NCHRP

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT 737

Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways

TRANSPORTATION RESEARCH BOARD
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NCHRP REPORT 737

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CRP STAFF FOR NCHRP REPORT 737

NCHRP PROJECT 15-40 PANEL
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FOREWORD

By B. Ray Derr
Staff Officer
Transportation Research Board

This report presents guidance for designing the transition from a high-speed rural highway to a lower-speed section, typically approaching a small town. The report includes a methodology for assessing these highway sections and a catalog of potential treatments for addressing problems. It will be useful to geometric designers and traffic engineers responsible for these situations.

The TRB website includes two significant products derived from this project. The first is a spreadsheet that can be used to create a straight-line diagram of a site that brings together all of the relevant information for analysis. The second is a Design Guidance document that a transportation agency can adapt to meet its own purposes and needs.

As rural and other high-speed highways approach built-up areas, there is usually a transition zone where drivers are encouraged and expected to reduce their speed to one suitable for the environment they are entering. A common example is a rural highway that passes through a small community or hamlet where 55-mph speeds are neither safe nor acceptable to that community. Design standards and policies exist for both the high-speed and low-speed environments, but differences between the two make design of the transition zone problematic. Many communities would like to use the transition zone as a gateway to the community and they often have unrealistic expectations as to the magnitude of speed reduction. The design of the transition zone must attempt to meet many objectives while maintaining safety.

In NCHRP Project 15-40, MRIGlobal and HDR Engineering reviewed existing literature, including *NCHRP Synthesis 412: Speed Reduction Techniques for Rural High-to-Low Speed Transitions*, to identify techniques that demonstrate an effective and safe reduction in speed and document their effectiveness. Field research was performed to develop additional information on the effectiveness of roundabouts, transverse pavement markings, and welcome signs at community entrances. The researchers then developed a process for analyzing the transition zone, for selecting appropriate techniques to address issues in the zone, and for evaluating the effectiveness of the techniques after implementation. These materials were brought together in this report.

The following items are available on the TRB website (http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2721):

- Appendix A—Vehicle Speed Profiles
- Appendix B—Design Guidance Document
- Appendix C—Potential Changes for Consideration in the Next Editions of the *Green Book* and *Roadside Design Guide*
- Transition Zone Straight Line Diagram Workbook (Microsoft Excel spreadsheet)

CONTENTS

SUMMARY

Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways

This report presents the results of a study undertaken to develop improved design guidance for high-speed to low-speed transition zones on rural highways. The primary steps of the research included a literature review and state-of-practice review on speed reduction treatments utilized in transition zones (both domestically and internationally) and observational field studies of several key treatments that have been implemented in the United States. Several important or fundamental findings from the observation field studies are as follows:

- Roundabouts and transverse pavement markings (TPMs) increase the rate of compliance of vehicles traveling at or below the speed limit at the end of a transition zone by 15 and 20 percent, respectively, compared to no treatment.
- Roundabouts increase the rate of compliance of vehicles traveling within 5 mph of the speed limit at the end of a transition zone by 11 percent, compared to no treatment.

The findings support previous research (Forbes, 2011) indicating the need to provide additional measures through the community to maintain any speed reduction downstream of the transition zone.

This report also provides design guidance for selecting geometric design, traffic control device, pavement surface, and roadside treatments for transitioning from high- to low-speed roadways on rural highways. The design guidance covers a wide range of issues to be considered in the design of high- to low-speed transition zones, including the following:

- Definitions and site characteristics to define the geographical limits or boundaries of the transition zone study area.
- A methodology for assessing whether a high- to low-speed transition zone has speed-limit compliance or safety issues to support the need for and the selection of an appropriate treatment to address the issue(s).
- Guiding principles and design concepts to be considered in the design of a transition zone.
- A catalog of potential transition zone treatments with a description and illustration of the treatments and information on effectiveness, cost, contraindications, and installation location.
- The importance of evaluating the effectiveness of transition zone treatments after implementation.
- Legal/liability issues to be considered when evaluating and designing transition zones.

In the United States, the development of national design guidelines for rural high- to low-speed transition zones would be valuable. This document and other recent reports and documents are steps toward achieving this goal, but more work needs to be done. Several suggested steps for building upon the guidelines in this report are as follows. First, more

accurate and reliable information needs to be collected on the effectiveness of transition zone treatments on reducing speeds and improving safety (and potentially other benefits). This can only be accomplished by more agencies conducting evaluations of treatments using the most scientifically valid methodologies.

Second, the AASHTO *Green Book* does not address transition zones. In the next edition of the *Green Book,* it is proposed that a paragraph be added to Chapters 6 and 7, explaining the transition zone related issues and the need to consider further design guidance for transition zones. In each chapter, the new text could refer the reader to other research, such as this report, for more details. Incorporation of detailed design guidance for rural high- to low-speed transition zones in the *Green Book* does not seem appropriate. Guidance on design of transition zones is almost of the same nature as design guidance on traffic calming, and detailed guidance on traffic calming is not provided in the *Green Book;* therefore, reference in the *Green Book* to an external document seems most appropriate. It is also proposed that the next edition of the *Roadside Design Guide* include a general discussion of issues related to transition zones.

SECTION 1

Introduction

1.1 Background

The American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets* (AASHTO, 2011), commonly known as the *Green Book,* makes a distinction between design criteria for high-speed facilities and low-speed facilities. The boundary between high-speed design and low-speed design is in the range of 45 to 50 mph. The lower limit for high-speed design is 50 mph, and the upper limit for low-speed design is 45 mph. Where high-speed facilities meet low-speed facilities, there is a transition zone where drivers in one direction are expected to reduce their speed to one suitable for the environment they are entering. An example of this is where a high-speed rural two-lane highway (e.g., with a posted speed limit of 55 mph) enters an area where lower speeds are expected of drivers, such as a community or other developed area (e.g., with a posted speed limit of 35 mph). Through the community, higher speeds are not appropriate for a number of potential reasons that include turning maneuvers at intersections and driveways, higher development density, on-street parking, higher pedestrian and bicycle activity levels, and use of curb and gutter cross sections. AASHTO's current policy provides a sufficient level of detail for designing roads in both the high-speed environment and the low-speed environment; however, the *Green Book* lacks sufficient guidance on appropriate design of the transition zones between the two facility types. Such design guidance is needed to increase safety through the transition zone and entire low-speed environment (i.e., the community) and to encourage motorists to reduce their travel speeds to a level consistent with the low-speed environment.

A transition zone is defined to be a section of road that is continuous with and connects a road section with a high posted speed limit to a road section with a lower posted speed limit (Forbes, 2011). The transition zone should not be considered as a specific point along a roadway where a speed change is to occur; rather, it extends over a length of roadway. Designs that encourage gradual speed reductions over the length of a transition zone are preferred to designs that bring about sudden reductions in speed at the downstream end.

Drivers need well-designed transition zones with explicit traffic control devices and roadway design features that convey the need to reduce speeds and that encourage gradual, smooth reductions in speed as they transition from high- to low-speed facilities. The treatments for reducing vehicle speeds at transition zones include effective use of geometric design features. But in achieving this goal, a broader scope of guidelines is needed that considers the potential effects of traffic engineering and traffic control, land use and adjacent development, streetscape, community context, aesthetics, and multimodal travel demands.

The design of high- to low-speed transition zones is closely related to the basic concepts of traffic calming. Traffic calming has been used extensively in the United States in urban and suburban areas but has been used to a lesser degree in rural areas or at rural/suburban or rural/urban boundaries. The use of traffic calming in rural areas internationally is more advanced than in the United States. Several countries including Denmark, Ireland, the Netherlands, Sweden, and the United Kingdom have developed guidelines for the use of traffic calming treatments in rural towns along national routes, particularly in the transition zone into a community. In developing guidance for the design of high- to low-speed transition zones for rural highways, the principles of traffic calming play a central role and much can be learned from global experiences.

Recently, the National Cooperative Highway Research Program (NCHRP) published *NCHRP Synthesis 412: Speed Reduction Techniques for Rural High-to-Low Speed Transitions* (Forbes, 2011). The synthesis is a state-of-the-practice report on effective and ineffective rural high- to low-speed transition treatments that have been tried by state departments of transportation (DOTs) in the United States and some that have been tried in other countries. This research builds upon the results published in *NCHRP Synthesis 412*.

1.2 Research Objective and Scope

The objective of this research is to develop design guidance for selecting effective geometric, streetscape, and traffic engineering treatments for transitioning from high- to low-speed roadways, particularly rural highways entering communities. The design guidance identifies specific treatments for use in encouraging drivers to reduce their speeds and, where possible, quantifies the effectiveness of those techniques. In developing the design guidance, consideration is given to transition zone-specific factors such as land use; community context; aesthetics; and the accommodation of trucks, parking, pedestrians, bicyclists, and public transportation services.

The scope of the research includes the development of design guidance for high- to low-speed transition zones on rural two-lane highways and rural multilane divided and undivided highways (i.e., non-freeways). The research focuses on that portion of the highway near the change from a high-speed to a low-speed environment (i.e., the transition zone), but consideration is also given to vehicles as they continue through the low-speed environment (i.e., through the community). Furthermore, this research focuses on engineering treatments that encourage drivers to reduce their speeds through transition zones. Other speed management components such as driver education and enforcement programs can be employed to reduce speeds and improve safety through transition zones, but these other speed management components and programs are not addressed in detail in this research.

1.3 Overview of Research Methodology

In Phase I of the research, the literature was reviewed to identify geometric, streetscape, and traffic engineering treatments that have been implemented, or could potentially be implemented, in a transition zone and that have been evaluated to assess their effectiveness in either reducing speeds, decreasing crashes, or both. In particular, the review focused on previous evaluations that provided quantitative assessments. As part of this effort, draft material for *NCHRP Synthesis 412* was reviewed in addition to other domestic and international resources.

Also in Phase I, a survey of state and county highway agencies was conducted to create an inventory or catalog of transition zone treatments implemented across the United States. Results of the literature review and survey were used to develop a prioritized list of practical, implementable transition zone treatments, and for which more reliable information on their effectiveness in reducing speeds through transition zones was desired.

In Phase II of the research, field studies were performed to evaluate the effectiveness of several treatments in reducing speeds through transition zones and through the community. Crash data were also obtained to assess the safety experience near the study locations.

Combining results from the field studies in Phase II with the information gathered in Phase I, the research team developed design guidance for high- to low-speed transition zones on rural highways. The design guidance addresses issues associated with defining the geographical limits of a transition zone and assessing the need for some type of improvement to increase compliance with desired speeds through the community. The design guidance also addresses issues to consider when selecting potential treatments for implementation and provides a catalog of transition zone treatments, including effectiveness assessments. Finally, the design guidance describes a methodology for evaluating the effectiveness of treatments following implementation and possible litigation issues that agencies should consider during the planning and design of transition zones projects.

1.4 Outline of Report

This section outlines the entire research effort, with the remainder of the document organized as follows:

- Section 2 summarizes findings of the literature review, including a review of international guidelines.
- Section 3 describes the field studies conducted to evaluate the effectiveness of several transition zone treatments in reducing speeds and presents the analysis results.
- Section 4 presents design guidance for selecting geometric, traffic control device, pavement surface, and roadside transition zone treatments for transitioning from high- to low-speed rural highways.
- Section 5 provides final conclusions and recommendations for next steps.
- Section 6 presents a list of references cited in the report.

For practitioners who wish to focus on the primary product of this research rather than the details of the research methodology, Section 4 on design guidance will be of most interest.

SECTION 2

Literature Review

This literature review is divided into three sections. The first section presents key findings from *NCHRP Synthesis 412* (Forbes, 2011). The second section provides a summary of existing practice and research, and the third section presents a summary of international guidelines related to transition zones. This section does not provide a detailed account of the transition zone literature. The reader is referred to *NCHRP Synthesis 412* for more details. Recent reports by Dixon et al. (2008), *Determining Effective Roadway Design Treatments for Transitioning from Rural Areas to Urban Areas on State Highways,* and Hallmark et al. (2007), *Evaluation of Gateway and Low Cost Traffic Calming Treatments for Major Routes in Small Rural Communities,* also provide a detailed account of the transition zone–related literature.

2.1 Key Findings from *NCHRP Synthesis 412*

NCHRP Synthesis 412 (Forbes, 2011) was prepared to document what is known about effective and ineffective transition zone design treatments. The focus was on engineering measures used to transition motorists from high- to low-speed areas. The effectiveness of each transition zone treatment was reported in terms of operational (i.e., reductions in speed) and/or safety benefits. In general, the transition zone treatments were grouped into four categories: geometric design, traffic control devices, surface treatments, and roadside features.

Forbes reported that most existing transition zone design guidelines are generally consistent in providing the following information:

- More extensive and aggressive measures tend to produce greater reductions in speed and crash occurrence than less extensive and passive measures.
- There needs to be a distinct relationship between a community speed limit and a change in the roadway character.
- No particular measure is appropriate for all situations. Each community must be assessed and treated based on its own characteristics and merits.
- It is necessary to provide additional measures through the community to maintain a speed reduction downstream of the transition zone; otherwise, speeds may rebound to previous levels within a distance as short as 820 ft from the start of the lower speed zone.

Forbes also reported that there appears to be an emphasis placed on the precise location at which vehicles are expected to be traveling at the lower (i.e., community) speed and the nature of the roadway at this point. However, treatments located along the segment of highway preceding this location are critical to alerting the driver of the change in desired speed and the need to provide adequate distance for this transition to take place. Thus, the effects of treatments in combination along the entire transition zone length appear to produce the most meaningful results.

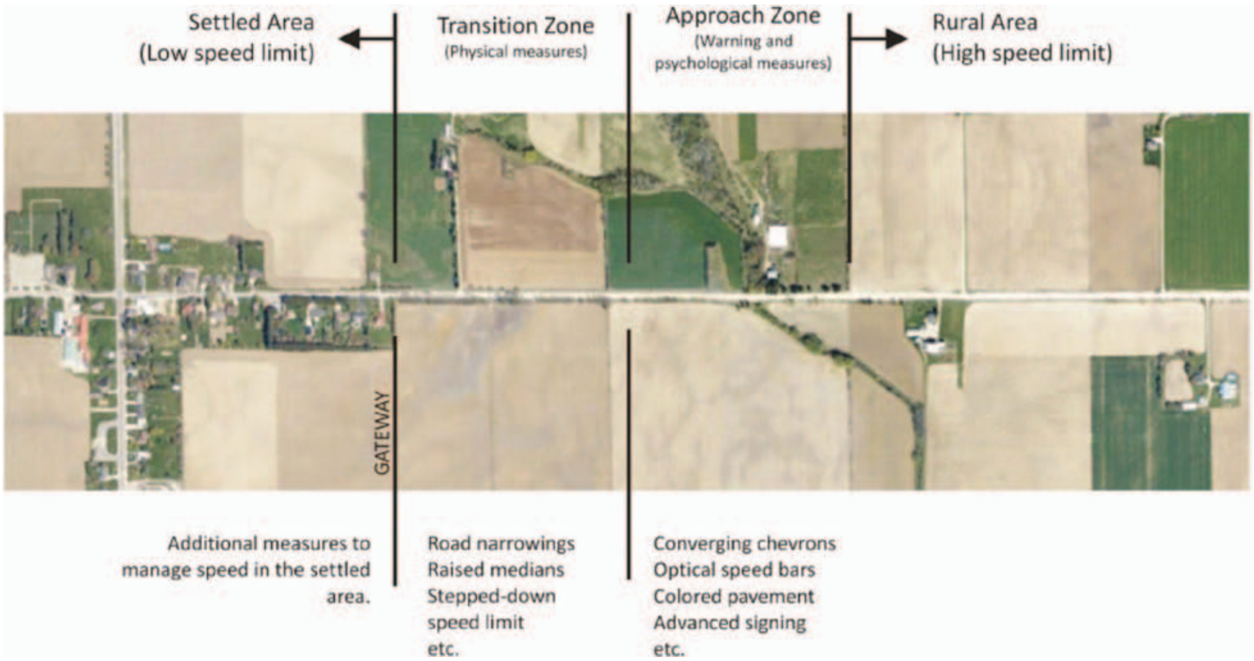


Figure 2-1. Transition zone and approach zone concepts (Forbes, 2011).

The basic principle is that motorists are first provided with warning devices and psychological measures early in the transition zone, and are then presented with physical measures closer to the community. This approach to transition zone design is intended to better satisfy driver behavior and avoid abrupt appearance of a gateway or physical traffic calming feature. The basic approach to transition zone design is illustrated in Figure 2-1.

Finally, Forbes reported on the separate directions that European and North American countries are heading concerning speed management approaches. Several European countries are currently experimenting with minimizing and removing traffic control and design features that physically separate the road users. This is an attempt to create a measure of uncertainty in the driving environment, causing drivers to pay closer attention to the road and reduce their speeds. This is in stark contrast to the North American approach to speed management, which has been to add measures.

2.2 Summary of Existing Practice and Research

In addition to reviewing *NCHRP Synthesis 412,* other resources were reviewed to identify geometric, streetscape, and traffic engineering treatments that demonstrate an effective and safe reduction in speed and are potentially applicable for use in the design of transition zones for rural highways. In addition, a survey was conducted to create an inventory of practical speed reduction treatments for implementation in transition zones. This section combines the results of the literature review and survey and presents a catalog of potential treatments for inclusion in design guidelines for high- to low-speed transition zones. The catalog of potential treatments is divided into groups consisting of geometric design, traffic control devices, pavement surface, and roadside treatments and is presented in Figures 2-2 through 2-5. Figure 2-6 presents information on gateway treatments (i.e., combinations of transition zone treatments).

For each transition zone treatment in the catalog, information regarding effectiveness in reducing speeds and/or improving safety is provided (when available). The **bold** values presented in

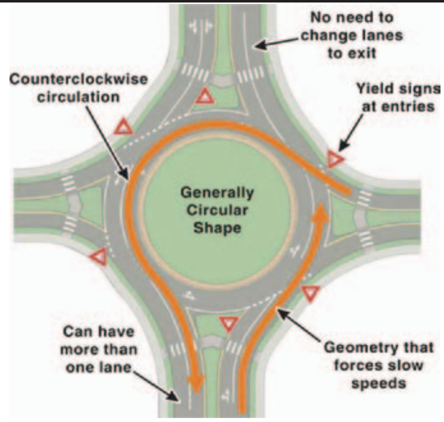
Figures 2-2 through 2-6 are effectiveness estimates as summarized in Chapter 4 of *NCHRP Synthesis 412* (Forbes, 2011). Although not specifically stated in the synthesis document and chapter, it is implied that the effectiveness estimates presented in Chapter 4 are the most reliable effectiveness estimates for the respective speed reduction treatments. The other effectiveness estimates in Figures 2-2 through 2-6 (i.e., non-bold text) are based on findings from the literature review conducted as part of this research.

The reliability and/or accuracy of the documented effectiveness estimates in Figures 2-2 through 2-6 are rated using a star rating system developed as part of this research. The star rating system takes into consideration the robustness of the data supporting the estimates of effectiveness, the appropriateness of the analysis methods, applicability to U.S. conditions, whether the results are based upon field data or simulation, and applicability to transition zones in rural areas. A star rating system from one to four is used, with one star (★) representing "least reliable" and four stars (★★★★) representing "most reliable." No formal procedure was developed to calculate the star rating for a given effectiveness estimate; rather, the rating was based on a qualitative assessment of the factors listed above.

Figures 2-2 through 2-6 provide a definition or description of a specific treatment and information on the expected effectiveness of the given treatment in reducing speed or improving safety. The figures do not include speed reduction treatments considered inappropriate for use in high- to low-speed transition zones. For example, treatments involving vertical deflections of the pavement surface such as speed humps or raised intersections are not included. Introducing such measures in a transition zone has too much potential to lead to loss of vehicle control; therefore, they are considered inappropriate for this type of application.

Treatment: Roundabout

Description: A roundabout is a form of circular intersection in which traffic travels counterclockwise (in the United States and other right-hand traffic countries) around a central island. Entering traffic must yield to circulating traffic. The channelized approaches and geometry induce reduced travel speeds through the circular roadway.



Source: Rodegerdts et al., 2010

Speed Estimate:
Rodegerdts et al. (2007, 2010) developed speed prediction models for roundabouts: ★★★.

$$V_{exit} = MIN\left[aR_3^b; \frac{1}{1.47}\sqrt{(1.47aR_2^b)^2 + 13.8d_3}\right] \quad V_{enter} = MIN\left[aR_1^b; \frac{1}{1.47}\sqrt{(1.47aR_2^b)^2 + 8.4d_1}\right]$$

where:
- **V_{exit} = predicted exit speed (mph)**
- **V_{enter} = predicted entry speed (mph)**
- **d_1 = distance between point of interest on the entry and midpoint of path on circulating roadway (ft)**
- **d_2 = distance between point of interest on the entry and the midpoint of path on the circulating roadway (ft)**
- **d_3 = distance between the midpoint of path on the circulating roadway and point of interest on the exit (ft)**
- **R_1 = path radius on entry to roundabout (ft)**
- **R_2 = path radius on circulating roadway (ft)**
- **R_3 = path radius on exit from roundabout (ft)**
- **a,b = regression parameters**

Speed Prediction Parameters:

	Superelevation (e) = +0.02	Superelevation (e) = –0.02
a	3.4415	3.4614
b	0.3861	0.3673

Safety Estimate:
Converting a two-way stop-controlled intersection to a roundabout reduces total crashes by 71% and fatal and all injury crashes by 87% (AASHTO, 2010) ★★★.

Converting a signalized intersection to a roundabout reduces total crashes by 48% and fatal and all injury crashes by 78% (AASHTO, 2010) ★★★.

10% to 40% reduction in injury crashes (Elvik and Vaa, 2004) ★.

Treatment: Chicane or Horizontal Deflection

Description: Chicanes incorporate the use of pavement markings, planting strips, on-street parking, etc., to create a sequence of horizontal curves (i.e., horizontal deflections) intended to slow vehicles.

Source: San Francisco Municipal Transportation Agency (Forbes, 2011)

Speed Estimate:
A gateway treatment with and without horizontal deflections reduced speeds of the same magnitude (Lamberti et al., 2009) ★★.

Reduced 85th percentile speed from 31 to 28 mph (Macbeth, 1998) ★.

6% reduction in 85th percentile speeds (Corkle et al., 2001) ★.

85th percentile speed reduced from 45 to 35 mph. Reduction in mean speed from 36 to 29 mph. Number of vehicles traveling 10 mph above speed limit reduced from 35% to 3% (Hallmark et al., 2007) ★.

Reduced speeds by 26% (Charlton and Baas, 2006) ★.

Safety Estimate:
No data found.

Treatment: Bulbout/Curb Extension

Description: At an intersection, the curb line is extended into the street to effectively reduce the street width. By reducing the street width, the pedestrian crossing distance is reduced.

Source: Peter Lagerway (Harkey and Zegeer, 2004)

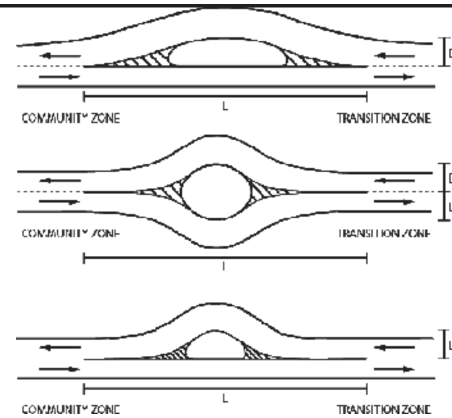
Speed Estimate:
Narrowing street width at the intersection reduced speeds by 2.6 mph (Ewing, 1999) ★.

Safety Estimate:
No data found.

Figure 2-2. Catalog of potential transition zone treatments and their expected speed reduction and safety effects (geometric design treatments).

Treatment: Center Island/Raised Median

Description: A channelizing island that creates separation between the two opposing directions of travel. Center islands/raised medians can create shifts or deflections in the travel paths of vehicles and often reduce the effective widths of the roadways. Center islands/raised medians can be created through a combination of pavement markings, raised curbs, planting strips, etc.



Source: Adapted from Berger and Linauer (1998)

Speed Estimate:
Berger and Linauer (1998) developed speed prediction models for center islands: ★★.

$V_{85} = 9.194\mathrm{Ln}(L/2d) + 12.290 \qquad V_m = 8.020\mathrm{Ln}(L/2d) + 11.031$

where: V_{85} = **85th percentile speed (mph)**
V_m = **mean speed (mph)**
L = length of island + length of both tapers (ft)
d = lateral deflection of lane (ft)

Reduced 85th percentile speeds up to 9.6 mph (Dixon et al., 2008) ★★.

17% reduction in vehicles exceeding the speed limit (Forbes and Gill, 1999) ★★.

Median resulted in 3.4-mph reduction in mean speed (Dixon et al., 2008) ★★.

Median with gateway reduced mean speeds by 10.2 mph and 85th percentile speeds by 5.6 mph (Dixon et al., 2008) ★★.

Median with pedestrian crosswalks reduced mean speed by 10 mph and 85th percentile speeds by 5.6 mph (Dixon et al., 2008) ★★.

Median with tubular markers reduced speeds by up to 3 mph (Hallmark et al., 2007) ★.

Painted median had no significant effect on operating speeds (Hallmark et al., 2007) ★.

Median reduced speeds by 9% (Charlton and Baas, 2006) ★.

Reduced speeds by 3 mph (Harvey, 1992) ★.

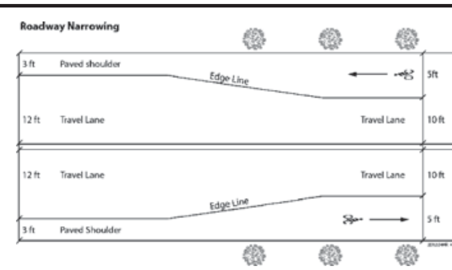
Center islands and curb extensions reduced speeds by 5 mph; center islands alone reduced speeds by 2 mph (TAC, 1998) ★.

Raised medians with signage reduced 85th percentile speeds by 9 mph; signage alone reduced 85th percentile speeds by 6 mph (Crowley and MacDermott, 2001) ★.

Safety Estimate:
No data found

Treatment: Roadway Narrowing

Description: Can be achieved either by physically reducing the roadway width or by narrowing the widths of the travel lanes. This technique is often installed in conjunction with adding bicycle lanes or adding a raised median.



Speed Estimate:
2.6-mph reduction in speeds was achieved using a variety of roadway narrowing strategies (Ewing, 2001) ★.

11% to 20% reduction in operating speeds (Charlton and Baas, 2006) ★.

Safety Estimate:
No data found.

Treatment: Bicycle Lanes

Description: A portion of a roadway designated by striping, signing, and pavement markings for the preferential or exclusive use of bicyclists. Bicycle lanes are often installed in conjunction with roadway narrowing and indicate a change in environment (i.e., increased bicycle activity).

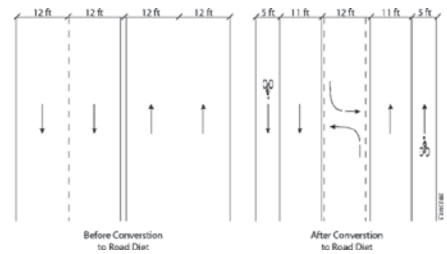
Speed Estimate:
No data found.

Safety Estimate:
No data found.

Figure 2-2. (Continued).

Treatment: Road Diet

Description: A reduction in the number of through lanes (e.g., converting a four-lane road to a three-lane roadway with a two-way left-turn lane or converting a four-lane roadway to a two-lane roadway with a raised median or on-street parking). Bicycle lanes are often installed in conjunction with road diets.



Sample Road Diet

Speed Estimate:
5-mph or less reduction in operating speeds, but up to 70% reduction in excessive speeding (Knapp and Rosales, 2007) ★★.

5-mph reduction in 85th percentile speeds and 60% to 70% reduction in vehicles traveling more than 5 mph over the posted speed limit (Knapp and Geise, 2003) ★.

4-mph reduction in mean and 85th percentile speeds (Corkle et al., 2001) ★.

Safety Estimate:
20% to 40% reduction in crashes (Knapp and Rosales, 2007) ★★.

17% to 62% reduction in crashes (Knapp and Geise, 2003) ★.

29% reduction in crashes (FHWA, 2012) ★.

Key to Star Ratings for Reliability of Speed and Safety Estimates:
★ —least reliable
★★
★★★
★★★★ —most reliable

Figure 2-2. (Continued).

Treatment: Transverse Pavement Markings

Description: Pavement markings placed perpendicular to the direction of travel to draw attention to a change in the roadway environment. Often the markings are placed in decreasing intervals to give the illusion of increasing speed.

Speed Estimate:
3- to 9.5-mph reduction in speed (Arnold and Lantz, 2007) ★.

1.0-mph reduction in 85th percentile speed (Fitch and Crum, 2007) ★.

Up to 2-mph reduction in 85th percentile speeds (Hallmark et al., 2007) ★.

3- to 5-mph reduction in mean speeds and 5- to 7-mph reduction in 85th percentile speeds for painted chevrons (Hallmark et al., 2007) ★.

3- to 7-mph reduction in 85th percentile speeds from transverse pavement markings with speed feedback signs (Hallmark et al., 2007) ★.

Up to 4-mph reduction in 85th percentile speed with painted chevron and speed marking (Hallmark et al., 2007) ★.

Transverse lines reduced speeds by 8% to 14% (Charlton and Baas, 2006) ★.

Safety Estimate:
No data found.

Treatment: Lettered Pavement Markings

Description: Pavement markings with lettered descriptions such as "Slow."

Source: Hallmark et al., 2007

Speed Estimate:
Speed pavement marking with red background reduced 85th percentile speeds by up to 9 mph (Hallmark et al., 2007) ★.

Speed markings on pavement inside of elongated circles (speed roundels) reduced mean speeds on 40-mph approaches by 3 mph. Roundels on 30-mph approaches had no significant effect (Barker and Helliar-Symons, 1997) ★★.

Safety Estimate:
No data found.

Figure 2-3. Catalog of potential transition zone treatments and their expected speed reduction and safety effects (traffic control device treatments).

Treatment: Speed-Activated Feedback Sign

Description: A variety of warning and/or dynamic speed signs that indicate a reduction in the speed limit and alert the driver that he/she is traveling above the posted speed limit for that portion of roadway.

Speed Estimate:
6-mph reduction in mean speeds (Donnell and Cruzado, 2008) ★★★.

Mean speed reduction of 4.3 mph (Farmer et al., 1998) ★★.

