DETERMINING EFFECTIVE ROADWAY DESIGN TREATMENTS FOR TRANSITIONING FROM RURAL AREAS TO URBAN AREAS ON STATE HIGHWAYS

Final Report

SPR 631

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16. Abstract

This report reviews an Oregon research effort to identify ways to calm operating speeds as the vehicles transition into developed suburban/urban areas from rural roads. Drivers of vehicles approaching the urban environment have few visual cues to reduce their speeds until their vehicles are well into the more urban environment. This report specifically reviews a simulator study for rural-to-urban transitions. The study included two pilot studies and one full scale study. The scenarios evaluated were ones that either physically or perceptually narrow the road at these transition locations. The specific transition treatments included in the full scale simulation were:

- Layered landscape
- Gateway with lane narrowing
- Median treatment only
- Median with gateway treatment
- Medians in series with no pedestrian crosswalks
- Medians in series with pedestrian crosswalks

Though all enhanced speed reductions were minimal, the scenarios with the most effective speed reduction results included the median treatments (particularly the medians in a series or the treatment combined with a gateway). The layered landscape treatment and the gateway with lane narrowing treatment did not result in statistically significant speed reductions.

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

NOTE: Volumes greater than 1000 L shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DETERMINING EFFECTIVE ROADWAY DESIGN TREATMENTS FOR TRANSITIONING FROM RURAL AREAS TO URBAN AREAS ON STATE HIGHWAYS

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EXECUTIVE SUMMARY

As cities continue to grow, transportation agencies and their designers are increasingly challenged with developing elements for transitioning roadway corridors at locations where highways change from high speed rural environments to more suburban/urban environments. Traffic operating speeds in these transition corridors are typically high, even at locations with reduced posted speed limits.

There is a need, therefore, to identify ways to calm operating speeds as the vehicles enter the developed suburban/urban areas. Drivers of vehicles approaching the urban environment have few visual cues to reduce their speeds until their vehicles are well into the more urban environment. This lack of timely information to these drivers translates into higher than desirable speeds along the fringes of the urban regions. In addition, a driver navigating a rural corridor, that is characterized by high operating speeds and few distractions, may be less alert as he or she enters the busier urban areas.

In recent years, engineers have used traffic calming features for local roadway systems characterized by low operating speeds and traffic volumes. Similar or additional traffic/speed calming features need to be developed and tested for highways that carry significant volumes of through traffic, such as major arterials. This report reviews research evaluating potential traffic calming strategies for rural-to-urban transitions on state highways in Oregon.

The report also reviews a simulator study for rural-to-urban transitions. The study included two pilot studies and one full scale study. Though several speed reduction strategies are recommended in the published literature, many of these are not candidate treatments for a simulator evaluation. As a result, the scenarios evaluated were ones that either physically or perceptually narrow the road at these transition locations.

The specific transition treatments included in the full scale simulation were:

- Layered landscape
- Gateway with lane narrowing
- Median treatment only
- Median with gateway treatment
- Medians in series with no pedestrian crosswalks
- Medians in series with pedestrian crosswalks

Though all enhanced speed reductions were minimal, the scenarios with the most effective speed reduction results included the median treatments (particularly the medians in a series or the treatment combined with a gateway). The layered landscape treatment and the gateway with lane narrowing treatment did not result in statistically significant speed reductions.

1.0 POTENTIAL TREATMENTS AT TRANSITIONS – LITERATURE REVIEW

1.1 INTRODUCTION

A typical application of traffic calming measures is the low-speed local street network; however, the basic concept of traffic calming or speed calming should extend to higher level highway facilities. The application of traffic calming, for example, from rural-to-urban highway transitions is largely untested but the benefits of successful implementation of traffic calming in such regions are substantial.

This chapter reviews potential traffic calming measures for higher speed transition locations. Much of the literature regarding the application of traffic calming to high speed transitions is anecdotal and largely untested. This chapter identifies the various speed reducing applications and the extent to which they have been proven.

Many national, state, or local jurisdictions maintain traffic calming guidelines. The Institute of Transportation Engineers (ITE) provides a traffic calming web site that contains resources including one of the most frequently cited references, *Traffic Calming State of the Practice* by Ewing (*1999*). Though many of these available resources focus on highways with relatively low operating speeds of 30 mph (48 km/h) or less, they may still provide valuable insight into prospective treatments for the higher speed environment.

Drivers need well defined transitional speed zones with explicit guidance and roadway features to inform and encourage them to slow down gradually as they transition from high speed rural conditions to lower speed urban locations. The transitional speed zone will also provide a region for drivers to increase operating speeds as they exit an urban area. Unfamiliar drivers depend on roadway features and roadside conditions to help them identify changes in road environment so that they can know to adjust their driving speed and behavior in a timely manner.

