CITY OF ESSEX JUNCTION
BIKE WALK ADVISORY COMMITTEE
REGULAR MEETING AGENDA

Online & 2 Lincoln St.
Essex Junction, VT 0545
Monday, May 20th 2024,
7:00 PM

E-mail: cyuen@essexjunction.org *www.essexjunction.org* *Phone: 802-878-6944, ext. 1607*

This meeting will be held in-person at 2 Lincoln Street and available remotely. Options to join the meeting remotely:

- **JOIN ONLINE**: Join Zoom Meeting
- **JOIN CALLING:** *(toll free audio only)*: (888) 788-0099 | Meeting ID: 953 1240 7791; Passcode: 040339

1. **CALL TO ORDER** [7:00 PM]
2. **DETERMINE WHO WILL TAKE MINUTES**
3. **AGENDA ADDITIONS/CHANGES**
4. **MINUTES**
   a. April 25th, 2024
5. **PUBLIC TO BE HEARD**
   a. Comments from Public on Items Not on Agenda
6. **BUSINESS ITEMS**
   a. Staffing changes
   b. UVM Capstone Project Presentation North / Grove Street and Ivy Lane Concepts*
   c. Bike Repair Station purchases and Bike Rack purchases
   d. Collaboration with Brownell Library for summer programming
   e. Essex Pride Festival
   f. VT Walk/Bike Summit
   g. Bike Rack Inventory
   h. Walk to Shop program update
   i. Rescheduling June 17 Meeting to June 10
7. **MEMBERS UPDATES**
8. **STAFF UPDATES**
9. **READING FILE**
   a. VTrans Speed Countermeasure Toolbox*
10. **ADJOURN**

*attachments included in the packet

This agenda is available in alternative formats upon request. Meetings of the Planning Commission, like all programs and activities of the City of Essex Junction, are accessible to people with disabilities. For information on accessibility or this agenda, call the City Manager's office at 802-878-6944 TTY: 7-1-1 or (800) 253-0191.

City of Essex Junction
Bike/Walk Advisory Committee
Meeting Minutes
Thursday, April 25th, 2024

1. Members Present: Chris Yuen, Staff Representative; Micah Hagan, Chair; Michael Giguere; John O'Brien; Tacy Lincoln; Philip Bieber; Russ Miller-Johnson; Christopher Kline
2. Call to Order by Micah at 7:05 pm
3. Determine who will take minutes - Michael
4. Agenda additions/changes
    a. Essex Pride Festival - added by Micah
    b. VT Walk/Bike Summit - added by Michael
5. Minutes
    a. Feb 21, 2024
    b. Mar 18, 2024
    c. Motion by Micah to approve both minutes, seconded by Philip. Voting: unanimous (7-0); motion carries
6. Public to be heard
    a. No members of the public were present at this meeting and no public comments were submitted for review
7. Business items
    a. Chris Y. brought forward a public request for better minutes to be taken. Examples were provided for future reference
    b. Collaboration with Brownell Library for summer programming - Micah
        i. The library requested the purchase of a bike repair station, Local motion provided some examples from Dero to consider
        ii. Youth bicycle educational session
            1. In an effort to help Brownell Library achieve a specific bike-friendly certification, they requested that BWAC assist with an educational session for youth programming
            2. Mon, July 1st was the proposed date from the library
            3. committee considering reaching out to Local Motion for additional curriculum
            4. More details and other potential dates will be coordinated with Erna from Brownell by a smaller group of committee members interested in assisting with this event (John, Michael, Phil)
    c. Consider bike repair station purchase - Micah
        i. Compared different options (Dero, Greenspoke) with regards to price, length of warranty, and shipping lead time
        ii. Determining ownership of the long-term maintenance and upkeep of the station was discussed, ensuring that the library would have the resources they need to continue proper use if BWAC purchased the repair station for them

- iii. A public bike repair station is already very close to the library at Nest Coffee & Bakery
- iv. The library loans out some bike-related materials, which could be a more budget-friendly option and serve as educational resources for the previously discussed library collaboration event
- v. Discussion about how this would fit into the remaining FY budget was held, as well as the need to have items physically arrive before July
- vi. Motion by Micah to vote on the purchase of a repair station, seconded by Michael. Voting: unanimous (7-0); motion carries

d. Consider Bike Rack purchase - Micah

- i. The Committee discussed the potential purchase of inverted-u bike racks for future use by the City or through partnerships with local businesses. Zoning does not require existing businesses to provide bike racks if they do not go through a site plan amendment. Site plan amendments are only required for major renovations or a change of use. The City could partner with businesses in high-traffic locations which are not otherwise required to install bike parking, to provide them with bike racks free-of-charge through a cost-share program to be installed at agreed-upon locations on their properties.
- ii. Public works is willing to store a few of these at the public works facility.
- iii. Currently uncertain how partnering with businesses for a financial kickback would work. Asking businesses to cover installation costs could be sufficient.
- iv. Motion by Phil to vote on the purchase of ten bike racks, seconded by John. Voting: unanimous (7-0); motion carries

e. Walk to shop program update - Tacy

- i. Walk to Shop is an organization that provides mobile trolleys for shopping and also provide educational and advocacy resources
- ii. $50 per trolley, made in Vermont
- iii. Opportunity to get businesses to encourage more walking and commerce in the community as a long-term development project
- iv. Could purchase a small number as a promotional or raffle item for community events
- v. Could partner with the library for storage and promotion
- vi. Unclear how the trolley purchasing and distribution process works
- vii. Tacy to reach out to Walk to Shop to inquire about purchasing details

f. UVM Student Projects - Russ

- i. Russ to attend project presentations on Friday 4/26 at the Davis Center from 5pm - 7pm
- ii. Students have an interest in presenting their projects to BWAC, details and date to be determined

g. Pride Festival - Micah

- i. June 1st at Maple Street Park

        ii. Great opportunity for outreach and opportunity to partner with Walk to Shop and/or Local Motion
        iii. Need to develop goals for what BWAC would like to achieve from this event
        iv. Essex Junction Democrats looking to install a rainbow crosswalk downtown for the event
            1. John to gather more information and report back to BWAC
    h. Vermont Walk/Bike Summit - Michael
        i. Thursday, June 20 in St. Johnsbury
        ii. Registration reimbursement would be available if committee members were interested in attending
    i. Street mural installations - Philip
        i. Can be used as a community gathering point and help with traffic calming
        ii. This could be a topic to consider budgeting for in the future
        iii. Could help pilot programs to find options more durable than paint
        iv. Could partner with local schools for designs
    j. Reschedule Mon, June 17 meeting
        i. Tentatively rescheduled for Mon, June 10 pending city staff availability
8. Reading file
    a. None this month
9. Adjourn
    a. Micah adjourned at 8:48 pm

Essex Junction Pedestrian/Cyclist Safety and Connectivity Design

Anthony Adoniou, Lukas De Schepper, Robert Frederick, Chris Ramos
UVM CEE 4950 Capstone Design
Prepared For: Essex Junction BWAC

May 3rd, 2024

Date: 5/3/2024

Essex Junction BWAC
2 Lincoln Street
Essex Junction, VT

RE: UVM Capstone Design Project: North Street/Grove Street Intersection and Ivy Lane Pedestrian and Bicycling Infrastructure

Dear BWAC Committee Members,

We are pleased to provide this report of design alternatives for improving pedestrian and bicycling infrastructure in Essex Junction. The report details considerations for improving safety in the North Street/Grove Street intersection and enhancing connectivity through Ivy Lane. We conducted an evaluation comparing design alternatives and our recommendations are included in the report.

We sincerely appreciate your engagement with our student team of emergent engineers. We look forward to following the continued progress of community connectivity in your city.

UVM Capstone Design Team (Spring Semester 2024):

Anthony Adoniou

Lukas De Schepper

Robert Frederick

Chris Ramos

Table of Contents

Executive Summary

The Essex Junction Bike Walk Advocacy Committee (BWAC) requested the services of the UVM Capstone Design Project Team to assess pedestrian and bicycling safety and connectivity in the city of Essex Junction, VT. BWAC identified the crosswalk at the intersection of Grove Street/North Street as an area that garnered safety concern from the public with close calls of vehicle/pedestrian crashes. The Capstone Team identified Ivy Lane as a street that could be redesigned to improve non-vehicle travel connectivity. This report focuses on the needs of pedestrians and bicyclists and assesses alternatives to improve their traveling experience in both these locations.

Four alternatives, which included a do-nothing scenario were considered for the study area. Alternatives for the Grove Street/North Street intersection included a pedestrian refuge island, rectangular rapid flashing beacons (RRFBs) with the existing crosswalk, or a new, shorter raised crosswalk. Alternatives for Ivy Lane included repaving with decorative asphalt, reconfiguring the existing parking, or adding a bicycle lane. Our designs, which focused on biking and walking, were constrained by the existing motor vehicle and train infrastructure that require discrete space and traffic impact considerations.

Our assessment of the alternatives determined a pedestrian refuge island to be the recommended design for the North Street/Grove Street intersection and decorative pavement with parallel parking as the recommended design for Ivy Lane. We determined that these changes would offer improved protection and visibility for pedestrians and bicyclists while simultaneously calming vehicle traffic. The combination of the two designs will improve the overall connectivity through the study area.

Limitations

This design report represents work performed within a limited time and with limited resources, by students. This work was supported and overseen by our faculty and advisors, as applicable. This support and oversight were for guiding our student work in an academic setting, where emphasis is on learning about the process of engineering practice and is different than for work produced to a client by a professional engineering organization. Therefore, you are advised that before fully relying on any elements of this report and design, the recommendations and designs need to be independently reviewed by a qualified Licensed Professional Engineer.

Needs Evaluation

INTRODUCTION

Pedestrian and bicycling safety was presented as a primary focus for our assessment of the study area. To achieve this, walkers and bikers need their own space to travel and when traversing vehicle intersections; they need to be visible and have adequate time to cross. Bicycling connectivity was a second issue addressed in our study. To achieve this, bicyclists need their own routes that are clearly defined, with smooth road surfaces and enough room to maneuver. The study area was assessed with these considerations in mind (Figure 1).

Figure 1: Study Area

BACKGROUND

The Grove Street/North Street intersection is a four-way intersection with stop signs for three directions. Vehicle traffic traveling eastbound on North Street have no stop sign, crossing train tracks and entering the intersection. There is a 69-foot-long crosswalk that crosses the intersection diagonally. The crosswalk connects an existing paved recreation path to the north section Grove Street which leads to Essex High School (Figures 2 & 3).

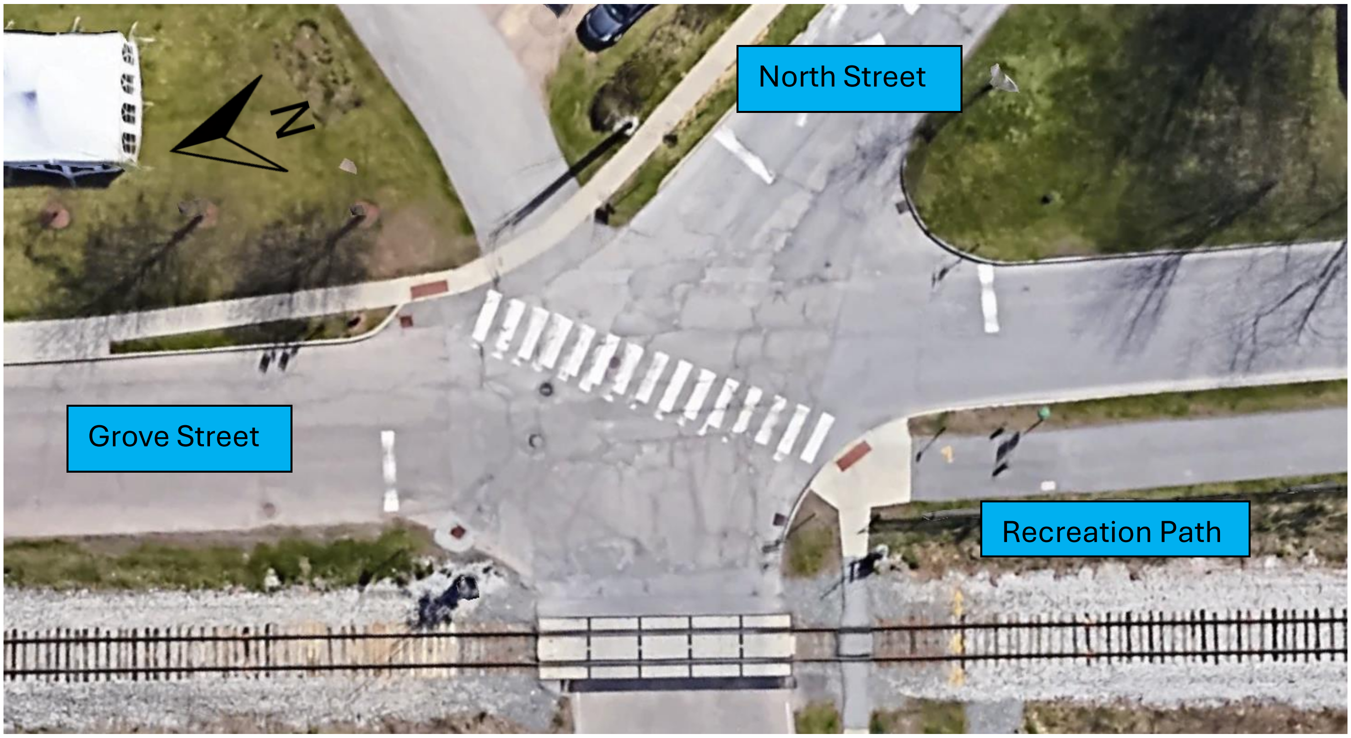


Figure 2: Satellite imagery of North Street/Grove Street current conditions

Figure 3: North Street/Grove Street current conditions (photographed 4/14/2024)

The recreation path is less than one-quarter mile long and connects the Grove Street/North Street intersection to Ivy Lane. It was built over an improvised foot path reportedly used mainly by high school students. The Capstone Team assessed the path to be in good condition and it is not evaluated for alternatives in this report.

Ivy Lane is a 500-foot-long street that runs along the train tracks directly across from the Amtrak station. It currently has one-way vehicle traffic traveling north from Main Street to Central Street and 25 diagonal vehicle parking spaces. A scoping study for the redesign of the Amtrack station and related traffic identified a preferred alternative that reverses the vehicle traffic direction on Ivy Lane (RSG, 2016). There are no existing pedestrian or bicycling amenities on Ivy Lane and none identified in the design from the study (Figures 4 & 5).

Figure 4: Satellite imagery of Ivy Lane current conditions

Figure 5: Ivy Lane current conditions (photographed 4/14/2024)

This report of alternatives considers the designs and recommendations outlined in documents pertaining to development in Essex Junction, including:

- Bicycle and Pedestrian Plan – Town of Essex, Village of Essex Junction (2014)
- Essex Junction Train Station Access and Circulation Study (2016)
- Design 5 Corners: Implementation Plan (2019)

PURPOSE AND STAKEHOLDER NEEDS

The purpose of this report is to present infrastructure design alternatives that improve the safety for pedestrians and bicyclists that travel through the Grove Street/North Street intersection and Ivy Lane. The design alternatives also consider pedestrian and bicycling mobility and aim to improve overall connectivity for non-vehicle travelers between Main Street and Grove Street.

A general list of community stakeholders was outlined to identify their needs within the study's scope. These needs were used to guide the development and evaluation of each alternative (Table 1).

Table 1: Stakeholder Needs

Stakeholder		Needs
Pedestrians	• Residents • High school students • Non-local pedestrians	Pedestrians need safe accommodations for crossing intersections. This can be achieved by giving them dedicated space, time, and visibility. Pedestrians need designed routes to access various amenities around the city.
Bicyclists	• Residents • Commuters • Recreational	Bicyclists need clearly defined routes to travel through the city. These routes need to provide enough lane width and smooth road surfaces for safe maneuvering.
Motorists	• Local through traffic • School related traffic • Public parking	Motorists need to travel through the city with minimal added travel delay. They need roadway signs to understand and anticipate interactions with pedestrian and bicycling infrastructure.
Essex Junction Residents	• Near study area • High School families • Commuters	Residents need infrastructure that offers choices in how they travel through their city. They need minimal added travel delay in commuting. Residents need consideration for changes in air, noise, and light pollution.
Essex Junction Businesses	• Railroad Avenue • Main Street • 5 – Corners	Local businesses need to maintain and grow their customer base. They need their patrons to be able to access their locations by multiple modes of travel, which may include parking access for vehicles.
Amtrak	• Train tracks • Vehicle Parking • Traffic Circulation	The Amtrak operation needs safe intersections with the track infrastructure. The station needs enough vehicle parking for patrons and minimal added traffic disruption on the adjacent streets.
Green Mountain Transit (GMT)	• Bus access • Pedestrian access • Scheduling	GMT operation needs space for buses to access the station located on Railroad Avenue. The bus service needs safe pedestrian amenities for its users and minimal disruption to route scheduling.

Alternatives Evaluation

Four alternatives were considered for the North Street/Grove Street intersection and for Ivy Lane, which includes a do-nothing scenario as Alternative 1. Each subsequent alternative provides a design change to both areas. Alternative 2 was considered the most extensive overall change to existing conditions, and Alternative 4 was considered the least.

Alternative 1

North Street/Grove Street Intersection
This alternative maintains the 69-foot-long painted crosswalk with diagonal alignment across the intersection.

Ivy Lane
This alternative maintains one-way vehicle traffic flow from Main Street to Central Street, 25 diagonal vehicle parking spots, and no pedestrian/bicycling infrastructure.

Alternative 2

North Street/Grove Street Intersection
This alternative maintains the current 69-foot-long crosswalk alignment and adds a pedestrian refuge island in the middle of the intersection. The feature would provide physical protection for pedestrians from vehicle traffic. The island would also serve as a traffic circle, converting the intersection into a miniature roundabout. This is designed to be a traffic calming measure to further improve safety for pedestrians. The design maintains existing curb and sidewalk infrastructure (Appendix A – Figure 9).

Ivy Lane
This alternative transforms the street into a space exclusively for pedestrians and bicyclists. The roadway surface would be repaved with decorative asphalt and all vehicle parking spaces would be removed. At both ends of the street, removable bollards would be installed to restrict vehicle access. At the north end of Ivy Lane, a crosswalk would be painted across Central Street to connect to the existing recreation path (Appendix A – Figures 10, 11, 12, 17).

Alternative 3

North Street/Grove Street Intersection
This alternative realigns the intersection crosswalk to shorten its length from 69 feet to 55 feet. The crosswalk would be raised to enhance the visibility of the feature and serve as a traffic calming measure. The existing sidewalk and curb by the recreation path is maintained and the curb on the north end of the crosswalk would be adjusted for a connection with the new raised feature (Appendix A – Figure 13).

Ivy Lane
This alternative transforms the street into a multi-modal space for vehicles, pedestrians, and bicyclists. The roadway surface would be repaved with a decorative asphalt and one way vehicle traffic would be reversed in

direction, flowing from Central Street to Main Street. Vehicle parking would be changed from 25 diagonal spaces to 10 left-side parallel parking spaces (22-feet long by 9.5-feet wide). For pedestrian and bicyclist considerations, signs will indicate a shared road space for vehicle parking and all other users. At the north end of Ivy Lane, a crosswalk would be painted across Central Street to connect to the existing recreation path (Appendix A – Figures 14, 15, 17).

Alternative 4

North Street/Grove Street Intersection
This alternative maintains the current 69-foot-long crosswalk alignment and adds rectangular rapid flashing beacons (RRFBs) at both ends. These warning lights are user-activated and indicate to vehicle traffic that pedestrians are at the crosswalk. The RRFBs would be positioned to face perpendicular to the crosswalk alignment to provide optimal viewing angle for vehicles entering the intersection eastbound from North Street where travel across the train tracks does not have a stop sign. The design maintains existing curb and sidewalk infrastructure (Appendix A – Figure 16).

