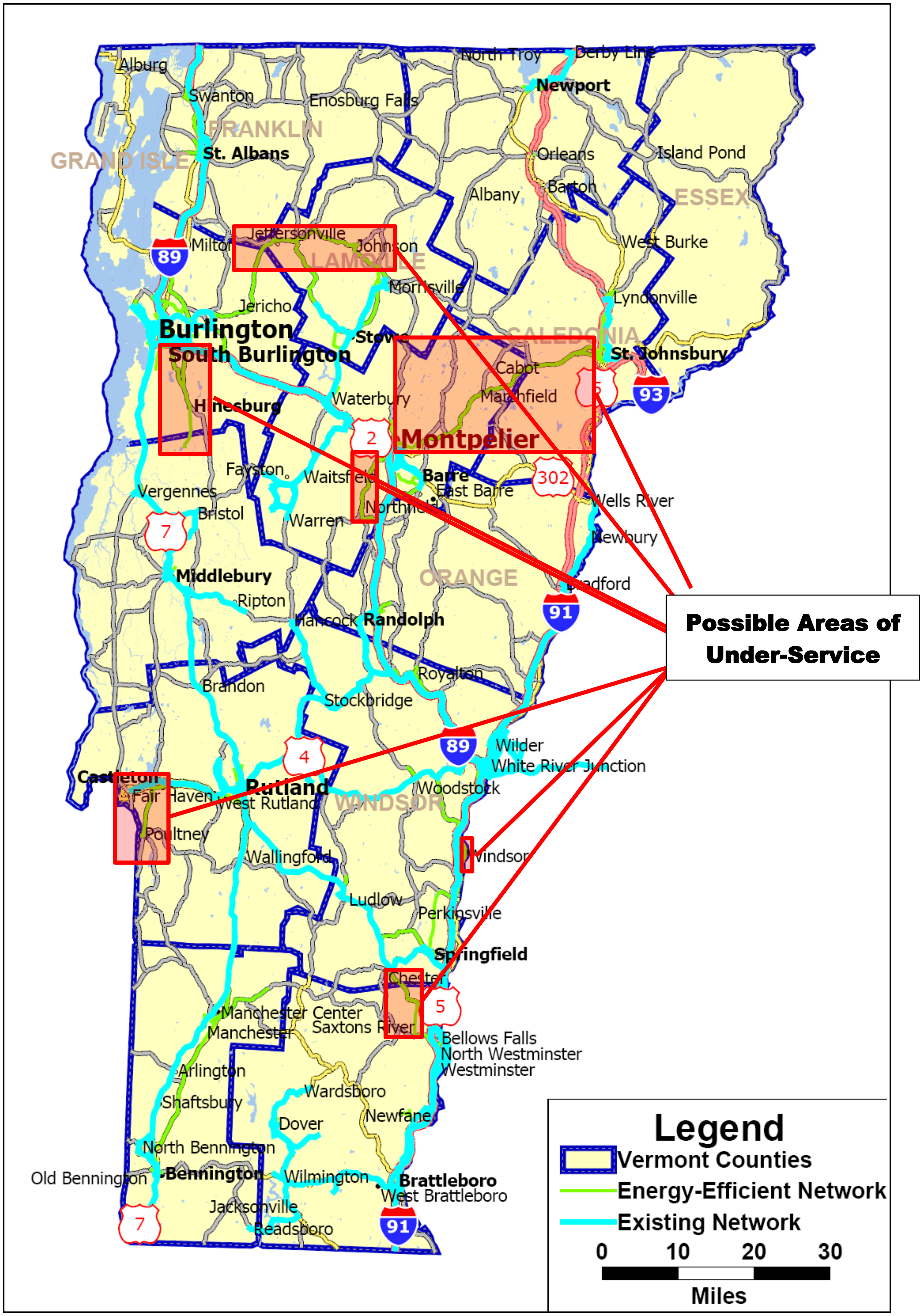

Figure 3-2 Transit Under-Service Analysis Using the E-E Network

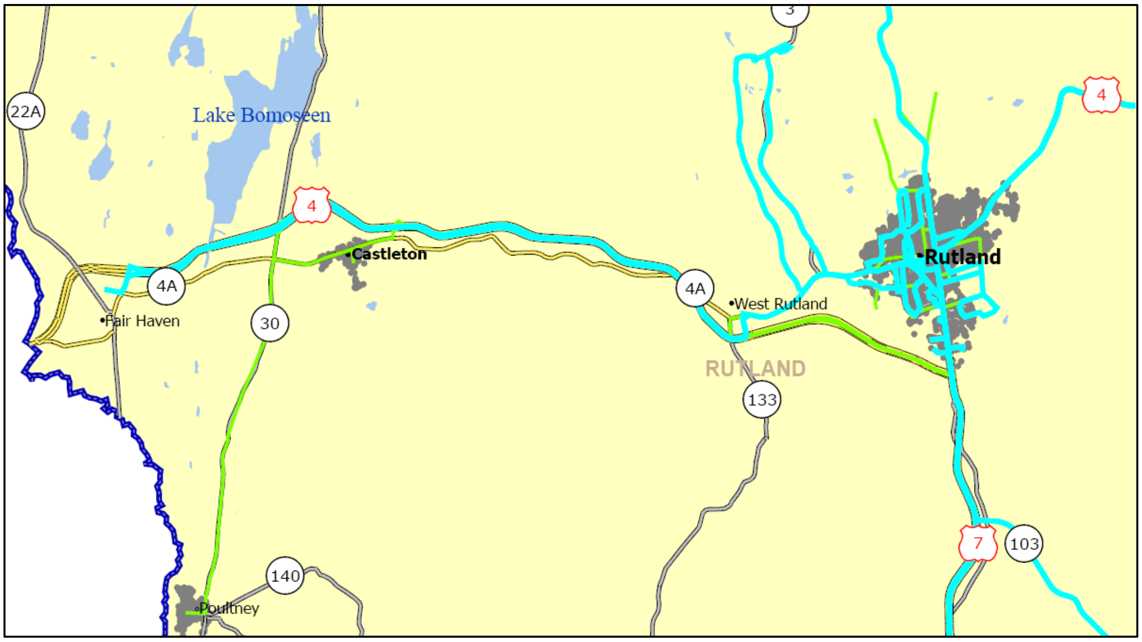