The prospective traffic calming measures reviewed in this chapter are divided into physical roadway calming strategies, traffic control strategies, and other prospective perceptual speed calming measures. Each of these strategies is reviewed in detail in the following sections.

1.2 TRAFFIC CALMING TREATMENTS

Traffic calming strategies that may be suitable for calming vehicle speeds can range from re-construction of physical road features to simple traffic control strategies. Many traffic calming measures are not appropriate for high-speed environments as they could potentially introduce safety problems for vehicles with high operating speeds. Table 1.1 depicts a variety of traffic calming strategies, their perceived influence on vehicle operating speed, and appropriate roadway environment applications. Highlighted items are those that are identified in the literature as 'suitable for the high-speed road environment.' Those traffic calming strategies that are highlighted **and** also identified to have known or perceived speed reduction influences are reviewed in further detail in the following sections.

Table 1.1: Traffic Calming Roadway Design Treatments

Treatment	Speed Reduction Influence	Road Type Application
Physical Treatments		
Horizontal Displacement:		
Bulbout (Curb Extension)	Possible	Low-Speed Arterial & Residential
Chicanes / Horizontal Curvature/ Curvilinear Street	Reduce	Residential
Choker (Neckdown to One Lane)	Reduce	Residential
Diverter / Entrance Barrier	Reduce	Residential
Driveway Link	Reduce	Residential
Full Street Closure	Reduce	Residential
Gateway	Reduce	Arterial & Residential
Center Island / Raised Median	Reduce	Arterial & Residential
Intermediate Median Barrier	None	Arterial
Realigned or Modified Intersections	Reduce	Residential
Partial Street Closure	None	Residential
Reducing Number of Lanes	Reduce	Arterial & Residential
Roadway Narrowing	Reduce	Arterial & Residential
Traffic Circles	Reduce	Residential
Roundabout	Reduce	Arterial
Woonerf	Reduce	Residential
Vertical Displacement:		
Raised Crosswalk	Reduce	Residential
Raised Intersection	Reduce	Low-Speed Arterial & Residential
Speed Cushions	Reduce	Low-Speed Arterial & Residential
Speed Humps and Tables	Reduce	Residential
Traffic Control Signs & Pavement Marking:		
Enhanced Warning or Speed Limit Signs	Possible	Arterial & Residential
Stop Sign Reversal	Possible	Residential
Transverse Road Markings	Possible	Arterial & Residential
Colored or Textured Pavement	Possible	Arterial & Residential

Treatment	Speed Reduction Influence	Road Type Application
Photo-Radar Enforcement	Reduce	Arterial
Landscaping	Possible	Arterial & Residential
Other Treatments		
Banners	Possible	Arterial
Sidewalks & Shoulders	None	Arterial & Residential
Street Furniture & Lighting	Possible	Arterial & Residential
Truck Prohibition	None	Arterial & Residential
Higher Visibility Crosswalk	Possible	Arterial & Residential

Source: *Burden,* 2000; *Boulder, undated*; *Ewing, 1999*; and *NYSDOT, 1999.*

1.2.1 Physical Treatments

Physically constructed traffic calming strategies can be one of the more expensive and also most effective speed reduction treatments, since these modifications permanently alter the roadway so that users are directly affected by the change. As shown in Table 1.1, physical treatments can be further separated into three categories: horizontal displacement, vertical displacement, and traffic control strategies (signing, marking, etc.). The following sections review the possible speed reduction treatments that may be suitable for application to arterial roads for each of the three categories.

1.2.1.1 Horizontal Displacement

Horizontal displacement treatments are intended to modify the vehicle path so that there is less available space to maintain high speed operations. The use of horizontal displacement strategies must be balanced with the need to maintain a safe operating environment with little adverse impact to the progress of emergency services operations. In general, horizontal displacement strategies will either shift the path of the vehicle or narrow the travelway. Both of these operational modifications are known to have varying influences on reducing operating speeds.

1.2.1.1.1 Bulbout (Curb Extension)

Bulbouts or curb extensions occur at intersection and/or pedestrian crossing locations. At these sites, the curb line is extended into the street and this effectively reduces the street width. As a result, pedestrian crossing distances are reduced and motorists are less likely to park and block pedestrian ramps. Bulbouts can also be used at other locations to help delineate the limits of on-street parking or to simply help reduce the effective width of very wide streets. Because the bulbout protrudes into the road, this traffic calming strategy is commonly used in conjunction with on-street parking in locations such as central business districts. This traffic calming strategy, therefore, does not appear to be an appropriate option for the high-speed transition from rural to urban environments where on-street parking is generally prohibited.

1.2.1.1.2 Gateway

The traffic calming strategy referred to as a gateway is defined by Burden (*2000*) as "a physical or geometric landmark on an arterial street, which indicates a change in environment from a major road to a lower speed residential or commercial district."