Ivy Lane
This alternative will add a 6-foot-wide painted bicycle lane to the street. The painted lane will direct bicyclists in the same direction as 1-way vehicle flow, southbound from Central Street to Main Street. The right-side lane would have a dashed white edge line to delineate a space where bicyclists have the right of way but would allow vehicles to encroach when necessary for maneuvering and when cyclists are not present. At the north end of Ivy Lane, a crosswalk would be painted across Central Street to connect to the existing recreation path (Appendix A – Figures 17, 18).

Alternative Selection

Each alternative was evaluated using a weighted decision matrix. The applied weights to each criterion were decided using team judgement and informed by the design review feedback from BWAC. Their main concerns included the safety of pedestrians and the cost of the proposed designs. Criteria corresponding to these concerns are weighted highly (4 or 5). Safety was divided into more specific evaluation criteria such as added space for pedestrians and improved visibility of pedestrians to vehicle traffic. Network connectivity is another issue that was the focus of this project and was given high weights for both locations (4 or 5).

Evaluation Criteria

Below are the different criteria, their corresponding weights, and the score scale used to evaluate the design alternatives. Each alternative is considered under the following weighted criteria on a 1-5 scale, where 1 is least important, and 5 is most important. These assigned values can also be seen in the "Weights" column in Table 3 through Table 6.

- **Cost** (*Weight: 5*): Are the construction, operations, and maintenance costs low?
- **Construction Disruption** (*Weight: 2*): Are the impacts to intersection and roadway use during construction low?
- **Space Added for Pedestrians** (*Weight: 4*): Is enough physical space added to existing infrastructure for pedestrian use?
- **Space Added for Cyclists** (*Weight: 4*): Is enough physical space added to existing infrastructure for bicycling use?
- **Parking Relocation** (*Weight: 3*): Are the displaced vehicle parking spots limited?
- **Network Connectivity** (*Weight: 5, 4*): Is there substantial continuous lengths of pedestrian and bicycle space being added?
- **Crossing Time** (*Weight: 3*): Are pedestrians and cyclists exposed to traffic on the roadway for limited amounts of time?
- **Pedestrian/Cyclist Visibility** (*Weight: 5, 4*): Are pedestrians and bicyclists more visible to motorists?

Scores were decided for each criterion across the different project alternatives. These scores follow the scale below:

Table 2: Decision Matrix Scoring Scale

Value Ratings				
1	2	3	4	5
Least preferred	Less preferred	Neutral	More preferred	Most preferred

Table 3: Decision Matrix – North Street/Grove Street Intersection

Criteria	Sub-Criteria	Weight	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Cost		5	5	1	2	3
Construction disruption		2	5	1	1	4
Network Connectivity		4	1	5	2	3
Safety	Space Added for Pedestrians	4	1	5	5	1
	Space Added for Cyclists	4	1	1	1	1
	Crossing Time	3	1	5	4	1
	Pedestrian Visibility	5	1	5	3	5
	Cyclist Visibility	4	1	5	4	2
	Totals	155	59	**111**	87	79
	Percent of Theoretical Max[1]	100%	*38.06%*	*71.61%*	*56.13%*	*50.97%*

Table 4: Decision Matrix – Ivy Lane

Criteria	Sub-Criteria	Weight	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Cost		5	5	1	2	3
Construction Disruption		2	5	1	1	2
Parking Relocation		3	5	1	2	5
Network Connectivity		5	1	5	5	3
Safety	Space Added for Pedestrians	4	1	5	5	1
	Space Added for Cyclists	4	1	3	4	3
	Pedestrian Visibility	4	1	5	5	1
	Cyclist Visibility	4	1	3	4	4
	Totals	155	71	99	**115**	85
	Percent of Theoretical Max[1]	100%	45.81%	63.87%	74.19%	54.84%

The scores from the decision matrixes were used to determine our recommended alternatives.
-North/Grove Street intersection, **Alternative 2** scored highest
-Ivy Lane, **Alternative 3** scored highest
Further analysis of these two alternatives can be found in the Recommended Alternatives section of this report.

Sensitivity Analysis

A sensitivity analysis was conducted to grade the alternatives from the perspective of motorists. Drivers will be interacting with these infrastructure changes more than pedestrians and cyclists. Should this project be presented to the Essex Junction city council, the team recognizes members may value the perspective of drivers and would like to satisfy their concerns with the changes for this project. The team presumed drivers will value minimal impacts to their normal commutes and travel, and not consider how the design changes impact cyclists and pedestrians as highly. A decision matrix for this scenario was created with several criteria weights reduced including space added, network connectivity, and visibility. The construction disruption and parking relocation weights were increased.

Table 5: Decision Matrix for Sensitivity Analysis – Driver Perspective

North Street/Grove Street intersection

Criteria	Sub-Criteria	Weight	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Cost		4	5	1	2	3
Construction disruption		5	5	1	1	4
Network Connectivity		1	1	5	5	1
Safety	Space Added for Pedestrians	1	1	1	1	1
	Space Added for Cyclists	1	1	5	4	1
	Exposure Time	3	1	5	2	3
	Pedestrian Visibility	2	1	5	3	5
	Cyclist Visibility	2	1	5	4	2
	Totals	95	55	55	43	**58**
	Percent of Theoretical Max	100%	*57.89%*	*57.89%*	*45.26%*	*61.05%*

Table 6: Decision Matrix for Sensitivity Analysis – Driver Perspective
Ivy Lane

Criteria	Sub-Criteria	Weight	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Cost		4	5	1	2	3
Construction Disruption		5	5	1	1	2
Parking Relocation		5	1	5	5	1
Network Connectivity		1	1	3	4	3
Safety	Space Added for Pedestrians	1	5	1	2	5
	Space Added for Cyclists	1	1	5	5	3
	Pedestrian Visibility	2	1	5	5	1
	Cyclist Visibility	2	1	3	4	4
	Totals	105	61	59	**67**	48
	Percent of Theoretical Max	*100%*	*58.10%*	*56.19%*	*63.81%*	*45.71%*

At the North Street/Grove Street intersection (Table 5), the sensitivity analysis favors Alternative 4, adding RRFBs, since it is presumed to cause the least construction disruption. Our recommendation of Alternative 2, scored roughly 2% lower than Alternative 4 in this scenario. At Ivy Lane (Table 6), our recommendation of Alternative 3 scores highest based on minimal changes to vehicle infrastructure. Our sensitivity analysis suggests that for that our recommendations of Alternative 2 for North Street/Grove Street intersection and Alternative 3 for Ivy Lane, are generally not in conflict with the interests of motorists in study area.

<u>Evaluation Limitations</u>

In collaboration with the community partners at BWAC, differing views on certain criteria were brought forward. BWAC members questioned the utility of measuring space added for pedestrian and cyclist safety. Our team decided it warranted inclusion in our decision-making process, as we view the addition of dedicated space to be a directly measurable improvement for pedestrian and bicyclist use.

At the request of our community partners, we researched and considered crash modification factors (CMFs) to grade the improved safety of the design alternatives. The CMF statistics indicate measured reduction in crashes due to specific infrastructure improvements (CMF Clearinghouse, 2024). We found CMF values that indicate crash reductions, but we could not confirm the detail in similarity of infrastructure in the statistical study to our designs. In general, the statistics were gathered from urban areas. We used the data to inform our judgement of safety but did not directly implement CMF scores into the matrices.

RECOMMENDED ALTERNATIVE

North Street/Grove Street Intersection – Alternative 2: Pedestrian Refuge Island

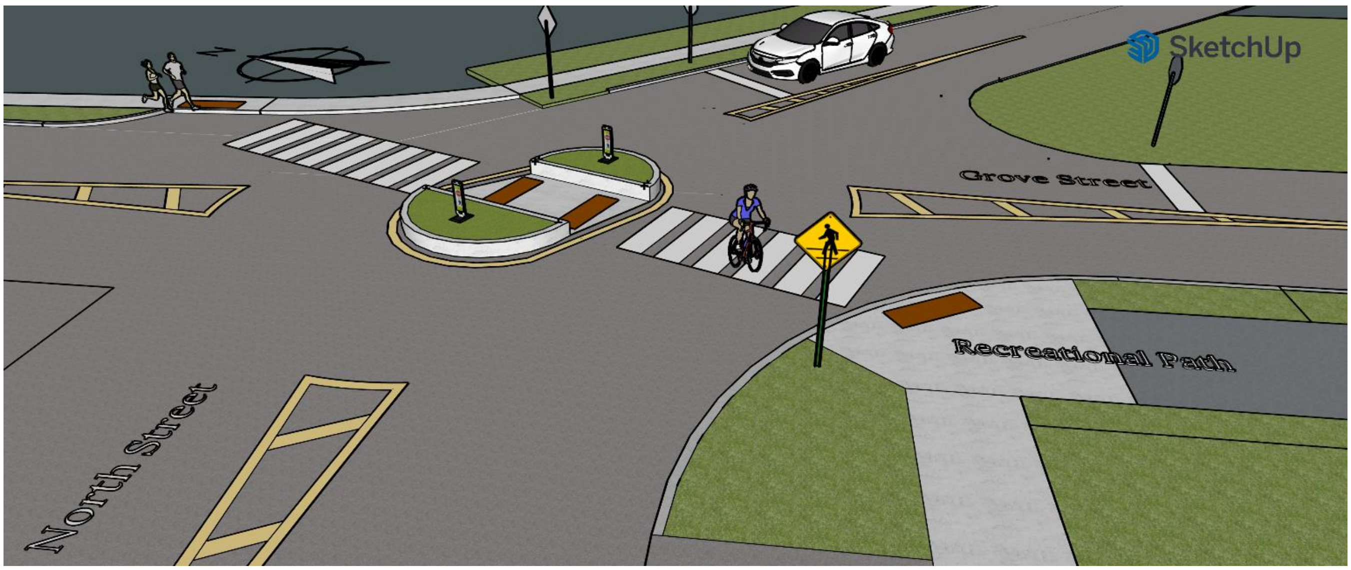


Figure 7: North Street/Grove Street Intersection with Pedestrian Refuge Island

This alternative received the highest score in the decision matrix (Table 3). The design best reduces the continuous time pedestrians and bicyclists spend in the roadway. The direct alignment of the crosswalk is maintained, following the natural crossing pattern pedestrians would take to continue north on Grove Street. Pedestrian islands are effective visual indicators for drivers that a crossing point is ahead.

The centralized location of this pedestrian island will also act as a low-speed neighborhood traffic circle. Currently there is minimal queuing across the tracks at this intersection. Queuing was observed on Grove Street heading south during the school dismissal rush hour period. This design is not intended to reduce the flow of traffic enough to cause queuing across the train tracks. There are no other regulations involving train tracks close to an intersection that we found.

An example of a low-speed neighborhood traffic circle is found in the nearby city of Burlington, VT, at the four-way intersection of Blodgett Street and Strong Street. Similarities include roadway dimensions, speed limit, and residential location type. The differences are that the example intersection does not have stop signs and the circle does not serve as a pedestrian island. We recognize this existing circle as a model of scale for residential streets like North Street and Grove Street.

Local Motion, a Vermont-based advocacy group for active transportation, published a report suggesting three alternatives for trial infrastructure projects to improve pedestrian and bicycling safety of the intersection (Local

Motion, 2023). Alternative 2 from the report proposed installing median island buffers to create a pedestrian refuge. This alternative proposed the same pedestrian protections as our pedestrian island design.

Pedestrian islands combined as traffic circles are not common. We designed a unique feature for an atypical intersection. The intersection proportions were considered to accommodate the flow of traffic around a circle, but the design of the roadway feature is foremost a pedestrian island.

Ivy Lane – Alternative 3: Resurface with Decorative Asphalt and Parallel Parking

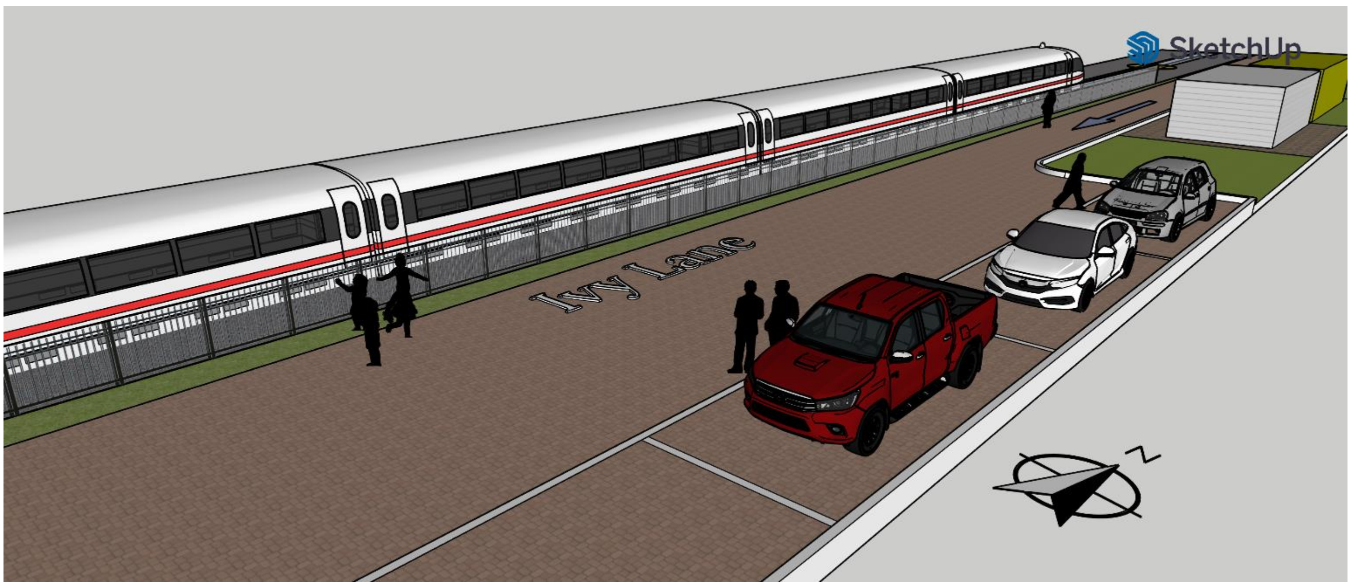


Figure 8: Ivy Lane with Decorative Asphalt and Parallel Parking

This alternative received the highest score in the decision matrix (Table 4). The road surface design incorporates a textured decorative asphalt surface to calm vehicle speed and visually indicates a pedestrianized environment. The road will serve as a continuation of the pedestrian path across Central Street, improving connectivity to Main Street.

Examples of textured decorative asphalt surfaces are used in the neighboring city of Burlington, VT. They can be found on multi-modal roadways on the University of Vermont campus. The consolidated crossing plaza section of University Place is surfaced with a brick-look decorative asphalt (see call-out photo in Figure 10) and this color and texture is used to alert drivers of the presence of pedestrians and cyclists in the roadway.

Downsides to this alternative should be noted, particularly added cost due to the resurfacing with a colored and textured surface. Adjusting the existing angled vehicle parking to parallel parking will reduce the number of spots from 25 to 10. There are other public parking areas within 500 feet of Ivy Lane, including street parking on Railroad Avenue, Railroad Street, and a free parking lot on Maple Street.

Additionally, we recognize that Ivy Lane is owned by Central Vermont Railway and New England Central Railroad. A scoping study done in 2016 investigated alternative uses for Ivy Lane during construction of the Amtrak train station renewal. The preferred alternative from that study showed a reversal of the traffic direction on Ivy Lane and subsequently reangling the parking spots to face the flow of traffic. There are minimal pedestrian and cyclist accommodation incorporated in the design (RSG, 2016). Our design acknowledges the bounds of the preferred alternative of the scoping study and adds a safe space for pedestrians and cyclists.

Conclusions and Recommendations

In Essex Junction, the 4-way intersection of Grove Street and North Street has garnered complaints from the public about close calls with vehicle and pedestrian collisions. The single crosswalk is 69-feet-long and aligns diagonally across the four-way intersection. This intersection is a key link in the bike and walk infrastructure connecting the city high school, residential sidewalks, and a recently constructed recreational path. This path leads to Ivy Lane, a low-volume one-way street, which was identified as a potential link for a continuous bike and walk corridor. These two areas were considered for design alternatives that improved safety and connectivity for pedestrians and cyclists.

The table below briefly describes each alternative's design features at each study area. Refer to Alternatives Evaluation for more detailed descriptions of each design.

Table 7: Summary of Design Alternatives

Alternative 1 (do-nothing)	North/Grove Streets	Existing 69 ft crosswalk with diagonal alignment
	Ivy Lane	Existing 1-way road, no pedestrian/cycling infrastructure
Alternative 2	**North/Grove Streets**	**Pedestrian island**
	Ivy Lane	Fully pedestrianized, decorative asphalt, no vehicle parking
Alternative 3	North/Grove Streets	Realigned raised 50 ft long crosswalk
	Ivy Lane	**Decorative asphalt, 10 parallel parking vehicle spaces**
Alternative 4	North/Grove Streets	Existing crosswalk with RRFBs, additional streetlight
	Ivy Lane	5 ft painted bike lane with dashed edge line

The four alternatives were compared using a decision matrix (Tables 3, 4) calibrated to emphasize critical criteria identified by BWAC. The committee stressed safety and costs to be the paramount criteria projects are judged by, and the team added construction disruption and network connectivity for a more holistic evaluation. For the North Street/Grove Street Intersection, we recommend **Alternative 2: Pedestrian Island**. For Ivy Lane, we recommend **Alternative 3: Decorative Asphalt and Parallel Parking**.

North Street/Grove Street Intersection

The recommended design at the North Street/Grove Street intersection focuses on shortening the continuous time spent in the path of traffic by allowing pedestrians to seek refuge on the island. The island also creates more awareness for those pedestrians from the viewpoint of a driver as vehicles are forced to alter their direction of travel to navigate the intersection. Existing sidewalks and crosswalks will be maintained to keep overall costs and construction time down, reducing financial impacts on Essex Junction residents when deciding how to fund the project and alleviating potential delays throughout the construction process for users of the intersection.

Ivy Lane

On Ivy Lane, the chosen design prioritizes pedestrian/cyclist connectivity but still allows vehicle access and some parking. Proper signage and decorative asphalt alerts drivers that they are the secondary users of the space and must yield to pedestrians and cyclists. Repaving Ivy Lane is expected to comprise most of the costs, but using decorative asphalt rather than individual pavers will reduce the lifetime upkeep expenses.

Design Considerations

A life-cycle cost assessment (Appendix C) indicates the selected alternatives will cost $362,000 for the North Street/Grove Street intersection and $502,000 for Ivy Lane, with each including engineering and contingency costs. The cost data is from 2024 and thus does not account for inflation (Vermont Agency of Transportation, 2024). The main expenses come from the yearly crosswalk repainting at North Street/Grove Street ($127,000 for a 40-year lifespan) and the decorative asphalt on Ivy Lane with one repave ($138,000 for a 40-year lifespan). During winter, snowplows will have to navigate the pedestrian island at the North Street/Grove Street intersection and may have difficulty seeing the raised section, leading to increased wear on the structure. The 40% contingency cost covers this, as it is difficult to assume how often the structure will have to be repaired or replaced. The pavement life on Ivy Lane is assumed to be 20 years, though if accelerated wear is noticed, the contingency cost can be used for maintenance on this as well.

The proposed designs comply with applicable regulatory guidelines. The North Street/Grove Street intersection redesign keeps the existing crosswalk and associated transitions to sidewalks which are ADA compliant, and Ivy Lane's decorative pavement will indicate to visually impaired persons that they are able to utilize the space. The Manual on Uniform Traffic Control Devices (MUTCD) guidelines regarding minimizing queuing across railroad tracks will comply due to a consistent flow of traffic through the North Street/Grove Street intersection. Little queuing was observed across the railroad tracks on North Street in the existing configuration of the intersection and the redesign is not expected to significantly alter traffic patterns.

The *Envision* Sustainability *Framework* system is a series of indicators that quantifies how sustainable and equitable an engineering project is. Based on the team's own assessment of the project's performance on the *Envision* system, it scores a 51% Platinum rating, with 336 of 660 points applicable. The majority of the *Envision* score comes from Quality-of-Life improvements, specifically Community Wellbeing and Mobility. Other subcategories that scored well include Planning, Economy, Emissions, and Resilience. These categories indicate the design will benefit Essex Junction's community connectedness and overall economy as access to the downtown Five Corners area is improved significantly.