Reduced average mean speeds by 5.4 mph, also found to be capable of reducing the number of drivers who exceed the speed limit by up to 80% (Winnett and Wheeler, 2002) ★★.

Reduced speeds by 11% (Charlton and Baas, 2006) ★.
6.9-mph reduction in the 85th percentile speeds (Sandberg et al., 2006) ★★.

7-mph reduction in 85th percentile speed (Hallmark et al., 2007) ★.

3% to 12% reduction in mean speeds and 1% to 14% reduction in 85th percentile speeds (Russell and Godavarthy, 2010) ★.

4% to 11% reduction in mean speeds and 3% to 15% reduction in 85th percentile speeds for mobile speed trailers (Russell and Godavarthy, 2010) ★.

Safety Estimate:
34% reduction in casualty crashes (Winnett and Wheeler, 2002) ★★★.

Key to Star Ratings for Reliability of Speed and Safety Estimates:
★—least reliable
★★
★★★
★★★★—most reliable

Figure 2-3. (Continued).

Treatment: Transverse Rumble Strips

Description: Rumble strips placed in the travel lanes perpendicular to the direction of travel to alert drivers of a change in the environment. As motor vehicle tires pass over the rumble strips, drivers receive auditory and tactile warnings to reduce their speeds.


Source: Corkle et al., 2001A

Speed Estimate:
Rumble strips reduced the mean speed by 1.3 mph but the result was not statistically significant (Ray et al., 2008) ★★.

Rumblewave surfaces were responsible for speed reductions of 1% to 6% (Department for Transport, 2005) ★★.

Up to 6% reduction in operating speeds (Charlton and Baas, 2006) ★.

Safety Estimate:
Rumblewave surfaces experienced a 55% reduction in fatal and injury crashes (Department for Transport, 2005) ★★.

Treatment: Colored Pavement

Description: The use of colored pavement to delineate the functional space of the roadway and to alert drivers of a change in the environment.


Source: Russell and Godavarthy (2010)

Speed Estimate: Up to 17% reduction in mean and 85th percentile speeds (Russell and Godavarthy, 2010) ★.

Safety Estimate: No data found.

Key to Star Ratings for Reliability of Speed and Safety Estimates:
★—least reliable
★★
★★★
★★★★—most reliable

Figure 2-4. Catalog of potential transition zone treatments and their expected speed reduction and safety effects (pavement surface treatments).

Treatment: Welcome Sign

Description: A physical landmark or sign that indicates to drivers that they are entering a community. Welcome signs are generally placed to the right of the roadway, but some may be large enough to span the roadway.

Speed Estimate:
Reduced 85th percentile speeds by up to 3 mph (County Surveyor's Society, 1994) ★.

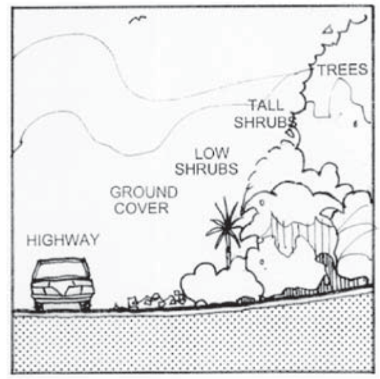
Safety Estimate:
Are not detrimental to safety (Veneziano et al., 2009) ★★.

Treatment: Layered Landscaping

Description: Roadside landscaping is provided to enhance the aesthetics of the roadside environment and to increase driver awareness of the environment. Plants are grouped according to height, with smaller plants (i.e., ground cover) placed closer to the roadway and taller plants (i.e., trees) placed further from the roadway.

Speed Estimate:
Layered landscaping did not result in statistically significant speed reductions (Dixon et al., 2008) ★★.

Safety Estimate:
No data found.



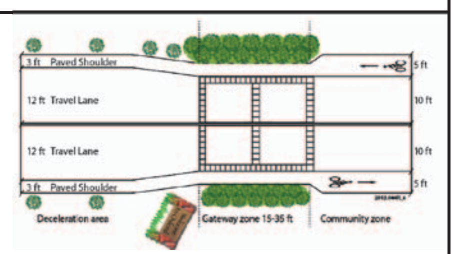
Source: Transit New Zealand (2006)

Key to Star Ratings for Reliability of Speed and Safety Estimates:
★ —least reliable
★★
★★★
★★★★ —most reliable

Figure 2-5. Catalog of potential transition zone treatments and their expected speed reduction and safety effects (roadside treatments).

Treatment: Gateway

Description: A combination of treatments installed to indicate a change in environment (e.g., welcome sign, roadway narrowing, raised median, bicycle lane, roundabout, etc.).



Speed Estimate:
Gateways on the approach to a community reduced 85th percentile speeds by 3 to 10 mph (County Surveyor's Society, 1994) ★★.

4.2-mph reduction in mean speed and 7.2-mph reduction in 85th percentile speed (Pyne et al., 1995) ★★.

5.5-mph reduction in mean speed and 3.0-mph reduction in 85th percentile speed for gateway used with lane narrowing (Dixon et al., 2008) ★★.

Gateways including a variety of measures resulted in a 6.9- to 10.6-mph reduction in mean speeds (Lamberti et al., 2009) ★★.

A variety of gateway treatments resulted in an 11% reduction in mean speeds and 15% reduction in motorists traveling over the posted speed limit (Herrstedt et al., 1993) ★.

6.2-mph reduction in average speed 6 months after installation; 3.3-mph reduction in average speed 12 months after installation (Alley, 2000) ★.

0% to 3% reduction in speeds for gateways with signing and pavement markings. 7.5% reduction in speeds for gateways of high visibility. 15% to 27% reduction in speeds for gateways with high visibility and physical features (Charlton and Baas, 2006) ★.

Safety Estimate:
Gateways with combined physical and visual measures reduced injury crashes by 28%, but increased property-damage only crashes by 36% (Andersson et al., 2008) ★★.

55% reduction in fatal and serious injury crashes and 19% reduction in all injury crashes (Wheeler and Taylor, 2000) ★★.

Key to Star Ratings for Reliability of Speed and Safety Estimates:
★ —least reliable
★★
★★★
★★★★ —most reliable

Figure 2-6. Catalog of potential transition zone treatments and their expected speed reduction and safety effects (gateway treatment).

2.3 Summary of International Guidelines

Internationally, the use of transition zone treatments is more advanced than in the United States. Several countries have developed guidelines for the use of transition zone treatments along rural routes approaching communities.

2.3.1 Australia/New Zealand

In Australia, speed has been identified as a major factor in the occurrence and severity of roadway crashes. Austroads, an association of Australian and New Zealand road transport and traffic authorities, funded research to identify and review different approaches to speed management on rural roads, with a particular focus on engineering-based treatments (Turner, 2008). A number of treatments were assessed at locations with transitions from high to low speeds, including the following:

- Advance warning,
- Buffer zones,
- Countdown signs,
- Transverse rumble strips,
- Pavement numerals/speed limit markings, and
- Rural thresholds/gateway treatments.

When used in isolation, these treatments appeared to have limited benefits in reducing speeds and improving safety; however, when used in combination, treatments were found to have significant effects (e.g., combinations of signs and pavement markings).

Guidelines published by the Land Transport Safety Authority (LTSA) (LTSA, 2002) outline the principles of rural-urban speed reduction treatments and promote good design practice and consistency. Given the clearly established correlation between vehicle speeds and crash severity, and the increased exposure to risk, the guidelines seek to provide a framework to reduce traffic speeds to appropriate levels at the outer fringes of urban areas. The focal treatment in these guidelines is referred to as a threshold. Thresholds are defined as locations at boundaries between rural and urban areas and consist of physical and optical narrowing of the roadside to form "pinch points." When designed correctly, thresholds lead to a reduction in vehicle speeds, as drivers perceive a change in the road environment ahead. Figure 2-7 provides an example of threshold pavement markings.

Vertical design features are recommended at transition zones because they improve the visibility of the threshold for approaching drivers. Examples of vertical elements include trees and shrubs, combined speed restriction and place name signs, and the structures or poles that support these signs. Street lighting can also be incorporated as a vertical element. Trees, lighting poles, and poles used to support signs in the threshold area must be frangible (i.e., breakaway) to reduce injury risk to occupants of errant vehicles. Research indicates that drivers travel at a reduced speed where the height of vertical features is greater than the width of the street (LTSA, 2002). Figure 2-8 illustrates the relationship between optical width, optical height, and vehicle speed.

Unless thresholds stand out from the surroundings, road users may not notice the approaching change of environment and fail to reduce speed as required. In addition to the vertical and horizontal elements described above, there are a number of measures that can enhance conspicuity such as the following:

- Brightly colored flowers or shrubs as part of the landscaping,
- Trees or shrubs that contrast in color with the surrounding landscape,

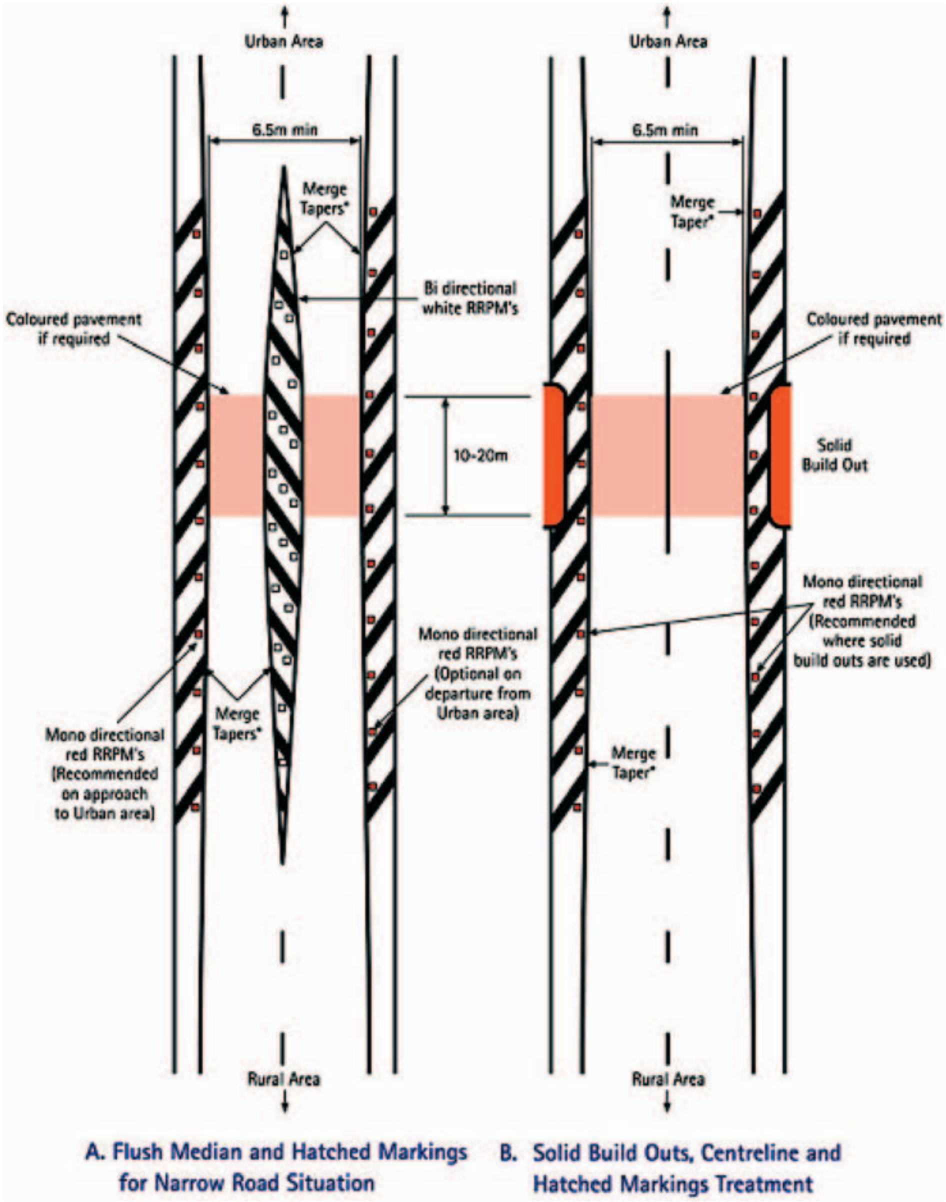


Figure 2-7. Pavement markings and RRPMs without solid islands (RRPM = retroreflective pavement markings) (LTSA, 2002).

- Colored paving materials through the threshold pinch point, and
- Size and color of the combined speed limit and place name sign.

Nighttime conspicuity of the threshold can be enhanced by using reflectorized paint or reflective strips on all curbs used in build-outs or median islands.

Australian research also indicates that the use of speed humps or vertical roadway shifts within rural thresholds is not recommended. Research indicates these vertical deflections of the roadway "could create a safety hazard that would cause many more problems than existed previously" (Schnull and Lange, 1994). Figure 2-9 and Figure 2-10 illustrate an untreated and a treated approach to a community.

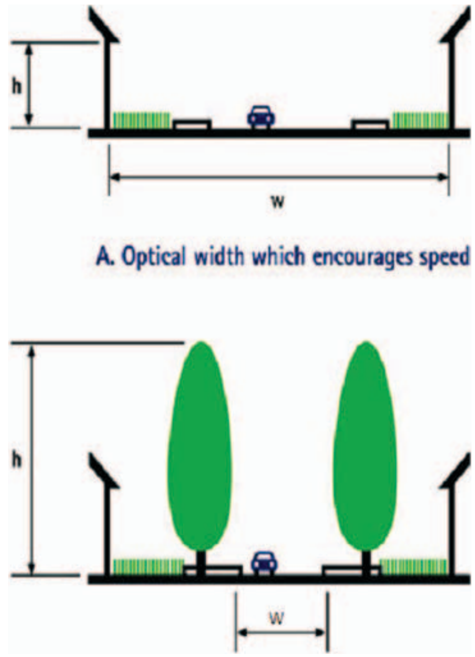


Figure 2-8. Optical width (Devon County Council, 1992).

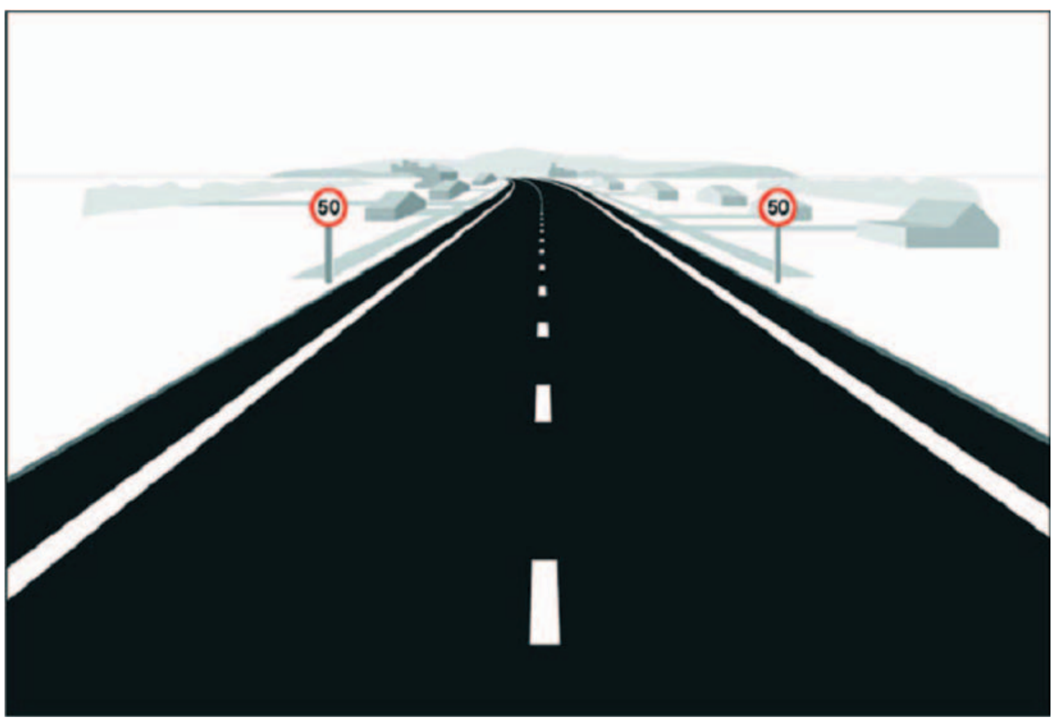


Figure 2-9. Typical untreated approach to a community (LTSA, 2002).

Figure 2-10. Completed threshold (LTSA, 2002).

2.3.2 United Kingdom

A leading document in the United Kingdom (UK), *Traffic Calming Techniques* (IH and TCS, 2005), provides updates to designers on the current state-of-the-practice for traffic calming, including guidance on when treatments are appropriate, design and implementation practice, currently used and successful treatments, and the future of traffic calming designs. According to the guidance, successful design is more likely to be achieved by adopting an overall "package" approach, rather than by using a scattering of different measures. This will help avoid one of the most common sources of objection to traffic calming, which is that treatments appear to be ill thought out and the result of a formulaic approach. Guidelines in the UK focus on traffic calming treatments in general, rather than their specific use in transition zones.

To determine which designs are most applicable to manage speeds, the UK guidelines recommend the analysis of the following roadway data:

- Crash Information:
  - Rates
  - Types
  - Causes
- Vehicle Flow:
  - Speed
  - Composition
- Physical Roadway Characteristics:
  - Widths
  - Alignment
  - Pavement markings
  - Signing
  - Visual condition
  - Street lighting
  - Locations of bus stops
  - On-road parking
  - Special features for vulnerable road users
  - Storm sewers/ditches
- Perceived Risk
- Road Hierarchy:
  - Existing road function
  - Intended road function
  - Local distribution routes
  - Public transportation corridors
  - Pedestrian networks
  - Cycling networks
  - Emergency vehicle routes
  - Abnormal or hazardous materials routes
- Environment:
  - Traffic noise
  - Ambient noise
  - Vegetation
  - Buildings
- Uses for the street (consideration of the different kinds of activities that may take place).

The UK guidelines indicate traffic calming treatments need to be visible both day and night, as well as in adverse weather conditions. The effects of traffic calming treatments on drainage and along steep grades is also an important consideration, as some treatments may adversely affect the driving environment.

Traffic calming treatments used in the UK are grouped into the following categories:

Road Narrowings, Footway Build-Outs, and Chicanes

Roadway narrowing can take the form of the following:

- A gateway feature that retains two-way flow of traffic.
- A pinch point where traffic can only pass through the feature in one direction at a time.
- Central islands to prevent passing.
- Chicanes to force traffic to deviate from a straight throughpath.
- Reduced width over a length of road.
- Reduced width over a length of road with the use of bicycle lanes to visually narrow the street.
- Reduced width over a length of road such that smaller vehicles can pass each other but larger vehicles have to stop and let other vehicles proceed.

Speeds can be reduced by up to 5 mph using these various road-narrowing techniques. Chicanes have been found to lower speeds to around 20 mph, but this depends greatly on the path angle created.

Some disadvantages of these road-narrowing techniques found in UK research include the following:

- When features built into the roadway are not conspicuous, drivers may crash into the features or overrun curbs.
- If traffic speeds remain high, pedestrians and bicyclists may still feel vulnerable using the features created for them.
- Narrow roadways can be difficult for large vehicles to negotiate.
- Some drivers may encroach on the opposing lanes to avoid slowing down.

Alerting Measures (Rumble Devices and Surface Features)

These treatments cause an audible or visual effect to alert drivers to slow down. Rumble strips can be installed in new pavement, ground in, or built up. "Rumblewave Surfacing" is a new product developed with the intention of providing an optimized, sinusoidal profiled surface that generates significant horizontal vibrations in a passing vehicle but minimal external noise.

Color patches can be useful for visually alerting drivers to slow down. These can be solid painted areas or transverse pavement markings. Disadvantages of this treatment include the following:

- Some people view them as intrusive.
- They can wear quickly.
- There is little hard evidence to demonstrate their effectiveness.

Parking Management and Control

By permitting parking along a roadway, the effective driving space can be reduced, causing vehicles to slow down. This treatment can be especially effective when combined with the narrowing of traffic lanes or the introduction of chicanes.

Gateway Features

Gateways are structures built on the sides of a roadway to alert drivers that they are entering a specially designed area where a new speed limit is in place. The gateway feature might be a gate, fence, wall, or even a work of art. It is important that consideration be given to safety, maintenance, and suitability of the feature to the local environment. Experience suggests that the speed reduction achieved by a gateway alone is not likely to be significant unless used in combination with other measures, or it is particularly conspicuous.

Figure 2-11. Highway sign in the UK warning drivers of the risks of speeding (IH and TCS, 2005).

Lighting for Traffic Calming Schemes

The necessity for, and design of, appropriate street lighting needs to be carefully considered wherever traffic calming measures are being installed. A lamp source giving good color rendering (i.e., distinction between colors) is necessary to assist the motorist in safely navigating the traffic calming feature, especially when the calming measure involves the use of color.

Speed-Activated Feedback Signs

The purpose of installing a speed-activated feedback sign is to warn drivers of a change in the environment ahead, or to remind them of a speed limit in force. UK guidelines indicate that such signs should be used in addition to, not instead of, conventional signing. The guidelines indicate that sites should be considered for the use of interactive signs if the following:

- There is a recent history of crashes in which inappropriate speed was a factor.
- Excessive speed for the conditions (i.e., approaching intersections or curves) is a concern.
- Other crash remedial measures have been considered and found unsuitable.

Advertising and Publicity

To raise awareness of road safety and inform the public of safety concerns at sites, it may be effective to carry out an advertising campaign. Figure 2-11 shows a temporary sign erected to advertise the concerns of excessive speed.

2.3.3 Germany

A European Conference of Ministers of Transport (ECMT) document on speed management (ECMT, 2006) addresses guiding principles on transition zone design in Germany. When entering a lower speed zone, in particular after a period of driving at a high speed, the document states that drivers will generally underestimate their speed and consequently not reduce their speed enough to comply with the lower speed limit. Two principles to consider in the design of transition zones are as follows (European Transport Safety Council [ETSC], 1995):

- Measures at the transition zone should be such that they achieve a cumulative effect, finishing at the actual gateway to the community.
- Complementary measures along the through-route within the urban area are required.

A cumulative effect can be achieved by a combination of road narrowing and the introduction of trees and other vertical elements, culminating in the gateway. Chosen speeds are found to be lower where the height of the vertical elements is greater than the width of the road. However, the vertical elements need to be chosen very carefully so as not to become roadside obstacles which can have a negative effect on safety.

German research has found that, if applied in a consistent way, infrastructure-based measures can help to reduce speeds and help drivers to recognize the traffic situation and comply with the corresponding speed limit. Nevertheless, guidelines recommend that speed management involving road engineering changes should be accompanied by education, information, and enforcement to make road users aware of the posted speed, the speeding problem, and the "why" and "what" of countermeasures to increase incentives for compliance.

Constructions similar to medieval gates have also been used to indicate the change from one traffic environment to another. In today's driving environment, the border between the community and the country is less distinct, and this is one of the reasons why many drivers ignore the local speed limits. Gates are used to indicate the beginning of an area where new traffic behavior, and especially a new speed, is required. Figure 2-12 shows such a gate in Germany. Gates may be in the form of an actual building structure, as in ancient times, but they may also be constructed using different forms of plantings, lighting, and the like.

Gates improve drivers' understanding of the different traffic behavior required by delineating the start of a different road design on the same stretch of road. If there is a bicycle lane through the city, it should desirably start at the gate. The change from two lanes into a single roadway, or the narrowing of a lane should also preferably start at the gate location. Speed reductions at these locations depend on the treatment design and changes in road design between previous and following road sections, as well as on the neighboring environment. The speed reduction effect is greatest if the alignment requires a distinct steering maneuver where both visual elements and other traffic calming measures, such as a change in the road profile, road surface, or others are utilized.

Other useful treatments for slowing vehicles at transition zones are central islands and roundabouts. Central islands can be one-sided (i.e., divert only the path of incoming vehicles) or two-sided (i.e., divert both incoming and outgoing vehicles). Two-sided islands are preferred, as these prevent vehicles exiting the community from speeding up prematurely. The influence

Figure 2-12. Gate into a German community (ECMT, 2006).

of central islands on speed has been found to be only moderate, but in addition to speed reduction they also provide the opportunity to build a new, more attractive, urban space by dividing the old street profile. Roundabouts in Germany have been found to provide very effective speed reduction at at-grade intersections.

In general, German research indicates that the aim of these measures should be to produce safe, "self-explaining" roads, where drivers recognize the type of road and are guided to adapt their speed to the local conditions. The purpose of German design guidelines for urban roads is to enforce speed reduction at the entrances into urban areas by using several treatments to slow down motorists.

2.3.4 Netherlands

Safe Road Design—A Practical Manual (World Bank and Dutch Ministry of Transport [WBDMT], 2005) is a document summarizing speed reduction treatments in the Netherlands. One common treatment to decrease speeds through built-up areas is to create a clear boundary at the community. The guidelines indicate that the main requirements for the boundary of the community center are as follows:

- The border of the built-up area is characterized by consecutive buildings alongside the road, with such a size and density that the road user notices a considerable difference between the road environment inside and outside the built-up area.
- At the location of the border, there must be a significant change in road characteristics such that the difference in character of the road before and after the border is emphasized as much as possible.

Often, the border is in an uninhabited area, so it is not surprising that drivers ignore the speed limit. The clearer it is that the road and the environment have the character of a built-up area near the border, the less the need for specific traffic calming measures and the greater is the driver's understanding. An example of a community border treatment is presented in Figure 2-13.

The Dutch recommend the following guidelines for determining if a particular area should be considered a built-up area:

- The distance from the buildings to the centerline of the road is, at maximum, three times the height of the adjoining buildings with a maximum of 82 ft.

Border of village before reconstruction **Border of village after reconstruction**

Figure 2-13. Sample community border treatment (WBDMT, 2005).

Figure 2-14. Gateway treatment—rural distributor to 30-km/h (20-mph) urban access (AVV, 2001).

- The length of the built-up area is at least 1,300 ft.
- Building density (i.e., building frontage related to road length) should be ≥50 percent on one side of the road and ≥30 percent for buildings on both sides.

In determining the precise location of a border (transition zone), the following aspects need to be considered:

- Select a location (preferably) where the different characteristics of the landscape join.
- Take account of short-term spatial developments.
- Try to support the border with new environmental characteristics.
- Ensure the border, at the planned location, is visible at the actual approach speeds.

Dutch guidelines recommend the following treatments to make drivers aware of community boundaries:

- Replace an intersection before the border with a roundabout.
- Realign lanes outward on both sides to create a central island.
- Introduce curves suitable for a speed of approximately 30 mph for passenger cars.
- Install a 30-mph plateau, a raised crossing area with slopes designed to be crossed at a maximum of 30 mph.

An additional Dutch guide, *Sustainable Safety—A Preventative Road Safety Strategy for the Future* (AVV, 2001), provides recommendations for transitioning from one roadway class to another. These transition zones are termed “gateways” and specific guidance is given depending on the types of roadways between which the transitions are to occur. According to the guide, “If the transition is between a distributor and an access road, then a minimum requirement is a double transverse line over the width of the road and supported by 20-mph (30-km/h) zone road signs on either side. Where the nature of the area is not self-evident, additional measures must be implemented.” Figure 2-14 illustrates a transition between a rural road and an urban area with a 20-mph (30-km/h) speed limit.

SECTION 3

Field Studies

The objective of the field studies was to evaluate the effectiveness of a treatment (or combination of treatments) in reducing speeds through a transition zone and through the community. Results of the field studies are used to supplement information gathered during the literature review on effectiveness estimates of treatments implemented within transition zones, and the combined results are used to develop the design guidelines presented in Section 4.

The effectiveness of the following three treatments (and combinations of treatments) in reducing speeds through a transition zone and through the community are assessed:

- Roundabouts (RAs),
- Transverse pavement markings (TPMs), and
- Welcome signs (WSs) at community entrances.

In addition to evaluating the effectiveness of these treatments in reducing speeds through a transition zone and through the community, crash data are also presented to document the safety experience associated with the treatments and sites.

3.1 Treatment and Site Selection

The three treatments were selected for evaluation by first conducting a survey of state and county highway agencies within the United States and combining the results with the survey from *NCHRP Synthesis 412.* The purposes of combining results from the two surveys were as follows:

1. To develop a catalog of speed reduction treatments that appear most reasonable for implementation within transition zones and have the greatest likelihood for achieving the desired results.
2. To identify potential sites for the field data collection.

After organizing the results of both surveys, 11 treatments were identified for potential further investigation (Table 3-1). The treatments were also prioritized for evaluation based upon the reliability of effectiveness estimates of the treatments to reduce speeds and improve safety, expected benefits (e.g., reducing speed), and availability of data collection sites. Working with contacts at state highway agencies to identify potential study locations, three treatments from the high-priority list—roundabouts, transverse pavement markings, and welcome signs—were selected for further evaluation.

Field data were collected at 15 treatment and seven non-treatment sites. A treatment site is defined as a location at which one or more speed reduction treatments was installed within the transition zone leading to the lower speed environment (i.e., a community), and a non-treatment

Table 3-1. Prioritized list of treatments for further evaluation.

Priority for further evaluation	Treatment(s)
High priority	Roundabouts Transverse pavement markings Raised medians Center islands Welcome signs Landscaping
Medium priority	Transverse rumble strips Roadway narrowing Bicycle lanes
Low priority	Speed-activated feedback signs Pedestrian crossings

site is defined as a location at which no particular speed reduction treatment was installed near the transition zone with the exception of reducing the posted speed limit. Where possible, field data were collected on multiple approaches to a community (see Figure 3-1).

All sites included in the study had at least a 15-mph reduction in the posted speed limit going from the high-speed to the low-speed environment. In addition, study locations were chosen with few or no intersections or driveways in close proximity to the transition zones. This was important in order to keep to a minimum the number of vehicles that may enter or exit the stream of traffic between speed data collection points. Limiting the number of intersections/driveways in the transition zone also helped to ensure that observed accelerations and decelerations were a result of compliance to posted speed limits and/or in response to the speed reduction treatment, rather than to accommodate vehicles entering and exiting the roadway.

Table 3-2 lists the locations of the data collection sites and the types of treatments implemented within the transition zones. At several locations, multiple treatments were installed in combination. At these locations, the primary treatment (i.e., the treatment that likely has the greatest impact on speed) is listed first and the secondary treatment is shown in parentheses.