Burden goes on to suggest that gateways can be a combination of narrowed streets, medians, signs, arches, roundabouts, or other unique features. The objective of a gateway treatment is to make it clear to a motorist that he or she is entering a different road environment that requires a reduction in speed. Harkey and Zegeer (*2004*) further note that the gateway provides the initial indication that the motorist is entering a lower speed region, but if the entire area is not designed to support this lower limit, the speed reductions that occur in the vicinity will only be localized and temporary. Based on this general definition, it is clear that the gateway is a combination of several possible traffic calming strategies including entry to center islands, medians, landscaping, street art, etc. A recent Iowa project, for example, determined that a wide variety of gateway treatments have, at best, a modest influence on increased speed reductions (*Hallmark et al., 2007*). Each of these individual components to a gateway system is discussed in further detail in the following sections. An example of strategic gateway planning can be reviewed at the online Gateway Design Guidelines for Binbrook Village Community Core Urban Design (see Figure 1.1 and Figure 1.2). This case study presented two alternative gateway designs: a gateway treatment with road narrowing, and a gateway design that utilized a median.

The proposed gateway design elements for this case study included a combination of:

- street trees
- upgraded pavement treatments
- median
- lighting
- signage and graphics
- sculptures or public art

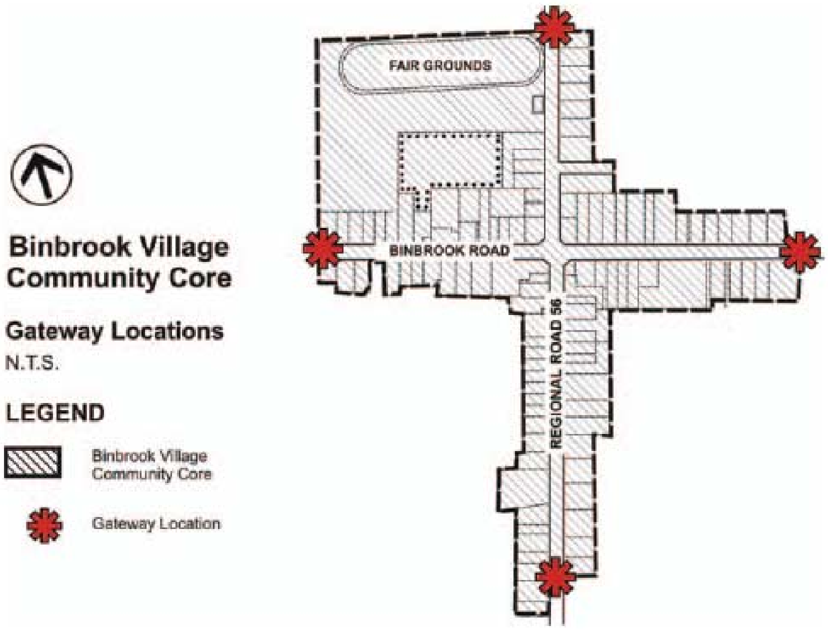

Figure 1.1: Gateway Placement Strategies *(Binbrook, 2005)*

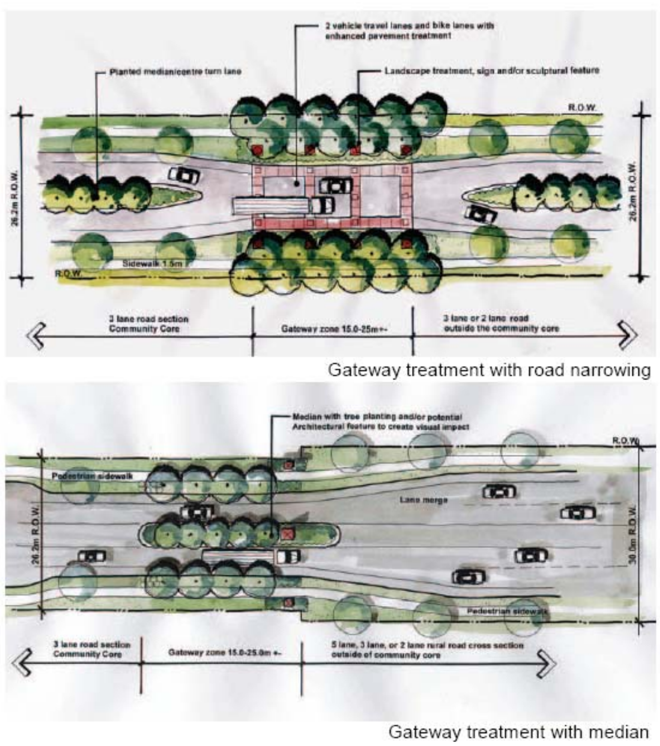

Figure 1.2: Example Gateway Design (*Binbrook, 2005*)

1.2.1.1.3 Center Island / Raised Median

A raised center island or a median that extends the length of the road are two traffic calming strategies often used as a means of narrowing the travelway, separating opposing directions of travel, and providing a refuge location for pedestrians. The geometry of the island or median may also have a direct influence on reducing vehicle operating speeds. Medians also provide an opportunity to enhance aesthetics with strategic, frangible landscaping configurations.

