Route 15 Corridor Improvement Plan
Burlington to Essex Rail Project
Travel Demand Modeling Methodology and Results

Prepared for Chittenden County Metropolitan Planning Organization

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smart mobility

Aldrich House, Suite #3
16 Beaver Meadow Road
P.O. Box 750
Norwich, VT 05055-0750
802.649.5422 phone
802.649.3956 fax

In association with:
DMJM + HARRIS, Boston, MA
Resource Systems Group, Inc., White River Junction, VT

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Executive Summary

The ridership forecasting methodology for the Burlington-Essex Rail Project uses an enhanced version of the Chittenden County Metropolitan Planning Organization (CCMPO) Transportation Model, which was developed during the Phase 1A Burlington-Essex Corridor Alternatives Analysis study. The purpose of the enhancements is to provide more realistic demand forecasts for alternative transportation modes than are possible with the basic version of the CCMPO Transportation Model.

The Chittenden County Metropolitan Planning Organization (CCMPO) initiated the Phase 1A Burlington-Essex Alternatives Analysis to evaluate alternatives for addressing transportation problems in the Route 15 corridor using a variety of transportation modes, including a No-Build, Transportation System Management (TSM), Highway, Express Bus, and Commuter Rail (hourly and half-hourly service) alternatives. The transportation modeling results for the Phase 1 A study were presented in the *Burlington-Essex Corridor Alternatives Analysis Phase 1A Report.* [1]

The Alternative Analysis recommended a multi-modal solution that included commuter rail, feeder bus service, and intersection improvements on Route 15, which was collectively defined as the Route 15 Corridor Improvement Plan. The corridor plan serves as an "umbrella" for a number of proposed improvements and includes the Burlington-Essex Rail Project, among others. The Burlington-Essex Rail Project (Phase 1B) project reflects the refinement of the commuter rail alternative developed through the Phase 1A Alternatives Analysis and includes feeder bus service.

In Phase 1B, the enhanced transportation model has been used to estimate ridership for future years 2005 (which reflects the assumed inception of the Burlington-Essex rail service) and 2025 for both the no-build and build (commuter rail) alternatives. This report documents the methodology used to forecast travel demand, including rail ridership, and presents the results of the Phase 1B transportation modeling effort.

The CCMPO travel demand model is an advanced model for an MPO of its size, having been continuously improved since its creation. Both the 1993-94 and 1998-99 model versions were applied in studies of transit ridership. In this work, the question of model sensitivity has become critical. Aggregate implementation of a disaggregate, non-linear model introduces significant problems. First, aggregation introduces model bias (i.e. a mode may appear more or less attractive than the data indicate) because zone averages are used as inputs to the

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[1] *Burlington-Essex Corridor Alternatives Analysis Phase 1A Report*, DMJM+HARRIS, August 2001.

model rather than data for individual people. Second, aggregation causes decreased model sensitivity. Where in reality transit is very attractive to subgroups of the population, an aggregate model instead treats transit as unattractive to the entire population, because on average it is.

In Phase 1A, the regular aggregate mode choice model was replaced with a disaggregate mode choice model. The 1998 household survey data were reanalyzed and individual utility models for individual respondents were estimated. For each respondent of the stated preference survey, a stand-alone model was generated.

A core feature of the disaggregate application is the generation of synthetic population. The general approach simultaneously matches large-area household types while controlling small area control totals for population, income and auto availability. This work is based on TRANSIMS research at Los Alamos National Laboratory.

An integrated land use allocation model precedes the trip generation step in the CCMPO travel demand model. The rest of the CCMPO travel demand model follows the regular four-step modeling process: trip generation, trip distribution, mode choice, and assignment.

Model estimation was based, in part, on an onboard survey of Champlain Flyer riders conducted March 28 - 29, 2001, soon after service was expanded to the entire day. A total of 139 surveys were completed. This represented about 90 percent of total riders as only a few passengers declined to participate. Of the 139 surveys, 29 (21 percent) were for people who made roundtrips without disembarking, just taking a train ride. Excluding these riders, 88 percent were taking the train to or from work.

A peer review was conducted as a part of the Phase 1A Burlington-Essex Corridor Alternatives Analysis, as a way to ensure that the travel demand forecasts being developed under that study would be consistent with acceptable modeling practices, and thus appropriate for submission to the Federal Transit Administration under the New Starts Criteria guidelines.

In Phase 1B, the enhanced model has been used to estimate ridership for future years 2005 and 2025 for both no build and build alternatives. Both work and non-work trips are modeled. However, purely recreational train rides are not modeled.

The scenarios tested: include 2000 base, 2005 no-build and build, and 2025 no-build and build (here “build” and “no-build” refer to the expanded rail system only – other transit and all roadways are held constant). The future scenarios include the MTP Committed Highway Network being studied in the CCMPO’s Long Range Plan. The MTP Committed Network includes the following major projects: Construction of Segments A and B of the Circumferential Highway, extending VT 289 southerly from where it currently ends at VT

117, to Interstate 89, completion of the Southern Connector, Shelburne Road (US 7) widening, and Kennedy Drive reconstruction.

The build rail system includes stations at Burlington's Union Station, Winooski, Fort Ethan Allen, Fairgrounds, Essex Junction, and IBM. The future year transit network also includes feeder bus routes to serve the three of the Burlington Essex Commuter rail stations as well as the current CCTA bus service.

Daily regional person trips by mode for each alternative are presented below.

Daily Regional Person Trips by Mode

Person Trips	**2000 Base**	**2005 No-Build**	**2005 Rail Build**	**2025 No-Build**	**2025 Rail Build**
Auto	645,333	699,212	697,006	1,030,182	1,026,547
Walk	24,743	24,940	24,940	37,578	37,154
Bus	5,309	5,419	5,119	7,276	6,786
Rail	185	650	1,960	1,305	3,295
Total Transit	5,494	6,069	7,079	8,581	10,081
Total	675,570	730,222	729,025	1,076,341	1,073,783

1. Introduction

The ridership forecasting methodology for the Burlington-Essex Rail Project uses an enhanced version of the Chittenden County Metropolitan Planning Organization (CCMPO) Transportation Model, which was developed during the Phase 1A Burlington-Essex Corridor Alternatives Analysis study. The purpose of the enhancements is to provide more realistic demand forecasts for alternative transportation modes than are possible with the basic version of the CCMPO Transportation Model.

The Chittenden County Metropolitan Planning Organization (CCMPO) initiated the Phase 1A Burlington-Essex Alternatives Analysis to evaluate alternatives for addressing transportation problems in the Route 15 corridor using a variety of transportation modes, including a No-Build, Transportation System Management (TSM), Highway, Express Bus, and Commuter Rail (hourly and half-hourly service) alternatives. The transportation modeling results for the Phase 1 A study were presented in the *Burlington-Essex Corridor Alternatives Analysis Phase 1A Report.* [1]

The Alternative Analysis recommended a multi-modal solution that included commuter rail, feeder bus service, and intersection improvements on Route 15, which was collectively defined as the Route 15 Corridor Improvement Plan. The corridor plan serves as an "umbrella" for a number of proposed improvements and includes the Burlington-Essex Rail Project, among others. The Burlington-Essex Rail Project (Phase 1B) project reflects the refinement of the commuter rail alternative developed through the Phase 1A Alternatives Analysis and includes feeder bus service.

In Phase 1B, the enhanced transportation model has been used to estimate ridership for future years 2005 (which reflects the assumed inception of the Burlington-Essex rail service) and 2025 for both the no-build and build (commuter rail) alternatives. This report documents the methodology used to forecast travel demand, including rail ridership, and presents the results of the Phase 1B transportation modeling effort.

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[1] *Burlington-Essex Corridor Alternatives Analysis Phase 1A Report*, DMJM+HARRIS, August 2001.

2. Demand Forecasting Methodology

2.1 Overview of Demand Forecasting Methodology

2.1.1 HISTORY OF THE CCMPO TRAVEL DEMAND MODEL

The CCMPO travel demand model is an advanced model for an MPO of its size, having been continuously improved since its creation. Different generations of the model include:

- 1989-90 vehicle trip model,
- 1993-94 multi-modal model with integrated land use allocation model, and
- 1998 update with enhanced rail modeling capability.

1989-90 Model

The original model was estimated based on a household trip diary survey. The model included three of the four steps: trip generation, trip distribution and vehicle assignment. A custom module to implement the trip generation model was developed. Trip distribution and trip assignment were performed within the TMODEL2 software.

1993-94 Model Update

A major update was completed in 1993-94. Transportation Analysis Zones (TAZ's) were split into smaller zones and more network detail was added, especially in the Burlington CBD and in primary suburban growth areas (South Burlington, Williston, Essex, and Colchester). A major focus of the project was to add transit to the model. This process included the addition of a transit network, a mode choice model, and a transit assignment procedure. Mode choice parameters were estimated from a stated preference, which included questions concerning rail transit. Model modes include drive alone, shared ride, transit, and walk/bike.

Another important part of this update was the implementation of an integrated land use allocation model, which allocates future households and employment differently for different transportation alternatives

Parking costs and parking-based trip distribution were added to the model as well. Parking costs affect trip distribution, mode choice, and land use allocation by changing the generalized cost for drive alone auto trips, and to a lesser extent shared ride auto trips. However, the magnitude of the effect is relatively small now given current parking charges. Parking location in the model affects auto assignment but does not constrain the number of auto trips to an area – this constraint (if necessary) must be achieved through pricing.
The first version of the Integrated Transportation Model (ITM) was implemented to manage the forecasting process with all steps of the modeling process except auto assignment which is still handled within TMODEL2.