Table 3-3 presents the site characteristics of the study locations within the transition zones. The speed limit columns indicate the posted speed limit at the beginning and end of the transition zone and the posted speed limit through the community. The reductions in speed limits through the transition zones ranged from 15 to 35 mph. All of the roadways through the transition zones were two-lane undivided facilities (2U). Lane widths ranged from 11 to 13 ft, and shoulder widths ranged from 0 to 10 ft, both paved and unpaved. The horizontal alignment column indicates whether the study location was a tangent (TAN) section of roadway or if there was some degree of curvature (Curve) in the vicinity of the transition zone. The vertical alignment column indicates whether there was rolling terrain, a constant grade (i.e., level or downgrade), or vertical curvature

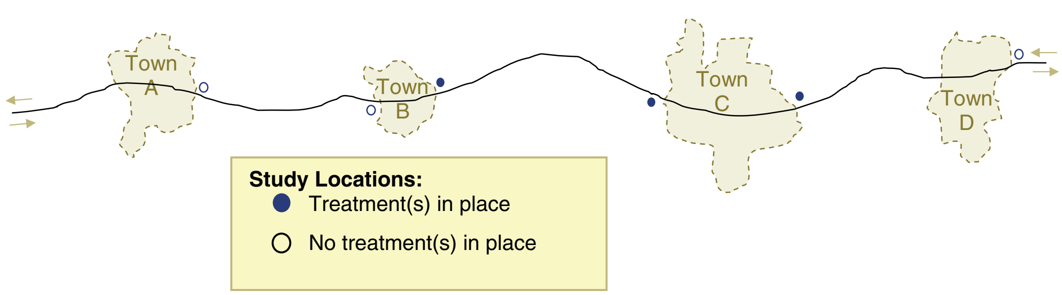


Figure 3-1. Study locations on multiple approaches to a community.

Table 3-2. Study locations and treatment types.

Site no.	Treatment	Community (state)	Route (direction)
KS01	TPM	Rossville (KS)	US 24 (WB)
KS02	None	Rossville (KS)	US 24 (EB)
KS03	Welcome sign	McLouth (KS)	SR 92 (WB)
KS04	Welcome sign	McLouth (KS)	SR 92 (EB)
KS06	TPM (welcome sign)	Silver Lake (KS)	US 24 (EB)
KS09	Roundabout (rumble strips)	Fredonia (KS)	K 47/US 400 (WB)
KS10	Welcome sign	Burden (KS)	US 160 (EB)
KS11	Welcome sign	Burden (KS)	US 160 (WB)
KS12	None	Rock (KS)	US 77 (NB)
KS13	None	Rock (KS)	US 77 (SB)
KS14	TPM	Meriden (KS)	Rt 4 (SB)
KS15	TPM	Meriden (KS)	Rt 4 (NB)
NE01	Roundabout (welcome sign)	Blair (NE)	US 30/Rt 133 (EB)
NE02	None	Blair (NE)	US 75 (SB)
NE03	Roundabout	Winnebago (NE)	US 77 (NB)
NE04	None	Winnebago (NE)	US 77 (SB)
IA01	TPM (welcome sign)	Roland (IA)	Rt 77 (NB)
IA02	TPM (welcome sign)	Union (IA)	Co Rd D65 (EB)
IA03	TPM	Union (IA)	SR 215 (SB)
IA05	None	McCallsburg (IA)	Co ED E18 (WB)
VA01	Roundabout	Amherst (VA)	US 60 (EB)
VA02	None	Amherst (VA)	US 60 (WB)

Note: KS = Kansas, NE = Nebraska, IA = Iowa, VA = Virginia, WB = westbound, EB = eastbound, NB = northbound, and SB = southbound.

Table 3-3. Site characteristics of study locations within the transition zones.

Site no.	Treatment	Speed limit (mph)			ADT	Number of lanes	Lane width (ft)	Shoulder		Horiz. align.	Vert. align.
		Begin	End	Comm.				Width (ft)	Type		
KS01	TPM	65	45	30[2]	4,540	2U	12	4	paved	Tan	Level
KS02	None	65	30	30	4,310	2U	12	3	paved	Tan	Level
KS03	Welcome Sign	55	35	35	2,940	2U	12	0	none	Tan	Rolling
KS04	Welcome Sign	55	35	35	2,980	2U	12	0	none	Tan	Rolling
KS06	TPM (welcome sign)	65	30	30	4,240	2U	12	3	paved	Curve	Level
KS09	Roundabout (rumble strips)	65	30	30	2,200	2U	12	3	paved	Tan	Level
KS10	Welcome Sign	65	40	30[2]	1,700	2U	12	1.5	unpaved	Tan	Crest
KS11	Welcome Sign	65	30	30	870	2U	12	0	none	Tan	Sag
KS12	None	65	45	45	2,480	2U	12	5	unpaved	Tan	Level
KS13	None	65	45	45	2,800	2U	12	5	unpaved	Curve	Level
KS14	TPM	65	45	45	6,700	2U	13	2	paved	Tan	Downgrade
KS15	TPM	65	45	45	7,890	2U	13	4	paved	Tan	Downgrade
NE01	Roundabout (welcome sign)	60	45	45	15,150	2U	12	8	paved	Tan	Downgrade
NE02	None	60	45	45	5,685	2U	12	8	paved	Curve	Level
NE03	Roundabout	60	30	30	4,465	2U	12	8	paved	Tan	Downgrade
NE04	None	60	30	30	6,235	2U	12	10	paved	Tan	Level
IA01	TPM (welcome sign)	55	25	25	670	2U	11	2	unpaved	Tan	Rolling
IA02	TPM (welcome sign)	55	25	20[2]	470	2U	11.5	0	none	Tan	Rolling
IA03	TPM	55	30	30	1,120	2U	12	2	unpaved	Tan	Downgrade
IA05	None	55	45	25[2]	790	2U	11	1	unpaved	Tan	Crest
VA01	Roundabout	55	35	35	2,400	2U	12	2	paved	Curve	Rolling
VA02	None	55	35	35	6,200	2U	12	2	paved	Curve	Rolling

Note: Comm. = community, ADT = average daily traffic, horiz. = horizontal, align. = alignment, and vert. = vertical.
[1]Highest approach volume through the roundabout.
[2]At these locations, the speed limit at the end of the transition zone was not the same as the speed limit through the entire community. This occurred either because the speed limit changed within the community zone downstream of where the transition zone should have ended and/or because of unique site characteristics that limited the data collection location.

(i.e., crest or sag) in the vicinity of the transition zone. In addition to the characteristics listed in Table 3-3, none of the transition zones had sidewalks, and all of the roadsides had grass ditches for drainage.

Table 3-4 lists the site characteristics of the study locations within the communities, downstream of the transition zones. At a few locations, multilane roadways were present through the communities (i.e., three-lane roadway [3T] including a center two-way left-turn lane [TWLTL]; four-lane undivided roadway [4U]; and five-lane roadway [5T] including a center TWLTL), and in some instances, the travel lanes were wider through the communities than within the transition zones. On-street parking, sidewalks, and curbs were present in several of the communities. The number of signalized and unsignalized intersections through the community, the length of the community, the land area, and population size are several other indicators of the level of activity through the community that could potentially affect speeds.

3.2 Speed Study

A speed study was conducted to evaluate the effectiveness of a treatment (or combination of treatments) in reducing speeds through the transition zone and maintaining that reduction through the community.

3.2.1 Speed Data Collection Methodology

Speed data were collected using traffic classifiers and laser guns. Traffic classifiers were used to collect information about the flow of traffic as it approached the transition zone, exited the transition zone, and entered or passed through the community. Key information obtained from the classifiers included the following:

- Spot speeds of vehicles,
- Vehicle classifications, and
- Vehicle spacing.

Traffic classifiers were used to collect data at three locations at each study site. Figure 3-2 illustrates the conceptual layout of the traffic classifier locations relative to the transition zone and community. The locations of the traffic classifiers at each study site were determined using the following protocols:

- **Location C—Transition Zone Perception/Response Speed:** The speed at this location represents the speed of vehicles along the high-speed portion of roadway prior to the transition zone. At this location, there should be no effect on vehicle speed either due to a transition zone treatment intended to reduce speed or due to a speed limit sign that indicates a reduction in the speed limit.
  - This traffic classifier was placed approximately 200 to 400 feet upstream of the first speed limit sign to indicate a reduction in the speed limit, or the first treatment intended to reduce vehicle speeds, whichever was first encountered by vehicles.
  - Placement of this traffic classifier was not influenced by the presence/location of "Reduced Speed Limit Ahead" warning signs.
- **Location B—Transition Zone Exit Speed:** The speed at this location represents the speed of vehicles slightly downstream of the transition zone.
  - This traffic classifier was placed approximately 3 to 5 seconds downstream of the final speed reduction treatment or the first speed limit sign to indicate the speed limit through the community, whichever was located further downstream (i.e., closest to the community).

Table 3-4. Site characteristics of study locations within the community.

Site no.	Number of lanes	Lane width (ft)	Shoulder		Horiz. align.	Vert. align.	On-street parking	Sidewalks	Curbs	Number of intersections		Length of comm. (mi)	Area of comm. (mi^2)	Pop.
			Width (ft)	Type						Signal	Stop			
KS01	2U	12	13	paved	Curve	Level	N	Y	Y	0	10	2.5	0.61	1,151
KS02	2U	12	11	paved	Curve	Level	Y	N	Y	0	10	2.5	0.61	1,151
KS03	2U	12	0	N/A	Tan	Level	N	N	N	0	11	0.9	0.59	880
KS04	2U	12	0	N/A	Tan	Level	N	N	N	0	11	0.9	0.59	880
KS06	2U	12	2	paved	Curve	Level	Y	Y	Y	0	15	1.3	0.60	1,439
KS09	2U	12	1	paved	Tan	Level	N	N	N	0	18	1.5	2.45	2,482
KS10	2U	21.5	0	N/A	Tan	Level	N	Y	Y	0	7	0.7	0.54	535
KS11	2U	21.5	0	N/A	Tan	Crest	N	Y	Y	0	7	0.7	0.54	535
KS12	2U	12	2	paved	Tan	Level	N	N	N	0	3	0.4	5.53	222
KS13	2U	12	2	unpaved	Tan	Level	N	N	N	0	3	0.4	5.53	222
KS14	2U	13	4	paved	Curve	Upgrade	N	N	N	0	5	2.3	0.79	813
KS15	2U	13	3	paved	Curve	Level	N	N	N	0	5	2.3	0.79	813
NE01	5T	12	0	N/A	Curve	Level	N	Y	Y	5	17	3.0	5.51	7,990
NE02	2U	13	4	paved	Curve	Downgrade	N	Y	Y	5	17	3.0	5.51	7,990
NE03	3T	15	0	N/A	Tan	Crest	N	Y	Y	0	10	1.1	0.20	774
NE04	3T	15	0	N/A	Tan	Crest	N	Y	Y	0	10	1.1	0.20	774
IA01	2U	11	0	unpaved	Tan	Level	N	Y	N	0	7	0.7	1.08	1,284
IA02	2U	26.5	0	N/A	Tan	Downgrade	Y	Y	Y	0	9	0.5	0.55	397
IA03	2U	12	8	paved	Tan	Level	Y	Y	Y	0	12	0.7	0.55	397
IA05	2U	11	0	N/A	Tan	Level	N	Y	N	0	8	0.6	0.53	333
VA01	4U	12	3	paved	Tan	Level	N	N	N	0	3	0.4	4.92	2,231
VA02	4U	12	2	paved	Tan	Level	N	N	N	0	3	0.4	4.92	2,231

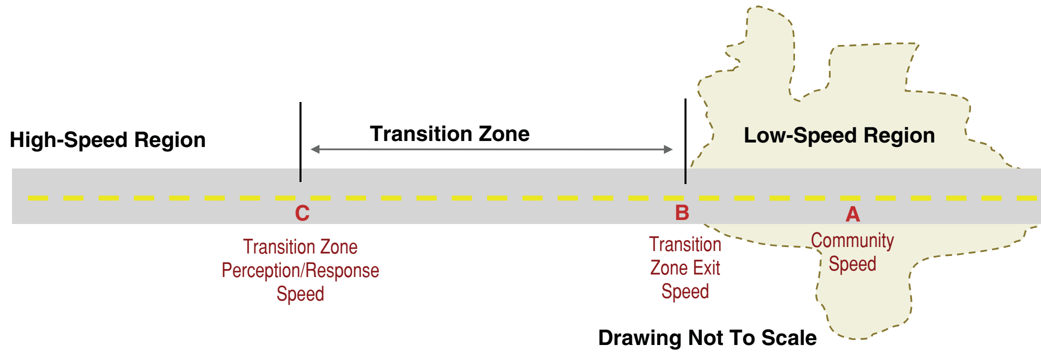


Figure 3-2. Setup of field equipment.

- **Location A—Community Speed:** The speed at this location represents the speed of vehicles through the community.
  - This traffic classifier was placed approximately 750 to 1,000 feet downstream of the final speed reduction treatment or the first speed limit sign to indicate the speed limit through the community, whichever was located further downstream.
  - This traffic classifier was placed prior to any signal or stop-controlled intersection that would have the potential to affect the speeds of vehicles.

Placements of the classifiers at the study sites were adjusted as necessary to account for unique field conditions. For sites with no treatment, the traffic classifiers were placed in locations analogous to Locations A, B, and C. In general, at least 6 to 8 hours of speed, classification, and headway data were collected at each study site on a weekday.

Speed data were also collected using laser guns to assess vehicle speed profiles through portions of the transition zones. Speed data from the laser guns were collected for a sampling of free-flow vehicles to supplement the information collected from the traffic classifiers and to provide more detailed information on the deceleration characteristics of vehicles.

While speed data were being collected from the traffic classifiers and a laser gun, traffic operations within the transition zone were also recorded using a video camera positioned on the roadside. In general, 2 to 3 hours of vehicle operations were recorded at each study location. The video recordings enabled the research team to go back and review driver behavior, as necessary, within the transition zone.

During reduction of the speed data from the traffic classifiers, an effort was made to track individual vehicles traveling through the transition zone and community from classifier Locations C to B to A based upon speed, headway, and time stamp (i.e., internal clocks) data from the respective classifiers. Being able to track individual vehicles through the study area would have created a more robust dataset, but because of the distances between the classifiers and due to some vehicles entering from intersections/driveways within the study area, it was too difficult to track individual vehicles reliably using the classifier data. Therefore, the speed data presented below and the subsequent analyses are based upon speeds of individual free-flow vehicles measured at each data collection location grouped together as a whole, rather than representing speed profiles of individual vehicles through the study area.

3.2.2 Descriptive Speed Statistics

Speed data were collected at a total of 22 sites. Of the 22 sites, 15 sites represent a total of six unique treatment combinations, and seven sites had no treatment. The sites, their treatment

Table 3-5. Treatment combinations and study sites.

Treatment combination (primary and secondary)		Site no.	Reduction in posted speed limit (mph)	
			From C to B	From B to A
Roundabout (RA)	None	NE03	30	0
		VA01	20	0
	Transverse Rumble Strips (TRSs)	KS09	35	0
	Welcome Sign (WS)	NE01	15	0
Transverse Pavement Markings (TPMs)	None	IA03	25	0
		KS01	20	15
		KS14	20	0
		KS15	20	0
	Welcome Sign (WS)	IA01	30	0
		IA02	30	5
		KS06	35	10
Welcome Sign (WS)	None	KS03	20	0
		KS04	20	0
		KS10	25	10
		KS11	35	0
None		IA05	10	20
		KS02	35	0
		KS12	20	0
		KS13	20	0
		NE02	15	0
		NE04	30	0
		VA02	20	0

combinations, and reduction in posted speed limits from Location C to B and Location B to A are shown in Table 3-5.

Summary speed statistics from the classifiers (box plots) and speed profiles from the laser gun (blue distributions) used concurrently at each site are graphically displayed in Appendix A, separately for each site; an example diagram is shown below in Figure 3-3. Selected site details such as locations of posted speed limits, intersections, and treatment(s) are also indicated in each figure. Other details about these figures are given in Appendix A. In all analyses, tables, and figures, only speeds recorded between 6 a.m. and 10 p.m. were considered.

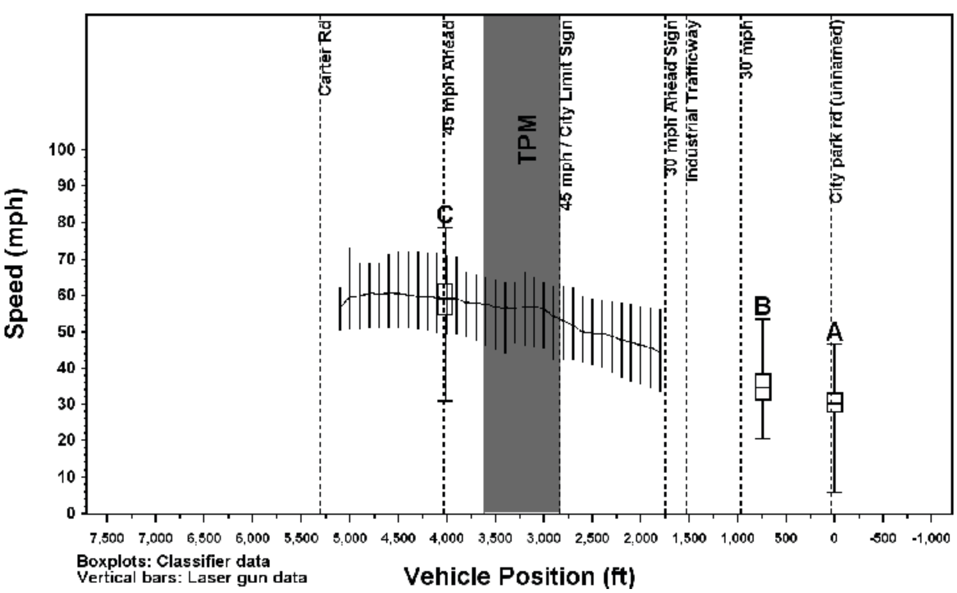


Figure 3-3. Vehicle speed profile example.

Table 3-6. Classifier speed statistics at sites with a roundabout.

Treatment type	Site no.	Classifier location	Posted speed limit (mph)	Number of vehicles	Speed statistics (mph)					Percentage of vehicles exceeding speed limit by X mph		
					Mean	Standard deviation	Median	85th percentile	95th percentile	5	10	15
Roundabout (RA)	NE03	C	60	1,556	52.4	6.1	52	59	63	0.8	0.1	0.0
		B	30	2,051	30.7	4.0	32	36	36	18.2	0.2	0.0
		A	30	2,303	27.8	3.6	28	31	34	1.8	0.1	0.0
	VA01	C	55	596	48.7	10.4	51	58	61	7.9	1.0	0.3
		B	35	1,881	31.9	5.4	32	37	40	3.8	0.1	0.0
		A	35	1,915	36.1	5.0	36	41	44	18.8	3.1	0.2
Roundabout (RA) and Transverse Rumble Strips (TRSs)	KS09	C	65	348	58.6	7.8	60	65	68	1.1	0.3	0.0
		B	30	750	32.4	4.4	32	37	40	20.3	4.8	0.0
		A	30	260	42.1	8.6	44	52	56	85.8	55.4	32.7
Roundabout (RA) and Welcome Sign (WS)	NE01	C	60	2,172	55.6	7.1	56	63	66	6.4	1.0	0.1
		B	45	4,273	43.5	6.3	45	49	52	10.4	1.0	0.0
		A	45	4,771	40.2	7.7	42	46	48	2.2	0.1	0.0

Tables 3-6 through 3-9 present basic distribution statistics for all classifier speeds collected at Locations C, B, and A for each type of treatment, respectively. These statistics include the following for each location at each site:

- Posted speed limit.
- Number of free-flow vehicles (passenger cars and trucks combined) traveling between 6 a.m. and 10 p.m., for which valid speed data were available; this number represents the number of valid speed measurements recorded by each classifier (i.e., after data cleanup prior to statistical analysis) and as such is not a true representation of traffic volume.

Table 3-7. Classifier speed statistics at sites with transverse pavement markings.

Treatment type	Site no.	Classifier location	Posted speed limit (mph)	Number of vehicles	Speed statistics (mph)					Percentage of vehicles exceeding speed limit by X mph		
					Mean	Standard deviation	Median	85^{th} percentile	95^{th} percentile	5	10	15
Transverse Pavement Markings (TMPs)	IA03	C	55	457	53.9	8.7	55	62	66	19.5	5.9	2.2
		B	30	466	35.3	6.8	35	42	46	49.4	23.0	5.2
		A	30	484	32.1	5.9	32	38	42	27.5	6.8	2.3
	KS01	C	65	729	58.9	6.3	59	65	68	1.9	0.3	0.0
		B	45	957	35.1	5.1	35	41	44	0.3	0.0	0.0
		A	30	888	30.2	4.7	30	34	38	13.0	2.6	0.3
	KS14	C	65	2,147	63.8	5.5	65	69	71	7.4	0.5	0.2
		B	45	1,758	48.2	6.2	48	56	60	31.7	16.1	3.3
		A	45	2,145	43.6	5.6	43	48	54	9.2	3.7	0.9
	KS15	C	65	2,545	60.5	5.5	61	66	68	1.1	0.1	0.0
		B	45	2,568	43.6	5.0	43	48	52	8.1	1.2	0.2
		A	45	2,621	44.1	6.1	45	48	52	8.4	2.1	0.3
Transverse Pavement Markings (TMPs) and Welcome Sign (WS)	IA01	C	55	200	48.4	6.5	49	56	58	1.0	0.0	0.0
		B	25	208	30.9	6.4	30	37	42	47.1	25.0	6.7
		A	25	224	25.3	4.4	25	29	31	9.4	1.8	0.4
	IA02	C	55	125	51.0	7.5	51	59	63	11.2	0.0	0.0
		B	25	149	30.0	7.0	28	36	44	49.7	26.2	5.4
		A	20	234	24.4	4.7	24	30	32	41.0	9.4	0.9
	KS06	C[a]	65	1,131	48.2	4.7	49	53	55	0.0	0.0	0.0
		B	30	1,122	33.8	5.6	33	39	44	34.6	10.9	3.2
		A	20	851	29.8	3.7	30	33	36	5.2	0.4	0.0

[a]85th percentile speed is more than 5 mph below the speed limit at the beginning of the transition zone; the site will be excluded from the speed analysis.

Table 3-8. Classifier speed statistics at sites with a welcome sign.

Treatment type	Site no.	Classifier location	Posted speed limit (mph)	Number of vehicles	Speed statistics (mph)					Percentage of vehicles exceeding speed limit by X mph		
					Mean	Standard deviation	Median	85th percentile	95th percentile	5	10	15
Welcome Sign (WS)	KS03	C	55	955	47.6	7.2	49	54	57	1.3	0.0	0.0
		B	35	977	30.0	7.1	32	36	40	0.8	0.2	0.0
		A	35	1,236	29.1	4.3	29	33	36	0.3	0.0	0.0
	KS04	C	55	205	44.4	7.1	45	51	55	0.0	0.0	0.0
		B	35	775	33.7	5.2	34	38	43	8.8	1.9	0.5
		A	35	1,128	30.5	5.4	31	36	39	1.5	0.1	0.0
	KS10	C[a]	65	535	47.5	6.8	48	54	58	0.2	0.0	0.0
		B	40	506	30.7	6.4	31	37	40	0.0	0.0	0.0
		A	30	407	24.8	4.4	25	29	32	1.0	0.0	0.0
	KS11	C[a]	65	333	46.1	7.6	46	54	58	0.3	0.3	0.0
		B	30	297	29.6	5.9	28	36	40	21.5	0.7	0.3
		A	30	403	25.3	4.1	25	30	32	0.5	0.0	0.0

[a]85th percentile speed is more than 5 mph below the speed limit at the beginning of the transition zone; the site will be excluded from the speed analysis.

- Mean speed.
- Speed standard deviation.
- 50th percentile speed (median).
- 85th percentile speed.
- 95th percentile speed.
- Percentage of vehicles traveling 5 mph over the posted speed limit.
- Percentage of vehicles traveling 10 mph over the posted speed limit.
- Percentage of vehicles traveling 15 mph over the posted speed limit.

Table 3-9. Classifier speed statistics at sites with no treatment.

Treatment type	Site no.	Classifier location	Posted speed limit (mph)	Number of vehicles	Speed statistics (mph)					Percentage of vehicles exceeding speed limit by X mph		
					Mean	Standard deviation	Median	85th percentile	95th percentile	5	10	15
None	IA05	C	55	223	60.0	8.4	60	68	75	44.8	22.0	9.0
		B	45	221	32.8	7.8	32	41	46	2.3	0.0	0.0
		A	25	232	32.2	6.5	32	38	44	57.8	28.9	9.9
	KS02	C	65	815	57.5	6.8	58	64	67	1.0	0.1	0.0
		B	30	841	33.1	4.8	33	38	41	31.0	8.2	1.3
		A	30	865	29.7	4.7	30	34	37	8.2	1.5	0.3
	KS12	C	65	1,029	53.6	7.0	53	62	66	0.5	0.0	0.0
		B	45	1,029	45.1	5.7	45	50	55	13.8	4.9	1.7
		A	45	804	41.8	7.1	43	48	51	6.3	1.6	0.2
	KS13	C[a]	65	1,059	49.6	5.2	50	55	58	0.0	0.0	0.0
		B	45	890	43.0	4.8	44	48	52	7.3	1.6	0.1
		A	45	1,087	40.7	8.2	43	47	51	5.2	0.6	0.1
	NE02	C	60	2,284	50.2	5.4	50	56	59	0.2	0.0	0.0
		B	45	2,278	46.5	5.4	46	52	55	23.6	5.7	0.8
		A	45	2,558	37.7	6.7	39	44	47	1.2	0.0	0.0
	NE04	C[a]	60	2,162	46.0	5.3	46	51	54	0.0	0.0	0.0
		B	30	2,256	36.9	8.4	38	44	48	65.3	36.9	10.8
		A	30	2,337	29.6	3.6	30	33	35	4.9	0.4	0.0
	VA02	C	55	499	48.4	6.9	49	55	58	1.4	0.2	0.0
		B	35	674	36.9	5.3	36	40	44	13.2	3.7	0.3
		A	35	889	36.7	5.5	37	42	45	22.9	4.3	0.8

[a]85th percentile speed is more than 5 mph below the speed limit at the beginning of the transition zone; the site will be excluded from the speed analysis.

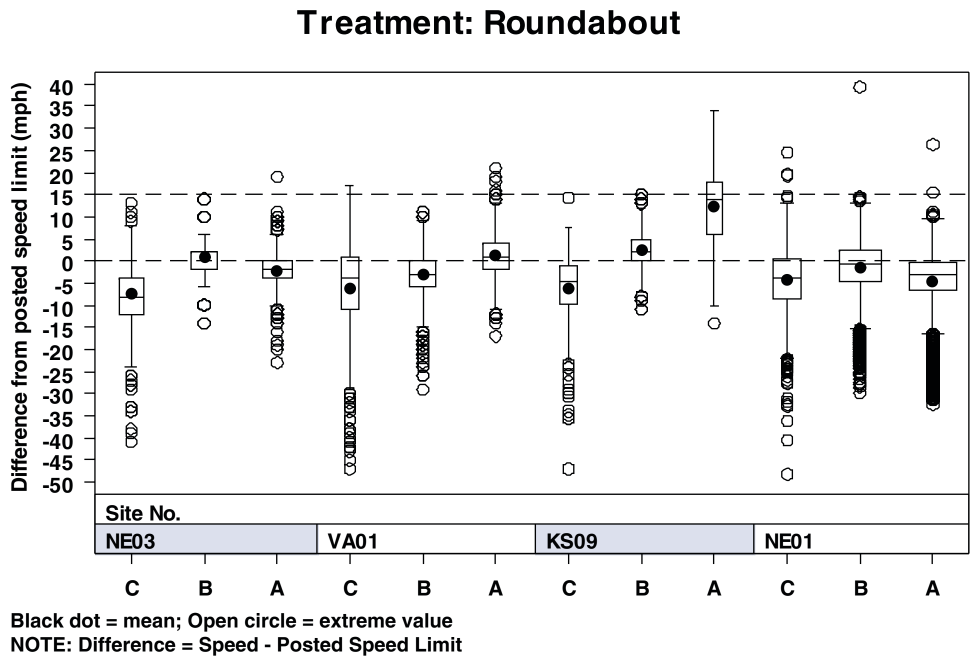


Figure 3-4. Speed differences from posted speed limit—roundabouts.

At each site and classifier location, speed differences between vehicle speeds and posted speed limit were calculated (i.e., a positive difference indicates that the vehicle exceeded the posted speed limit). The distribution of these speed differences is shown in the form of box plots in Figures 3-4 through 3-7, separately for each primary treatment type. (The box represents the middle 50 percent of the speed differences [25th to 75th percentiles; the distance between these two percentiles is called the interquartile range, IQR]; the horizontal line within a box represents the median speed difference [50th percentile]; vertical lines connect the box to the point at

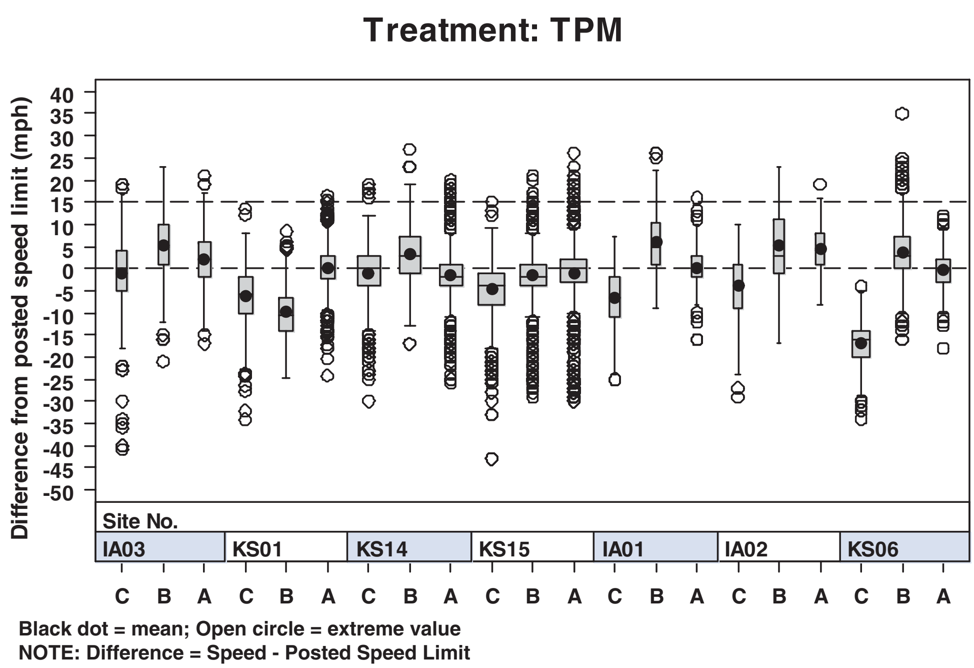


Figure 3-5. Speed differences from posted speed limit—TPMs.