Center Island

A center island extends a short length and its purpose is to draw attention to the changing environment while helping to reduce operating speeds due to a more constrained pathway. A large variety of center island configurations are used for traffic calming purposes. Harvey (*1992*) indicates that the construction of central islands have only a limited effect on speed reduction unless used in conjunction with other traffic calming elements. On average, he suggests possible average speed reductions of 3 mph (5 km/h) at the central island locations. The *Canadian Guide to Neighborhood Traffic Calming* (*TAC*, *1998*) focuses on local and collector streets, but also suggests that the use of a center island can have a speed reduction of 2 mph (3 km/h) for the lower speed locations. The guide also indicates that if the center island is used in conjunction with curb extensions, the speed reduction can be as great as 5 mph (8 km/h).

In a study by Berger and Linauer (*1998*), they described the influence of various raised traffic islands on vehicle operating speeds. They tested these island configurations at city and town limits in Austria. As shown in Figure 1.3, they were observing actual speeds well in excess of legal speeds as motorists traversed through urban areas on roadways free of speed reduction treatments. Table 1.2 and Figure 1.4 show four center island configurations evaluated in Berger and Linauer's study.

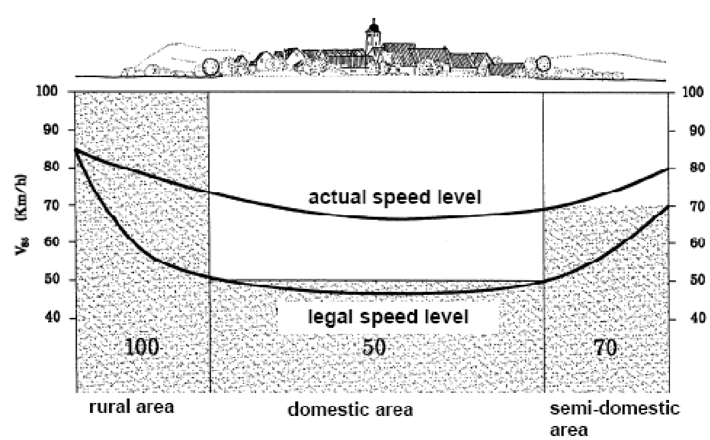

Figure 1.3: Speed Level in Rural Area

Table 1.2: Four Example Raised Islands

	Inbound lane (from rural to urban)	Outbound lane (from urban to rural)
1	Travel path shifted Minimally	Straight Travel Path
2	Travel path shifted Moderately	Straight Travel Path
3	Travel path shifted Moderately	Travel path shifted Moderately
4	Travel path shifted Dramatically	Straight Travel Path

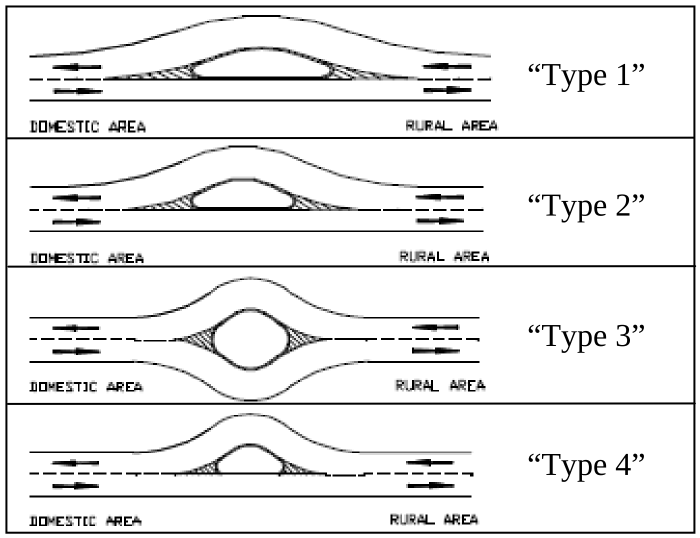

Figure 1.4: Four Types of Raised Islands *(Berger and Linauer, 1998)*

The Austrian research team determined that in general the use of raised islands at the boundary of urban and rural areas are very effective measures to slow down approaching traffic. They further found that their "Type 3" raised island configuration (see Figure 1.5) had an additional advantage of preventing vehicles from illegally using the straight outbound lanes as they approached the city at high speeds. Before-after tests performed on these island configurations indicated that the "Type 1" island had no affect on the mean or 85^{th} percentile speeds. "Type 2" and "Type 3" islands resulted in a speed reduction from 17% up to 28% at the various test sites. Island "Type 4" with the dramatic lane shift, resulted in mean and 85^{th} percentile speed reductions of 38% and 42% respectively.