Figure 3-4 Poultney

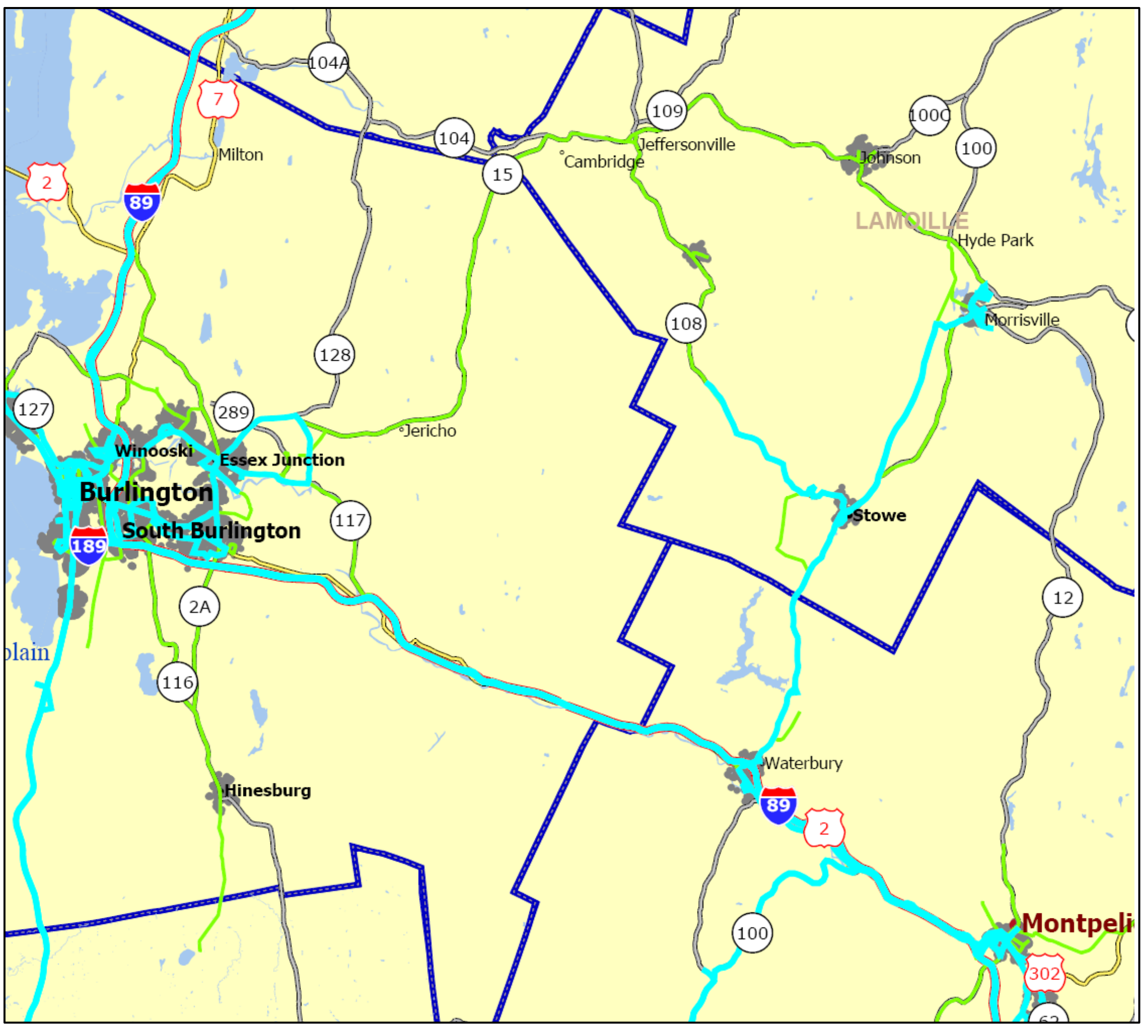

Figure 3-3 Hinesburg, Johnson, and Morses Mill (Not Labeled)