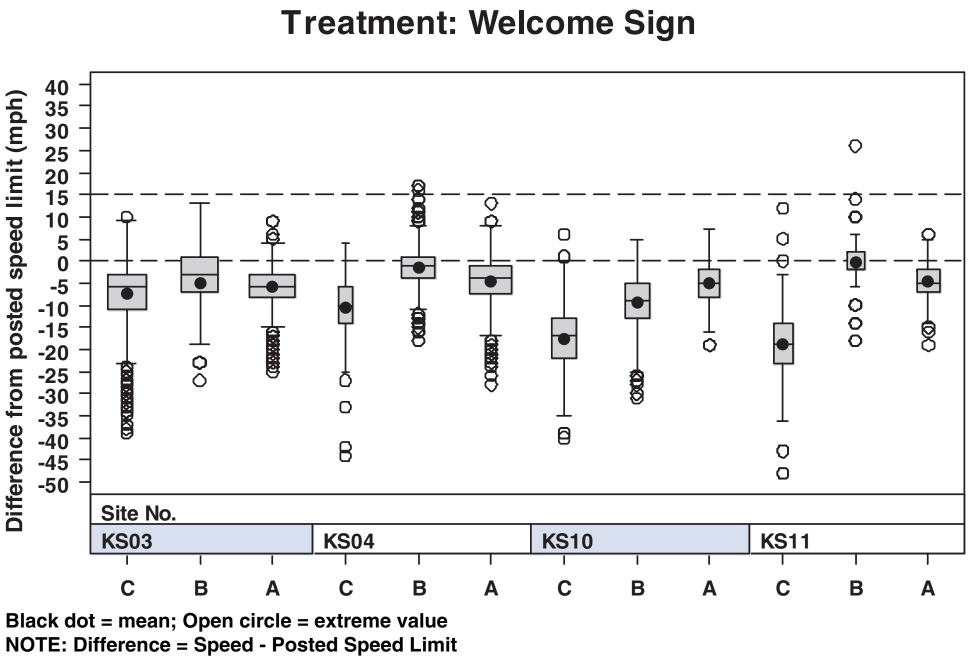


Figure 3-6. Speed differences from posted speed limit—welcome signs.

1.5 × IQR below the 25th percentile and the point at 1.5 × IQR above the 75th percentile; and speed differences beyond the lines are represented with open circles.)

Horizontal lines are drawn at 0 and 15 mph to highlight speeds at or below the speed limit (i.e., in compliance) and speeds exceeding 15 mph above the posted speed limit. For example, the percentages of data points above the +15-mph line are directly comparable to the corresponding statistic shown in the last column of Tables 3-6 through 3-9. The speed distributions shown in theses plots are "raw" speeds recorded at each location, that is, they summarize speed differences

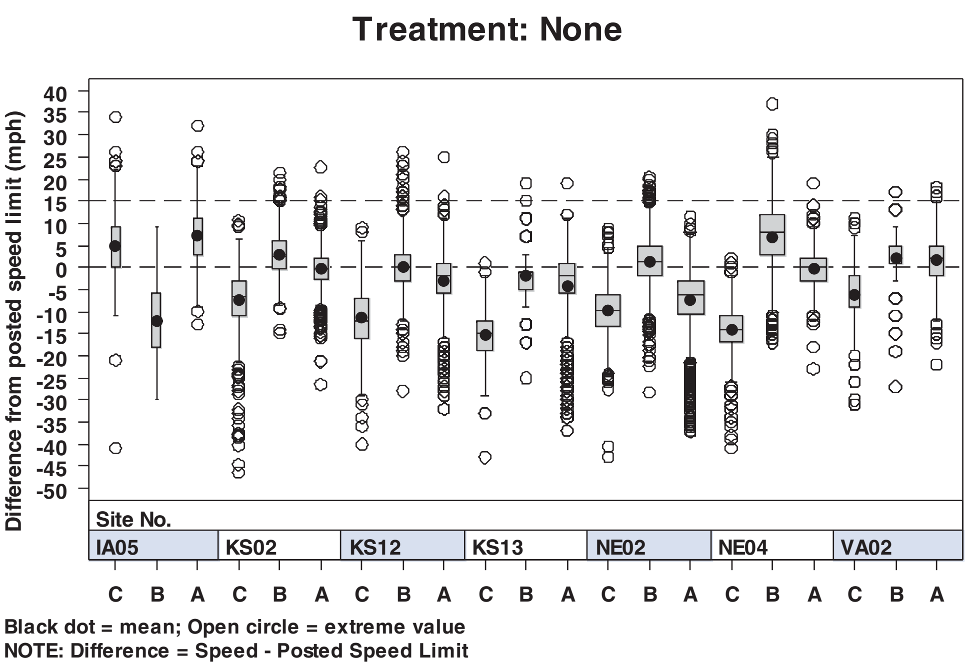


Figure 3-7. Speed differences from posted speed limit—no treatment.

without regard to individual site characteristics (aside from posted speed limits); and, therefore, do not allow for a direct assessment of a particular treatment across sites. However, at a particular site, the box plots allow for comparison of speed trends from Location C (upstream of the transition zone), to Location B (transition zone exit), and to Location A (community).

Table 3-10 provides a qualitative assessment of deceleration behavior through the transition zone based upon the speed data from the laser gun. The qualitative assessment was made to determine if drivers did the following:

- Decelerated early within the transition.
- Decelerated at a steady or gradual rate.
- Maintained a relatively constant speed through most of the transition zone and decelerated late within the transition zone.

In most cases, the laser gun data showed drivers decelerated at a steady or gradual rate through the length of the transition zone, but in a few cases there was a noticeable reduction in speeds (i.e., an increase in deceleration rate) at the downstream end of the transition zone. In particular, greater deceleration occurred towards the downstream end of the transition zone at three of the four sites with a roundabout treatment.

Inspection of the speed distributions in Figures 3-4 through 3-7 and Tables 3-6 through 3-9 shows a few sites where speeds upstream of the transition zone (Location C) are relatively low compared to the posted speed limit. A review of these sites (e.g., considering the placement of the classifier relative to an intersection) did not yield a good explanation for why speeds were so low

Table 3-10. Laser gun speeds—qualitative summary by site.

Treatment	Site no.	Deceleration behavior in transition zone			Comment
		Early	Steady	Late	
Roundabout	NE03		✓		
	VA01			✓	
Roundabout and Transverse Rumble Strips	KS09		✓	✓	Assumed deceleration after TRS based on classifier data at Location B
Roundabout and Welcome Sign	NE01		✓	✓	
Transverse Pavement Markings	IA03		✓	✓	
	KS01		✓		
	KS14		✓		
	KS15		✓		
Transverse Pavement Markings and Welcome Sign	IA01		✓		
	IA02		✓	✓	Assumed deceleration after TPM based on classifier data at Location B
	KS06		✓		
Welcome Sign	KS03		✓		
	KS04		✓		
	KS05		✓		
	KS10		✓		
	KS11		✓		
None	IA05		✓		
	KS02		✓		
	KS12		✓		
	KS13		✓		
	NE02		✓		
	NE04		✓		
	VA02				Site characteristics not conducive to determine deceleration behavior

at these upstream locations. It was determined, however, that such sites are not good candidates to include in an analysis to evaluate the effectiveness of transition zone treatments in reducing speeds. It was not considered useful to estimate the effects of transition zone treatments at the end of the transition zone and within the community, when free-flow speeds at the upstream end of the transition zone are already low. The following rule was applied to determine which sites to include or exclude from further analyses to assess the effect of a particular treatment in reducing speeds in the transition zone and through the community:

- If the 85th percentile speed at the upstream end of the transition zone (i.e., Location C) is more than 5 mph below the posted speed limit at that location, exclude the site; otherwise, keep the site.

Applying this inclusion/exclusion rule, Sites KS06 (TPM), KS10, KS11 (welcome sign) and KS13, and NE04 (no treatment) are excluded from further analyses to assess the effect of a particular treatment in reducing speeds in the transition zone and through the community.

3.2.3 Analysis Approach

The primary measures analyzed to assess the effectiveness of a transition zone treatment in reducing speeds include the following:

1. **Transition zone exit speed.** Speeds collected with the classifier tubes at Location B were used. The percentage of vehicles in compliance with posted speed limits at the end of the transition zone represents whether the transition zone treatment achieved its objective. Similarly, the percentage of vehicles exceeding speed limits by 5, 10, or 15 mph is a measure of the effect of the treatment on the upper portions of the speed distributions.
2. **Transition zone speed reduction.** Speeds collected with the classifier tubes at Locations C and B were used. Total speed reductions were measured as the difference in mean speeds upstream and downstream of the transition zone.
3. **Community speed.** The implementation of the treatment is intended to contribute to reduced vehicle speeds through the community. However, whether vehicles maintained a reduced speed through the community can be thought of as a measure of the "halo" effect of the treatment, although many other factors may contribute to speeds through the community. Specifically, if the transition zone treatment is implemented upstream of the community and not in the community itself, the effect of the treatment is not expected to directly impact the community speed. Using the speeds recorded with the classifier tubes at Location A, the percentage of vehicles in compliance with posted speed limits or speed limits plus 5, 10, or 15 mph was the measure of interest.

The statistical approach to estimate the effect of the treatment on speeds depended on the measure of interest and the location along the roadway. In all cases, basic speed distributions—mean, standard deviation, median, 85th, and 95th percentile speeds—were tabulated separately for each site and location (upstream, transition zone exit, and community). Percentages of vehicles exceeding the speed limit or the speed limit plus 5, 10, or 15 mph were also tabulated. The individual analysis approaches were as follows:

1. **Analysis of transition zone exit speed.** A logistic regression model was used to compare the treatments based on the probability that vehicles drive at or below the posted speed limit exiting the transition zone. (Note: this probability is one minus the probability that vehicles exceed the posted speed limit.) This analysis was repeated using speed limit + 5 mph as the criterion. The primary factor of interest in the regression model is the treatment type. To account for site differences such as posted speed limits upstream and downstream of the transition zone, the reduction in posted speed limit from C to B was included in the regression model. To

also account for speed-limit compliance by drivers upstream, the percentage of speeds at or below speed limit at Location C was included in the model. The statistical significance of treatment, after accounting for C to B posted speed reduction and for compliance upstream was evaluated, and the results from each treatment were compared to those obtained for the non-treated sites.

- A generalized linear model (GLM) with a binomial distribution and a logit link function was used to model the compliance proportions. Least squares mean differences between treatment and no treatment sites were estimated after accounting for the potential effect of the additional factors in the model and tested for statistical significance. All analyses were performed using the GENMOD procedure of SAS (2011).

2. **Analysis of transition zone speed reduction.** At each site and location, the effect of a particular treatment is confounded with that of the posted speed limit sign. Since the sites vary with respect to their posted speed limits at Locations C and B, the interest is in the estimated effect of a particular treatment compared to no treatment beyond that of the posted speed reduction at each site. Given that speeds were recorded for a population of vehicles rather than individual vehicles, this analysis could not be performed based on individual vehicles' speed reductions, but on overall speed differences upstream and downstream of the treatment. To account for the posted speed limit at each location, the overall speed differences at each location for each site were estimated, and the difference in differences between sites with treatment and no treatment was evaluated and tested for significance.
   - A generalized linear mixed model with a normal distribution and identity link function was used to model the speed differences, accounting for the random site effect. The reduction in posted speed limit from Location C to Location B was also included in the model. Least squares mean differences between treatment and no treatment sites were estimated after accounting for the potential effect of the additional factors in the model and tested for statistical significance.
3. **Analysis of community speed.** The analysis approach is similar to that used to evaluate the treatment effect at the transition zone exit (discussed above) with some additional considerations. Since site characteristics, such as on-street parking, presence of sidewalks and curbs, and horizontal roadway alignment may influence driver behavior in the community, these factors were initially considered in the logistic model. Multicollinearity between these additional factors was evaluated prior to their inclusion in the model. As for the transition zone exit speed, the percentage of speeds at or below speed limit at Location B was included in the model. Again, the model was repeated for the speed limit + 5 mph criterion.

3.2.4 Analysis Results

Transition Zone Exit—Speed-Limit Compliance Evaluation

The effect of treatment type—roundabout, TPM, and welcome sign—on exit speed (Location B) was estimated as compared to that of no treatment. Two dependent variables were of interest, as follows:

- Percentage of vehicles driving at or below speed limit at Location B and
- Percentage of vehicles driving at or below speed limit + 5 mph at Location B.

The percentage of vehicles driving at or below the speed limit at Location B was calculated for each site. Similarly, the percentage of vehicles driving at or below the speed limit at Location C was calculated for each site. The same calculations were performed using speed limit + 5 mph as the criterion. The relationship between observed compliance at exit and upstream is illustrated in Figure 3-8 (speed limit criterion) and Figure 3-9 (speed limit + 5 mph criterion).

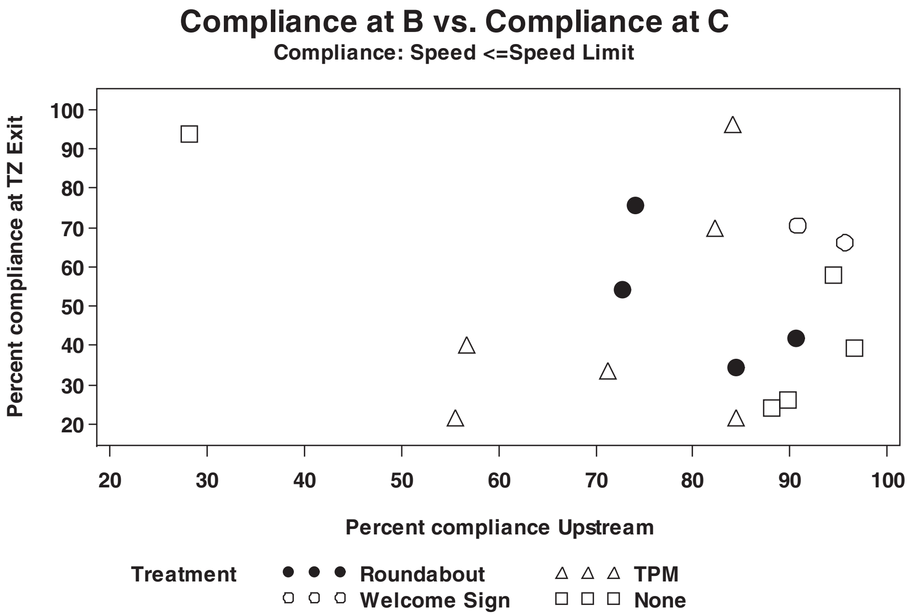


Figure 3-8. Observed exit (Location B) compliance versus upstream (Location C) compliance—posted speed limit criterion (TZ = transition zone).

A logistic regression model was then developed to investigate the relationship between the percentage of vehicles driving at or below the speed limit at Location B and the treatment type, posted speed limit nearest Location C, and the speed reduction from Location C to Location B. The percentage of vehicles driving at or below the speed limit at Location C was also included in the model to account for speed-limit compliance behavior upstream of the transition zone.

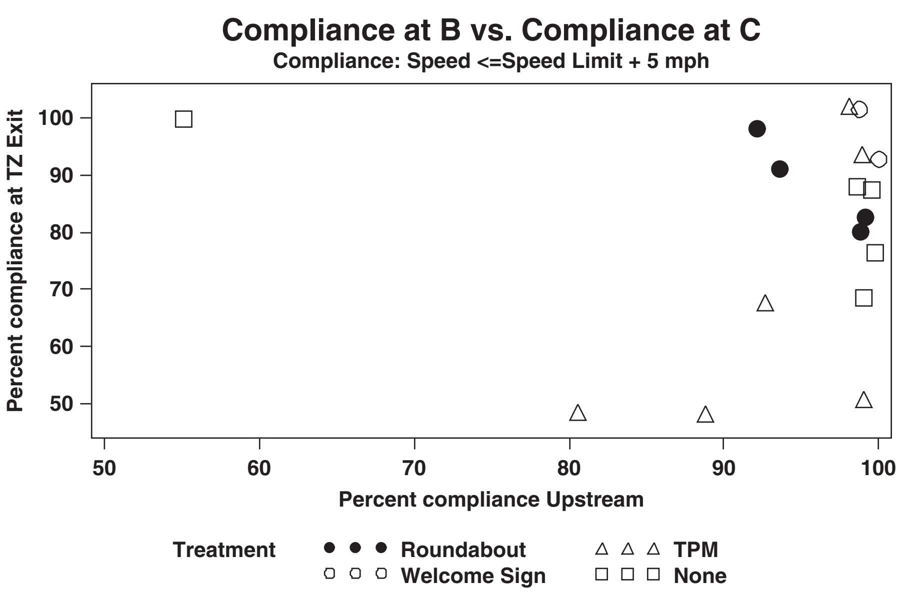


Figure 3-9. Observed exit (Location B) compliance versus upstream (Location C) compliance—posted speed limit + 5 mph criterion.

The analysis showed that of the variables considered in the model in addition to treatment type—speed reduction from C to B, speed limit at C, and percentage of speeds at or below the speed limit at C—only the speed reduction was statistically significant at the 10 percent level. This model also showed that the estimated percentage of vehicles driving at or below the speed limit was considerably higher (by approximately 10 percent) at sites with a welcome sign than at other treated sites. Although it is reasonable to assume that a psychological treatment such as a welcome sign can be effective in reducing speeds, the findings seem illogical. A welcome sign to a community is intended to raise the awareness of drivers that they are entering into a community, but the treatment does not change the overall roadway characteristics extensively enough to suggest that at these sites the significant reduction in measured speeds was solely due to this psychological treatment (i.e., the welcome sign). Therefore, the remaining two sites with a welcome sign (KS03 and KS04) were excluded from the analysis and a new logistic model was evaluated based on the remaining 15 sites.

The final modeling results are shown in Table 3-11, separately for each speed criterion. Only two treatment types remain—roundabout and TPM. For each criterion, the table summarizes the overall significance of the treatment and speed reduction from C to B. A 10 percent significance level was used to assess significance. The table shows estimated percentage of speeds exceeding the criterion with upper and lower 90 percent confidence limits. The last column indicates whether either treatment significantly improved speed-limit compliance as compared to no treatment, after accounting for posted speed reduction from C to B.

In summary, if speed-limit compliance were defined as driving at or below posted speed limit at the exit of the transition zone, then the study data show the following, accounting for the effect of speed reduction in posted speed limits from Location C to B:

- The compliance rate upstream of the transition zone had no significant effect on the compliance rate at the exit of the transition zone.
- The overall treatment effect on compliance rate was not statistically significant at the 10 percent significance level.
- On average, the rate of compliance at sites with a roundabout or TPM is higher than that at sites with no treatment by an amount of 15 percent (not statistically significant) and 20 percent (statistically significant), respectively.
- On average, the rate of compliance for sites with TPM (57 percent) was slightly higher than that for sites with a roundabout (52 percent).

Table 3-11. Analysis results of speed-limit compliance at transition zone exit (Location B).

Treatment type (number of sites)	Percent speeds at or below criterion at Location B			Treatment significantly better than none at 90% confidence level? (p-value)
	Estimate	90% Lower limit	90% Upper limit	
CRITERION: SPEED LIMIT AT LOCATION B • Overall treatment effect: not significant (p = 0.16). • Compliance rate at Location C: not included (not statistically significant). • Posted speed reduction from C to B: significant (p = 0.10).				
Roundabout (4)	52	40	64	No (0.11)
TPM (6)	57	42	70	Yes (0.06)
None (5)	37	23	54	
CRITERION: SPEED LIMIT+ 5 MPH AT LOCATION B • Overall treatment effect: significant (p < 0.01). • Compliance rate at Location C: not included (not statistically significant). • Posted speed reduction from C to B: significant (p = 0.09).				
Roundabout (4)	88	81	93	Yes (0.06)
TPM (6)	79	69	87	No (0.41)
None (5)	77	65	86	

If speed-limit compliance were defined as driving at or below the posted speed limit + 5 mph at the exit of the transition zone, then the study data show the following, accounting for the effect of speed reduction in posted speed limits from Location C to B:

- The compliance rate upstream of the transition zone had no significant effect on the compliance rate at the exit of the transition zone.
- The overall treatment effect on compliance rate was significant at the 10 percent significance level.
- On average, the rate of compliance for sites with a roundabout (88 percent) was significantly higher than that for sites without a treatment (77 percent) by an amount of 11 percent.
- On average, the rates of compliance at sites with TPM (79 percent) and sites with no treatment (77 percent) are the same, for all practical purposes.
- The average rates of compliance for sites with a roundabout (88 percent) and sites with TPM (79 percent) were not statistically different from each other ($p = 0.17$; this comparison is not shown in Table 3-11).

Evaluation of Speed Reduction from Upstream to Transition Zone Exit

An attempt was made to evaluate the effect of the treatment on the upstream to transition zone exit speed reduction (i.e., C to B reduction). Ideally, this would be done based on paired C to B speed differences if each speed collected at Location C could have been paired with the matching vehicle's speed at Location B. However, since an individual vehicle could not be tracked from Location C to B with classifier tubes, an individual vehicle's speed reduction was not available (see earlier discussion). As a result, speed reduction from C to B, even at a single site, could only be evaluated for all vehicles as a whole.

Table 3-12 shows simple speed reduction statistics for each site—mean speed reduction and its lower and upper 95 percent confidence limits. For comparison purposes, the table shows the drop in posted speed limit from C to B. The last column shows the mean speed difference as a percentage of the speed reduction difference. In all but two cases, average speed reductions at a given site are below the reduction in posted speed limits. This is in line with the fact that at Location C average speeds are below posted speed limit at all but one site (IA05) as shown in Tables 3-6 through 3-9. The sites without treatment exhibit the widest range of relative speed reductions as compared to the posted speed reduction.

Table 3-12. Speed reduction from Location C to B by treatment type and site.

Treatment type	Site no.	Posted speed limit reduction C to B (mph)	Vehicle speed reduction from C to B (mph)			Relative speed reduction[a] (%)
			Estimated mean	Lower 95% confidence limit	Upper 95% confidence limit	
Roundabout	KS09	35	26	25	28	74
	NE01	15	14	11	18	93
	NE03	30	22	21	22	73
	VA01	20	17	16	18	85
TPM	IA01	30	18	15	20	60
	IA02	30	21	18	24	70
	IA03	25	19	17	21	76
	KS01	20	22	19	24	110
	KS14	20	16	15	16	80
	KS15	20	17	16	18	85
None	IA05	10	27	24	30	270
	KS02	35	22	19	26	63
	KS12	20	9	7	10	45
	NE02	15	4	1	7	27
	VA02	20	12	11	13	60

[a]Relative speed reduction = 100 × mean speed reduction/speed limit reduction.

Table 3-13. Analysis results of speed reduction from upstream (Location C) to transition zone exit (Location B), adjusted for speed limit reduction.

Treatment type	C to B reduction adjusted for speed limit reduction (mph)			Treatment versus no treatment difference in C to B reduction adjusted for speed limit reduction (mph)		
	Estimated mean[a]	Lower 95% confidence limit	Upper 95% confidence limit	Estimated mean	Lower 95% confidence limit	Upper 95% confidence limit
Roundabout	5.2	–2.3	12.7	0.0	–10.1	10.0
TPM	5.6	–0.5	11.7	0.4	–8.7	9.5
None	5.2	–1.5	11.9			

[a]Mean = [Avg($Speed_C$ – Speed $Limit_C$) – Avg($Speed_B$ – Speed $Limit_B$)].

Next, taking into account the posted speed limit at each site and location, the potential additional effect of the treatment on speed reduction from C to B was estimated. This was done by calculating the difference between each vehicle's speed and the posted speed limit at each site and each location. (Note that the average of the rescaled C to B differences for each site is the same as the difference between Column 3 "Posted speed limit reduction C to B (mph)" and Column 4 "Estimated mean" in Table 3-12.) The effect of the treatment on these rescaled differences was then assessed using a mixed linear model approach. The factors considered in the model were treatment type, location (C and B), and reduction in posted speeds from C to B; site was included in the model as a random factor. The analysis of variance (ANOVA) showed that the reduction in posted speed limit was not statistically significant (p-value = 0.24); this factor was therefore removed from the model.

The final analysis results are summarized in Table 3-13 as follows:

- For each treatment, Column 2 shows the mean speed reduction from C to B, after adjusting each vehicle's speed for the speed limit at the respective site and location. Each mean can be expressed as: [Avg($Speed_C$ – Speed $Limit_C$) – Avg($Speed_B$ – Speed $Limit_B$)].
- Columns 3 and 4 show the 95 percent confidence limits for the adjusted mean speed reduction.
- Columns 5 to 7 show the mean and 95 percent confidence limits for the difference in adjusted C to B speed reductions between treated and no treatment sites.

After adjusting for posted speed limit at each location, speed reductions from C to B were comparable for sites with treatment and no treatment, at just over 5 mph, with confidence limits ranging from approximately –2 to +12 mph. In summary, based on the study sites, there is no evidence that either treatment (i.e., roundabouts or TPMs) has a statistically significant effect on reducing average speeds from upstream to the transition zone exit beyond that due to the posted speed limit reduction.

Community—Speed-Limit Compliance Evaluation

Of the 15 sites in the analysis, 12 had no further speed limit reduction from the transition zone exit to the community; the other three sites had reductions in speed limits of 5 mph (TPM), 15 mph (TPM), and 20 mph (no treatment). Compliance rates in the community were calculated with respect to the two criteria defined earlier. The relationship between compliance in the community and at the transition zone exit is illustrated in Figure 3-10 (speed limit criterion) and Figure 3-11 (speed limit + 5 mph criterion).

The analysis of the effect of the treatment in the transition zone on speed-limit compliance in the community was performed using the same approach as that for transition zone exit compliance with a few exceptions. Speed reduction from B to A (none for 12 of the 15 sites) was not

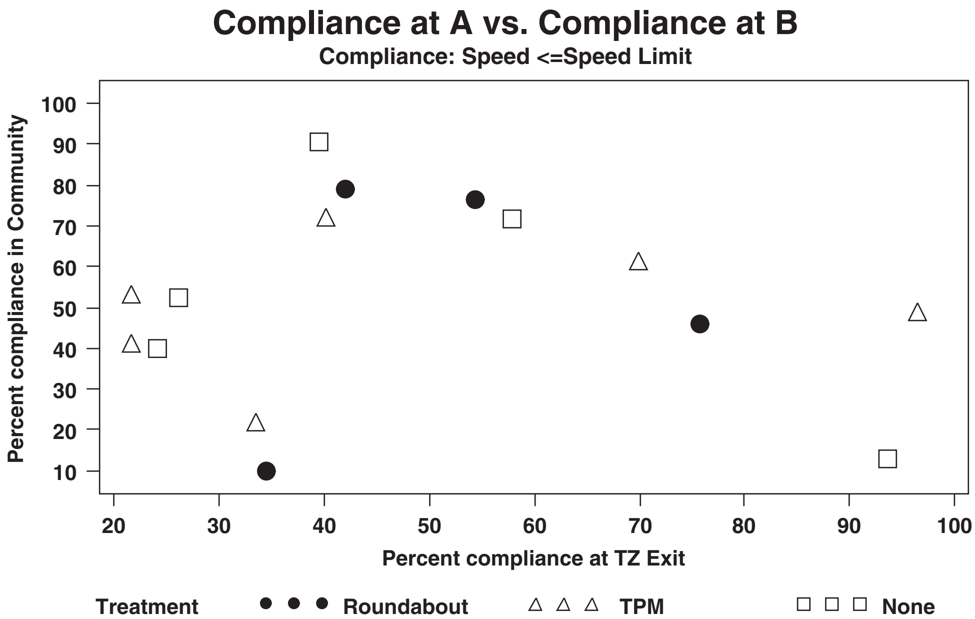


Figure 3-10. Observed community (Location A) compliance versus exit (Location B) compliance—posted speed limit criterion.

considered in the logistic model; however, to account for the potential effect of site characteristics in the community, the inclusion of the following categorical variables was initially considered:

- On-street parking—yes (three sites), no (12 sites);
- Presence of sidewalks—yes (eight sites), no (seven sites);
- Presence of curbs—yes (seven sites), no (eight sites); and
- Horizontal alignment—tangent (nine sites), curve (six sites).

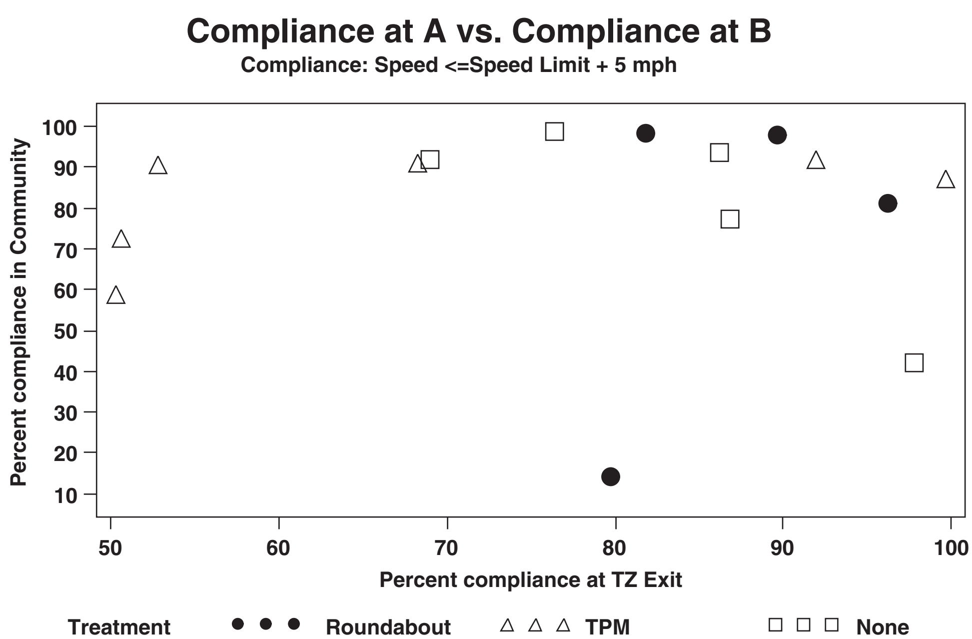


Figure 3-11. Observed community (Location A) compliance versus exit (Location B) compliance—posted speed limit + 5 mph criterion.