Figure 1.5: "Type 3" Raised Island *(Berger and Linauer 1998)*

Crowley and MacDermott (*2001*) tested the influence of a raised center island on operating speeds in Ireland. They placed a "Traffic Calming Ahead" sign upstream of the speed reduction zone. They then included a "Do Not Pass" sign at raised island locations. For sites with the "Do Not Pass" sign and the raised center island, they recorded 85^{th} percentile speed reductions of 9 mph (14 km/h) compared to the upstream "Traffic Calming Ahead" sign location. At locations with the signage but no raised center islands, they observed speed reductions of 6 mph (10 km/h).

Forbes and Gill (*1999*) evaluated traffic calming strategies for an arterial road connecting two residential areas in Ontario, Canada. Mohawk Road is a two-lane road with a 31 mph (50 km/h) speed limit. Prior to the evaluation, the researchers found that approximately 67% of the vehicles were exceeding the legal speed limit at the test location. They constructed a series of various dimension landscaped speed control islands to help slow down traffic at the site. Following a before and after study for test sites as well as control sites, the Canadian researchers observed the number of vehicles exceeding the speed limit at the control sections was reduced from 88% to 85%. At the test sections with the speed control islands, the number of motorists exceeding the speed limit was reduced from 67% to 47%. This observed 20% reduction in speeding was statistically significant and led to the conclusion that the speed control islands are an effective strategy for reducing vehicle operating speeds in transitional zones. For this Canadian study, Forbes and Gill collected before and after speed data, each for a 48-hour duration, using a series of automatic speed counters positioned in the test section. Figure 1.6 depicts an example speed control island used in the Mohawk Road case study.

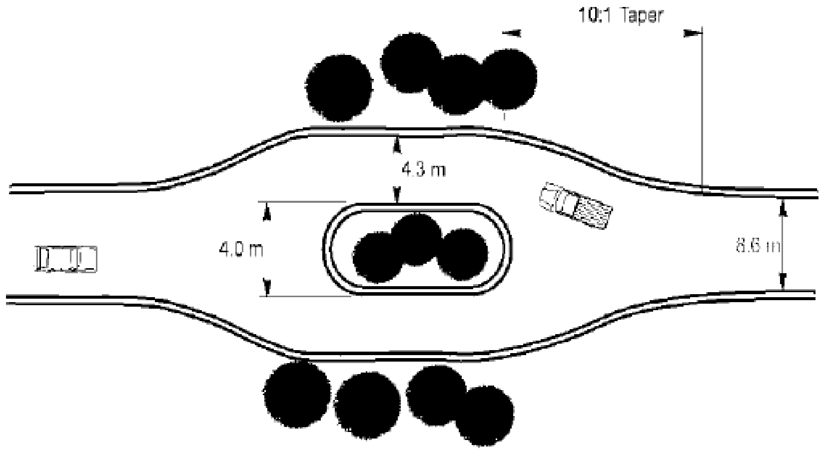

Figure 1.6: Ontario, Canada Speed Control Island

Medians

The function of medians is to physically separate opposing directions of travel. A median can be traversable or raised. An example of a traversable median is one that is painted but can be easily driven across by all vehicles. Traversable medians are not known to positively influence speed reductions and so are not considered a candidate treatment for this study. Raised medians are typically bordered by a raised curb and can serve other purposes such as access management, pedestrian refuge, or aesthetic landscape planters. Median configurations can also create physically narrow travelways or be constructed to create a visual perception of narrower roads. As a result, raised medians are often considered as a speed reduction strategy (*Burden, 2000*). Figure 1.7 depicts a schematic of a landscaped median.

Harder and Carmody (*2002*) evaluated the influence of medians as well as a combination of medians and chokers on vehicle operating speeds. The study used comparative evaluations for a control road that did not have median islands, chokers, or plantings. The researchers then tested drivers' reactions to the addition of medians only, chokers only, medians and chokers (combined), and landscaping complementing these channelization devices. The study used a wrap-around driving simulator located at the University of Minnesota. The research team found a small speed reduction when only chokers were added (with no median). Sites with medians (but no chokers) also resulted in minor speed reductions, but the combined choker and median island configuration resulted in the larger speed reduction. The authors found that modest reduction in average speed when comparing the control section to a roadway section comprising all three elements was approximately 3.3 mph (5.2 km/h).

