Executive Summary
Ski Corridor Traffic Management Study

Introduction

The Southern Windsor County Regional Planning Commission (SWCRPC), the Rutland Regional Planning Commission (RRPC), and the Two Rivers-Ottauquechee Regional Commission (TRORC), working in partnership with the Vermont Agency of Transportation (VTrans) and two major ski areas, are working to develop a new analytical tool for assessing the impact of development-related traffic growth in regionally-significant highway corridors. The process is ongoing and will be completed over time.

For years, local, regional, and state bodies responsible for development review have relied on traffic engineering measures such as Level of Service (LOS) in their evaluation of projects. But given growing concern about the adequacy of these measures, planners and engineers around the country have begun to search for appropriate alternatives.

This document reports on the results of one such effort currently underway in Vermont, an effort that was precipitated by a need to gauge the impacts of traffic related to ski resort development. While originally planned to include development and deployment of a new traffic impact assessment model, the project was subsequently scaled-back. Tasks such as the identification of specific performance thresholds will be completed later, after the model is calibrated using locally collected data.

Existing Conditions

The setting for the study is the geographic region bounded by VT Route 103 from U.S. Route 7 to U.S. Route 5 in the south and west; U.S. Route 4 from west of Rutland to I-89 in the north; and I-91 in the east. Communities in the study area face the significant challenge of preserving their historic Vermont townscapes and small-town lifestyle, while addressing the transportation needs of residents, employers, employees, and the tourism and recreational industry in general.

Skiers at the resorts in the study area—Okemo and Killington—are drawn primarily from the New York metropolitan area, other parts of New York State, and New England, including the Boston, Springfield, Hartford and New Haven metro areas. Most visitors arrive by car, both for one-day trips and for overnight or multi-night stays. Periodic traffic congestion results from the peaking of visitor arrivals and departures that are characteristic of the ski industry, with Friday afternoons, Saturday mornings, and Sunday evenings usually the busiest travel times.

Ski-related traffic congestion in the Region tends to focus at specific intersections, rather than longer corridor segments. (This is in part due to the heavy travel peaks of a resort-oriented area and

the predominantly rural character of surrounding land uses.) Several specific intersection-related traffic bottlenecks have been identified in Ludlow, Chester, Woodstock, and Rutland.

Planned expansion at Killington and Okemo ski areas will boost the number of skier visits and very likely increase traffic on their primary access highways. The confluence of heavy skier traffic along Vermont Route 100 in and around Ludlow and at the historic bottlenecks in Woodstock, Chester, and Rutland has already caused concern among some area residents over delays, the changing character for the region's villages, and "quality of life".

Existing Traffic Impact Methods

Recent research findings suggest that traditional Level of Service (LOS) measures, in and of themselves, are not acceptable for quantifying congestion in such settings. LOS is primarily based upon traffic counts and speed/flow relationships. It indicates service quality and comfort as drivers would experience them but does not reflect impacts on non-drivers or the system as a whole.

Research also confirms that measuring congestion is a difficult process that is highly variable depending on data available, the congestion measure used, context of congestion, and causes of congestion. And while communities may enhance the process by establishing the thresholds of where congestion begins, in so doing they may understate or overstate the congestion level that motorists perceive.

Development of an Alternative Traffic Measure

In an attempt to create a framework for the development of an appropriate alternative traffic measure, the project technical committee established several goals. These goals—which stress the importance of factors such as reasonable data collection requirements, analysis costs, speed of analysis, ease of technique, comprehensibility of output, and defensibility—were subsequently used to screen an extensive list of potential measures.

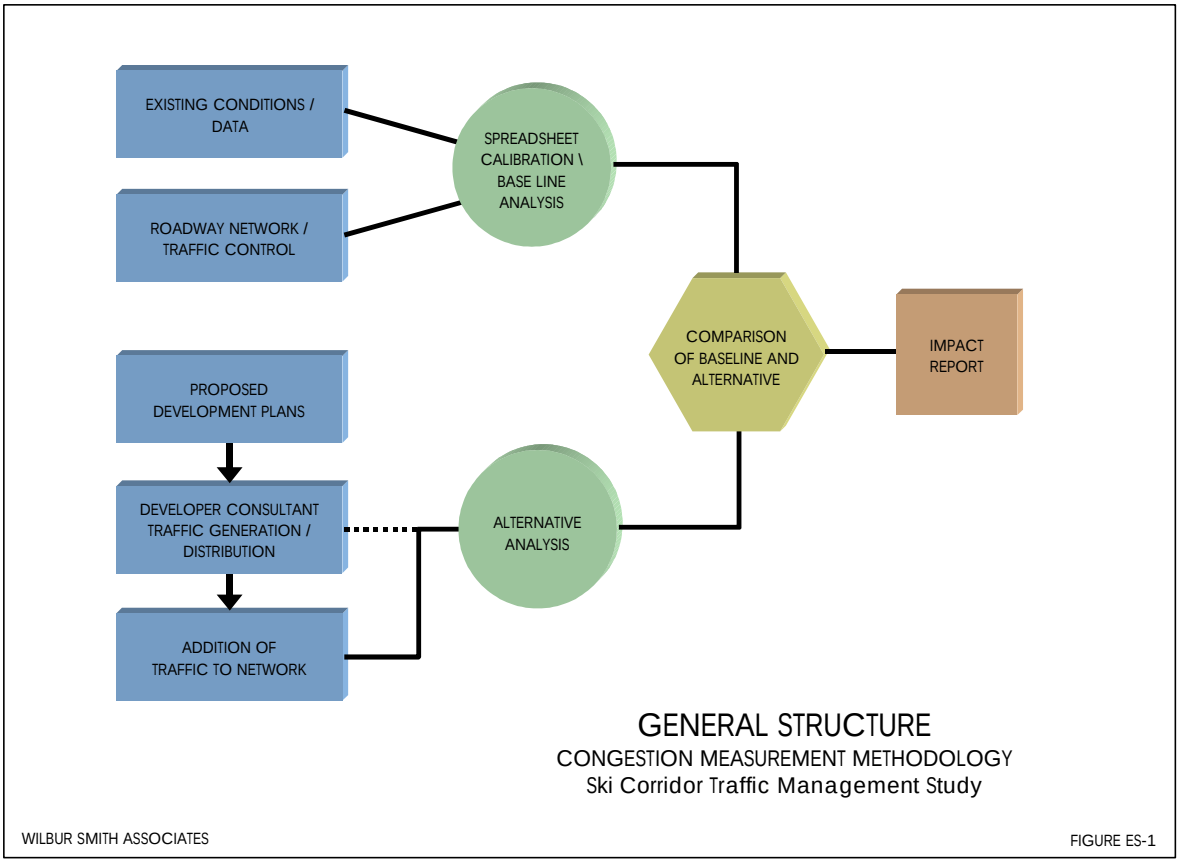
One potential measure that survived this screening process involves the calculation of the total change in vehicle hours of travel that would be caused by new development**.** According to study participants, application of this technique appeared most promising at the "micro" segment or intersection level but was less appropriate in other respects. As a consequence, the measure was refined to produce point-to-point travel time changes for a single vehicle. Study participants later agreed that the revised technique fulfilled the requirements of the study and requested that the technique be developed to a full-scale area-wide system for application.

The new alternative measure is best described as a measure of the average time it would take for a vehicle to travel the length of a given corridor during peak traffic conditions (30^{th} highest hour). Existing travel times are to be measured in the field and used as a baseline. Future travel times are to be estimated with an electronic spreadsheet (Microsoft Excel) using as inputs project-related

traffic growth and outputs from widely available traffic analysis software (namely the Highway Capacity Manual / Software Analysis).