On-street parking was confounded with treatment type and was therefore not included in the model. Also, the presence of sidewalks and that of curbs are confounded; therefore the presence of sidewalks was not considered in the model.

An attempt was made to address pedestrian activity in the community as potentially affecting drivers' speed compliance. Lacking pedestrian volume data, community population (last column in Table 3-4) was considered as a surrogate measure. Population size ranged from 222 to 7,990 with a highly skewed distribution to the low side [i.e., 13 of the 15 communities had a population below 2,500 (10 below 1,300) and the remaining 2 were at 7,990]. Furthermore, no roundabouts were installed near communities with a population below 500 and no TPMs were installed near communities with a population above 2,200. Thus, the uneven distribution of community population size across treatment types did not warrant including community population as a factor in the analysis.

In summary, the independent variables considered for inclusion in the model were: treatment type, posted speed limit at Location A, presence of curbs, horizontal alignment, and compliance rate at Location B. The final modeling results are shown in Table 3-14, separately for each speed criterion.

Whether one defines compliance in the community as driving at or below the speed limit or at or below the speed limit + 5 mph, the highlights of Table 3-14 can be summarized as follows:

- The compliance rate at the exit of the transition zone had no statistically significant effect on the compliance rate in the community.
- Horizontal alignment of the roadway in the community had no statistically significant effect on the compliance rate in the community.
- Both posted speed limit in the community and presence of curbs had a statistically significant effect on the compliance rate in the community.

Table 3-14. Analysis results of speed-limit compliance in the community (Location A).

Treatment type (number of sites)	Percent speeds at or below criterion at Location A			Treatment significantly better than none at 90% confidence level? (p-value)
	Estimate	90% lower limit	90% upper limit	
Criterion: Speed Limit at Location A • Overall treatment effect: not significant (p = 0.90). • Compliance rate at Location B: not included (not statistically significant). • Horizontal alignment: not included (not statistically significant). • Posted speed limit in community: significant (p < 0.01). • Presence of curbs: significant (p < 0.01).				
Roundabout (4)	58	47	68	No (0.44)
TPM (6)	54	42	66	No (0.33)
None (5)	59	45	71	
Criterion: Speed Limit + 5 mph at Location A • Overall treatment effect: not significant (p = 0.84). • Compliance rate at Location B: not included (not statistically significant). • Horizontal alignment: not included (not statistically significant). • Posted speed limit in community: significant (p < 0.01). • Presence of curbs: significant (p < 0.01).				
Roundabout (4)	89	82	94	No (0.43)
TPM (6)	86	76	92	No (0.37)
None (5)	88	77	94	

After accounting for the significant effect of posted speed limit in the community and that of the presence of curbs, it was found that, for the study sites, the type of treatment in the transition zone had no significant effect on compliance rates in the community. These compliance rates range, on average and for all site types, from 54 percent to 59 percent (using the speed limit criterion) and from 86 percent to 89 percent (using the speed limit + 5 mph criterion).

Overall Summary of Speed Evaluations

The primary findings from the speed evaluations can be summarized as follows:

- Compared to non-treatment sites, roundabouts and TPMs do not significantly decrease mean speeds from upstream to downstream of the transition zone beyond the speed reduction due to the change in posted speed limit. A small reduction in mean speed was observed, but this reduction was not statistically significant. However, speed-limit compliance rates were significantly higher at roundabouts and TPMs as compared to rates at non-treatment sites. Roundabouts and TPMs increase the rate of compliance of vehicles traveling at or below the speed limit by amounts of 15 and 20 percent, respectively, as compared to no treatment. Roundabouts also increase the rate of compliance of vehicles traveling at or below the speed limit + 5 mph by an amount of 11 percent when compared to no treatment.

  The fact that the decrease in mean speeds from upstream to downstream of the transition zone was not significantly larger at treatment sites than at non-treatment sites, while speed-limit compliance rates increased with the treatment in place, indicates that there was a reduction in speed variance from upstream to downstream of the treatments at the study sites. While speed variance data were not provided in the analysis results above, in general, the data show a reduction in speed variance from upstream to downstream of the transition zone at all sites and the speed variance was overall lower at the treatment sites (i.e., roundabouts and TPMs) than at the non-treatment sites. This supports the findings that roundabouts and TPMs do not necessarily decrease means speeds from upstream to downstream of the transition zone any more than does no treatment, but roundabouts and TPMs do increase speed-limit compliance.
- Neither roundabouts nor TPMs significantly affect compliance rates of vehicles traveling at the speed limit within the community further downstream from the transition zone exit. These findings support guidance from previous research (Forbes, 2011) for the need to provide additional measures through the community to maintain a speed reduction downstream of the transition zone through the community.
- The effect of welcome signs at community entrances on mean speeds and compliance rates to speed limits could not be determined because speeds upstream of the transition zones at several of the data collection sites were inexplicably low, leaving too few sites to conduct a reliable analysis of speeds and/or speed-limit compliance rates at transition zones due to welcome signs.

3.3 Crash Data Analysis

Crash data were obtained for all of the sites included in the speed study. The primary purpose of analyzing the crash data was not to conduct a rigorous statistical crash analysis (the number of sites included in the study is not sufficient for such an analysis), but rather to verify that all of the treatments evaluated are operating both safely and efficiently, with no unusual crash history or patterns at the sites, and to identify potential trends in the crash data. The crash data are first summarized by severity and then by collision type.

For this analysis, the most recent 5 years of available crash data were obtained for each site, either from 2005 to 2009 or 2006 to 2010. Crash data were obtained for the transition zone, consistent with the boundaries defined for the speed study (i.e., from classifier Location C to B), and 0.25 mi downstream of the transition zone into the community. For the sites where speed data were collected on both approaches to the community—and the length of the community (i.e., from classifier Location B on one approach to classifier Location B on the other approach) was less than 0.5 mi—the length of the community was divided in half, and crashes were assigned to the respective study site. Both intersection and roadway segment crashes were included in the analysis, while animal crashes and parking lot/driveway related crashes were excluded. Also, for single-vehicle crashes that occurred along the roadway, the vehicle must have been traveling from the high-speed environment to the low-speed environment to be included in the analysis.

Of the 80 crashes (i.e., all severity levels) included in the database for analysis, six crashes could be identified as being speed-related crashes (e.g., based upon data elements such as major cause or contributing circumstances). All six crashes occurred at treatment sites, two prior to installation of the treatment and four after installation of the treatment.

3.3.1 Severity Level

For the combined transition zone and community, Table 3-15 summarizes the crash data for total crashes and Table 3-16 summarizes the data for fatal and all injury crashes. An empty cell in the tables indicates that no crash data were available prior to installation of the treatment. Each table presents the combined site length, the number of before and after years of crash data (i.e., crash data for the years before treatment installation and for the years after treatment installation), and the observed crash frequency for each period. The last two columns present the crash frequencies on a per mile per year basis so direct comparisons can be made across sites. Crash data before treatment installation were not available for seven out of the 15 treatment sites.

Table 3-15. Total crashes by site in the combined transition zone and community.

Treatment type	Site no.	Site length (mi)	Number of years		Crash frequency		Crashes/mi/yr	
			Before	After	Before	After	Before	After
Roundabout	KS09	1.31	3	1	1	0	0.25	0.00
	NE01	0.73		5		6		1.65
	NE03	0.79	3	1	4	3	1.70	3.82
	VA01	0.94		5		12		2.55
TPM	IA01	0.50		5		0		0.00
	IA02	0.57		5		3		1.06
	IA03	0.53		5		1		0.38
	KS01	0.87	3	1	3	0	1.15	0.00
	KS06	0.78	2	1	1	1	0.64	1.29
	KS14	0.55	3	1	4	0	2.41	0.00
	KS15	0.62	3	1	0	0	0.00	0.00
Welcome Sign	KS03	0.65	2	2	5	1	3.87	0.77
	KS04	0.37	2	2	1	1	1.33	1.33
	KS10	0.48		5		0		0.00
	KS11	0.38		5		1		0.52
None	IA05	0.58	5		1		0.34	
	KS02	0.61	5		7		2.29	
	KS12	0.27	5		0		0.00	
	KS13	0.28	5		3		2.11	
	NE02	0.33	5		5		3.07	
	NE04	0.51	5		3		1.19	
	VA02	0.97	5		13		2.68	

Table 3-16. Fatal and all injury crashes by site in the combined transition zone and community.

Treatment type	Site no.	Site length (mi)	Number of years		Crash frequency		Crashes/mi/yr	
			Before	After	Before	After	Before	After
Roundabout	KS09	1.31	3	1	0	0	0.00	0.00
	NE01	0.73		5		4		1.10
	NE03	0.79	3	1	3	2	1.27	2.55
	VA01	0.94		5		7		1.49
TPM	IA01	0.50		5		0		0.00
	IA02	0.57		5		1		0.35
	IA03	0.53		5		1		0.38
	KS01	0.87	3	1	2	0	0.77	0.00
	KS06	0.78	2	1	0	0	0.00	0.00
	KS14	0.55	3	1	2	0	1.20	0.00
	KS15	0.62	3	1	0	0	0.00	0.00
Welcome Sign	KS03	0.65	2	2	2	0	1.55	0.00
	KS04	0.37	2	2	1	0	1.33	0.00
	KS10	0.48		5		0		0.00
	KS11	0.38		5		1		0.52
None	IA05	0.58	5		1		0.34	
	KS02	0.61	5		1		0.33	
	KS12	0.27	5		0		0.00	
	KS13	0.28	5		1		0.70	
	NE02	0.33	5		4		2.45	
	NE04	0.51	5		2		0.79	
	VA02	0.97	5		4		0.82	

Focusing on the crash frequencies summarized in the "crashes/mi/yr" columns of Tables 3-15 and 3-16, it appears that treatment sites are operating as safely as expected. Only one site (NE03) seems to have a significant increase in crashes after installation of the treatment (a roundabout), but it is only based on 1 year of after data. In general, crash frequencies for the treatment sites after installation appear to be consistent with crash frequencies before installation of the treatment and consistent with crash frequencies of sites with no treatment, so from a qualitative level it does not appear that the installation of the treatments at the study sites improved or negatively impacted safety at these sites.

To assess the potential treatment effect in a more quantitative and scientifically based manner, the following two approaches were used to analyze total crashes:

1. Using a simple analysis where crashes at the 15 treatment sites in the after period were compared to crashes at all sites in the before period (i.e., 8 treatment sites and 7 no treatment sites). A generalized linear model (GLM) with a negative binomial distribution and a log link was used to model crashes/mi/yr; average daily traffic (ADT) (continuous variable) and treatment (at four levels—RA, TPM, WS, and None) were included in the model. For the roundabout sites with data before and after installation (i.e., sites KS09 and NE03), the before period data were not included in this analysis, because these sites were unique in that they both had a major intersection near the entrance to the community compared to the other sites, which had a limited number of intersections within the transition zone. The objective was to estimate the significance of the treatment effect and, if statistically significant, to compare each treatment to no treatment.
2. Using a cross-sectional type of analysis where only the eight treatment sites (two RA, four TPM, two WS) with both before and after treatment installation crash data were included. The data were analyzed in a similar fashion as just described with the addition of the period (before/after) as a categorical variable and site as a random factor to account for the within-site temporal correlation.

Table 3-17. Collision types at all study sites.

Collision type	Crash frequency
Angle	25
Bicycle	1
Fixed Object	10
Head On	2
Multiple vehicle—Other	4
Pedestrian	1
Rear End	33
Sideswipe—Opposite Direction	1
Sideswipe—Same Direction	2
Single vehicle—Other	1

Neither analysis showed any significant treatment type or before/after treatment installation effect. The p-value for the overall treatment effect associated with the first approach was 0.16. The p-value for the overall before/after effect at treated sites associated with the second approach was 0.38. In summary, the quantitative analysis of the crash data did not yield any significant conclusions regarding the safety effect of the treatments considered at the study sites.

3.3.2 Collision Type

The 80 crashes (i.e., all severity levels) from the 22 study sites fell into 10 collision types as shown in Table 3-17. Only two crashes involved vulnerable road users (i.e., pedestrians and bicyclists), and a majority (84 percent) of the crashes involved multiple vehicles. Rear-end, angle, and fixed-object crashes accounted for 85 percent of the crashes. These crashes were further categorized by the following parameters:

- Crash location (intersection or roadway segment);
- Treatment type (RA, TPM, WS, None);
- Site number;
- Location (transition zone or community);
- Time period (before or after treatment installation); and
- Crash type (10 types listed in Table 3-17).

Table 3-18 shows the distribution of collision types of the 51 total crashes that either occurred at an intersection or were intersection related, across all of the sites. No particular trends in collision types were evident at any of the sites going from the before to the after period. Very few sites (four of the 22) had a collision type that was occurring on average at least once per year, in either the transition zone or the community. At three of the four sites, rear-end crashes were the most common (i.e., highest crashes/yr).

Table 3-19 shows the distribution of the 29 total crashes across those same categories, related to roadway segments. No particular trends in collision types are evident.

3.3.3 Overall Summary of Crash Analysis

The primary purpose of the crash analysis was to verify that all of the treatments evaluated at the sites included in this research were operating both safely and efficiently, with no unusual crash history or patterns, and to identify potential trends in the crash data. Based upon the summary crash statistics, no specific trends and/or anything unusual in the data

Table 3-18. Collision types by site, location, and before/after treatment at intersections.

Treatment	Site	Location	Time period	Collision type	Total crash frequency	Crashes/yr
Roundabout	KS09	TZ	Before	Rear End	1	0.33
	NE01	TZ	After	Fixed Object	1	0.20
				Rear End	1	0.20
	NE03	Community	After	Rear End	1	1.00
			Before	Angle	1	0.33
				Bicycle	1	0.33
		TZ	Before	Angle	1	0.33
	VA01	TZ	After	Angle	2	0.40
				Rear End	6	1.20
TPM	IA02	Community	After	Angle	1	0.20
	IA03	Community	After	Angle	1	0.20
	KS14	Community	Before	Angle	2	0.67
				Rear End	1	0.33
Welcome Sign	KS03	Community	Before	Angle	3	1.50
		TZ	After	Rear End	1	0.50
			Before	Rear End	1	0.50
	KS04	Community	After	Rear End	1	0.50
		TZ	Before	Rear End	1	0.50
None	KS02	Community	Before	Angle	3	0.60
				Rear End	1	0.20
		TZ	Before	Multiple Vehicle—Other	1	0.20
	KS13	Community	Before	Angle	1	0.20
				Rear End	2	0.40
	NE02	Community	Before	Angle	2	0.40
				Multiple Vehicle—Other	2	0.40
				Pedestrian	1	0.20
	VA02	TZ	Before	Angle	4	0.80
				Fixed Object	1	0.20
				Rear End	5	1.00
				Sideswipe—Same Direction	1	0.20

Table 3-19. Collision types by site, location, and before/after treatment on roadway segments.

Treatment	Site	Location	Time period	Collision type	Total crash frequency	Crashes/mi/yr
Roundabout	NE01	Community	After	Angle	1	0.80
				Rear End	1	0.80
		TZ	After	Fixed Object	1	0.42
				Sideswipe—Same Direction	1	0.42
	NE03	TZ	After	Angle	1	1.85
				Fixed Object	1	1.85
			Before	Rear End	1	0.62
	VA01	Community	After	Head On	1	2.22
		TZ	After	Fixed Object	2	0.47
				Rear End	1	0.23
TPM	IA02	Community	After	Rear End	2	1.60
	KS01	Community	Before	Fixed Object	1	1.33
		TZ	Before	Fixed Object	1	0.54
				Rear End	1	0.54
	KS06	Community	After	Rear End	1	4.00
		TZ	Before	Fixed Object	1	0.94
	KS14	Community	Before	Rear End	1	1.33
Welcome Sign	KS03	Community	Before	Single Vehicle—Other	1	2.38
	KS11	Community	After	Head On	1	1.00
None	IA05	TZ	Before	Fixed Object	1	0.61
	KS02	Community	Before	Angle	1	0.80
		TZ	Before	Sideswipe—Opposite Direction	1	0.56
	NE04	TZ	Before	Angle	1	0.77
				Multiple Vehicle—Other	1	0.77
				Rear End	1	0.77
	VA02	Community	Before	Rear End	1	2.22
		TZ	Before	Rear End	1	0.23

were observed regarding the effects that installation of roundabouts, TPMs, or welcome signs have on safety. Additionally, two statistical methods were used to analyze the crash data and neither analysis approach showed any significant treatment or before/after effect. Based on this study's crash analysis of a combination of roadway segment and intersection crashes over an extended length of roadway beginning at the upstream end of the transition zone to 0.25 mi downstream of the end of the transition zone, there is no evidence to suggest that the installation of roundabouts, TPMs, or welcome signs in a transition zone either improves or negatively affects safety. This finding is not surprising given the limited crash dataset for this study.

Regarding the effects that the installation of roundabouts, TPMs, or welcome signs have on safety near a transition zone, the most reliable information available is for roundabouts and can be found in the *Highway Safety Manual* (HSM) and research by Rodegerdts et al. (2007, 2010) (see Figure 2-2).

SECTION 4

Design Guidance

This section provides design guidance for selecting geometric design, traffic control devices, pavement surface, and roadside treatments for transitioning from high- to low-speed roadways on rural highways. The design guidance identifies specific treatments for use in encouraging drivers to reduce their speeds, as intended by the designer, and where possible, quantifies the effectiveness of those treatments. The design guidance addresses transition zone-specific factors such as land use; community context; and the accommodation of trucks, parking, pedestrians, bicyclists, and public transportation services. The design guidance is applicable for rural two-lane highways and rural multilane divided and undivided highways (i.e., non-freeways).

The design guidance focuses on roadway and roadside treatments that encourage drivers to reduce their speeds through transition zones. Other speed management components can also be employed to reduce speeds and improve safety through these zones, such as driver education and enforcement programs, but these other speed management components and programs are not addressed in detail here.

The design guidance is intended for design and safety engineers at state and local highway agencies that have jurisdiction over the rural highway system, and, more specifically, where the rural highway network enters into a community. Practitioners from consulting companies will also have an interest in the guidelines, as well as members of groups and organizations with interest in managing speed on the approaches to and through their communities.

The design guidance covers a wide range of issues that ideally will be considered in the design of high- to low-speed transition zones. The design guidance is organized as follows. Section 4.1 describes the relationship between the design guidelines presented herein and the policies and design guidance provided in the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*) and the *Roadside Design Guide;* the *Manual on Uniform Traffic Control Devices* (MUTCD); and *NCHRP Synthesis 412: Speed Reduction Techniques for Rural High-to-Low Speed Transitions* (Forbes, 2011).

Section 4.2 provides definitions for the transition zone study area. Defining the geographical limits of the study area is critical for consistency in design practice.

Section 4.3 provides a methodology for assessing whether a high- to low-speed transition zone has speed-limit compliance or safety issues that should be addressed. The analytical framework is first described in general terms followed by more detailed descriptions of each step in the methodology.

Section 4.4 provides principles that should guide the design of a transition zone as well as two design concepts for consideration. The section also provides a catalog of potential transition zone treatments with a description and illustration of the treatments and information on effectiveness, cost, contraindications, and installation location.

Section 4.5 explains the importance of evaluating the effectiveness of transition zone treatments after implementation. This section also provides general information for conducting before/after evaluations to assess the affects of the transition zone treatments on speed-limit compliance and safety (i.e., crashes).

Section 4.6 summarizes legal/liability issues that should be considered in evaluating and designing transition zones.

With the exception of providing advance signing of a lower speed limit or posting of a stepped-down or intermediate speed limit to mitigate an abrupt change in speeds, most jurisdictions do not have an established policy for designing transition zones (Forbes, 2011). Appendix B presents the design guidance from this section in a stand-alone document that could be adopted in full, or modified as appropriate, by highway agencies looking to develop a policy for designing transition zones.

4.1 Relationship of Design Guidance to Other Documents

The design guidance presented here is to be used in conjunction with pertinent information from other policies and standards. The current edition of AASHTO's *Green Book* (2011) provides a sufficient level of detail for designing roads in a high-speed environment and a low-speed environment; however, the *Green Book* provides little guidance on the design of transition zones between the two facility types. The design guidance provided herein is intended to fill this gap and complement the policies described in the *Green Book.*

The design guidelines herein also address roadside design issues to some degree, focusing mainly on their impact on speed and to a lesser amount on safety. Roadside features need to be designed with careful consideration given to potential consequences. Roadways designed using this guide should have a balanced roadside design, considering operational and safety issues, consistent with the current edition of the *Roadside Design Guide* (AASHTO, 2011).

Furthermore, traffic control devices on roadways designed using these guidelines should be consistent with the current edition of the MUTCD (FHWA, 2009). In particular, the MUTCD provides general guidance on advance signing of a lower speed limit.

Finally, the design guidelines herein build upon *NCHRP Synthesis 412* (Forbes, 2011) and incorporate many of the findings from this previous work.

4.2 Definitions of the Transition Zone Study Area

The first step in planning for possible improvements to a high- to low-speed transition zone is to define the geographical limits of the transition zone study area. The study area should include a sufficient length of roadway to address critical issues within, and at either end of, the transition zone. Using basic background data, the transition zone study area and the transition zone itself can be preliminarily identified and later refined as necessary through further study and analysis. By defining the transition zone study area, an engineer (or planner) can systematically evaluate the need for improvements to better meet key objectives, such as improved safety, reduced vehicle speeds, and an enhanced pedestrian/bicycle environment. This section presents underlying transition zone definitions and characteristics for consistency in design practice.

4.2.1 Geographic Definition of the Transition Zone Area

NCHRP Synthesis 412 (Forbes, 2011) presents different possible geographic definitions and nomenclature for the transition zone study area. For example, one agency identifies three distinct

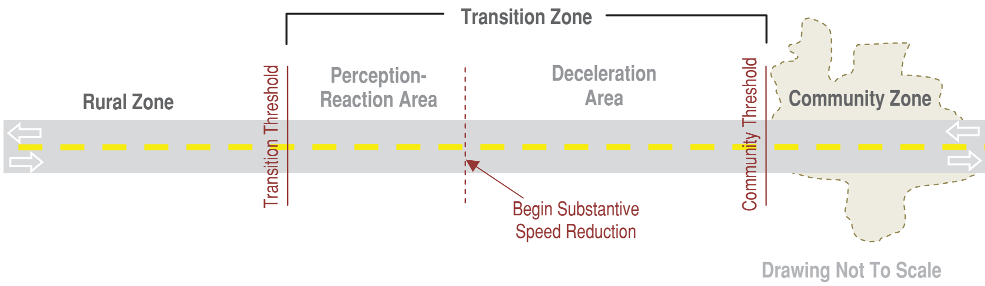


Figure 4-1. Transition zone study area.

zones (rural, transition, and community), while another identifies four zones (rural, approach, transition, and community). For this guide, a three-zone system is adopted to be clear and understandable to both practitioners and laypersons. A three-zone approach allows for a simple answer to questions regarding the limits of the transition zone; however, it is recognized that the transition zone includes two areas, a perception-reaction area and a deceleration area. Different design and driver-related issues need to be addressed regarding these two portions of the transition zone. This three-zone approach, with separate areas within the transition zone, is consistent with general roadway and traffic design principles. It is also consistent with the need for engineers to give greater attention to treating the transition zone as an extended length of roadway rather than a specific point on the roadway where a reduction in speed is to occur (Forbes, 2011).

The three zones defined in this guide are presented in Figure 4-1 and include the rural zone, transition zone, and community zone. The boundaries between each zone are identified as threshold locations, facilitating analyses and distance measurements. Typical characteristics for each zone are provided in Table 4-1.

4.2.1.1 Rural Zone

The rural zone is defined as a high-speed, rural roadway outside of a developed community. It has a high design speed (≥45 mph), little roadside development, few access points, and is designed to facilitate high-speed, longer distance travel. There are relatively few features or potential conflicts that require driver attention in this zone. The design within this zone should be consistent with the high design and posted speeds.

4.2.1.2 Transition Zone

Located between the rural zone and the community zone, the transition zone is the area in which drivers are expected to complete the necessary speed reduction to facilitate safe travel in a more developed area (Forbes, 2011). The theoretical location and length of this zone are determined by a series of physical, operational, and safety characteristics. It may include a section

Table 4-1. Characteristics of transition zone study area.

		Transition zone		
	Rural zone	**Perception-reaction area**	**Deceleration area**	**Community zone**
Design speed	≥ 45 mph	≥ 45 mph	varies (but decreasing)	≤ 35 mph
ADT	Lower	Lower	Increasing	Higher
Access density	Low	Low	Medium	High
Ped/bike activity	Low	Low	Medium	High
Land use	Rural/Low Density	Rural/Low Density	Increasing Density and Intensity	Higher Density and Intensity
On-street parking	No	No	Unlikely	Possibly

Note: Ped = pedestrian.

that has similar characteristics to the rural zone. It may also include the edge of the developed community. It should, however, have elements that differentiate it from the other two zones and inform and assist drivers in making the appropriate speed reduction. The two areas that make up the transition zone include the following:

- *Perception-Reaction Area*—The portion of the transition zone where drivers are made aware of an impending need to change their speed and driving behavior. The general physical and operational characteristics of this area are similar to the rural zone; however, some elements should begin to change. Drivers in this area should have clear lines of sight to signs as well as other warning and/or psychological devices that alert them to the changes ahead. These devices may be physically located in either the perception-reaction area and/or the deceleration area, depending on the device and design criteria. Some deceleration may occur in this area, but the primary objective is to mentally prepare drivers to adjust their driving behavior and speeds in the deceleration area.
- *Deceleration Area*—The portion of the transition zone where the driver is expected to decelerate to a safe operating speed for entering the developed area. Driver awareness and behavior should adjust with the change in the driving environment. The roadway and roadside characteristics as well as the land use and access are generally beginning to change in this area. The deceleration area may include physical measures to reinforce the needed speed transition. The length of the deceleration area is determined by factors such as the design speed profile, lines of sight, and design criteria for any physical features introduced in this area. The boundary between this area and the community zone should be set based on safety, roadway, traffic operations, and land-use criteria.

4.2.1.3 Community Zone

The community zone is that portion of roadway serving the more developed community area. This zone requires slower travel speeds for safety and community reasons. It typically has very different design characteristics from the other zones, including some or all of the following: lower design speeds, increased traffic control, on-street parking, sidewalks, curbs and gutters, higher land-use intensity, frequent access points, landscaping, street-trees, pedestrian and bicycle activity, narrow lanes, and turn lanes. This zone may extend through the community to the transition zone on the other side. Traffic calming measures may be implemented within this zone to maintain lower speeds.

4.2.1.4 Transition and Community Thresholds

The transition threshold is the upstream boundary for planning and designing the entire speed transition zone. It should be far enough upstream that all roadway geometry and line of sight issues can be addressed. It may, for example, be the point at which drivers first observe downstream signs or features that begin to alert them to upcoming roadway and speed changes. The community threshold defines the downstream end of the transition zone. At this threshold the 85th percentile speed should be consistent with the posted speed limit for entering the community. It should typically be set near the edge of development for the community as defined by land-use density, the number of access points, and changes in the roadway and roadside design. For safety reasons, a setback of a few hundred feet may be appropriate between the edge of the community and the transition zone. For a growing community, it may also be necessary to set the community threshold far enough away from the current development to allow for near-term growth. However, if this threshold is set too far from dense development, drivers may not maintain the desired lower speeds through the community.

4.2.2 Preliminary Identification of Transition Zone Study Area

Initially, the engineer may need to define the geographic extents of the transition zone based on readily available data such as posted speeds and local knowledge. However, during the next step in the process, the transition zone assessment, the geographic limits can be refined based on more detailed planning and engineering information. This will include the use of existing crash and speed data, as well as a review of the current roadway design features. Throughout the process it is important to communicate with local planners, engineers, and road users. As additional information is collected, the engineer can better define the extents of the transition zone study area and the nature of the issues. All of these topics are dealt with further in the next section, which outlines an analytical approach for assessing transition zones and then analysis steps that can guide the assessment.

4.3 Transition Zone Assessment

Engineers often have insights into whether or not a specific transition zone might have safety concerns that need to be addressed. This may be through direct observation, discussions with local residents or business owners, anecdotal evidence (e.g., a recent crash), or examination of relevant speed and safety data. To confirm or refute these initial opinions and decide if additional action is required, it is necessary to quantitatively evaluate operations within the transition zone. This section provides a methodology for assessing whether or not a high- to low-speed transition zone has speed-limit compliance or safety issues of a magnitude that may require one or more transition zone treatments.

The assessment process consists of a series of evaluations designed to address a range of topics from traffic safety and roadway design to land use and public/stakeholder input. This section begins by suggesting an analytical framework for assembling and measuring the most important data elements. Second, a project identification phase is suggested. This phase is intended to help the engineer quantify and document the potential safety concerns. It focuses on four important topics: speed, crash experience, highway access, and land use. Third, a set of possible more detailed follow-up analyses are presented. This section concludes with discussions on involving user groups and stakeholders throughout the planning process and a few lessons learned from previous experiences that engineers should be aware of early in a transition zone project.

4.3.1 Analytical Framework

Transition zones are unique when compared to most other portions of the roadway system. Typically, design continuity is very important for a roadway and abrupt changes in design are avoided to the extent possible. However, in a transition zone the roadway design necessarily changes, sometimes abruptly, from a rural design and context to a community design and context, and drivers are expected to change their behavior to match the new conditions. When drivers do not change their behavior, for whatever reason, safety and community livability issues may arise.

4.3.1.1 Transition Zone Factors and Straight-Line Diagram

To address these issues, it is important to consider the wide range of factors that affect traffic conditions in these unique roadway sections. It is also necessary to collect information to evaluate these factors and draw conclusions regarding both concerns and potential solutions. Some of the most important and basic factors include speed, crash experience, and roadway design; however, there are many other physical and operational factors that could affect the conditions in a transition zone. Potential factors include the following:

- Speeds: posted, design, and actual speed profiles;
- Crashes: frequency/rate, location, type, and severity;
- Access Points: location and density;

- Land Use and Zoning: current and future;
- Roadway Alignment: vertical and horizontal (and lines of sight);
- Traffic Volumes: daily and peak hour;
- Vehicle Types: cars, trucks, agricultural, and emergency response;
- Non-Motorized Transportation: pedestrians and bicyclists;
- Transit Design or Operational Features;
- Signs, Striping, and Traffic Control;
- Intersection Geometry;
- Roadway Design Elements (cross-section elements and widths, etc.);
- Roadside Design Elements (sidewalks, landscape, streetscape, etc.);
- Parking;
- Current Transition Zone Treatments.