Figure 1.7: Landscaped Median (*Route 550 Corridor Coalition, 1996*)

In addition to the above simulation tests, the Minnesota Department of Transportation also evaluated the influence of medians as a traffic calming strategy using before and after studies (*Corkle et al., 2001*). Their study used simulation tests to verify field observations. Similar to the study by Harder and Carmody, Corkle et al. found that the combined median/choker configuration was effective in modest speed reductions. The addition of landscaping resulted in a small speed reduction that was not statistically significant. The research team also evaluated the use of the simulator for testing traffic calming scenarios and concluded that the simulator does accurately predict the influence of traffic calming on vehicle speeds; however, the calibration of the simulator to field speeds is difficult and requires additional research efforts.

Fitzpatrick et al. (*1999*) evaluated the influence of design factors on driver speed for suburban arterials. They included a variety of road characteristics and performed spot speed studies as well as instrumented vehicle studies. For their study corridors, the Texas researchers found that if medians were evaluated in a statistical model that excluded speed limit as a variable (with the assumption that speed limit is directly associated with design features), higher speeds can be expected at locations with fewer access points and with both raised and traversable medians. The study did not specifically evaluate various median configurations; however, so the researchers did not perform any control studies for comparison to the median speeds.

The use of a median with landscaping can be controversial. Landscaping improves roadway aesthetics and many argue this enhanced roadway environment has a positive influence on speed reduction. This topic is reviewed in the landscaping section of this chapter. Included with landscaping may be a variety of curb treatments. Whereas the construction of a raised curb can provide positive guidance to vehicles, curb does not prevent an errant vehicle from departing the road and crossing into and/or over the median. One current method for permitting the use of non-frangible landscaping in a median is to construct a median skirt (see Figure 1.8). This elevated curb construction is intended to deter most vehicles from accessing the median, thereby permitting the use of rigid landscaping. There does not appear to be any literature on the influence of median skirts and their companion landscaping on adjacent vehicle operating speeds. Median skirts do restrict emergency vehicles from traversing the median.

Figure 1.8: Median Skirt Photo and Example Profiles *(Boulder, CO, 2003)*

1.2.1.1.4 Reducing Number of Lanes

A useful technique for reducing vehicle speeds at transition locations is to reduce the number or configuration of lanes. A common application of this strategy is to convert four-lane roads to two-lanes plus a median (or to three-lane roads). Figure 1.9 demonstrates one way of reducing the number of lanes and including a center island to facilitate the transition zone. Burden (*2000*) suggests a reduction in number of lanes may help reduce the "top end" speeders during most hours of the day; however, these speed reductions may not occur during light-volume, off-peak hours.

An important consideration when reducing the number of lanes is the associated reduction in roadway capacity.

Corkle et al. (*2001*) evaluated converting four-lane roadways to two-lane with continuous center left-turn lanes. Based on two case studies, they suggest that reducing the number of lanes will reduce vehicle speeds only if there is enough traffic volume to cause platoons and the resulting speed reductions. If traffic volumes are low, they determined that speed reductions cannot be expected. This finding is consistently suggested throughout the traffic calming literature.

Figure 1.9: Saratoga Springs, New York Transition *(Ewing, 2001)*

1.2.1.1.5 Roadway Narrowing

Narrowing the road can be achieved either by physically reducing the roadway width or by narrowing the widths of travel lanes, often in conjunction with the addition of bicycle lanes or medians (see separate discussion on medians). In addition to helping reduce vehicle operating speeds, roadway narrowing can also reduce pedestrian crossing distances resulting in a potential safety benefit.

Based on a United States case study sample size of seven sites, Ewing (*2001*) evaluated before-after conditions for roadway narrowing. He determined that average speed reductions in the range of 2.6 mph (4.2 km/h) occurred following deployment of a variety of roadway narrowing strategies. Since his evaluation depended upon data collected by a variety of agencies, Ewing did caution that speed measurement locations could vary between sites and that this could considerably influence observed speed values.

There is considerable anecdotal literature about the speed reduction benefits of roadway narrowing; however, most analytical studies have focused on low speed streets and have used bulbouts, or chokers (complimented by medians), to achieve the speed reductions. The use of the roadway constriction devices at isolated locations, such as bulbouts and chokers, create potential safety risks for high-speed vehicles and would therefore not be appropriate as the first traffic calming strategies encountered in transitional zones. The speed reductions of narrower lanes, however, are the subject of a recently completed NCHRP research project (NCHRP 03-75 "Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas"). In this NCHRP project, performed by the Midwest Research Center, an extensive literature review determined that there is no definitive conclusion regarding the speed influence of lane widths. For example, in general 11 or 12 foot lanes perform similarly. The placement of paved shoulders, raised curb, and channelization adjacent to the travel lane appear to directly influence speed selection at higher-speed arterial locations.