Figure 3-5 Northfield

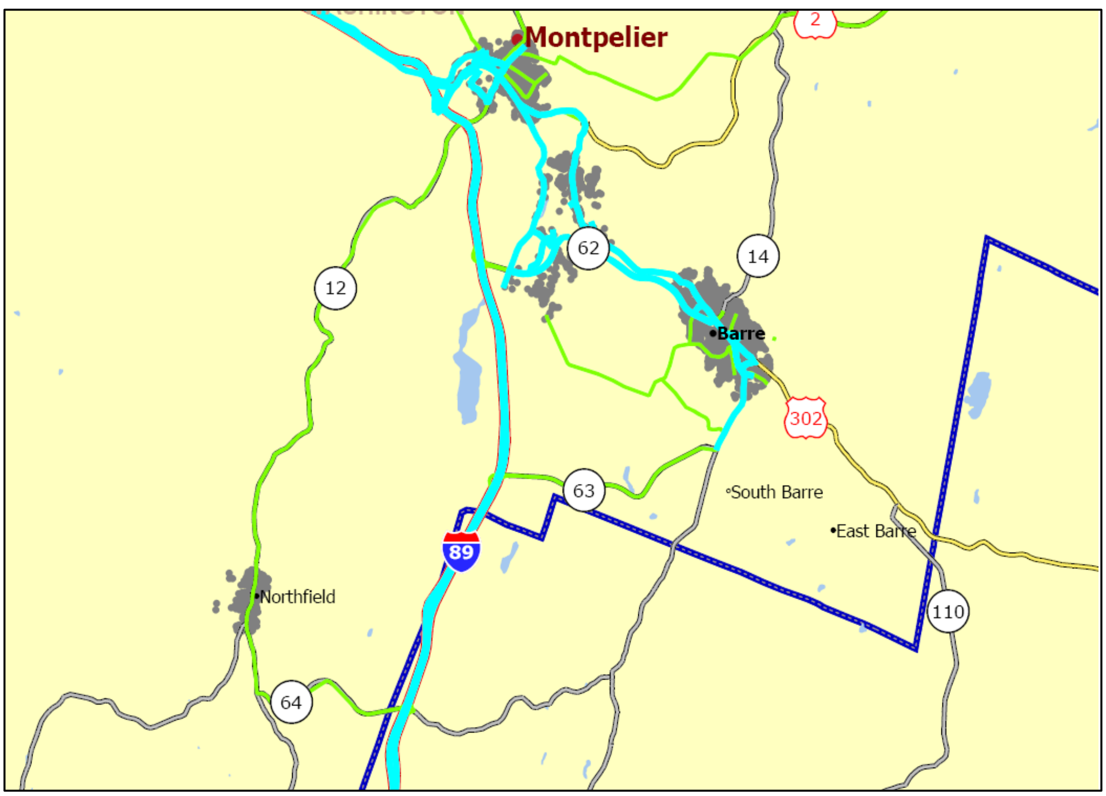

Figure 3-6 Saxton's River and the Putney School

network achieves full connectivity with only a moderate decrease in population reached per mile of network (see Table 3.1).

It is possible that transit-agency boundaries may be preventing the network from achieving full connectivity. The Newport – St. Johnsbury – Bradford connection may be too far geographically to fall under the jurisdiction of one provider. However, our results suggest that demand for transit may exist within and between these three areas. Inter-agency collaboration may be required to satisfy demand for travel between them.

Relative to the "Access-to-Critical Locations" Transit Network

Figure 3.8 provides an overlay of the existing transit network on the ACL transit network. The ACL transit network adds connectivity to/from all health care facilities in the state to the E-E network at a more equitable walking distance (¼-mile). Interestingly, many of these additional links were already part of the existing transit network:

- St. Albans – Enosburg Falls
- Middlebury – Bristol
- Middlebury – Ripton
- Waterbury – Warren/Fayston
- Randolph – Stockbridge/Hancock
- Manchester – North Bennington (via Route 7A)
- Rutland – Fair Haven
- Rutland – Woodstock

The presence of "Access-to-Critical Locations" transit links in the existing network provides expected evidence of planning for social equity by the current transit providers. State programs related to elderly and disabled transport likely have a significant influence of fixed-route transit decisions (VOC, 2006).

However, other links in the ACL network are not covered by existing transit. Most of these provide access to relatively remote towns with low populations, like Island Pond in Essex County (shaded in Figure 3.8). Other links improve upon the walking distance which was previously enforced at ½-mile, but is limited to ¼-mile in the ACL network. These links penetrate further into neighborhoods where transit services can be efficient, which would allow easier access to transit stops by elderly and disabled riders.