Given that many of these elements are physical features tied to physical locations in the study area, compiling as many of these elements as possible into one universal evaluation tool can provide insights and help draw connections that would be difficult to discern if the elements were treated separately. A straight-line diagram can be used to display much of the relevant planning and engineering data in one graphic as shown in Figure 4-2. A straight-line diagram ties information to a milepost and/or distance measurement. This permits the engineer to quickly observe trends and possible correlations over the length of the study area and across datasets. For example, the spatial relationship between speeds, crashes, and access point density can all be observed on one figure. Subsequently, more detailed quantitative analyses can still be conducted as necessary, but this tool quickly highlights potential areas of interest. It can also be used to show the information to policy makers and the public.

A straight-line diagram allows the engineer to more clearly define both the problem areas and the thresholds between the three zones. The quantitative elements of the straight-line diagram can also be used to evaluate the extent of specific concerns, such as where the 85th percentile speed exceeds the posted or design speed by more than 5 mph or where the observed crash frequency or crash rate exceeds a threshold value for a reference population of similar sites.

The straight-line diagram can be used to refine the actual threshold locations. By plotting the access point density along with the land uses and design features, it is possible to set the community threshold. Then the transition threshold can be set, taking into account the posted or design speeds, lines of sight, and other design factors. Methods for calculating these are discussed in more detail in later sections.

4.3.1.2 Elements of the Straight-Line Diagram

A hypothetical straight-line diagram is presented in Figure 4-2. While information could be added (or deleted), a figure similar to the one shown offers a reasonable starting point for the project identification phase. The elements of the diagram are briefly summarized in Table 4.2 followed by more detailed explanations for how to collect and analyze the respective data. Additional detailed analyses may be required following the project identification phase if it is determined that safety concerns exist and that improvements should be made to remedy the issue(s).

4.3.2 Project Identification Phase

The first phase in a transition zone assessment is to determine whether the high- to low-speed transition zone has speed-limit compliance or safety issues that deserve further investigation and to assess the magnitude and extent of the issues. During this phase, the engineer is moving beyond anecdotal evidence suggesting that a transition zone has speed or safety issues that should be addressed to quantifying the magnitude of the potential concern. At the end of the

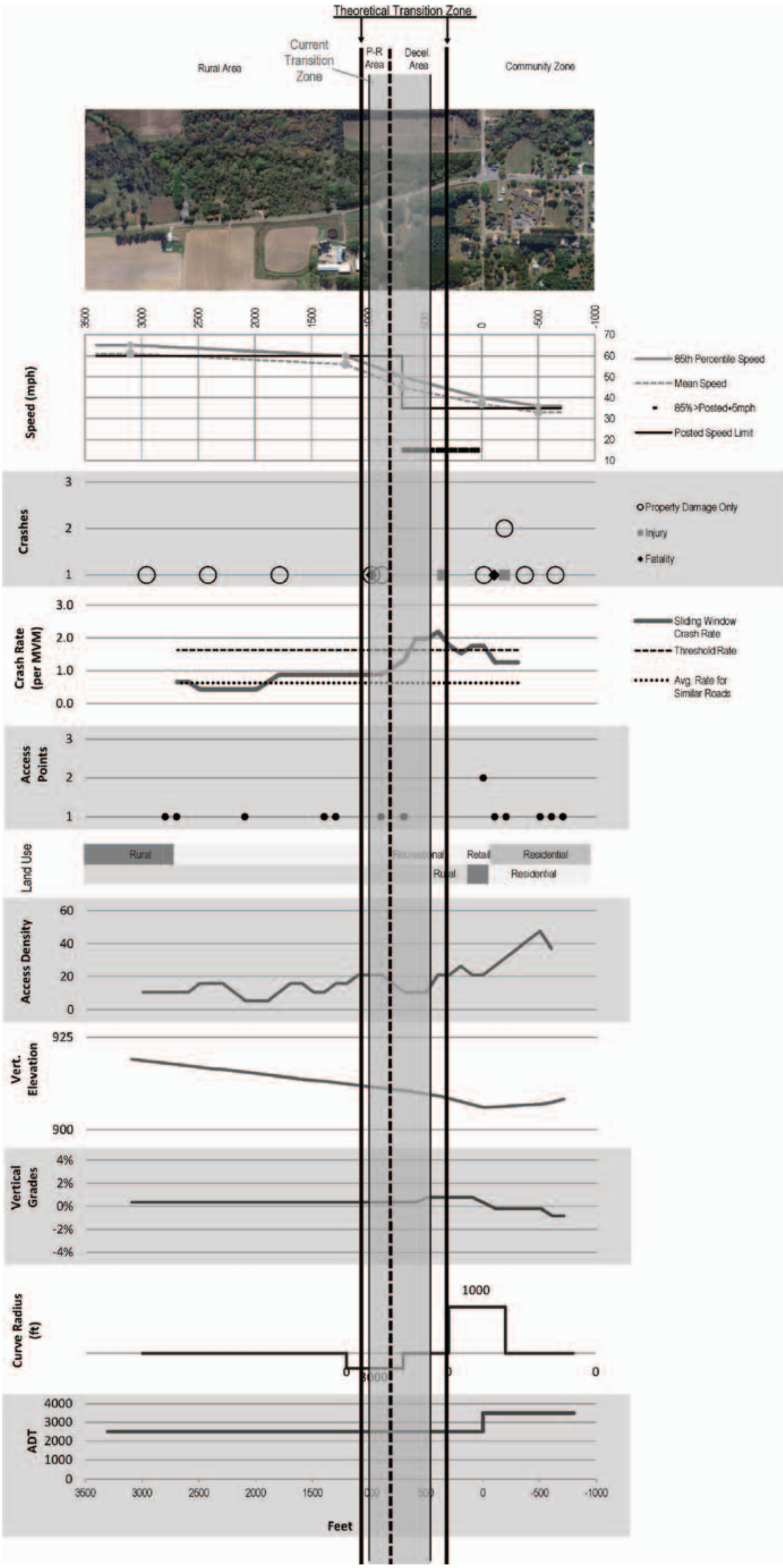


Figure 4-2. Straight-line diagram tool (P-R = perception-reaction, Decel = deceleration, Vert. = vertical).

Table 4-2. Straight-line diagram elements.

Project identification phase	
Aerial Photo	An aerial photo sets the context and facilitates data collection and evaluation.
Posted Speed	Posted speeds are graphed based on the location of the current speed limit signs.
Observed Speeds	Observed speeds are presented based on data collected at up to five data collection locations, with three proposed as the minimum necessary (within the community zone, near the community zone threshold, and near the transition zone threshold). For each location, the 85th percentile and mean speeds for low volume (free-flow) traffic conditions are recorded and connected using straight-line interpolation.
Crash Data	The most recent 3 to 5 years of crash data are recorded by location in a manner that allows the engineer to observe clusters and possible relationships. It may be of interest to distinguish the crashes by severity and type. The average observed crash frequencies (i.e., crashes/mi/yr) can be calculated and plotted for the transition and the community zones separately or calculated using a sliding window or peak searching approach (AASHTO, 2010) to divide the study area into smaller segments for analysis. The average observed crash frequencies can be compared to statewide and/or regional threshold values for the transition and community zones. Using crash and traffic volume data, the average observed crash rate (i.e., crashes/vehicle-miles-traveled/yr) can be calculated and plotted for the transition and the community zones separately or calculated using a sliding window or peak searching approach (AASHTO, 2010) to divide the study area into smaller segments for analysis. The average observed crash rates can be compared to statewide and/or regional threshold values for transition and community zones. When analyzing the crash data, consideration needs to be given to whether to include segment-related crashes, intersection-related crashes, or both, and whether to include only speed-related crashes or all crashes.
Average Daily Traffic (ADT)	The ADT for the transition zone and community zone are plotted for reference.
Access Points	Access points are plotted by location showing active driveways and intersections on both sides of the street.
Access Point Density	Using the above access point data, access point density is presented for a sliding window (e.g., 0.15 mi in either direction from the plotted location).
Land Use	Land-use types are plotted by location for the two sides of the street. Typical land uses include rural, residential, retail, industrial, office, mixed-use, and recreational.
Detailed follow-up analyses	
Vertical Profile	The vertical elevations are plotted, resulting in both a profile and a percent grade figure.
Horizontal Profile	The horizontal profile is provided in the aerial photo at the top of the diagram; however, data on the horizontal curves can be plotted on the diagram as well. This would be calculated or estimated based on plans or aerial photos and then entered by location.

project identification phase, it is perfectly acceptable to determine that no concerns exist or at least the concern is not of the magnitude of what was initially thought. On the other hand, results of the project identification phase may provide the necessary information to prompt further detailed investigation and possibly project development and prioritization. In general, it is important that the scope of the transition zone analysis match the extent and nature of the suspected problem given the context of the roadway being analyzed. Thus, care should be taken to make sure that major issues are not overlooked, but also that minor and/or follow-up issues are not given unnecessary time and attention.

At a minimum, the project identification phase should consider speed, crash, access point, and land-use data. The data should be entered into a straight-line diagram as discussed previously or some other similar analysis tool. If the engineer decides not to use the straight-line tool, the data can be noted on a plan view or aerial photo of the roadway. If the straight-line diagram tool is used, only a portion of the tool will be utilized in this phase. Additional data can be entered as needed later as part of the detailed assessment process.

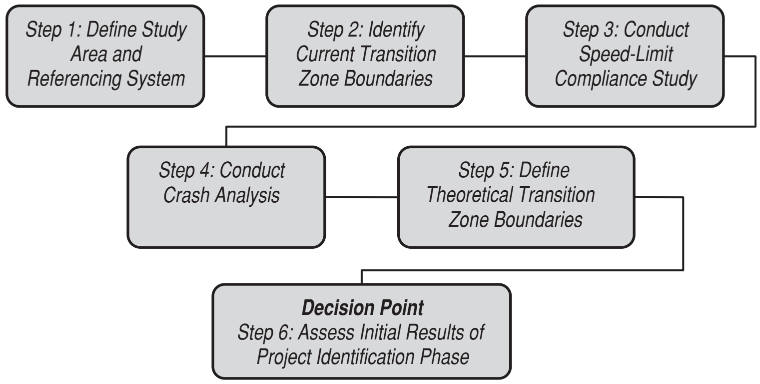


Figure 4-3. Recommended steps of project identification phase.

The recommended steps of the project identification phase are presented in Figure 4-3 and described below.

Step 1: Define Study Area and Referencing System

At the outset of the project identification phase, the engineer should define the geographic extents of the study area and the referencing system to be used to enter data. The study area should extend from within the community to the high-speed rural area clearly beyond the transition zone. This may be a distance of 1,000 to 3,000 ft or more depending on the context. Defining the reference system involves selecting a point within the community zone as a reference point for all measurements. It may be easiest to select a major intersection near the edge of the community as the reference point. That way it is relatively easy to correlate state or county mileposts with the study area reference system. This correlation can facilitate the entry of data recorded using the state or county system (e.g., crash data). In the example straight-line diagram, the state mileposts have been correlated to the study area reference system, which is in both feet and miles from a specific intersection.

Step 2: Identify Current Transition Zone Boundaries

The second step in the process is to identify the current transition zone based on the locations of the speed limit signs and advance warning signs. Assume the current transition zone begins approximately 200 to 400 ft in advance of the first reduced speed limit sign (regulatory sign) or speed reduction treatment and ends approximately 150 to 250 ft after the last (and possibly only) reduced speed limit sign or treatment prior to entering the community. The upstream boundary can be set in part based on when the speed limit sign becomes clearly visible to oncoming drivers. Thus, with good visibility geometry and signage, the values will be higher than for restricted visibility conditions. Using the above values, the minimum current transition zone length is approximately 350 ft, though many will be 500 ft or more. Alternatively, the engineer could assume the start of the transition zone is a few hundred feet in advance of the warning sign for the impending speed reduction (if such a sign is present). This is the point at which a driver becomes aware that a speed change will be required. This would result in a longer current transition zone.

Step 3: Conduct Speed-Limit Compliance Study

Speed data provide an important foundation for assessing speed-limit compliance issues in the current transition zone and/or community zone. By obtaining speed data at key locations, it is possible to create an operating speed profile for the transition zone study area. Time-mean

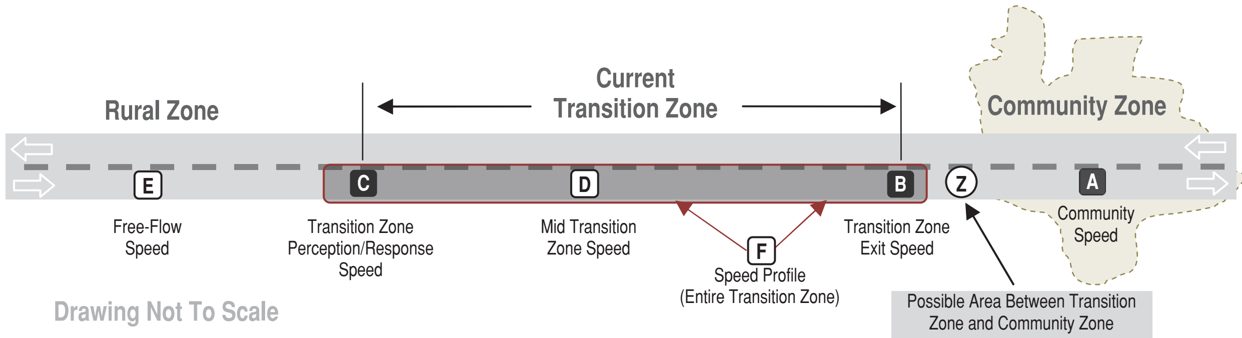


Figure 4-4. Speed data collection locations within the study area.

speeds should be collected during low volume, free-flow conditions. The data should be collected following proper sampling methods and in accordance with agency guidelines and/or the proper procedures (e.g., see Chapter 5 of the Institute of Transportation Engineers (ITE) *Manual of Transportation Engineering Studies* [ITE, 2010]).

Figure 4-4 shows recommended locations within the study area for collecting the initial speed data. Locations A, B, and C are highly recommended for the analysis. Locations B and C allow the engineer to estimate the transition zone entry and exit operating speeds. Location A gives the engineer information on whether speeds generally remain the same, increase, or decrease as vehicles continue through the community. Additional locations (e.g., D and E) may be useful for creating a more detailed operating speed profile through the study area. Optionally, a laser gun can be used to create a complete speed profile for the entire transition zone (F).

For each location, the 85th percentile and mean operating speeds (during free-flow conditions) should be computed. Using linear interpolation, the data can be used to generate an operating speed profile as presented in the straight-line diagram. If available, laser gun data can be used to create an even more accurate speed profile.

To identify potential speed-limit compliance issues, the operating speed profile should be compared to one or more speed profile metrics. This can be done in a manner similar to the method contained in FHWA's *Speed Concepts: Informational Guide* (Donnell et al., 2009), which presents a straight-line analysis analogous to the one proposed in this document. Potential speed metrics include the following:

- Posted speed limits,
- Design speed, and
- Inferred design speed.

The posted limit speed is known and the design speed can be obtained from the agency responsible for the original highway design (see the original design plans and documentation). The inferred design speed can also be determined from the design plans, though it will likely not be clearly identified. The inferred design speed may be beyond the scope of most project identification study phases. At a minimum, the engineer should compare the observed 85th percentile speeds at Locations B and C to the posted speed limits.

In accordance with the 2009 MUTCD guidelines, it is recommended that the 85th percentile speed profile be within 5 mph of the posted speed limits. If the 85th percentile speeds are 5 to 10 mph above the posted speeds, then speed-limit compliance may be an issue worth further investigation. If the 85th percentile speeds are more than 10 mph above the posted speed limit, then further study should be conducted, and it may be necessary to make adjustments and/or improvements to the transition zone to achieve better speed-limit compliance. If the 85th percentile speed at the end of the transition zone (i.e., Location B) is acceptable, but the 85th percentile speed through the community (i.e., Location A) is more than 10 mph over the speed limit, then consideration could be given to implementing speed reduction treatments (e.g., traffic calming measures) in the community zone. Comparisons of the observed speed profile to the other speed profile metrics could provide further insight into speed-limit compliance issues.

In addition to the speed analysis described above, the deviation of speeds from the average can create safety issues. The pace speed can be investigated along with the standard deviation to determine how far from the average speed most vehicles are traveling. This topic is addressed further in the detailed evaluation discussion.

The goal of the speed study is to determine whether drivers are complying with the posted speed limits in the transition and community zones. Higher speeds have been correlated with higher accident severity. Excessive speeds that are inconsistent with the roadway design in the community zone may also be correlated to higher crash frequencies. Thus, an assessment of the speed data can provide insight into potential crash frequency and severity issues within the transition and community zones.

Step 4: Conduct Crash Analysis

The fourth step in the process is to use the straight-line diagram tool (or similar tool) to plot the most recent 3 to 5 years of available crash data for the study area as defined in Step 1 above. Initially, the crash data are analyzed qualitatively. For example, the engineer assesses if there are crashes in the vicinity of the current transition zone or community zone, and if so, it is determined if speed may have been a contributing factor to the crashes. All pedestrian and bicycle crashes as well as any serious injury or fatal crashes should be investigated further to determine if transition zone related issues were involved. Such a qualitative analysis will provide a good indication of whether a more detailed crash analysis is necessary.

Concurrent with the crash analysis, traffic data should be obtained for the transition zone study area. At a minimum, the average daily traffic (ADT) should be obtained and plotted on the straight-line diagram tool for analysis purposes. If additional traffic volume data are available (e.g., hourly volumes, vehicle classifications, or additional count locations), then that should be obtained as well.

Based on the qualitative analysis, if sufficient evidence exists that a more detailed crash analysis is necessary, the crash data should be examined in accordance with the methods prescribed by the *Highway Safety Manual* (HSM) (AASHTO, 2010). At a minimum, the average observed crash frequency and crash rate should be calculated for the area from the start of the current transition zone to the community zone and separately within the community zone. These performance measures could be compared to threshold values from a reference population of similar sites. For example, the observed crash frequencies and rates for the transition and community zones could be compared to the average observed crash frequencies and rates for similar sites. If the observed crash frequencies and rates for the transition zone and/or community zone within the study area are greater than the threshold values, this is a good indication that safety concerns exist and transition zone and/or other design treatments should be considered for implementation to improve safety. As more data are available for the crash analysis (e.g., safety performance functions), more reliable performance measures should be used in the crash analysis (e.g., expected average crash frequency with empirical Bayes [EB] adjustments and excess expected average crash frequency with EB adjustments). Consideration could also be given to examining speed-related crashes separately as they are of most interest in the analysis. Intersection and non-intersection crashes could also be separated since they are affected by different factors; however, such subdivisions of the data reduce the number of data points for the analysis.

Depending upon the lengths of the transition and community zones, sliding window and peak searching methods can be used to identify the location(s) within the transition zone and/or community zone which could most likely benefit from implementation of a safety treatment (AASHTO, 2010).

High crash locations, pedestrian/bicycle crashes, and any fatal and serious injury crashes should be examined in more detail. This could include a detailed review of crash locations, types, severity, contributing factors, time of day, speeds, vehicle types, and other information. This information may be shown in figures and tables as necessary. Depending on the extent of the issues, it may be necessary to develop a collision diagram for the study area, showing all crashes with key information (e.g., see ITE, 2010 and AASHTO, 2010).

The results of the crash analysis should be correlated with the speed study for the transition zone to identify any potential problems as well as possible improvements. Some of the identified issues may not relate directly to the transition zone issues; however, some could be directly related. For example, research indicates that reducing speed reduces crash severity; however, it is not clear that reducing speeds reduces crash frequency. Research has also shown that there is a likely relationship between deviation from the mean travel speed and crash frequency (Donnell et al., 2009; Ray et al., 2008).

Step 5: Define the Theoretical Transition Zone Boundaries

Steps 3 and 4 are intended to assess how the current transition zone is operating with regard to speed and safety. In Step 5, the engineer compares the physical location of the current transition zone with the theoretical transition zone. The location of the current transition zone was approximated in Step 2, based on speed limit sign locations. The theoretical transition zone location is based on the community and roadway characteristics, combined with vehicle deceleration distances appropriate for the speed change. The theoretical transition zone could be different from the current transition zone.

The next step is to set the theoretical community threshold. There are several factors to consider in setting this threshold, such as access point density, current and future land use, future road improvements, future utility requirements, location of a major intersection, sight distance, safety, and the presence of other roadway or roadside features. With regard to the first two factors, the community threshold should be near or upstream from where the land use changes from low-density rural to more intense land uses and/or to where the number of access points increases. According to the HCM (TRB, 2010), access point densities of 16 per mile (both sides) are associated with rural two-lane highways, while densities of 32 per mile (both sides) are associated with two-lane highways traveling through rural communities. These values can be used as guidance in determining where to place the community threshold. Often, the transition in access point density is quite noticeable. It is important also to consider future land use changes. If development at the edge of the community is likely in the near term, then the community threshold may need to be located beyond that development area.

Other factors to consider when determining the location of the community threshold include the presence of a major intersection that requires slower approach speeds. In this case, *NCHRP Report 613* (Ray et al., 2008) may need to be consulted. Sight distance limitations may also necessitate moving the theoretical community threshold away from the community. Roadway and roadside design features such as the presence of sidewalks or a speed reduction treatment may also affect the placement of the threshold. For safety reasons it may also be beneficial to include a setback between the edge of the community as defined by access and land use and the transition community threshold. AASHTO-recommended stopping sight distances can be consulted to select values for this setback. The setback provides a buffer between the first few driveways or streets within the community and the end of the transition zone. In general, however, the com-

Community Zone Target Speed (mph)

Rural Zone Speed (mph)		20	25	30	35	40	45
45	P / D	170 / 385	170 / 345	170 / 305	170 / 255	- / -	- / -
	Total	**555**	**515**	**475**	**425**	**-**	**-**
50	P / D	190 / 450	190 / 415	190 / 380	190 / 330	190 / 270	- / -
	Total	**640**	**605**	**570**	**520**	**460**	**-**
55	P / D	210 / 510	210 / 480	210 / 440	210 / 400	210 / 340	210 / 265
	Total	**720**	**690**	**650**	**610**	**550**	**475**
60	P / D	230 / 595	230 / 565	230 / 520	230 / 485	230 / 425	230 / 365
	Total	**825**	**795**	**750**	**715**	**655**	**595**
65	P / D	240 / 680	240 / 655	240 / 600	240 / 570	240 / 510	240 / 465
	Total	**920**	**895**	**840**	**810**	**750**	**705**

P	D
Total	

P = Perception-reaction distance (ft)
D = Deceleration distance (ft)
Total is the Transition Zone Length (feet)

Notes:

Perception-reaction time is assumed to be 2.5 seconds, traveling at the rural zone speed.

Deceleration distances are based on AASHTO, 2011 pg. 10-115, Table 10-5.

Interpolation and extrapolation were used to obtain values not available directly from AASHTO.

The AASHTO values are average running speeds; however posted speeds are conservatively proposed for use in the transition zone straight-line diagram and analysis.

All distances have been rounded up to the nearest 10 ft.

Figure 4-5. Recommended minimum lengths of transition zones.

munity threshold should be located such that drivers can clearly discern that the nature of the roadway changes beyond that point.

Based on the 85th percentile speeds in the rural zone and the target speed in the community zone, the recommended minimum length of the transition zone can be approximated using Figure 4-5, thereby setting the upstream transition threshold. The deceleration and perception-reaction area lengths are also noted in Figure 4-5. The deceleration distance is based on a comfortable deceleration rate, while the perception-reaction time is set at 2.5 seconds.

While Figure 4-5 is useful for defining the minimum length of the transition zone, in many situations it will need to be longer due to various engineering and/or community factors such as sight distance limitations and grades. Human factors issues such as speed adaptation may also lead the engineer to lengthen the transition zone if there is a long stretch of high-speed roadway leading up to the community. While there may be an inclination to want to move the transition zone far from the community or to make it longer than warranted, this must be weighed against the fact that drivers will typically travel at a speed that is appropriate for the roadway design. Therefore, if the transition zone is too far from where the roadway changes to the community zone, then drivers may not travel at the desired speed.

At this point it is useful for the engineer to compare the location of the current transition zone with that of the theoretical transition zone. If there are problems with speed-limit compliance in the current transition zone, it may be beneficial to consider moving the transition zone closer to the theoretical location. This shift could be combined with the implementation of a transition zone treatment or treatments.

Step 6: Assess Initial Results of Project Identification Phase

The results of the speed study and crash analysis taken together will yield a first indication of whether improvements and/or further investigation are needed for the transition and community zones. If both studies do not raise questions or concerns, then the two zones may be functioning adequately. If the results indicate the need for improvements or further investigation, then additional data can be incorporated into the analysis to support the selection of one or more potential transition zone treatments (see Section 4.3.3, Detailed Assessment). It is also informative to consider the results of Step 5, comparing the current and theoretical transition zone. This information will be useful in assessing concerns, developing improvement plans, and evaluating the transition zone after treatments have been implemented.

4.3.3 Detailed Assessment Phase

As necessary, additional information can be collected and analyzed in the detailed assessment phase to facilitate a clear definition of concerns associated with the transition zone and to support the selection of an appropriate improvement treatment to address the issue(s). The detailed analysis may include as many of the considerations discussed below as are deemed necessary for the specific location. Some of this information can be added to the straight-line diagram discussed previously. These detailed studies would provide additional quantitative design and operational information to support a more informed decision.

4.3.3.1 Design Study

Now that a number of roadway and roadside design elements were considered in a general manner in the project identification phase, they may need to be examined more closely. Key issues to consider in this more detailed evaluation include the following:

- Roadway Geometry: vertical and horizontal alignments;
- Signs, striping, and traffic control;
- Roadway and intersection geometry;
- Roadway design elements (cross-section elements and widths, etc.);
- Roadside design elements (sidewalks, landscape, streetscape, etc.);
- Roadway type and function (functional class);
- Parking; and
- Current transition zone treatments.

This additional information can be added to the straight-line diagram and/or collected in tables, text, and figures. The design elements should be evaluated to determine their adequacy with respect to current design standards, taking into account the context of the roadway and community. This information could be useful later for setting design criteria to support the future selection and design of a transition zone treatment.

4.3.3.2 Sight Distance Analysis

If it has not already been conducted, a detailed sight distance study could be conducted to determine if the available sight distance throughout the study area is in accordance with *Green Book* (AASHTO, 2011) requirements. Any sight distance issues related to the roadway and/or roadside design should be noted. This includes any issues related to sign visibility. The locations at which warning signs, speed limit signs, and any speed reduction treatments become visible should be noted. If minimum sight distance requirements are not provided throughout the study area, then the transition zone may need to be extended (including one or both of the perception-reaction and deceleration areas). The sight distance assessment may also highlight the need for additional (or relocated) warning signs in the transition zone area and/or the need for more extensive improvements within the study area so that minimum AASHTO sight distance requirements are met.

4.3.3.3 Detailed Speed and Crash Studies

During the problem identification phase, both speed and crash data were examined. During the detailed assessment phase, it may be desirable to investigate these topics in more depth. This could include additional data collection or simply more extensive analysis of the data already collected but using different analysis tools and methods.

Detailed speed studies could involve collecting speed data at new locations along the approach to the community or within the community. It could also involve collecting data on different days or at different times. Other speed comparison metrics can also be employed, such as a comparison of the pace speed to the posted or design speeds. The pace speed is the 10-mph speed range that includes the most speed observations. The standard deviation for the observed speeds can also be calculated to determine the divergence from the mean speed, which can be a factor that affects crash frequency. These and other measures (such as quartiles) can help identify the spread of the speed data relative to the mean, posted, or design speeds. The inferred design speed can also be determined and included in the analysis during this phase. These more detailed analyses would be intended to provide support for, or rule out, selecting a treatment.

Detailed crash analyses in accordance with the HSM would also be appropriate during this phase. This could include gathering the necessary information and developing the required safety performance functions to evaluate the expected average crash frequency with empirical EB adjustments and the excess expected average crash frequency with EB adjustments. If possible, these equations could be developed separately for the transition and community zones. These more detailed crash analyses will provide more confidence that there are (or are not) crash issues in the study area. The detailed assessment phase is also an appropriate time to examine selected crashes or groups of crashes (e.g., by direction, involving speed, multi-vehicle, etc.). The preparation of collision diagrams for the study area may also be warranted during this phase.

4.3.3.4 Other Studies

Other possible supporting studies could address access management, non-motorized transportation, and transit facilities, parking, and land use. Some of these topics fall under the roadway and roadside design category; however, they could require more detailed studies depending on the nature of the community. Access management and bicycle/pedestrian facilities and flows are particularly likely for focused reviews. There are a number of good resources for these types of studies, such as the TRB *Access Management Manual* (TRB, 2003), *Traffic Engineering Handbook* (ITE, 2009), *Transportation Planning Handbook* (ITE, 2009), and *Manual of Transportation Engineering Studies* (ITE, 2010).

4.3.4 User Groups and Stakeholder Input

There are many interest groups and individuals that can provide valuable input into the need for transition zone improvements and the potential issues that should be addressed. Each stakeholder group/individual brings a unique perspective to identifying the need for a project and the types of issues that should be addressed. One example is bicycle/pedestrian groups, whose multimodal perspectives on sidewalks and adequate shoulder width to accommodate bicycles are important considerations. Another example is local law enforcement; which, as the group responsible for enforcing speed limits, would also bring a unique perspective to transition zone issues and improvements. Incorporating early, ongoing, and meaningful participation by the community and relevant agencies is critical for successful projects, and for ensuring that important issues are not overlooked. According to recent research, public and stakeholder input is a major reason for considering and implementing transition zone improvements. In fact, at the county level, it was the most frequent reason for pursuing improvements (Forbes, 2011).

Table 4-3. Potential transition zone stakeholders.

Local residents	Local business owners	Community groups
Local motorists	Neighborhood associations	Police department
Through motorists	Commercial vehicle drivers	Fire department
Visitors/tourists	Agricultural vehicle drivers	EMS/other emergency responders
Bicyclists	Bus drivers and riders	State/local transportation agencies
Pedestrians	School districts	Elected officials
People with disabilities	Public transit agencies	Environmental agencies
Seniors/youths	Unique populations (e.g., Amish)	Other state/local public agencies

Given the importance of stakeholder input, it is useful to make a list of stakeholders at the very beginning of the study process. The stakeholders (including highway users) will vary for each project, but could include some or all of those listed in Table 4-3, as well as others that are not listed. Some of these groups are highway users, while others have responsibilities that relate directly or indirectly to the transition zone study area. Table 4-3 is not a comprehensive list for all situations, but it can provide a starting point.