Congestion Measure Methodology

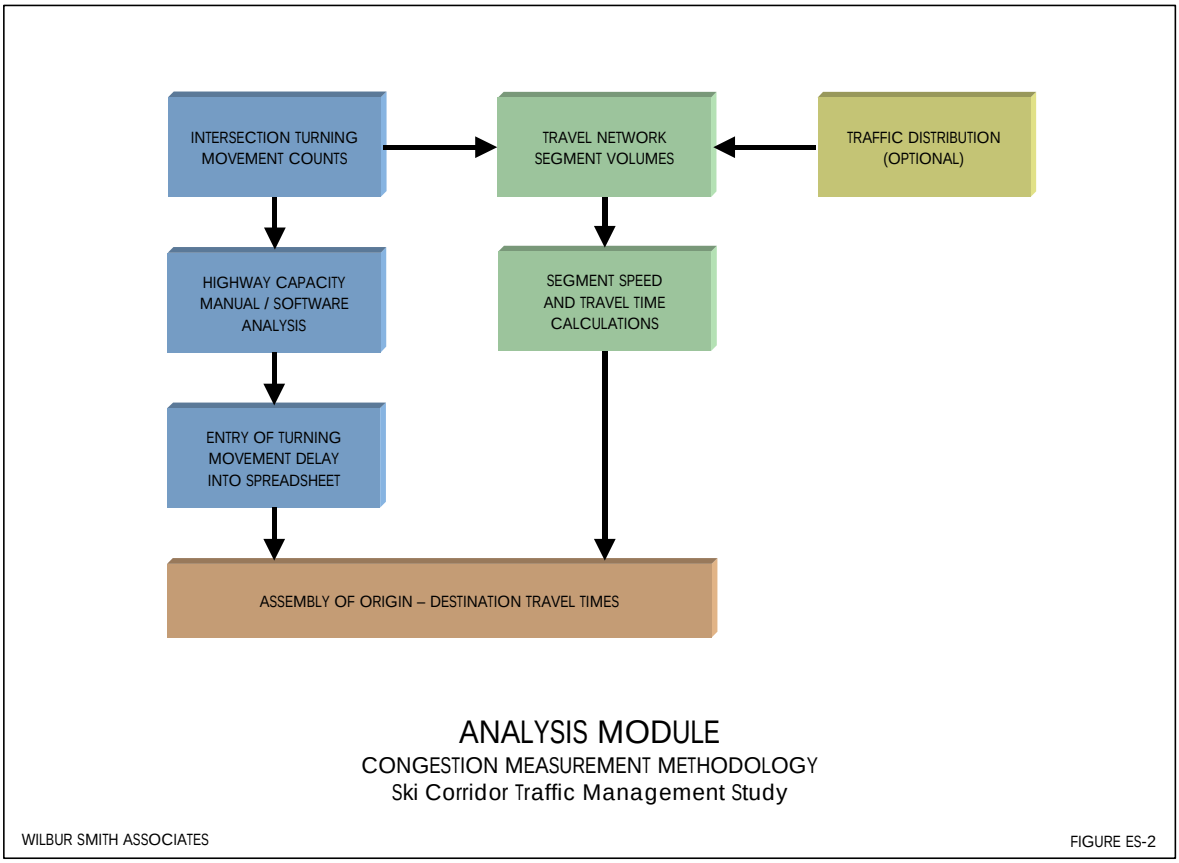
The general structure of the congestion methodology is shown in Figure 1 The Analysis Module is the analytical foundation for the methodology. The module is graphically illustrated in Figure 2. The module will operate for a single peak hour of analysis, e.g., Friday evening ski peak hour. If multiple peak hours of analysis are needed, each will be run separately. Using paths designated by the RPC, the origin-destination travel time will be summarized by adding together individual segment and intersection turning movement per vehicle delay.



Once the module has been calibrated and the baseline established, proposed development scenarios can be tested using the methodology. First, the appropriate baseline must be projected to the

analysis year. This information, which describes what conditions would be like without the addition of project-related traffic, may then be fed into the baseline of the analysis module and the intersection analysis and segment analysis are executed. The information from the analysis module is then recorded and summarized.

Next, the additional development traffic is added to the new baseline data, using data from the developer's consultant's traffic study and, if desired, traffic distribution estimates from the spreadsheet's traffic distribution module. Comparison of the projected baseline travel times and the development level travel times will then form the foundation for mitigation requirements.



One of the key limitations of the analysis methodology is the segment analysis process. The base equations used for the congested speed estimation are based on volume to capacity ratios. Below approximately 15 miles per hour average segment speeds, the equations become less accurate. In this case, the traffic on the segment could be modeled better with a queuing service system analysis.

Mitigation

The resort-oriented land use and transportation characteristics of the study area create distinct challenges and opportunities for traffic mitigation and travel demand management. Typically, ski area traffic peaks most heavily on a limited number of Friday and Sunday evenings and holiday weekends. The remainder of the year, the study area communities are relatively unaffected by traffic. However, at peak times, residents' quality of life is degraded by significant vehicular congestion and delay, as well as the associated noise and air pollution.

Traffic mitigation programs implemented in urban areas have incorporated a broad range of strategies, such as limitation on parking supply, carpool programs and ridematching, flex-time and compressed work week, and travel allowances and subsidies to encourage transit use. However, many of these strategies would not be appropriate in a rural, resort area. The strategies deemed most likely to be effective in the Ski Corridor study area include Travel Demand Management (TDM) Strategies such as Parking Control and Pricing, Travel Demand Time-Shifting, Transit Bus Services, and Guaranteed Ride Home Program. Several resort areas, including Killington, Okemo and Mount Snow, have utilized the local transit system to offer visitors and employees an alternative to travel by private car. These services have been extremely successful in gaining ridership over the last five years. The transit strategy is highly desirable in that it alleviates congestion on the Mountain Road and also increases the access to the resort areas younger (16 and under), non-driving employees and local visitors.

Other mitigation measures include Intelligent Transportation Systems (ITS) strategies, Highway Advisory Radio (HAR), Information Kiosks, Variable Message Signs (VMS), video monitoring, incident response planning, and Internet-based pre-trip planning.

ITS strategies utilize enhancements to the communications network to collect and process traffic information from traffic control officers, ski resort operators and managers, local public safety officials, and other participants. This information is then disseminated to the general public through a wide range of media. For example, informational kiosks--with a video display offering travel directions, visitor information and travel advisories and directions--provide visitors with information they need to avoid the most congested periods and adjust their travel in response to inclement weather or other delays.

FINAL REPORT
Ski Corridor Traffic Management Study

1. INTRODUCTION

1.1 Study Area Description

Study Scope – As originally conceived, this study was to address the following tasks: researching and summarizing available methods of assessing traffic congestion; identifying possible transportation "measures" for use within the study area; defining appropriate threshold levels; developing and demonstrating a proposed threshold methodology; providing a description of effective mitigation techniques; and producing a spreadsheet-based model and written report. Given challenges associated with the identification of a preferred measure and the development of performance thresholds, the scope was later narrowed to focus on the identification of an alternative measure and the development of a prototype model that is to be calibrated using locally collected data.

Study Area Definition - The study area for the Ski Corridor Traffic Management Study is the geographic region bounded by VT Route 103 from U.S. Route 7 to U.S. Route 5 in the south and west; U.S. Route 4 from west of Rutland to I-89 in the north; and I-91 in the east. (Figure 1)

The study area incorporates portions of three Regional Planning Commissions (RPC's) – the Rutland RPC in the western section of the study area, including the Killington and Pico ski resort areas; the Southern Windsor RPC in the central and eastern segment of the study area, including the Okemo, Ascutney and Magic Mountain ski resort areas, as well as numerous local communities, such as the towns of Killington, Ludlow, and Chester; and the Two Rivers – Ottauquechee RPC, which includes the northeastern portion of the study area, including the communities of Bridgewater and Woodstock.

The resort host communities face the significant challenge preserving their historic Vermont townscapes and small-town lifestyle, while addressing the needs of parking and transportation for visitors, employees, business customers and skiers.

Study Area Economy - The economy of the study area is heavily oriented to travel and tourism. In both Rutland and Southern Windsor RPC's, service sector employment, which includes workers in hotels, tourism attractions, and restaurants, is the largest single category of the total workforce. Major ski resorts in the study area include Killington Ski Resort, located in the towns of Killington and Mendon, and the Okemo Ski Resort, located in Ludlow. Both of these resorts draw the majority of their visitors from out-of-state, and each attracts more than 500,000 skier days per year. Smaller ski resorts in the study area include the Ascutney Mountain resort, in Brownsville, and Magic Mountain in Londonderry.

1.2 Regional Travel and Trip Generation Characteristics

Skiers at the Killington and Okemo resorts are drawn primarily from the New York metropolitan area, other parts of New York State, and New England, including the Boston, Springfield, Hartford and New Haven metro areas. Because of the size of these resorts, visitors from other parts of the U.S., and even international visitors, are drawn as well, but in smaller numbers. Most visitors arrive by car, both for one-day trips and for overnight or multi-night stays.

Periodic traffic congestion within the study area results primarily from the peaking of visitor departures, with secondary peaks associated with visitor arrivals. Previous studies of ski resort activity indicate that up to 50 percent of day-skier visitors arrive between 8:00 a.m. and 10:30 a.m. In the evening 50 percent of skiers leave the resort property during a single hour (typically 4:00 to 5:00 p.m.) before nightfall. As documented by WSA's review of existing data sources, Friday afternoons, Saturday mornings, and Sunday evenings are usually the busiest travel times.

Substantial variation also occurs in visitation levels over the course of the ski season as a result of holiday periods and normal weekend business levels. Thanksgiving, the Christmas-New Year week, Martin Luther King and Presidents' Day holiday weekends create the highest seasonal peaks, both overall, as well as on holiday Monday evenings.

1.3 Existing Context for Regulation of Trip Generation

1.3.1 Purpose of Regulation

Because local quality of life and economic vitality within the study area are so closely linked to development pattern and activity at the ski resorts, a decision was made by the affected RPC's "to lay a foundation for the management of resort-related traffic that will result in a smoothly functioning, efficiently maintained transportation infrastructure that serves the needs of its users and protects the interests and character of Vermont communities and resort visitors." In the pursuit of this goal, the RPCs have agreed to pursue the resolution of transportation issues in conjunction with the ski resorts. This coordinated approach should expedite the proceedings and result in positive determinations in the Act 250 process.

1.3.2 Memorandum of Agreement

Memoranda of Agreement (MOA) have been developed by the RPCs and the ski resorts to address transportation and land use issues. Two MOA are relevant to this project:

- An agreement reached by Killington, Ltd. (Killington), the Southern Windsor County Regional Planning Commission (SWCRPC), the Two Rivers-Ottauquechee Regional Commission (TRORC), and the Rutland Regional Planning Commission (RRPC); and

- An agreement between Okemo Mountain, Inc. (Okemo) and the SWCRPC.