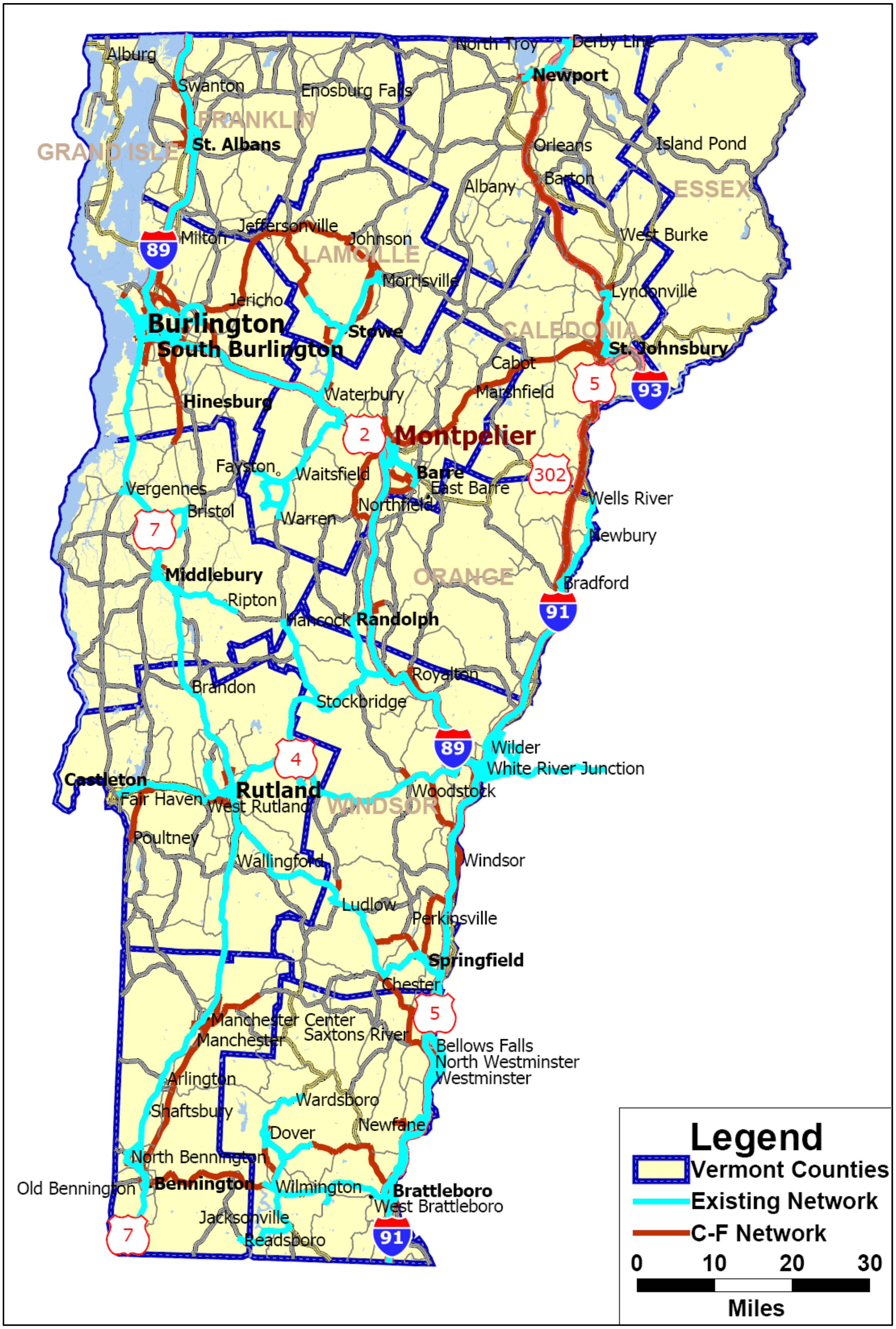

Figure 3-7 Transit Under-Service Analysis Using the C-F Network

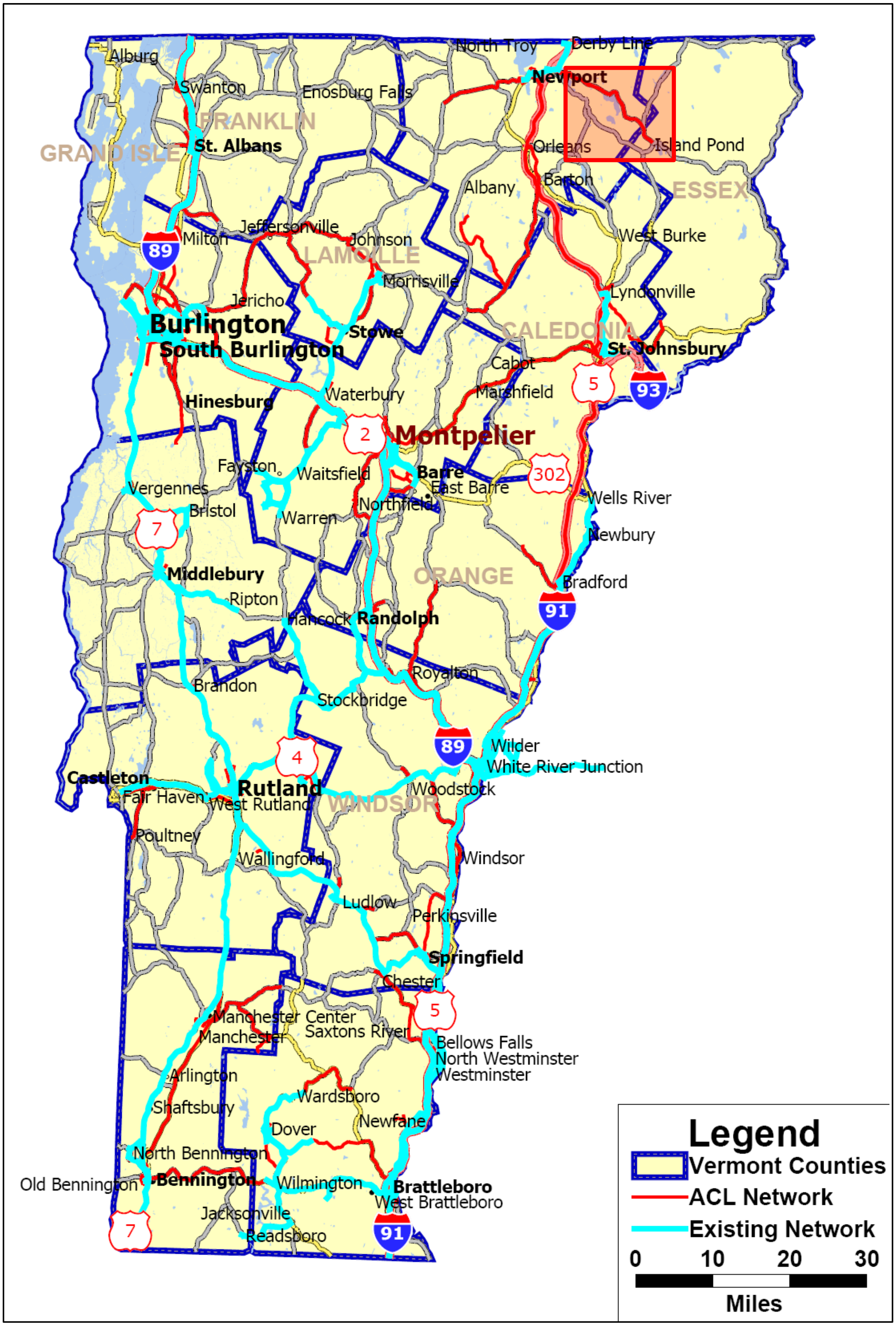

Figure 3-8 Transit Under-Service Analysis Using the ACL Network

3.2 Path/Route Discrepancies

Other discrepancies between the E-E transit network and the existing transit network are not related to access, but are related to specific choice. An example of this type of discrepancy is shown in Figure 3.9, between Manchester Center and North Bennington. The existing "Regional Route" provided by the GMCN travels along Route 7A in order to make stops in Arlington and Shaftsbury. However, the E-E network does not recognize Arlington or Shaftsbury as TSZs, and therefore utilizes the faster Route 7 to connect Manchester Center, North Bennington, and Bennington.

Other similar examples of route discrepancies exist throughout the state:

- Between Woodstock and Windsor (see Figure 3.10)
- Between Morrisville and Stowe (see Figure 3.11)
- Between Chester and Bellows Falls (see Figure 3.10)

It is beyond the scope of this study to determine whether route changes are needed in the existing network. However, this list should be considered a starting place for study of such re-alignments. The routes selected by our algorithm travel through the most transit supportive land use areas and may represent improvements to the network which would increase ridership.

