Route 100

VILLAGE SAFETY STUDY
Lowell, Vermont

Submitted to:
Northeast Vermont
Development
Association

By:

DuBois & King inc.

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Randolph, Vermont 05060
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September 2012

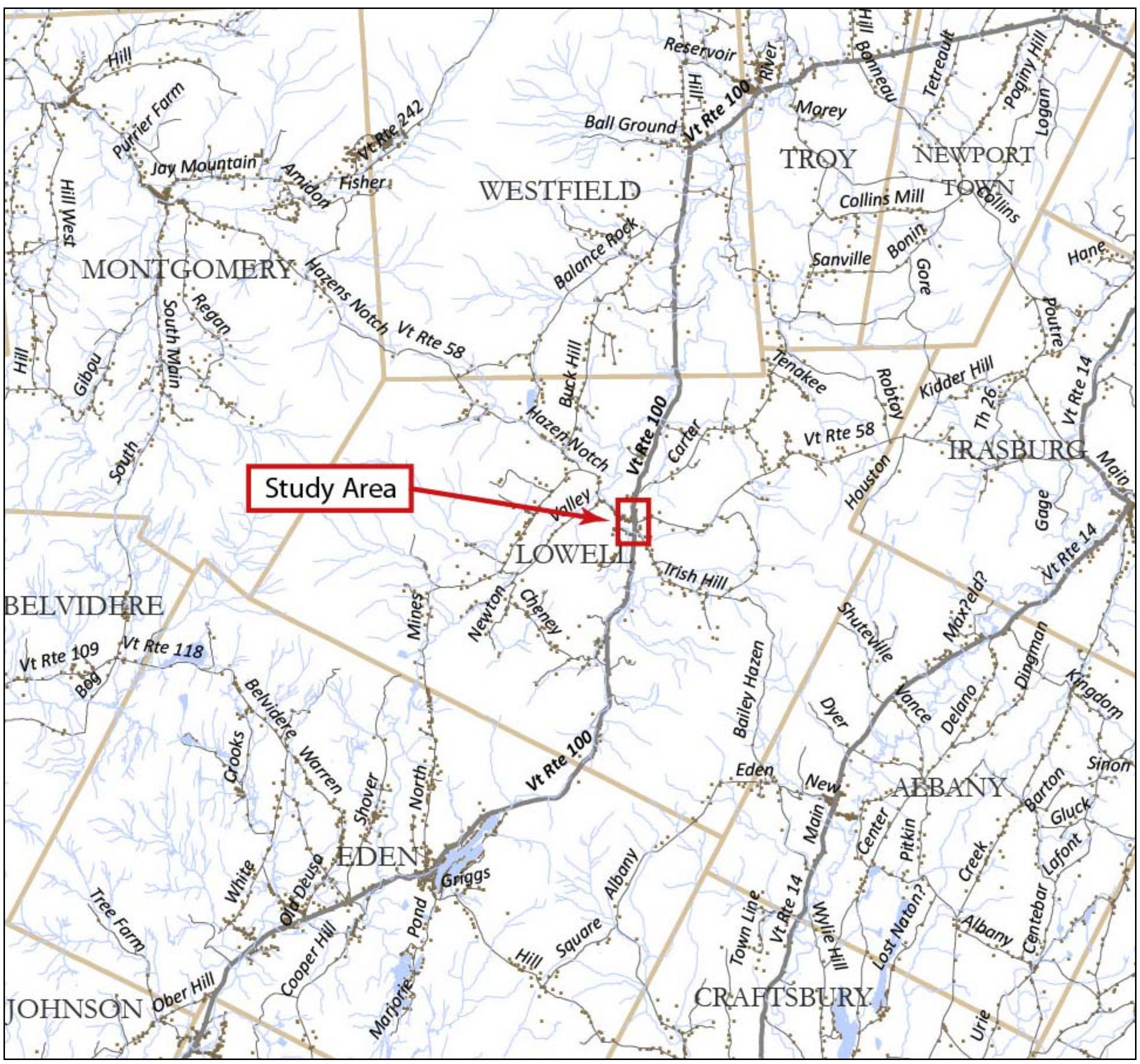
ENGINEERING ● PLANNING ● DEVELOPMENT ● MANAGEMENT

VT 100 Village Safety Study-Lowell

Introduction

The Town of Lowell is seeking to address safety concerns along VT 100 in the village area, specifically related to the intersection of Hazen's Notch Road/VT 58/VT 100, which is a High Crash Location based on crash data from 2006 to 2010; and pedestrian safety between the Lowell town offices and Lower Village Road. This study considers and evaluates alternatives for addressing these safety concerns. A Local Concerns Meeting and Alternatives Presentation were conducted to obtain input on project needs and alternatives. The minutes from these meetings are attached (see Appendix 1). Figure 1 shows the study area.

Figure 1: Project Location



Purpose and Need

The purpose of this study is to identify transportation improvements and other actions that will improve the safety for all users of the VT 100 corridor through the village area of Lowell, Vermont. The need exists due to the following:

- Conditions for pedestrians are unsafe along VT 100 in the village area of Lowell. There are several destinations for pedestrians on VT 100 north of VT 58, including the Lowell Village School, the town offices, historical society, a farmstand, and a Bed and Breakfast. In addition, many people walk the loop formed by Irish Hill Road, Hazen's Notch Road (VT 58), and VT 100 south of the VT 58 intersection for exercise and recreation. There are no pedestrian facilities on VT 100, so pedestrians travel on the road shoulder, which is typically 2 to 3 feet wide.
- Sight distance along VT 100 near the VT 58/Hazen's Notch Road intersection is restricted, and is likely a factor in the numerous crashes that have occurred in this High Crash Location. In addition to poor sight distance, VT 100 has a grade of about 6% through the intersection.

Project Area Conditions

Lowell is a very rural town with a village center that has a concentration of land uses and activities along Hazen's Notch Road and VT 100 (Figure 2). VT 100 is a state owned and maintained highway, and has a speed limit of 35 mph. The road's width is typically 26 to 28 feet through the study area, with 12 foot travel lanes and 2 foot shoulders. The shoulders are mostly too narrow to safely accommodate pedestrians. There are utility poles along the west side of the road right-of-way.

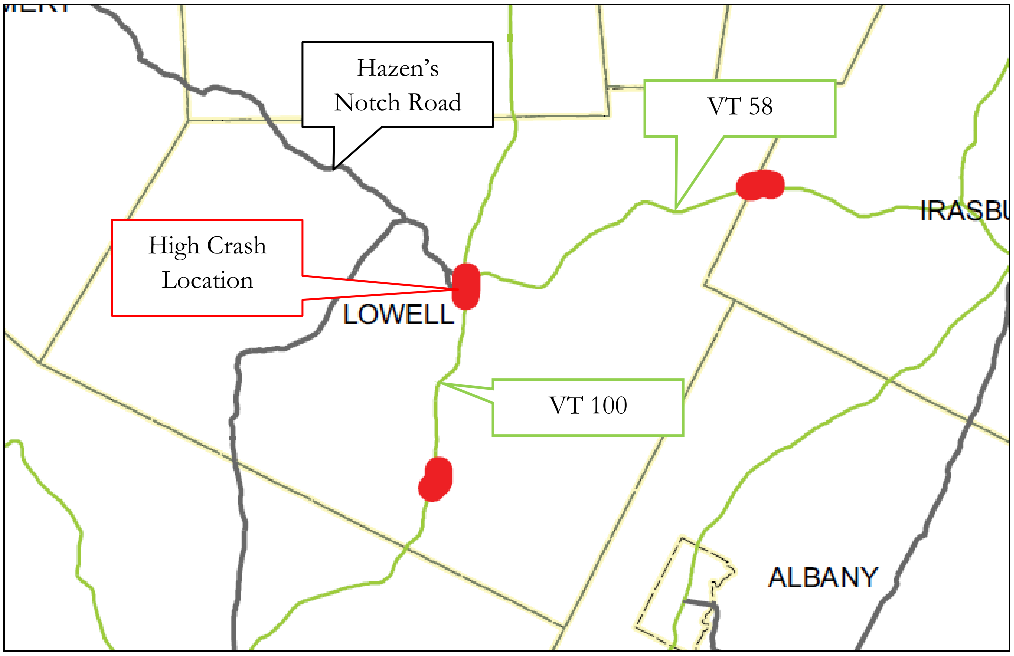
The intersection of VT 100, VT 58 and Hazen's Notch Road is within a high crash segment, as shown in Figure 3. Recently, VTrans conducted a safety review of this intersection, and developed some recommendations. The stopping sight distance along VT 100 was measured by VTrans to be 343 feet for northbound traffic and 341 for southbound traffic, which meet the requirements for speeds of 35 mph. The crashes were reviewed in the VTrans review analyzed the crash data, which shows that 6 out of 9 crashes were broadside crashes between a vehicle from VT 58 or Hazen's Notch Road and a vehicle on VT 100. While these are designated by VTrans as "failure to yield right-of-way", the underlying reason for the crashes may be the poor sight distance available at the stop approaches, combined with higher speeds on VT 100.

Pedestrians frequently travel along VT 100 between Lower Village Road and the town offices. Many residents of Lowell walk a loop formed by Lower Village Road, Hazen's Notch Road, and VT 100 for recreation and exercise. Children walk along VT 100 to the Lowell Village School from the village residential area on Hazen's Notch Road, and residents walk to the library or town offices. Bicycle travel includes both recreational road bike riders and children riding to school or the library. The current shoulders of approximately two feet are not sufficient to serve these non-motorized uses.

There is a planned VTrans resurfacing project, Lowell-Troy STP 2934(), that will begin engineering design in 2014 or 2015.

Figure 2: Project Area Map

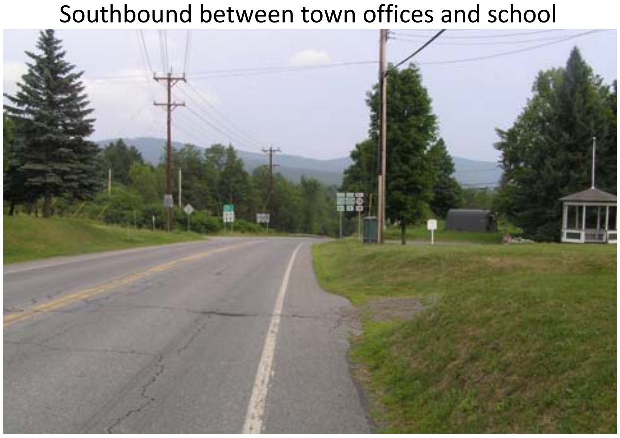
Figure 3: VTrans High Crash Location Map of Lowell



The following photos show the conditions along VT 100 in the study area.

Southbound between town offices and school


Southbound between school and fire station


Approaching VT 58/Hazen's Notch Rd Intersection


Southbound South of VT 58 Intersection

Alternatives

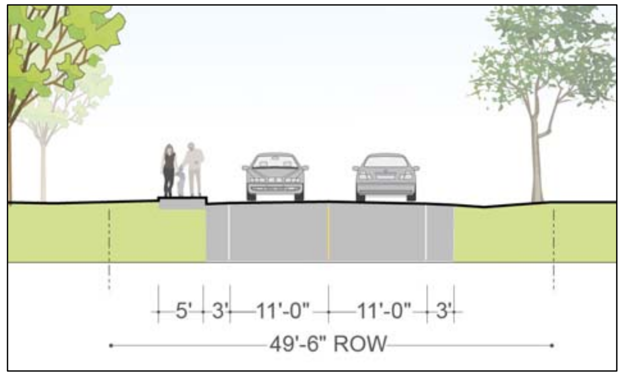
The following alternatives are proposed for consideration to address the safety concerns in the village.

1) Pedestrian Improvements

Two options for providing a safe pedestrian route through the village study area are described below

Alternative 1a: Construct Sidewalk

A sidewalk along VT 100 between Hazen's Notch Road and the town offices would provide a safe route for pedestrians, with a vertical or horizontal buffer from VT 100. Because of the continuous utility poles on the west side of VT 100, the sidewalk would need to be located immediately adjacent to VT 100, with vertical curbing. A potential cross section is shown to the right, assuming that the roadway width of VT 100 remains 28 feet wide.



Constraints include:

- The sidewalk would result in impacts to a historic home and property adjacent to road (see photo to right).
- The Town would need to provide winter maintenance of the sidewalk.
- Utilities in the VT 100 right-of-way would have to be considered in the sidewalk alignment.

Estimated Cost: A planning level cost estimate has been developed, using the VTrans Unit costs for sidewalk projects from 2010. The project length from the Town Office and School to the Hazen's Notch intersection is approximately 2,450 feet. The following table shows the estimated cost for construction of the sidewalk including contingency, engineering and project management.

Item	Units	Cost
Sidewalk Construction (basic concrete sidewalk with granite curb)	2,450 feet at $218 per foot	$534,100
Contingency	10%	53,400
Engineering/Project Management/Inspection	25%	146,900
Right of way acquisition		5,000
TOTAL		$739,400

Alternative 1b: Pedestrian Shoulder

A wider shoulder along VT 100 could be provided for pedestrian and bicycle travel. The current roadway has shoulders that are generally between 2 and 3 feet wide. In order to provide a basic degree of safety for pedestrians, and to meet accessibility guidelines, the width of the paved shoulders should be increased to at least 4 and preferably 5 feet. This option might possibly be implemented through the upcoming Troy-Lowell STP 2934 () VTrans resurfacing project. The town may be asked to share in the cost of providing shoulders.

2) VT 100/VT 58/Hazen's Notch Intersection Alternatives

Alternative 2a: Sight Distance Improvements at VT 100/58

The photos on the following page show the views from each side of this intersection. Sight distance along VT 100 is restricted to the north of the intersection due to a vertical curve in the road. There are no affordable options to address this other than further lowering of the road in order to improve sight lines. This type of improvement would be prohibitively costly, have impacts to historic structures, and require utility re-location.

Sight distance to the south from VT 58 and Hazen's Notch Road could be improved by cutting back the bank on the southwest quadrant of the intersection. Marginal improvements could result from shaving the slope and more frequent mowing and cutting brush. More substantial improvements would require right-of-way acquisition, relocating the utilities located at the top of the bank, and phase 1B archaeological investigations, making this also a costly option.

View to South from Hazen's Notch Road

View to North from Hazen's Notch Road

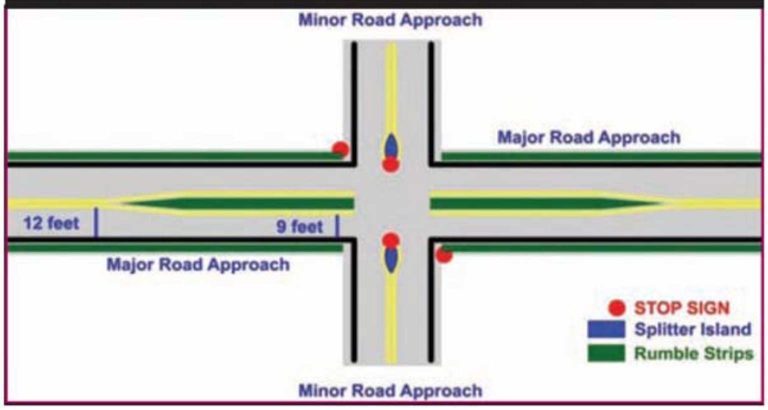
View to South from VT 58

View to North from VT 58

Alternative 2b: Improve Delineation of Intersection

Improvements to clarify the safest travel paths through the intersection, reduce speeds and alert drivers, as shown in the figure below, could be effective at this location and warrants further consideration. The following concept shows a general layout, including rumble strips along the center of the main road approaches, and small splitter islands at the side road approaches. An FHWA report[1] is attached and provides more information.

Figure 5. Illustration of concept 3.



This treatment should fit easily into the current footprint of the roads and have minimal impact to resources. It should be considered in the design of the Troy-Lowell STP 2934 () resurfacing project.

Alternative 2c: Flashing Beacon

Because of the limited visibility along the corridor, a flashing beacon at the VT 58/VT 100 intersection would alert oncoming vehicles to the intersection and potential for crossing traffic. This alternative could be done in combination with the above measures. The estimated cost for this is $24,000, plus an additional $3,000 for engineering, permitting and project management.

Alternative 2d: Roundabout

The concept of a modern roundabout at this location was discussed, as it would reduce speeds and address the limited sight distance. However, it was concluded that the costs and impacts of a roundabout are disproportionate with the needs and safety problems, and was not developed further.

3) Speed Reduction and Management

While speed data is not currently available for VT 100 in Lowell, there is a perception that most traffic exceeds the 35 mph speed limit. This is reinforced by the crash statistics at VT 100/58, as the available stopping sight distance may not be sufficient for actual prevailing speeds along the road. There are a number of actions that could contribute to reduced speeds in the study area. The following describe some alternative measures to reduce speeds, and these can be done alone or in combination with the other alternatives.

[1] FHWA, *Two Low Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roads*, Publication Number FHWA-HRT-08-063, September, 2008.

Alternative 3a: Enforcement

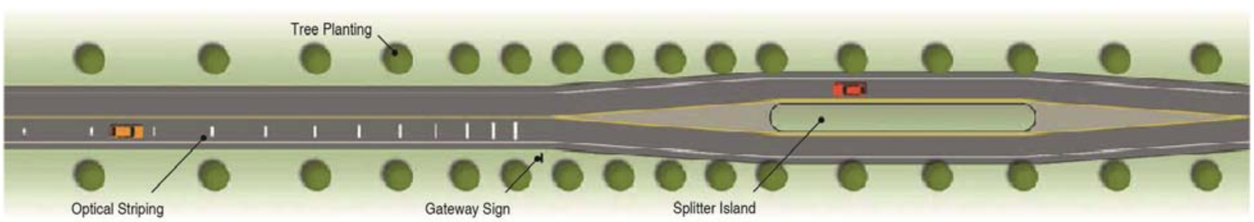
Enforcement of the existing speed limit is an effective way to reduce vehicle speeds through the village, and can be conducted alone or in combination with any of the following options.

Alternative 3b: Gateway and Transition Treatments

Installation of gateway treatments can reinforce the transition from the rural areas to a lower speed zone in the village. Among the elements that could be included in gateways are:

- Gateway signs announcing the entrance to the village
- Optical striping to alert drivers to transition
- Radar feedback signs inside reduced speed zone to alert speeding drivers.
- Roadside tree planting at the gateway, and/or throughout the study area, to reinforce the transition to the reduced speed zone and a sense of enclosure.
- Splitter islands at the gateway to mark the transition and deflect traffic, causing reduced speeds.

The following figure shows a schematic of how these types of elements can be combined to form a speed transition area.



The following photos show some of the elements that can be used in gateway transitions.

Radar Feedback Signs

Splitter Islands (under construction in Danville)

Optical Striping

Some of these elements, such as splitter islands or optical striping, should be considered for implementation in combination with the future resurfacing project, Troy-Lowell STP 2934 (). Other items could be implemented sooner by the town through the VTrans Transportation Alternatives funding program, which will likely require local matching funds between 10% to 20%. The table on the following page shows the estimated cost of these items.

Item	Number	Unit Cost	Total Cost
Gateway Signs (allowance – cost can vary greatly)	2	$1,500	$3,000
Radar Feedback Signs	2	10,000	20,000
Landscaping at gateway (allowance– cost can vary greatly)	2	5,000	10,000
Other Costs (mobilization, admin, final design)	1	12,400	12,400
TOTAL			$45,400

Alternative 3c: Roadway Treatments

There are several measures that could help narrow the road's appearance to drivers, resulting in lower speeds. The travel lanes should be maintained at 11 feet or possibly narrowed to 10 feet. Colored asphalt could be used on the shoulders in the village's reduced speed zone to reinforce the perception that the road is narrow and speeds should be low. The following photos show examples of colored shoulder treatments. A variety of materials and techniques have been used in other states.

Implementation of this treatment could be accomplished as part of the upcoming Troy-Lowell STP 2934() resurfacing project. The Town would likely be responsible for maintenance of the surface, and the cost and effort involved with that would depend on the type of treatment used. Ideally, the color would be integrated into the asphalt rather than a surface treatment that could wear off.

Recommendations

Based on input from the Alternatives Presentation and analysis of the alternatives shown above, the following actions are recommended.

Short Term (within 1 year):

- Consider increased enforcement of speed limits in center of Lowell.
- Request a reduce speed limit in the village area or a reduced speed school zone from VTrans.
- Request a speed study of VTrans or NVDA to determine travel speeds through the study area. Review stopping sight distance requirements for actual speeds (85th percentile). If stopping sight distances along VT 100 are not sufficient for actual speeds, request that VTrans consider the following as short term measures:
    - Flashing beacon at the VT 58 intersection to alert oncoming drivers
    - Radar Feedback signs just inside of speed transition to reinforce speed limit

- Consider enrolling in the Safe Routes to School program and applying for the infrastructure program for the following improvements:
    - Signs and flashing beacons for the reduced school zone speed limit
    - Radar feedback signs installed inside reduced speed zone.
    - Reinforce speed transition through elements such as gateway signage, landscaping, narrowing travel lanes and optical striping.

Medium (2 to 3 years):

- Request improvements to address safety concerns as part of the Lowell-Troy STP 2934() resurfacing project. These could include the following:
    - Reinforce gateway transition using narrower travel lanes, splitter islands and optical striping.
    - Provide 4 to 5 feet shoulders, with colored asphalt to provide a safe place for walking and visually narrow the road to reduce traffic speeds.
    - Consider intersection improvements as outlined by FHWA for low cost rural two lane two way stop controlled intersections, using splitter islands on the side approaches, rumble strips and lane narrowing on the main road approaches.

Long Term (5+ years):

- Monitor safety of pedestrians and of VT 100/VT 58 intersection area to determine if additional improvements are warranted. These could include construction of a sidewalk, or a roundabout at the intersection.

Appendices

1) Local Concerns and Alternatives Presentation Meeting Minutes
2) Natural Resources Review
3) Historic and Archaeological Resources Review
4) VTrans Highway Safety Report
5) FHWA Report: *Two Low Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roads*

621736F1

Route 100 Village Safety Study: Lowell, Vermont
Kick-off and Local Concerns Meeting
July 17, 2012, 6:00 p.m.

Attendees:
Doug Morton, NVDA
Beth Viera, Town of Lowell
Lucy Gibson, DuBois & King

Major Areas of Concern:

- Sightlines at VT 58/VT100. The intersection is a high accident location, and it is very difficult to see oncoming Route 100 coming from the south, from Hazen's Notch Road.
- Pedestrian safety along Route 100 between Route 58 and the town offices and school.
    - Some children walk to school, and high school students are dropped off at Town Garage or at Route 58 and walk along Route 100 to their destination.
    - Residents also like to walk the "loop" from Irish Hill Road, Hazens Notch Road, and Route 100 south from Route 58.
    - It would also be nice to be able to walk to the farm stand near the town offices.

Ideas to Consider:

- Blinking light and School Zone speed limit, or may radar feedback speed sign
- No roundabout at the intersection
- A sidewalk was considered but is opposed by some landowners who would lose their already small front yards, so instead provide a wider shoulder for walkers.
- Pedestrian path along the VAST trail to the farm stand.
- Bicycle tour groups come through occasionally. Would like to attract more, and have the roads be safe for them.

Town of Lowell

Route 100 Village Safety Study

- Local Concerns Meeting: July 17, 2012
- Alternatives Presentation: Tonight
- Final Report: September 30, 2012
- Study Goal: Define projects that the town can pursue.
  - Conceptual designs and cost estimates
  - Implementation Strategy
  - Identify issues to be resolved in next steps

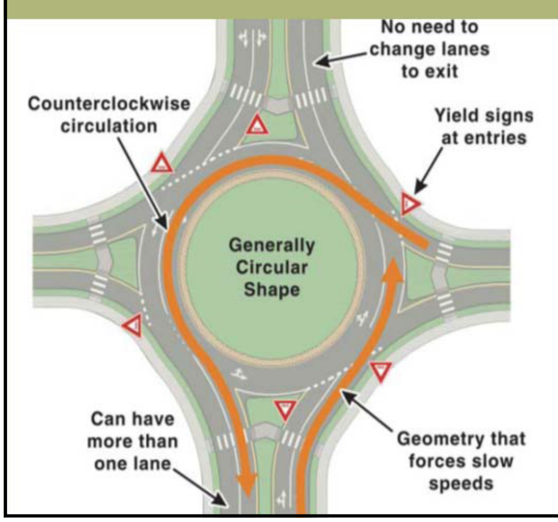
Study Area

Concerns

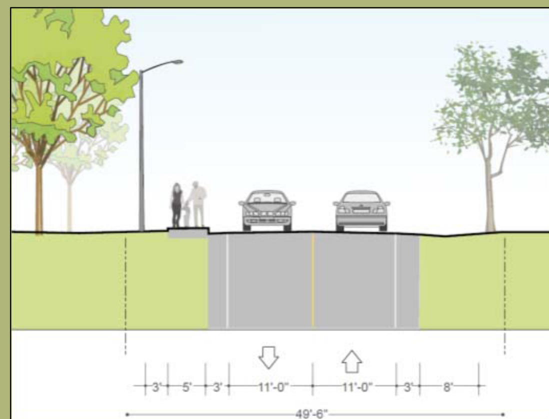
- Safety for pedestrians and others on Route 100
  - Between Lower Village Road and Town Offices
  - Narrow shoulder, high speeds, are unsafe
- Intersection of Routes 100 and 58
  - VTrans High Crash Location
  - Poor sight distance to south from Route 58 eastbound

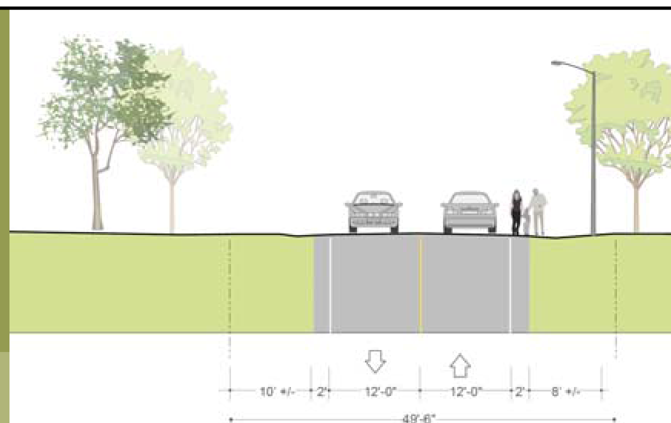
Issues to Resolve:
-Utility Relocation
-Archaeological Sensitivity

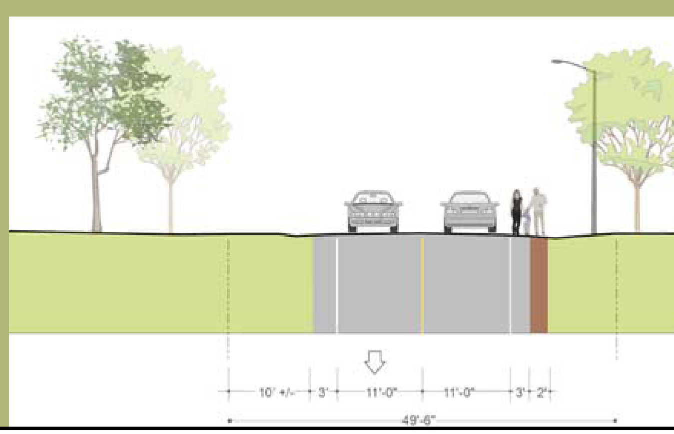
Roundabout Alternative



Sidewalk Cross Section



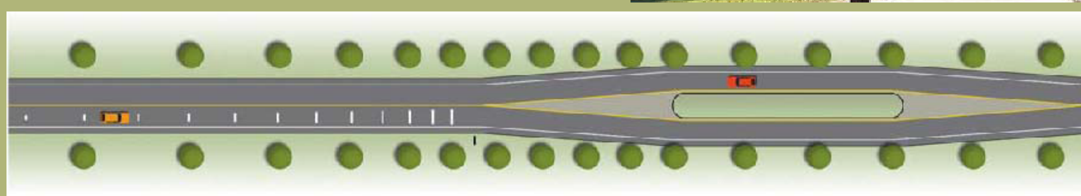




Shoulder Widening to 5 feet

Traffic Calming

- Splitter Islands
- Radar Feedback Signs



Recommendations

- Participate in VTrans Resurfacing to widen west side shoulder to 5 feet.
- Pursue removal of bank through hazard elimination grant or roundabout through STIP.
- Consider enhancement funding for traffic calming measures (splitter islands, gateway signs, radar feedback signs)

Natural Resource Review

Route 100 Village Safety Study - Lowell, Vermont

Wetlands – There are no VSWI-indexed wetlands (Class I or Class II) within the immediate VT Route 100 corridor. There are, however, two areas of Class II wetlands near the southern limits of the project. The first and closest is located to the west of VT Route 100 and north of Lower Village Road. The second is located to the south and east of the project and is roughly centered along Irish Hill Road. Depending on the extent of disturbance beyond the existing roadway associated with the preferred alternative, a field review of wetlands may be warranted. This may include identification of Class III wetlands and/or delineation of wetland boundaries.

Surface Waters – The VT Route 100 corridor includes one stream crossing near the southern terminus of the project of an unnamed tributary of the East Branch of the Missisquoi River. If physical modifications to the existing bridge are proposed, streambank impacts will need to be assessed.

Floodplains – There is a small area of Zone A mapped floodplain associated with the unnamed tributary described above. Although adverse impacts to the floodplain are unlikely as a result of this project, any physical modifications to the stream crossing or placement of fill in this area should be reviewed during the design process.

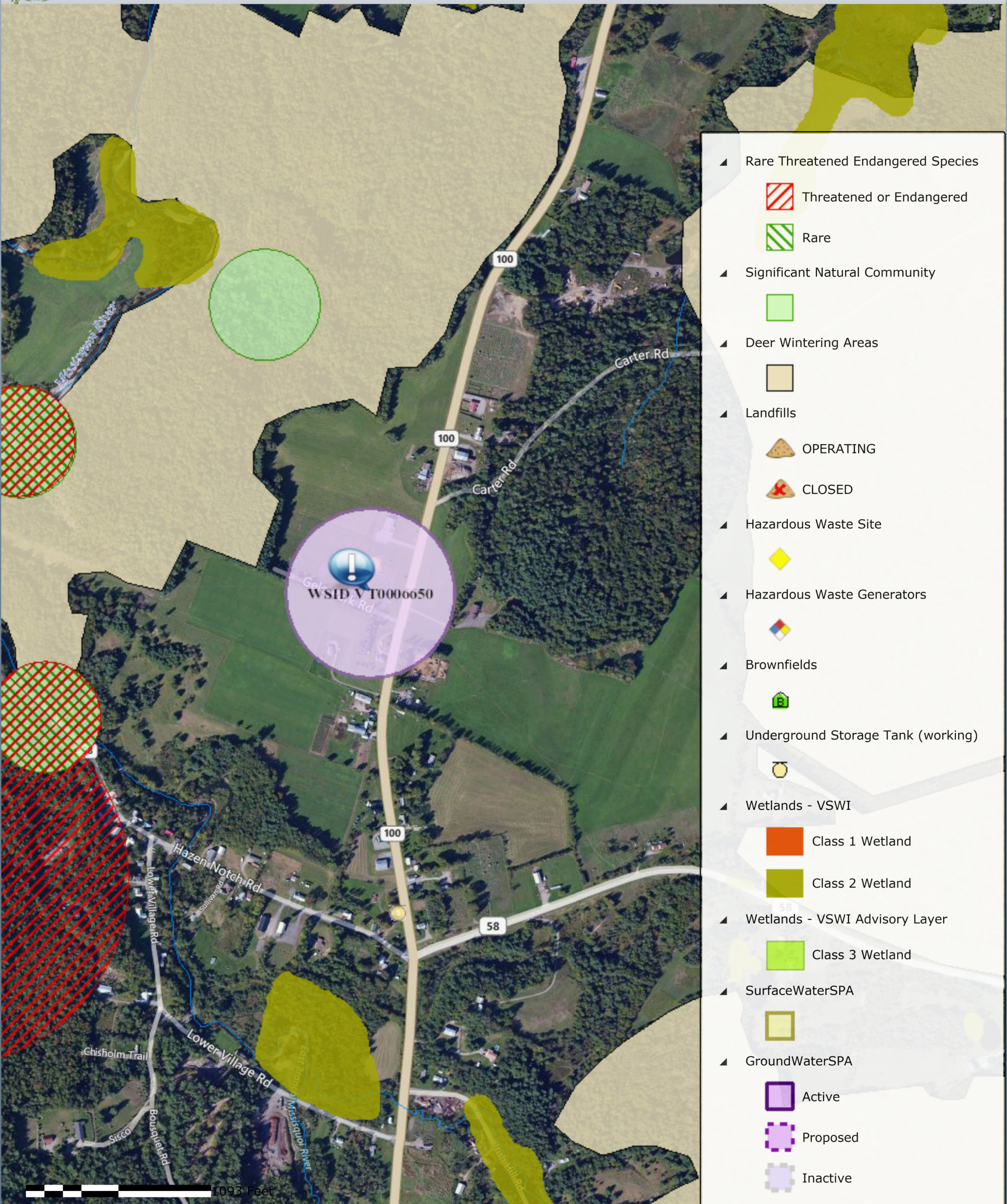
Endangered Species/Flora/Fauna – There are no species of concern or deer wintering yards identified within the project area.

Stormwater – There are no existing stormwater permits identified within the project area. As this project progresses through the design phase, the amount of total earth disturbance and additional impervious area should be reviewed to determine if either a construction or operational stormwater permit is required. Even if the project falls below jurisdictional thresholds, standard erosion control and sediment prevention practices should be employed during construction.

Hazardous wastes – There are no hazardous waste sites identified within the project corridor. There is a spill report at the VEC Substation, located at 2337 VT Route 100. The spill incident was related to upgrades at the substation in 2011. If the preferred alternative involves ground disturbance near the substation, VT DEC Waste Management Division should be consulted prior to construction.

Other – There is one active groundwater source protection area that extends into the project area. WSID VT 0006650 is located at the Lowell Village School.

Natural Resource Atlas - Rt 100 Lowell



ARCHEOLOGICAL RESOURCE ASSESSMENT AND HISTORIC ARCHITECTURE ASSESSMENT

VT Route 100 Village Pedestrian and Safety Study

Towns of Lowell and Westfield
Orleans County, Vermont

HAA # 4538-11

Submitted to:
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August 2012

ABSTRACT

The Route 100 Village Pedestrian and Safety Study project is located in the Towns of Lowell and Westfield, Orleans County, Vermont. Thomas R. Jamison and Walter R. Wheeler of Hartgen Archeological Associates, Inc. were the project manager and architectural historian for the project, respectively. The project requires review under Section 106 of the National Historic Preservation Act of 1966, as amended and the lead agency is the Vermont Agency of Transportation (VTrans).

The area of potential effects (APE) in Lowell extends from the intersection of Route 100 and Hazen Notch Road approximately 1,173 meters (3,850 ft) north to the town offices. The high bank in the southwest quadrant of the intersection is being considered for removal as a traffic hazard, obstructing traffic sight lines. In addition, the 321 meter (1,053 ft) alignment of a VAST trail between Route 100 and Hazen Notch Road was included in the investigation as a possible additional pathway. These project components encompass approximately 9,130.8 sq meters/98,247.4 sq ft or 0.91 ha (2.26 ac).

In Westfield, the APE consists of 580 meters (1,903 ft) along Route 100, 100 meters (328 ft) along North Hill Road and 77 meters (253 ft) along School Street. The APE is assumed to be approximately 2.5 meters (8 ft) in width, making the total APE in Westfield approximately 11,506.4 sq meters/123,809 sq ft or 1.15 ha (2.84 ac).

Background research and a site visit to the project area on July 24, 2012 identified areas of archeological sensitivity and historic structures along the APE. In addition, areas of disturbance were defined as could be determined based on evidence of buried utilities and roadside cutting and filling. Areas of archeological sensitivity for precontact and historic deposits were defined in Lowell at the north end of the alignment, along the VAST trail alignment and at the high bank to be removed. In Westfield, areas of archeological sensitivity were defined along the north leg of the alignment on Route 100, in the village green and south of the green on either side of Mill Brook. These areas of sensitivity should be avoided if possible, but if not, a Phase IB archeological reconnaissance survey is recommended. Prior to defining such a survey, precise location of underground utilities should be determined to provide better definition to the boundaries of disturbance.

The architectural survey identified nine structures in Lowell and 19 structures in Westfield which are within the project APEs and which are in excess of 50 years in age. Photographs of each of these structures are presented to assist VTrans in determining whether any additional documentation of historical architecture will be necessary for the project.

Traffic Safety Section

Highway Safety Improvement Program

Location Review

Town:	**Lowell**	**HSIP No.:**	**N/A**
Route:	**SNTH 58**	**Mile point:**	**VT 100 (4.350 – 4.767)** **VT 58 (0.000 – 0.038)** **SNTH 58 (4.055-4.150)**
Reviewed By:	**Nancy Avery, Traffic Safety**	**Date Reviewed:**	**08/08/2012**
	Derek Lyman, Traffic Design		
	Douglas Bonneau, Structures		
	Alden Warner, Lowell Selectboard member & Lowell Fire Chief		

Location Map:

Note: THIS DOCUMENT IS EXEMPT FROM DISCOVERY OR ADMISSION UNDER 23 U.S.C. 409

Observations:

- The Annual Average Daily Traffic (AADT) for
  State Numbered Town Highway (SNTH) 58 for 2010 is **669** actual.
  VT Route 58 for 2010 is **1200** estimated
  VT Route 100 south of the intersection with Hazen Notch Road for 2010 is **2700** estimated and north of the intersection with Hazen Notch Road for 2010 is **2100** estimated.
- The VT 100 / SNTH 58 intersection is wide; with no clear stop bar.
- A Sign Project Replaces all the signs along VT Route 100 in 2010-2011 sign project
- A new 36" STOP sign, installed on 2-posts, 11 feet west from the edge of VT Route 100 and a Legal Load Limit was installed 90 feet west of the edge of VT Route 100 for SNTH 58 as part of the 2010-2011 sign project along VT Route 100
- Paving is in fair condition on SNTH 58.
- A 6.1±% grade from mm 4.276 – mm 4.456
- Posted Speed limit on
  - State Numbered Town Highway (SNTH) 58 = 35 MPH
  - VT Route 100 = 35 MH from mm 4.24 – mm 4.89
  - VT Route 58 = 50 MPH
- Stopping site distance to SNTH 58 traveling on VT Route 100 is approximately 343 ft for northbound traffic and 341 ft for southbound traffic. Required stopping site distance according to the 2011 American Association of State Highway and Transportation Officials (AASHTO) for a posted speed limit of 35 mph is 250 ft.
- The intersection of SNTH 58 with VT Route 100 is a large paved apron area where several vehicles double-up in the westbound lane to either travel through the intersection or the left or right.
- The stop bar is faded out and is about 11 ft from the edge of VT Route 100.
- The Agency painted a double yellow centerline that starts about 25 ft in from the edge of VT Route 100 along SNTH 58.
- The Stop Ahead sign on SNTH 58 is completely covered by vegetation and is not visible to approaching traffic.
- The 36" Stop sign on 2-post is not visible to approaching traffic until a vehicle is about 120 feet from VT Route 100 intersection due to the maple tree branches blocking visibility.

Past Work Orders:

Work Order No.	Work Order Date	Complete Date	Description
VT Route 58			
96-086	03/04/1996	06/06/1996	Snowmobile Traffic Signs
77-088	09/02/1977	09/12/1977	Route Review
None listed	07/11/1977	08/05/1977	Intersection Sign upgrades
VT Route 100			
01-371	11/13/01	03/08/02	Destination sign
98-146	04/20/1998	06/10/1998	Destination sign replacement
96-07	03/01/1996	06/05/1996	Upgrade snowmobile signs
89-186	08/04/1989	08/18/1989	Route Review
87-217	10/26/1987	10/28/1987	Traffic Sign Upgrades

Past/ Present Work in Area:

HSIP 10-014 location VT Route 58 mm 0.000 – 0.300
VT 58 was paved in 2000 SMA0009 401
VT 100 was paved in 1994 CM-F029-2(11)
VT 100 sign project installed signs through this area 2010-2011
VT 58 proposed September 2012 Paving project from mm 0.000 – 4.940 (Hot mix)

Traffic Safety Section

Highway Safety Improvement Program

Location Review

Crash Summary						Period:	2007 - 2011
			Roadway Condition				
No.	Date	Time (Military)	*Pavement*	*Weather*	*Light*	Type of Crash	Cause
VT Route 58							
1	12/06/2007	18:15	D	S	N	Injury	Failed to yield right of way – Head-on
2	11/17/2009	13:47	D	C	L	PDO	Under the influence of drugs/alcohol. Opp. Dir. Sideswipe
3	08/23/2008	18:10	D	K	L	INJURY	Avoiding animal on road.
VT Route 100							
4	07/20/2008	16:45	W	R	L	PDO	Failed to yield right of way. Broadside
5	07/12/2009	13:20	D	C	L	INURY	Failed to yield right of way. Broadside
6	11/13/2009	07:55	D	C	L	INJURY	Failed to yield right of way. Broadside
7	12/17/2009	08:30	S	C	L	PDO	Failed to yield right of way. Broadside
8	08/14/2010	16:20	D	K	L	PDO	Failed to yield right of way. Broadside
9	11/15/2009	17:35	S	S	N	PDO	Following too closely - rear end
State Numbered Town Highway 58							
None listed							

<u>Roadway Conditions</u>

Pavement: D = Dry W = Wet I = Icy S = Snow

Weather: C = Clear R = Rain F = Fog S = Snow K = Cloudy

Light: L = Daylight N = Night (Dark) U = Dusk

Note: THIS DOCUMENT IS EXEMPT FROM DISCOVERY OR ADMISSION UNDER 23 U.S.C. 409

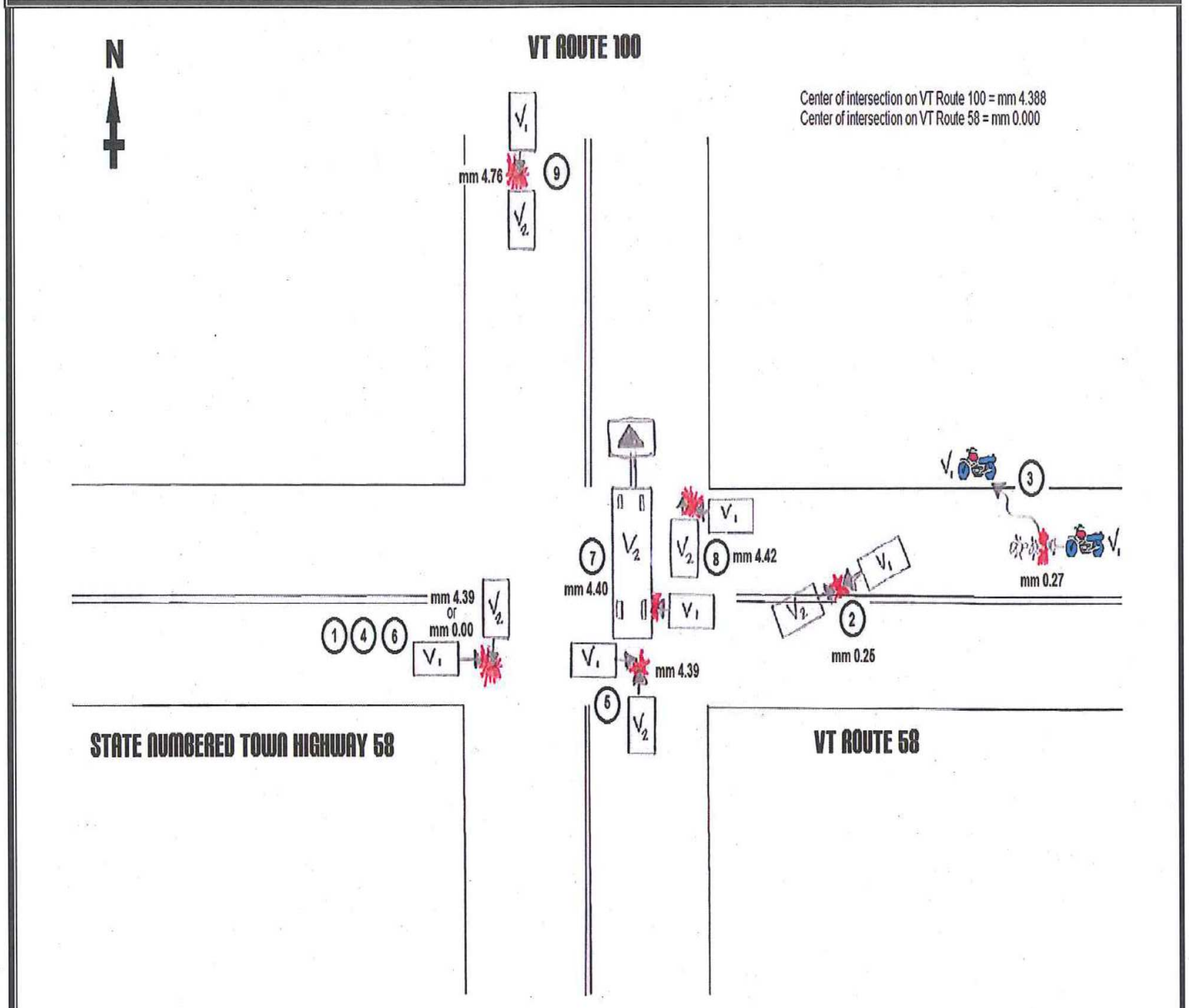
Traffic Safety Section

Highway Safety Improvement Program

Location Review

COLLISION DIAGRAM

PREPARED BY: **NLA**	*MILE MARKER:* **VT 100 (mm 4350-4.767)**
LOCATION ID: **SNTH 58**	**VT 58 (mm 0.00 – 0.038)**
DISTRICT: **9**	**SNTH 58 (mm 4.055-4.150)**
PERIOD: **2007 - 2011**	*TOWN:* **Lowell**



COLLISION SYMBOLS		CONDITION CODES
VEHICLE PATH BACKING VEHICLE NON-INVOLVED VEH. PEDESTRIAN PATH FIXED OBJECT PARKED VEHICLE PERSONAL INJURY FATALITY	REAR-END COLLISION HEAD-ON COLLISION SIDE SWIPE OUT OF CONTROL OVERTURNED VEHICLE LEFT TURN COLLISION RIGHT ANGLE COLLISION	PAVEMENT CONDITION: D = DRY W=WET I=ICY WEATHER CONDITION: C=CLEAR R=RAIN F=FOG S=SNOW LIGHT CONDITION: L=DAYLIGHT N=NIGHT (DARK) TIME OF DAY (MILITARY)

CRASH SUMMARY ATTACHED

Field Photos taken (05/09/2011)

Field Photos taken (08/08/2012)

Recommendations:

Crash patterns indicate that the main factor that contributed to the crashes at this intersection is the fact that several vehicles from SNTH 58 failed to yield the right-of-way to vehicles traveling along VT Route 100. Most of the crashes state that vehicles from SNTH 58 attempted to cross or enter VT 100 after stopping.

- Install new Stop bar closer to the intersection for better corner sight distance for vehicles stopped on SNTH 58.
- Add STOP text to the approach to VT 100 on SNTH 58.
- Extend double yellow centerline on SNTH 58 to newly painted stop bar. Match up the centerline at VT58 (west of the intersection) with the centerline of VT 58 (east).
- Along SNTH 58 update signage as follows:
  - Remove existing Stop Ahead sign and post
  - Install new large Stop Ahead sign on 2-posts closer to intersection
  - Remove Speed Limit 35 sign and post.
  - Relocate existing legal Load limit sign closer to the VT 100 intersection. Install a new 30" Stop sign on left side of highway at same location for vehicles approaching the intersection from the west.
  - Install a new Speed Limit 35 sign below the relocated Legal Load Limit Sign.
  - Retain existing 36" Stop sign on 2-posts at its current position.
- Town to trim brush/branches around existing and proposed signs and those areas where approaching sign visibility is being obstructed.
- Turning radii were review for traffic on SNTH 58 and pavement requirements where adequate for movement of a WB-67 vehicle. (67 feet)

SUMMARY
REPORT

Two Low-Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways

FHWA Publication No.: FHWA-HRT-08-063

FHWA Contact: Joe Bared, HRDS-05, (202) 493-3314,
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Overview

The Federal Highway Administration (FHWA) Office of Safety has identified intersections as one of its safety focus areas. As part of the FHWA efforts to reduce intersection crashes and the related injuries and fatalities, two concepts have been identified: (1) rumble strips on outside shoulders and in a painted yellow median island on major road approaches and (2) channelizing separator islands on side road approaches with supplemental STOP signs. Specifically, the strategies are low-cost countermeasures for intersections at two-lane, two-way roadways with two-way STOP-control (TWSC). The lane narrowing concept (concept 1) features the introduction of rumble strips on the outside shoulders and in a painted yellow median island on the major road approaches (figures 1 and 2).

Figure 1. Concept 1.

U.S. Department of Transportation
Federal Highway Administration

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Turner-Fairbank Highway Research Center
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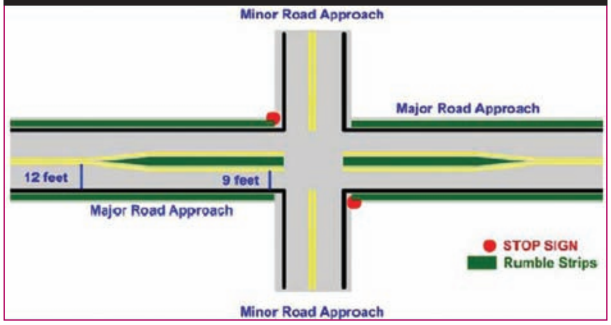
www.tfhrc.gov

Figure 2. Illustration of concept 1.



The objective of this first concept is to induce drivers on major roads to reduce approach speeds at intersections by effectively reducing the lane width. The minor road splitter island concept (concept 2) features channelizing separator islands on the side road approaches on which supplemental STOP signs are installed (figures 3 and 4). The objective of the second concept is to provide redundancy of the STOP sign and increase driver-compliance with the STOP sign. A third concept includes the combination of concepts 1 and 2 (figure 5). The concepts have greater potential for effectiveness on intersections of high-speed roadways. However, they can also be applied to intersections with lower posted speed limits. With the cooperation of several transportation agencies, these two strategies were deployed at a limited number of sites in the United States. This paper documents an evaluation of the operational and safety effectiveness of these strategies.

Introduction

Intersections represent a significant safety issue from several perspectives. In 2005, more than 50 percent of all crashes in urban areas and over 30 percent in rural areas were intersection-related.[1] Crash severity at intersections is also a concern for certain States; over 60 percent of fatal intersection crashes in Minnesota occur at rural intersections.[2] In addition, specific driver populations, including older and younger drivers, are over-represented in these fatalities.

Driver compliance with the STOP sign is a major contributing factor of intersection crashes. Statistics for crashes reported at STOP-controlled intersections on rural highways in Minnesota indicate that 26 percent of drivers who were involved in multivehicle crashes ran the STOP sign at the intersection.[3] A recent publication by the National Highway Traffic Safety Administration (NHTSA)[4] indicates that drivers failed to obey the STOP sign for 21 percent of fatal crashes at STOP-controlled intersections. An additional 23 percent failed to yield to crossing main road traffic.

Intersections present several hazards that are different from road segments. First, drivers on the minor road must identify the STOP sign and bring their vehicle to a complete stop at the appropriate location. Each driver's ability to identify the STOP sign can be affected by a number of factors, including the placement,

Figure 3. Concept 2.

size, and retroreflectivity of the sign. At TWSC intersections, drivers on the minor approach must also identify and select a safe gap for entering the traffic stream on the major road. A driver's ability to judge gaps may be influenced by speeds on the major road (i.e., if speeds on the major road are higher than expected, gaps that appear sufficient may, in fact, be too small). Therefore, strategies for reducing speeds on the major approach and for increasing driver compliance on the minor approach have the potential to enhance safety. Concepts 1 and 2 address the issues of speed on the major road and driver compliance on the minor road, respectively.

Concept 1 focuses on reducing speeds on the major approaches by narrowing the lane width and will hereafter be referred to as the lane narrowing concept. While there was no literature related to this exact concept, other studies have shown that the roadway environment can affect drivers' speed. For example, one study indicated that speed perception was greater when the roadway was lined with trees, creating a narrowing effect.[5] With respect to safety, the effects of lane-narrowing techniques have not been studied thoroughly. Regarding the use of rumble strips, shoulder and centerline rumble strips have been shown to enhance safety by reducing run-off-road and cross-over crashes. However, there is a concern that centerline rumble strips could have a negative impact on safety. The shoulder rumble strip application is more common than the centerline rumble strip, and drivers may have a general a priori expectancy to steer left when encountering rumble strips while unaware of their lane position. A recent study[6] verified this concern using a simulator experiment and concluded that some drivers (about 27 percent) initially steered left when encountering centerline rumble strips while unaware of their lane position. While this concern may hold for applications of the lane narrowing concept, the rumble strips are more of a lane-narrowing device than a warning for unaware motorists. For those drivers that are aware of their lane position, the use of rumble strips as

Figure 4. Illustration of concept 2.

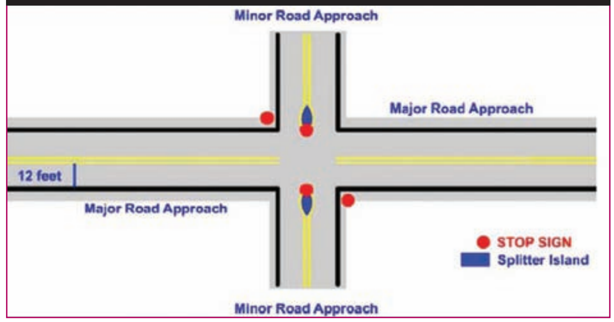
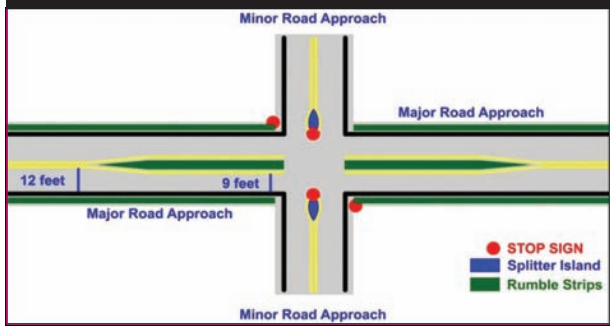


Figure 5. Illustration of concept 3.



a lane narrowing device should not be a safety issue. It is likely that the concern would only hold for those drivers who cross the centerline while unaware of their lane position at the approach to the intersection.

Concept 2 focuses on increasing intersection awareness by adding a supplemental STOP sign on the minor approaches via a separator island, hereafter referred to as the minor road splitter island concept. Similar implementations were found to produce a 30 percent reduction in total crashes in New Zealand[7] and a 30 percent reduction in angle and crossing crashes in France.[8]

Participating States

Several local and State agencies were solicited for participation in the deployment of the proposed concepts. Favorable responses were received from agencies in many States including Maryland, Virginia, New Mexico, Illinois, Pennsylvania, Kentucky, Missouri, Florida, and California. For this study, the lane narrowing concept was implemented at

10 sites, and speed changes were evaluated at 9 sites, including sites in Florida, Kentucky, Missouri, and Pennsylvania. The speed change results were consistent between the first 9 sites; therefore, the tenth site was not included in the speed study. The minor road splitter island concept was implemented and evaluated at one site in Lorton, VA. Concept 3 was implemented at one site in Cumberland, MD. Participating agencies selected the sites for deployment of the proposed concepts; however, the research team worked closely with the participating agencies to provide guidance during the site selection process. Selected intersections exhibited one or more of the following characteristics:

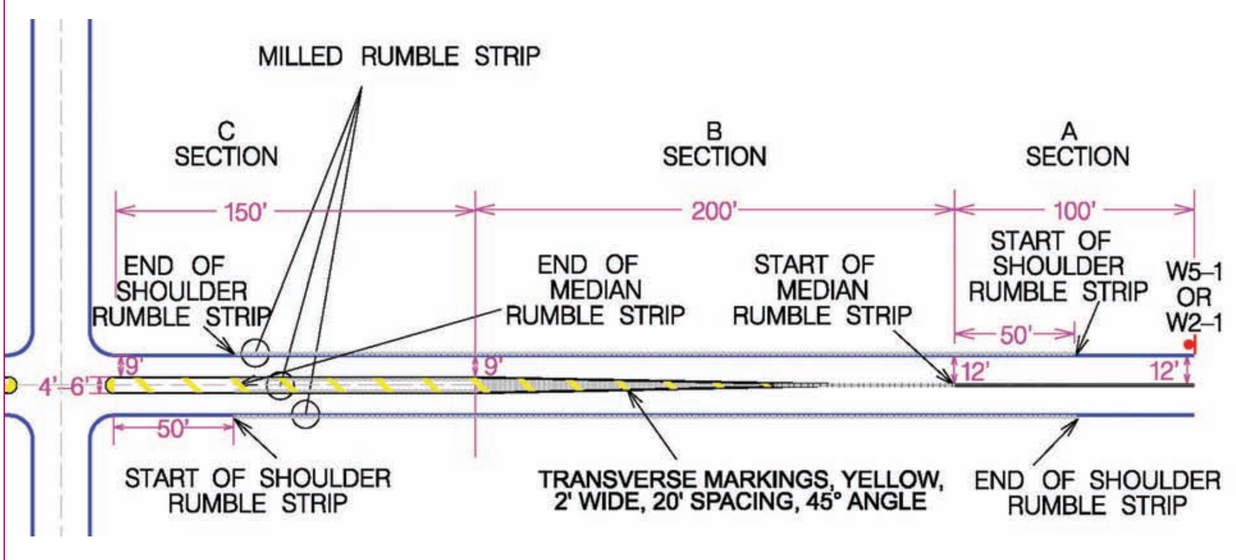
- The presence of the intersection is difficult to detect for approaching drivers.
- Speeding was identified as an issue at the intersection.
    - Measured speeds are higher than established criteria (e.g., estimated safe intersection approach speed).
    - The patterns of crashes indicate speed-related causation.
- Lack of compliance at STOP signs was observed frequently at the intersection.

Typical Design of Concepts

The lane narrowing concept features the introduction of a narrow median island formed by pavement markings in conjunction with rumble strips placed between the two travel lanes of a major road. It also includes the introduction of rumble strips outside of the edgelines within the existing pavement width as shown in figure 3. The median island and rumble strips effectively reduce the travel lane width prior to an intersection. The objective of this concept is to induce drivers to slow down as they approach an intersection. The installation of this concept is relatively low cost. While Pennsylvania spent between $50,000 and $70,000, the installations in other States were much less expensive. Based on data from the remaining States, the implementation costs for the lane narrowing concept ranged from $10,000 to $30,000 per intersection, excluding construction costs unrelated to the concept implementation.

A typical design template for the lane narrowing concept is shown in figure 6. For this scenario, lane widths on the major road are reduced from 3.66 m (12 ft) to 2.75 m (9 ft), as measured from the inside edges of the pavement markings. The effective lane width after implementation is

Figure 6. Typical design of concept 1.



1 ft = 0.305 m

3.05 m (10 ft), as measured from the inside edges of the rumble strips. The design template shows three distinct sections (A, B, and C). Prior to the lane narrowing, appropriate signing is placed at the beginning of section A to warn motorists of the upcoming taper or intersection. The end of section A corresponds with the beginning of section B (i.e., the lane taper). Section B gradually transitions from a median width of 0 m (0 ft) to the full width of the median at the end of the section. Section C carries the full width of the median for 45.75 m (150 ft) up to the intersection, but the rumble strips end 15.25 m (50 ft) prior to the intersection. Table 1 indicates the lengths of each section based on the posted speed of the roadway. For example, if the posted speed of the major road is 88.55 km/h (55 mi/h), then the lengths of sections A, B, and C would be 30.5 m (100 ft), 61 m (200 ft), and 45.75 m (150 ft), respectively.

Table 1. Concept 1 section lengths.

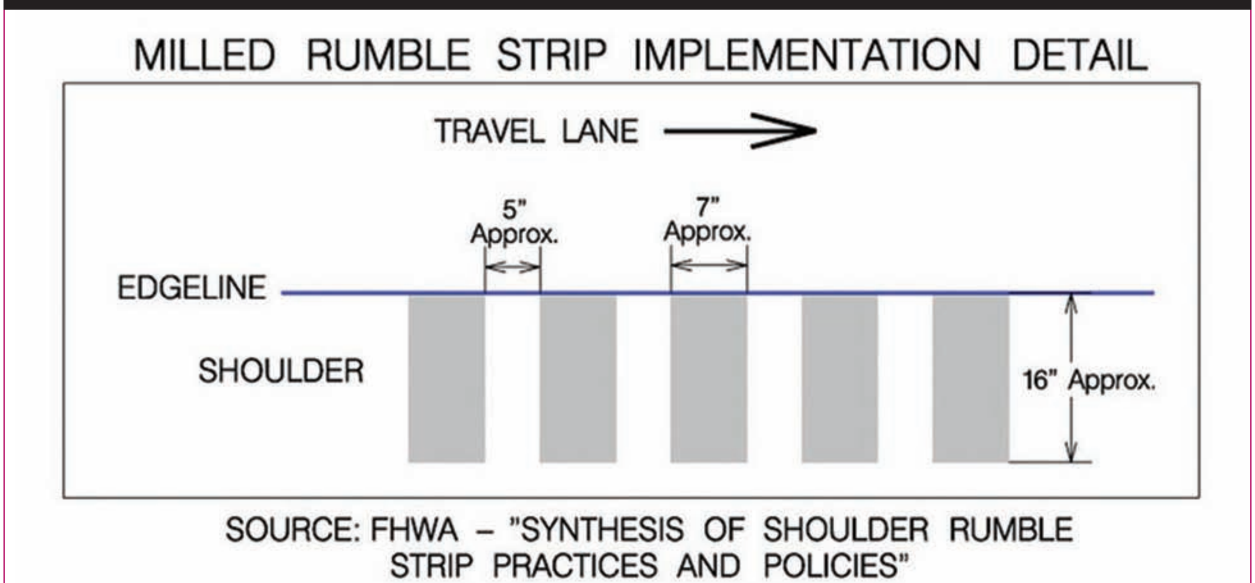
Speed (mi/h)	Section A (ft)	Section B (ft)	Section C (ft)
45–55	100	200	150
60	150	200	150

1 ft = 0.305 m

Milled rumble strips are installed within the median and along the shoulders. The median rumble strips start at the beginning of section B and continue through section C, ending 15.25 m (50 ft) prior to the intersection. Traveling toward the intersection, shoulder rumble strips start 15.25 m (50 ft) prior to the beginning of section B and end 15.25 m (50 ft) prior to the intersection. Traveling away from the intersection, shoulder rumble strips start 15.25 m (50 ft) past the intersection, continuing through sections C and B, and ending at section A. A typical design for rumble strips is shown in figure 7. Transverse pavement markings are shown in the median. The yellow transverse markings are 0.61 m (2 ft) wide and placed at a 45-degree angle with a spacing of 6.1 m (20 ft).

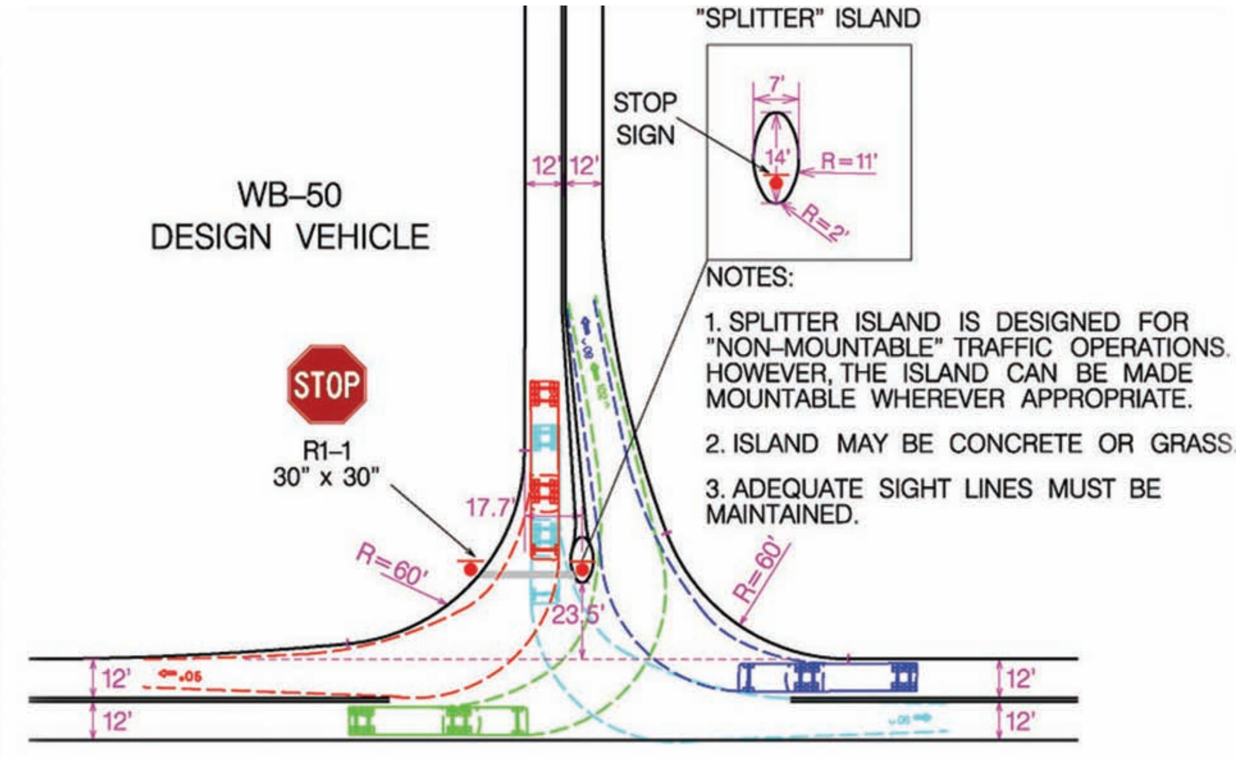
The minor road splitter island concept features channelizing islands on the minor approaches of one-way or two-way STOP-controlled intersections as shown in figures 4 and 8. The objective of this concept is to improve the conspicuity of the STOP sign and increase driver compliance. This concept primarily focuses on increasing driver awareness of the intersection by adding a supplemental STOP sign on the minor approaches via a separator island.

Figure 7. Typical rumble strip design.



1 ft = 0.305 m

Figure 8. Typical design of concept 2.



1 ft = 0.305 m

A typical design template is shown in figure 8. For the minor road splitter island concept, the major design considerations are the type of separator island (traversable or nontraversable) and the turning radius of large vehicles. The typical design of the separator island is an oval, 4.27 m (14 ft) in length and 2.135 m (7 ft) in width, constructed of either earth material or concrete. A secondary STOP sign is placed on the separator island at the nose closest to the cross road. The double yellow pavement markings on the minor road are separated prior to the island and extended along the sides of the island to guide motorists as per the *Manual on Uniform Traffic Control Devices* (MUTCD).[9] Guidance for calculating the minimum taper length for the pavement markings can be found in the MUTCD, Section 3B-10.[9] To accommodate larger vehicles turning from the minor approach, the separator island is offset left of center.

For the design template, the center of the island is located 5.3 m (17.5 ft) from the right edge of the traveled way on the minor approach, and the nose of the island is set back 7.2 m (23.5 ft) from the nearest edge of traveled way on the crossing roadway. These dimensions are, however, dependent on the turning radius of the design vehicle. The minor approach may also need to be flared depending on the existing turning radius to accommodate the design vehicle.

Implementation of Concepts

Design templates, shown previously in figures 6 and 8, were provided to the States for the applicable treatment. However, the States did not always follow the template exactly (table 2). As per the design templates, lane widths on the major road were reduced from 3.66 m (12 ft) to 3.05 m (10 ft). The 3.05-m (10-ft) effective lane width is measured as the distance between the inside edges of the rumble strips. Field measurements indicated that lane widths actually varied from one point to the next because of limited accuracy in pavement

Table 2. Design variations among sites.				
State	**Location**	**Lane width prior to taper (ft)**	**Lane width within narrowed section (ft)**	**Painted median width (ft)**
Pennsylvania	PA 4	12	10	4
Kentucky	KY 2	12	9.5	3.5
Missouri	MO 1	11	9	3
Missouri	MO 2	11–12	9–10	4–6
Missouri	MO 3	11–12	9–10	4–6

1 ft = 0.305 m

marking techniques and rumble strip milling techniques. For the lane narrowing concept, typical lane widths on the major approaches ranged from 3.36 m (11 ft) to 3.66 m (12 ft) before implementation. After implementation, typical lane widths on the major approaches ranged from 2.75 m (9 ft) to 3.05 m (10 ft) within the narrowed section. Field visits also revealed different installation practices among contractors. For example, contractors measured between the inside edges of the pavement markings when calculating the effective lane widths for the intersection approaches at a few locations. Several other variations of the design were actually implemented as shown in figures 9 through 12.

Figures 9 and 10 illustrate an installation of the lane narrowing concept in Pennsylvania. Prior to implementation of the concept, the major road approaches included 3.66-m (12-ft) lanes. The deployment of the lane narrowing concept effectively narrowed the major approaches to 3.05 m (10 ft). In this example, milled rumble strips were installed beginning at the outside edge of the pavement markings, similar to the design shown in figure 7. A painted median was also implemented at a width of 1.22 m (4 ft) and is clearly visible with cross-hatching. The double rumble strips in the median were each 4.06 m (16 inches) wide, which almost covers the full width of the median at the widest point. The rumble strip layout and cross-hatching within the median are desirable design characteristics.

Figures 11 and 12 provide an example of the lane narrowing concept in Florida. Much of the design is similar to the installation shown in figures 9 and 10; however, the median is slightly narrower at the location in Florida. The median rumble strips fully cover the width of the median between the inside edges of the pavement markings. In addition, a double solid (as opposed to a single solid) yellow pavement marking was used along each side of the median rumble strips, and raised pavement markings were installed along the centerline. Both the shoulder and median rumble strips end 15.25 m (50 ft) prior to the intersection. The rumble strip and pavement marking layouts are desirable characteristics for the lane narrowing concept.

Figure 9. Concept 1 at PA 4.

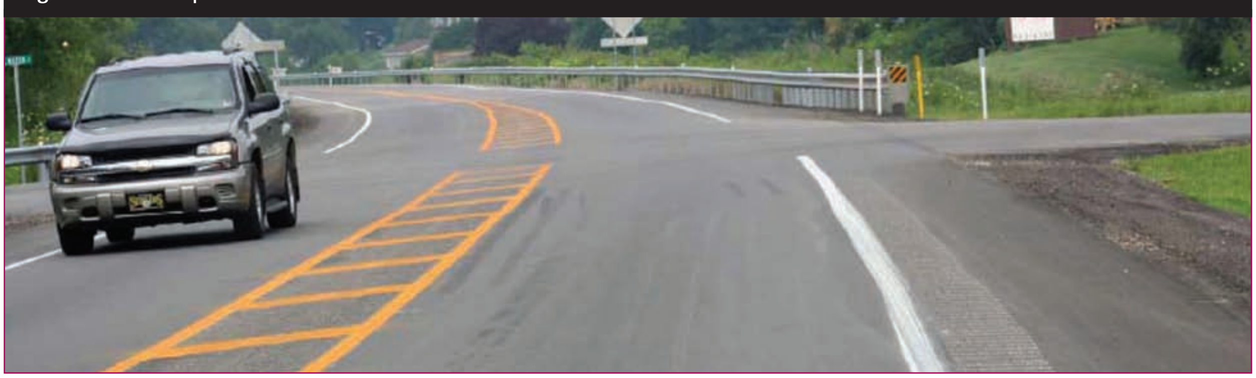
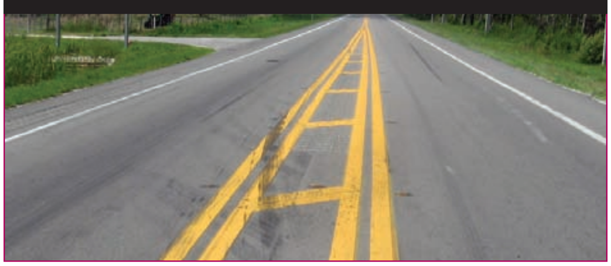


Figure 10. Example 2 of concept 1 at PA 4.

Figure 11. Concept 1 at FL 1.

Figure 12. Example 2 of concept 1 at FL 1.



Figures 13 through 15 show examples of the lane narrowing concept at two different sites in Kentucky. At both sites, the concept was implemented at intersections with left-turn lanes on the major approaches. This was accomplished by creating extra space between the left-turn lane and the opposing and adjacent through lanes. Rumble strips were then installed between the left-turn lanes and the opposing and adjacent through lanes as well as along the shoulders. A combination of milled and rolled rumble strips were installed. The previous examples show the median rumble strips ending prior to the intersection to accommodate turning vehicles. At both sites in Kentucky, however, the median rumble strips were installed up to the intersection. Additionally, rumble strips were installed along only the right edge of the white painted median that separates the left-turn lane from the through lane in the same direction. Beyond these similarities, there are subtle differences between the two sites.

At the first site (figures 13 and 14):

- The median is very obvious due to cross-hatching.
- Rumble strips are installed along both inside edges of median prior to the left-turn lane.
- Rumble strips are installed along both edges of the yellow painted median that separates the left-turn lane from the opposing through lane.
- Pavement markings are painted directly on the rumble strips, which are referred to as rumble *stripes*. This is in contrast to the previous designs where the pavement markings are painted closer to the traffic. Rumble stripes create a vertical edge, providing better visibility at night and in wet weather conditions.
- White skip-lines are installed across side road approaches to designate the right edge of the travel way for through vehicles.
- White arrows are painted on the road to designate left-turn and through lanes.

At the second site (figure 15):

- There is a lack of cross-hatching between the left-turn and opposing through lanes which reduces the conspicuity of the median. This is an undesirable design characteristic.
- Rumble strips are only installed along the left inside edge of the painted median prior to the left-turn lanes, which narrows the lane for drivers leaving the intersection but not for drivers approaching the intersection.

- Rumble strips are installed along only the left edge of the painted median that separates the left-turn lane from the opposing through lane.

- Rumble strips are installed along only the right edge of the painted median that separates the left-turn lane from the through lane in the same direction.

A typical design of the lane narrowing concept with left-turn lanes is shown in figure 16. Due to the presence of left-turn lanes, section C from figure 6 was modified slightly to create sections C and D as shown in figure 16. In this design, sections C and D include narrowed lanes with a painted median that extends to the intersection. Rumble strips are installed along both inside edges of all painted median islands and end 15.25 m (50 ft) prior to the intersection. Section C is now 30.5 m (100 ft) rather than 45.75 m (150 ft), but there is the added length of the turn lane (section D) to increase the length of the lane narrowing. Again, the lane width between pavement markings is 2.75 m (9 ft), but the effective lane width (i.e., distance between rumble strips) is 3.05 m (10 ft).

Figures 17 and 18 illustrate installations of the lane narrowing concept in Missouri. At both sites, a painted median as well as milled shoulder and median rumble stripes were installed. Prior to the installation, lane widths ranged from 3.36 to 3.66 m (11 to 12 ft). The deployment of the lane narrowing concept effectively narrowed the major approaches to 2.75 to 3.05 m (9 to 10 ft). There were a few noteworthy differences between the two sites.

At the first site (figure 17):

- The painted median and rumble stripes end 15.25 m (50 ft) prior to the intersection and only a single dashed yellow centerline extends to the intersection. It is desirable to extend the painted median to the intersection.

- Rumble stripes cover the entire width of median. However, cross-hatching is not installed, which may have contributed to the increase in rear-end crashes.

Figure 13. Concept 1 at KY 1.

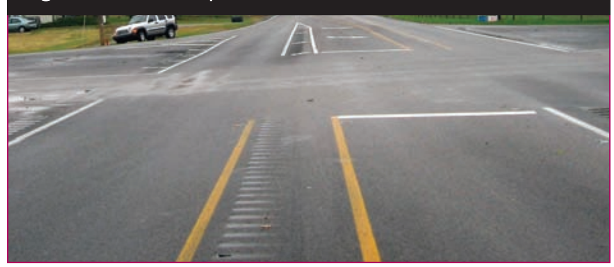
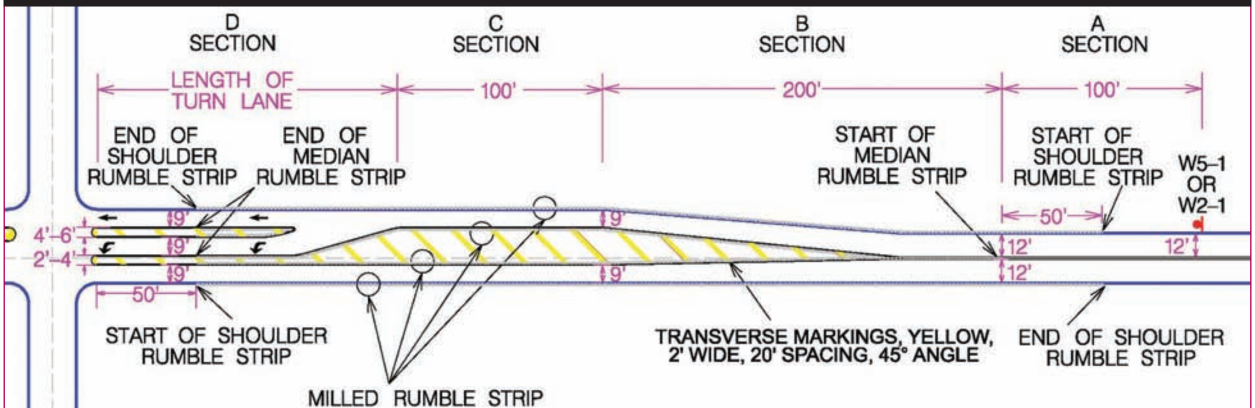


Figure 15. Concept 1 at KY 2.

Figure 14. Example 2 of concept 1 at KY 1.

Figure 16. Typical design of concept 1 with left-turn lanes.



1 ft = 0.305 m

At the second site (figure 18), there are several desirable characteristics:

- Median rumble stripes cover nearly the entire width of the median. All rumble stripes end 15.25 m (50 ft) prior to intersection.
- Cross-hatching is installed in the painted median, which extends to the intersection.

Figure 19 shows an example of the only deployment of the minor road splitter island concept included in this study. The minor road splitter island concept was deployed in Lorton, VA, at a four-legged intersection with STOP-control on the minor approaches. Prior to the installation of the minor road splitter island concept, the intersection was STOP-controlled on the minor approaches with a single STOP sign per approach located to the right of the traveled way. The deployment of the minor road splitter island concept included the installation of a separator island on the minor approaches near the intersection and the placement of a second STOP sign on the separator islands. The separator islands are nontraversable with vertical edges. Since the separator islands are nontraversable, the turning radius of the design vehicle must be accommodated. The lane markings are also separated on the minor approaches prior to the intersection and painted along both sides of the separator islands. Providing cross-hatching between the pavement markings or painting the separator islands would improve the conspicuity of the treatment.

Figures 20 and 21 show an example of concept 3 in Cumberland, MD. This was the only deployment of concept 3 included in this study. The combined concept was implemented at a three-legged intersection with STOP-control on the minor approach. Prior to the installation of concept 3, the intersection was

Figure 17. Concept 1 at MO 1.

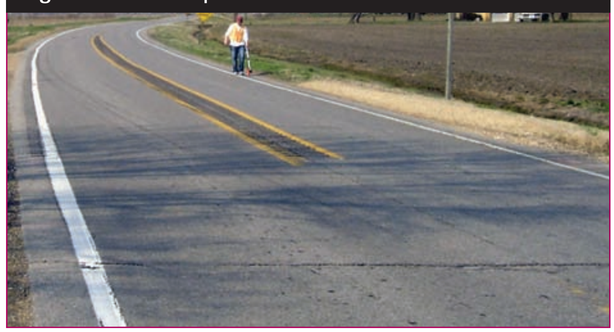


Figure 18. Concept 1 at MO 2.

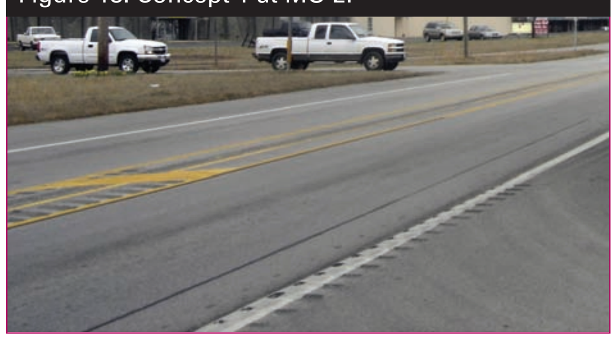


Figure 19. Concept 2 at VA 1.

STOP-controlled on the minor approach with a single STOP sign to the right of the traveled way. The deployment of concept 3 included the installation of a traversable separator island on the minor approach. Also, a secondary STOP sign was installed on the separator island. The lane markings are separated on the minor approach prior to the intersection and painted along both sides of the separator island. However, in this case, cross-hatching is included between the pavement markings to improve the conspicuity of the concept. The major road approaches were effectively narrowed by installing shoulder and centerline rumble stripes. Unlike the typical implementation of the lane narrowing concept, this deployment did not include a painted median and the rumble stripes continue to the intersection, which is not desirable.

Data Collection

Speed and driver behavior data were collected before implementation at 9 sites for the lane narrowing concept and one site for the minor road splitter island concept. Similar data were collected at all 10 sites in the after period. The lane narrowing concept was deployed at a tenth site in Florida; however, speed data were not available

Figure 20. Concept 3 at MD 1 (minor approach).

Figure 21. Concept 3 at MD 1 (major approach).

in the before period. Data indicated that results were consistent at the other 9 sites where the lane narrowing concept was deployed; therefore, speed data were not collected at the tenth site. Hi-Star traffic sensors with sequential speed profile measuring capabilities were temporarily placed on the road to collect individual driver speeds, vehicle counts, headways, and traffic composition for a 24-hr period both before and after implementation. These automated devices continuously recorded speed data for each individual vehicle that passed through the site on the approaches of interest. Additionally, speeds were captured by radar and used to validate the speed data recorded by the temporary sensors. Post-implementation data collection occurred at least 3 months after implementation to allow sufficient time for possible short-term "novelty effects" of the concepts to fade. All data were collected on weekdays.

The data collection points were different for the two strategies. For the lane narrowing concept, speed data were collected at four different locations (figure 22) along each of the major approaches to determine whether or not speed reductions were occurring as desired. The locations of the data collection points were as follows:

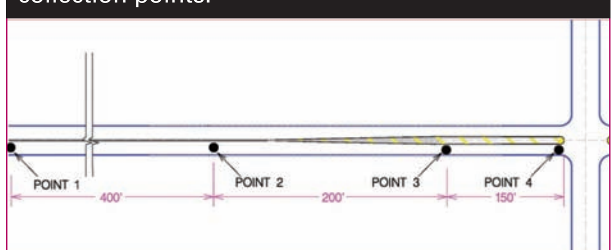
1. Control point: Located 122 m (400 ft) prior to the beginning of the taper (Point 1).
2. Beginning of lane-narrowing taper: Approximately 106.75 m (350 ft) from intersection (Point 2).
3. End of lane taper: Approximately 45.75 m (150 ft) from intersection (Point 3).
4. At the intersection (Point 4).

For the lane narrowing concept, speed observations were screened to eliminate vehicles that had been affected by any other factors such as turning maneuvers or vehicle platoons. To obtain the desired dataset, it was necessary to eliminate vehicles with relatively small headways and vehicles traveling below a certain speed. The cut-off speed for the lane narrowing concept dataset was 64.4 km/h (40 mi/h).

The speed cut-off for the lane narrowing concept was based on speed observations in North Carolina. Speed data were collected on road segments with 2.75-m (9-ft) lanes in North Carolina to determine the relationship among speed, lane width, and driver behavior. The road segments selected in North Carolina were two-lane, rural roadway segments with minimal horizontal and vertical curvature. It was observed that drivers could travel at speeds up to 72.45 km/h (45 mi/h) on 2.75 m (9 ft) wide lanes without crossing into the opposing lane. Therefore, the application of the lane narrowing concept is expected to affect vehicles with speeds greater than or equal to 64.4 km/h (40 mi/h). The final dataset for the lane narrowing concept included vehicles with headways greater than 20 seconds and approach speeds of 64.4 km/h (40 mi/h) or greater.

For the minor road splitter island concept, speed data were collected on the minor approaches. There was only one speed data collection point per approach located 45.75 m (150 ft) upstream

Figure 22. Illustration of concept 1 at speed data collection points.



1 ft = 0.305 m

from the STOP line or pavement marking on each minor approach. The dataset for the minor road splitter island concept included all vehicles on the minor road approach.

Driver behavior data were collected at the intersection for both strategies. A pole-mounted camera located at the intersection recorded driver behavior during the same periods as the speed data were collected. The videos were then analyzed and driver behaviors were recorded as follows:

- STOP sign compliance, as measured in terms of the percent of motorists that did not stop, performed a "rolling" stop, or performed a complete stop.
- Infringement on major road vehicles by vehicles on the minor approach.
- Percentage of drivers entering intersection from minor approach when gap is less than desirable if one of the following is observed:
    - Start/Stop maneuvers on minor road.
    - Braking/Severe braking on major road to avoid merging/crossing vehicles from minor approach.
    - Erratic maneuvers on either road.

Crash and traffic volume data were collected for each site in the before and after periods. If data were available, at least 5 years of crash data were obtained for the before period, and 2 years of data were obtained for the after period. Crash data included the total number of crashes occurring at the intersection as well as crash severity (i.e., fatal, injury, or property damage) and crash type (i.e., angle, rear end, or other).

Operational Performance

The operational effectiveness of each concept is based on the selected measure of effectiveness (MOE). For the lane narrowing concept, the primary MOE is the reduction of speed on the major approaches. For the minor road splitter island concept, there are two MOEs: (1) the reduction of speed on the minor approach (i.e., at the upstream data collection point), and (2) increased driver compliance with the STOP sign on the minor approach. For the lane narrowing concept, the analysis was conducted for two subsets of vehicles: all vehicles and trucks only. This was done to identify differential vehicle effects of the concept.

Lane Narrowing Concept

For each site, the mean and 85th-percentile speeds were calculated for each approach at each of the four data collection points for both the before and after periods. Again, point 4 is closest to the intersection and point 1 is farthest from the intersection. An unpaired T-test was used to determine if the speed reduction from point 1 to point 4 (1 to 4) was statistically different from the reduction from point 2 to point 4 (2 to 4) in the before period. The test indicated that there was no significant difference between 2-4 and 1-4 at a 95-percent confidence level (p = 0.45, where p is the probability of error) Since there was no difference between the 2-4 and 1-4 points, it was decided that the remaining analysis would focus on speed reductions from point 2 to point 4. Speed reduction from the before data showed no statistical difference of speeds between points 2 and 4.

Table 3 shows the speed reduction from point 2 to point 4 for all vehicles after the deployment of the lane narrowing concept. The mean and standard deviation were calculated for the reduction in all speeds and the reduction in 85th-percentile speeds. For all vehicles, the mean speed was reduced by 5.64 km/h (3.5 mi/h) with a standard deviation of 0.36. The confidence interval does not include zero; therefore, the reduction is statistically significant at the 95-percent confidence level. The mean reduction in the 85th-percentile speed was even greater (7.25 km/h (4.5 mi/h)) with a standard deviation of 0.25. Again, this reduction is statistically significant at the 95-percent confidence level.

Table 3. Speed reductions for all vehicles.									
				All speeds			85th-percentile		
				Reduction after treatment (mi/h)		95% confidence interval	Reduction after treatment (mi/h)		95% confidence interval
Sites	Posted speed limit (mi/h)	Approach lane width within rumble strips	Number of observations	Mean	S.D.		Mean	S.D.	
PA 1	55	10'	376	4.6	0.29	(3.88, 5.33)	5.2	0.21	(4.68, 5.73)
PA 2	55	10'	535	4.3	0.31	(3.53, 5.08)	4.9	0.25	(4.28, 5.53)
PA 3	50	10'	487	3.8	0.41	(2.78, 4.83)	4.3	0.33	(3.48, 5.13)
PA 4	55	10.5'	356	3.7	0.61	(2.12, 5.23)	4.4	0.23	(3.83, 4.98)
KY 1	55	10'	352	1.8	0.32	(1.00, 2.60)	4.2	0.23	(3.63, 4.78)
KY 2	50	10'	317	2.6	0.34	(1.75, 3.45)	4.1	0.17	(3.68, 4.53)
MO 1	55	9'	428	3.9	0.42	(2.85, 4.95)	4.1	0.19	(3.63, 4.58)
MO 3	55	10.5'	408	2.9	0.25	(2.28, 3.53)	4.5	0.28	(3.80, 5.20)
FL 1	55	10'	423	3.4	0.33	(2.58, 4.23)	4.5	0.30	(3.75, 5.25)
All			**3,682**	**3.5**	**0.36**	**(2.61, 4.42)**	**4.5**	**0.25**	**(3.88, 5.08)**

1 mi = 1.61 km
1 ft = 0.305 m

Table 4 shows the speed reduction from point 2 to point 4 for trucks only after the deployment of the lane narrowing concept. For trucks, the mean speed was reduced by 7.1 km/h (4.4 mi/h) with a standard deviation of 0.36, and the reduction is statistically significant at the 95-percent confidence level. The mean reduction in the 85th-percentile speed was slightly greater (7.73 km/h (4.8 mi/h) with a standard deviation of 0.27. Again, this reduction is statistically significant at the 95-percent confidence level. Speed reductions were also disaggregated by time of day and lane width. The speed reductions were not significantly different by time of day. Based on the limited sample size, the degree of speed reduction was not linearly proportional to lane width (i.e., narrower lanes were not always associated with greater speed reductions).

Table 5 shows the maximum speed reduction after implementation from point 2 to point 4. For all vehicles combined, a maximum speed reduction of 19.32 km/h (12.1 mi/h) was observed. For trucks, a maximum speed reduction of 16.26 km/h (10.1 mi/h) was observed. The results indicate that the observed speed reduction is attributable to the lane narrowing concept. All reductions are statistically significant at a 95-percent confidence level and the reductions in the 85th-percentile speed appear to be greater than the reductions in the average speed. Furthermore, the speed reduction from point 2 to point 4 is greater for trucks than for all vehicles combined.

Speed reductions were also disaggregated by time of day and lane width. The speed reductions were not significantly different by time of day. Based on the limited sample size, the degree of speed reduction was not linearly proportional to lane width (i.e., narrower lanes were not always associated with greater speed reductions). This may be counterintuitive but may be explained to some extent by the variation in lane widths for the same lane at a given intersection. It is hypothesized that narrower lane widths will produce greater speed reductions; however, a larger sample size and better field implementation of the concept is needed to support or refute the hypothesis.

Based on driver behavior data from the cameras, a large number of vehicles routinely contacted the rumble strips after implementation. This is likely due to the narrower lane widths and relative proximity of the rumble strips to the lane. While rumble strip contact helps to alert

Table 4. Speed reductions for trucks only.									
				All speeds			All speeds		
				Reduction after treatment (mi/h)		95% confidence interval	Reduction after treatment (mi/h)		95% confidence interval
Sites	Posted speed limit (mi/h)	Approach lane width within rumble strips	Number of observations	Mean	S.D.		Mean	S.D.	
PA 1	55	10'	65	4.4	0.38	(3.45, 5.35)	4.8	0.25	(4.18, 5.43)
PA 2	55	10'	87	4.5	0.26	(3.85, 5.15)	5.1	0.22	(4.55, 5.65)
PA 3	50	10'	79	4.6	0.29	(3.88, 5.33)	4.9	0.32	(4.10, 5.70)
PA 4	55	10.5'	66	4.2	0.41	(3.18, 5.23)	4.6	0.33	(3.78, 5.43)
KY 1	55	10'	54	3.9	0.44	(2.80, 5.00)	4.2	0.24	(3.60, 4.80)
KY 2	50	10'	73	4.2	0.43	(3.13, 5.28)	4.4	0.13	(4.08, 4.73)
MO 1	55	9'	90	4.8	0.33	(3.98, 5.63)	5.1	0.27	(4.43, 5.78)
MO 3	55	10.5'	55	3.8	0.28	(3.10, 4,50)	4.4	0.38	(3.45, 5.35)
FL 1	55	10'	49	4.5	0.48	(3.30, 5.70)	4.9	0.34	(4.05, 5.75)
All			**618**	**4.4**	**0.36**	**(3.47, 5.26)**	**4.8**	**0.27**	**(4.08, 5.42)**

1 mi = 1.61 km
1 ft = 0.305 m

Table 5. Maximum speed reductions.		
Sites	All vehicles (mi/h)	Trucks only (mi/h)
PA 1	10.4	9.6
PA 2	6.9	6.9
PA 3	9.1	5.4
PA 4	12.1	7.4
KY 1	5.5	4.5
KY 2	6.9	6.2
MO 1	7.1	7.1
MO 3	8.3	8.0
FL 1	10.2	10.1
All	**12.1**	**10.1**

1 mi = 1.61 km

the driver of the edge of the travel way, it may have secondary benefits as well. The contact creates a significant noise outside the vehicle, which may help increase awareness for other motorists near the intersection.

Minor Road Splitter Island Concept

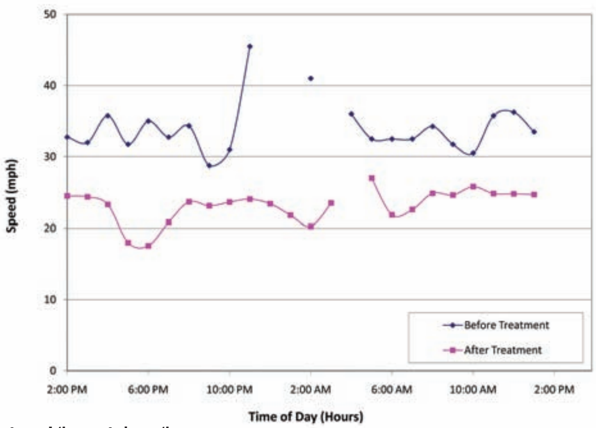
Descriptive statistics were calculated for both approaches on the minor road for the before and after periods. Again, these results are based on just one implementation of the minor road splitter island concept. Figures 23 and 24 show the average speed comparisons by time of day before and after deployment for the northbound and southbound minor road approaches, respectively, 45.75 m (150 ft) from the STOP sign. For the northbound (minor) approach, speed reductions ranged from 8.05 to 33.81 km/h (5 to 21 mi/h) after deployment, averaging 17.39 km/h (10.8 mi/h) with a standard deviation of 4.7. For the southbound (minor) approach, speed reductions ranged from 4.83 to 24.15 km/h (3 to 15 mi/h) after deployment, averaging 15.78 km/h (9.8 mi/h) with a standard deviation of 3.0. The speed reductions on both approaches are significant at the 95-percent confidence limit.

Based on driver behavior data from the camera, there were other benefits associated with the minor road splitter island concept. After implementation, there were minor improvements in STOP sign compliance as well as driver behavior. These results are, however, based on a limited sample at a single site. Further analysis is necessary to verify the operational effectiveness of the minor road splitter island concept.

Traffic Safety Performance

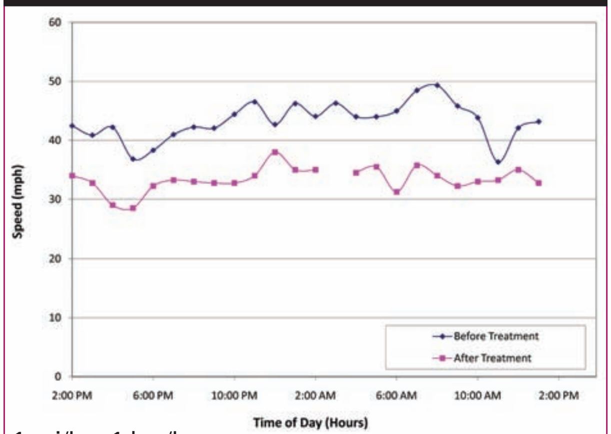
Crash data were analyzed using a simple before-after comparison method. Crash rates were

Figure 23. "Before-After" average speeds for northbound approach on minor road.



1 mi/h = 1 km/h

Figure 24. "Before-After" average speeds for southbound approach on minor road.



1 mi/h = 1 km/h

calculated for each year as the total number of crashes divided by the total number of vehicles entering the intersection per year. Crash rates were also computed for each level of crash severity and crash type. All crash rates are expressed as the crashes per million entering vehicles (MEV). Due to limited sample size and length of the after period, it was not possible to conduct an Empirical Bayes before-after evaluation—a more statistically robust method for isolating the effects of a treatment. While the sample size and duration of crash data are relatively limited, the simple before-after crash evaluation provides initial insights on the safety effectiveness of these strategies. An Empirical Bayes evaluation is planned in the near future using a longer period of crash data.

Lane Narrowing Concept

Crash data for the lane narrowing concept are shown in table 6 for Pennsylvania, Kentucky, Missouri, and Florida. For one site in Pennsylvania (PA 3), the lane narrowing concept was only implemented for a short period of time (less than 6 months). Due to the relatively short duration of implementation, the site was excluded from the crash analysis. The following summarizes the crash findings for the remaining implementations of the lane narrowing concept:

- For the three sites in Pennsylvania, there was a reduction in the crash rate for total crashes, fatal/injury crashes, and related crashes (i.e., angle and rear end) after the implementation of the lane narrowing concept.
    - For total crashes, reductions ranged from 30 to 83 percent.
    - For fatal/injury crashes, reductions ranged from 1 to 79 percent.
    - For related crashes, reductions ranged from 18 to 100 percent.
- The two implementations in Kentucky showed mixed results. For KY 1, there was a general reduction in crash rate for total, fatal/injury, and angle crashes, all around 30 percent. However, there was a 39-percent increase in rear-end crashes. For KY 2, there was a reduction in fatal/injury (24 percent) and angle (13 percent) crashes but an increase in total (34 percent) and rear-end (87 percent) crashes. While there was an increase in the crash rate for rear-ends at both sites in Kentucky, the crash frequency is relatively low (2 or less), which may skew the results. In addition, the one rear-end crash in the after period at KY 1 occurred during wet roadway conditions. The increase in rear-end crashes at KY 2 appears to be contributing to the increase in total crash rate as well. Based

Table 6. Crash data summary for concept 1 implementations.								
	Period (years)		**Crash rate (crashes per MEV per year)**		**Percent change in crash rate** *(minus indicates a reduction)*			
Sites	**Before**	**After**	**Before**	**After**	**Total crashes**	**Fatal + Injury crashes**	**Angle crashes**	**Rear-end crashes**
PA 1	5.25	1.08	3.23	1.02	-69%	-64%	-76%	NA
PA 2	5.25	1.08	1.46	1.01	-30%	-1%	-18%	-100%
PA 3	Lane narrowing removed after 6 months; therefore, PA 3 was not included in crash analysis.							
PA 4	6.00	1.92	1.36	0.23	-83%	-79%	-100%	-100%
KY 1	5.75	1.17	2.13	1.48	-30%	-31%	-28%	39%
KY 2	5.00	1.50	1.52	2.04	34%	-24%	-13%	87%
MO 1	6.92	0.99	2.15	2.47	15%	116%	-59%	906%
MO 2	6.92	0.99	1.32	0.90	-32%	-20%	-46%	-100%
MO 3	6.92	0.99	2.31	2.05	-11%	26%	-47%	144%
FL 1	4.50	1.50	1.36	1.05	-23%	11%	68%	4%
Combined	**52.51**	**11.22**	**1.85**	**1.27**	**-31%**	**-20%**	**-42%**	**54%**

Note: MEV = million entering vehicles and NA indicates that no crashes were observed in the before period.

on a review of the crash data, it does not appear that the implementation of the lane narrowing concept is contributing to the increase in rear-end or total crash rates.

- The three implementations in Missouri also showed mixed results.
    - For MO 1, there was a decrease in the angle crash rate (59 percent), but an increase for total, fatal/injury, and rear-end crashes.
    - For MO 2, there was a general reduction in crash rate for all categories.
    - For MO 3, there was a decrease in the crash rate for total (11 percent) and angle (47 percent) crashes but an increase in the crash rate for fatal/injury and rear-end crashes.
    - While the increase in rear-end crash rates appears to be substantial at two of the sites, the change in crash frequency is relatively minor. For MO 1 there was just one rear-end crash in each of the before and after periods. For MO 3, there were 11 rear-ends in the before period and just 4 in the after period. Also, 3 of the 4 rear-ends in the after period at MO 3 occurred during wet roadway conditions.
    - A more concerning issue is the increase in fatal/injury crashes at MO 1 and MO 3. A detailed review of the crash data indicated that the severity rate fluctuates substantially from one year to the next in the before period. For MO 1, the minimum fatal/injury crash rate was 0.00 crashes per MEV and the maximum was 3.49 crashes per MEV, averaging 1.43 fatal/injury crashes per MEV. The fatal/injury crash rate in the after period was 2.47 crashes per MEV; however, this was based on less than 1 year of data. For MO 3, the minimum fatal/injury crash rate was 0.00 crashes per MEV and the maximum was 1.54 crashes per MEV, averaging 0.81 fatal/injury crashes per MEV. The fatal/injury crash rate in the after period was 1.02 crashes per MEV, but, again, this was based on less than 1 year of data. It is possible that yearly variations not captured in the relatively short after period are contributing to the apparent increase. These sites should be monitored to confirm the trend in fatal/injury crashes.
- For the one implementation in Florida, there was a reduction in total crash rate but an increase in the crash rate for fatal/injury and

related crashes. While the increase in crash rates for fatal/injury and related crashes may be concerning, the duration of the after period was relatively short. A review of the police reports did not reveal any evidence that the implementation of the lane narrowing concept was contributing to the increase in crash rates; however, this site should be monitored to confirm the crash trend.

- Overall, there appears to be a reduction in the crash rate for total, fatal/injury, and angle crashes after implementing the lane narrowing concept, as shown in the combined analysis at the bottom of table 6. There are several common features that should be noted when comparing the installations where crashes were reduced:
    - Rumble strips were installed along both inside edges of the median, which covers the entire width of narrow medians (figures 9, 10, and 18).
    - Shoulder and median rumble strips ended 15.25 m (50 ft) prior to the intersection (figures 9 and 18).
    - Pavement markings were obvious, with a painted median that extended to the intersection (figures 9, 13, and 18).
    - Cross-hatching was installed in the median to increase conspicuity (figures 9, 11, 13, and 18).
- The crash rate for rear-end crashes increased in the after period. While the after period was relatively short for many of the sites, there was some consistency in the increase in rear ends. The following are possible reasons why rear ends may increase:
    - Speed differential: The lane narrowing concept is intended to reduce driver speeds on the major road. Rear ends could result if some drivers reduce their speed when entering the lane narrowing concept while other drivers maintain their previous speed.
    - Turning vehicles: The lane narrowing concept employs shoulder and median rumble strips to effectively reduce the lane width. Prior to the installation, right-turning drivers may use the shoulder to decelerate, rather than the through lane. Where shoulder and centerline rumble strips extend to the intersection, drivers may avoid the shoulder and decelerate in the through lane. This would lead to speed differentials and could result in rear-end crashes as discussed previously.
    - Passing vehicles: Prior to the installation, drivers may use the shoulder or cross the centerline to pass turning vehicles. Where shoulder and centerline rumble strips extend to the intersection, drivers may abort a passing maneuver after encountering the rumble strips, resulting in a rear-end collision.
- A Wilcoxon Signed-Rank Test was used to determine whether or not the change in crash rate was significant for total crashes and for fatal/injury crashes (i.e., fatal plus injury). The null hypothesis postulates that there is no difference between the crash rates in the before and after periods. The total sample size is 9 sites. The critical value is 29 for a sample size of 9 and a 5-percent significance level.
    - For total crashes, the test-value (27) was compared to the critical value (29) at a 5-percent significance level; results are not significant.
    - For fatal/injury crashes, the test-value (33) was compared to the critical value (29) at a 5-percent significance level; results are significant, which leads to the conclusion that fatal/injury crashes were reduced after the lane narrowing concept was implemented.

Minor Road Splitter Island Concept

Crash data are shown in table 7 for the one implementation of the minor road splitter island concept in Virginia. For this site, there were 4 years of data in the before period and nearly

Table 7. Crash data summary for concept 2 implementation.

Sites	Period (years)		Crash rate (crashes per MEV per year)		Difference in crash rate			
	Before	After	Before	After	Total crashes	Fatal + Injury crashes	Angle crashes	Rear-end crashes
VA 1	4.00	1.92	2.59	0.82	-68%	-74%	-74%	-100%

Note: MEV = million entering vehicles.

2 years after implementation. The following points summarize the crash findings for the one implementation of the minor road splitter island concept.

- Based on the single implementation of the minor road splitter island concept, it appears that this concept is effective for enhancing safety.
    - The crash rate for total crashes was reduced by 68 percent after deploying the minor road splitter island concept.
    - The crash rate for fatal/injury crashes was reduced by 74 percent after deploying the minor road splitter island concept.
    - The crash rates for angle and rear-end crashes were reduced by 74 and 100 percent, respectively, after deploying the minor road splitter island concept.

Ideas for Future Deployment

The typical design and actual implementation of concepts 1 and 2 have been discussed in detail in the preceding sections. Based on the operational and safety analysis, as well as lessons learned from current deployments and observations in the field, the following points are presented as ideas to enhance future deployments of the treatments. Figures 25 and 26 illustrate the potential enhancements to the lane narrowing concept for both rumble strip and rumble stripe designs, respectively.

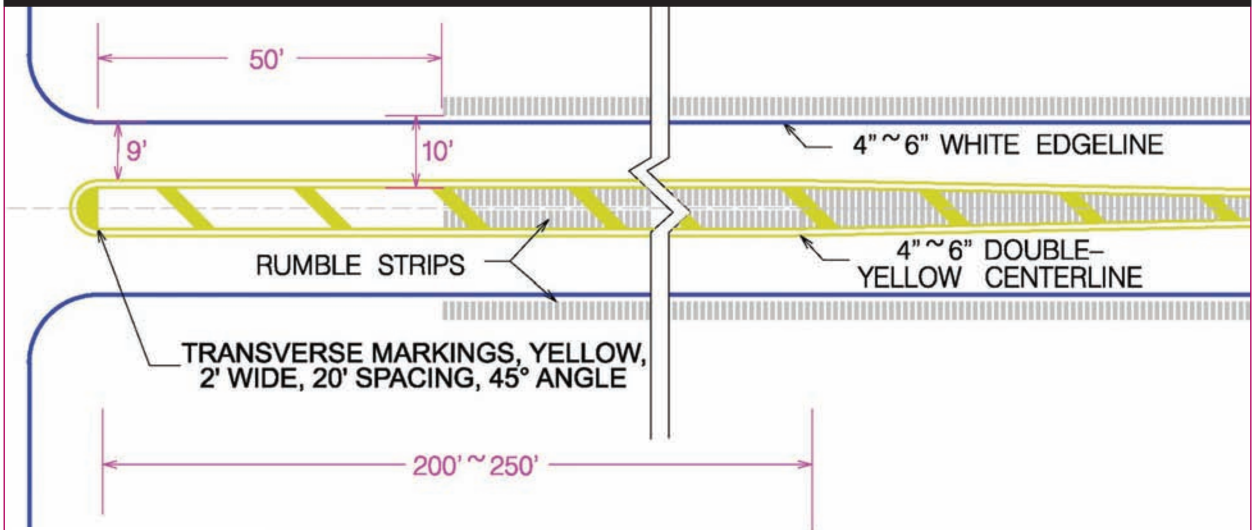
Lane Narrowing Concept

- Increase the length of the narrowed section for the lane narrowing concept. Currently, the design template shows a length of 45.75 m (150 ft) for the narrowed section on the major approaches. This may be too short to achieve the desired effect. If the length is increased to 61 m (200 ft) or 76.25 m (250 ft), then drivers will travel a greater distance in the narrowed section, which may induce lower speeds. While current speed reductions on the major approaches are statistically significant, there is an opportunity to further reduce driver speeds. The nearest 15.25 m (50 ft) from the intersection should not have rumble strips.

- Use a different rumble strip pattern in the median. Concerns have been raised that drivers may react similarly (i.e., steer to the left) when encountering both shoulder and centerline rumble strips with the same pattern. A recent study verified this concern and concluded that some drivers initially steered to the left when encountering centerline rumble strips;[6] therefore, future deployments may consider the use of centerline rumble strips that produce a distinct sensation and noise to avoid confusion with shoulder rumble strips.

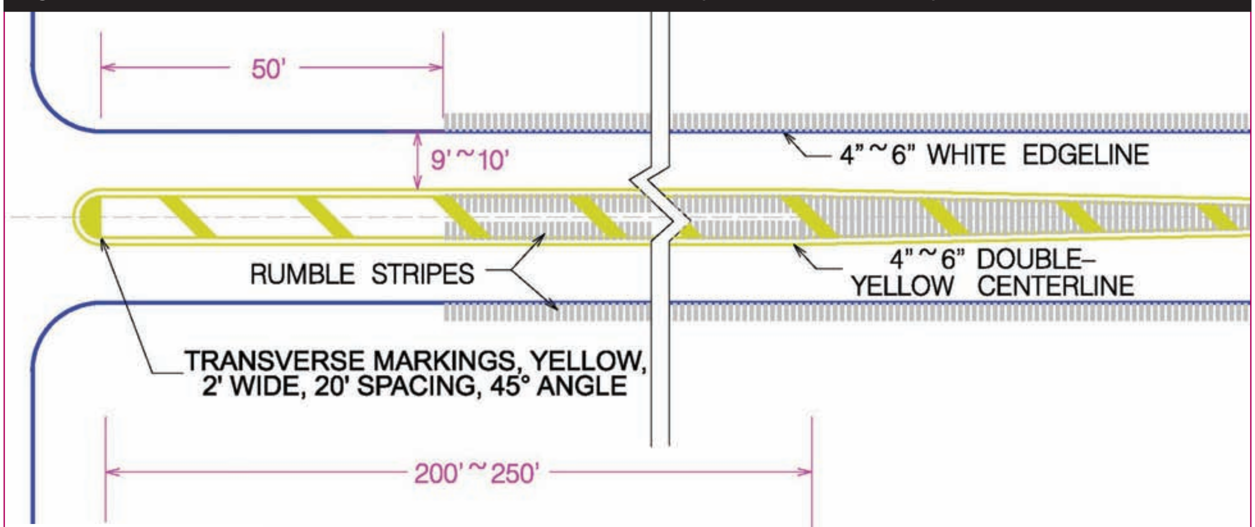
- Some States expressed a concern that 2.75-m (9-ft) lanes are too narrow for the treatment section of the lane narrowing concept. The American Association of State Highway and Transportation Officials (AASHTO) "Green Book"[10] indicates that lane widths of 2.75 m (9 ft) to 3.66 m (12 ft) are generally used, with a 3.66 m (12 ft) lane predominant on most high-type highways. One State indicated that it was required to submit a design exception to implement the lane narrowing concept, while three other States indicated that they were not required to submit a design exception to install 2.75 m (9 ft) or 3.05 m (10-ft) lanes as part of the deployment of the lane narrowing concept. For

Figure 25. Illustration of enhancements to section C of concept 1 with rumble strips.



1 ft = 0.305 m

Figure 26. Illustration of enhancements to section C of concept 1 with rumble stripes.



1 ft = 0.305 m

two-way, two-lane, rural highways, wider lanes provide desirable clearance between heavy vehicles in opposite directions.[10] For the lane narrowing concept, the presence of a painted median should provide adequate clearance for opposing vehicles, even with 2.75 m (9 ft) lanes. For those States that would still prefer wider lanes, the pavement markings (i.e., center and edge lines) could be placed in the rumble strips to increase the lane width without changing the placement of the rumble strip. An alternative method for increasing the effective lane width is to use a wider edge line and place the shoulder rumble strips closer to the shoulder.

- Rumble stripes create a vertical surface that provides enhanced visibility during nighttime and wet weather conditions. However, the operational and safety benefit of rumble strips (pavement markings on side of rumble strip) versus rumble stripes (pavement markings within the rumble strip) has yet to be determined. At this time, States could deploy either rumble strips or rumble stripes based on their typical applications.

- Provide cross-hatching in the median for the lane narrowing concept. Cross-hatching will better define the presence and width of the median. In some of the deployments of the lane narrowing concept, cross-hatching was not used in the median (figure 13). The treatment is much more conspicuous when cross-hatching is used in the median (figures 9, 10, 11, and 14).

- Install rumble strips along both sides of the median and consider installing rumble strips across the entire width for narrow medians. Providing rumble strips across the entire median enhances the conspicuity of the treatment.

- Add a speed advisory plaque to the warning sign (i.e., intersection ahead or lane narrowing) located prior to point 1 in figure 22. Data from North Carolina indicated that vehicles can travel up to 72.45 km/h (45 mi/h) on highways with 2.75 m (9 ft) lanes without crossing into the opposing lane. Where the posted speed is greater than 72.45 km/h (45 mi/h), it may be appropriate to provide a supplemental speed advisory plaque of 72.45km/h (45 mi/h) prior to the deployment of the lane narrowing concept.

- Add signing to warn of slowing vehicles. The crash data from Kentucky and Missouri indicated that rear-end crashes increased after the implementation of the lane narrowing concept. The intent of the lane narrowing concept is to reduce speeds on the major road; however, this may create greater speed differentials and may increase the chance of rear-end crashes. Advance signing could help to mitigate this issue.

- Install both W5-1 and W2-1 warning signs prior to the treatment. Both signs are applicable to this concept and each sign has a specific meaning; W5-1 indicates that the lane narrows and W2-1 indicates that there is an intersection ahead. The use of a single sign does not convey both messages.

Minor Road Splitter Island Concept

- Design the separator island as a traversable island. The AASHTO "Green Book"[10] indicates that curbed islands generally should not be used in rural areas and at isolated intersections unless the intersection is lighted and curbs are delineated. The policy also indicates that traversable islands may be preferable under certain conditions including: lightly developed areas, intersections where approach speeds are relatively high, areas with little pedestrian traffic, areas without fixed-source lighting, areas requiring significant snow plowing, and areas where signs and supports are not needed.[10] Nontraversable separator islands require additional right-of-way due to the required turning radius for large vehicles. If the island is traversable, the turning radius is reduced along with the required right-of-way. Aside from the reduced right-of-way, the fact that these materials can be snowplowed is an added advantage in the northern States. There are several materials currently available for use as traversable separator islands. Examples include materials similar to those used for traversable traffic circles and speed humps. Where traversable separator islands are used, the maximum height of the island is 76.2 mm (3 inches).

- Use materials that can be prefabricated and nailed in place on-site. There are several examples of materials that can be prefabricated from recycled materials including some of those used for traffic calming devices. Prefabricated islands will reduce the disruption of traffic during deployment and may reduce implementation costs.

- Reduce the width of the separator island. The current design template shows a width of 2.135 m (7 ft) for a non traversable separator island. The width could be reduced to a minimum of 1.22 m (4 ft) provided that the surface area exceeds the minimum of 6.975 sq-m (75 sq-ft).[10]

- Delineate the separator island or construct the island of colored material. The AASHTO "Green Book"[10] indicates that islands are sometimes difficult to see at night because of glare from oncoming headlights. Therefore, appropriate delineation should be provided to increase the conspicuity of the island. A similar effect could be achieved by using colored materials to construct the island such as those used for traffic calming devices.

- Use cross-hatching to better delineate the approach to the separator island for the minor road splitter island concept. As shown in figure 15, the centerline splits prior to the separator island and continues along either side. The deployment of the minor road splitter island concept in Lorton, VA, did not include cross-hatching where the centerline splits prior to the island. Providing cross-hatching will further enhance the conspicuity of the separator island.

Summary

Lane Narrowing Concept

For the lane narrowing concept, the major points of this study can be summarized as follows:

Speed

- After implementation, the average (5.64 km/h (3.5 mi/h)) and 85th-percentile (7.25 km/h (4.5 mi/h)) speed reductions were statistically significant at the 95-percent confidence level for all vehicles on the major approach with an approach speed of 64.4 km/h (40 mi/h) or greater.
- After implementation, the average (7.084 km/h (4.4 mi/h)) and 85th- percentile (7.728 km/h (4.8 mi/h)) speed reductions for trucks on the major approach were statistically significant when the vehicles had an approach speed of 64.4 km/h (40 mi/h) or greater.
- The reductions in the 85th-percentile speed appear to be greater than the reductions in the average speed for all vehicles as well as for trucks only.
- The speed reduction is greater for trucks than for all vehicles combined.

Driver Behavior

- Driver behavior data indicated a large number of rumble strip contacts on the major approaches after implementation.

Safety

- Based on limited crash data, there appears to be a general reduction in the crash rate for total, fatal/injury, and angle crashes after implementing the lane narrowing concept, but there is an increase in the crash rate for rear-end crashes.
- A Wilcoxon Signed-Rank Test indicates that there is no significant difference between the total crash rates in the before and after periods; however, there is a significant reduction in fatal/injury crashes.

Minor Road Splitter Island Concept

For the minor road splitter island concept, the major points of this study can be summarized as follows:

Speed

- After implementation, the speed reductions on the minor approaches range from 4.83 to 33.81 km/h (3 to 21 mi/h) comparing speeds by time of day, averaging 17.39 km/h (10.8 mi/h) and 15.78 km/h (9.8 mi/h) for the northbound and southbound approaches, respectively.
- After implementation, the average speed reductions were statistically significant at a 95-percent confidence level for both minor approaches.

Driver Behavior

- Driver behavior improved slightly after implementation based on increased STOP sign compliance.

Safety

- Based on limited crash data, there appears to be a general reduction in the crash rate for total, fatal/injury, angle, and rear-end crashes after implementation.

Conclusions

The general conclusion from this research is that positive operational and safety effects can be expected with the installation of concepts 1 and 2. The lane narrowing concept is shown to significantly reduce speeds on the major road approaches at rural, two-lane, TWSC intersections. The results are consistent across sites, which are combined in the main analysis. The minor road splitter island concept is shown to improve driver compliance as well as reduce speeds on the minor approaches at rural, two-lane, TWSC intersections. While the results for the minor road splitter island concept are based on just one site, the initial indications are promising.

Based on the limited after period, there appears to be a general reduction in crashes associated with the implementation of concepts 1 and 2. For the lane narrowing concept, total, fatal/injury, and angle crashes were reduced in the after period, but rear-end crashes increased at some sites. The apparent increase in rear-end crashes should be monitored as additional after data become available. For the minor road splitter island concept, the crash rate decreased for all categories in the after period. While the simple before-after method used in this study does not account for some issues related to safety analysis (e.g., regression-to-the-mean, temporal effects, and other changes that may occur other than the safety improvements themselves), it does provide a preliminary understanding of the safety effectiveness of concepts 1 and 2. Also, it may not be worth conducting a more rigorous evaluation until sufficient data are available for the after period.

It is likely that the lane narrowing concept will be most effective at rural, TWSC intersections with a relatively high posted speed (64.4 km/h (40 mi/h) or greater) on the major road. However, this concept may be applicable at urban and low-speed intersections. While the limited sample did not indicate a linear relationship between speed reduction and lane width, other research has shown a positive association between the two variables (i.e., speed decreases as lane width decreases). Positive features of the lane narrowing concept include highly visible pavement markings with cross-hatching in the median and rumble strips that cover the entire width of the median. For the minor road splitter island concept, it is likely that the implementation will be most effective at rural, TWSC intersections with STOP sign compliance or conspicuity issues on the minor approach. However, this concept may be applicable at other TWSC intersections as well.

Based on the relative low cost and initial effectiveness of concepts 1 and 2 with respect to operational and safety measures, it is expected that these strategies will prove to be cost-effective methods for improving intersection safety. However, more comprehensive analysis is needed before wide-scale implementation can be recommended. There is also a need to develop guidelines for where these strategies should be implemented.

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