The MOAs were prepared to facilitate the participation of certain parties—the signatories—in the Act 250 development review process. Large-scale development programs in the form of "Master plans" prepared by the resorts fall under the jurisdiction of Act 250, which requires conformance with 10 criteria and numerous additional sub-criteria. By law, the RPCs have automatic party status in Act 250 proceedings affecting their regions.

Traditionally, the RPCs have exercised their party status by raising concerns about particular aspects of development proposals; however, on rare occasions they have opposed projects outright. The cooperative relationship outlined in the MOAs builds upon the Ski Country Traffic Management Plan (SCTMP). Involving the same parties as have signed the MOA, the SCTMP was originally established to achieve three main objectives:

- To identify new and potentially more appropriate measures of traffic congestion than those traditionally used in traffic impact analyses (including the Act 250 process);
- To select specific threshold levels of congestion above which conditions are considered unacceptable; and
- To identify promising mitigation techniques that may be deployed by the ski resorts (and other applicants) when forecasts determine that development proposals will likely cause traffic levels to exceed the thresholds.

As noted in the MOAs, monitoring is to be used to determine "if the mitigation strategies do not achieve the desired results." In the event traffic levels caused by new development exceed the threshold, additional strategies will be implemented until traffic levels drop below the threshold.

By signing the MOA, the ski resorts agree to incorporate the measures, thresholds, and mitigation techniques into their traffic impact analyses for specific development projects. In return, the RPCs agree to employ the measures and thresholds when evaluating the impacts of the specific projects for conformance with Act 250.[1] Significantly, the signatories to the MOAs agree to carry out the terms of the MOA whether or not approval of the Master Plans is obtained. In the MOA between Killington and the RPCs, those terms include Killington's agreement to follow the recommendations of its own traffic consultant Resource Systems Group (RSG), while in the MOA between Okemo and the RPCs, the terms include Okemo's agreement to follow the recommendations of its traffic consultant Bruno Associates.

In their respective MOAs, the ski resorts also agree to continue to support the development of the TMP and to assist in the identification of transportation measures and thresholds. The RPCs similarly agree to continue to support the development of the TMP and to define, in cooperation with the ski resorts, new transportation measures and thresholds that trigger the implementation

[1] One specific sentence of the MOAs suggests that use of the measures by the RPCs might occur only if the MOAs are incorporated by the District Environmental Commission into Findings of Fact for criteria 5 and 9(K). However, it is WSA's opinion that, when read as a whole, the MOAs do not make this condition a prerequisite.

of mitigation techniques. They also agree to inform the respective District Environmental Commissions that, by signing the MOAs, the ski resorts should be considered to have "met the requirements for positive findings … under Criterion 5 and Criterion 9(K)."

1.3.3 Act 250 Permits

As noted above, before an Act 250 permit can be issued to an applicant, a District Environmental Commission (DEC) (or, on appeal, the state Environmental Board (EB)) must find that the development or subdivision meets a series of 10 criteria and numerous related sub criteria. For large-scale and conceptual development proposals, such as those embodied in the Master Plans prepared by the Killington and Okemo ski resorts, so-called "master permits" may be obtained "to the extent that the district commission or the board has made affirmative findings and has imposed conditions as required by [the law]."

Actual construction may be authorized only to the extent that a particular component of the Master Plan (for example, infrastructure) is found to comply with all Act 250 criteria and sub-criteria. As noted in the Environmental Board's policy on Master Permit Policy, partial positive findings for the remaining elements of the Master Plan "will provides guidance and greater predictability to the applicant in preparing final plans for the project or for subsequent phases." Both Killington and Okemo have submitted Master Plans for Act 250 review, although neither has received positive findings under criteria 5 and 9(K).

In a decision issued in April of 1999, District 1 Environmental Commission, which covers most of Rutland County, concluded that:

> *Based on deficiencies in traffic data, the commission concludes that the applicant [Killington] has not met the burden of production under … criterion [5] or under criterion 9K. We conclude that a two-phase coordinated approach to traffic analysis will have to be organized by the applicant, and coordinated with the state AOT and with the Regional Planning Commissions. In summary, a new and more comprehensive regional traffic study is required, followed by an agreed-upon series of mitigation measures proposed in response to more accurate traffic analyses.*

The DEC's decision on the Killington Phase One Master Plan (Application #1R0835-EB) was appealed to the Vermont Environmental Board. However, issues considered on appeal did not relate to either criterion 5 or criterion 9(K).

Similarly, in a decision issued in February of 2000, the District 2 Environmental Commission concluded that Okemo had not presented sufficient evidence on traffic and related impacts. However, it noted that:

> *Agreement* [by the ski resorts] *with the involved regional planning commissions and the Vermont Agency of Transportation will be helpful in providing a more complete*

assessment of traffic impacts and solutions that can be implemented on local and regional levels. We will look to the result of these cooperative and collaborative partnerships to provide evidence in future individual project applications for assessment of conformance with both Criteria 5 Traffic and 9(K) Impact on Public Investments.

In both decisions, the DECs take particular note of the respective MOAs described in the first section of this Report. Indeed, in the Killington decision, District 1 Environmental Commission writes that in connection with criteria 5 and 9(K) it "specifically adopts" the recommendations contained in the MOA. In the Okemo decision, the District 2 Commission quotes substantial portions of the MOA verbatim.

Specific traffic-related areas of concern identified in the decisions include the intersection of the Killington Road and US 4 and the intersection of VT 100 North and US 4, both in Killington, as well as intersections along US 7 in Rutland City and Rutland Town and along US 4 in Woodstock. In the Okemo decision, problem areas identified include the Route 103 corridor and, in particular, the Buttermilk Falls Road, Second Access Road, and Depot Road intersections in Ludlow.

1.3.4 Conclusion

The MOA's represent a significant commitment on the part of the project partners to address transportation needs in the ski corridors study area. Because the MOA's have been formally incorporated into the Act 250 review of the Killington and Okemo master plan applications, the process is becoming institutionalized. As a result, over time it will have ever-increasing chances of success.

1.4 Study Coordination

As noted above, the study has come from a complex set of agreements among regional agencies, towns, the State, and the ski resorts. A technical committee for the project was formed consisting of:

- Rutland RPC;
- Southern Windsor County RPC;
- Two Rivers – Ottauquechee RPC;
- Vermont Agency Of Transportation – Planning and modeling;
- Okemo Mountain Resort; and,
- Killington Resort.

The study was coordinated by a consultant, Wilbur Smith Associates, who participated in the technical committee meetings also.

The study included a Steering Committee including all of the members of the technical committee, plus the addition of:

- Rutland Region Transportation Council;
- Southern Windsor County Transportation Advisory Committee;
- Two Rivers-Ottauquechee Transportation Advisory Committee;
- Windham Regional Commission;
- Town of Ludlow;
- Town of Cavendish;
- Town of Chester;
- Town of Woodstock; and,
- Ludlow Transportation Advisory Committee.

2. EXISTING CONDITIONS

2.1 Roadway Physical Characteristics

2.1.1 VT Route 103

Function - Route 103 runs in a northwest-southeast direction from a junction with U.S. Route 7 just north of Rutland Airport in the Town of Clarendon to an interchange with I-91 (Interchange 6) in the Town of Rockingham. It has been designated as a rural principal arterial, and forms a component of the National Highway System (NHS).

Land Use - Land uses along this route are predominantly rural, including substantial areas of forested land, limited farming activity, and protected natural areas. Retailers, restaurants, lodging and service businesses are concentrated in the villages of Ludlow and Chester, with smaller clusters of service businesses (gas stations, repair services, etc.) in cross-roads hamlets, such as Cuttingsville, East Wallingford and Gassets.

Geometry - Two travel lanes (one in each direction) are provided throughout most portions of Route 103. Relatively short climbing lane sections are located to the east of the village of Ludlow, and as one approaches the Green Mountains from both eastbound and westbound directions. Geometry is constrained in village areas, and by the bridge in Chester, as noted below.

Pavement Conditions - Many segments of Route 103 are rated poor--interspersed with some segments of acceptable conditions --between US 7 and area between Mount Holly and Ludlow. It is rated poor east of Ludlow village and rated good for majority of mileage between Chester village and Rockingham town line. Finally, it is rated fair in Rockingham, between Chester and Cavendish, and west of Ludlow. Sufficiency ratings (based on report for 1996): Except for an approximately 2.5 mile segment between Rockingham and Chester, the route earned rating of poor or fair.

Safety Conditions – The study area segment of Route 103 has one High Accident Location (HAL) segment, located in Ludlow. There have also been recent major accidents experienced in Clarendon, Shrewsbury, and Mount Holly.

2.1.2 U.S. Route 4

Function - U.S. Route 4 is a major east-west route through central portion of Vermont. Classified as a rural principal arterial and a component of the NHS, the study area segment of Route 4 has Average Annual Daily Traffic (AADT) volumes ranging from 3,000 near Bridgewater to nearly 13,000 in downtown Rutland.

Land Use - Adjacent land uses are predominantly rural, including forested land, farmland and natural areas, such as the Green Mountain National Forest. Residential, retail and other commercial development is concentrated in Rutland City, Rutland Town, the Killington resort area, and the village of Woodstock.

Geometry - West of Rutland, Route 4 is a four-lane, divided highway. East of Rutland, the route is primarily a two-lane highway with wide shoulders and climbing/passing lanes approaching Green Mountains. There are also occasional turning lanes (e.g., in Rutland). In Woodstock, the route narrows and becomes a village "Main Street".