3.3 Analysis of Coincidence Ratios by Service Area

The coincidence ratio (CR) can also be used to dissect the statewide networks back down to the existing service-provider level, for a more focused analysis. Table 3.2 contains the CRs for each service provider's existing network relative to both the EE and the ACL idealized networks.

Table 3-2 Coincidence Ratios by Service Provider

Agency	Service Area Type	Coincidence Ratio (EE to Existing)	Coincidence Ratio (ACL to Existing)
Advance Transit (AT)[1]	Town	0.09	0.14
Addison County Transit Resources (ACTR)	County	0.71	0.71
Town of Brattleboro Bus Line	Town	0.73	0.73
Chittenden County Transportation Authority (CCTA)	County	0.84	0.84
Connecticut River Transit (CRT)	Valley Region	0.56	0.63
Deerfield Valley Transit Association (DVTA)	Valley Region	0.03	0.24
Green Mountain Community Network (GMCN)	Town	0.31	0.31
Green Mountain Transit Agency (GMTA)	Mountain Region	0.57	0.57
Greyhound	State	0.72	0.73
Marble Valley Regional Transit District (MVRTD)	Valley Region	0.75	0.75
Rural Community Transportation (RCT)	Towns (2)	0.27	0.40
Stagecoach Transportation Services (STSI)[1]	Two-Valley Region	0.051	0.451
Entire Networks		0.58	0.64
Note: Service areas for AT and STSI include out-of-state routes which were not considered for the EE and SE networks, so the CRs for these providers may not be accurate.			