1998-99 Model Update

The 1998 model update was based on a new household trip diary survey and updated socioeconomic inputs. Trip types were changed to better match observed trip-making activity during the morning and afternoon peak hours.

The ability to model rail transit was enhanced over the somewhat ad hoc methods in the earlier version. In particular walk access, bus access, and drive access are all modeled explicitly. As is discussed below, the mode choice model is typical of standard four-step models. It relies on disaggregate estimation from stated preference data, but model sensitivity is limited by aggregate application using TAZ averages. Presence of feeder bus service increases rail trips in the mode choice model by providing a transit-only alternative to the other modes (which include auto and combined auto/rail). Drive access and bus trip segments are calculated and assigned in the auto and transit assignment steps.

2.2.2 MODE CHOICE MODEL RE-ESTIMATION

Both the 1993-94 and 1998-99 model versions were applied in studies of transit ridership. Transit services modeled have included Charlotte-to-Burlington commuter rail, the Burlington to Essex Commuter Rail Feasibility Study, Central Business District-area Light Rail Transit, and enhanced bus services.

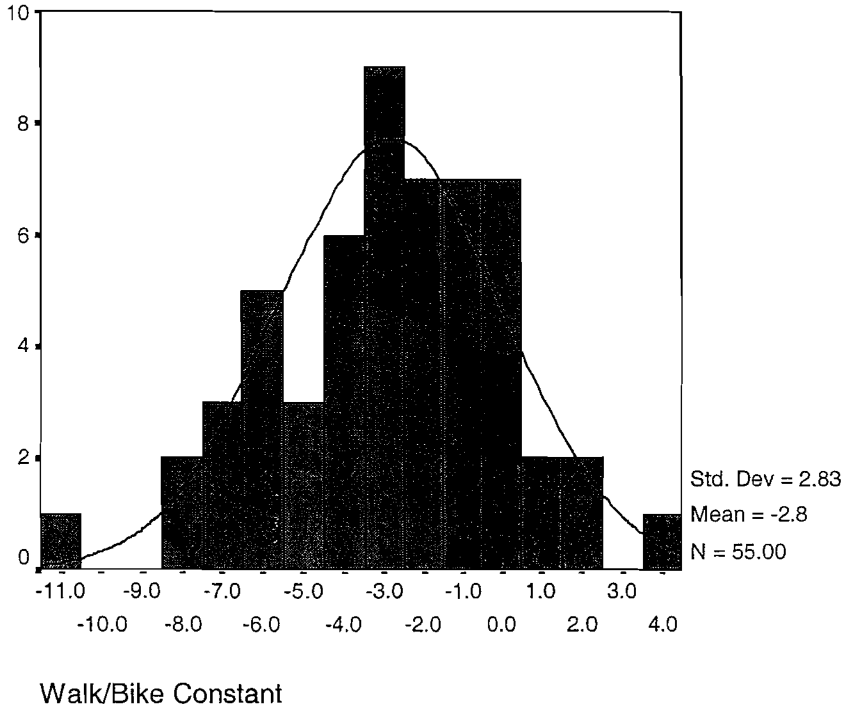
In this work, the question of model sensitivity has become critical. Although the mode choice model form used is similar to that used in the largest cities, the sensitivity issue may be more important in Chittenden County because of the small current transit mode share (less than 1 percent with school buses being excluded).

Aggregate implementation of a disaggregate, non-linear model introduces significant problems. First, aggregation introduces model bias (i.e. a mode may appear more or less attractive than the data indicate) because zone averages are used as inputs to the model rather than data for individual people. That is, aggregate implementation of a disaggregate, logit mode choice model will produce incorrect results. Second, aggregation causes decreased model sensitivity. Where in reality transit is very attractive to subgroups of the population, an aggregate model instead treats transit as unattractive to the entire population, because on average it is.

In Phase 1A, the regular aggregate mode choice model was replaced with a disaggregate mode choice model. The 1998 household survey data were reanalyzed and individual utility models for individual respondents were estimated. For each respondent of the stated preference survey, a stand-alone model was generated.

The benefit of this approach can be seen in the example shown in Figure 1. Bike/walk modes are generally unattractive to the population, on average, for work trips. However, for a subset of those surveyed, walk modes are highly attractive.

Figure 1: Example of Disaggregate Utility Estimation for Work Model Partial Sample



The individual utility models were randomly applied to individuals in appropriate market segments within the synthetic population (described below).

2.2.3 SYNTHETIC POPULATION

A core feature of the disaggregate application is the generation of synthetic population. The general approach simultaneously matches large-area household types while controlling small area control totals for population, income and auto availability.

For this project the large area is Public Use Microdata Area ("PUMA") 00100 which corresponds to Chittenden County. The small areas are Transportation Analysis Zones (TAZs), although there is an additional complication in that the current TAZs are smaller than the TAZ structure used in the most recent available Census Transportation Planning Package (CTPP) data (1990). The PUMS database includes data for about 5 percent of persons, 4241 persons in total. In a second step, the process was extended to create synthetic population consistent with the latest (2000) household estimates by TAZ. Similarly, the process was extended to develop forecasts for future analysis years through 2025.

This work follows a lineage of work from TRANSIMS research at Las Alamos National Laboratory, through Mark Bradley's Pascal implementation for Portland, Oregon to a C programming language implementation done by Parsons Brinckerhoff for the state of Oregon.

Enhancements to the model for the Phase 1A Burlington-Essex Corridor Alternatives Analysis included:

- making the software work with both Census Summary File 3 data (as in the Oregon implementation) and also Census Transportation Planning Package (CTPP) data (for our application),
- allowing the socioeconomic variables for which the synthetic population is balanced (household size, household income, number of vehicles) to be specified by the user, and
- supporting future year forecasts.

2.2.4 Land Use Allocation Model

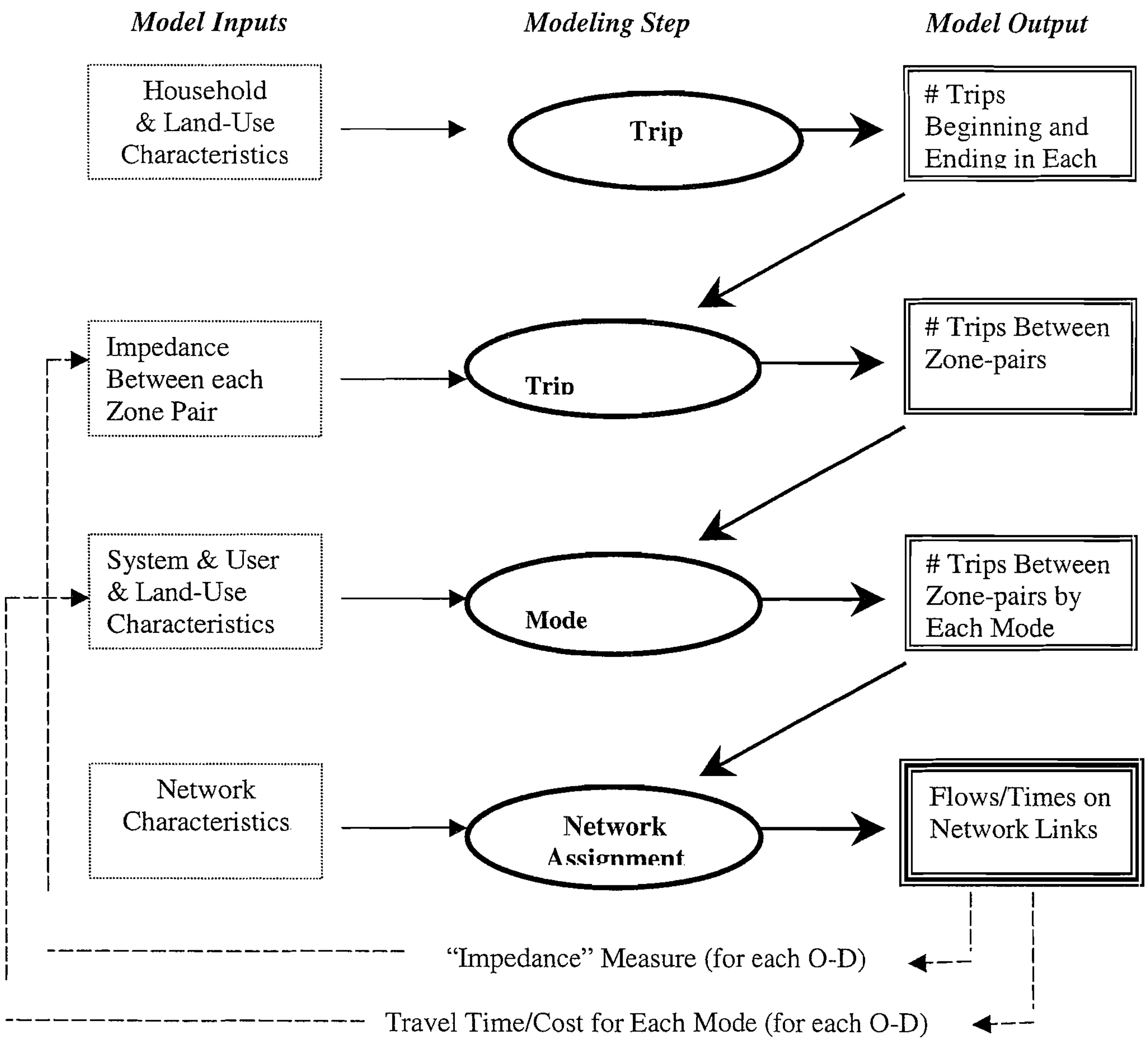
An integrated land use allocation model precedes the trip generation step in the CCMPO travel demand model. It allocates future development based on allowable development and on multi-modal accessibility. Allowable development is a user input, and alternative assumptions concerning allowable uses and allowable densities can be modified in different scenarios (e.g. a zoning change that allows higher density around transit stations). In addition the model supports exogenous land use increments, i.e. specifying that households or employment will be constructed in a particular location at a particular future date. This capability is used routinely for permitted land uses that have not yet been constructed. It also can be used to evaluate specific land use scenarios such as high-density mixed-use development around transit stations. Therefore, there are three ways to increase future density in certain areas in the model: 1) simply entering it as an assumption, 2) entering the results of modified zoning, and/or 3) increasing accessibility from that area (most effective when accessibility is improved to and from the entire region).