Pavement Conditions – Route 4 pavement conditions are rated poor for much of the area between Rutland and West Bridgewater. They are rated good approaching I-89 in Woodstock (between Woodstock and I-89) and are fair or acceptable in the majority of other locations. In terms of sufficiency ratings, Route 4 earns good rating west of US 7. However, east of US 7, with the exception of the "flats" between Sherburne village and West Bridgewater (which also earns a good rating), the route earns only fair or poor ratings.

Safety Conditions - There are no identified HAL's along Route 4 within the study area.

2.1.3 VT Route 100

Function – Route 100 is a north-south route through the central portion of Vermont. It is classed as a rural minor arterial

Land Use - Land use is predominantly rural and recreational outside Ludlow.

Geometry - Route 100 has one travel lane in each direction.

Pavement Conditions - Pavement conditions are variable. Throughout the study area, Route 100 has a sufficiency rating of fair or fair to poor.

Safety Conditions - Potential safety problems may exist in Ludlow and in Plymouth.

2.2 Roadway Traffic Volume Characteristics

Due to the distinct travel peaks of a resort-oriented area, and the predominantly rural character of the surrounding land uses, regional ski-related traffic congestion tends to impact specific intersections, rather than longer corridor segments. Specific regional traffic congestion hotspots or areas with high levels of activity identified in the existing data sources include:

Killington Area

- Intersection of the Killington Road and US 4; and
- Intersection of US 4 and VT 100 (north).

Rutland Area

- Woodstock Avenue (US 4 East) and North Main Street (US 7 North);
- West Street and (Business US 4 West) South Main Street; and
- Allen Street and South Main.

Woodstock Area

In Woodstock, areas experiencing significant congestion are concentrated along US 4. Key problem areas include the intersections of US 4 with Route 12 north (Elm Street) and Route 106 (South Street). Traffic flow is also affected by constraints such as the bridge on the western edge of the historic village and the sharp curve east of the village.

Ludlow/Okemo Area

With a major ski resort – Okemo Mountain – located at the western edge its business district, Ludlow village is a major destination for shoppers, restaurant patrons, and those looking for hotel/motel accomodations along Route 103. Ludlow is also at the confluence of two major ski traffic patterns -- Okemo ski resort traffic intersects with Route 103 at Mountain Road and at the Okemo Ridge Road; and Killington resort traffic enters Route 103 at the intersection with Route 100 approximately two miles north of Ludlow village.

The major intersection serving the business district is Route 103 at Mountain Road. In this area, a turn lane is provided in the northbound direction on Route 103. Mountain Road has one travel lane in each direction with a left and a right turn lane at the end where it meets Route 103. The intersection has a stop sign for Mountain Road traffic, while a "free" movement (unsigned/unsignalized) exists on Route 103. Police control of traffic is used at this intersection during peak periods. Traffic congestion has a significant impact on village character and quality of life.

Identified problem areas include intersection of Route 103 with:

- Route 100 Junction (approx. two miles north of Ludlow);
- Buttermilk Falls Road;
- Mountain Road;
- Okemo Ridge Road;
- Depot Street (Main Street); and
- High Street (Main Street).

Chester Area

In Chester, significant congestion is focused at the intersection of Route 103 (Depot Street) and Route 11 (Main Street). The width and geometric configuration of the old bridge north of Chester village also constrains traffic flows. Other traffic-related concerns include:

- Sharp turn north of town; and
- Multiple non-aligning intersections.

As in Ludlow, traffic congestion has a significant impact on village character and quality of life.

3. REVIEW OF TRAFFIC IMPACT ASSESSMENT METHODS

3.1 Existing Approaches and Experience

3.1.1 Literature Review - WSA's background research utilizing the national Transportation Research Information Service (TRIS) database turned up the following articles and research reports which were incorporated into the development of our revised methodology:

- *Access to the Tarentaise Ski Resort Management of Peak Traffic*, Intelligent Transport Systems World Congress, Yokohama, Japan, 1995.

- *Resort Transportation Improvements: Case of Little Cottonwood Canyon, Utah,* Transportation Research Record, Issue 710, 1979.

- *Traffic Flow and Air Quality in a Mountain Community*, Transportation Research Record, 1986.

- *Recreational Traffic Management Strategies*, ITE Journal, September, 1982.

- *Quantifying Congestion*, National Cooperative Highway Research Program (NCHRP), Report Number 398, 1997.

- *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, National Cooperative Highway Research Program (NCHRP), Report Number 387, 1997.

Several different techniques for measuring and quantifying congestion are outlined in these reports, in particular, *Quantifying Congestion*, a 1997 publication sponsored by the National Cooperative Highway Research Program (NCHRP).

3.1.2 Advantages and Limitations of a Congestion-Based Approach - One of the key conclusions of *Quantifying Congestion* is that traditional Level of Service (LOS) measures are not acceptable for quantifying congestion. The reason for this is that LOS is primarily based upon traffic counts and speed/flow relationships. It does not take into account travel times and "crush" capacities. Additionally, the result of LOS analysis is typically an LOS of "F" for congested facilities. This threshold is reached very quickly in certain cases (for instance, unsignalized intersections).

The report concludes congestion measures used today have four components:

Duration – the amount of time congestion affects the travel system;
Extent – the number of people, vehicles, and / or geographic area affected by congestion;
Intensity – severity of congestion; and,
Reliability – how predictable is the congestion.

Certainly the first three of these are applicable to the ski corridor problem. The fourth is less applicable since ski peaks occur relatively infrequently (seasonally) and are largely affected by weather, holidays, snow, etc. Perhaps the most applicable measurement for the ski corridors is Total Delay. Once a corridor is selected, a standard amount of travel time to travel the distance of the corridor is established. This can be either based on non-congested conditions (such as weekday morning periods during a particular season) or can be based on an "acceptable" condition (such as an existing medium volume ski weekend.) When travel time is re-measured along the corridor during the peak analysis period, the resultant measure is the difference in travel time between acceptable and congested conditions. This difference is then multiplied by the total vehicles to get a total delay in minutes or hours.

In other words:

- *Congestion is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.*

- *Unacceptable congestion is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day.* [2]

Congestion measures can also be used to address multi-modal aspects of congestion and delay. (Highway Capacity Manual and LOS techniques are only applicable to the drivers of vehicles on the roadway.) This may not necessarily be a consideration for the "measurement" aspect of this project, but may come into play when assessing mitigation measures which involve transit. The congestion measures also address person movement measures rather than just vehicle movement measures. (Total delay for vehicles is multiplied by vehicle occupancy in many of the measures.) Again, this is important if high occupancy vehicles and carpooling are used in the mitigation strategies.

Another problem with traditional techniques involves the use of 30th highest hour for design purposes. This volume-based measure may not take into account the problems associated with congestion delay. For instance, the peak hour may occur on a good weather day with heavy ski traffic and no traffic accidents. However, the worst congestion conditions in terms of total delay (and driver frustration) may very well occur on a lower volume day where traffic accident related problems cause increased delay. It is very important to keep this in mind as the peak hour factors are examined.

3.1.3 Identifying Other Parameters for Traffic Impact Assessment - Carrying the perception of congestion concept further, the report notes that congestion can further vary by the "perceivers" of congestion, even if they are in similar vehicles on the same road. The local communities and

[2] *Quantifying Congestion*, National Cooperative Highway Research Program, Report Number 398, 1997, page 20.

their perception of congestion and its effect on their lives are also a consideration for the project. For instance, a local driver making a 10 minute trip would perceive a 5 minute delay as a 50% increase in trip time. However, a skier from Connecticut whose total trip is 3.5 hours would perceive a 5 minute delay as a 2.4% increase in trip time. In fact, the long distance traveler would probably not perceive the 5-minute delay at all.

3.1.4 Conclusion from Literature Survey and NCHRP Report 398 – Measuring congestion is a difficult process and is highly variable depending on data available, use of congestion measure, context of congestion, and causes of congestion. Additionally, communities may establish the thresholds of where congestion begins, but should realize that these may understate or overstate the congestion level which motorists perceive. This is very important in the Ski corridor case since the setting of congestion thresholds affects not only the measures, but also the mitigation requirements.

3.2 Development of Alternative Traffic Impact Assessment Methods

3.2.1 Criteria for Congestion Measurement

Given the literature survey and meetings with the Technical Committee, several goals for the congestion measurement methodology were established:

- Reasonable Data Collection Costs – Although data is currently collected by the ski areas, RPCs, and VAOT, the coverage and sufficiency of this data for any applied congestion measurement technique should be studied with the goal of keeping additional data collection costs low.

- Reasonable Cost of Analysis – The analysis of the congestion will need to be accomplished by each RPC or other governing body and therefore the technique needs to be executable for a reasonable cost.

- Reasonable Speed of Analysis – RPCs will frequently only have a few weeks to review expansion plans from the Ski Resorts before a public hearing. Therefore, the technique should be executable in a reasonable time frame.

- Reasonable Ease of Technique – The technique should take into account the level of expertise and experience available at the RPCs since the RPC staff will be executing the technique. As such, the analysis should be relatively easy to learn and execute.

- Comprehensibility of Quantity and Threshold – The quantities / thresholds used to measure the congestion need to be understood by a wide variety of professionals: town, county, and state personnel and politicians, ski resort owners, developers, and consultants, and public interest groups, plus the public at large.