1.2.1.1.6 Roundabouts

A roundabout is a circular, raised island used to facilitate traffic flow movements at intersections. The raised circular island and splitter islands on each approach help to channelize traffic into a counter-clockwise pathway. All vehicles must exit the roundabout by turning right onto a leg (no left-turn movements permitted). Priority is given to vehicles within the roundabout and entering vehicles are controlled by YIELD signs. Figure 1.10 shows an example application of a roundabout at a speed transition location. The Federal Highway Administration developed a publication titled "Roundabouts: An Informational Guide" (*FHWA, 2000*) that reviews various roundabout configurations, uses, and influences on speed and safety. The guide indicates that roundabouts have been used successfully at the interface between rural and urban regions where speed reductions (reduced speed limits) are implemented. The guide further indicates that the speed reductions are due to physical geometry rather than traffic control devices or traffic volumes. As a result, speed reductions should occur during all traffic conditions and at all times of the day. The guide also stresses that these speed reductions are achieved for one-lane roundabouts. Speed reduction benefits diminish for multi-lane roundabouts.

The *Traffic Calming Primer* by Pat Noyes & Associates (*1998*) suggests that a roundabout should primarily be used at locations where there is a need to increase intersection capacity and should not really be considered as a traffic calming strategy.

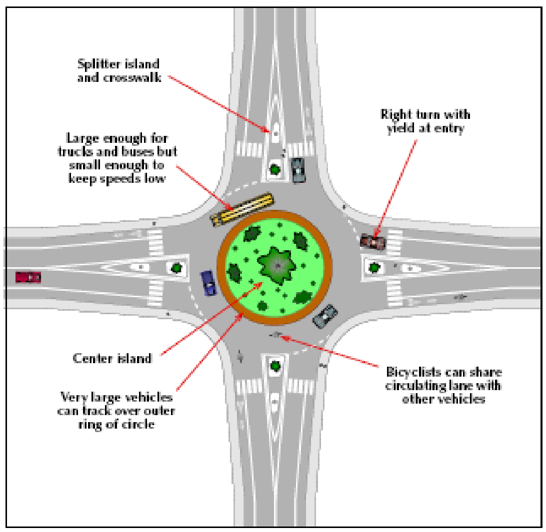

Figure 1.10: Roundabout Intersection at Transitional Area (*ODOT, 1999*)

Pates (*1998*) reviewed traffic calming techniques deployed in various countries. In the Danish example depicted in Figure 1.11, the addition of a roundabout resulted in clearly defined operating speed reductions. This observation is consistently presented in the literature for single-lane roundabouts.

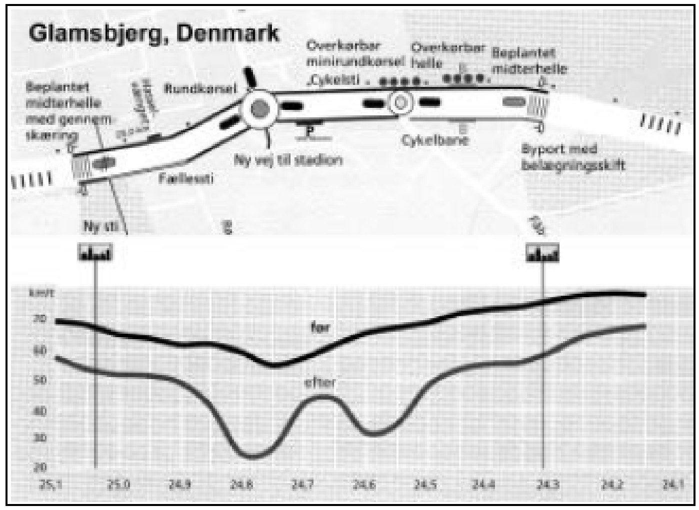

Figure 1.11: Before and After Study of Roundabout *(Pates, 1998)*

Ewing (*1999*) and Zein (*2003*) identify roundabouts as safe traffic calming alternatives to conventional intersections that can serve as both psychological and physical indicators of a transition from a rural high-speed environment to the lower-speed urban street. Ewing also indicates that the center islands of the roundabouts can be landscaped and possibly include sculptures or monuments. Many European countries use a series of roundabouts to designate transition zones. In general, they try to keep the first roundabout free of any rigid center island obstacles, but by the third roundabout (and presumably considerably lower adjacent speeds) they may include street art within the center island region.

1.2.1.2 Vertical Displacement

Vertical displacement treatments are in the form of raised pavement that requires vehicles to reduce operating speeds or experience uncomfortable travel disruptions. In general, the design speed for vertical calming treatments is quite low and, as a result, this calming strategy is typically reserved for low-speed roads. Emergency service vehicles may experience difficulty in navigating these treatments unless they are carefully designed to facilitate uninterrupted travel by such vehicles. Though four specific vertical displacement treatments were identified in Table 1, these treatments generally do not apply to high-speed roads as they tend to limit emergency service activities and substantially reduce roadway capacity. The use of the raised intersection and the speed cushion are extended to lower-speed arterials in many countries, so these specific treatments are further reviewed in this section. Though these treatments may not be appropriate for initial speed reductions, they may be suitable for use as part of a combination of speed reduction configurations.