The accessibility function in the land use allocation model is a composite function of roadway and transit accessibility to potential destinations. Research results were presented at the 1996 TRB Annual Meeting assessing model sensitivity to the Charlotte-Burlington commuter rail service and the Circumferential Highway. It was demonstrated that the model was sensitive to both the highway and transit alternatives. However, the impact of the transit service on land use allocation was quite small because the scope of the rail service analyzed could serve only a very small fraction of regional trips. The explanation given is: "the increase in accessibility of a single rail line is limited and automobile access and mobility is very high in the suburban area served."

2.2.5 Four Step Process in the CCMPO Travel Demand Model

Except for the special features described above, the CCMPO travel demand model follows the standard four-step process as shown in Figure 2.

Figure 2: Four Step Process in Current CCMPO Travel Demand Model



Trip Generation

Person trip generation is estimated in the CCMPO travel demand model using cross-classification tables based on household size and auto availability. Trip types modeled in the morning and afternoon peak hours are shown in Table 1. Different trip types are modeled during the two periods because observed behavior was different during the two periods. (CCMPO has never made daily travel modeling a priority and no current daily model exists.)

Table 1: Distribution of Person Trips (Percent of Total), by Trip Type, for the AM and PM Peak Hours, Chittenden County, 1998

AM Peak Hour		PM Peak Hour	
Home destination	3.4	Home origin	16.0
Home to work	37.9	Work to home	25.2
Home to school	31.5	Non-work to home	29.2
Home to other	13.6	Work to non-home	14.5
Non-home-based	13.6	Non-work to non-home	15.2

Trip generation practice in the enhanced model is the same except that the cross-classification tables are applied at the individual level and aggregated to the TAZ level for the trip distribution step. The disaggregate trip generation values are saved and used again in the mode choice stage.

Trip Distribution

Trip distribution in both the standard and enhanced models uses a gravity model with a composite multi-modal impedance. The attractiveness functions use a gamma functional form which we have found works well for both short and long trips. Parameters for the different trip types were estimated from household survey and CTPP data.

Mode Choice

The mode choice model includes drive alone, carpool, bus, rail, and walk/bike modes. Service attributes include cost (perceived driving cost, parking cost, transit fares) and travel time (including combined drive/rail/bus times). The current model supports differential terminal times by mode. This capability can be used to model scenarios where transit access is made more convenient than auto access.

Capabilities of the basic model were maintained and supplemented. The resulting model is sensitive to household factors such as income and auto availability, individual factors such as age and gender, and also factors related to the built environment such as pedestrian and transit accessibility.

Inputs to the mode choice model include both the aggregate TAZ-to-TAZ person trip tables by type from the trip distribution step, and disaggregate individual-based trip generation. In model application, all home-based trips are paired; i.e. each home-based trip in the trip tables is matched to a specific household. This is accomplished with randomly drawing the individuals who made the trips until all households have been assigned. Both individual and household variables for the individual are used in application of the mode choice model. Aggregate mode choice application continues to be used for non-home-based trips; as the model does not include trip chaining, and it is impossible to know much about the characteristics of the travelers.

Parking costs also are randomly assigned in the enhanced model. Parking costs are included in the model for TAZs where parking is not free currently, and can be applied to any TAZ. A problem with aggregate mode choice application is that many employees have free parking available, and many others do not. This often is a primary determinant in the decision to use transit, and the aggregate solution of assigning an intermediate cost to everyone is a poor solution. In the enhanced model, either the entire cost is assigned or no cost is assigned, based on a user-specified probability for each TAZ.

While the random disaggregate approach offers many advantages, one disadvantage is that the results are also somewhat random. Therefore, the mode choice step is replicated and the results are averaged. Through testing, it was determined that 3 iterations of the entire process including synthetic population was sufficient to give stable results.

Assignment

The assignment step includes both auto and transit assignments. In some cases, auto assignment is to parking TAZ rather than to employment or household TAZ. Parking spaces are implemented in two ways in the model. First, for rail passengers using park-and-ride lots, vehicle trips are tracked from the park-and-ride lot to the final destination. Similarly, linked feeder bus/rail trips are assigned to both the rail and bus networks. Second, for the Burlington

CBD, University of Vermont (UVM) and Fletcher Allen Hospital areas, vehicle assignment is done to TAZs based on parking rather than land use. UVM and Fletcher Allen Hospital, and other "Hill" institutions jointly support a Transportation Management Association, Campus Area Transportation Management Association (CATMA) which operates shuttle buses serving satellite parking areas. In the Burlington CBD, parking generally is accessed by walking. However, given the small 1-block size of the CBD TAZs, parking often is located in a different TAZ than the land use attraction.

Transit assignment is done within the ITM software. Vehicle assignment is currently done within TMODEL2.

2.2 Travel Markets

The primary travel market for the proposed commuter rail service is to bring travelers into Burlington job centers including the CBD and the "Hill" institutions, especially the University of Vermont and the Fletcher Allen Medical Center. These destinations attract large numbers of workers and others. If the Downtown Winooski Redevelopment Project follows current plans, it will present another significant urban destination.

The other station locations are intended to be primarily origins for riders except for the IBM stop in Essex Junction. This IBM facility is the largest employer in Vermont with about 8,000 employees, and does offer potential for a successful reverse commuter service. However, only about 24 percent of all employees live generally to the west and southwest of the facility, and would be likely riders.

The markets described above are the markets that are modeled. In addition, the existing Champlain Flyer has attracted a significant number of recreational riders, especially on weekends and during the summer and fall seasons. While some number of these are using the train to get to the lakefront for a special event, or traveling south to the Shelburne Museum, it appears that the majority of these riders are simply taking the train in both directions without disembarking. These are not transportation trips and are not included in the CCMPO travel demand model.

2.3 Geographic Area System

The CCMPO travel demand model encompasses all of Chittenden County, Vermont. All of the rail service studied is within the central part of the county.

The CCMPO model has 325 internal transportation analysis zones (TAZs). During Phase 1A, TAZs were split in areas around possible new rail stations in Winooski and Essex Junction in order to provide greater model detail in these areas. The enhanced model has 348 internal TAZs.

2.4 Highway Networks

The 2000 base network includes the existing highway system, as it is today, and takes into account all programmed roadway improvements identified prior to May 2001 when the Phase 1A modeling was completed. The 2025 base network is equivalent to the MTP Committed Network being studied in CCMPO's Long Range Plan. The MTP Committed Network includes the following major projects: Construction of Segments A and B of the Circumferential Highway (extending VT 289 southerly from where it currently ends at VT 117, to Interstate 89) completion of the Southern Connector, Shelburne Road (US 7) widening, and Kennedy Drive reconstruction.

2.5 Year 2001 Transit Networks

The base model year is generally 2000, except for the rail transit, which was not fully operational until 2001.

The 2001 base rail transit network includes the Champlain Flyer with stations in Burlington, South Burlington, Shelburne, and Charlotte. The Champlain Flyer is modeled with hourly service (1 train per hour) throughout the day. Rail travel time between Charlotte and Shelburne is 7 minutes. Travel time between the Shelburne and South Burlington stations is approximately 8 minutes. Lastly, rail travel time between South Burlington and downtown Burlington is 9 minutes. Therefore, the Champlain Flyer arrives at Burlington's Union Station 24 minutes after departing the Charlotte station. The 2001 base transit network also includes the current CCTA bus service.

Champlain Flyer riders were surveyed soon after service was expanded beyond the morning and afternoon peak periods to the entire day. On the afternoon of Wednesday, March 28, 2001 and the morning of Thursday, March 29, 2001, all riders were asked to participate in the onboard survey.

A total of 139 surveys were completed. This represented about 90 percent of total riders as only a few passengers declined to participate. Of the 139 surveys, 29 (21 percent) were for people who made roundtrips without disembarking, just taking a train ride. Excluding these riders, 88 percent were taking the train to or from work.

Only three stations, Burlington, Shelburne, and Charlotte, were operational in March 2001. Mode of access for each station is summarized in Table 2 below.