The provider-specific CRs in Table 3.2 provide a rough assessment of the extent to which each provider is achieving goals of efficiency and equity in their region. The EE network CRs reveal that the service of providers who are responsible for the more urban regions in the state (CCTA, MVRTD, Brattleboro, and ACTR) are much closer to the energy efficient network in their areas. In addition, the CR of these providers does not change when the ACL network is considered, suggesting an emphasis on efficiency. However, the service networks of the more rural providers, however, coincide poorly with energy-efficiency indicating a need to planning more for equity.

Figure 3-9 Path Discrepancy Between Manchester Center and North Bennington

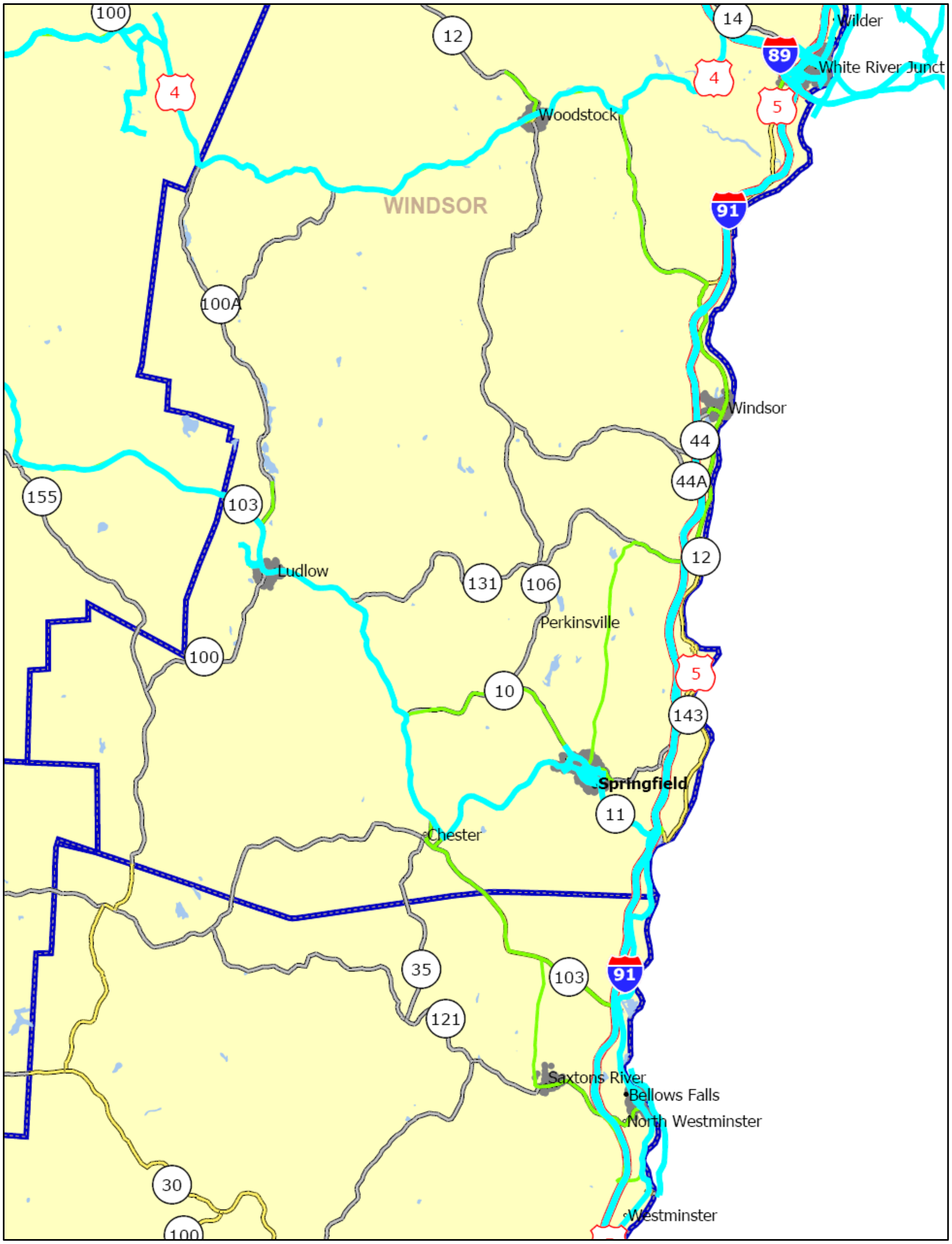

Figure 3-10 Path Discrepancies Between Woodstock & Windsor and Chester & Bellows Falls