- Applicability to Regions, Sub-Regions, Towns, and Corridors – Given the wide area of impact and concern at different levels of the stakeholders in this process, the measure should have the ability to be applied at more than just the regional level since residents of one town, for instance, will likely want to know the impact on their town, not just the region.

- Measurability after Construction – Since mitigation will be required as part of the congestion management system, it will be necessary to quantify the congestion measurement technique after construction and application of mitigation to determine if the mitigation has been effective, or if additional mitigation is necessary to reach local, regional, and state goals.

- Defensibility of Approach – Since there are a large number of partners, stakeholders, and interested parties, and since the congestion measures involve the interaction of public and private entities, it is necessary that the methodology be defensible by sound engineering and planning practices. This requirement will reduce friction which may be generated in the future between public and private organizations which otherwise could result in the nullifying of this approach.

3.2.2 Initial Methodologies Considered

In the first phase of the study, several different types of methodologies were suggested. The methods suggested include:

- Standard Intersection Level of Service (LOS) (Signalized / Unsignalized) – this technique is an industry standard which has been developed and refined over 25 years. Utilizing intersection turning movement volumes and traffic control device settings as well as other factors, a standard "grade" of service is established.

- Intersection Level of Service Extended – this technique extends the standard grades to greater distinguish between poor levels of service.

- Standard Arterial Level of Service – this technique uses peak roadway segment volumes and roadway geometry as well as other factors to establish a standard "grade" on the segment.

- Percentage Increase in Through Traffic – this technique would simply examine the change in through traffic at intersections or roadway segments due to development traffic.

- Turning Gap Probability – this technique would use the probability of finding a gap in oncoming traffic to make a turn (particularly at sign controlled intersections). This

concept also forms the basis for the standard intersection LOS analysis, although that technique is much more sophisticated.

- Average Network Speed – would examine the average speed on the overall regional network as the ratio of total vehicle miles of travel to total vehicle hours of travel.

Each technique was reviewed in terms of difficulty of analysis, type of threshold, defensibility, and relative pros and cons. The chart below gives a summary of this review:

Congestion Analysis Alternative Measures

Analysis Method	Description	Difficulty of Analysis	Type of Threshold	Defensi-bility	Pros	Cons
Intersection Level of Service	Standard traffic engineering analysis based on approach delay	Off-the-shelf software availability	A-F Designation	High	Existing Standard Technique with well developed software	Often gives LOS of F for all unsignalized intersections
Intersection Level of Service Extended	Extension of first technique	Off-the-shelf software in development	A-F,F1, F2, F3 Designation	High	Will distinguish between several different LOS F	May not be ready for several months
Arterial Level of Service	Standard traffic engineering analysis based on arterial capacity speed / flow curves	Off-the-shelf software availability	A-F Designation	High	Existing Standard Technique with well developed software	Does not look at intersections, Often gives LOS of F in congested conditions
Percentage Increase in Through Traffic	Measures change in main roadway traffic due to a project during peak periods	Simple calculations	Percentage change from existing	Low	Ease of Calculation	Difficulty in setting threshold, hard to defend, interpretation of threshold difficult
Turning Gap Probability	Measures probability of left and right turn gap based on peak period volumes	Simple calculations	Probability change from existing	Medium	Ease of Calculation, easier setting of thresholds	May not be sufficient to describe situation

Analysis Method	Description	Difficulty of Analysis	Type of Threshold	Defensi-bility	Pros	Cons
Average Speed for Network	Calculation of average travel speed over network covering area	More difficult calculations – will require development	Average Speed	Medium	Better defensibility, distinguishes between different congested conditions	Need to build local network and add data

These techniques were reviewed with the study's Steering committee during a meeting in June of 2000. Much of the concern which was raised at the meeting had to do with the measurability and comprehensibility of the thresholds to be applied. Also, it was suggested that more precise techniques, such as simulation models and queuing models, could be used to get more precise measures of the travel network.

3.2.3 Further Refinement of Congestion Measurements

Given the comments regarding a more refined and comprehensive approach, the Technical Committee then considered the possibility of using a more precise modeling technique, CORSIM. CORSIM is a micro-simulation model designed for analyzing traffic operations on roadway networks. It individually simulates the movements of vehicles on a traffic network. The Technical Committee considered the pros and cons of this technique and found the following:

Pros

- Many varied detailed outputs
- Precise modeling of intersection operations
- Precise modeling of queuing along roadway segments

Cons

- Large amount of roadway and intersection data needed
- Large amount of traffic count data needed
- Complexity of analysis, cost of analysis, speed of analysis
- Comprehensibility of technique and thresholds

Through further discussions with the Technical Committee members, the idea of using CORSIM was dropped primarily due to the costs and complexity of the analysis.

The Technical Committee continued conversations focusing on the goals outlined earlier, directing WSA to continue suggesting congestion analysis techniques. The next congestion measure considered was the total change in vehicle hours of travel. This measurement consists

of using standard Highway Capacity Manual (and Software) techniques to analyze intersection delay times and formulas from NCHRP reports to calculate travel speeds and times on roadway sections between intersections. This technique met most of the criteria for the project and was presented and discussed with the technical committee. It was decided that the technique was useful and promising at the "micro" segment or intersection level, but that the concept of change in total travel time over many different vehicles and routes failed the comprehensibility and measurability requirements. WSA was asked to further refine the measurement technique to produce point-to-point travel time changes for a single vehicle.

Examples of point-to-point travel times using the intersection and segment change in per vehicle travel times were compiled and presented to the Technical Committee (TC.) The TC agreed that the technique fulfilled the requirements of the study and requested that the technique be developed to a full-scale area-wide system for application. This then became the "congestion measurement methodology."

4. TECHNICAL OVERVIEW OF CONGESTION MEASUREMENT METHODOLOGY

This section of the report is designed to give a detailed overview of the methodology for congestion measurement and its application. Sections include:

- Network Overview;
- General Structure;
- Analysis Module;
- Detailed Intersection Analysis;
- Detailed Segment Analysis;
- Summarizing Origin-Destiantion Travel Times;
- Data Requirements;
- Methodology Calibration;
- Methodology Application; and,
- Limitations.

4.1 Network Overview

Figure 2 gives an overview of the roadway network to be used in the study. The network covers most of the major state routes and major roadways affected by ski travel in the study area. Intersections involved in the study are also shown. In general, segments end at interstate interchanges or other major junction points on the boundary of the study area.

Figures 3 to 7 show detail of intersections covered by the network in Rutland, Ludlow, Woodstock, Chester, and Springfield.

4.2 General Structure

The general structure of the congestion methodology is shown in Figure 8. Each box is reviewed below.

Existing Conditions / Data – the existing conditions and data on the current roadway network will be entered into the system. This data will consist of turning movement and other data throughout the study area. Data will be collected for appropriate "ski peak" hours. (See the section on Methodology Application for more details.)

Roadway Network / Traffic Control – Data for the roadway network was collected by WSA for the study. This data included length of travel segments, shoulders on travel segments, lanes on travel segments, speed limits, intersection layouts, and intersection control. This information appears as default information on the analysis spreadsheet and in the appendix to this report.

Calibration / Baseline Analysis – Using the Analysis Module (see below), the baseline conditions before the proposed development is implemented will be established. The module will use the turning movement counts and roadway network information to record the existing ski peak travel times and delays for all of the network segments and intersections. Further refinements in the measurements of total O-D travel time can be made through the use of additional automatic traffic volumes recorded on key segments and actual "speed and delay" data collected by a vehicle moving through the traffic stream. The module will summarize the travel times and delays on roadway segments and intersections to form complete O-D pair travel time estimates.

Proposed Development Plans – The development plans proposed by ski resorts and other developers will be subject to regular planning and development review. The proposals will continue to contain traffic impact studies detailing traffic generation and traffic distribution which may be used in the congestion impact methodology as noted below.

Developer Consultant Traffic Generation / Distribution – Typically the ski resort traffic consultants are able to estimate the traffic "generated" by the development during peak hours. This information is often reviewed by the RPCs and the state and will continue to be so reviewed. Additionally, the ski area consultants often estimate the distribution of generated traffic over various parts of the transportation network, resulting in increased turning movements at the network intersections. Again, this will continue to be the case, with review by the RPCs.

Addition of Traffic to Network – Using the traffic generation from the ski resort consultants, the increase in traffic for each turning movement at network intersections will be added to the spreadsheet system. Alternatively, the distribution of traffic may be carried by the RPC to test the sensitivity of the transportation network to traffic using different traffic distributions. The analysis module will assist in this process. (This is the reason for the dashed line connecting the developer consultant traffic generation / distribution box to the alternatives analysis module.)

Alternative Analysis – Using the same Analysis Module, the impact of the development traffic on individual street segments and intersections will be estimated. As noted above, the module will also summarize the travel times and delays on roadway segments and intersections to form complete O-D pair travel time estimates.

Comparison of Baseline and Alternatives – The final step in the methodology is to compare the baseline and alternative analysis O-D pair delay times and determine if any of these times have exceeded the thresholds for mitigation measures.

Impact Report – A report by the RPC will be issued to the developer, state, and district environmental commissions covering the RPC's analysis using the methodology and recommendations regarding mitigation.

4.3 Analysis Module

The Analysis Module is the analytical foundation for the methodology. The module is graphically illustrated in Figure 9. The module is primarily built in a MS Excel spreadsheet, but contains components outside of the program, namely the Highway Capacity Manual / Software Analysis.