Table 2 – Champlain Flyer Mode of Access from March 2001 Survey (Percent)

	Auto	Bus	Walk/Bike
Burlington	32.9	7.9	59.2
Shelburne	77.8	0.0	22.2
Charlotte	97.5	0.0	2.5

2.6 Year 2005 and 2025 Transit Networks

The 2005 and 2025 rail transit networks include the Champlain Flyer and the proposed Burlington-Essex Commuter Rail line. The service is assumed to be an extension of the existing hourly service from Charlotte to Burlington. The Burlington-Essex Commuter Rail includes stations at Burlington's Union Station, Winooski, Fort Ethan Allen, Fairgrounds, Essex Junction, and IBM. The fares assumed for the bus and rail transit services in Chittenden County are one dollar. However, there are areas in Burlington where the bus service is modeled as being free of charge representing the College Street Shuttle. Table 3 below summarizes the rail travel times between these stations.

Table 3 – Essex Commuter Rail Station-to-Station Travel Times

From Station	To Station	Travel Time (minutes)
Burlington	Winooski	7
Winooski	Fort Ethan Allen	3
Fort Ethan Allen	Fairgrounds	4
Fairgrounds	Essex Junction	4
Essex Junction	IBM	2

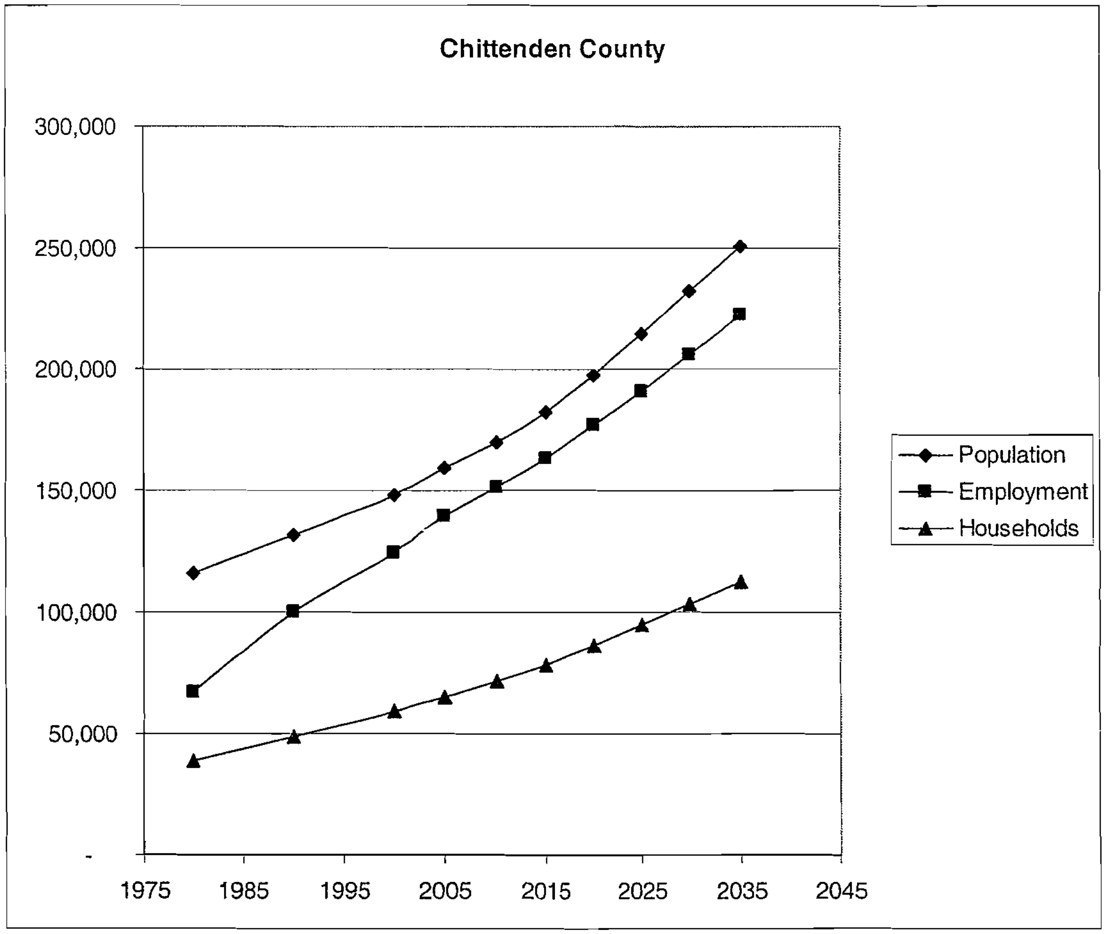
The future year transit network also includes feeder bus routes to serve the three of the Essex Commuter rail stations as well as the current CCTA bus service. Two feeder bus routes serve the Essex Junction station. One feeder bus serves the Fairgrounds station, and another serves the downtown Winooski station. Finally, a feeder bus route with service between the lakefront and Route 15 serving the Winooski and Fort Ethan Allen stations has also been added to the transit network.

2.7 Socioeconomic Projections

The macro level socioeconomic projections were developed by Economic and Policy Resources Inc (EPR). of Williston, Vermont for the CCMPO. Forecasted variables include population, employment, and households.

Historical trends (1980 – 2000) and forecasts (2000-2035) for these variables are shown in Figure 3 below.

Figure 3: Socioeconomic Trends and EPR Forecasts for Chittenden County



For the 2000-2025 study period, EPR forecasts growth of 44.4 percent in population, 53.4 percent in employment, and 60.5 percent in households. Average household size is forecast to decline from 2.52 in 2000 to 2.23 in 2025. Mean household income is forecast to increase by 12 percent over the 25 years.

The land use allocation module of the CCMPO travel demand model is used to distribute the net increment of new houses and employees to transportation analysis zones (TAZs). The synthetic population module populates the future region so that regional control totals for average household income and average household size are realized. The existing distributions of income and household size also influence the forecasts. Areas with larger households now are forecast to continue to have larger households (on average) in the future. However, the averages are lower in the future, because of the overall drop in household size.

2.8 2000 Afternoon Peak Hour Trip Tables

The 2000 afternoon peak hour trip tables are outputs from the CCMPO transportation model that are based on:

- 1998 validated CCMPO transportation model,
- updated 2000 household and employment inputs,
- disaggregated transportation analysis zone (TAZ) structure in the vicinity of possible rail stations,
- inclusion of the synthetic population and disaggregate mode choice modules described in detail below, and
- 2001 Champlain Flyer service characteristics (in order to validate model for rail).

2.9 Year 2005 and 2025 Afternoon Peak Hour Trip Tables

Future trip tables were developed through the normal operation of the CCMPO travel demand model, including iteration with the land use allocation model. The land use allocation model is typically run at 5-year intervals in the model. Therefore, the 2025 model runs also include intermediate outputs for years 2005, 2010, 2015, and 2020.

The inclusion of the land use allocation step means that trip tables are slightly different for the different alternatives – no build and build. While trip table differences have been discouraged in other studies by the Federal Transit Administration, they are justified in this case. The primary justification is that this is the normal method in which the CCMPO travel demand model has been operated for several years. The model is not varying from any official forecast. Rather, the different model outputs are alternative-specific official forecasts. Sensitivity analyses of the land use allocation model for both rail and highway alternatives were presented at a national conference at the Transportation Research Board Annual Meeting in 1996. An excerpt from the written report follows:

> "These scenario analyses involved tests with a proposed commuter rail project and the proposed Circumferential Highway. The proposed commuter rail project is a modest single line system running 13 miles from the Burlington CBD to the south paralleling the Shelburne Road/Route 7 corridor. It would run on existing track. The frequency would be two per hour during peak periods.
>
> Service was assumed to be implemented in 1998 and ridership for the year 2013 was forecast both with feedback and without feedback. Forecast

> ridership is modest in both cases but is two percent higher in the case with feedback This result is reasonable for this scenario. The increase in accessibility of a single rail line is limited, and automobile access and mobility is very high in the suburban area served.
>
> The proposed Circumferential Highway is a limited access partial beltway to the northeast of the City of Burlington. It would provide a bypass to the urban section of I-89 and congested arterials, and provide improved radial access to suburban growth areas.
>
> This highway was implemented in the model in 2003 and traffic volumes were forecast with and without model feedback. Segment volumes with feedback were 10 - 30 percent higher than without feedback, with an average of about 20 percent. There was considerable variation among segments, but about 80 percent of the difference was due to trip distribution feedback with the remaining 20 percent due to land use allocation.
>
> The results again appear reasonable. The land use allocation impact of 20 percent of the average change due to feedback (20 percent) or about four percent of traffic volumes is significant but fairly small. This result was obtained after 10 years of land use effects and would be expected to grow larger over time. The trip distribution effect of 16 percent (80 percent of 20 percent) is very significant and also appears plausible. Trip distribution feedback is included in many urban models, and should be included in all urban models." (Marshall, Norman and Stephen Lawe, "Land Use Modeling in Uni-Centric and Multi-Centric Regions." Presented at Transportation Research Board Annual Meeting, January 1996.)

2.10 Mode Choice Model

As described above, demand was estimated using an enhanced version of the CCMPO travel demand model. The purpose of the enhancements was more realistic demand forecasts for alternative transportation modes in the Burlington to Essex corridor. The core enhancement was a new disaggregate mode choice model. This is supported by synthetic population estimation.

2.10.1 Peer Review

A peer review was conducted as a part of the Burlington-Essex Corridor Alternatives Analysis, as a way to ensure that the travel demand forecasts being developed under that study would be consistent with acceptable modeling practices, and thus appropriate for submission to the Federal Transit Administration under the New Starts Criteria guidelines.