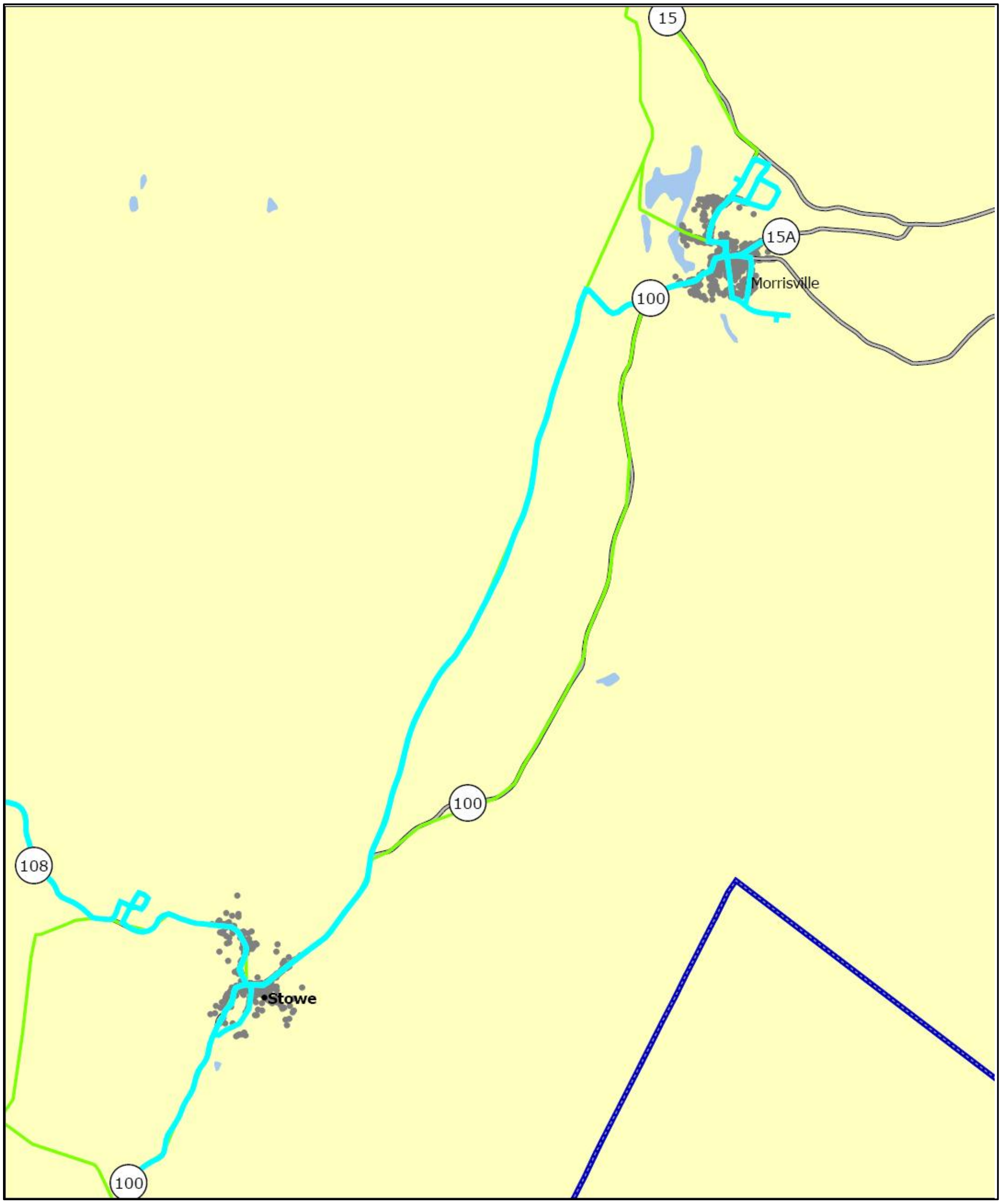

Figure 3-11 Path Discrepancies Between Morrisville and Stowe

4. Relative Location of Ride Share Lots and Transit Networks

In order to investigate the relationship between actual rideshare lots and transit systems in Vermont, the locations of rideshare lots throughout the state (CCMPO and VTrans) was mapped alongside the existing and E-E transit networks (see Figure 4.1). Visual inspection of the map reveals some evidence of these interactions. Generally, rideshare lots seems to be co-located with the existing transit network – indicating the planned intention of having the lots complement the transit network. A more detailed inspection of the co-located rideshare lots, though, indicates that many of them do not fall within a reasonable walking distance of the transit network. Therefore, it is unlikely that these lots will be used to complement the existing transit network. Overall, 34 of the 56 rideshare lots in the state are within ½-mile walking distance of the existing transit network.

A comparison of the rideshare lots in the state with the E-E transit network yields similar results, except that 3 more lots are co-located. A total of 37 of the 56 lots are within a 0.5-mile walking distance of the E-E transit network.

The rideshare locations were also compared statistically to the existing and the optimal transit networks. A "goodness-of-fit" measure was determined by taking the root-mean-square (RMS) of the distances from the rideshare locations to each of the networks. Excluding "inactive" lots, the existing transit network actually provided a better statistical "fit" to rideshare lots (RMS = 3.2 miles) than the E-E transit network (RMS = 4.7 miles). Taken together, the merged network of existing and E-E transit has an average distance to rideshare lots of 0.9 miles, still farther than would be expected for walking.