The next step to seeing these proposed redesigns become more concrete is a trial run of the pedestrian island at the North Street/Grove Street intersection. Temporary implements like cones and soluble paint would be used to guide drivers around the intersection as the team observes their behavior. Ideally, this trial would be conducted during school arrival/dismissal when the intersection is the busiest. A similar strategy could be used on Ivy Lane with a simple repaint to create parallel parking spaces and installation of temporary signs to encourage use by pedestrians and cyclists. Based on these trial runs, several tweaks to the design will have to be made and placed before the Essex Junction city government for review and potential approval. The geometry of the pedestrian Island at the North Street/Grove Street intersection may need to be adjusted to accommodate larger vehicles, and additional signage or markings may need to be added so drivers understand the changes made to the intersection. At Ivy Lane, parking usage with the reduced number of spaces should be investigated to see if other municipal lots are becoming overburdened. Pedestrian/cyclist usage of the shared space should be monitored to see if any pavement markings are needed to improve usability, such as adding a dedicated bike lane. These trials will guide the design adjustments to make the recommended alternatives presented in this report successful additions to Essex Junction pedestrian and bicycling infrastructure.

References

Banayan, N., and Haggerty, M. (2023). "Billions of dollars are available for bike projects." *PeopleForBikes*, <https://www.peopleforbikes.org/news/billions-of-dollars-are-available-for-bike-projects> (Feb. 24, 2024).

Bushell, M. A., Poole, B. W., Zegeer, C. V., and Rodriguez, D. A. (2013). "Costs for Pedestrian and Bicyclist Infrastructure Improvements." *UNC Highway Safety Research Center*, <https://www.pedbikeinfo.org/cms/downloads/Countermeasure%20Costs_Report_Nov2013.pdf> (Feb. 26, 2024).

Community Development Projects - City of Essex Junction, Vermont. (n.d.). from https://www.essexjunction.org/departments/community-development/projects

"Crash modification factors clearinghouse." (n.d.). *CMF Clearinghouse*, <https://www.cmfclearinghouse.org/> (Mar. 27, 2024).

Gates, T. J., Noyce, D. A., Bill, A. R., and Van Ee, N. (2005). *Recommended Walking Speeds for Pedestrian Clearance Timing Based on Pedestrian Characteristics*, rep., Transportation Research Board of the National Academies, Washington, DC, 38–47.

Kahn, R., and Kahn Goedecke, A. (2011). "Roadway striping as a traffic calming option." *National Association of City Transportation Officials*, <https://nacto.org/docs/usdg/roadway_striping_as_a_traffic_calming_option_kahn.pdf> (Feb. 27, 2024).

Lincoln, T. (2024). *City of Essex Junction Bike/Walk Advisory Committee Meeting Minutes January 11, 2024*. https://www.essexjunction.org/fileadmin/files/Bike_Walk/Meetings/01_11_2024_BWAC_Minutes.pdf?828f0db8faeef9aae18ba48f84457529c049e8a2

Local Motion. (2023) "Essex Junction Grove/North Intersection Pop Up Demonstration Preliminary Project Proposal."

Lofgren. (2023, September 14). *VT Annual Average Daily Traffic (AADT) - 2022*. Retrieved November 26, 2023, from https://geodata.vermont.gov/datasets/VTrans::vt-annual-average-daily-traffic-aadt-2022/explore

Pease, B., and Hall, W. (n.d.). "Using raised crosswalks to elevate pedestrian safety." *Purdue University Libraries*, <https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=4661&context=roadschool> (Feb. 28, 2024).

Pierce, R. (2020). *Putting the Village Back in Essex Junction*, rep., Vermont Natural Resources Counsil. https://vnrc.org/people-places-transportation/putting-the-village-back-in-essex-junction/

Pierce, R., et al. (2019). *Design 5 Corners: Implementation Plan*, rep., Chittenden County RPC. https://www.ccrpcvt.org/wp-content/uploads/2019/03/D5C-Implementation-Plan_Final-Report.pdf

RSG. (2016). “FINAL SCOPING REPORT: ESSEX JUNCTION TRAIN STATION ACCESS AND CIRCULATION STUDY.” *Chittenden County Regional Planning Commission*, <https://studiesandreports.ccrpcvt.org/wp-content/uploads/2017/01/Final-Scoping-Report-Essex-Junction-Train-Station-4-6-2016.pdf> (Mar. 27, 2024).

“Standard Specifications for Construction.” (2024). *Vermont Agency of Transportation*, <https://vtrans.vermont.gov/sites/aot/files/documents/2024 March Average Prices - 5 year.pdf> (May 1, 2024).

Appendices

Appendix A- Design Renderings

The initial drawings for all alternatives were done in ArcGIS Pro and were used for dimensional calculations.