The Peer Review occurred on February 8, 2001, at the offices of AECOM Consulting Transportation Group in Fairfax, Virginia. Participants in the review included the following:

Joseph F. Segale,	Chittenden County Metropolitan Planning Organization (CCMPO)
Charles B. Mudd,	Mudd and Associates, Ltd.
Thomas Adler,	Resource Systems Group, Inc. (RSG)
Norman Marshall,	Resource Systems Group, Inc.
William Woodford,	AECOM Consulting Transportation Group (AECOM)
Jeffrey Bruggeman,	AECOM Consulting Transportation Group
Peter K. Mazurek,	AECOM Consulting Transportation Group.

The panel discussed the "synthetic population" approach proposed here and concluded that while this was a new approach, it is also being developed in some other areas and it would be the sensible way to proceed.

The panel noted that the "individual disaggregate" synthetic population approach removes the need for socioeconomic/demographic terms or income quartiles in the mode choice model since the mode choice model is applied for each synthetically generated person, whose socioeconomic characteristics are explicitly known.

2.10.2 Model Estimation

The CCMPO travel demand model is complex. Integration of new mode choice models takes time, and even running the full model can be time consuming. This presents a hurdle to model testing. In order to speed up the mode choice model development process, the models were tested first with synthetic population data with different service offerings, but without linkage to the full travel demand model.

New disaggregate work and non-work mode choice models were estimated for application to the Burlington to Essex Corridor Study. These models include coefficients calculated for each survey respondent. Modes in the models are: auto drive alone, auto shared ride, walk/bike, and two transit modes (regular bus and premium – commuter rail or bus rapid transit).

The disaggregate models were tested within a "model tester." The tester used the same 2000 synthetic population that was later used in the full model application. However, rather than calculating service attributes for each mode for each traveler, the tester uses the same service attributes for all.

These simplifications allow a series of tests to be completed quickly. Tests included varying rail travel times, fares, and headways. The resulting response curves ("elasticities") are consistent with published data from U.S. transit services.

A major update of the Chittenden County Travel Demand Model was completed in 1993-94. A major focus of the project was to add transit to the model. This process included the addition of a transit network, a mode choice model, and a transit assignment procedure. Mode choice parameters were estimated from a stated preference survey which included questions concerning rail transit. Model modes include drive alone, shared ride, bus, Light Rail Transit, and walk/bike.

This standard mode choice model is consistent with the state of practice in mode choice modeling. However, the aggregate implementation of a disaggregate, non-linear model introduces significant problems. First, aggregation introduces model bias (i.e. a mode may appear more or less attractive than the data indicate) because zone averages are used as inputs to the model rather than data for individual people. That is, aggregate implementation of a disaggregate, logit mode choice model will produce biased results. Second, aggregation causes decreased model sensitivity. Where in reality transit is very attractive to subgroups of the population, an aggregate model instead treats transit as unattractive to the entire population, because on average it is.

Utility functions were estimated for each individual respondent, and stand-alone work trip and nonwork trip models were generated for each respondent. Both the work and non-work models were estimated first as "aggregate" models. Then, disaggregate individual models were estimated for each respondent, i.e. each individual has their own individual model with their own coefficients which represent their personal preferences.

The aggregate models shown below describe the model forms of the work and non-work models. The coefficients of these aggregate models are estimated across all respondents in the work and non-work categories, which is a good approximation for the average coefficients (preferences) of all respondents in the sample.

Work Model

Table 4 summarizes the estimated aggregate form of the work model, including estimated coefficients and t-statistics. Table 5 shows which variables are applied to each mode. Figure 4 illustrates the nesting structure for the work model. This structure has the same theta for both the Auto/Shared Ride nest and the Bus/LRT nest. The stated preference survey included questions about LRT, so the variables are named "LRT." However, the model formulation is generic with the bus and LRT constants constrained to be equal. In application, the second transit model could be any premium service including LRT, commuter rail, or Bus Rapid Transit (BRT).

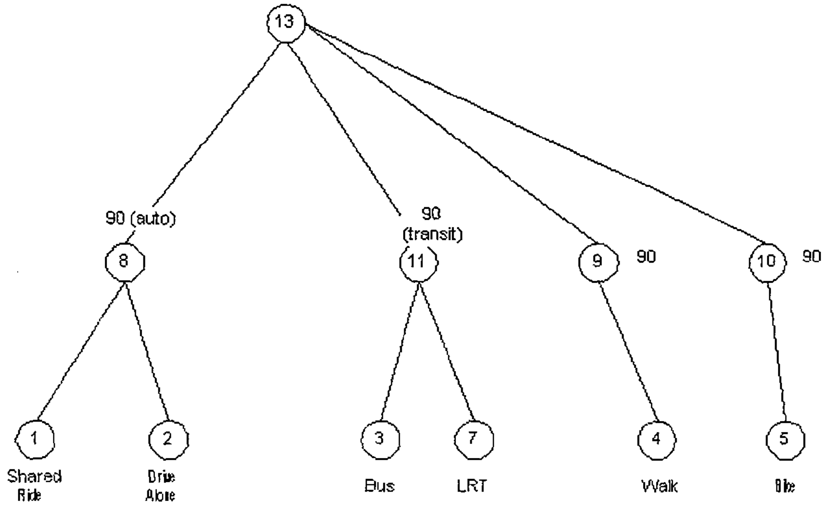
Table 4: Aggregate Work Model Coefficients

Variable	**Units**	**Var Name**	**Coefficient**	**t-statistic**
In Vehicle Time	Minutes	VehTime	-0.079	-7.8
Total Trip Cost	Cents	VehCost	-0.003	-6.2
Access/Egress Time	Minutes	VehAETime	-0.106	-8
Headway	Minutes	Headway	-0.017	-3.7
Total Walk/Bike time	Minutes	WBtime	-0.036	-1.9
Walk/Bike Constant	Utils	WBcon	0.431	1
Shared Ride Contstant	Utils	SRCon	-0.561	-2
Number of Passengers in Carpool	Passengers	SRparty	-0.180	-1.9
Carpool Destination UVM Campus/Medical Center	Dummy	SRcampus	0.294	1.8
Bus/LRT Constant	Utils	BusLRTcon	0.115	0.7
Auto Transit Theta		AuttraNest	0.639	7.9

Table 5: Work Model Variables Applied to Each Mode

	Mode					
Variable	**Drive Alone**	**Shared Ride**	**Bus**	**Walk**	**Bike**	**LRT**
In Vehicle Time	x	x	x			x
Total Trip Cost	x	x	x			x
Access/Egress Time	x	x	x			x
Headway			x			x
Total Walk/Bike time				x	x	
Walk/Bike Constant				x	x	
Shared Ride Contstant		x				
Number of Passengers in Carpool		x				
Carpool Destination UVM Campus/Medical Center		x				
Bus/LRT Constant			x			x

Figure 4: Work Model Nesting Structure



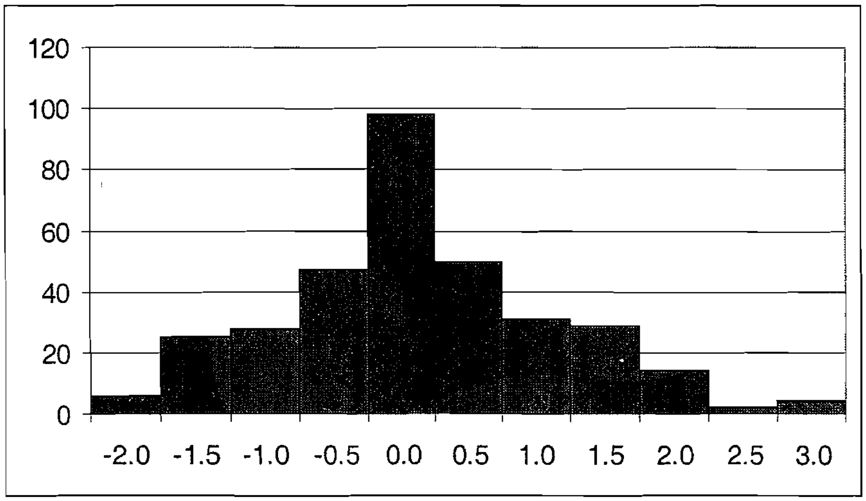
An alternative-specific Central Business District dummy variable was tested in preliminary models for all modes and was found to be insignificant for all modes. An alternative-specific campus variable was also tested for all modes. This variable was found to be significant only for the shared ride mode.

The work model indicates a value of time of $15.58 per hour. Access/Egress time is 1.4 time more onerous than in-vehicle time, which is considered a reasonable ratio.

The transit constant is slightly positive relative to auto, as is the walk/bike constant. The shared ride constant is negative relative to auto. However, respondents are more likely to carpool if they are going to the UVM Campus, as indicated by the Carpool Destination UVM Campus/Medical Center dummy variable. Large carpools are less likely to be chosen as the preferred alternative than are smaller carpools. This behavior is represented in the Number of Passengers in Carpool variable.

The disaggregate transit constants are graphed in Figure 5. The bell-shaped distribution is centered around 0, i.e. no preference on average between transit and auto given identical service characteristics, but moderately strong individual preferences in the tails of the distribution.

Figure 5: Disaggregate Work Transit Constants



Non Work Model

Table 6 summarizes the estimated aggregate form of the non-work model, including estimated coefficients and t-statistics. Table 7 shows which variables are applied to each mode. Figure 6 illustrates the nesting structure for the non-work model. This structure has the same theta for both the Auto/Shared Ride nest and the Bus/LRT nest. The structure shows a transit theta for a Bus/Premium Transit nest. No other nests were statistically significant.