The module will operate for a single peak hour of analysis. (For instance, Friday evening ski peak hour.) If multiple peak hours of analysis are needed, each will be run separately through the Analysis Methodology and Analysis Module steps. Details of each component of the module are given below:

Intersection Turning Movement Counts – Hourly count data will be entered for all intersections in the study area. (This may be existing counts, future "no-build" counts, or forecasted counts with development in place.) Data will be entered for a single peak hour on a 15 minute basis.

Travel Network / Segment Volumes – Given the turning movement counts, the module will compute average directional segment volumes for each segment of the network. For existing conditions / calibration purposes, these can be compared to automatic traffic recorder counts on corresponding segments.

Traffic Distribution (Optional) – Should the RPC decide to distribute the traffic differently than that which is provided by the ski resort consultant and perform sensitivity tests of different distribution patterns, this function will assist the RPC by allowing them to choose what percentage of expansion related traffic accesses the ski resort from each direction. Also, the path of access can be selected. Then, the spreadsheet will automatically distribute the traffic over the network

Highway Capacity Manual / Software Analysis – This portion of the module does not occur in a spreadsheet, but rather is an application of the traditional HCM / HCS methodology. The turning movement counts are entered into the HCS, intersection operation is chosen, and the outputs are then fed back into the module spreadsheet. Additional details are included in "Detailed Intersection Analysis".

Segment Speed & Travel Time Calculations – This portion of the module utilizes equations from NCHRP reports to estimate travel capacity and travel speed based on roadway characteristics and volumes from the Travel Network Segment Volumes section. Details of these calculations can be found in "Detailed Segment Analysis."

Entry of Turning Movement Delay Into Spreadsheet – based on the results of the HCS analysis, the average delay for each turning movement at all of the network intersections is entered back into one of the spreadsheet forms.

Assembly of Origin-Destination Travel Times – Using paths designated by the RPC, the origin-destination travel time will be summarized by adding together individual segment and intersection turning movement per vehicle delay.

4.4 Detailed Intersection Analysis

The intersection analysis for this methodology will be based on turning movements either collected in the field, forecasted from base counts, or estimated from traffic generation and distribution tasks. The intersection Analyses are based on standard Highway Capacity Manual procedures as realized through either the Highway Capacity Software (HCS) or the Synchro program.

Initially, HCS and Synchro layouts for each intersection will be provided. These layouts include number of lanes, street names, turning lanes, type of traffic control, etc. In the case of unsignalized intersections, the HCS methodology must be use. In the case of signalized intersections, the HCS or Synchro methodology can be used with similar results. (WSA recommends the use of the Synchro software package since it has more complete analysis and optimization tools which are easier to use.) In the case of any intersection (signalized or unsignalized) being controlled by a traffic officer, the analysis technique used will vary from intersection to intersection, but will be based on the signalized methodology of HCS.

The procedure for unsignalized intersections is as follows:

- Open "standard" format HCS file for the specific intersection to be studied
- Check all lane layouts and other variables for changes or errors
- Enter turning movement count data as appropriate
- Print executed analysis
- Enter "Control Delays" into module spreadsheet for each approach as appropriate

The procedure for signalized intersections is as follows:

- Open "standard" format Synchro or HCS file
- Check all lane layouts and other variables for changes or errors
- Enter turning movement count data as appropriate
- Optimized signal cycle and/or split if applicable
- Print executed analysis
- Enter "Percentile Delay" into module spreadsheet for each approach as appropriate

(Note: If Synchro software is to be used, the analysis methodology in Synchro must be set to "Webster Delay".)

The procedure for traffic officer intersections will be the same as the signalized procedure above, except the optimization of the signal cycle and split will be different. The traffic officer is

working in real time and does not know any of the key performance measures associated with signal optimization routines such as volume to capacity ratios and does not have a complete feel for minimum signal delay. To account for this, there are two different types of intersection operational "control" optimization that can be applied.

The first of these approaches, queue balancing, is applied at intersections where two heavy queues converge. An example of one of these intersections is the split between VT 103 and VT 100 north of Ludlow. During Sunday ski-peak hours, traffic volumes southbound into Ludlow are heavy on both routes. A traffic officer is posted at this location. The queue balancing technique assumes the officer will balance the average length of the queues, never letting one or the other get drastically longer during the control period. To simulate this situation, it is first necessary to optimize the signal cycle length in Synchro. Then, adjust the signal split such that the 50^{th} percentile queue length for these two heavy movements is approximately equal. If this cycle split is more than about 60% / 40% of cycle length, then the second method should be used. Once balanced, the report is printed and the percentile delays are entered into the module spreadsheet.

The second approach, minimum time balancing, should be used when there is only one dominant flow through an intersection. An example of this is the Depot St. and Route 103 intersection in Ludlow. Here, the dominant Sunday ski peak flow is eastbound through the intersection. However, there is also a smaller northbound flow which is actually from VT 100 south of Ludlow which is diverted onto Pleasant Street and Depot Street. Once the turning movements are entered, the intersection cycle length is optimized. Then, the minimum total intersection time delay is found by varying the intersection split. Once found, the minimum time number is divided by .9 (in order to account for human error) and the split is readjusted away from the lowest time delay split, towards the 50/50 split, until the adjusted overall intersection delay is reached. Then the percentile delays are fed back into the module spreadsheet.

4.5 Detailed Segment Analysis

Network segments are defined as the major segments between network intersections. These segments are highlighted in the maps of the networks. The segment by segment analysis is carried out by the MS Excel spreadsheet. It is not necessary for the analyst to conduct separate calculations unlike the intersection detailed analysis.

Each segment is analyzed for carrying capacity and speed, based on roadway characteristics and directional segment average volumes. The first step in the process is to determine the capacity of the segment. For the two-lane rural highway segments (which encompasses most of the segments), formula 8-9 of *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications, NCHRP 387* is used:

$$\text{Capacity} = 1{,}400 * N * F_w * F_{hv} * PHF * F_{dir} * F_{nopass}$$

Where:

1,400 = theoretical capacity of one-lane of roadway

N = number of lanes in one direction (in this case, always 1)

F_w = lane width and clearance factor, 0.8 if narrow lanes or shoulders are present (less than 12 foot lanes, less than 3 foot shoulders), 1.0 otherwise

F_{hv} = heavy vehicle adjustment factor = 1.0 / (1.0 + 7.5 * HV) for the average rolling to mountainous terrain, here HV = percentage of heavy trucks and recreational vehicles, assumed to be .03 (3.0%) for this study

PHF = peak-hour factor (total hourly volume divided by 4 * peak fifteen minute volume), calculated from 15 minute turning movement counts

F_{dir} = directional adjustment factor = 0.71 + 0.58 * (1 – peak direction proportion), where peak direction proportion is the percent of two-way traffic going in the peak direction.

F_{nopass} = no-passing zone factor = 0.94 – 0.1 * (NoPass) for average rolling to mountainous terrain, where NoPass is the percentage of the segment where passing is not allowed, assumed to be 0.7 for this study

A different formula is used for four-lane urban arterial segments, which for this study is US Route 7 from the Route 103 Junction to the US 4 junction in Rutland. The formula, 8-10 from NCHRP 387, is:

$$\text{Capacity} = 1{,}900 * N * F_w * F_{HV} * PHF * F_{park} * F_{bay} * F_{CBD} * g/C * F_c$$

Where:

1,900 = theoretical one-lane capacity

N = number of lanes in one direction at critical intersections (not including short turn lanes)

F_w = lane width factor = .93 if narrow lanes less than 12 feet, assumed to be 1.0 in the case of US 7 since the lanes are broad and relatively newly reconstructed

F_{HV} = heavy vehicle adjustment factor = 1.0 / (1.0+HV), where HV is the percentage of heavy vehicles, assumed to be .03 (3.0%) for this study

PHF = peak-hour factor (total hourly volume divided by 4 * peak fifteen minute volume), calculated from 15 minute turning movement counts

F_{park} = on-street parking factor, assumed to be 1.0 since no parking exists on the roadway

F_{bay} = exclusive left turn lane adjustment, assumed to be 1.1 since a left turn pocket or continuous lane is provided virtually everywhere on the studied section of US 7

F_{CBD} = Central Business District Factor, assumed to be 1.0 since CBD refers to major metropolitan CBDs.

g/C = ratio of effective green time per cycle, assumed to be 0.45 for this study

Once the effective capacity of the segment is determined, the Peak-Hour Speed is determined using formula S-4 of *Quantifying Congestion, NCHRP Report 398*:

Peak-Hour Speed (mph) =
60 / [(60 / free flow speed) * (1 + effective signal density)$^{0.3}$ * (1+ (v/c)^4) $^{0.7}$]

Where:

Free flow speed = average speed limit over the segment weighted by length of each speed segment

Effective signal density = signals per mile * (1 – through band capacity / cycle length),

- Assumed to be 1.0 on all segments except US Route 7 in Rutland
- On Route 7 in Rutland assumed to be: Signals per mile = 1.5 south of US 4, = 5.8 from US 4 to US 4 East
- On Route 4 from US 7 to Stratton Road, assumed to be = 3.0.
- through band capacity / cycle length assumed to be 0.45 for this study

v/c = One-Way Volume (from network analysis) / Capacity (from previous equations)

Once the peak hour speed is determined, the peak hour travel time for the segment is determined:

Travel Time (Min.) = Segment Length (miles) / Peak Hour Speed (mph) * 60 (min. / hour)

These formulas form the basis for segment analysis for the study.