It is suggested that information be obtained from as many of the identified groups as possible, beginning in the project identification phase. This can be done in various ways from public meetings and workshops to newsletters, surveys, and focus groups. Informal discussions can also be used to gather information and input. During the detailed assessment and treatment selection phases, follow-up information may be requested. For example, in a tourist area, there may be a local organization or state agency that can provide data on seasonal visitation that could be helpful and may influence planning with respect to signage and driver expectancy issues. Emergency response agencies and commercial trucking firms may also have comments on the treatment design. By engaging with stakeholders throughout the process, and keeping them informed, it is more likely that the project will meet key stakeholder needs and that the stakeholders will support the proposed improvement(s).

4.3.5 Lessons Learned

At the end of the transition zone assessment process when agencies are transitioning from the planning to the design stage, the following lessons learned during the course of implementation of previous transition zone projects may be helpful for agencies to consider (FHWA, 2009A):

- Design vehicles should be considered when selecting the type of transition zone treatment to implement.
- Routine maintenance of a treatment should be considered when selecting the type of transition zone treatment to implement.
- Community buy-in is important, not only from the community leaders but from the general population as well.
- Smaller communities may not be familiar with the various types of transition zone treatments and may need some educating.

4.4 Transition Zone Treatments

A transition zone should be designed in a holistic manner. Characteristics of the transition zone and community should collectively be considered. Proceeding from the transition threshold to the community threshold, treatments should be selected based upon the appropriateness of treatments depending upon the type of facility and its function to achieve a cumulative effect. In the perception-reaction area, advance warning and psychological treatments should be selected to alert drivers of changes ahead, and in the deceleration area, physical treatments to the roadway and roadside should be used to induce the intended driver response.

This section provides several guiding principles to be followed in designing effective transition zones. These principles are generally consistent with most existing transition zone design guidelines from the literature. This section also provides a catalog of treatments that could be used either individually, or in combination, in the design of a transition zone. The treatments included in this section are considered the most appropriate for use in a transition zone and are considered the most likely to induce the intended response by the driver. Finally, this section describes two transition zone design concepts that, in general, reinforce the importance of treatment combinations and concludes with a brief discussion of treatments within the community zone.

4.4.1 Guiding Principles for Transition Zone Design

Several principles should guide the design of a transition zone as follows (Forbes, 2011; ECMT, 2006; National Roads Authority [NRA], 2005; LTSA, 2002; ETSC, 1995):

- More extensive and aggressive treatments tend to produce greater reductions in speed and crash occurrence than less extensive and passive treatments.
- There needs to be a distinct relationship between the community speed limit and a change in the roadway character. Emphasizing a change in environment increases awareness.
- Physical changes to the roadway and roadside are favored treatments because they have permanent and lasting effects. The impacts of enforcement and education programs are more transient and less effective.
- Each transition zone and community has its own unique characteristics. As such, no particular treatment is appropriate for all situations. Each transition zone and community must be assessed on a case by case basis before selecting a treatment or combinations of treatments for a given context.
- Before selecting a treatment, consideration should be given to the two areas that make up the transition zone. In the perception-reaction area, warning and/or psychological treatments are appropriate, while in the deceleration area physical treatments should be installed.
- Combinations of treatments are more effective at reducing speeds and improving safety within a transition zone and through a community than a single treatment.
- To maintain a reduction in speed downstream of the transition zone, it is necessary to provide additional treatments within the community; otherwise, speeds may increase downstream of the community threshold.
- Appropriate use of landscaping elements such as grass, shrubs, and trees which change in composition and degree of formality along the length of the transition zone can reinforce the changing characteristics of the environments.
- Consideration should be given to prohibiting passing within the transition zone.

4.4.2 Catalog of Transition Zone Treatments

This section provides a catalog of treatments that may be implemented within a transition zone to reduce speeds and improve safety within the transition zone and through the community. This catalog builds upon the toolbox of treatments specified by Forbes (2011) in Chapter 4 of *NCHRP Synthesis 412,* which includes information on all of the treatments reviewed as part the synthesis project. The catalog of treatments included here is a shorter list of treatments that appear to be the most practical and/or effective for use within a high- to low-speed transition zone. This catalog of treatments should not be interpreted as the only types of treatments to be implemented within a transition zone; rather, it is a starting point for practitioners to begin and as more knowledge is gained this list can be modified as appropriate. This list is not meant to discourage creative approaches to transition zone design, but to provide information for engineers to develop informed decisions.

Although this catalog lists treatments individually, one of the guiding principles for transition zone design is that combinations of treatments are more effective at reducing speeds and improving safety than a single treatment implemented by itself. Section 4.4.3 (Design Concepts) reinforces the need to use treatments in combination.

The treatments are categorized into four groups, as follows: geometric design, traffic control devices, roadside features, and surface treatments, and are presented in Figures 4-6 through 4-15. Information provided with each individual treatment is as follows:

- A description and illustration of the treatment.
- An estimate of the effectiveness of the treatment, if known, in terms of reducing speeds or improving safety. The general reliability of the estimate(s) is also provided based on a star rating system, with one star (★) representing "least reliable" to four stars (★★★★) representing "most reliable." The star rating is based on a qualitative assessment of the robustness of the data supporting the estimate of effectiveness, the appropriateness of the analysis method, applicability to U.S. conditions, whether the results are based upon field data or simulation, and applicability to transition zones in rural areas.
- The relative cost of implementing the treatment.
- Possible contraindications associated with installation of the treatment.
- Recommended location for implementation.

Treatment: Center island/raised median

Category: Geometric Design

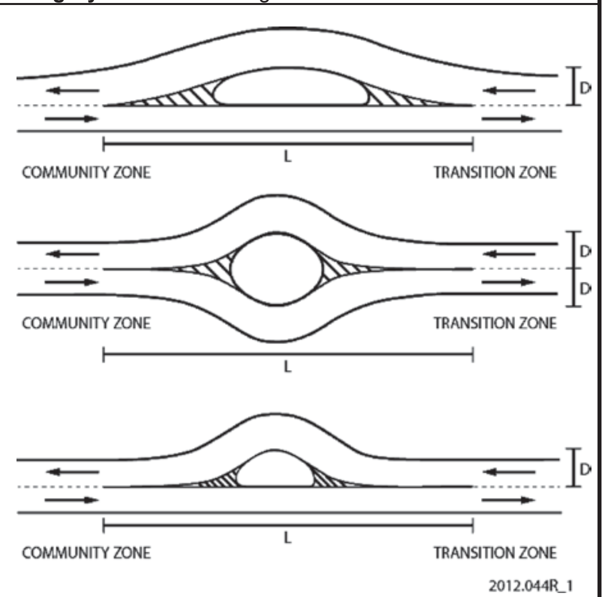
Description: A channelizing island that creates separation between the two opposing directions of travel. Center islands/raised medians can create shifts or deflections in the travel paths of vehicles and often reduce the effective widths of the roadways. Center islands/raised medians can be created through a combination of pavement markings, raised curbs, planting strips, etc.

Effectiveness: Berger and Linauer (1998) developed speed prediction models for center islands. The models can be used to calculate the mean and 85th percentile speeds as vehicles travel past the island. ★★

V_{85} = 9.194 Ln(L/2d) + 12.290
V_m = 8.020 Ln(L/2d) + 11.031

where: V_{85} = 85th percentile speed (mph)
V_m = mean speed (mph)
L = length of island + length of both tapers (ft)
d = lateral deflection of lane (ft)

In general, installation of a center island or raised median could be expected to reduce mean speeds by 3 to 10 mph and 85th percentile speeds by 5 to 10 mph (Dixon et al., 2008). ★



Source: Adapted from Berger and Linauer (1998)

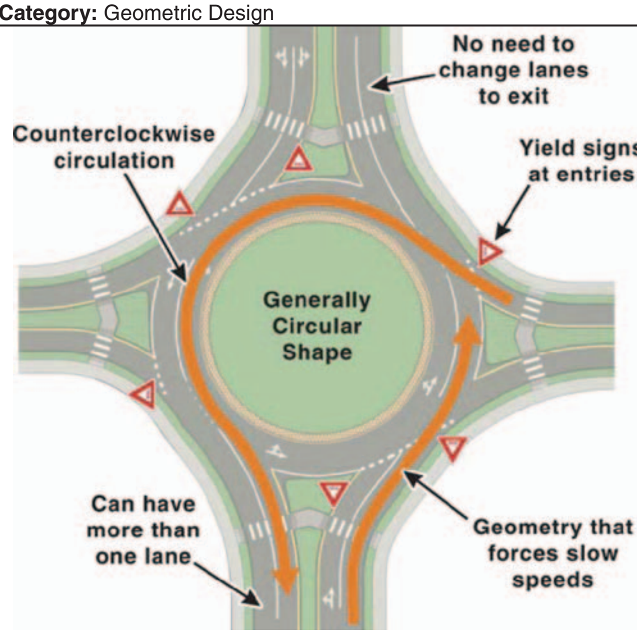
Cost	Contraindications	Installation Location
Cost: Moderate to high for raised center islands. Low for painted islands. The need to acquire right of way will increase the cost.	**Contraindications:** A raised center island may increase the potential for single-vehicle crashes.	**Installation Location:** Downstream end of deceleration area within the transition zone and/or in conjunction with a gateway treatment.

Figure 4-6. Center island/raised median (adapted from Forbes, 2011).

Treatment: Roundabout

Category: Geometric Design

Description: A roundabout is a form of circular intersection in which traffic travels counterclockwise (in the United States and other right-hand traffic countries) around a central island. Entering traffic must yield to circulating traffic. The channelized approaches and geometry induce reduced travel speeds through the circular roadway.



Source: Rodegerdts et al., 2010

Effectiveness: Rodegerdts et al. (2007, 2010) developed prediction models for estimating entry and exit speeds for roundabouts: ★★★

$$V_{exit} = MIN\left(aR_3^b;\ \frac{1}{1.47}\sqrt{\left(1.47aR_2^b\right)^2 + 13.8d_3}\right) \qquad V_{enter} = MIN\left(aR_1^b;\ \frac{1}{1.47}\sqrt{\left(1.47aR_2^b\right)^2 + 8.4d_1}\right)$$

where:
- V_{exit} = predicted exit speed (mph)
- V_{enter} = predicted entry speed (mph)
- d_1 = distance between point of interest on the entry and midpoint of path on circulating roadway (ft)
- d_2 = distance between point of interest on the entry and the midpoint of path on the circulating roadway (ft)
- d_3 = distance between the midpoint of path on the circulating roadway and point of interest on the exit (ft)
- R_1 = path radius on entry to roundabout (ft)
- R_2 = path radius on circulating roadway (ft)
- R_3 = path radius on exit from roundabout (ft)
- a,b = regression parameters

Speed Prediction Parameters

	Superelevation +0.02	Superelevation –0.02
a	3.4415	3.4614
b	0.3861	0.3673

Roundabouts increase the rate of compliance of vehicles traveling at or below the speed limit at the end of a transition zone by 15% compared to no treatment and increase the rate of compliance of vehicles traveling at or below the speed limit + 5 mph at the end of a transition zone by 11% compared to no treatment. ★★★

Converting a two-way stop-controlled intersection to a roundabout reduces total crashes by 71% and fatal and all injury crashes by 87% (AASHTO, 2010). ★★★

Converting a signalized intersection to a roundabout reduces total crashes by 48% and fatal and all injury crashes by 78% (AASHTO, 2010). ★★★

Cost: High.

Contraindications: A roundabout can be challenging for visually impaired pedestrians to navigate.

Installation Location: Downstream end of deceleration area within the transition zone.

Figure 4-7. Roundabout (adapted from Forbes, 2011).

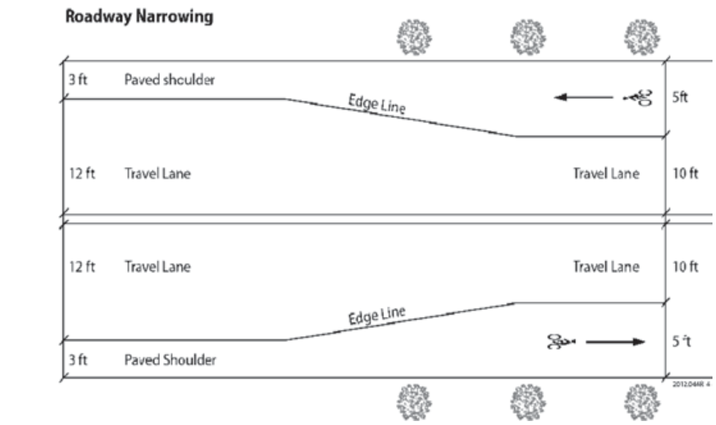
Treatment: Roadway narrowing	**Category:** Geometric Design	
Description: Roadway narrowing can be achieved either by physically reducing the roadway width or by narrowing the widths of the travel lanes. This technique is often installed in conjunction with adding bicycle lanes or adding a raised median.		
Effectiveness: Roadway narrowing strategies can be expected to reduce mean speeds by about 2 to 3 mph (Ewing, 2001). ★★		
Cost: Low to moderate costs depending upon whether the treatment is implemented by modifying pavement markings or physical changes to the roadway.	**Contraindications:** Narrower lanes could negatively impact large trucks, agricultural vehicles, and emergency response vehicles.	**Installation Location:** Narrower lanes could potentially be implemented throughout the full length of a transition zone, but more than likely would be implemented within the deceleration area.

Figure 4-8. Roadway narrowing (adapted from Forbes, 2011).

Several points to note concerning the treatments included in the catalog and the information presented with each treatment are as follows:

- Only the most reliable information on the effectiveness of a treatment in reducing speeds and improving safety is presented.
- A decision was made not to include treatments such as speed humps, raised intersections, and raised crosswalks. Such treatments that create vertical deflections are considered inappropriate for high- to low-speed transition zones.
- Guidance on the use of reduced speed ahead signs and stepped-down speed limits is not provided. The MUTCD should be referred to for general guidance on these topics.

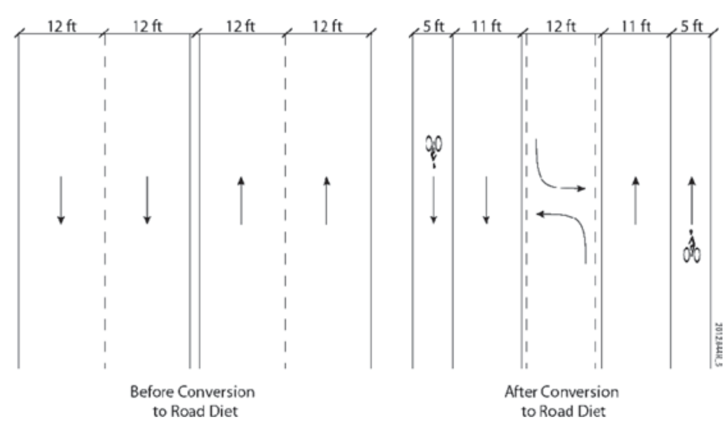
Treatment: Road diet	**Category:** Geometric Design	
Description: A reduction in the number of through lanes (e.g., converting a four-lane road to a three-lane roadway with a two-way left-turn lane or converting a four-lane roadway to a two-lane roadway with a raised median or on-street parking.) Bicycle lanes are often installed in conjunction with road diets.	 Sample Road Diet	
Effectiveness: A road diet could be expected to reduce operating speeds by up to 5 mph with up to a 70% reduction in excessive speeding (Knapp and Rosales, 2007). ★★		
Cost: Medium to High.	**Contraindications:** A road diet may reduce the capacity of a facility depending upon the number and types of turns, the presence of heavy vehicles, and the number and frequency of transit stops.	**Installation Location:** A road diet could be implemented at the beginning of the transition zone and extend into and/or through the community. It is also possible that a road diet may begin downstream of a gateway, within the community.

Figure 4-9. Road diet (adapted from Forbes, 2011).

<table>
<tr><td colspan="2">Treatment: Transverse pavement markings</td><td>Category: Traffic control devices</td></tr>
<tr><td colspan="2">Description: Pavement markings placed perpendicular to the direction of travel to draw attention to a change in the roadway environment. The markings are placed in a pattern of progressively reduced spacing to give drivers the impression that their speed is increasing.
Section 3B.22 of the MUTCD provides guidance for the application of speed reduction markings. In several cases, agencies have installed the pavement markings across a good portion of the travel lane, and in some cases have used a chevron pattern.</td><td></td></tr>
<tr><td colspan="3">Effectiveness: Transverse pavement markings increase the rate of compliance of vehicles traveling at or below the speed limit at the end of a transition zone by 20% compared to no treatment. ★★★</td></tr>
<tr><td>Cost: Low.</td><td>Contraindications: Depending upon where the pavement markings are placed relative to the wheel paths of vehicles, maintenance costs may increase.</td><td>Installation Location: Transverse pavement markings could potentially be implemented anywhere within the transition zone, but more than likely should be implemented within the perception-reaction area.</td></tr>
</table>

Figure 4-10. Transverse pavement markings (adapted from Forbes, 2011).

- The information presented in this catalog was developed to be as consistent as possible with information in Chapter 4 of *NCHRP Synthesis 412* (Forbes, 2011).

4.4.3 Design Concepts

Based upon international experience and policies, two design concepts merit consideration when designing a transition zone. The first design concept is that of a gateway that marks the end of the transition zone and the beginning of the community zone. The second design concept,

<table>
<tr><td colspan="2">Treatment: Speed-activated feedback sign</td><td>Category: Traffic control devices</td></tr>
<tr><td colspan="2">Description: A variety of electronic signs that measure the speed of an approaching vehicle and alert the driver, as necessary, that he/she is traveling above the posted speed limit for that portion of roadway. Some speed-activated feedback signs display the actual travel speeds to motorists. Other signs simply display a message such as “Slow Down.” MUTCD Section 2B.13 provides guidance on the application of speed-activated feedback signs.</td><td></td></tr>
<tr><td colspan="3">Effectiveness:
Speed-activated feedback signs can be expected to reduce mean speeds by 4 to 6 mph (Donnell and Cruzado, 2008; Farmer et al., 1998; Winnett and Wheeler, 2002). ★★

Speed-activated feedback signs can also be expected to reduce fatal and all injury crashes by about 34% (Winnett and Wheeler, 2002). ★★★</td></tr>
<tr><td>Cost: Low. Cost of installation would increase if a source of electricity is not readily available.</td><td>Contraindications: Signs that display actual speeds may encourage higher speeds. Also, implementation may increase the potential for single-vehicle, fixed-object crashes.</td><td>Installation Location: Speed-activated feedback signs could potentially be implemented anywhere within the transition zone, but more than likely should be implemented within the deceleration area or near the community threshold.</td></tr>
</table>

Figure 4-11. Speed-activated feedback sign (adapted from Forbes, 2011).

Treatment: Rumble strips

Category: Surface treatment

Description: Rumble strips are placed in the travel lanes perpendicular to the direction of travel to alert drivers of a change in the environment. Milled rumble strips are currently the prevalent type among transportation agencies. Milled rumble strips are made by a milling machine, which cuts grooves in the pavement surface. Other types of rumble strips include rolled, formed, and raised. They differ primarily by the installation method, their shapes, and sizes. A similar type of experimental pavement surface treatment is known as the rumblewave surface. This is an undulating road surface that resembles a series of closely spaced speed humps using a sinusoidal profile. The amplitude of the waves are about 1/4 of an inch, and the wavelength is about 1.1 ft.

Source: Corkle et al., 2001A

Effectiveness:

The estimated effects of rumble strips on speeds are unknown (Ray et al., 2008). ★★

Rumblewave surfaces can be expected to reduce both mean and 85th percentile speeds by about 1 to 6% (Department for Transport, 2005). ★★

Rumblewave surfaces can also be expected to reduce fatal and injury crashes by about 55% (Department for Transport, 2005). ★★

Cost	Contraindications	Installation Location
Cost: Low. Rumblewave surfaces are more costly (moderate to high).	**Contraindications:** Rumble strips (or rumblewave surfaces) may cause maintenance concerns, particularly in climates with snow and ice. Rumble strips may also generate excessive noise for nearby residents.	**Installation Location:** Rumble strips (or rumblewave surfaces) can be implemented within the perception-reaction area or near the start of the deceleration area.

Figure 4-12. Rumble strips (adapted from Forbes, 2011).

Treatment: Colored pavement

Category: Surface treatment

Description: The use of colored pavement to delineate the functional space of the roadway and to alert drivers of a change in the environment.

Effectiveness: Colored pavement can be expected to reduce the mean and 85th percentile speeds by 17% (Russell and Godavarthy, 2010). ★

Source: Russell and Godavarthy (2010)

Cost	Contraindications	Installation Location
Cost: Moderate.	**Contraindications:** The friction properties of the pavement surface could potentially be compromised.	**Installation Location:** Colored pavement can be implemented anywhere in the transition zone, but may be best suited to the perception-reaction area and/or in conjunction with a gateway treatment.

Figure 4-13. Colored pavement.

Treatment: Welcome sign	**Category:** Roadside treatment	
Description: A physical landmark or freestanding structure on the roadside that indicates a change in environment. This landmark/structure can be a simple sign with the name of the community or an archway that bridges the roadway.		
Effectiveness: Welcome signs consisting of freestanding structures and roadside signs are not detrimental to safety (Veneziano et al., 2009). ★★		
Cost: Low.	**Contraindications:** Implementation may increase the potential for single-vehicle, fixed-object crashes.	**Installation Location:** A welcome sign should be implemented within the deceleration area of the transition zone at or near the community threshold and/or in conjunction with a gateway treatment.

Figure 4-14. Welcome sign.

optical width, has to do with the relationship between the horizontal and vertical elements of the roadway and the roadside. Although discussed separately, these two design concepts can be viewed as complementary to the other.

4.4.3.1 Gateway

A gateway consists of one or more physical treatment(s) within the roadway and/or along the roadside intended to force drivers to comply with the desired speed (i.e., the posted speed

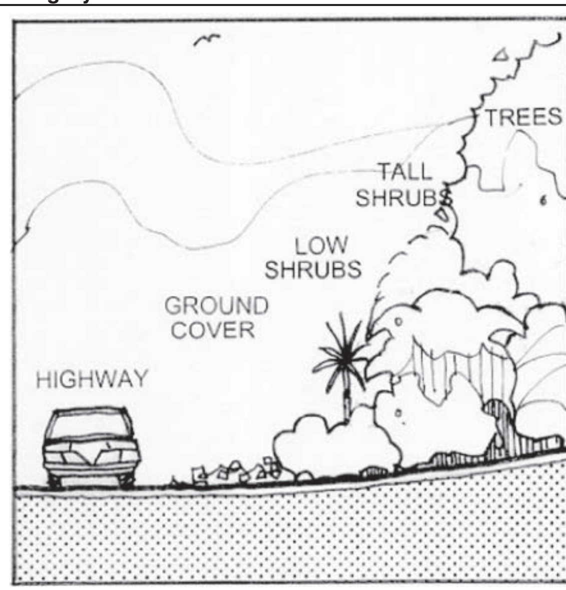
Treatment: Layered landscaping	**Category:** Roadside treatment	
Description: Roadside landscaping is provided to enhance the aesthetics of the roadside environment and to increase driver awareness of the environment. Plants are grouped according to height, with smaller plants (i.e., ground cover) placed closer to the roadway and taller plants (i.e., trees) placed further from the roadway.	 **Source: Transit New Zealand (2006)**	
Effectiveness: The estimated effects of layered landscaping on speeds are unknown (Dixon et al., 2008). ★★		
Cost: Low to moderate.	**Contraindications:** Larger features of the landscaping become fixed obstacles along the roadside and may increase the potential for single-vehicle, fixed-object crashes.	**Installation Location:** Layered landscaping would be implemented throughout the full length of a transition zone.

Figure 4-15. Layered landscaping.

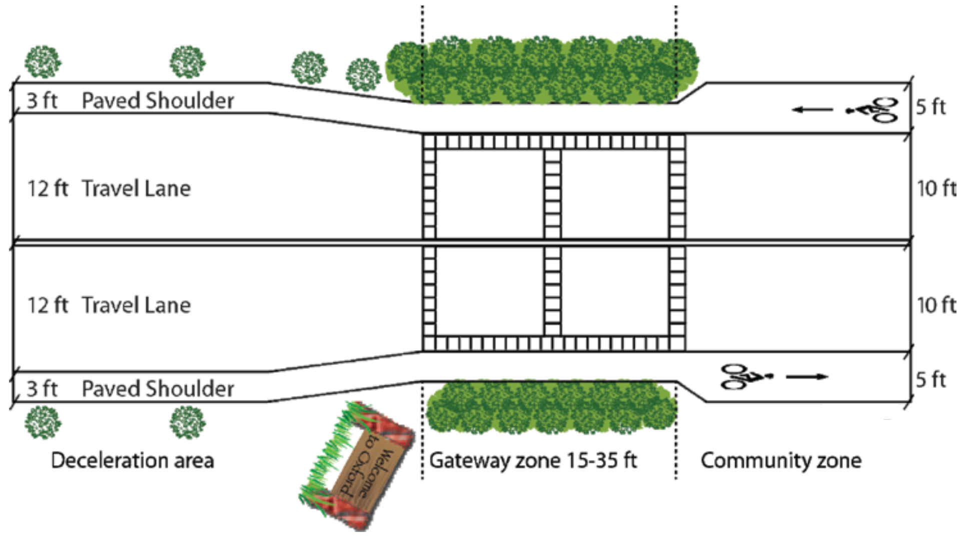


Figure 4-16. Rendering of a gateway.

limit) through the community (Forbes, 2011; ECMT, 2006; NRA, 2005; LTSA, 2002; ETSC, 1995; ODOT, 1999). For example, a raised center island could be installed within the roadway in combination with narrowing of the travel lanes, and on the roadside a sign could be placed welcoming drivers entering the community. As such, a gateway usually consists of a combination of transition zone treatments. Whether it is through the horizontal deflection of vehicle trajectory or directing a vehicle through a narrower cross section, the treatments introduced at the gateway are meant to cause drivers to decelerate prior to entering the community. Figure 4-16 illustrates what a gateway into the community could look like.

A gateway is to be located at the downstream end of the transition zone (i.e., at the community threshold). The features of the roadway environment are distinctly different upstream and downstream of the gateway. On the upstream end, the roadway environment has the characteristics of a high-speed roadway, and on the downstream end the roadway has the characteristics of a low-speed roadway. One example of how the roadway environment could change distinctly from one side of the gateway to the other is the phasing out of the paved shoulder and introducing curbs within the community zone. Another example is by introducing sidewalks or bicycle lanes on the downstream side of the gateway entering into the community, signaling the potential for increased pedestrian and bicycle activity. A distinct change in the roadway environment increases the awareness of drivers of the need to reduce their speeds through the community.

Several guidelines to consider in the design of a gateway are as follows (Forbes, 2011; ECMT, 2006; NRA, 2005; LTSA, 2002; ETSC, 1995; ODOT, 1999):

- The gateway should be visually linked to the entry into the community.
- The gateway should be conspicuous and the most prominent element in the transition zone.
- The gateway should be visible over the stopping sight distance for the 85th percentile approach speed.
- The gateway should not interfere with sightlines at intersections, driveways, and the like.
- The gateway should be located taking into consideration the likelihood of future development.
- Landscaping is an important element to promote the character of the area and to reinforce the vertical character of the roadside.
- Surface treatments and roadway narrowings at the gateway should extend between 15 to 35 ft in length.

- Design of the gateway must consider potential impacts to trucks, agricultural vehicles, emergency response vehicles, and so forth.
- Roadside features should be set back sufficiently to avoid vehicles coming into contact with these elements and the potential negative consequences that could be caused by such features.
- Where provided, consider extending roadway lighting upstream of the gateway.
- Consider coloring or texturing the roadway surface for the length of the gateway.
- Place a reduced speed limit sign at the gateway location.
- Introduce bicycle and pedestrian facilities downstream of the gateway.

Types of treatments that might be incorporated within a gateway, or the entry/exit of a gateway, include the following:

- Central island/raised median,
- Roadway narrowing,
- Speed-activated feedback signs,
- Colored pavement,
- Welcome signs, and
- Landscaping.

4.4.3.2 Optical Width

The optical width concept is an approach that several countries have incorporated into their design guidelines for transition zones (NRA, 2005; LTSA, 2002). The concept is based upon the principle that altering the physical relationship between the width of the road and the height of nearby vertical elements influences a driver's perception of the appropriate speed (Figure 4-17). Where the optical width of the road is greater than the height of nearby vertical elements, speeds are higher. Where the optical width of the road is less than the height of nearby vertical elements, speeds are lower. Thus speeds can be lowered throughout the length of the transition zone by progressively reducing the horizontal elements (e.g., lane narrowings), increasing the vertical dimensions (e.g., planting appropriate sized trees closer to the pavement edge), or some combination of both.

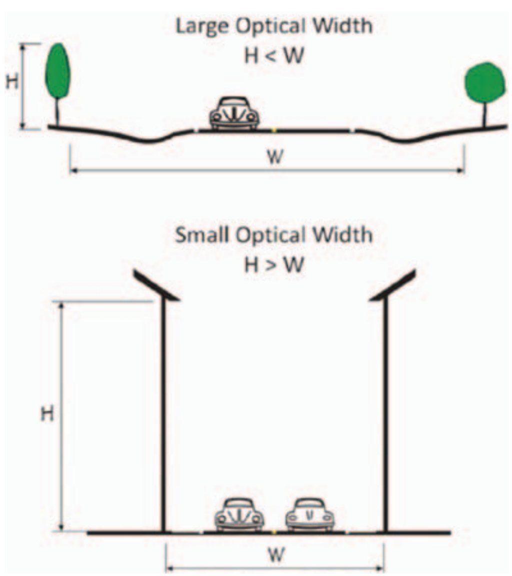


Figure 4-17. Relationship between horizontal elements and vertical dimensions (Forbes, 2011).

It is important to note that the optical width of the road extends beyond the limits of the roadway (i.e., outside edge of shoulder) to features located along the roadside. Also, the vertical elements that factor into the height dimension of the road include features such as landscaping (i.e., grass, shrubs, and trees), street signs and the poles that support the signs, light poles, welcome signs, and buildings.

In many ways the optical width concept is complementary to the gateway treatment discussed above. The optical width of the roadway should be reduced throughout the length of the transition zone, and it should be at the gateway where the vertical elements achieve their greatest dominance.