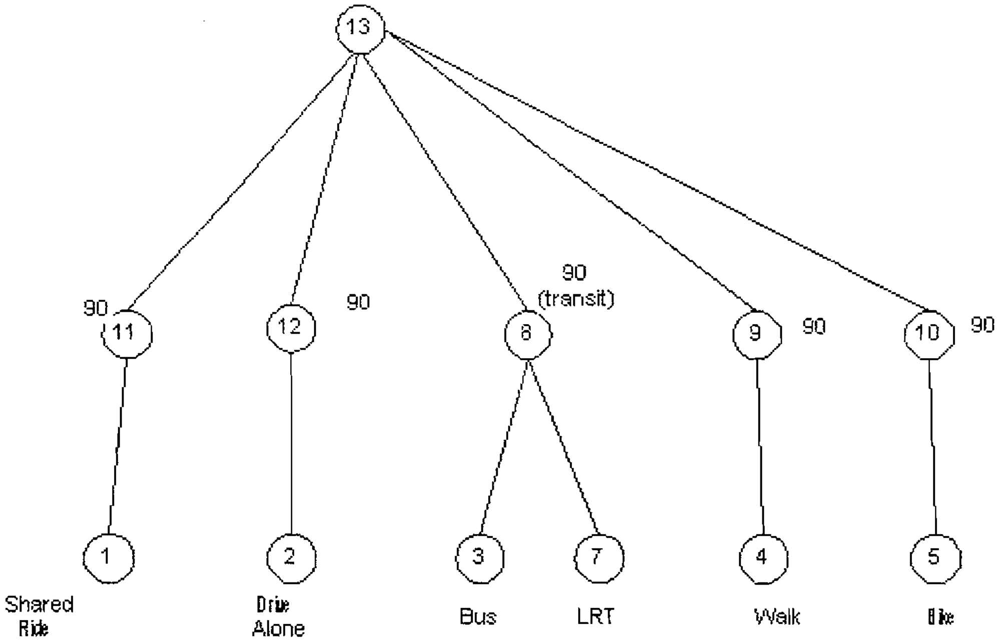
Table 6: Aggregate Non-Work Model Coefficients

Variable	Units	Var Name	Coefficient	T-Statistic
In Vehicle Time	Minutes	VehTime	-0.042	-2.1
Total Trip Cost	Cents	VehCost	-0.002	-1.7
Access/Egress Time	Minutes	VehAETime	-0.066	-2.6
Headway	Minutes	Headway	-0.030	-3.6
Total Walk/Bike time	Minutes	WBtime	-0.088	-2.1
Walk/Bike Constant	Utils	WBcon	1.907	2
Shared Ride Contstant	Utils	SRCon	0.459	1
Number of Passengers in Carpool	Passengers	SRparty	-0.713	-1.9
Bus/LRT Constant	Dummy	BusLRTcon	0.345	1.7
Transit Theta		traNest	0.706	2.2

Table 7: Non-Work Model Variables Applied to Each Mode

			Mode			
Variable	Drive Alone	Shared Ride	Bus	Walk	Bike	LRT
In Vehicle Time	x	x	x			x
Total Trip Cost	x	x	x			x
Access/Egress Time	x	x	x			x
Headway			x			x
Total Walk/Bike time				x	x	
Walk/Bike Constant				x	x	
Shared Ride Contstant		x				
Number of Passengers in Carpool		x				
Bus/LRT Constant			x			x

Figure 6: Non-Work Model Nesting Structure



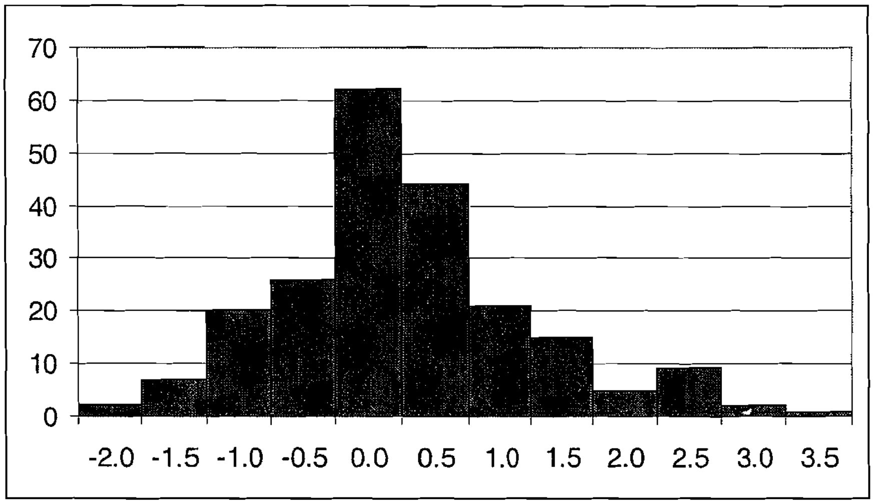
An alternative-specific Central Business District dummy variable was tested in previous models for all modes and was found to be insignificant for all modes. An alternative-specific campus variable was also tested for all modes and this too was found to be insignificant for all modes. As this is a non-work model, respondents would not be traveling to work and neither a campus nor a CBD dummy variable would be expected to increase or decrease the utility of any particular mode.

The non-work model indicates a value of time of $10.78 per hour. Access/Egress time is 1.59 times more onerous than in-vehicle time, which is considered a reasonable ratio. The non-work model has a lower value of time than the work model. This is also considered reasonable, as non-work trips are often less time critical than work trips.

For the non-work model, the Bus/LRT constant is positive relative to auto, as is the walk/bike constant. Unlike the work model, the shared ride constant is positive for the non-work model. This appears reasonable as non-work trips are expected to be made with a higher occupancy, as they are often made in groups for leisure activities. Like the work model, respondents are less likely to carpool with a larger number of passengers. This behavior is represented in the Number of Passengers in Carpool variable.

Figure 7 shows the disaggregate transit constants from the non-work model. As with the work transit constants, the distribution is centered around 0. However, the non-work distribution is somewhat skewed towards positive values, i.e. towards those with a preference for transit over drive alone, given identical service characteristics. This is the cause of the positive average value.

Figure 7: Disaggregate Non-Work Transit Constants



2.10.3 Model Testing

Synthetic population

A core feature of the disaggregate application is the generation of synthetic population. The general approach matches both the detailed information available only at the county level and control totals for other variables that are known at a smaller geographic level, the Census block group.

For this project the large area is Public Use Microdata Area ("PUMA") 00100 which corresponds to Chittenden County. The small areas are Transportation Analysis Zones (TAZs). The PUMS database includes data for about 5 percent of persons, 4241 persons in total. In a second step, the process has been extended to create synthetic population consistent with the latest (2000) household estimates by TAZ. Similarly, the process has been adapted to generate forecasts through the year 2025.

Our work is following a lineage of work from TRANSIMS research at Las Alamos National Laboratory, through Mark Bradley's Pascal implementation for Portland, Oregon to a C programming language implementation done by Parsons Brinckerhoff for the state of Oregon.

For the model tests, the 1990 Census population was transformed to represent the synthetic population for the year 2000. This involved: 1) adjusting the TAZ household totals to 2000 estimates, and 2) adjusting regional averages for household size, income and vehicle availability to estimates for 2000. Other variables such as work status and age that are correlated with these control variables have also changed.

Tester Operation

The tester assumes that every adult in the region makes exactly one work trip and one non-work trip. Except for households with no autos, it assumes that every adult has service for all modes. Furthermore, the service attributes (time, cost, headway) are identical for all individuals, and are assumed to be fairly favorable for the rail mode. Therefore, the aggregate rail mode shares from the tester are likely to be considerably higher than the aggregate rail share that are calculated by the full model.

The tester first calculates work mode shares. For each household, the tester randomly matches a survey respondent with the same income class (based on the six categories used in the survey). The shares for each mode are calculated. If the household includes more than one person aged 18 or over, the calculated shares are applied for each adult in the household. The resulting mode shares are summed within income class for analysis within a spreadsheet. Then a parallel process is followed for non-work trips.

The tester results are intended not to forecast mode shares, but instead to test the model's response to different service attributes. A base condition was developed, and then service characteristics were varied one at a time along each of three dimensions: in-vehicle travel time, rail fare, and rail headway.

Tester Results

For the base condition, auto travel time was assumed to take 20 minutes with perceived nominal cost. Rail was assumed to take 10 minutes longer (30 minutes) plus an additional 10 minutes of out-of-vehicle time. One-way fares were assumed to be $1.00. The service was assumed to operate at 30-minute headways. A low quality bus service was assumed to operate in parallel with a 60-minute travel time and 60-minute headways.

The aggregate mode shares for work and non-work trips are shown in Figures 8 and 9. The aggregate shares appear reasonable given the assumption that all modes are available to each traveler and that the rail transit service is fairly good. The possible exception is the walk/bike mode share, particularly in the work model. Survey responses generally indicated that walk/bike time has a lower perceived cost than in-vehicle time. This may be a reasonable result for relatively short trips, but will produce unreasonable high walk/bike mode shares if applied to long trips. It is necessary to screen out unreasonably long walk/bike trips in the full model application.