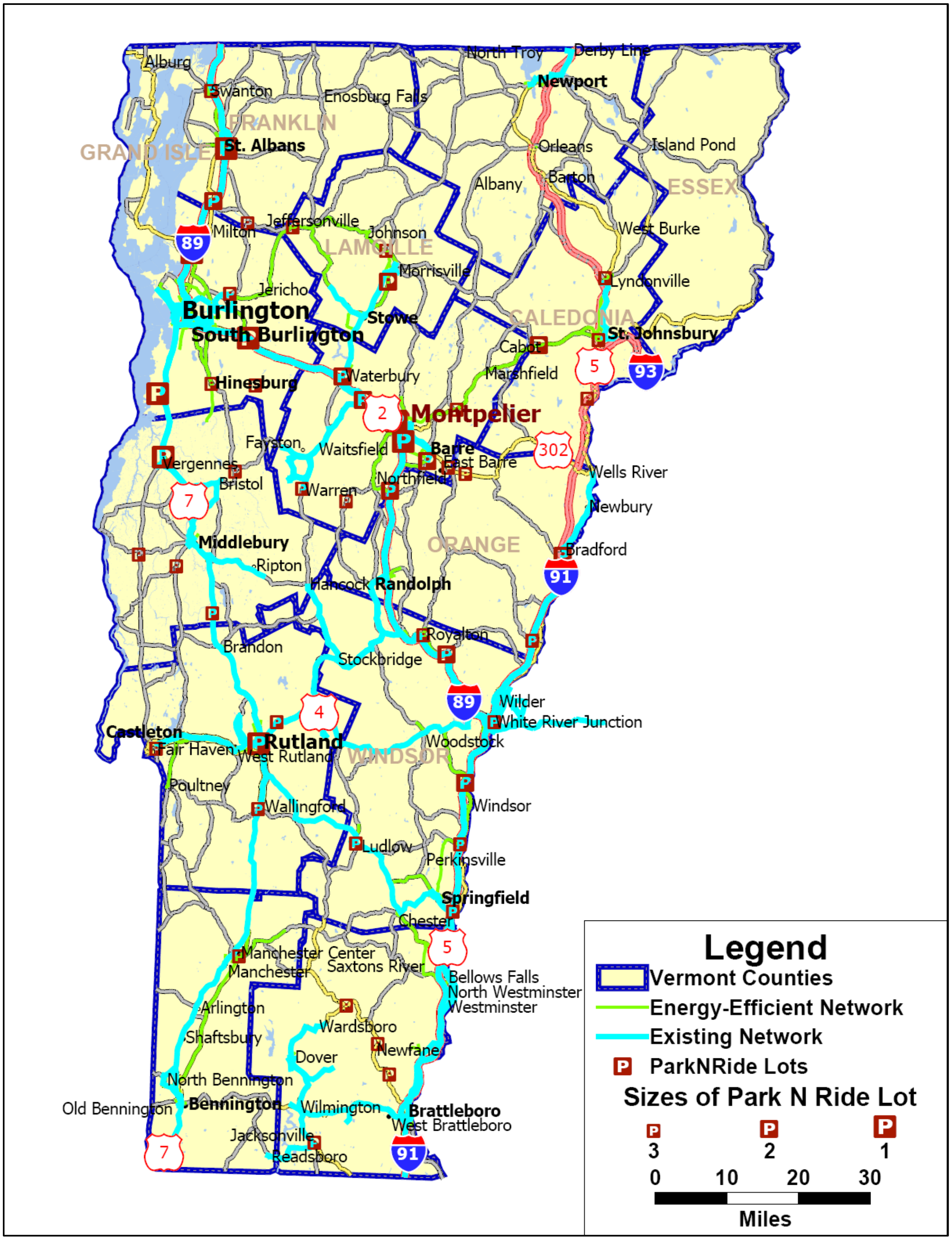

Figure 4-1 Existing Park N' Ride Lots, the E-E Transit Network, and the Existing Transit Network

5. Conclusions

Results of this study suggest that even in rural areas, opportunities may exist to improve the energy-efficiency of transportation system by implementing targeted fixed-route transit service. In the relatively rural state of Vermont, a substantial portion of the population is located in dense clusters which could support energy-efficient fixed-route transit. Our results suggest that nearly 75% of the state's population can be reached by connecting just 99 of its 255 towns. The state's existing transit network, implemented by 12 separate agencies, combines elements of efficiency and equity in its "total network length" throughout the state. While it is not clear from these results which routes or links in the existing fixed-route transit system are targeted at efficiency and which are needed for equity, results suggest, as would be expected, that urban systems are more energy efficient.

Clarifying the distinction between equity and efficiency will aid in the development of more effective goals and measures for the transit providers. Connections based on equity should not have the same types of performance-measures as those based on service efficiency. For equity-based links, ridership may not be critical, but quality of service to a targeted demographic might be.

The existing transit network has reasonable connection to the state park and ride lots however improvement is possible. In particular, it is unclear that walking is possible between park and ride lots and the transit network.

Based on these results, VTrans should consider the following:

- A statewide analysis of origins and destinations to allocate a new statewide network of fixed routes.
- Elimination of fixed-route service to a few towns to be replaced by demand-responsive transit.
- Addition of some critical links to some medical / service centers.
- A focused effort to increase the linkage between the transit network and park and ride lots.
- A more detailed study of how best to connect the northeast kingdom to the rest of Vermont.

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