Alternative 2

Figure 9: Alternative 2— North Street/Grove Street Schematic

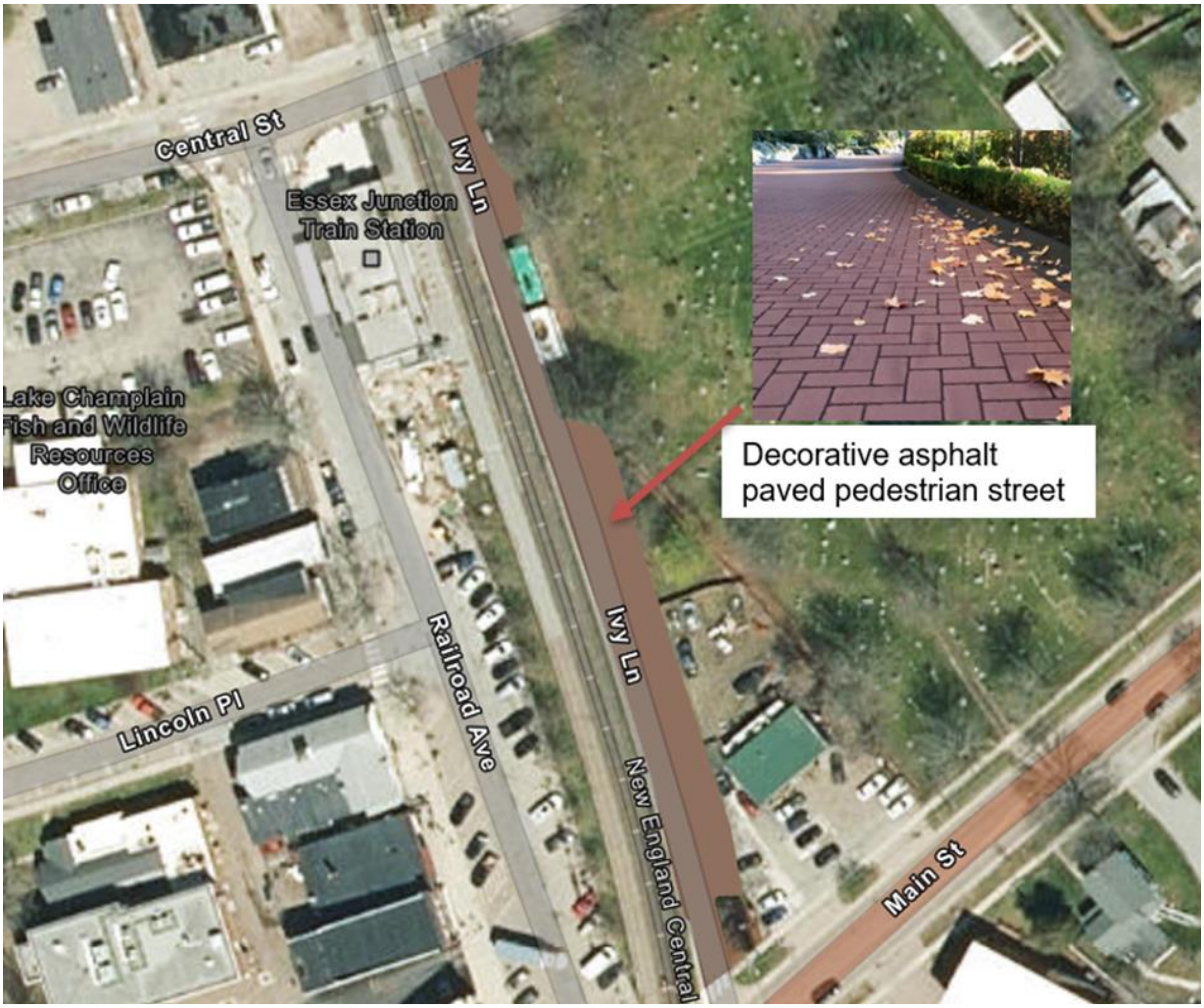


Figure 10: Alternative 2 - Ivy Lane Overview

Figure 11: Alternative 2 — North Entrance to Ivy Lane

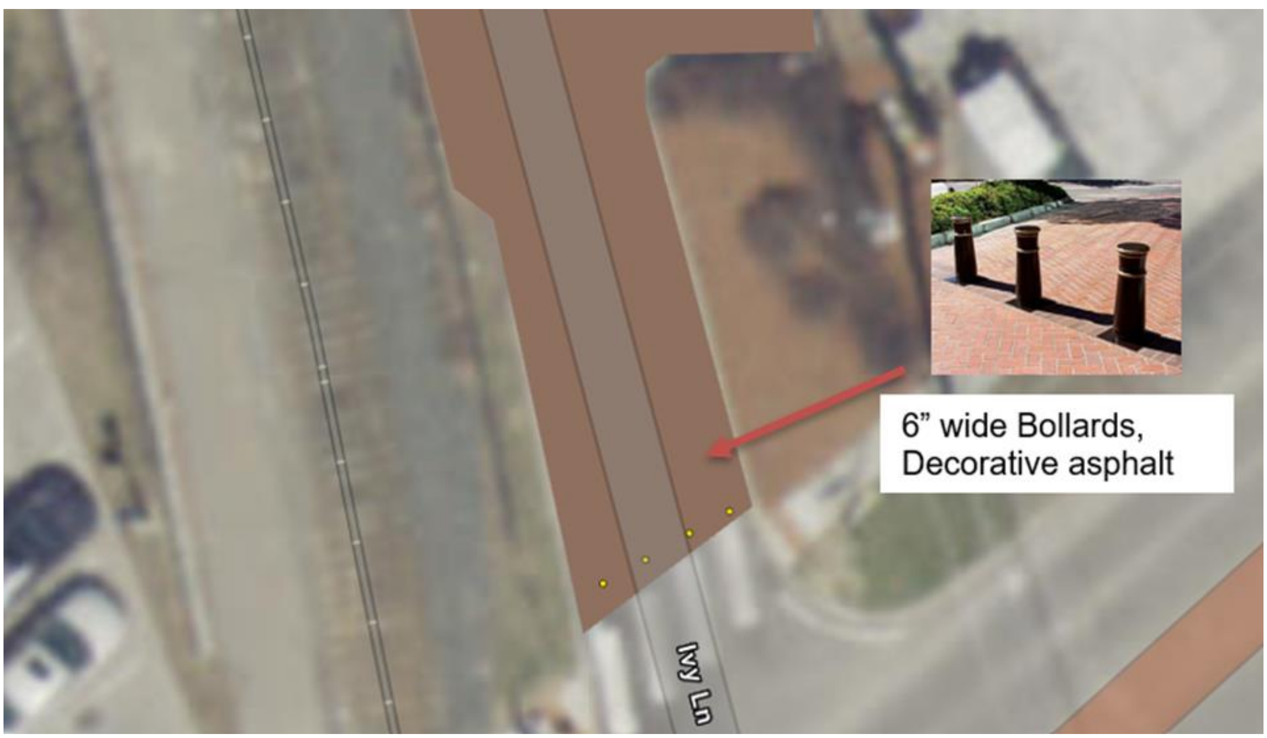


Figure 12: Alternative 2 — South Entrance to Ivy Lane

Alternative 3

Figure 13: Alternative 3 — North Street/Grove Street Raised Crosswalk

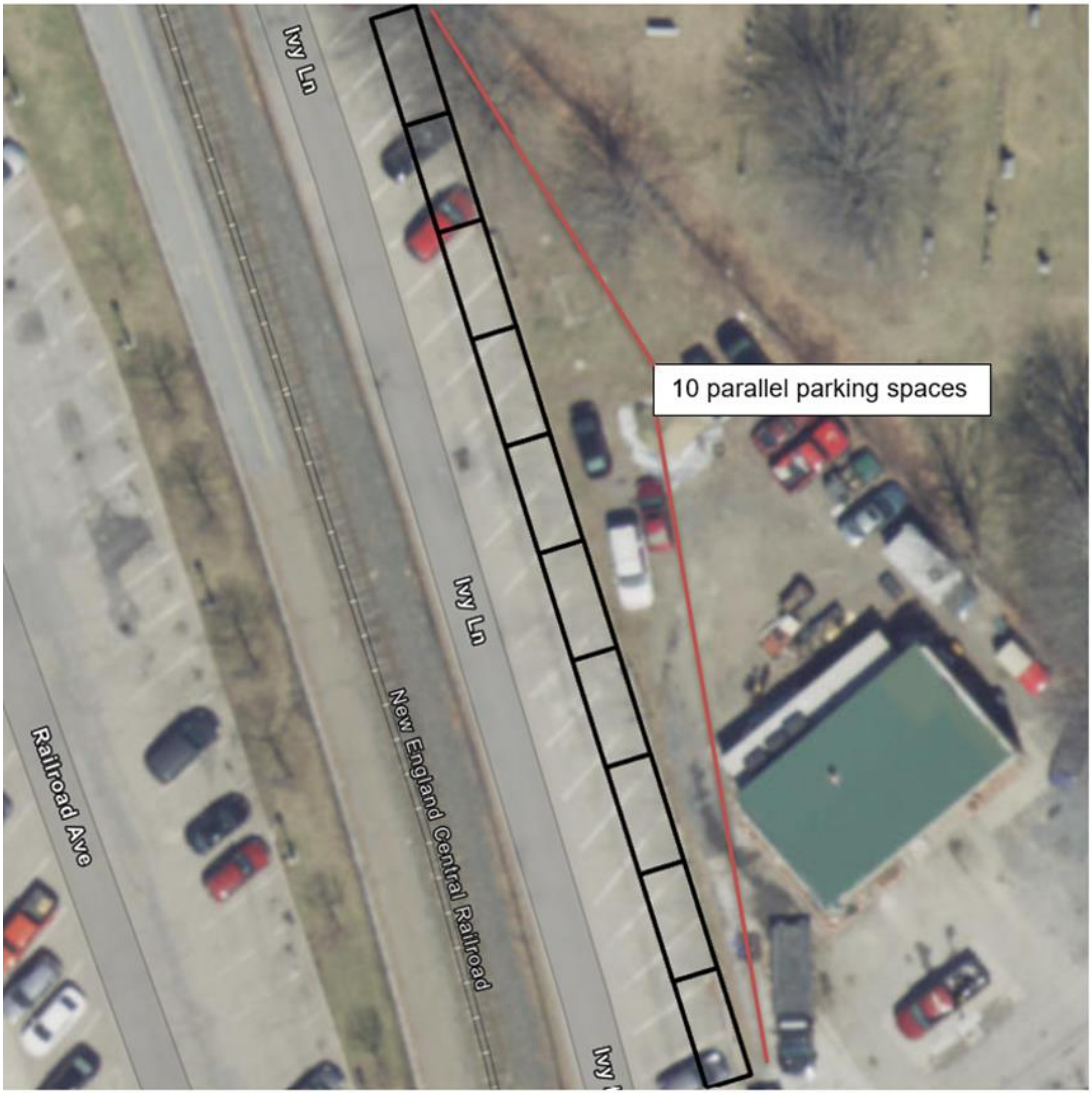


Figure 14: Alternative 3 —Ivy Lane Parallel Parking

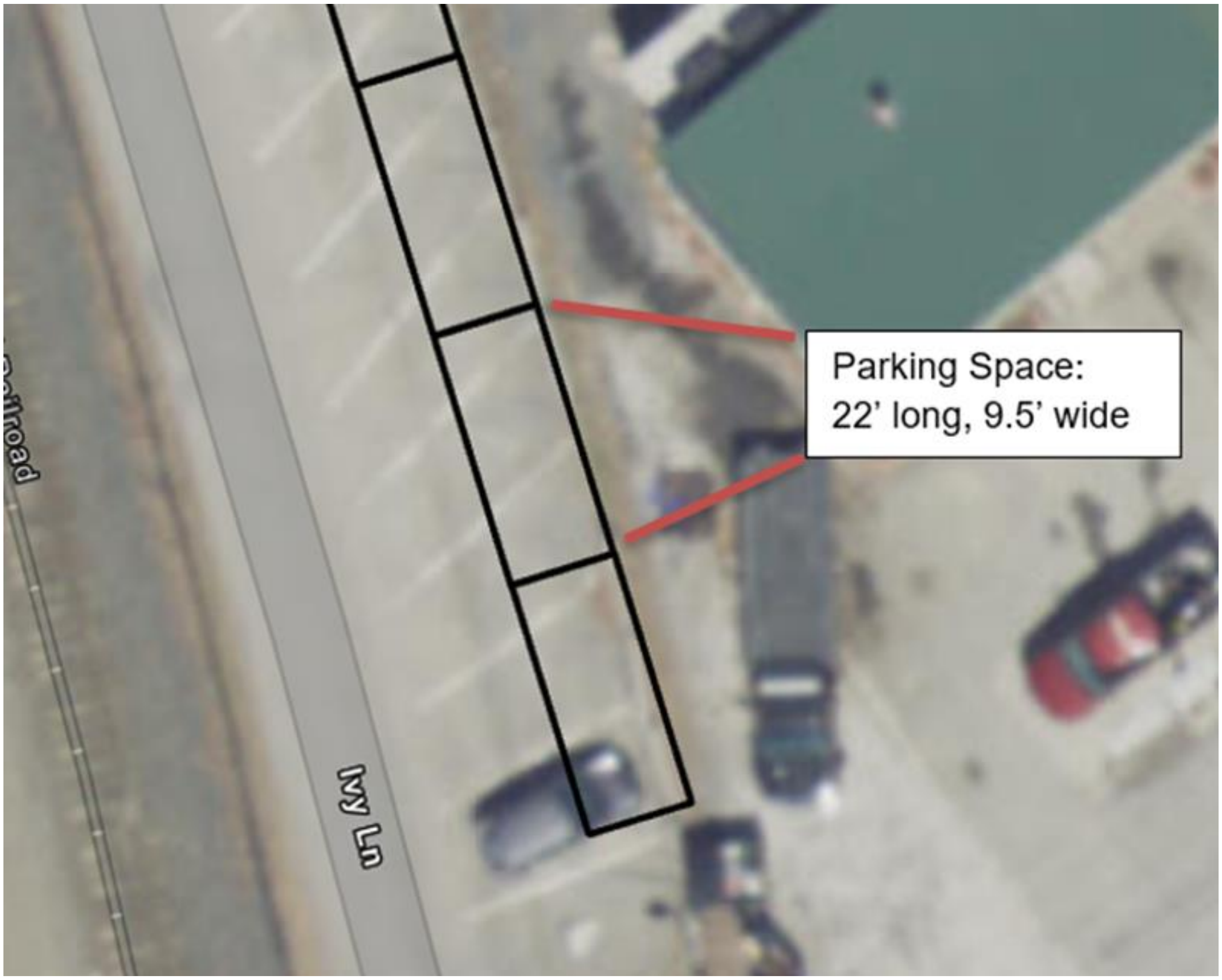


Figure 15: Alternative 3 — Ivy Lane Parallel Parking Dimensions

Alternative 4

Figure 16: Alternative 4 – North Street/Grove Street Lighting

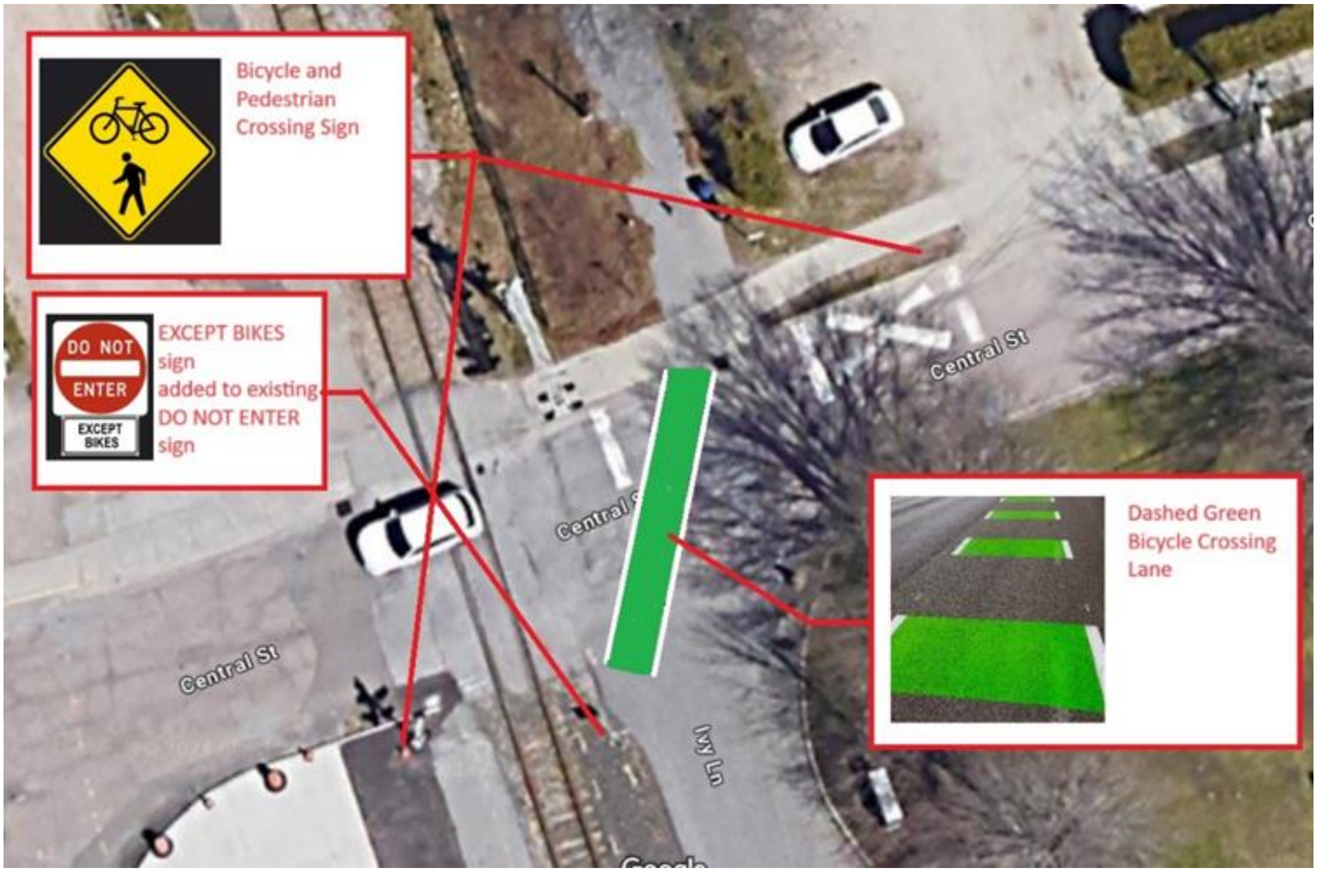


Figure 17: Alternative 4 – Ivy Lane/Central Street Crossing

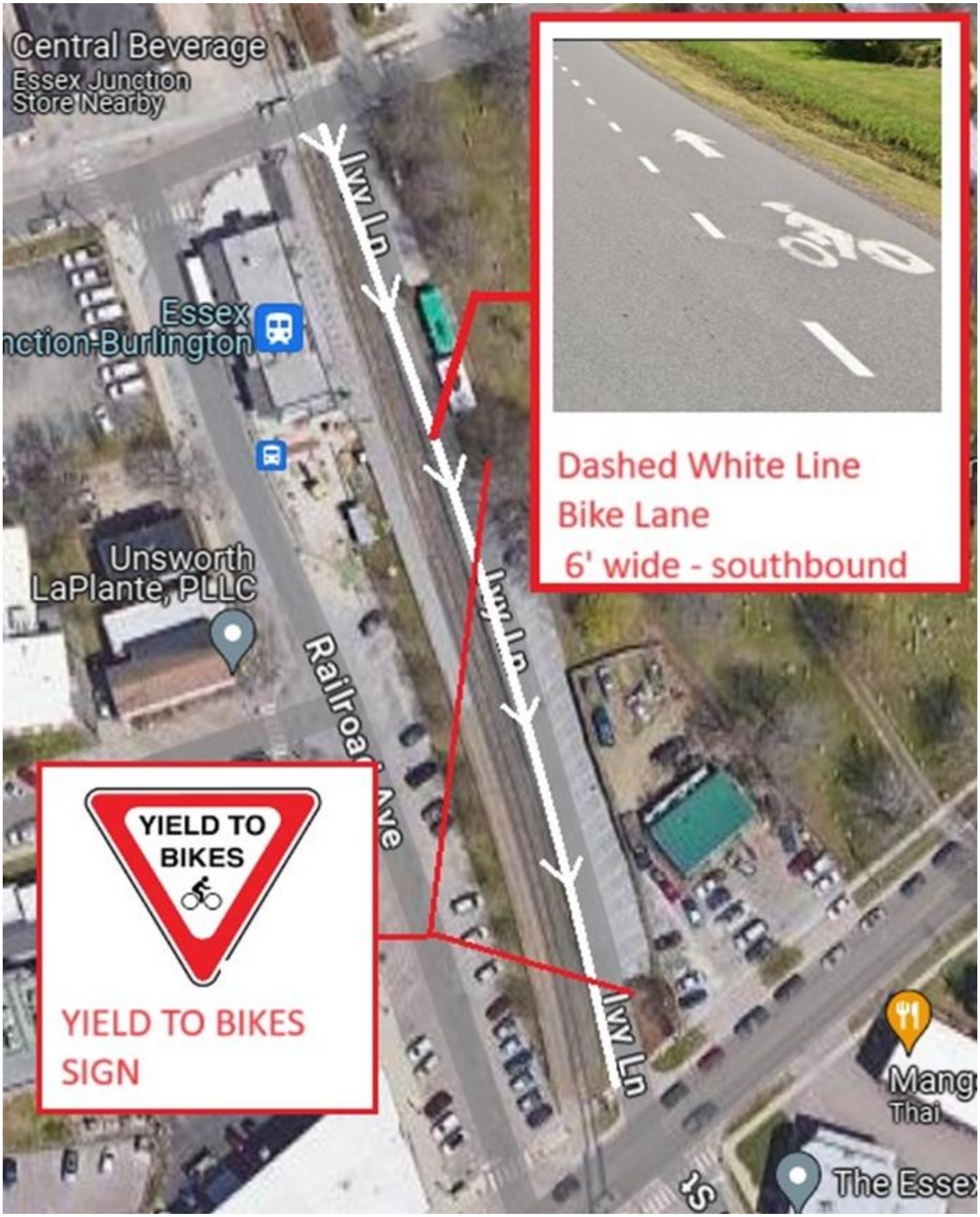


Figure 18: Alternative 4 —Ivy Lane Bike Lane

Appendix B- Design Calculations

Elderly people have a walking speed of 2.9 ft/s (Bill, 2005)

$$69\ foot\ crosswalk * \frac{s}{2.9\ ft} = 23.8\ seconds\ of\ crossing$$

All other pedestrians have a walking speed of 4 ft/s (Bill, 2005)

$$69\ foot\ crosswalk * \frac{s}{4\ ft} = 17.25\ seconds\ of\ crossing$$

After installing a 14 ft diameter pedestrian island in the existing crosswalk, the distance a pedestrian would spend in the roadway would be 69 ft – 14 ft = 55 ft total

For elderly people, this results in a 19 second crossing time in the roadway.

$$55\ foot\ crosswalk * \frac{s}{2.9\ ft} = 18.96\ seconds\ of\ crossing$$

All other pedestrians would cross the roadway in 14 seconds.

$$55\ foot\ crosswalk * \frac{s}{4\ ft} = 13.75\ seconds\ of\ crossing$$

Appendix C- Cost Calculations

For each alternative, a 25% engineering cost and 40% contingency cost is applied, as suggested by Professor Matthew Scarborough. A 40-year lifetime is assumed for the design.

North Street/Grove Street Intersection

Alternative 1- Do-nothing maintenance

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Crosswalk Painting	$46	ft	69	1	$3,174	$126,960
Sidewalk Repair	$8	ft	20	10	$160	$640
Curb Repair	$82	linear ft	20	5	$1,640	$13,120
Total					**$4,974**	**$140,720**

Total	Engineering cost	Contingency cost	Full total
$145,694	$36,423.50	$58,277.60	**$240,395**

Alternative 2- Pedestrian Island

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Pedestrian Island	$16,000	Each	1	40	$16,000	$16,000
Crosswalk Painting	$46	ft	69	1	$3,174	$126,960
Sidewalk Repair	$8	ft	20	10	$160	$640
Curb Repair	$82	linear ft	50	5	$4,100	$32,800
Added Signage	$300	Each	7	5	$2,100	$16,800
Total					**$25,534**	**$193,200**

Total	Engineering cost	Contingency cost	Full total
$218,734	$54,683.50	$87,493.60	**$360,911**

Alternative 3- Raised Crosswalk

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Raised Crosswalk	$18,000	Each	1	40	$18,000	$18,000
Crosswalk Painting	$46	ft	69	1	$3,174	$126,960
Sidewalk Repair	$8	ft	20	10	$160	$640
Curb Repair	$82	linear ft	50	5	$4,100	$32,800
Added signage	$300	Each	4	5	$1,200	$9,600
					$26,634	**$188,000**

Total	Engineering cost	Contingency Costs	Full total
$214,634	$53,658.50	$85,853.60	**$354,146**

Alternative 4- Rectangular Rapid Flashing Beacons (RFFBs)

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
RRFB	$28,000	Per Pair	1	40	$28,000	$28,000
Lighting	$12,000	Each	1	20	$12,000	$24,000
Crosswalk Painting	$46	ft	69	1	$3,174	$126,960
Sidewalk Repair	$8	ft	20	10	$160	$640
Curb Repair	$82	linear ft	20	5	$1,640	$13,120
Total					**$44,974**	**$192,720**

Total	Engineering cost	Contingency Costs	Full total
$237,694	$59,423.50	$95,077.60	**$392,195**

Ivy Lane

Alternative 1- Do-nothing maintenance

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Parking painting	$3	ft	450	1	$1,350	$54,000
Repaving	$5	ft^2	2300	10	$11,500	$46,000
Total					**$12,850**	**$100,000**

Total	Engineering cost	Contingency Costs	Full total
$112,850	$28,212.50	$45,140.00	**$186,203**

Alternative 2- Full pedestrianization

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Repaving the parking lot at 4 Maple St	$5	ft^2	12500	10	$62,500	$250,000
Brick-look decorative asphalt	$30	ft^2	2300	20	$69,000	$138,000
Bollards	$500	Each	12	25	$6,000	$9,600
Painting a crosswalk in the Central St-Ivy Ln intersection	$20	ft	35	1	$700	$28,000
Added Signage	$300	Each	3	5	$900	$7,200
Total					**$139,100**	**$432,800**

Total	Engineering cost	Contingency Costs	Full total
$571,900	$142,975.00	$228,760.00	**$943,635**

Alternative 3- Parallel parking

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Painting a crosswalk in the Central St-Ivy Ln intersection	$20	ft	35	1	$700	$28,000
Parallel parking paint lines	$4	ft	350	1	$1,400	$56,000
Shared street warning sign	$600	Each	2	5	$1,200	$9,600
Brick-look decorative asphalt	$30	ft^2	2300	20	$69,000	$138,000
Total					**$72,300**	**$231,600**

Total	Engineering cost	Contingency Costs	Full total
$303,900	$75,975.00	$121,560.00	**$501,435**

Alternative 4- Bike lane

	Unit Cost	Unit	Qty	Maintenance Interval (years)	Capital cost	Lifetime cost
Parking painting	$3	ft	450	1	$1,350	$54,000
Repaving	$5	ft^2	2300	10	$11,500	$46,000
Bike Lane Boundary Painting	$3	ft	525	1	$1,575	$63,000
Painted Symbols	$300	Each	4	1	$1,200	$48,000
Added Signage	$300	Each	2	5	$600	$4,800
Total					**$16,225**	**$215,800**

Total	Engineering cost	Contingency Costs	Full total
$232,025	$58,006.25	$92,810.00	**$382,841**

VERMONT

AGENCY OF TRANSPORTATION

Speeding Countermeasures for Vermont

Final Project Report

James L. Sullivan

Dr. Dana Rowangould

University of Vermont Transportation Research Center

May 2023

Research Project

Reporting on Project VTRC 21-01

Final Report 2023-03

A Report from the University of Vermont Transportation Research Center

Traffic Safety Toolbox - Addressing Speeds

Final Report

May 2023

TECHNICAL DOCUMENTATION PAGE

1. Report No. 2023-03	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Traffic Safety Toolbox - Addressing Speeds		**5. Report Date** May 2023 **6. Performing Organization Code**
7. Author(s) Sullivan, James L. (ORCID 0000-0002-4435-9002) Rowangould, Dana (ORCID 0000-0001-9839-368X)		**8. Performing Organization Report**
9. Performing Organization Name and Address University of Vermont Transportation Research Center Mansfield House 25 Colchester Avenue, Burlington, VT 05405		**10. Work Unit No.** **11. Contract or Grant No.** VTRC20-002
12. Sponsoring Agency Name and Address Vermont Agency of Transportation (SPR), Research Section 219 N. Main Street Barre, VT 05641		**13. Type of Report / Period Covered** Final Report / April 2022-March 2023 **14. Sponsoring Agency Code**

15. Supplementary Notes

Toolbox: https://vtrans.vermont.gov/sites/aot/files/documents/20230606%20Toolbox.pdf

16. Abstract

Reducing speeding and aggressive driving is one of seven critical emphasis areas identified in the Vermont Highway Safety Plan, which targets reductions in major crashes on Vermont highways. Vermont towns recognize the need to discourage speeding and implement countermeasures that will bring speeds down to posted speed limits, especially in transition zones from high-speed rural highways to low-speed village streets. Vermont's villages and towns often lack the resources and capacity needed to select and implement speeding countermeasures that will be effective and appropriate for a particular context. There is a need for targeted, digestible guidance to assist these municipalities. This goal of this project was to create a clear and concise "Traffic Safety Toolbox" to distill key information about speeding countermeasures appropriate for small and rural communities in Vermont. This Toolbox will help the towns where the responsibility of addressing speeds and improving safety often falls to local engineers or DPW superintendents, many of whom have limited experience in traffic safety.

The objectives of this project were to:

1. Evaluate applicability of speed countermeasures in the Vermont context.
2. Profile proven speed countermeasures including describing their use and effectiveness in Vermont communities.
3. Create a clear and concise "Traffic Safety Toolbox" to support local decision-makers in villages and towns across Vermont

17. Key Words	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages**	**22. Price**

Acknowledgments

The authors would like to acknowledge VTrans for providing funding for this work. The input of the project technical advisory committee (TAC) members was also greatly appreciated:

VTrans

Emily Parkany
Ashlie Mercado
Steffanie Lemieux
Jon Kaplan
Christopher Taft
Joshua Taylor
Ian Degutis
Matthew Arancio
Taylor Sisson
Theresa Gilman
Benjamin Howe
Mario Dupigny-Giroux
Todd Eaton
Greg Young

External

Paul Ravelin
Paul White
Bill Jenkins
Sai Sarepalli

Disclaimer

The information contained in this report was compiled for the use of the Vermont Agency of Transportation. Conclusions and recommendations contained herein are based upon the research data obtained and the expertise of the researchers and are not necessarily to be construed as Agency policy. This report does not constitute a standard, specification, or regulation. The Vermont Agency of Transportation assumes no liability for its contents or the use thereof.

This material is based upon work supported by the Federal Highway Administration under SPR-B VTRC 20-2. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration.

Table of Contents

Figures and Tables

Executive Summary

Reducing speeding and aggressive driving is one of seven critical emphasis areas identified in the Vermont Highway Safety Plan, which targets reductions in major crashes on Vermont highways. Vermont towns recognize the need to discourage speeding and implement countermeasures that will bring speeds down to posted speed limits, especially in transition zones from high-speed rural highways to low-speed village streets. Vermont's villages and towns often lack the resources and capacity needed to select and implement speeding countermeasures that will be effective and appropriate for a particular context. There is a need for targeted, digestible guidance to assist these municipalities. This goal of this project was to create a clear and concise "Traffic Safety Toolbox" to distill key information about speeding countermeasures appropriate for small and rural communities in Vermont. This Toolbox will help the towns where the responsibility of addressing speeds and improving safety often falls to local engineers or DPW superintendents, many of whom have limited experience in traffic safety.

The objectives of this project were to:

1. Evaluate applicability of speed countermeasures in the Vermont context.
2. Profile proven speed countermeasures including describing their use and effectiveness in Vermont communities.
3. Create a clear and concise "Traffic Safety Toolbox" to support local decision-makers in villages and towns across Vermont

Although there is a large body of research establishing the effects of speed countermeasures on vehicle speeds, local officials face significant barriers to selecting and implementing effective countermeasures that meet their needs. Municipal decision makers must determine whether each countermeasure is appropriate in the context of a particular facility which may have specific design requirements (e.g. a state highway) as well as how to fund and implement the countermeasure. This requires navigating detailed roadway and countermeasure design standards and guidelines, understanding roles and responsibilities of federal, state, and local agencies, and reviewing the large body of documents pertaining to the effectiveness and applicability of speed countermeasures. This report contains an exhaustive review of the public-agency and scholarly literature pertaining to providing toolbox-like guidance for states and municipalities throughout North America and evaluating the effectiveness of speeding countermeasures in a variety of contexts. Special attention is given to those resources that provide guidance or findings that are relevant to the Vermont context.

Vermont's particular context is unique, in that it is a rural northern state where the presence of snow and ice on its roadways is a concern for nearly half the year, and traffic volumes are higher than expected due to the presence of visitors from surrounding metropolitan areas on its roadways. With this context in mind, a set of feasible speeding countermeasures for Vermont was selected in collaboration with the project's technical advisory committee (TAC) through a series of meetings in June, August, and October of 2022. Initially, a broader set of countermeasures was drawn from literature, then distilled to regions with similar characteristics to Vermont and from the FHWA guidance on traffic calming in transition zones. Similar regions included the Province of Quebec, the city of Kingston, Ontario, and the city of Ottawa, Ontario. After this process, 14 countermeasures were selected for inclusion in the Vermont toolbox. One last countermeasure was added as a follow-up with the Minnesota DOT following a TAC member's suggestion, bringing the list to 15:

- Horizontal deflections
    - Lane or street narrowing
    - Lateral shift
    - Bulbout / pinchpoint / choker
    - Median island
    - Mini-roundabout
    - Neighborhood traffic circle
- Vertical deflections
    - Speed hump or cushion
    - Raised crosswalk / speed table
    - Raised intersection
- Perceptual, or passive, measures
    - Road diet
    - Radar speed feedback signs
    - Transverse line markings
    - Gateway signing/landscaping
    - Transverse mumble strips
    - [SLOW] / [-- MPH] pavement word marking

Once the set of countermeasures to be included in the Toolbox was agreed upon, the research team offered a selection of templates for the profile sheets for the TAC to choose from. Votes for each TAC members top 3 choices were solicited, and the template receiving the highest number of first or second-place votes was used for the development of the 15 profile sheets.

To further enhance the relevance of the Toolbox to the experiences of Vermont towns, a series of case studies and field tests were conducted at selected towns throughout the state for inclusion in the Toolbox. The case studies consisted of identifying and interviewing contacts at selected towns with experience in the selection and implementation of speeding countermeasures. Towns were identified with input from the TAC supplemented by a review of the online press to find notable examples. From these towns, the research team reached out to relevant contacts for an interview. The final set of case studies consists of the towns that were willing to provide an interview for inclusion in the Toolbox – Lincoln, Middlebury, Newfane, and Williston. The field tests consisted of identifying transition zones throughout the state where speeding is or was a problem for a village or town center and speeding countermeasures have been implemented or are being considered. From the initial set of sites identified by the research team, a subset was identified where field data collection would be feasible. For the subset of sites, the research team collected comprehensive hourly speed and volume data for the transition direction of flow after the lowest reduced speed limit posting. In most cases, this location coincided with the end of the state-maintained highway.

For each case study and field test, a fact sheet was prepared summarizing the site, the effort by the research team and the results. For the field tests, the fact sheets contain details of the observation period for the data collection. For the case studies, these results consist of lessons learned, but for the field tests they consist of a chart of the data collected, and the conclusions drawn from the data.

Based on the literature review, the research team offered the option of developing a Toolbox that would be either html-based, consisting of a series of web pages with appropriate linkages, or pdf-based, consisting of a stand-alone document with internal linkages and links to external resources on the web. Ultimately, it was decided that a pdf format would be preferable since some users might want to print the document and an html-based series of web pages would not facilitate printing.

A set of 12 templates for the profile sheets with free availability were identified by the research team and offered to the TAC for selection. The templates receiving the two highest rankings were selected for use in the Toolbox. The most preferred template was used as a basis for the profile sheets, and the second-most preferred template was used as the basis for the fact sheets.

To support the user's experience with the profile sheets, the team decided to add an applicability/acceptability (A/A) table as a linked navigation page. The A/A table is a common feature of almost all the toolboxes identified during the literature review:

Applicability / Acceptability Table for Speeding Countermeasures in Vermont

++ most favorable / most common
\+ moderately favorable / moderately common
– not favorable / not common

Type	Speeding Countermeasure	Frequency of Use in Vermont	Snow and Ice Control	Emergency Response	Cost / Maintenance	Speed Reduction Potential	Within Village or Town Center (< 35 mph)	Transition Zone (> 35 mph)	Acceptable on VT Highways?
Horizontal deflections	Lane or street narrowing	+	+	+	+	+	++	++	seek
	Lateral shift	+	+	+	+	+	+	+	seek
	Bulbout / pinchpoint / choker	+	+	+	+	+	++	–	seek
	Median island	+	+	+	+	+	+	+	seek
	Mini-roundabout	+	–	+	–	++	++	–	seek
	Neighborhood traffic circle	+	+	+	–	++	++	–	no
Vertical deflections	Speed hump or cushion	+	–	+	–	++	++	–	no
	Raised crosswalk / speed table	+	–	+	–	++	++	–	no
	Raised intersection	–	–	+	–	++	++	–	no
Perceptual, or passive, measures	Road diet	+	++	++	+	+	++	+	seek
	Radar speed feedback signs	++	++	++	+	+	++	+	seek
	Transverse line markings	+	++	++	+	+	+	++	no
	Gateway signing / landscaping	++	++	++	++	+	–	++	seek
	Transverse mumble strips	–	+	+	+	+	+	+	no
	[SLOW]/[-- MPH] pavement word marking	–	++	++	+	+	+	–	no

The opening matter of the Toolbox was added, also influenced by similar documents that the research team had reviewed, with notable additions at the request of the TAC. The profile sheets were populated with a selection of photographs, diagrams and illustrations and brief sections on the appropriate context and design considerations for each countermeasure were added. Sources were included at the bottom of each profile sheet to provide the user with links to find additional detailed information about the countermeasure, and a complete list of resources used to build the Toolbox was added at the end of the document. Once the pdf document pages had been compiled, linkages were created to make the document more dynamic and user-friendly. The final version of the Toolbox is included as an appendix to this report.

1 Introduction

In 2016 the share of Vermont traffic fatalities that were speeding-related was among the highest in the U.S. at 47% (topped only by Washington D.C. and New Hampshire) (NHTSA, 2021). Consequently, reducing speeding and aggressive driving is one of seven critical emphasis areas identified in the Vermont Highway Safety Plan, which targets reductions in major crashes on Vermont highways (VHSA, 2021). Vermont towns recognize the need to discourage speeding and implement countermeasures that will bring speeds down to posted speed limits, especially in transition zones from high-speed rural highways to low-speed village streets. There is a need for clear and concise guidance on speeding countermeasures that can be readily used by decision-makers in villages and towns across Vermont.

Many small and rural communities in Vermont seek to reduce vehicle speed limits in their communities in order to improve safety outcomes. However, reducing speed limits does not necessarily reduce travel speeds or mitigate the risk, as drivers typically set their travel speed based on their surroundings (roadway design and context, weather and lighting, density and type of land uses, vehicle and pedestrian traffic levels, etc.) rather than the posted speed limit. When a speed limit reduction is sought by local officials, the Agency often determines that changes to posted speed limits are inappropriate and speeding countermeasures are needed instead.

Vermont's villages and town often lack the resources and capacity needed to select and implement speeding countermeasures that will be effective and appropriate for a particular context. There is a need for targeted, digestible guidance to assist these municipalities. This goal of this project was to create a clear and concise "Traffic Safety Toolbox" to distill key information about speeding countermeasures appropriate for small and rural communities in Vermont. This Toolbox will be an invaluable resource for municipal decision-makers seeking to improve traffic safety outcomes in their Vermont communities. This project will help the towns where the responsibility of addressing speeds and improving safety often falls to local engineers or DPW superintendents, many of whom have limited experience in traffic safety. By creating this resource, we will be improving VTrans' workflow as well as providing access to a much-needed resource for the most effective ways to reduce speeding and prevent future speeding-related fatalities on our roadways.

The objectives of this project were to:

1. Evaluate applicability of speed countermeasures in the Vermont context.
2. Profile proven speed countermeasures including describing their use and effectiveness in Vermont communities.

3. Create a clear and concise “Traffic Safety Toolbox” to support local decision-makers in villages and towns across Vermont

Section 2 provides an exhaustive review of the public-agency literature and the scholarly literature used in developing the information included in the Toolbox. Section 3 describes the selection of specific speeding countermeasures for Vermont, based on a subset of the public-agency literature reviewed. Section 4 describes the case studies and field tests conducted to supplement the profile sheets included in the Toolbox and Section 5 describes the development of the Toolbox itself. The final version of the Toolbox is included as an appendix to this report.

2 Literature Review

Although there is a large body of research establishing the effects of speed countermeasures on vehicle speeds, local officials face significant barriers to selecting and implementing effective countermeasures that meet their needs. Municipal decision makers must determine whether each countermeasure is appropriate in the context of a particular facility which may have specific design requirements (e.g. a state highway) as well as how to fund and implement the countermeasure. This requires navigating detailed roadway and countermeasure design standards and guidelines, understanding roles and responsibilities of federal, state, and local agencies, and reviewing the large body of documents pertaining to the effectiveness and applicability of speed countermeasures.

2.1 Public Agency Literature

2.1.1 Federal Guidance

In 1999, Reid Ewing presented the traffic calming state of the practice to the Institute of Transportation Engineers (ITE) (Ewing, 1999). These slides are intended to act as a guidance for transportation professionals in distributing information about traffic calming to their stakeholders and/or constituents. The following sections were introduced:

1. Introduction
2. Brief History of Traffic Calming
3. Toolbox of Traffic Calming Measures
4. Engineering and Aesthetic Issues
5. Traffic Calming Impacts
6. Legal Authority and Liability
7. Emergency Response and Other Agency Concerns
8. Warrants, Project Selection Procedures, and Public Involvement
9. Beyond Residential Traffic Calming
10. Traffic Calming in New Developments

These topics continue to be used in many traffic calming manuals and guidance documents. Amongst the 20 communities featured in this resource, we find a conspicuous lack of snowbelt communities (Figure 1).

Figure 1 20 communities featured by Ewing (1999)

This resource defines traffic calming as reducing traffic speeds but also adds the goal of reducing or preventing cut-through traffic in the interest of safety or livability. Other goals listed are crime prevention and urban redevelopment. The goal of preventing cut-through traffic still appears in some traffic manuals and guidance documents but the speed reduction goal pervades today (Ewing, 1999). The volume reduction and re-routing goals of some traffic calming efforts do not seem to be as well supported by the evidence. For example, in Ewing's 1999 slide resource, traffic safety improvements are given as a coarse crash count, rather than a crash rate, which would be more suitable for assessing safety improvements, especially since traffic calming measures are known to change traffic volumes (Ewing, 1999). The claims of crime reduction success in Dayton, Ohio are equally suspicious, and do not seem to be the types of measures that have endured with this topic. At first glance, these non-speed-related goals may simply consist of shifting issues with safety and crime to other neighborhoods.

However, this resource provides a useful history of traffic calming, noting that its origins are in Europe and that it was practiced earliest in the U.S. by Seattle (Ewing, 1999). Seattle's efforts in the 1970s seemed to consist primarily of the installation of circular diverters, similar to roundabouts, which are widely known today to reduce traffic speeds, improve safety outcomes, and improve emissions, as well as half-closures. These measures have both increased in use in the U.S. since that time, especially in the 1990s, when the consideration of traffic calming measures seems to have grown rapidly in the U.S. By 1999, hundreds of municipalities had installed speed humps, half-closures, or circular diverters (Ewing, 1999). He notes growing interest by ITE and the early presence of the Canadian Guide to Traffic Calming (TAC, 2018), whose current editions are discussed later in this document. He also notes that early efforts to institute traffic calming measures drew opposition from fire protection agencies due to concerns over access with larger, wider fire suppression vehicles. Evidence provided for effectiveness at the time seems to include sparse data, often from other jurisdictions, and most of the examples provided seem to be in residential suburbs.

By 2009, comprehensive design and implementation guidelines for engineering traffic calming measures are published by Reid Ewing in both the Institute of Transportation Engineers' (ITE) Traffic Engineering Handbook (Ewing and Gulden, 2009) and the U.S. Traffic Calming Manual (Ewing and Brown, 2009). The ITE handbook chapter appears to be more of a summary-level treatment of the topic than the U.S. Traffic Calming Manual, and there is significant overlap in the content of each. The Traffic Calming Manual contains the same concept-level design drawings as the ITE chapter, but more information and examples of design considerations. It also provides a complete traffic calming planning/guidance document for municipalities, including the process of developing a municipal plan and involving the community, a "toolbox" section consisting of descriptions and pictures of physical countermeasures, as well as sections on selection, design and implementation of calming measures (with concept drawings) (Ewing and Brown, 2009). Emerging new measures are discussed in these documents, as evidence that the field was still evolving at this time. Speed lumps are introduced as an emerging technology for speed reduction in the ITE handbook chapter (Ewing and Gulden, 2009), Appendix D of the U.S. Traffic Calming Manual (Reid and Brown, 2009) and detailed in a publication later the same year (Gulden and Ewing, 2009). The advantages of speed lumps over humps are that they are prefabricated modular humps of recycled rubber, so they are potentially removable, and they can be bypassed by emergency vehicles when installed correctly (Gulden and Ewing, 2009).

ITE also maintains a set of useful technical web resources. These include a technical resource web page dedicated entirely to Traffic Calming with a focus area dedicated to Traffic Calming Measures (https://www.ite.org/technical-resources/traffic-calming/traffic-calming-measures/), and a focus area dedicated to Measures for Managing Speed (https://www.ite.org/technical-resources/topics/speed-management-for-safety/measures-for-managing-speed/) within the technical resource dedicated to Speed Management for Safety. ITE's measures for managing speed are categorized as enforcement or Engineering, with the Engineering measures broken down as follows:

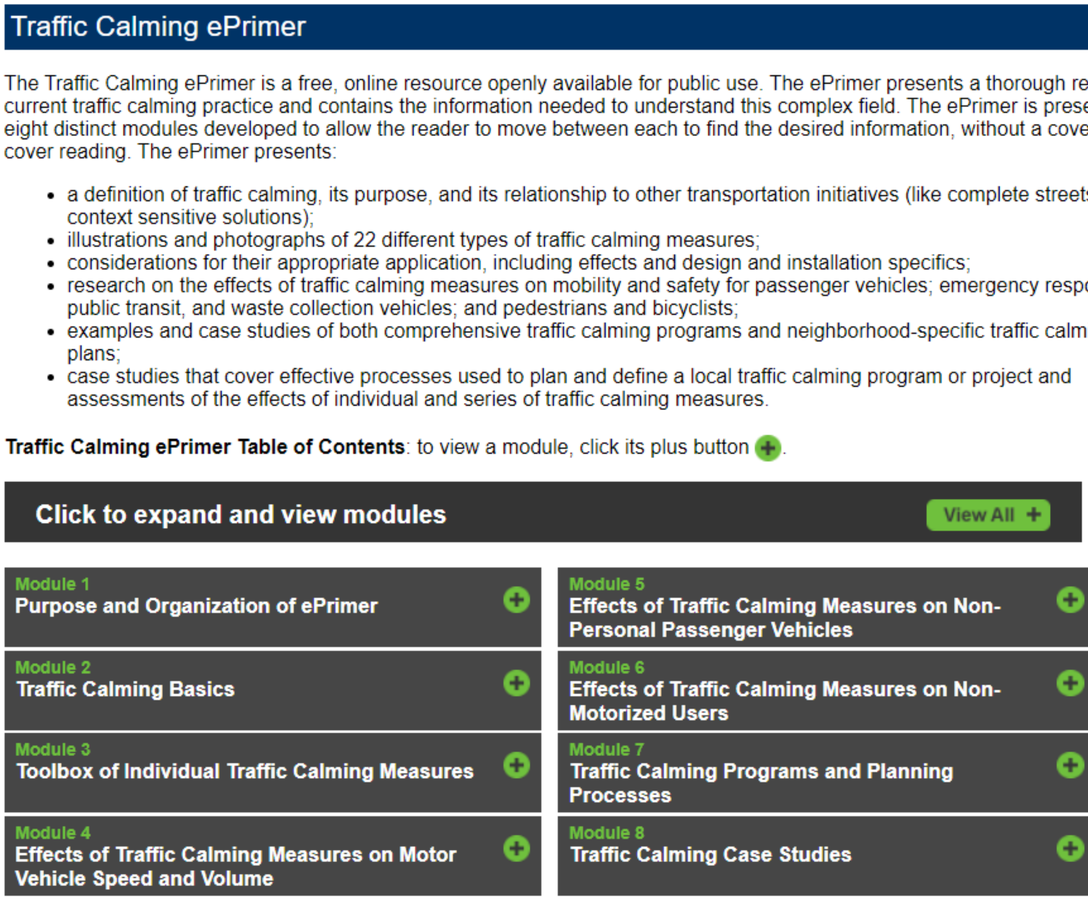
- Traffic Calming - combination of physical measures to reduce the effects of motorist behaviors and improve conditions for all street users.
- Self-enforcing road - a road that encourages drivers to select operating speeds consistent with the posted speed limit.
    - Horizontal deflection
    - Vertical deflection
    - Street width reduction

Individual measures are listed in each category and linked to a pdf fact sheet describing the measure.

In a 2013 report supported by the Centers for Disease Control, the connection between vehicle speeds and public health is advanced, with a call for policies and practices to reduce speeds in communities (McCabe et al, 2013). This report advocates for the installation of calming measures specifically to protect vulnerable users and reduce injuries and fatalities. Guidance documents from FHWA begin to appear around 2014, with a 2-page leaflet summarizing common speed management countermeasures – speed humps, speed feedback signs, roundabouts, road diets, and curve delineation (with signs) (FHWA, 2014). This leaflet makes frequent reference to a 2014 Desktop Reference of Potential Effectiveness in Reducing Speed which could not be found. In 2015, FHWA follows suit with ITE by publishing a Toolkit-style document, which provides the now-common matrix-style presentation of traffic calming countermeasures (FHWA, 2015). The FHWA toolkit is a landscape-oriented document with tabulated data presumably intended for quick reference by planners and designers in finding critical information about traffic calming treatments and their known effectiveness. The following tabulated references of effects on safety and speed reduction are provided for:

- Roadway Design and Traffic Calming
- Pavement Treatments, Markings, and Signs
- Traffic Speed Management and Operations
- Enforcement and Publicity measures

Safety improvement data is presented as crash modification factors specific to each measure, and speed reduction data is presented as the % reduction in 85th percentile speed for each measure (FHWA, 2015). FHWA follows up on this publication with a web resource containing a more technically exhaustive presentation of traffic calming and speed reduction measures, borrowing heavily from the ITE resources (FHWA, 2017). This Traffic Calming ePrimer is presented as a base web page (Figure 2) with an expandable table of contents which links to "modules" which are other web pages.


Traffic Calming ePrimer

The Traffic Calming ePrimer is a free, online resource openly available for public use. The ePrimer presents a thorough review of current traffic calming practice and contains the information needed to understand this complex field. The ePrimer is presented in eight distinct modules developed to allow the reader to move between each to find the desired information, without a cover-to-cover reading. The ePrimer presents:

- a definition of traffic calming, its purpose, and its relationship to other transportation initiatives (like complete streets and context sensitive solutions);
- illustrations and photographs of 22 different types of traffic calming measures;
- considerations for their appropriate application, including effects and design and installation specifics;
- research on the effects of traffic calming measures on mobility and safety for passenger vehicles; emergency response, public transit, and waste collection vehicles; and pedestrians and bicyclists;
- examples and case studies of both comprehensive traffic calming programs and neighborhood-specific traffic calming plans;
- case studies that cover effective processes used to plan and define a local traffic calming program or project and assessments of the effects of individual and series of traffic calming measures.

Traffic Calming ePrimer Table of Contents: to view a module, click its plus button.

Click to expand and view modules View All

Module 1
Purpose and Organization of ePrimer

Module 2
Traffic Calming Basics

Module 3
Toolbox of Individual Traffic Calming Measures

Module 4
Effects of Traffic Calming Measures on Motor Vehicle Speed and Volume

Module 5
Effects of Traffic Calming Measures on Non-Personal Passenger Vehicles

Module 6
Effects of Traffic Calming Measures on Non-Motorized Users

Module 7
Traffic Calming Programs and Planning Processes

Module 8
Traffic Calming Case Studies

Figure 2 Opening web page of the FHWA ePrimer (FHWA, 2017)

This document contains a more complete distillation of research on the effectiveness of these measures, along with more detailed design drawings, presumably borrowed from the Delaware guidance discussed later in this review. This time the research findings on the effectiveness of speed humps, speed tables, chicanes, and traffic circles in reducing speed are presented more objectively, and they note the effects on the 85th percentile speed and the maximum speed. Data is not presented for measures whose effects have not been well established in the literature (FHWA, 2017). The organization of this resource puts the selection and design guidelines up front, and the case studies and community-involvement toward the back – reversing the trend seen previously in the ITE documents (Ewing and Gulden, 2009).

A year later FHWA published a similar primer on its website focused on transition zones and town centers (FHWA, 2018). This primer was intended for rural communities that face the challenges of slowing traffic on high-speed state highways as it channels through rural villages and town centers. Much of the information presented is relevant to Vermont, including the context (Figure 3), the use of more of Vermont's peer states for examples (North Dakota, Maine, western Massachusetts, and Colorado), the consideration of case studies from snowbelt regions (Iowa and New Jersey) with removable devices, and guidelines for community involvement in the process of selecting and implementing speed reduction measures (FHWA, 2018).

Figure 3 Illustration of the context for transition zones and town centers (FHWA, 2018)

Another FHWA guidance document published in 2020 for the ITE focuses more on speed management, that is, the setting and enforcing of speed limits, than on specific speeding countermeasures (Hawkins and Hallmark, 2020). In fact, this document, which features a series of case studies, includes only one short chapter on traffic calming measures, which are distinguished here from enforcement actions as "self-enforcing roadways". However, in the brief chapter, an excellent case study is presented of the use of roundabouts and a center median to reduce speeding in the city of Golden, Colorado. This case study is applicable to Vermont's context, and shows that the 85th percentile of vehicle speeds were reduced from 48 to 33 mph, although this reduction includes the effects of additional nearby roundabouts (Ariniello, 2004).

The NHTSA also discussed countermeasures for speeding in the 10th edition of their guidance for state highway safety offices (Venkatraman et al., 2021). Chapter 3 of the guide covers countermeasures for speeding, but it only includes setting speed limits, and enforcing speed limits, not any engineering strategies associated with driver behavior change. No specific design or implementation guidance is provided.

2.1.2 Other National Guidance

In its chapter on Bicycle Boulevards, the NACTO Urban Bikeway Design Guide includes a discussion of self-enforcing measures to reduce the 85th percentile of vehicle speeds to 25 mph (NACTO, 2014). These are categorized as vertical and horizontal deflections, and largely reference design concepts from ITE (Ewing and Gulden, 2009) and APA (Ewing and Brown, 2009) for details. Measures recommended for consideration include:

- Vertical Deflections
    - Speed hump
    - Speed cushion or speed lump
    - Speed table
    - Split speed table
    - Raised crosswalk
- Horizontal Deflections
    - Curb extension or bulb-out
    - Edge island
    - Neighborhood traffic circle
    - Chicane
    - Pinchpoint, or choker
    - Neckdown
    - Center island
    - Skinny street

A useful aspect of the NACTO guide is its exceptional use of 3D concept illustrations for each measure, as shown in Figure 4 for a Pinchpoint implementation.

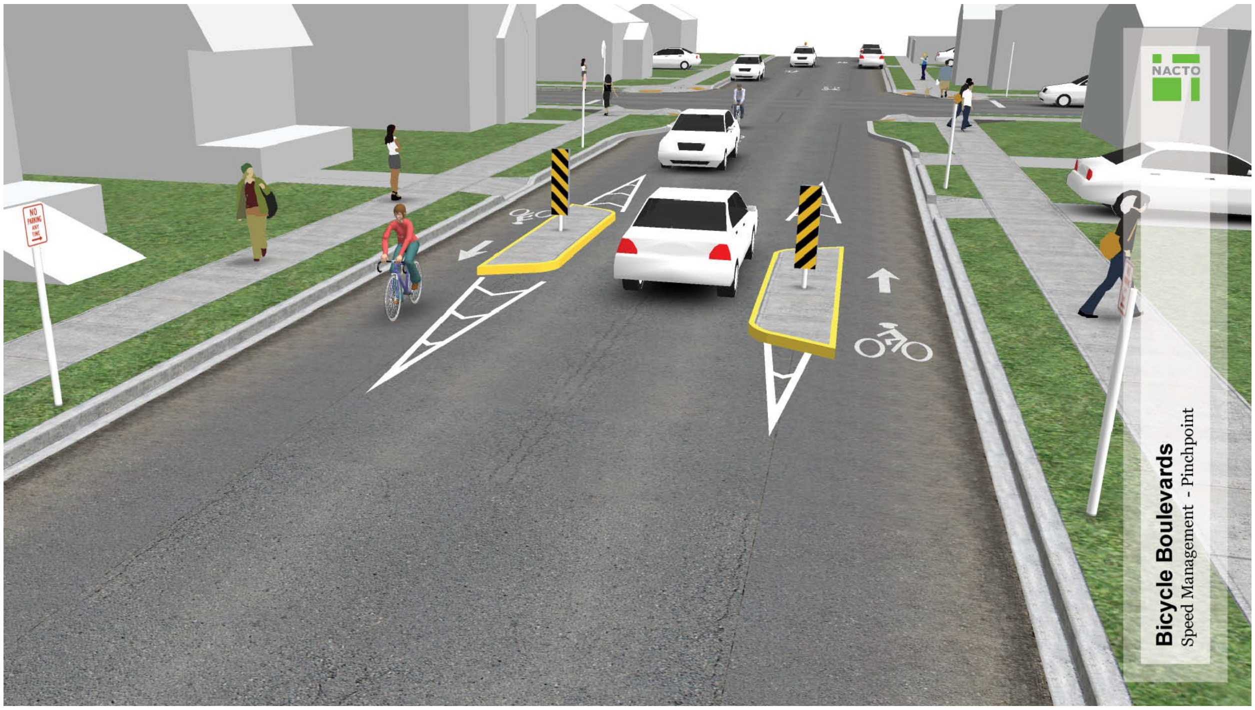


Figure 4 Pinchpoint concept illustration from the NACTO guidance (NACTO, 2014)

The Global Designing Cities Initiative (GDCI), which began as a program of the National Association of City Transportation Officials (NACTO), also publishes a Global Street Design Guide (GDCI, 2016), which features a section on traffic calming strategies with a more generalized and expanded list of measures:

- Lane Narrowing
- Corner Radii
- Buildings and Trees
- Gateway Treatments
- Pinchpoints
- Chicanes and Lane Shifts
- Medians and Refuge Islands
- Mini Roundabouts
- Speed Humps
- Speed Cushions
- Speed Tables
- Pavement Materials and Appearance
- Narrowing Two-Way Streets
- Signal Progression
- Diverters
- Shared Streets

These updated guidelines also include 3D illustrations of the calming measures.

2.1.3 Vermont Guidance

Traffic calming appears in the Chapter 11 (Specialized Design) of the 1998 publication of the Roadway Design Manual for the State of Vermont Agency of Transportation (VTrans, 1998). Generalized concepts are offered for 17 calming techniques in the following categories:

- Horizontal alignment changes
- Vertical alignment changes
- Surface treatments
- Other traffic calming techniques (road closures, reduced turn radii, and streetscaping)

The design manual notes that traffic calming should only be considered in locations with average daily traffic of less than 4,000 vehicles per day but lacks a description of the conditions appropriate for implementing specific traffic calming measures.

As early as 2003 in Vermont, an evaluation process and preliminary designs were being considered for traffic calming studies (BFJ, 2003). The state issued an official policy guideline for the use of speed feedback signs on state highways in 2009 (VTrans, 2009). This policy offered specific warrants for the consideration of these signs as traffic calming measures:

1. The 85th percentile speed, as determined by a speed study, exceeds the posted speed limit by at least 3 MPH during the time period of concern (e.g. the ½ hour before to ½ hour after a school arrival/dismissal time or other peak traffic period)
2. Where a speed transition exists (e.g. going from a 40 MPH posted speed to a 30 MPH posted speed or in a School Speed Zone)
3. Where the posted speed is 35 MPH or less

Radar speed feedback signs (RSFS) would only be considered where all of the warrants are met. The rest of the policy clarifies the technical requirements of the RSFS, presumably due to the presence of unwarranted or incorrectly installed RSFS by municipalities.

The Traffic Calming Manual for the City of Burlington (Stantec, 2020) notes that traffic calming is really only designed for streets with posted speeds less than or equal to 30 mph, and is appropriate when there is a problem with speeding, crashes, and truck volumes. A set of warrants is provided that must be met before a traffic calming measure is considered. Speed data collection over a 48-hour period may be necessary to determine the 85th percentile differential measurement, operating under typical traffic conditions. The Speed warrant is that the 85th percentile speed is greater than the posted speed. The manual points out that the process of considering and evaluating traffic calming measures is often more important than the selected speed countermeasures themselves.

Details of the following 13 calming measures are provided, along with a matrix of which of Burlington's street typologies are suited to each:

- Low-Impact Physical Design
    - Rumble Strips
    - Reallocation of Pavement Space
    - Curb Extension
    - Choker
    - Chicane
    - Speed Hump
- High-Impact Physical Design
    - Raised Crosswalk
    - Raised Intersection
    - Median Refuge Island (intersection treatment)
    - Median Island (midblock treatment)
    - Neighborhood Traffic Circle
    - Road Closure
- Other Traffic Calming
    - Parking Conversion (or modification of parking space)

References for the details are listed as FHWA (2017) and an ITE web resource that summarizes FHWA (2017). Other municipalities in Vermont also use the comparison of the 85th percentile speed with the posted speed limit to evaluate the need for traffic calming (RRPC, 2020). Critical Emphasis Area 2 of the 2021 Vermont SHSP (VHSA, 2021) is to "Curb Speeding and Aggressive Driving". Within that CEA, Strategy 4 is "Advance the use of infrastructure techniques and technology to manage and enforce speeds". However, the plan contains nothing else about traffic calming or speed reduction countermeasures.

A traffic calming toolbox subsection was included in a Traffic Calming Feasibility Study prepared for the town of Middlebury and the Addison County Regional Planning Commission in 2015 (ACRPC, 2015). 18 different strategies were highlighted in the toolbox, including advisory bike lanes for lower-volume roads. Overall, though, the document is focused on feasible countermeasures for a few small streets in the town, not for any of the multiple transition zones that enter the town.

2.1.4 Guidance from Other States

For most of Vermont's peer states (rural snow-belt), as recently as 2021 the term traffic calming is still suggested as a novel concept for its larger municipalities, with no known policy or design guideline. Two exceptions are New York State and Pennsylvania. The New York State DOT includes a chapter on traffic calming in it's Highway Design Manual (NYDOT, 1999). The NYDOT chapter provides general warrants, including community concerns and municipal calming plans in the decision process, on top of the typical warrants for traffic safety, speed, and volume. It also outlines a specific process for community involvement in the process.

The NYDOT design guidelines are provided for 4 speed categories, based on the design speed of the subject roadway:

I. 15 to 25 mph
II. 25 to 35 mph
III. 35 to 50 mph
IV. Greater than 50 mph

A cross-tabulation is provided to connect each of 9 categories of 46 calming measures with these 4 categories of speeds.

Pennsylvania's Traffic Calming Handbook (PennDOT, 2012) adds a summary of the history of traffic calming and a discussion of the legal issues associated with traffic calming measures. It also provides a guideline for the process of evaluating and implementing traffic calming measures, including the process for community involvement. 18 specific speed reduction measures in 4 categories (horizontal deflection, vertical deflection, physical obstruction, and signing / pavement marking) are then ranked and detailed.

An undated MaineDOT document was found which provides guidelines for the use of traffic calming devices. However, it appears to be a proposed policy. Other states (like New Hampshire) seem to leave the subject of traffic calming to the design standards already set for traffic calming measures, and the engineering processes previously developed for determining if warrants exist for installation of those devices. In these cases, the subject of traffic calming is not identified or distinguished.

Two other non-peer states have traffic guidelines that contribute to the state of the practice, South Carolina and Delaware (SCDOT, 2019; DelDOT, 2012). Delaware's guidelines contain some sections that are not present in other state guidelines. They specify a process for project development, but also provide direction for funding sources for implementing the measure, and for maintaining the project, which are important considerations for a constructed traffic calming measure. Guidelines are also provided for non-traditional measures, like neighborhood road signs (for placement on private property at the discretion of the homeowner), re-aligned intersections, and forced turn islands (DelDOT, 2012). Details are also provided for signage and markings associated with traffic calming measures. The guidelines also explicitly caution against the use of signage or measures that are not engineered in cooperation with DelDOT, which has been described as a problem in Vermont as well.

South Carolina's guidelines (SCDOT, 2019) are briefer, at only 9 pages of content, with specific construction details on a selected set of traffic calming measures:

- Speed Humps (Parabolic, Flat Topped)
- Raised Crosswalks and Raised Intersections
- Traffic Circles, Mini-Roundabouts, and Roundabouts
- Raised Landscaped Medians
- Road Closures
- Physically Reducing Lane Widths

The SCDOT guidelines refer frequently to the ITE guidance (Ewing and Gulden, 2009) and the DelDOT guidelines (DelDOT, 2012).

2.1.5 Canadian Guidance

The earliest references to traffic calming were found in Great Britain in 1992 (DCC, 1992). However, to capitalize on its relevance to the Vermont context, the review of international resources was focused on Canada. For example, most of the Canadian sources reviewed took note of the need to consider snow and ice control when implementing traffic calming measures.

Canada publishes a Canadian Guide to Traffic Calming (TAC, 2018) which was not reviewed due to its high cost ($225). However, four different Canadian municipalities were found to publish traffic calming guidance (Swan, 2019 (for Ottawa); Toronto, 2016; Kingston, undated; Hamilton, 2020), and all of them refer to the Canadian guide (TAC, 2018) for additional information and details. Toronto publishes a booklet called the 2016 Traffic Calming Guide for Toronto, which seems uniquely formatted to be digestible to a wide array of readers (Toronto, 2016). It contains a brief guidance of the policy, the warrants, and the process flowchart, along with a lookup table of measures and the most appropriate roadway for their use. The formatted pdf links the lookup table to a set of summary-level design guidelines, one example is shown in Figure 5 for Speed Humps.

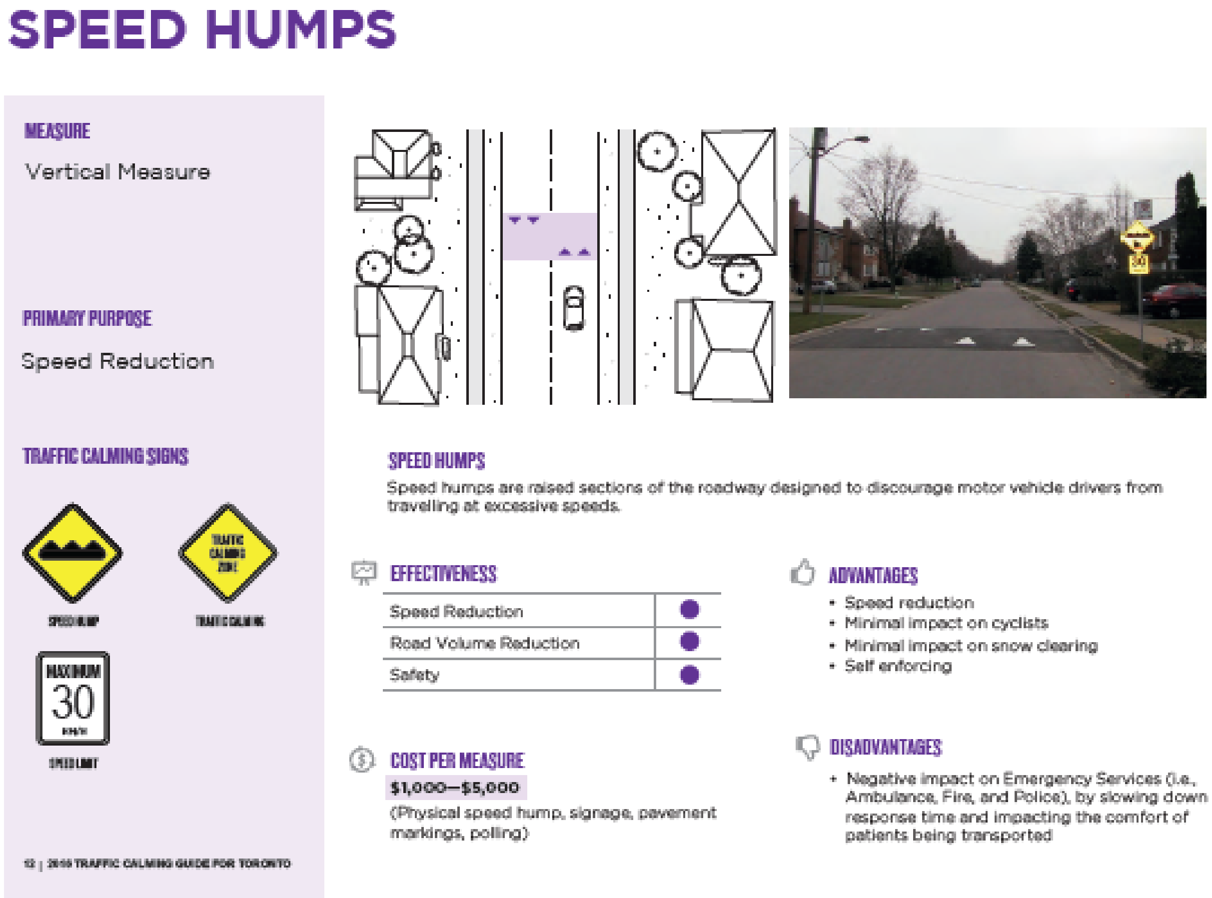


Figure 5 Toolbox fact sheet (Toronto, 2016)

The Kingston guidance takes the approach of deferring almost entirely to the Canadian guidance (TAC, 2018), while providing a "tool kit", or summary-level design guidelines that are presumably more digestible than those to be found in the national guidance. After a brief description of traffic calming measures by type (Type I – Minor adjustment measures and Type II – Engineered-based measures) and a reference to the design standards in the Canadian guidance (TAC, 2018), it launches into the Toolkit, which contains a summary description of 30 calming measures. Toolkit descriptions include applicability, potential benefits, design considerations, and other considerations, with an illustration of its use.

The Ottawa guidance (Swan, 2019) describes itself as an "Ottawa-specific" supplement to the Canadian guide (TAC, 2018), adding a Traffic Calming Toolbox to the elements found in other design guidance documents. The toolbox is a more digestible document than the guidance, including elements like lookup tables to determine the applicability of calming measures (Figure 6), and 3D illustrations to help explain certain design details (Figure 7).

The Ottawa guidance also contains some guidance on the use of temporary or seasonal measures, as might be needed for a “pop-up” style implementation or a ground-level measure that might interfere with snow and ice control or become non-functional when covered with snow:

- removable rubber products (e.g. curbing, speed humps, tables, cushions);
- removable / flexible posts and bollards;
- pavement markings; and
- temporary speed display boards.

Measure	Location Applicability ✓ Generally Applicable O Use with Care × Nominal to Low Applicability * Depending on the local context criteria (i.e. Traditional Mainstreets, Village Mainstreets, etc.), the measure indicated may or may not be appropriate for the street classification.		
	Local / Collector Streets	Major Collector / Urban Arterial Streets	Rural Arterial Streets
Communication and Enforcement			
Information Signage	✓	✓	✓
Speed Display Device	✓	✓	✓
Educational Campaigns	✓	✓	✓
Minor Adjustments			
Full-lane Transverse Bars	✓	O	✓
On-Road Messaging	✓	✓	✓
Street Parking	✓	O	×
Vertical Centreline Treatments	✓	×	✓
Engineering			
Vertical Deflection			
Raised Crossings	✓	×	×
Raised Intersections	✓	×*	×
Speed Cushions	✓	×	×
Speed Humps / Tables	✓	×	×
Horizontal Deflection			
Chicanes (one-way streets)	Locals Only	×	×
Chicanes (two-way streets)	✓	×	×
Corner Tightening / Curb Radius	[illegible]	[illegible]	[illegible]

Figure 6 Ottawa acceptability/applicability table (Swan, 2019)

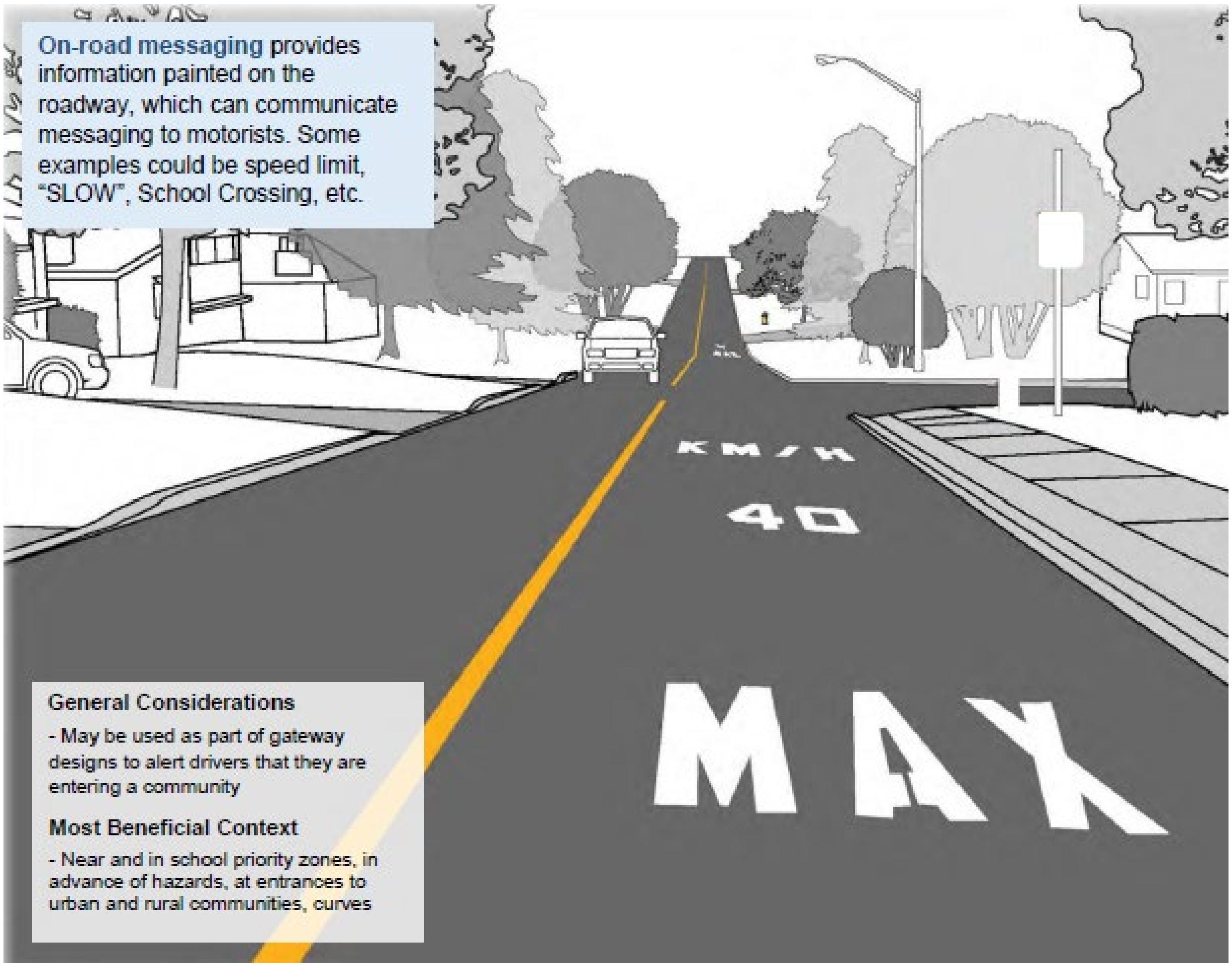


Figure 7 Ottawa 3D illustrations for speeding countermeasures (Swan, 2019)

Overall, the Ottawa guidance is the most exhaustive Canadian guidance found, including:

- Traffic Calming Plans, including a description of public and stakeholder involvement
- Design Considerations, including Ottawa-specific considerations (accessibility and equity, active transportation, transit, street maintenance (including snow and ice control), and emergency response) and references to the Canadian guidance (TAC, 2018)
- Temporary / Seasonal Measures
- Quality Control
- Public Education
- Comprehensive Appendices
    - Traffic Calming Implementation Options
    - Potential Traffic Calming Stakeholders
    - Comparison of Various Forms of Vertical Deflection Traffic Calming

- Key Emergency Response Streets Identified by Fire and Paramedic Services
- Traffic Calming Design Guidelines Feedback Form
- Log of Changes to the Traffic Calming Design Guidelines

Ottawa's guidance was the first found to mention the use of transverse rumble strips as a perceptual calming measure.

The Hamilton guidance (2020) distinguishes "passive" and "physical" types of calming. RSFS are considered an example of a passive calming measure, but in other sources that type of measure was referred to as "perceptual" as opposed to "engineered" or "self-enforcing". Hamilton identifies three types of physical measures – vertical, horizontal, and obstructions, and describes the complete process of considering and evaluating the conditions for a traffic calming measure, including data collection, if necessary. The policy requirement is also described for a formal traffic calming plan document, including the findings of the evaluation, the preferred alternative, and design considerations.

Although published in the Journal of Civil Engineering and Architecture, speed reduction countermeasures guidance for Quebec are provided by Berthod and Leclerc (2013). This article summarizes efforts by the Quebec Ministry of Transport to distill its most popular traffic calming measures into a series of fact sheets that are more digestible for its municipalities. Each fact sheet includes:

- the implementation context for the measure;
- advantages and disadvantages;
- geometry;
- signage;
- effectiveness at reducing speed and road safety;
- costs;
- references.

The Ministry conducted a survey of its municipalities to determine what the most common measures in use or being considered are. The top 4 measures in 2009 were speed humps (and cushions), raised and/or textured crosswalks, raised intersections, and reduction of the width of the street.

This article also notes the importance of considering winter snow and ice control in the implementation of speed countermeasures. However, the authors also note that speeding is not as much of a problem for municipalities in Quebec, based on complaints received. For these reasons, and the threat of damage to snow removal equipment, or deterioration of installed measures from salt, some municipalities in Quebec use temporary measures that are removed in winter. However, it is noted that snow removal will likely be more costly once a speed countermeasure is installed, particularly in the case of a vertical deflection like a speed hump. The authors focus in this publication on speed humps and speed cushions, two of the most widely used vertical deflections in Canada and worldwide. A speed cushion is similar to a speed hump, except that the width of the raised section is reduced so that emergency vehicles can pass over it but passenger vehicles can not. Speed cushions can be removable. The rest of the article provides the information used to populate the fact sheets for these two countermeasures.

2.1.6 Questions Remaining

After reviewing the regulatory guidance, a few questions remain about the specific methods used to measure effectiveness of traffic calming efforts. Research questions surround the site-specific geography of before/after testing, as well as the specific comparison methods used to assess the before/after data. Most of the guidance documents refer to reductions in the 85th percentile of speed, and some also refer to maximum speeds. However, it was not clear if distributional comparisons were attempted, and if they would support the 85th percentile findings. It was also not clear how long speed measurements were collected before the installation and after the completion of construction. The U.S. Traffic Calming Manual (Ewing and Brown, 2009) mentions using 6 months of data, but that may not be adequate for an installation in a community with four seasons and heavy snow. Additionally, adequate time should be given for motorists to become accustomed to the change before "after" speed measurements are collected.

Site-specific locations for data collection are also a concern. For example, the reductions reported by Ariniello (2004) are associated with a single roundabout, but actually occur on a roadway with a series of 4 consecutive roundabouts. It is important to better understand how the speeds throughout the 4-roundabout system have changed. There may be intermediate locations where speeds are not reduced, or even increased, as motorists try to maintain a similar travel time with the new design. It might be more effective to come up with a "zone of influence" for each measure, ebbing the distance upstream and downstream that speeds are reduced, instead of a measure of reduction in the 85th percentile of speeds. It is also unclear how some of the reductions were determined, whether through a before/after data collection at the installation site, or through the pairing of the installation site with a similar uncalmed site nearby.

2.2 Scholarly Literature

With these questions in mind, an investigation and review of the scholarly literature was undertaken, using the key words traffic calming, speed reduction, and speeding countermeasures. To limit the search, studies newer than 6 years whose findings are not likely already incorporated into the regulatory guidance documents were given preference, as were studies with real-world data collected in small rural northeastern U.S. communities. The following types of studies were avoided or excluded:

- Studies focused solely on the effect of speed countermeasures on crashes and crash severity
- Studies focused solely on enforcement or regulatory deterrents to speeding
- Studies focused on the influence of media and non-infrastructure counter measures on driver behavior
- Studies focused on areas very unlike Vermont (New York City, Southeast Asia, Ghana, etc.)

2.2.1 Studies using a trajectory along a segment instead of a single point in the measurement of speed

A comprehensive study from Denmark attempts to answer many of these questions (Agerholm et al, 2017) with regard to the design of speed humps and chicanes. They look at the effect of a variety of speed hump designs on the mean speed, 85th percentile, maximum speed, and standard deviation of speeds to measure before/after effects using floating car data. An advantage of this study is that the use of floating car data allowed speeds across the entire length of the road segment where the measure was installed to be used, as opposed to only using point speeds at the precise location where the measure was installed. The effects of chicanes were found to be less desirable, with a lower reduction of mean speeds on the segment and an increase in speed variance in some locations on the segment. This is contrasted with speed humps, which showed reductions in the mean, the 85th percentile, and the variance of the speeds on the segment. The only drawback to this study is that the floating car data did not include winter driving, which is of interest in Vermont.

Another study of speeds from the same research group in Denmark, also using floating car data, employed a regression analysis with street characteristics (including the presence of traffic calming) as the independent variables, and mean, 85th percentile, and max speeds as the dependent variables (Jorgensen et al., 2013). This study found that none of the specific calming measures was nearly as important as the spacing between calming measures. With spacing of about 150 meters or less, the effects of the calming measures on overall speeding on the segment are minimal.

A study of traffic calming measures' effects on speeding in Iran, although not relatable to Vermont climatologically, did consider rural transition zones as the focus for its investigation (Akbari and Haghighi, 2020). Using a driving simulator along with a variety of transition zones with and without traffic calming signs and pavement markings intended to alert drivers to the speed limit reduction. The authors compared mean speeds and lateral position using a MANOVA analysis, and found reductions in mean speed and improvements in lateral position to be statistically significant for all calming measures employed. Interestingly, none of the measures tested involved actual physical adjustments to the roadway, all interventions were perceptual. Although the use of pavement markings for reducing speeds is potentially problematic in Vermont, they also noted that the use of custom speed-warning signs with text on them improved drivers attention to them. In some cases these signs were nearly as effective as the pavement markings (Akbari and Haghighi, 2020).

Gitelman et al. (2020) used a survey of drivers to collect drivers' opinions about appropriate speeds instead of collecting speed data. Multivariate regression models were then developed to examine the relationship between street characteristics, finding higher pedestrian activity, visual narrowing, and presence of non-signalized junctions to be important.

Antic et al (2013) measured spot speeds 40 meters upstream, at, and 40 meters downstream of speed bumps of varying heights to evaluate their impact on speeds one day, and 30 days, after installation. Their evaluation was done using an ANOVA analysis, but it was not clear if the same days of the week were measured, or if other unusual traffic conditions were present to make the comparison inaccurate. In addition, other research suggests that it may take travelers up to 2 months to find a new network equilibrium after a change to the network (Zhu et al., 2010).

Brewer et al (2018) investigate the need for speed reduction measures on approaches to roundabouts on high-speed roadways. Since safely navigating a roundabout requires speeds of 20-25 mph, finding a measure to effectively reduce speed on the approach will allow roundabouts to be used more widely on roadways with speed limits of 45 mph or more. However, the authors simply summarize the existing guidance on speed countermeasures but do not provide results or data specific to the case of roundabout approaches.

2.2.2 Studies with findings about the use of signs and perceptual measures for reducing speed

Akbari and Haghighi (2020) investigate the effects of a variety of pavement markings on speed reduction and lateral position in transition zones in Iran. Their test, though, takes place with the use of driving simulator, offer more flexibility in the variation of parameters of the markings – continuous peripheral markings, hatched markings, and transverse rumble strips. They found each of the speeding countermeasures tested to be effective at reducing overall speeds from around 90 km/h to as low as 60 km/h. Ambros et al (2021) used reported speed preference to compare the potential incidence of speeding with perceptive roadway factors, including road width, roadside vegetation, pedestrian crossings, paved shoulders, and safety barriers. Width, roadside vegetation, and pedestrian crossings were found to be statistically significant in the model at predicting the driver's preferred speed. Ding et al (2020) evaluate the effects of peripheral transverse line markings (PTLMs) on speed and headway in a variety of angles and spacing in China. PTLMs are used on the road surface to enhance the driver's visual perception of their speed, and often to provide the perception that speed is increasing when it is not, thereby causing the driver to reduce speed.

2.2.3 Studies that used a more comprehensive comparison than change in 85th percentile of speeds

Most scholarly studies do not rely solely on measured changes in the 85th percentile of speeds to assess the effectiveness of speeding countermeasures. Although the 85th percentile is used extensively by practitioners, it is effectively an arbitrary percentile to attribute the entire measured reduction to. More comprehensive statistical tests are preferable, like the multivariate analysis of variance (MANOVA) used by Akbari and Haghighi (2020). Ambros et al (2021) and Gitelman et al (2020) used linear regression models and mixed-effects models to determine the relationships between speed indicators, but also to explain the speed indicators with roadway characteristics and personality characteristics of drivers.

Anderson et al (2022) conducted rudimentary comparisons of the mean, median, and 85th percentile of speeds, but also created a series of regression models comparing speeds. The models included a binary dummy variable identifying whether the speed occurred before or after a city-wide reduction in speed limits in Portland, Oregon. This approach was significant because although they found that speed reductions were statistically significant, they also noted that the reductions were very small, and not evident in the rudimentary comparison alone.

Ding et al (2020) used a two-way ANOVA analysis to evaluate the effects of intersecting angle and spacing of PTLMs on speed reductions, finding that all of their configurations reduced speed with statistical viability. The greatest reduction came from PTLMs with a roadway angle of 150 degrees, and a spacing of 2 meters. 90-degree PTLMs are perpendicular to the traffic flow, but the 150-degree PTLM is angled against the traffic flow (Figure X). This configuration was shown to reduce speeds, on average, 1.5 m/s (3.36 mph). The authors argue that even a reduction of this minor amount has a significant effect on traffic safety on high-speed highways, as their test section was on a 50-mph rural highway.

3 Selection of Speeding Countermeasures for Vermont

Many rural communities have different needs than their urban and suburban counterparts, which affects the suitability of many speeding countermeasures. One of the biggest challenges for rural communities is managing speeds in transition zones where drivers entering a village or town center must be made aware of reduced speed limits. Vermont's particular context is unique, in that it is a rural northern state where the presence of snow and ice on its roadways is a concern for nearly half the year, and traffic volumes are higher than expected due to the presence of visitors from surrounding metropolitan areas on its roadways.

With this context in mind, a set of feasible speeding countermeasures for Vermont was selected in collaboration with the project's technical advisory committee (TAC) through a series of meetings in June, August, and October of 2022. Initially, a broader set of countermeasures was drawn from literature, then distilled to regions with similar characteristics to Vermont and from the FHWA guidance on traffic calming in transition zones (FHWA, 2018). Similar regions included the Province of Quebec (Berthod and Leclerc, 2013), the city of Kingston, Ontario (Kingston, undated), and the city of Ottawa, Ontario (Swan, 2019). After this process, 14 countermeasures were selected for inclusion in the Vermont toolbox. One last countermeasure was added as a follow-up with the Minnesota DOT (MnDOT, 2022) following a TAC member's suggestion, bringing the list to 15:

- Horizontal deflections
    - Lane or street narrowing
    - Lateral shift
    - Bulbout / pinchpoint / choker
    - Median island
    - Mini-roundabout
    - Neighborhood traffic circle
- Vertical deflections
    - Speed hump or cushion
    - Raised crosswalk / speed table
    - Raised intersection
- Perceptual, or passive, measures
    - Road diet
    - Radar speed feedback signs
    - Transverse line markings
    - Gateway signing/landscaping
    - Transverse mumble strips
    - [SLOW] / [-- MPH] pavement word marking

Each of these countermeasures are included and described in at least one of the Vermont guidance documents reviewed, so there do not seem to be any potential conflicts between recommending these countermeasures to consider and existing guidance in Vermont.

Once the set of countermeasures to be included in the Toolbox was agreed upon, the research team offered a selection of templates for the profile sheets for the TAC to choose from. Votes for each TAC members top 3 choices were solicited, and the template receiving the highest number of first or second-place votes was used for the development of the 15 profile sheets.

4 Case Studies and Field Tests

To further enhance the relevance of the Toolbox to the experiences of Vermont towns, a series of case studies and field tests were conducted at selected towns throughout the state for inclusion in the Toolbox.

The case studies consisted of identifying and interviewing contacts at selected towns with experience in the selection and implementation of speeding countermeasures. Towns were identified with input from the TAC supplemented by a review of the online press to find notable examples (Table 1).

Table 1 Initial list of VT towns identified for case studies

Town	Countermeasure(s) Implemented	Status
Brattleboro	Narrowed lanes Gateway signing	Implemented
Bethel	Portable bulbouts	Implemented
Bristol	Vertical deflections	Planned
Lincoln	Advisory shoulders Radar speed feedback signs (RSFS)	Implemented
Vergennes	Bulbouts RSFS	Implemented
Middlebury	Bulbouts and on-street parking	Implemented
Newfane	RSFS	Implemented
Burlington	Raised intersection	Implemented
Williston	Speed table	Implemented

From these towns, the research team reached out to relevant contacts for an interview. The final set of case studies consists of the towns that were willing to provide an interview for inclusion in the Toolbox – Lincoln, Middlebury, Newfane, and Williston.

The final case studies included in the Toolbox provide specific examples of the implementations of speeding countermeasures in Vermont for a better understanding of context and an opportunity for a real-world example that can be visited and reviewed. Additionally, the case studies provide a contact from a Vermont village or town center who can attest to the lessons learned from the implementation. Lessons learned include examples of unsuccessful and successful implementations.

The field tests consisted of identifying transition zones throughout the state where speeding is or was a problem for a village or town center and speeding countermeasures have been implemented or are being considered. From the initial set of sites identified by the research team, a subset was identified where field data collection would be feasible. For the subset of sites, the research team collected comprehensive hourly speed and volume data for the transition direction of flow after the lowest reduced speed limit posting. In most cases, this location coincided with the end of the state-maintained highway. The field tests demonstrate the type of speed data collection that is often needed to support implementation of speeding countermeasures by Vermont towns. They also provide a site-specific evaluation of the effectiveness of selected countermeasures in Vermont.

The first field test was conducted on VT-22A northbound transitioning from a 50 mph posted speed limit to a 30 mph posted speed limit where the state highway ends in the town of Vergennes. Gateway signing and a radar speed feedback sign (RSFS) on the 2nd 30 mph posting are currently used to discourage speeding in this transition zone. Data was collected about 200 feet past the 2nd 30-mph posting. The site is on a significant downgrade, which likely exacerbated speeding problems in this area.

The second field test, selected to compare to the Vergennes site, was on VT-30 northbound transitioning from 50 mph to 35 mph where the state highway ends in the town of Middlebury. Although the roadway narrows slightly at the 35 mph posting, no explicit countermeasures are in place to encourage reduced speeds. Data was collected about 200 feet past the 35 mph posting, where the site is on a significant upgrade.

The third field test was conducted on VT-125 eastbound transitioning from a 50 mph posted speed limit to a 40-mph posted speed limit, then down again to a 25-mph posted speed limit where the state highway ends in the town of Middlebury. After the 25-mph posting, a narrowed cross-section project consisting of crosswalks with bulbouts and on-street parking have been added to encourage reduced speeds. Data was collected about 200 feet past the 25-mph posting and the start of the road diet segment, where the site is on a slight upgrade.

The fourth field test, selected to compare to the Middlebury VT-125 site, was on VT-14 northbound transitioning from 50-mph to 40-mph, then again to 25 mph. The state highway ends at the 2nd 25-mph posting in the town of Hardwick. Although the roadway narrows slightly at the 2nd 25-mph posting, no explicit countermeasures are in place to encourage reduced speeds. Data was collected about 100 feet past the 2nd 25-mph posting, where the site is relatively flat.

For each field test, contact was made with the Vermont State Police, local police, local department of public works, and other relevant stakeholders before setting up the data collection. Data was collected using the mobile traffic monitoring platform (MTMP) shown in Figure 8.

For each case study and field test, a fact sheet was prepared summarizing the site, the effort by the research team and the results. For the field tests, the fact sheets contain details of the observation period for the data collection. Results of the case studies are presented as lessons learned; results for the field tests consist of a chart of the data collected and the conclusions drawn from the data.

Figure 8 The mobile traffic monitoring platform

5 Toolbox Development

The selection of a format for the Toolbox, and the selection of key design elements for the Toolbox heavily involved the input of the project TAC over a series of meetings in June, August, and October of 2022 and March of 2023. Based on the literature review, the research team offered the option of developing a Toolbox that would be either html-based, consisting of a series of web pages with appropriate linkages, or pdf-based, consisting of a stand-alone document with internal linkages and links to external resources on the web. These options were derived from the formats evident from other similar resources. Ultimately, it was decided that a pdf format would be preferable since some users might want to print the document and an html-based series of web pages would not facilitate printing. A pdf format would also be linkable from the VTrans Research website, and could be opened within most browsers, so it would essentially offer the same advantages of an html-based resource with improved opportunities for design and opportunities for dynamic linkages within the document and to external resources.

The next step was to select a design format for the speeding countermeasure profile sheets and for the fact sheets that would be used to document the case studies and field tests. The profile sheets are the primary content of the Toolbox so the selection of a template that would highlight these pages was critical. A set of 12 templates with free availability were identified by the research team and offered to the TAC for selection. The templates receiving the two highest rankings were selected for use in the Toolbox. The most preferred template was used as a basis for the profile sheets for the specific speeding countermeasures, and the second-most preferred template was used as the basis for the fact sheets used to describe the Case Study and Field Test sites.

To support the user's experience with the profile sheets, the team decided to add an applicability/acceptability (A/A) table as a linked navigation page. The A/A table is a common feature of almost all of the toolboxes identified during the literature review. The A/A table provides cross-tabulated information about the context within which each countermeasure is best suited (in a transition zone, or within the village or town center itself), and how it fares across a series of criteria:

- Snow and ice control
- Emergency response
- Cost / maintenance
- Speed reduction potential

Additionally, columns were added to describe the relative frequency of use of the countermeasure in Vermont and its acceptability on state highways. The cells in the A/A table contain a three-tiered evaluation scoring, consisting of:

- ++ most favorable / most common
- \+ moderately favorable / moderately common
- – not favorable / not common

Initially, the research team populated the A/A table with scores that were derived from the literature most relevant to the Vermont context. To enhance the relevance of the A/A table to the Vermont context, it was also circulated to the TAC for independent scoring. Six TAC members provided independent scores for each cell in the table. Their scores were averaged and compared to the initial A/A table scoring from the literature. 96 of the 105 individual scores in the initial A/A table were in agreement with the averaged independent scoring received from the TAC members. Discrepancies were resolved in the final TAC meeting in March of 2023, resulting in a final A/A table with relevance to the Vermont context and a solid basis from the literature. Following the March 2023 TAC meeting, it was determined that a final column should be added to the A/A table to indicate its acceptability on state-maintained highways in Vermont (Table 2).

Table 2 Applicability / Acceptability Table for Speeding Countermeasures in Vermont

++ most favorable / most common + moderately favorable / moderately common – not favorable / not common		Frequency of Use in Vermont	Snow and Ice Control	Emergency Response	Cost / Maintenance	Speed Reduction Potential	Within Village or Town Center (< 35 mph)	Transition Zone (> 35 mph)	Acceptable on VT Highways?
Type	**Speeding Countermeasure**								
Horizontal deflections	Lane or street narrowing	+	+	+	+	+	++	++	seek
	Lateral shift	+	+	+	+	+	+	+	seek
	Bulbout / pinchpoint / choker	+	+	+	+	+	++	–	seek
	Median island	+	+	+	+	+	+	+	seek
	Mini-roundabout	+	–	+	–	++	++	–	seek
	Neighborhood traffic circle	+	+	+	–	++	++	–	no
Vertical deflections	Speed hump or cushion	+	–	+	–	++	++	–	no

++ most favorable / most common + moderately favorable / moderately common – not favorable / not common		Frequency of Use in Vermont	Snow and Ice Control	Emergency Response	Cost / Maintenance	Speed Reduction Potential	Within Village or Town Center (< 35 mph)	Transition Zone (> 35 mph)	Acceptable on VT Highways?
Type	**Speeding Countermeasure**								
	Raised crosswalk / speed table	+	–	+	–	++	++	–	no
	Raised intersection	–	–	+	–	++	++	–	no
Perceptual, or passive, measures	Road diet	+	++	++	+	+	++	+	seek
	Radar speed feedback signs	++	++	++	+	+	++	+	seek
	Transverse line markings	+	++	++	+	+	+	++	no
	Gateway signing / landscaping	++	++	++	++	+	–	++	seek
	Transverse mumble strips	–	+	+	+	+	+	+	no
	[SLOW]/[-- MPH] pavement word marking	–	++	++	+	+	+	–	no

Following the March 2023 TAC meeting, additional text was added to the Toolbox introduction and describing the countermeasure profile sheet, case study and field test sections. After some introductory text defining speeding countermeasures and explaining the purpose of the Toolbox, there is a subsection on the importance of considering maintenance in the selection of countermeasures. Another subsection was added to clarify the definitions of roadway features that are frequently mistaken as speeding countermeasures.

Finally, the profile sheets were populated with a selection of photographs, diagrams and illustrations and brief sections on the appropriate context and design considerations for each countermeasure were added. Sources were included at the bottom of each profile sheet to provide the user with links to find additional detailed information about the countermeasure, and a complete list of resources used to build the Toolbox was added at the end of the document, Once the pdf document pages had been compiled, linkages were created to make the document more dynamic and user-friendly:

- Created links to the profile sheets from each countermeasure name in the A/A table
- Created links to the case study and field test fact sheets from the profile sheets where they are mentioned under "Use in Vermont"
- Created links back to the Toolbox table of contents from each profile sheet and fact sheet
- Created links to the Resources page at the end of the document from the sources listed at the bottom of each profile sheet
- Created links to the live Google Streetview from all Google Streetview images used in the profile sheets
- Created links to the field test fact sheets from their mention in the introductory text
- Created links to the live web location of each resource from the list of Resources at the end of the document

The final Toolbox is included as an Appendix to this report.

6 References

ACRPC, 2015. Traffic Calming Feasibility Study. Prepared for the Town of Middlebury, Addison County Regional Planning Commission by DuBois & King, Inc., December, 2015.

Agerholm, Niels, Daniel Knudsen, Kajan Variyeswaran, 2017. Speed-calming measures and their effect on driving speed – Test of a new technique measuring speeds based on GNSS data. Transportation Research Part F: Traffic Psychology and Behaviour, Volume 46, Part B, April 2017, Pages 263-270.

Akbari, Ali, and Farshidreza Haghighi, 2020. Traffic calming measures: An evaluation of four low-cost TCMs' effect on driving speed and lateral distance. IATSS Research Volume 44, Issue 1, April 2020, Pages 67-74.

Ambros, Jiří, Richard Turek, Eva Šragová, Kryštof Petr, Matúš Šucha, and Jindřich Frič, 2021. How fast would you (or should you) drive here? Investigation of relationships between official speed limit, perceived speed limit, and preferred speed. Transportation Research Part F: Traffic Psychology and Behaviour, Volume 83, November 2021, Pages 164-178.

Anderson, Jason C., Christopher Monsere, and Sirisha Kothuri, 2022. Effect of Residential Street Speed Limit Reduction on Driving Speeds in Portland, Oregon. Findings, January 2022.

Ariniello, A. J., 2004. Are Roundabouts Good for Business? Conference Paper for the Transportation Research Board's National Roundabout Conference, Vail Colorado, December 2004.

Berthod, Catherine and Carole Leclerc, 2013. Traffic Calming in Québec: Speed Humps and Speed Cushions. Journal of Civil Engineering and Architecture. Apr. 2013, Volume 7, No. 4 (Serial No. 65), pp. 456-465.

BFJ, 2003. The Vermont Agency of Transportation Traffic Calming and Approval Process for State Highways. Prepared by Buckhurst Fish & Jacquemart, Inc (BFJ) in association with Stevens & Associates, P.C. for the Vermont Agency of Transportation with the Windham Regional Commission, September 2003.

Boodlal, Leverson, Eric T. Donnell, Richard J. Porter, Dileep Garimella Thanh Le, Kevin Croshaw, Scott Himes, Philip Kulis, and Jonathan Wood, 2015. Factors Influencing Operating Speeds and Safety on Rural and Suburban Roads. Publication no. FHWA-HRT-15-030 of the Turner-Fairbank Highway Research Center, Federal Highway Administration, May 2015.

Brewer, Marcus A., Tomas Lindheimer, and Susan T. Chrysler, 2018. Treatments for Speed Reduction on High-Speed Approaches to Roundabouts. Paper No. 18-03268 of the Transportation Research Board 97th Annual Meeting, Washington DC, United States, January 2018.

Cooper, Ryan and Sam Wright, 2014. Centreline Removal Trial. Prepared by Outcomes Design Engineering, Road Space Management Directorate, Surface Transport, Transport for London, August 2014.

DCC, 1992. Traffic Calming Guidelines. Devon County Council, Engineering and Planning Department, Devon County, Great Britain.

DelDOT, 2012. Delaware Traffic Calming Design Manual, 2012 Edition. Updated in 2012 by the Delaware Department of Transportation, Traffic Section with the assistance of Rummel, Klepper & Kahl, LLP.

Ding, Naikan, Shunying Zhu, Nisha Jiao, and Bing Liu, 2020. Effects of peripheral transverse line markings on drivers' speed and headway choice and crash risk in car-following: A naturalistic observation study. Accident Analysis & Prevention, Volume 146, October 2020.

Distefano, Natalia, and Salvatore Leonardi, 2019. Evaluation of the Benefits of Traffic Calming on Vehicle Speed Reduction. Civil Engineering and Architecture 7(4): 200-214, 2019.

Ewing and Brown, 2009. U.S. Traffic Calming Manual. First published in 2009 by the American Planning Association; published in 2017 by Routledge. Available for purchase at https://www.amazon.com/U-S-Traffic-Calming-Manual-Ewing/dp/1932364617

Ewing, Reid, 1999. Traffic Calming State of the Practice. Prepared for the Institute of Transportation Engineers with funding from the Federal Highway Administration, September 1999.

Ewing, Reid, and Jeff Gulden, 2009. Traffic Calming. Chapter 15 of the Institute of Transportation Engineers' Traffic Engineering Handbook, 6th Edition, 2009.

FHWA, 2010. Mini-Roundabouts: Technical Summary. Report No. FHWA-SA-10-007 of the U.S. Department of Transportation Federal Highway Administration.

FHWA, 2014. Speed Management Countermeasures: More than Just Speed Humps. Publication no. FHWA-SA-16-077of the Federal Highway Administration Office of Safety, 2014. Accessed on January 22, 2022 at https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa16077/fhwasa16077.pdf.

FHWA, 2015. Speed Management Toolkit. Publication no. FHWA-SA-15-017 of the Federal Highway Administration Office of Safety, 2015.

FHWA, 2016a. Low-Cost Treatments for Horizontal Curve Safety 2016. Report No. FHWA-SA-15-084 of the Federal Highway Administration Office of Safety, January 2016.

FHWA, 2016b. Small Town and Rural Multimodal Networks. Report No. FHWA-HEP-17-024 of the Office of Planning, Environment, and Realty of the Federal Highway Administration, December 2016.

FHWA, 2017. Traffic Calming ePrimer. Free online resource of the Federal Highway Administration Office of Safety Programs. Updated February 2017. Accessed on January 22, 2022 at https://safety.fhwa.dot.gov/speedmgt/traffic_calm.cfm.

FHWA, 2018. Speed Management ePrimer for Rural Transition Zones and Town Centers. Free online resource of the Federal Highway Administration Office of Safety Programs. Updated January 2018.

GDCI, 2016. The Global Street Design Guide. Published by the Global Designing Cities Initiative, the National Association of City Transportation Officials, and Island Press with funding from the Bloomberg Philanthropies, 2016.

Gitelman, Victoria, Pesahov, Fany, and Carmel, Roby, 2020. Speed perception by drivers as dependent on urban street design; a case-study. Transactions on Transport Sciences, 11(2), 5–18.

Gulden, Jeff and Reid Ewing, 2009. New Traffic Calming Device of Choice. Published in the ITE Journal, December 2009.

Hallmark, Shauna L., Neal Hawkins and Skylar Knickerbocker, 2015. Use of DSFS as a Speed Transition Zone Countermeasure in Small, Rural Communities. 2015 IEEE 18th International Conference on Intelligent Transportation Systems.

Hamilton, 2020. City of Hamilton Traffic Calming Policy. Appendix "A" to Report PW20044. City of Hamilton Public Works Department, July 2020.

Hawkins, Neal and Shauna Hallmark, 2020. Noteworthy Speed Management Practices. Publication no. FHWA-SA-20-047 of the Federal Highway Administration Office of Safety prepared by the Institute of Transportation Engineers, August 2020.

Hu, Wen, and Jessica B. Cicchino, 2020. The effects of left-turn traffic-calming treatments on conflicts and speeds in Washington, DC. Journal of Safety Research 75 (2020) 233-240.

Jørgensen, M., Agerholm, N., Lahrmann, H., and Araghi, B. N., 2013. Driving speed on thoroughfares in minor towns in Denmark. Paper presented at 26th ICTCT Workshop, Maribor, Slovenia.

Kingston, undated. City of Kingston Traffic Calming Guidelines. City of Kingston Department of Roads, Traffic, and Sidewalks.

Lav, A. Hakan, Ertugrul Bilgin, A. Hilmi Lav, 2018. A fundamental experimental approach for optimal design of speed bumps. Accident Analysis & Prevention, Volume 116, July 2018, Pages 53-68.

Li, Ran, Karim El-Basyouny, and Amy Kim, 2015. Before-and-After Empirical Bayes Evaluation of Automated Mobile Speed Enforcement on Urban Arterial Roads. Transportation Research Record: Journal of the Transportation Research Board, No. 2516, Transportation Research Board, Washington, D.C., 2015, pp. 44–52.

Matírnez, A., D.A. Mántaras, P. Luque, 2013. Reducing posted speed and perceptual countermeasures to improve safety in road stretches with a high concentration of accidents. Safety Science, Volume 60, December 2013, Pages 160-168.

McCabe, Kathleen, Karen Schoneman, and Mariana Arcaya, 2013. Community Speed Reduction and Public Health: A Technical Report. A report from Health Resources in Action, December 2013.

MnDOT, 2022. Rumble strips and stripes: What's the difference? Accessed at https://www.dot.state.mn.us/trafficeng/safety/rumble/index.html#:~:text=What%20are%20mumble%20strips%3F,not%20have%20the%20wave%20pattern

Mohammadipour, Amir, Alireza Mohammadipour & Seyed Hafez Alavi, 2020. Statistical analysis of geometric characteristics and speed reductions for raised pedestrian crosswalks (RPC), Journal of Transportation Safety & Security, 12:3, 380-399.

Montella, Alfonso, Francesco Galante, Filomena Mauriello, and Luigi Pariota, 2015. Low-Cost Measures for Reducing Speeds at Curves on Two-Lane Rural Highways. Transportation Research Record: Journal of the Transportation Research Board, No. 2472, Transportation Research Board of the National Academies, Washington, D.C., 2015, pp. 142–154.

MUTCD, 2009 (2022). The Manual of Uniform Traffic Control Devices for Streets and Highways, 2009 Edition. Including Revision 1 dated May 2012, Revision 2 dated May 2012, and Revision 3 dated July 2022. A publication of the U.S. Department of Transportation, Federal Highway Administration.

NACTO, 2014. Urban Bikeway Design Guide: Bicycle Boulevards. A publication of the National Association of City Transportation Officials, Second Edition, March 2014.

NHTSA, 2021. FARS Speeding Data Visualization. https://icsw.nhtsa.gov/nhtsa/fars/speeding_data_visualization/. Accessed Mar. 9, 2021.

NYDOT, 1999. Highway Design Manual, Chapter 25 - Traffic Calming (Revision 36). February 5, 1999.

PennDOT, 2012. Pennsylvania's Traffic Calming Handbook. Pennsylvania Department of Transportation Bureau of Maintenance and Operations (BOMO), Publication No. 383, July 2012.

Pérez-Acebo, Heriberto, Xabier Otxoa-Muñoz, Mikel Marquina-Llaguno, Hernán Gonzalo-Orden, 2021. Evaluation of the Efficiency of Traffic Lights Turning Red in Case of Exceeding Speed Limit with Previous Panels Indicating the Speed. Transportation Research Procedia Volume 58, 2021, Pages 45-52.

Richard, Christian M., Joonbum Lee, Randolph Atkins, and James L. Brown, 2020. Using SHRP2 naturalistic driving data to examine driver speeding behavior. Journal of Safety Research Volume 73, June 2020, Pages 271-281.

Rossi, Riccardo, Massimiliano Gastaldi, Francesco Biondi, Claudio Mulatti, 2013. Warning sound to affect perceived speed in approaching roundabouts: experiments with a driving simulator. Procedia - Social and Behavioral Sciences 87 (2013) 269 – 278.

Rossi, Riccardo, Massimiliano Gastaldi, Gregorio Gecchele, Francesco Biondi, and Claudio Mulatti, 2014. Traffic-Calming Measures Affecting Perceived Speed in Approaching Bends: On-Field Validated Virtual Environment. Transportation Research Record: Journal of the Transportation Research Board, No. 2434, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 35–43.

RRPC, 2020. Town Farm Road Traffic Study. Prepared for the Town of Brandon by the Rutland Regional Planning Commission. January 2020.

SCDOT, 2019. South Carolina Department of Transportation Traffic Calming Guidelines, Revised 2019. Prepared by the Traffic Engineering Section of the South Carolina Department of Transportation.

Stantec, 2020. Traffic Calming Manual: Burlington, Vermont. Prepared by Stantec for the City of Burlington Department of Public Works, October 2020.

Swan, J., 2019. Traffic Calming Design Guidelines. City of Ottawa Transportation Services Department, Area Traffic Management Branch, April 2019.

Swan, J., 2019. Traffic Calming Design Guidelines. City of Ottawa Transportation Services Department, Area Traffic Management Branch, April 2019.

TAC, 2018. Canadian Guide to Traffic Calming – Second Edition (2018). Publication PTM-TRAFCALM18-E of the Transportation Association of Canada, February 2018. Available for purchase at https://www.tac-atc.ca/en/publications/ptm-trafcalm18-e

Toronto, 2016. 2016 Traffic Calming Guide for Toronto. City of Toronto Transportation Services Division.

VCASLA, 2002. Landscape Guide for Vermont Roadways & Transportation Facilities. Prepared for the Vermont Agency of Transportation by the Vermont Chapter of the American Society of Landscape Architects, June 2002.

Venkatraman, V., Richard, C. M., Magee, K., & Johnson, K. (2021, July). Countermeasures that work: A highway safety countermeasures guide for State Highway Safety Offices, 10th edition, 2020 (Report No. DOT HS 813 097). National Highway Traffic Safety Administration.

VHSA, 2021. Vermont Strategic Highway Safety Plan, 2017-2021: A Comprehensive Plan to Reduce the Number of Crashes on Vermont's Highways. A publication of the Vermont Highway Safety Alliance, 2021.

VTrans, 1998. Roadway Design Manual for the State of Vermont Agency of Transportation, Chapter 11 (Specialized Design), Traffic Calming subsection.

VTrans, 2009. The State of Vermont Agency of Transportation Guidelines for the Use of Radar Speed Feedback Signs on the State Highway System. VTrans RSFS Guidelines with Policy #3014, January 2009.

VTrans, 2012. Complete Streets Guidance. Prepared by the Vermont Agency of Transportation, March 2012.

VTrans, 2015. Planting Public Street Trees in the State Highway Rights of Way. Vermont Agency of Transportation Policy Manual, Effective Date 9/10/2015.

VTrans, 2019. Guidelines for Pedestrian Crossing Treatments, August 2019 Update. A publication of the Vermont Agency of Transportation Bicycle and Pedestrian Program, August 2019.

Yeo, Jiho, Jooyoung Lee, Junhan Cho, Dong-Kyu Kim, Kitae Jang, 2020. Effects of speed humps on vehicle speed and pedestrian crashes in South Korea. Journal of Safety Research 75 (2020) 78-86.

Zhu, Shanjiang, David Levinson, Henry X. Liu, and Kathleen Harder, 2010. The traffic and behavioral effects of the I-35W Mississippi River bridge collapse. Transportation Research Part A: Policy and Practice Volume 44, Issue 10, December 2010, Pages 771-784.

Appendix