Figure 8: Work Mode Share for Base Condition

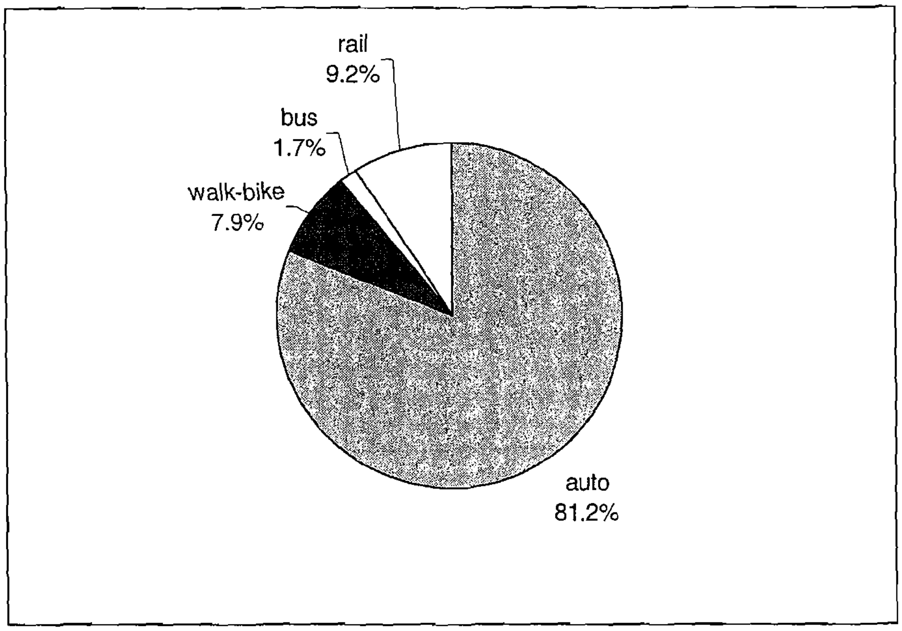
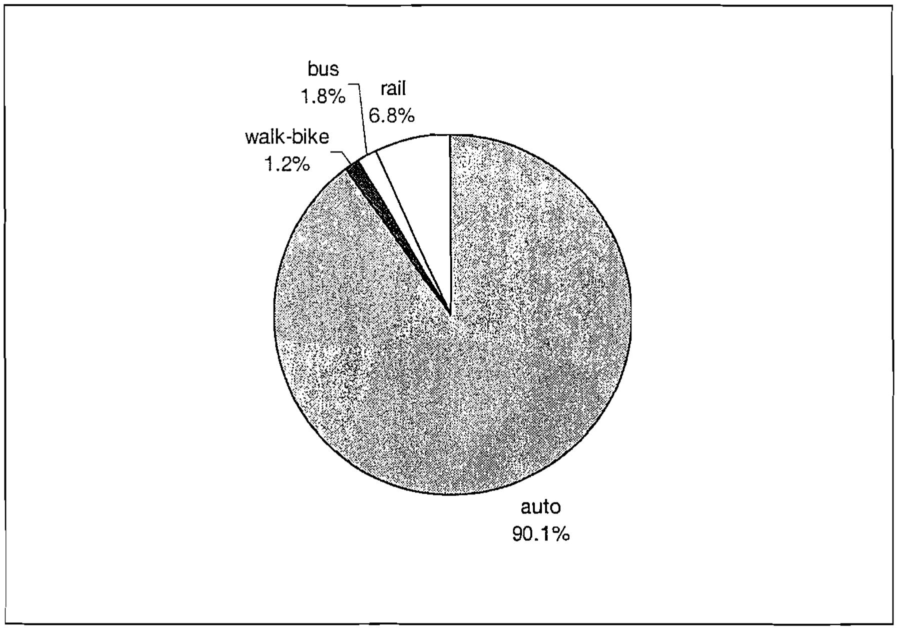
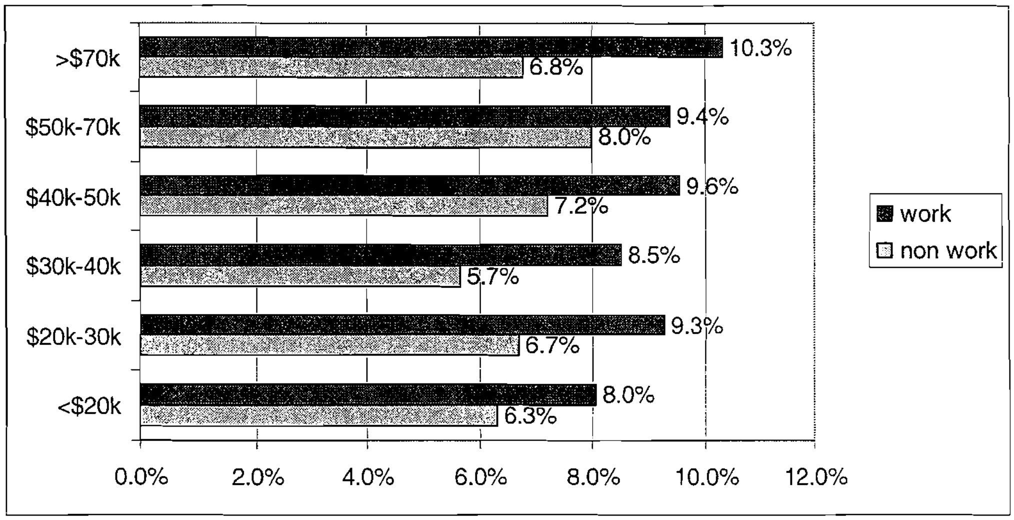


Figure 9: Non-Work Mode Share for Base Condition



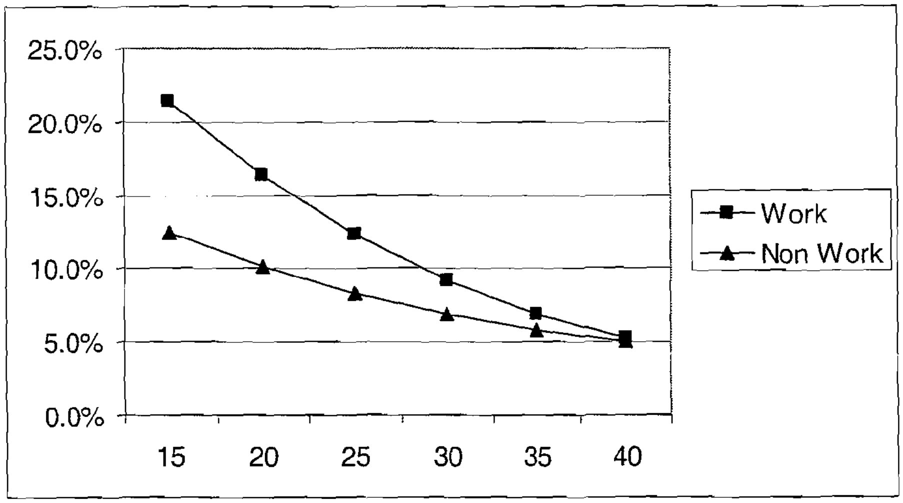
The tester matched synthetic people to survey respondents' individual mode choice models within the appropriate household income class. The predicted rail share does not vary greatly by income class. This result was expected because income was not found to be a very significant variable when aggregate models were tested. Figure 10 summarizes rail mode shares for the base case ("Inc 1" is the lowest income category and "Inc 6" is the highest)

Figure 10: Work and Non-Work Rail Share by Income Group for Base Conditions



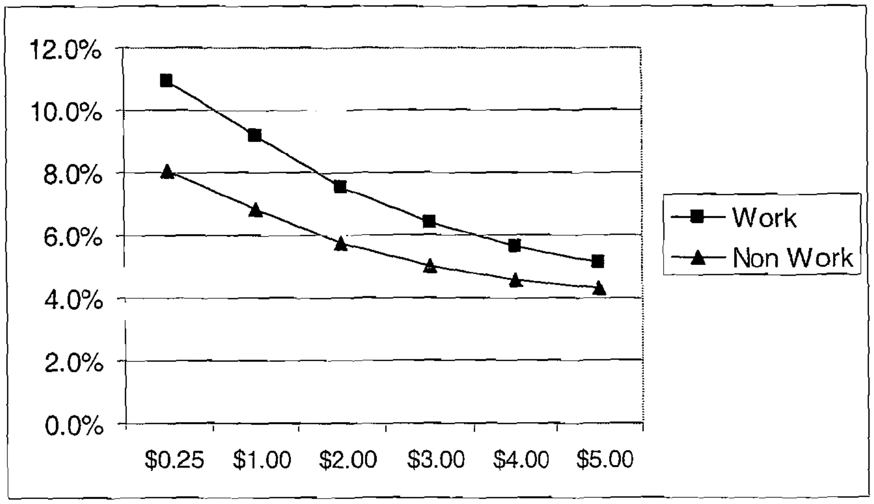
The following three figures (11, 12 and 13) show the response of the work and non-work models to changes in rail service attributes. In the first case (Figure 11), in-vehicle travel time is varied from 15 minutes (i.e. 5 minutes faster than auto) to 40 minutes (20 minutes slower than auto). As expected, rail shares are lower for longer travel times. The work mode shares are higher but the work model is more sensitive to in-vehicle travel time.

Figure 11: Rail Mode Share as a Function of Rail In-Vehicle Time (15 – 40 Minutes)



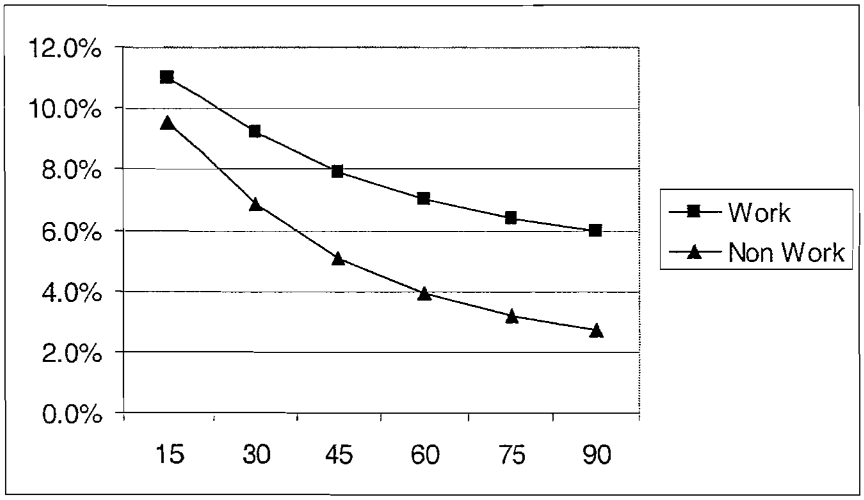
In the second case (Figure 12), one-way rail fare is varied from $0.25 to $5.00. Again, the work mode shares are higher than the non-work mode shares. Rail mode shares are lower for higher fares.

Figure 12: Rail Mode Share as a Function of One-Way Rail Fare ($0.25 - $5.00)



In the third case (Figure 13), headway is varied from 15 minutes to 90 minutes. Rail mode shares drop with increased headway. The non-work mode share is more sensitive to headway than the work mode share. This is somewhat contrary to the historical pattern, but may reflect the changing nature of the workplace including more flexibility in work schedules.

Figure 13: Rail Mode Share as a Function of Headway (15 – 90 minutes)



In the full model application, aggregate mode shares are considerably different because service characteristics for the different modes are different for each individual traveler. However, the general response to changes in service characteristics is the same.

Elasticity, a basic concept from economics, is the metric most commonly used to quantify service response. The elasticity is the ratio of a demand response (e.g. transit ridership) to a change in service supply (e.g. price). Mathematically, the elasticity varies along each point of the supply curve. The arc elasticity uses a logarithmic form to calculate the elasticity across a change interval

Travel Response to Transportation System Changes: Interim Handbook (TCRP Project B-12, Richard H. Pratt and others, March 2000) includes a full discussion of elasticity formulae and summarizes elasticity values from throughout the United States. In the discussion that follows, this reference will be referred to simply as "TRTSC."

TRTSC includes elasticity values calculated for both headway and its inverse, frequency. For example, a headway of 30 minutes corresponds to a frequency of 2 transit vehicles per hour. In TRTSC, the results are summarized in terms of frequency because of the results are more intuitive as service (frequency) is positively correlated with ridership. Table 8 presents arc elasticity results from the model tests.

Table 8: Arc Elasticity Results: Rail Mode Share Response to Rail Frequency

	Work		Non-Work	
frequency	rail share	elasticity	rail share	elasticity
4.0	11.0%		9.5%	
2.0	9.2%	0.26	6.8%	0.48
1.3	7.9%	0.37	5.1%	0.73
1.0	7.0%	0.42	3.9%	0.89
0.8	6.4%	0.41	3.2%	0.95
0.7	6.0%	0.35	2.7%	0.92

For comparison purposes, TRTSC summarizes a wide result of bus studies of elasticity to frequency as: "average slightly above 0.5" (p. 9.8). It goes on to state that fewer results for commuter rail are similar. In comparison, the Chittenden County tester results are slightly lower for work trips and slightly higher for non-work trips (particularly for low frequency/long headways). The calculated elasticity values are well within the range of results reported in TRTSC.

Table 8 shows parallel results for the tests across a range of fares.

Table 9: Arc Elasticity Results: Rail Mode Share Response to Rail Fare

	Work		Non-Work	
rail fare	rail share	elasticity	rail share	elasticity
$ 0.25	10.9%		8.1%	
$ 1.00	9.2%	-0.13	6.8%	-0.12
$ 2.00	7.5%	-0.29	5.7%	-0.25
$ 3.00	6.4%	-0.40	5.0%	-0.32
$ 4.00	5.6%	-0.44	4.6%	-0.32
$ 5.00	5.1%	-0.43	4.3%	-0.27

The elasticity of rail share to rail fare is negative, i.e. an increase in fare causes a decrease in share. In comparison, TRTSC gives an average of –0.35 for 14 studies in cities of less than 500,000 population. In this case, the work model gives a slightly stronger elasticity (i.e. more negative) and the non-model a slightly weaker response. The only exception is for the increase from $0.25 to $1.00. It appears that the survey respondents did not think a fare of $1.00 (even in 1993) was very onerous.

The absolute value of the fare elasticity is less than the absolute value of the frequency elasticity. This is also consistent with TRTSC which states: " . . . response to service changes is almost always greater than fare changes of similar magnitude when service levels are low . . ." (p. 9-14). Even the highest frequency tested, 4 per hour or headways of 15 minutes, is fairly low relative to the transit frequencies in the national sample.
Table 10 shows the elasticity of rail mode share to rail in-vehicle travel time.

Table 18: 2005 Daily Rail Build Station-to-Station Trip Table

Station	IBM	Essex Jct.	Fairgrounds	FEA	Winooski	Burlington	So. Burlington	Shelburne	Charlotte	Total
IBM	0	28	10	25	7	26	5	4	2	107
Essex Jct.	28	0	25	45	58	107	28	14	9	314
Fairgrounds	10	25	0	11	16	38	9	2	2	113
FEA	25	45	11	0	59	88	25	12	7	272
Winooski	7	58	16	59	0	21	33	36	16	246
Burlington	26	107	38	88	21	0	79	82	30	471
So. Burlington	5	28	9	25	33	79	0	13	10	202
Shelburne	4	14	2	12	36	82	13	0	2	165
Charlotte	2	9	2	7	16	30	10	2	0	78
Total	107	314	113	272	246	471	202	165	78	**1968**

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Table 19: 2025 Daily Rail Build Station-to-Station Trip Table

Station	IBM	Essex Jct.	Fairgrounds	FEA	Winooski	Burlington	So. Burlington	Shelburne	Charlotte	Total
IBM	0	50	10	51	13	41	5	12	9	191
Essex Jct.	50	0	54	71	39	131	27	25	20	417
Fairgrounds	10	54	0	20	10	41	7	3	5	150
FEA	51	71	20	0	34	145	31	47	28	427
Winooski	13	39	10	34	0	100	17	24	18	255
Burlington	41	131	41	145	100	0	170	223	90	941
So. Burlington	5	27	7	31	17	170	0	56	12	325
Shelburne	12	25	3	47	24	223	56	0	9	399
Charlotte	9	20	5	28	18	90	12	9	0	191
Total	191	417	150	427	255	941	325	399	191	**3296**

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In the rail build alternative, five feeder bus routes serve the rail stations along the Burlington to Essex Rail corridor. The transit assignment module in the Integrated Transportation Model (ITM), which produces link-level transit volumes, was used to develop bus ridership forecasts on these feeder bus routes. The forecasted daily and annual bus ridership on the five feeder bus routes are presented in Tables 20 and 21 respectively. Daily forecasts were converted to annual ridership using a multiplier of 260 (the number of weekdays in a year).

Table 20: Daily Feeder Bus Ridership

Station	**Feeder Bus Route**	**2005**	**2025**
Essex Junction	Essex Loop	79	158
Essex Junction	South Route	198	356
Fairgrounds	Fairgrounds Route	79	119
Winooski	North Route	40	63
Cherry Street	Burlington to Route 15	165	190
	TOTAL	561	886

Table 21: Annual Feeder Bus Ridership

Rail Station	**Feeder Bus Route**	**2005**	**2025**
Essex Junction	Essex Loop	20,540	41,080
Essex Junction	South Route	51,350	92,430
Fairgrounds	Fairgrounds Route	20,540	30,810
Winooski	North Route	10,270	16,432
Cherry Street	Burlington to Route 15	42,900	49,400
	TOTAL	145,860	230,360

In addition to the ridership results presented above, metrics that describe the effectiveness of the region's highway system were also tabulated. Vehicle-miles of travel (VMT), vehicle-hours of travel (VHT), vehicle-hours of delay (VHD), system average speed, and average trip length in time and distance are the system measures of effectiveness (MOEs) most commonly reported. The MOE data is presented for the 2005 and 2025 no-build and rail-build scenarios in Table 22.

Table 22: Daily Regional Highway System Measures of Effectiveness

Measure of Effectiveness	2000 Base	2005 No-Build	2005 Rail Build	2025 No-Build	2025 Rail Build
Vehicle-Miles of Travel	4,140,942	4,466,855	4,462,481	6,101,039	6,119,107
Vehicle-Hours of Travel	120,074	133,863	133,621	231,414	232,808
Vehicle-Hours of Delay	23,084	29,282	29,139	88,121	89,121
Ave Speed (mph)	34.5	33.4	33.4	26.4	26.3
Ave Trip Length (miles)	8.00	7.95	7.97	7.40	7.45
Ave Trip Length (mins)	13.92	14.30	14.32	16.84	17.00