4.4.4 Community Zone Treatments

As one of the guiding principles indicates, to maintain a reduction in speed downstream of the community threshold, it may be necessary to provide additional treatments within the community. Types of treatments that may be implemented within the community include road diets; various traffic calming treatments such as bulbout/curb extensions, center islands, neckdowns/chokers; on-street parking; and streetscaping. Traffic calming treatments that create vertical deflections such as speed humps, raised crosswalks, and raised intersections could potentially be considered for implementation within the community as well, but should be installed with caution.

There are a number of relevant references for guidance in implementing traffic calming in the community zone. Two of these include *Traffic Calming: State of the Practice* (Ewing, 1999) and *U.S. Traffic Calming Manual* (Ewing and Brown, 2009). There are also numerous state and local agencies that have adopted traffic calming manuals, guidelines, and standards. These documents should be consulted during the planning and design of speed reduction treatments within the community zone.

4.4.5 Examples of Implemented Transition Zone Treatments

Associated with a single pilot project to reduce speeds through small rural communities in Iowa, a range of transition zone treatments was installed near the communities of Union, Roland, Dexter, and Slater (Hallmark et al., 2007; FHWA, 2009A). Gateway treatments were installed in Union and Roland. In Union, the treatments installed in combination to create the gateways included transverse pavement markings, center islands, and speed-activated feedback signs. In Roland, individual treatments incorporated into the gateways included transverse pavement markings, roadway narrowing, and lettered pavement markings. In Dexter, a combination of colored pavement and lettered pavement markings were installed, and in Slater the individual treatments installed included a center island/raised median, a speed-activated feedback sign, and lettered pavement markings.

The effectiveness of these transition zone treatments to reduce speeds into the respective towns ranged to some degree. In general, even the most effective treatments only reduced mean and 85th percentile speeds by a modest amount. To obtain more detailed information on this transition zone pilot project in Iowa, refer to *Evaluation of Gateway and Low Cost Traffic Calming Treatments for Major Routes in Small Rural Communities* (Hallmark et al., 2007) and *TechBrief: Traffic Calming on Main Roads Through Rural Communities* (FHWA, 2009A).

4.4.6 Working Example of Transition Zone Design

This section provides a working example of how one would design a transition zone following the steps of the project identification phase as outlined in Section 4.3.2 and considering the catalog of treatments provided in Section 4.4.2. The example makes use of the straight-line diagram tool and is based upon an actual location and real data. The example also illustrates that the guidelines presented in this document should not be followed as a "cookbook"; rather, the analyst/designer must exercise engineering judgment, especially when data are limited or when field conditions fall outside the boundaries of recommended methodology.

The location for this example is a small rural community with a population of 1,200. A rural two-lane highway approaches and runs through the middle of the community. The upper speed limit in the rural area approaching the community is 65 mph, and the speed limit through the community is 30 mph. Figure 4-18 shows a straight-line diagram of the site, complete with the relevant data. The objective of this example is to assess whether the existing transition zone has speed-limit compliance or safety issues of a magnitude that may require one or more transition zone treatments and to recommend potential treatment(s) for installation as appropriate. The following demonstrates the proposed steps of the project identification phase.

Step 1: Define Study Area and Referencing System

The first step is to define the geographic extents of the study area and the referencing system to be used. For this example, the first cross street within the community will serve as the origin (i.e., the "zero" point) for referencing purposes, and the study area is defined to run from 3,500 ft upstream of the zero point to 1,000 ft downstream of it. As illustrated in the next step, the defined study area extends from the rural zone, through the transition zone, and into the community. The road is fairly flat and straight, as evidenced by the vertical elevation, vertical grades, and curve radius portions of the straight-line diagram in Figure 4-18.

Site characteristic	Reference location
Upstream end of study area	3,500 ft
First cross street within community	0 ft
Downstream end of study area	–1,000 ft

Step 2: Identify Current Transition Zone Boundaries

The second step is to identify the current transition zone based on the locations of the speed limit signs and advance warning signs. At the zero point, as shown in the speed portion of the straight-line diagram, the posted speed is 30 mph. At approximately 2,200 ft upstream of the intersection (i.e., "zero" point), a 50-mph speed limit sign indicates the first reduction in posted speed, and at 900 ft upstream of the intersection a 30-mph speed limit sign is posted.

The road is relatively straight and flat, indicating that the speed limit signs should be clearly visible to drivers. There are no advance warning signs. It is assumed that the speed limit signs, given their size and location, could be observed approximately 300 ft upstream and therefore that value is used for the start of the current transition zone boundary, an estimated 2,500 ft upstream of the zero point. Similarly, the end of the current transition zone is estimated to be 200 ft downstream of the 30-mph speed limit sign, or 700 upstream of the zero point. It is also notable that the paved shoulders widen from 4 to 12 ft in the vicinity of the 50-mph speed drop. The grey portion of the straight-line diagram in Figure 4-18 illustrates the current transition zone boundaries based upon the positions of the existing speed limit signs and current field conditions.

Site characteristic	Reference location
Initial transition threshold	2,500 ft
50-mph speed limit sign	2,200 ft
30-mph speed limit sign	900 ft
Initial community threshold	700 ft

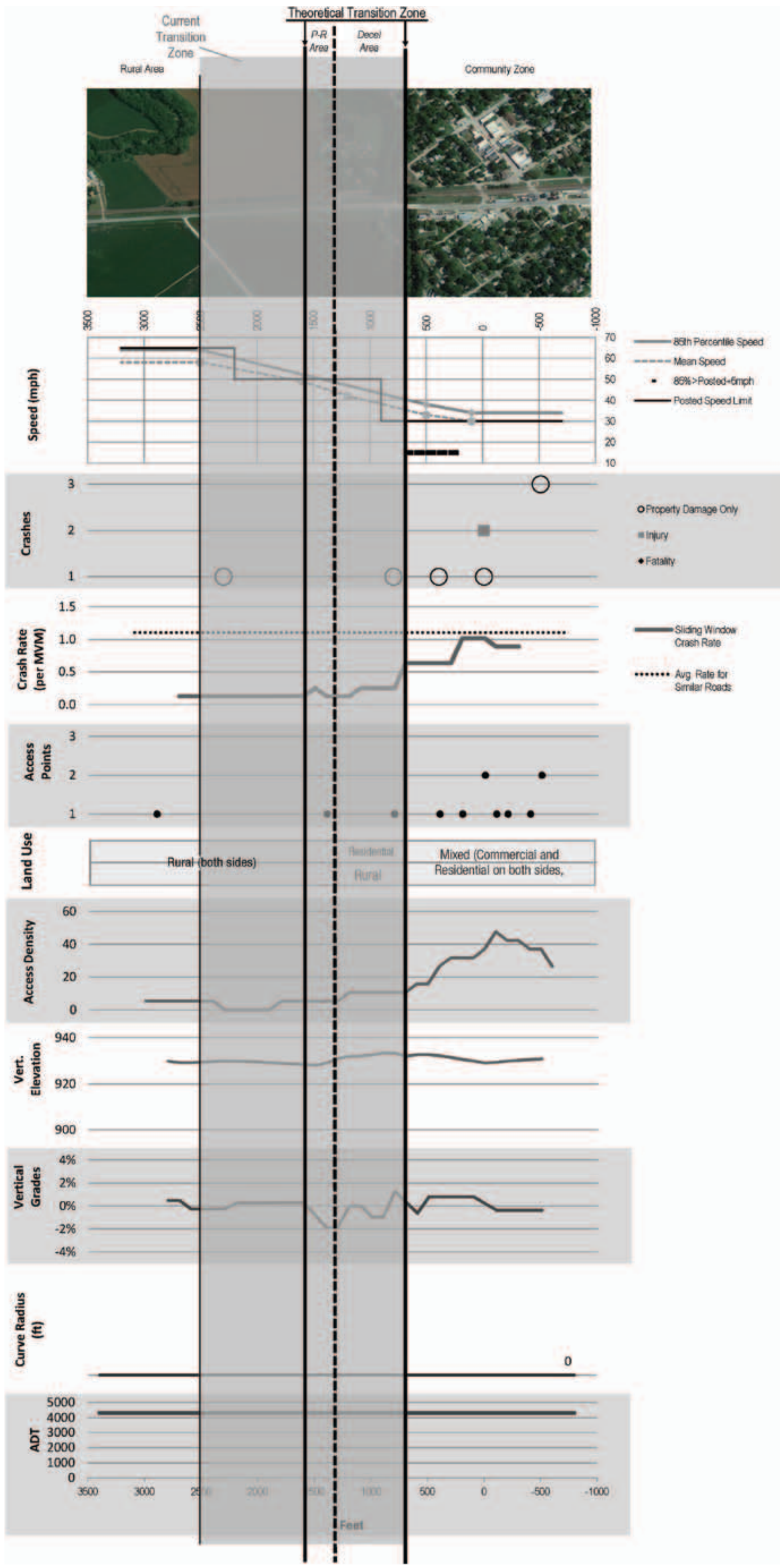


Figure 4-18. Straight-line diagram for example study site.

Step 3: Conduct Speed-Limit Compliance Study

The third step is to assess compliance with the current posted speed limits. In this example, speed data were collected using traffic classifiers positioned at approximately 2,400 ft, 450 ft, and 20 ft within the study area (as recommended in Figure 4-4). Additional speed data were also available between 2,300 and 1,000 ft within the study area. Based upon the available speed data and through interpolation, the measured mean and 85th percentile speeds are illustrated on the speed portion of the straight-line diagram. In the absence of knowledge of a design speed or inferred design speed, the posted speed is used by itself for comparison.

The speed graph shows that at the zero point, the mean speed matches the posted speed, while the 85th percentile speed is 4 mph above the posted speed, but at 700 ft at the current transition zone downstream boundary (i.e., the current community threshold), the mean speed is 6 to 7 mph higher than the posted speed, and the 85th percentile speed is approximately 10 mph above the posted speed. This latter difference leads to the conclusion that the transition zone is worth investigating further.

Step 4: Conduct Crash Analysis

The fourth step is to conduct a crash analysis. The crash portion of the straight-line diagram shows 5 years worth of reported crashes for the study segment, categorized by severity. Nine crashes were recorded: seven classified as property-damage only and two classified as injury. No fatal crashes were reported. As the diagram illustrates, two of the reported crashes occurred in the current transition zone, one near the start of the current transition zone (animal collision) and one near the end of the current transition zone (opposite-direction sideswipe). Most of the crashes, however, occurred in the community zone.

The crash rate portion of the straight-line diagram illustrates a sliding window of crash rates (300-ft window incrementally moved 100 ft) computed based on the crash data in the crashes graph and the traffic volume data in the ADT graph. The crash rate is highest downstream of the current transition zone. The graph also includes the average rate for similar roads (obtained from state records), and shows that nowhere does the crash rate for the study site exceed the statewide average. In this instance, an additional statistical threshold rate was not derived.

Based upon the crash analysis, this site operates relatively safely compared to similar sites.

Step 5: Define the Theoretical Transition Zone Boundaries

The fifth step is to define the theoretical transition zone boundaries. This step begins with setting the community threshold. Access density is suggested as a measure that can be used to help identify this location. The access points' portion of the straight-line diagram quantifies the location and numbers of driveways along the study segment.

Using an increase in access density from 16 per mile to 32 per mile as an indicator (as suggested), it can be seen in the access density graph that density begins to increase from a more rural spacing approximately 600 ft upstream of the zero point, crossing the 32-per-mile value approximately 250 ft upstream of the zero point. The edge of the community can therefore be thought of as somewhere within this 350-ft range. Examining the aerial photo in this range, a reasonable location for the edge of the community is the first access point in town past the bridge, located approximately 450 ft upstream of the zero point. In accordance with the recommended guidelines, a setback is added to locate the community threshold. In this case, a setback of 250 ft was employed to match the stopping sight distance for an assumed design speed of 35 mph (posted speed of 30 mph + 5 mph). Thus the theoretical community threshold is located 700 ft upstream of the zero point, corresponding to the bridge leading into the town. This community threshold becomes the downstream boundary of the theoretical transition zone.

Next, the analyst defines the upstream boundary of the theoretical transition zone using the values in Figure 4-5. Based on the rural zone 85th percentile speed of 64 mph (posted speed limit of 65 mph) and the community zone posted speed limit of 30 mph, a total transition zone length of 840 ft is selected (240 ft of perception-reaction distance plus 600 ft of deceleration distance). This places the upstream boundary of the transition zone (i.e., the transition threshold) approximately 1,540 ft upstream of the zero point.

This results in a theoretical transition zone that is considerably shorter than the current transition zone. The current and theoretical transition zones have the same downstream endpoints (i.e., community thresholds); however, the theoretical transition zone begins approximately 960 ft downstream from the current transition zone. The 50-mph speed limit sign is approximately 660 feet upstream from the theoretical transition threshold. The 30-mph speed limit sign is located approximately 400 ft downstream from the border between the theoretical perception-reaction area and the deceleration area and 200 ft upstream from the community threshold. The differences between these zones indicate that adjustments may be warranted as discussed further below.

Site characteristic	Reference location
Theoretical transition threshold	1,540 ft
Theoretical border between P-R area and decel. area	1,300 ft
Theoretical community threshold	700 ft

Step 6: Assess Initial Results of Project Identification Phase

In this final step the results of the speed and crash analyses taken together will yield a first indication of whether improvements and/or further investigation are needed for the transition and community zones. In this example only one property-damage only crash was reported within the theoretical transition zone, and nowhere along the study segment did the reported crash rate exceed the statewide rate. However, at the end of the theoretical transition zone, the 85th percentile speed exceeds the community target speed by approximately 10 mph, and the 85th percentile speed remains above the posted speed through the community by approximately 4 mph. Given these results, it should be left to engineering judgment as to whether further investigation is necessary. If further investigation is decided upon, the analyst could next perform a more detailed assessment, as described in Section 4.3.3, potentially including a design study, sight distance analysis, more detailed speed/crash studies, and other types of studies as appropriate to the site. Most likely the study would focus on simple measures to increase speed compliance further in advance of the community, since extensive safety countermeasures do not appear to be warranted.

One area for design consideration is signage and striping. It may be possible given the length differences between the current and theoretical transition zones to tighten the transition zone, while increasing drivers' awareness that they are entering a community. For example, consideration could be given to shifting the 50-mph speed limit sign closer to the boundary of the perception-reaction and deceleration areas (1,300 ft from the zero point). In conjunction with this change, a Reduced Speed Limit Ahead warning sign could be installed near the start of the theoretical transition threshold (1,540 ft from the zero point). In keeping with the deceleration table, at least 380 feet should be provided between the 50-mph and 30-mph speed limit signs. The current 30-mph speed limit sign location is 400 ft from the potential new 50-mph sign location, so it may not be necessary to move the 30-mph sign. However, a welcome sign indicating entrance into the community may be considered in the vicinity of the community threshold (in the vicinity of the bridge) to reinforce the need for a reduced speed.

In addition to the sign changes, it may be beneficial to narrow the lanes from 12 ft to 11 ft throughout the deceleration area (leading up to the bridge) to promote speed reduction. Trans-

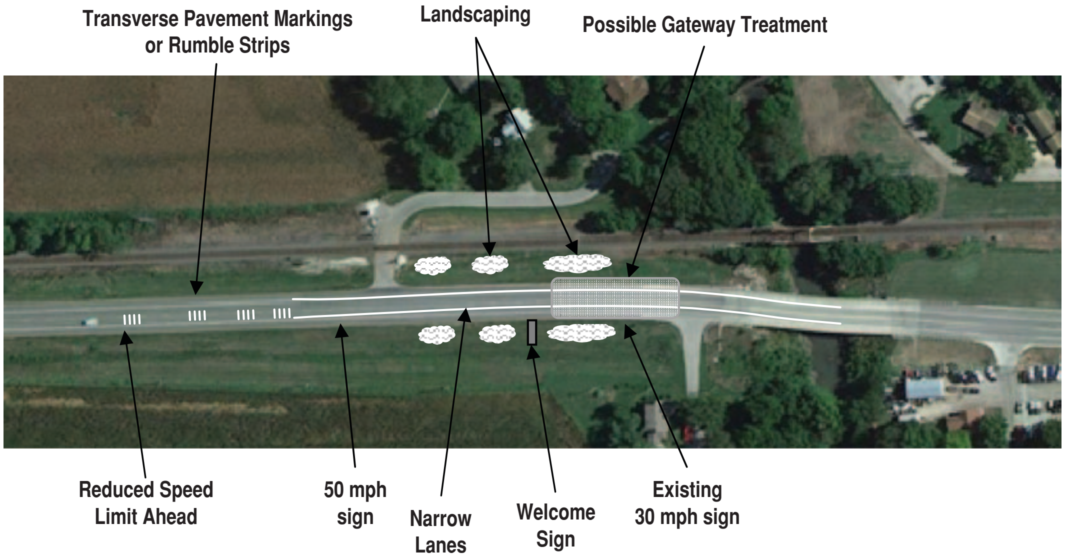


Figure 4-19. Suggested transition zone treatments to consider at example study site.

verse pavement markings in the travel way and/or in the shoulder areas may also be considered, starting at the speed reduction warning sign and continuing into the deceleration area.

If these improvements are determined not to be sufficient to achieve speed compliance at the community threshold, the highway geometry is such that a number of other options could be considered. These could be modest changes such as colored pavement or rumble strips (in the perception-reaction area and possibly extending into the deceleration area), or they could take the form of a comprehensive package of improvements. One more extensive option would be to create a gateway treatment. This could involve landscaping leading up to the gateway, both to indicate the change in character and to "narrow" the roadway. A special pavement treatment, bike lanes, or a walking trail could also be considered. It could also involve either a painted or raised median, though safety related to the horizontal deflection may be an issue due to the proximity of the bridge and stream. A welcome sign would also be a likely part of a gateway. Figure 4-19 illustrates several of the suggested transition zone treatments for consideration at this example study site. Note that if a gateway treatment was installed, it would likely require moving the existing 30-mph speed limit sign slightly upstream such that it would be positioned at the beginning of the gateway.

4.5 Evaluating the Effectiveness of Transition Zone Treatments

Following the installation of a transition zone treatment or combinations of treatments (e.g., a gateway), it is suggested that the effectiveness of the transition zone treatment(s) be evaluated. The primary purpose of such an evaluation would be to confirm that driver behavior through the transition zone and community zone is functioning as intended by the design, and that the project improved the safety experience through the study area rather than having a negative impact. Based on the evaluation, it can be determined whether additional improvements are necessary within the study area, and as a secondary benefit, the evaluation results can be shared and/or combined with similar projects to improve the knowledge and understanding of the effectiveness of the respective type of transition zone treatment. The primary type of study design to evaluate the effectiveness of a treatment in reducing speeds and crash frequency or severity would be an observational before/after study.

To conduct a before/after study, it is critical that the evaluation process/methodology be considered prior to construction of the transition zone treatment. Ideally, the speed and crash data gathered during the project identification phase could be used as the before period data for the analysis; otherwise, the same type of information would have to be collected/gathered a second time for the evaluation process. The following sections describe the general approaches for conducting a before/after speed study and a before/after crash analysis to determine the effectiveness of an implemented transition zone treatment.

4.5.1 Before/After Speed Study

The primary objective of a before/after speed study of a transition zone treatment is to determine if speeds through the transition zone and community have been reduced to a level consistent with the desired speed. Section 4.3.2 (Step 3: Conduct Speed-Limit Compliance Study) describes the recommended locations for collecting speed data prior to installation of a treatment. A minimum of three locations for collecting speed data are recommended: upstream of the transition zone near the transition threshold, downstream of the transition zone near the community threshold, and within the community. As resources are available, speed data can be collected at additional locations along the study area to gain more detailed information on driver behavior through the study area.

In selecting the locations to collect speed data during the before period, the key is to select relevant locations with respect to the transition zone boundaries, but also locations at which speed data could be collected at the exact same locations along the roadway after installation of the transition zone treatment. Issues to be considered when selecting locations for speed data collection include the following:

- Whether installation of the treatment will prohibit collecting speed data at the same location(s) in the after period.
- Whether it is desirable to collect speed data upstream or downstream of certain transition zone treatments.
- Whether the locations are away from influence of upstream or downstream intersections.

If the transition zone itself is proposed to be moved as part of the treatment project, it may be necessary to collect additional speed data at the future transition zone and community thresholds, even if they are quite different than the current thresholds.

The primary measures used to assess the effectiveness of a transition zone treatment in reducing speeds from the before period to the after period include the following:

- The percentage of vehicles in compliance with the posted speed limit at the end of the transition zone.
- The mean speed, 85th percentile speed, and overall speed distribution in comparison to the posted speed limit at the end of the transition zone.
- The percentage of vehicles in compliance with the posted speed limit within the community.
- The mean speed, 85th percentile speed, and overall speed distribution in comparison to the posted speed limit within the community.

Generalized linear models with the appropriate distributional assumption can be used to evaluate the before to after effect on the respective measure of effectiveness.

In this type of speed study, in most cases only speeds of free-flowing vehicles should be included in the analysis. If there is a high percentage of trucks in the traffic stream, consideration should be given to analyzing speeds of passenger cars and trucks separately, and combined.

The temporal effect of the treatment should also be assessed as part of a before/after speed study. Consideration should be given to collecting speed data approximately 3, 6, and 12 months after installation of the treatment to more properly assess the long-term effectiveness of the treatment in reducing speeds. It is possible that speeds may be reduced in the short term following installation of a treatment, but as drivers become accustomed to the treatment over time, speeds may increase to the same levels as before installation of the treatment.

4.5.2 Before/After Safety Study

The primary objective of a before/after safety study of a transition zone treatment is to assess whether the treatment improved the crash experience in the transition and community zones. Several of the key first steps in an evaluation are to define the study area and the boundaries of the transition and community zones. These likely would have been defined during the project identification phase, and it is important that the boundaries of the overall study area and the boundaries of the transition and community zones are the same for both the before and after period so that direct comparisons of the crash data before and after treatment can be made. If the transition zone boundaries are adjusted as part of the treatment project, it may be necessary to include a portion of the roadway upstream of the transition zone as part of the safety study (either in the before period or the after period) so the boundaries of the overall study area are the same from before to after. Ideally, 3 to 5 years of crash data for the before period are available for the analysis, and 3 to 5 years of after data.

Initially, the crash data should be analyzed qualitatively. The crash data can be summarized to determine trends before and after related to the following:

- The overall frequency of speed-related crashes.
- Where the crashes occurred in relation to the location of the transition zone treatment(s).
- The distribution of crash types across the study area.
- The severity distribution of crashes.

A detailed quantitative analysis of the crash data should be completed in accordance with methods described in the HSM (AASHTO, 2010). This requires inclusion of non-treatment sites in the analysis in one of two ways. An empirical Bayes (EB) methodology using safety performance functions (SPFs) developed using data from non-treatment sites can be used to compare the observed after crash frequency to the expected average after crash frequency estimated with the EB method. This approach is preferred because it compensates for regression-to-the-mean bias. Alternatively, a before/after study using the comparison group method could also be utilized. The comparison group allows consideration of general trends in crash frequency or severity whose causes may be unknown, but which are assumed to influence crash frequency and severity at the treatment site and comparison sites equally. Selection of an appropriate comparison group is key to the evaluation. Yearly traffic volume data are also key to the analysis to account for varying traffic volumes across the study period.

Several key decisions that need to be made regarding the analysis of crash data are as follows:

- Will the analysis focus only on speed-related crashes or will it incorporate all crashes? From a conceptual viewpoint, the analysis should focus only on speed-related crashes, but from a practical standpoint, sample size issues arise if the analysis is limited to speed-related crashes.
- Will the analysis include both intersection and non-intersection (i.e., segment) related crashes? Both intersection and non-intersection crashes can be highly dependent upon speed, but the intersection crashes also include factors beyond the influence of the treatment. Again, sample size issues may become more pronounced if intersection crashes are not included in the analysis. Also, separate SPFs are typically used to predict intersection and non-intersection crashes.
- Whether crashes in the transition zone will be analyzed separately from crashes that occurred in the community zone. The roadway characteristics should be distinctively different for transition zones and community zones, which suggests that the two zones should be analyzed separately at first and then analyzed together. This approach requires the use of separate SPFs in the analysis for the two zones.

4.5.3 Lessons Learned

In addition to the science-based approaches to evaluating the effectiveness of a transition zone treatment/project in reducing speeds and crash frequency/severity, consideration should also be given to collecting additional knowledge and understanding about the effectiveness of a transition zone project by gathering input from those stakeholders most affected by the treatment. For example, interviews could be conducted with public citizens, law enforcement, emergency responders (i.e., fire and ambulance personnel), personnel for towing agencies, and DOT maintenance personnel to gather their opinions of the project, how it has affected their daily job routines/activities either directly or indirectly, etc. The lessons learned from these various stakeholders could potentially be used to improve an existing project that was recently implemented and/or improve the planning and design processes of future transition zone projects.

4.5.4 Evaluating a Single Project

A before/after evaluation can be conducted for a single project at a specific site to determine its effectiveness in reducing speeds and crash frequency or severity. The evaluation results provide an estimate of the effectiveness of the treatment at that particular site. The results of such evaluations for a single site are of interest for many highway agencies. However, the results from an evaluation of a single site are not very accurate (AASHTO, 2010).

Combining results for groups of similar projects provides a better estimate of the overall effectiveness of a treatment. Effectiveness evaluations of groups of similar projects are of interest to highway agencies monitoring their improvement projects. As more transition zone treatments of a similar type are installed, effectiveness evaluations across sites will improve future decision making.

4.6 Legal/Liability Issues

According to ITE's *Traffic Calming: State of the Practice* (Ewing, 1999), there have been few major government liability issues involving traffic calming. It is expected that transition zone treatments will similarly have few major issues as long as the responsible government agency (1) has the proper authority, (2) respects the constitutional rights of all affected parties, and (3) takes steps to minimize the risks to travelers from the treatments. In general, it is within the authority of the appropriate state or local government agencies to impose reasonable restrictions on travel for the protection of the public. (There are, however, some states where local governments must gain specific statutory authority from the state to obtain this power.) One way to accomplish the second two goals listed above is to follow a "rational planning and implementation process." By following such a process, the government agency demonstrates that it is appropriately using its power to control traffic for the public welfare.

With regard to liability, there are two main types of government functions: discretionary functions and ministerial functions. Discretionary functions could include choosing between different reasonable and feasible transition zone treatments. These types of government functions are typically not subject to tort claims. This is particularly true if a rational selection process was followed. Ministerial functions include situations in which government action is required, such as constructing and signing a new transition zone treatment in accordance with appropriate design standards. These government actions are open to tort claims. It is incumbent on government agencies to take appropriate action to protect citizens from known dangers.

To minimize the potential for claims, as well as to maximize the potential for a successful cost-effective project, it is suggested that agencies follow a rational planning and implementation process. Some elements of such a process could include the following:

- Use traffic, speed, crash, design, and other data to clearly demonstrate a transition zone concern that requires government action.
- Develop and evaluate a range of possible solutions to address the concern.
- Use technical criteria as well as public and stakeholder input to select (and prioritize if necessary) a recommended solution that meets the project needs.
- Design and construct the treatment in conformance to appropriate design standards and guidelines, clearly documenting and addressing design exceptions or non-conforming features.
- Conduct follow-up analyses to determine if the recommended and implemented solution addressed the concern (if not, then taking action to adjust or remove the treatment).
- Maintain the treatment including all signage and markings.
- Document the process from project identification phase to follow-up analyses and any revisions to the implemented treatment.

By making sure that the agency has the necessary authority, by respecting all citizens' constitutional rights, and by following a process such as that outlined above, an agency will reduce its potential for legal challenges.

SECTION 5

Conclusions

In the United States, design guidance for high- to low-speed transition zones for rural highways is in its infancy. This research and other recent reports/documents, such as *Speed Reduction Techniques for Rural High-to-Low Speed Transitions* (Forbes, 2011); *Determining Effective Roadway Design Treatments for Transitioning from Rural Areas to Urban Areas on State Highways* (Dixon et al., 2008), *Evaluation of Gateway and Low Cost Traffic Calming Treatments for Major Routes in Small Rural Communities* (Hallmark et al., 2007), and *Main Street . . . When a Highway Runs Through It: A Handbook for Oregon Communities* (ODOT, 1999), are steps toward establishing national guidelines for rural high- to low-speed transition zones. Clearly, more work needs to be done to achieve such a goal.

One of the areas in which more work needs to be accomplished is the obtaining of more accurate and reliable information on the effectiveness of transition zone treatments on reducing speeds and improving safety. The primary findings from this research that contribute to the body of knowledge on the effectiveness of transition zone treatments include the following:

- Roundabouts and TPMs do not necessarily decrease mean speeds from upstream to downstream of the transition zone any more than does no treatment, but they do increase speed-limit compliance.
- Roundabouts and TPMs increase the rate of compliance of vehicles traveling at or below the speed limit at the end of a transition zone by 15 and 20 percent, respectively, compared to no treatment.
- Roundabouts increase the rate of compliance of vehicles traveling at or below the speed limit +5 mph at the end of a transition zone by 11 percent, compared to no treatment.
- The findings support previous research (Forbes, 2011), indicating the need to provide additional measures through the community to maintain a speed reduction downstream of the transition zone through the community.
- Based upon the crash analysis for this research, there is no evidence to suggest that the installation of a roundabout, TPMs, or welcome signs in a transition zone either improves or negatively impacts safety based upon an analysis of a combination of roadway segment and intersection crashes over an extended length of roadway beginning at the upstream end of the transition zone to 0.25 mi downstream of end of the transition zone. Given the limited crash dataset for this research, the most reliable safety information available for the three treatments analyzed (roundabout, TPMs, and welcome sign) is for roundabouts, which can be found in the HSM and research by Rodegerdts et al. (2007, 2010).

Still, more work needs to be done on the effectiveness of transition zone treatments, and this can only be accomplished by more agencies conducting evaluations of treatments using the most scientifically valid methodologies.

Finally, another recommendation for establishing national guidelines for rural high- to low-speed transition zones is the following. While the AASHTO *Green Book* (AASHTO, 2011) does not address transition zones, a paragraph could be added to the next edition in Chapters 6 and 7, explaining the transition zone related issues and the need to consider further design guidance for transition zones. In each chapter, the new text could refer the reader to this report for more details. Incorporation of detailed design guidance for rural high- to low-speed transition zones in the *Green Book* does not seem appropriate. Guidance on the design of transition zones is almost of the same nature as design guidance on traffic calming, and detailed guidance on traffic calming is not provided in the *Green Book;* therefore, reference in the *Green Book* to an external document seems most appropriate. It is also proposed that the next edition of the *Roadside Design Guide* include a general discussion of roadside issues related to transition zones.

SECTION 6

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Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation