VERMONT
AGENCY OF TRANSPORTATION

# Speeding Countermeasures for Vermont

## Final Project Report


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# Traffic Safety Toolbox - Addressing Speeds

## Final Report

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**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

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# 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.

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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.

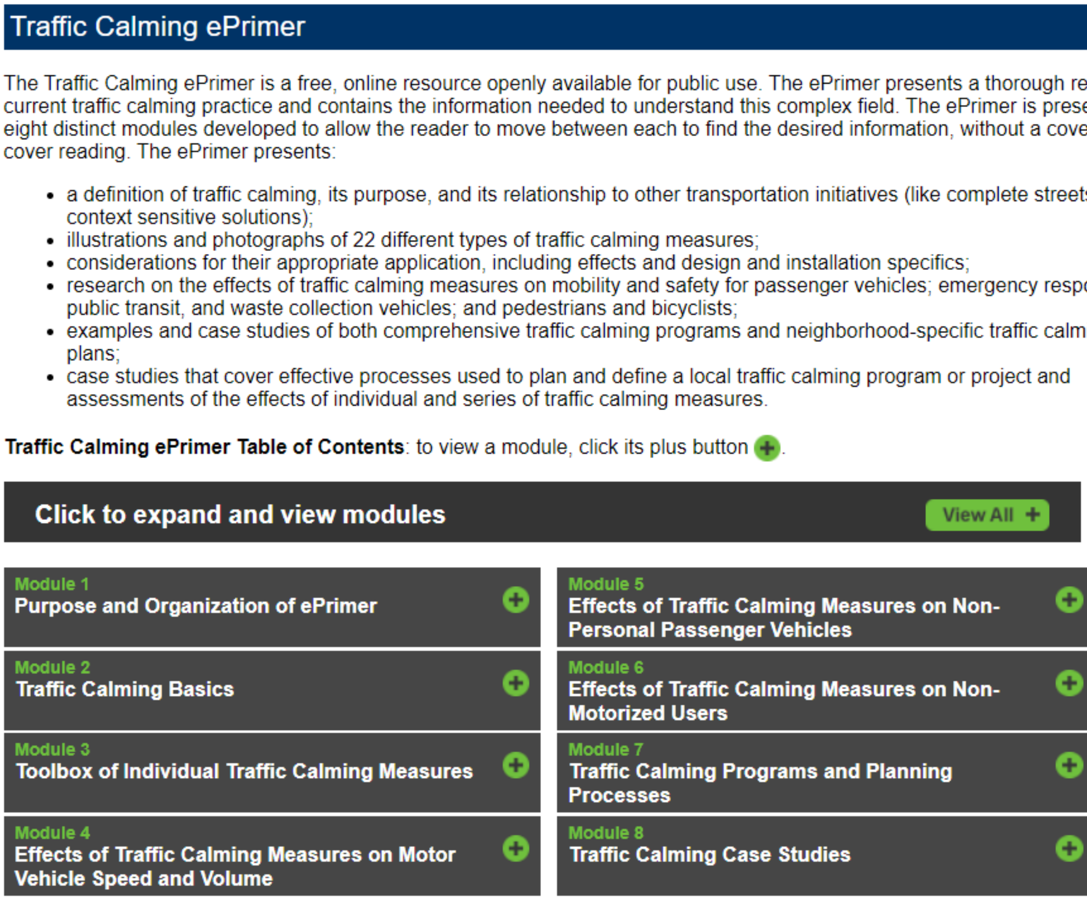


**Figure 2 Opening web page of the FHWA ePrimer (FHWA, 2017)**

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.

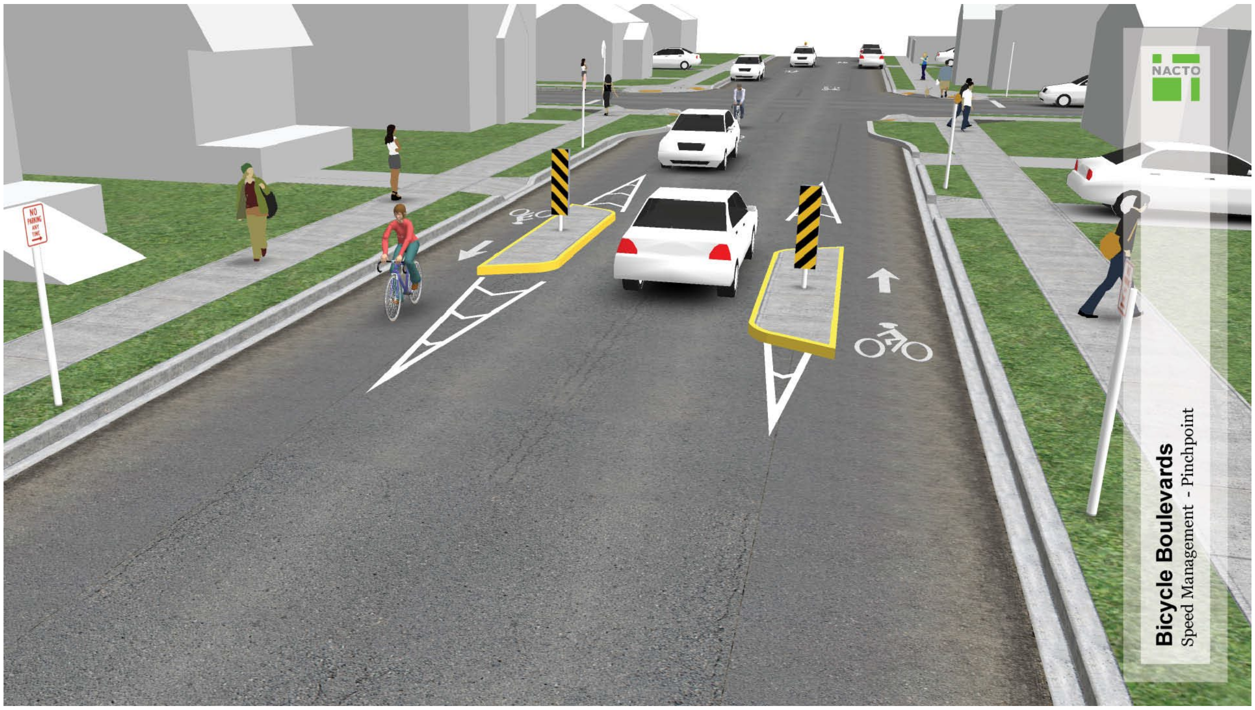


**Figure 4 Pinchpoint concept illustration from the NACTO guidance (NACTO, 2014)**

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.

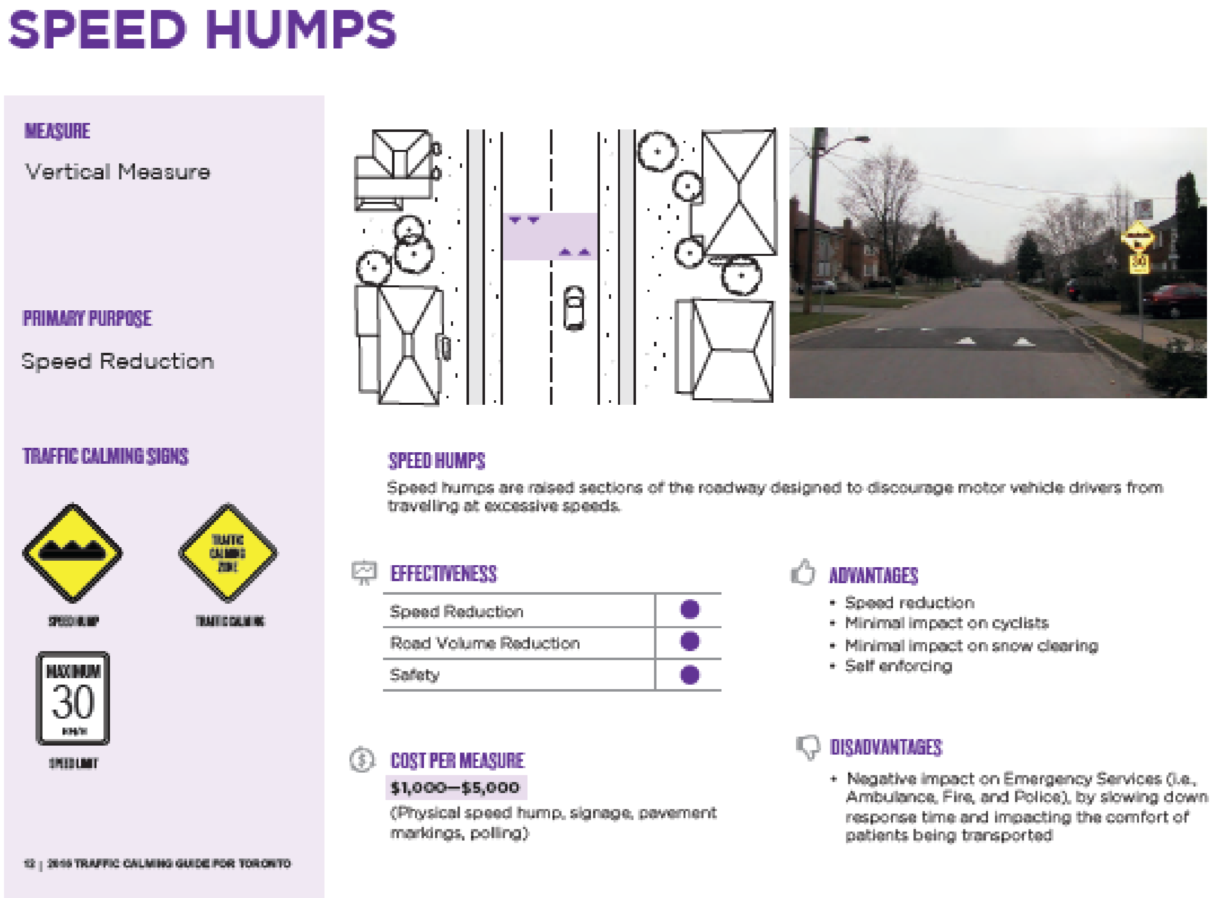


**Figure 5 Toolbox fact sheet (Toronto, 2016)**

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<br>✓ Generally Applicable<br>O Use with Care<br>× Nominal to Low Applicability<br>* 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)

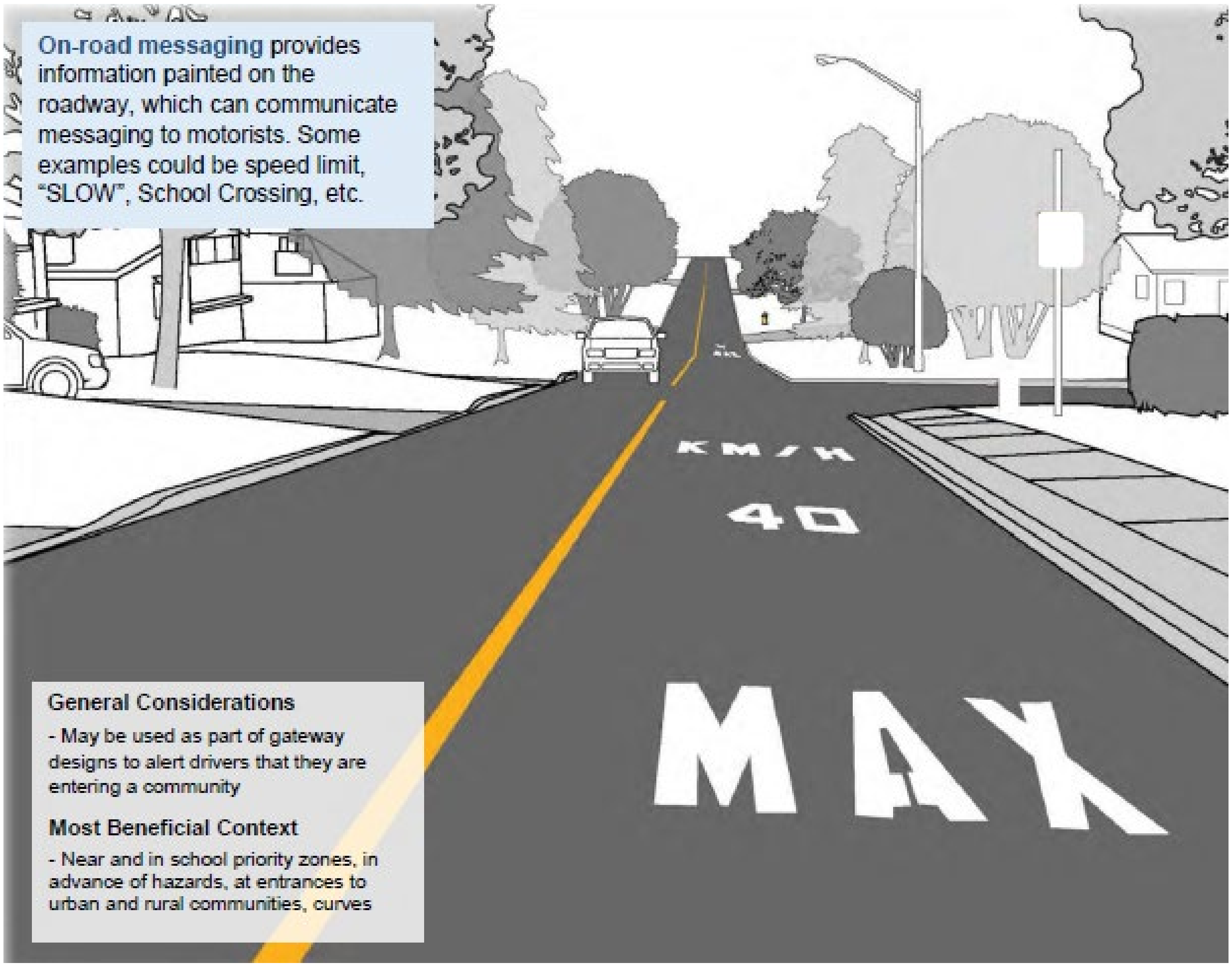


**Figure 7 Ottawa 3D illustrations for speeding countermeasures (Swan, 2019)**

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 85$^{th}$ percentile of speeds to assess the effectiveness of speeding countermeasures. Although the 85$^{th}$ 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<br>Gateway signing | Implemented |
| **Bethel** | Portable bulbouts | Implemented |
| **Bristol** | Vertical deflections | Planned |
| **Lincoln** | Advisory shoulders<br>Radar speed feedback signs (RSFS) | Implemented |
| **Vergennes** | Bulbouts<br>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 2$^{nd}$ 30 mph posting are currently used to discourage speeding in this transition zone. Data was collected about 200 feet past the 2$^{nd}$ 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 2$^{nd}$ 25-mph posting in the town of Hardwick. Although the roadway narrows slightly at the 2$^{nd}$ 25-mph posting, no explicit countermeasures are in place to encourage reduced speeds. Data was collected about 100 feet past the 2$^{nd}$ 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<br>+ moderately favorable / moderately common<br>– 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<br>+ moderately favorable / moderately common<br>– 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.

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# Appendix