4.6 Summarizing Origin – Destination Travel Times

The next step in the analysis module is summarizing the origin-destination (O-D) travel times. This summary consists of adding together the segment travel times and average turning movement intersection delays in a series of segments and intersections to achieve the total travel time from origin to destination.

It is possible with the module to summarize several different O-D pairs. The analyst will enter a series of alternating segments and intersection turning movements (using an index provided in the documentation), which the module will use to add up the total O-D travel time.

4.7 Data Requirements

The data needed to set up baseline and alternative analyses is more extensive than the data which is collected today.

Baseline data consists of turning movement volumes at all intersections in the network for each peak period to be analyzed. Turning movements should be collected and summarized for every fifteen minutes. Special note should be made for any unusual conditions such as accidents and extraordinary delays (such as a delivery truck blocking a lane, but not including congestion delays) as well as the type of control (unsignalized, traffic officer, signalized.) The turning movements need to be factored to the 30^{th} highest yearly volume hour using the nearest permanent VAOT count station. Additionally, it is recommended collecting base-line turning movement data for several similar peak periods. For example, three different Sunday ski-peak periods should be averaged together to get the baseline numbers.

It will also be helpful to collect data on total travel times and total volumes for the baseline data. Total travel times for the desired O-D pair measurements should be conducted during the ski peak periods for which turning movement counts are being made. At least three runs, and preferably six runs for each O-D pair should be collected to check the accuracy of the analysis module. Factors may be adjusted in the segment and intersection calculations to achieve calibration. (See Model Calibration below for more details.)

It is possible that the required baseline data could be collected over a series of seasons and updated regularly. Key intersections should be studied every year. This would include:

- Route 103 and Okemo Mountain Road, Ludlow
- Route 103 and Route 11, Chester
- Route 103 and Depot Road, Ludlow
- Route 4 and Killington Road, Killington
- Route 4 and Route 100 North, Killington
- Route 7 and Route 4 east/north, Rutland
- Route 7 and Business Route 4, Rutland

- Route 7 and Route 4 west/south, Rutland
- Route 106 South and Route 4, Woodstock
- Route 4 and Elm Street, Woodstock

It is recommended that all intersections be updated every three years. Due to the different growth in traffic over the years, for each baseline analysis, some intersection counts which have not been recently counted may need to be factored for background regional growth based either on key intersections counted every year or on VAOT permanent count stations.

Origin-Destination speed and delay runs should be updated every two to three years depending on the number of applications and location of applications each year.

4.8 Methodology Calibration

It will be necessary to calibrate the baseline analysis and analysis module before using the methodology. As noted in the Data Requirement section, it will be necessary to collect peak hour turning movement data at all intersections to calibrate the model. Additional origin-destination speed and delay data should be collected to further calibrate the methodology. Finally, additional data may be collected to further establish accuracy.

Intersections

Each intersection in the spreadsheet network will have to be counted for each period of analysis. For instance, if Friday evening, Saturday evening, and Sunday afternoon peaks are to be analyzed separately, it will be necessary to collect baseline data at each intersection during each of these time periods. In fact, this data should be collected for several different weekends during the peak ski season and averaged together to get a good base.

Also, to further understand the effect of traffic control officers on intersections, it may be useful to station a data collector at the intersections to write down the length of each phase of traffic movement the officer sets over the course of an hour, average these values, and use it to set the signal length and split during the Highway Capacity Software (Synchro) Analysis of the intersection.

During the course of the study, it was also suggested that intersection turning movement counts may not be an accurate picture of intersection travel demand when queues exist at the intersection. To test this theory, automatic traffic recorders or manual segment counts should be made on approaches to key intersections upstream of the beginning of "stopped" traffic. (However, if the traffic is just slowing down due to heavy volumes, it is not necessary to be upstream of these slow areas, only upstream of stop and go due to intersection operations.) Once completed, the upstream counts and intersection counts should be compared for large disparities in overall total traffic demand during the tested hours. Adjustments may include factors for

additional traffic demand not counted at the intersection for both baseline and development scenarios.

Segments

Segment calibration will be based on traffic counts and travel times. The traffic counts and upstream counts noted in the "intersections" calibration will also serve to calibrate the segment process.

Additional calibration for segments can be accomplished using "Travel Time Run" data. Travel Time Run (TTR) data is a common form of collecting travel time data on roadways. It is the recording of the travel time during congested periods between specific points in the roadway network. Additional breakdown of the data includes the time spent moving on a segment and the time spent stopped on a segment waiting for a traffic control device or officer. There are several techniques which can be used for gathering this information. Appendix XXX of this report, an excerpt from *Quantifying Congestion, NCHRP Report 398* gives several different methods of collecting this data. Perhaps the most simple method is "floating car". The floating car method involves operating a vehicle through congested traffic along pre-defined routes and recording moving and stop times and odometer readings. The distances are then divided by times to get average moving speeds on each segment, as well as stopped times due to intersection operations. This technique can use a simple stopwatch, vehicle odometer, and notepad. More sophisticated techniques are available including use of a micro-cassette recorder (especially when there is only one person in the car), Global Positioning System (GPS) readers, Distance Measuring Instruments (DMI), and Automatic Vehicle Identification (AVI) Systems. In the case of this study area, the stopwatch, vehicle odometer, and micro-cassette recorder will likely be the most cost effective method.

As noted in the NCHRP report, data of this type should be collected multiple times and averaged together on a segment by segment basis in order to form the "average" speeds and stop times. The "average moving travel speed" on each segment can then be compared to the results of the analysis module. If there is a desire to correct the calculations, factors can be added to each segment's speed and consequential travel time calculations to account for the differences.

4.9 Model Application to Proposed Improvements

Once the module has been calibrated and the baseline established, it becomes relatively easy to test proposed improvement scenarios using the methodology. First, the appropriate baseline needs to be projected to the analysis year, the year for which the proposal is to be tested. In other words, using standard regional growth rates, the turning movement data is projected to the analysis year. This information is then fed into the baseline of the analysis module and the intersection analysis and segment analysis are executed. (Keep in mind, full HCS analysis of the intersections is necessary at this new base traffic level.) The O-D information from the analysis module is then recorded and summarized.

Next, the additional development traffic is added to the new baseline data. This can be done in two different ways:

In the first method, the developer's consultant's traffic study will be used. The traffic generated by the development and its distribution throughout the local road network is given. This information can be directly added to the base-line data and the analysis module re-run for the baseline conditions plus the development traffic.

In the second method, the analysis module can help the analyst distribute the traffic from certain key sites across the roadway network. This allows the analyst to perform "sensitivity tests" of the traffic distribution. The analyst will choose the amount of traffic generated by the development, the split of traffic at the main exit road of the development, and the path this traffic will follow out of the study area. The analysis module will redistribute the traffic over the network using this information and provide segment travel time outputs, as well as intersection turning movements. It is then necessary for the analyst to use these turning movements and perform the HCS intersection analysis, and enter the intersection delay data back into the analysis module. The module will then summarize the O-D data.

Comparison of the projected baseline O-D travel times and the development level O-D travel times will then form the foundation for mitigation requirements.

4.10 Limitations

Limits of Segment Analysis

One of the key limitations of the analysis methodology is the segment analysis process. The base equations used for the congested speed estimation are based on volume to capacity ratios. Below approximately 15 miles per hour average segment speeds, the equations become less accurate. In this case, the traffic on the segment could be modeled better with a queuing service system analysis.

Limits of Intersection Analysis

The Highway Capacity Software and HCS Synchro analysis routines have been well developed over the last 25 years. However, once traffic exceeds certain levels, the estimates of travel delay can reach a maximum. It is very unlikely that this situation will occur in reality since the state would require expansion of these intersections and operational improvements long before this limitation is reached.

Limits of Data Collection

It is possible, as noted above, that turning movement counts may not accurately reflect demand at the intersections due to the queues before the intersections. It is suggested in the data collection notes above that traffic counts upstream of the stop and go sections of segments before intersections be counted manually and compared to the intersection operations.

5. TRAFFIC MITIGATION METHODS

5.1 Traffic Mitigation in the Study Area Context

The resort-oriented land use and transportation characteristics of the Ski Corridors study area create distinct challenges and opportunities for traffic mitigation and travel demand management. Typically, ski area traffic peaks most heavily on a limited number of Friday and Sunday evenings and holiday weekends. The remainder of the year, the study area communities enjoy a more relaxed, rural village lifestyle[3], but at these peak times, some residents' quality of life is reduced by significant traffic congestion and delay, as well as the associated noise and air pollution.

Traffic mitigation programs implemented in urban areas have incorporated a broad range of strategies, such as limitation on parking supply, carpool programs and ridematching, flex-time and compressed work week, and travel allowances and subsidies to encourage transit use. Many of these strategies would not be appropriate in a rural, resort area, however. The strategies most likely to be effective in the Ski Corridor study area fall within three categories:

- Roadway Mitigation Strategies;
- Intelligent Transportation Systems Strategies; and
- Travel Demand Management Strategies.

Of course, mitigation measures from each of these strategy categories should be implemented in a coordinated way with other strategies to increase the effectiveness of the combined approach.

5.2 Roadway Mitigation Strategies

At major intersections within the study area's rural, low-density setting, such as Route 103 in Ludlow and Chester, and Route 4 in the Killington/Killington area, motorists experience a change in travel character and expectancy, which can result in a higher rate of accidents and "near misses". Better coordination of land use and transportation policy through a Corridor Access Management Plan (CAMP) and/or a Traffic Calming Plan can be part of a potential solution to these problems. The typical CAMP encompass a set of strategies to improve traffic flow, to enhance safety, and to maintain traffic moving capacity on major roadways by coordinating access from side streets and private driveways. This can be accomplished by one or more of the following techniques:

Curb Cut Definition/Curb Reconstruction – Through driveway narrowing or consolidation (where feasible), the number of minor street intersections and driveways is reduced, which can enhance traffic safety. Also, backing-out maneuvers and unsafe mid-block turning movements are discouraged or eliminated with appropriate curb height in a business district.

[3] In some of the study area villages and roadways, particularly Woodstock, traffic often meets or exceeds the winter ski season peak hours during other times of the year, such as the fall foliage peak.

Channelization/Intersection Reconfiguration - Channelization of turning movements through left-turn pockets, right turn lanes and traffic islands also has the potential to improve roadway safety without a significant disruption of existing access patterns. This strategy can also incorporate pedestrian amenities such as crosswalks, sidewalk improvements and plantings, as an enhancement of the roadway area.

Roadway realignment – This strategy can involve more significant roadway reconstruction to convert offset intersections and driveways to four-way intersections. Control of roadway access from secondary roads – through the construction of service roads or internal circulation routes - can also be used as a traffic management technique, particularly in areas of new development.

Pedestrian and Bicycle Facilities – The inclusion of wider shoulders and sidewalks has the potential to enhance the roadway environment for bicyclists and pedestrians by providing a greater perception of safety and a more comfortable travel space for these modes. Obviously, the seasonal nature of pedestrian and bicycle activity limits the applicability of these strategies to respond to the peak congestion periods within the study area, but the improvements can still offer area residents an alternative for year-round travel with the village areas of Ludlow and Chester.

Zoning Controls - Zoning controls on setback, lot depth, and development of private roads or driveways can be used to guide future development toward a pattern that is safer and provides for enhanced traffic flow. This strategy can be enhanced in areas of new development or redevelopment by encouraging cross-property easements, shared driveways and clustered development.

5.3 Intelligent Transportation Systems (ITS) Strategies

ITS strategies utilize enhancements to the communications network to collect and process traffic information from traffic control officers, ski resort operators and managers, local public safety officials, and other participants. This information is then disseminated to the general public through a wide range of media, potentially including:

Highway Advisory Radio (HAR) – This is typically a low-power AM radio station which provides frequent updates for travelers regarding traffic and weather conditions, travel delays, and, in some cases, area attractions, upcoming events and special offers. In addition, a prepared message on the HAR can offer guidance regarding route alternatives and best times for arrival and departure.

Information Kiosks - Informational kiosks, with a video display offering travel directions, visitor information and travel advisories and directions are another useful way to provide visitors with information they need to avoid the most congested periods and adjust their travel in response to inclement weather or other delays.

Internet – The internet can be used to provide assistance with advance trip planning and to alert visitors to alternative transportation options, such as Amtrak and bus services.

Variable Message Signs (VMS) – Computerized electronic travel guidance and warning signs can also be used to give advance notice about delays, road conditions or alternate routes.

Video monitoring – Video monitoring at key intersections and chokepoints can be used to determine when alternate routes should be used.

Incident Response Planning – An incident response program consisting of designated tow-truck operators and response plans by individual public safety and resort staff members can be used in conjunction with other ITS strategy elements to reduce the delay time associated with vehicle breakdowns or traffic accidents.

5.4 Travel Demand Management (TDM) Strategies

Parking Control and Pricing - According to a 1991 report from the Institute of Transportation Engineers (ITE), "Parking is critical in traveler decision making. If parking is unrestricted, the traveler will generally opt to drive alone. On the other hand, if parking is restricted and there is competition for spaces, there is instant pressure to find and use alternatives."

Because the resort areas can control the parking and local access patterns of their visitors, parking pricing can be used to modify travel behavior. The drawback to this strategy is that a change in parking policy to implement a parking fee might have negative consequences for the relative competitiveness of study area ski resorts.

Travel Demand Time-Shifting – Incentives, such as coupons for lift tickets or discounts on dining, can be offered to reduce the levels of peak hour congestion during the times of heaviest visitation at the resorts. For example, a coupon or coupon book could be offered to visitors exiting after the peak period as an enticement to stay later in the evening or to stay over an additional night. This strategy also has the advantage of offering alternatives which enhance both the visitor experience (less time spent waiting in traffic) and the local economy, if coupons are offered for both on-site and off-premises activities.

Transit Bus Services – Several resort areas, including Killington, Okemo and Mount Snow, have utilized the local transit system to offer visitors and employees an alternative to travel by private car. These services have been extremely successful in gaining ridership over the last five years, and frequent proposal have been made at a number of systems for expansion as new funding permits. The transit strategy is highly desirable in that it alleviates congestion on the Mountain Road and also increases the access to the resort areas younger (16 and under), non-driving employees and local visitors.

Guaranteed Ride Home Program – As a supporting measure for employee-oriented transit and parking strategies, a Guaranteed Ride Home program could be initiated by resort-based employers to allow employees who use transit for their commute to be provided free transportation to their home in case of medical or other emergency problem.

Table 1
SUMMARY OF APPLICABILITY FOR TDM STRATEGIES

STRATEGY	LAND USE & DEVELOPMENT SETTING	TRANS-PORTATION CONDITIONS	APPLICABILITY STUDY AREA
Roadway Mitigation Strategies			
Curb Cut Definition/ Curb Reconstruction	Village locations. (Would not be applicable to non-village corridor segments)	Areas with relatively short distances between driveways and contiguous development.	Applicable in Ludlow, Chester and other village areas.
Channelization/ Intersection Reconfiguration	Intersections within village areas.	Areas with high turning movement volumes which cause congestion and safety problems.	Applicable in Ludlow, Chester and other village areas.
Roadway Realignment	Any type of development.	Does not require traffic congestion to be effective.	Applicable throughout study area.
Pedestrian and Bicycle Facilities	Any type of development.	Does not require traffic congestion to be effective, but interest may increase with higher levels of congestion.	Applicable throughout study area. Strong potential for community interest and support.

STRATEGY	LAND USE & DEVELOPMENT SETTING	TRANS-PORTATION CONDITIONS	APPLICABILITY STUDY AREA
Zoning Controls	Any type of development, especially areas with new development or redevelopment activity.	Does not require traffic congestion to be effective, but interest may increase with higher levels of congestion.	Applicable throughout study area, but joint effort between towns and property owners are needed for effective implementation.
Intelligent Transportation Systems Strategies			
Highway Advisory Radio	Any type of development	Does not require traffic congestion to be effective	Can reduce traffic delays and enhance visitor satisfaction.
Information Kiosks	Any type of development	Does not require traffic congestion to be effective	Can enhance visitor information and satisfaction.
Internet	Any type of development	Does not require traffic congestion to be effective	Can enhance visitor information and satisfaction.
Variable Message Signs	Any type of development	Does not require traffic congestion to be effective	Can reduce traffic delays and enhance visitor satisfaction.
Video Monitoring	Any type of development	Does not require traffic congestion to be effective	Can reduce traffic delays and enhance visitor satisfaction.
Incident Response Planning	Any type of development	Does not require traffic congestion to be effective	Can reduce traffic delays and enhance visitor satisfaction.
Travel Demand Management Strategies			
Parking Control and Pricing	Most applicable on resort property and facilities.	May require traffic and parking congestion to be effective.	Can reduce traffic delays, but may reduce visitor satisfaction and resort competitiveness.

STRATEGY	LAND USE & DEVELOPMENT SETTING	TRANS-PORTATION CONDITIONS	APPLICABILITY STUDY AREA
Travel Demand Time-Shifting	Any type of development	Does not require traffic congestion to be effective.	Can reduce traffic delays and enhance visitor satisfaction.
Transit Bus Service	Most applicable in village settings, but can be used to connect resort and intermodal centers.	Does not require traffic congestion to be effective.	Can reduce traffic delays and enhance visitor satisfaction. Can also increase access for employees and visitors.

Source: Wilbur Smith Associates

5.5 Threshold Setting for Mitigation

Once the baseline data is collected and the Analysis Module is calibrated, the issue of setting thresholds for mitigation will likely arise. At time of writing, there was no agreement on a process for setting these thresholds. However, study subconsultant Dr. Kathleen Harder of the University of Minnesota suggested in her review of problems giving rise to the study that an unbiased survey used to poll residents, day skiers, and weekend skiers could provide some answers to these questions. Such a survey should be constructed to get to the core of the issue and ask well constructed questions. The results should be able to pinpoint what exactly the different perception groups dislike about traffic and traffic congestion, as well as provide a basis for mitigation threshold setting.

6. CONCLUSIONS

Although not this report does not identify "threshold" levels of traffic that can be used as benchmarks for the review and evaluation of ski resort-related development proposals, it does describe an innovative tool for quantifying traffic congestion in regionally-significant highway corridors. It also describes several appropriate traffic mitigation techniques that could be implemented when a development project increases traffic above a threshold levels.

With the creation of a spreadsheet-based model, a foundation has been established for the refinement of local and regional traffic impact assessment methodologies.