1.2.1.2.1 Raised Intersection

Elevating the entire intersection to a level at or just below sidewalk height is one common traffic calming strategy. Often, a raised intersection is elevated anywhere from 3 to 6 inches (76 to 152 mm) above the approach travelway elevations. The intersection is also generally constructed of an alternative material such as concrete or pavers. This pavement material contrast draws the driver's attention to the elevated intersection. Each approach is ramped in a manner similar to the approach to a speed hump. Raised intersections are generally perceived to help reduce operating speeds, facilitate improved pedestrian safety, and create an attractive street feature. The use of raised intersections, however, has a few disadvantages. For example, they can be difficult to drain during inclement weather and are therefore more expensive to construct than a conventional intersection. Raised intersections are also not desirable at locations along an emergency response route as they create delays to the emergency vehicles. Finally, raised intersections often make the transition from sidewalk to roadway less defined. Though this integrates the street environment into the design, there is often a need to use supplemental devices such as bollards to help define street corners.

The Seattle publication, *Making Streets That Work* (*1996*), suggests that the best application of a raised intersection is at locations where 85-percent of vehicle operating speeds are greater than 35 mph (56 km/h). The publication indicated this traffic calming strategy is experimental. They evaluated speed reductions at one pilot site and observed only a small amount of speed reduction at the site.

Ewing (*1999*) compiled speed reduction observations for three raised intersection case studies. On average, speed reductions, after raising the intersection, were minimal at approximately 0.3 mph (0.5 km/h). The average speed of vehicles following deployment of traffic calming strategies was 34.3 mph (55.2 km/h), so the three site studies were already lower-speed facilities prior to traffic calming.

A 1994 pilot study in Toronto evaluated five raised and narrowed intersections along a lower-speed corridor and observed 85th-percentile speed reductions from 29 to 22 mph (47 to 36 km/h) and average speed reductions from 25 to 19 mph (40 to 30 km/h) (*Macbeth, 1995*).

1.2.1.2.2 Speed Cushion

An effective speed management strategy for low-speed roads with minimal emergency service vehicle activity is the speed hump. The speed hump has a more traversable vertical profile than the abrupt speed bump commonly used in parking lots or on private driveways. Due to the disruptive nature of the hump on general traffic as well as emergency service responders, its use is generally confined to residential roads. The speed cushion was developed in other countries as a way to overcome the discomfort associated with speed humps and to provide a mid-block vertical displacement traffic calming strategy that will limit delay to transit and emergency services (*TAU, 1998*) by constructing a lower profile vertical displacement with a narrower width. Speed cushions should be constructed in a series to assure sustained reductions in the operating speed. Figure 1.12 depicts a United Kingdom (UK) speed cushion. Vehicles with wide wheel bases have the ability to straddle the cushion. Researchers in the UK (*TAU, 1998*) determined that the speed cushions can reduce vehicle speeds, but that their overall speed influence is considerably less than that resulting from the more abrupt speed hump.

The effectiveness of speed humps has been widely studied and has a known speed reduction; however, the speed cushion is a relatively new strategy and has been deployed in only a few areas in the United States. One Michigan study (*Fincham, 2003*) positioned speed cushions on three corridors. After collecting speed data for one week in June 2002 (before installation) and again for one week a year later (after installation), they observed an average speed reduction of approximately 1 mph (1.6 km/h), but little overall change in the 85th percentile speed. The research team also observed a slight reduction in traffic volume at two of the three test sites.

Figure 1.12: Example United Kingdom Speed Cushion *(TAU, 1998)*

Many applications of speed cushions are in conjunction with other traffic calming devices such as gateway islands, signage, etc. One such study in the UK (*Davis, 2001*), noted average speed reductions up to 6 mph (9 km/h) and 85th percentile speed reductions up to 5 mph (8 km/h). This observation supports previous recommendations that combining traffic calming strategies is often more effective than the use of a solitary treatment.

1.2.1.3 Traffic Control Devices & Pavement Marking

The final physical treatment category for speed reduction as identified in Table 1.1 is the use of traffic control devices or pavement markings. Since design standards may differ between the various countries implementing traffic calming, several of the signing or marking strategies in the published literature were tested in other countries and though the treatments are innovative, they do not conform to the United States *Manual of Uniform Traffic Control Devices*. As a result, these techniques have not been widely used in the United States. The use of stop sign reversal is the only treatment shown in Table 1.1 that is reserved for residential-type facilities and so this particular strategy is not reviewed in the following sections. Stop sign reversal requires stop signs to be removed from the low volume roads and to be placed on the high volume roads. For the arterial application, the use of stop signs is assumed to be inappropriate at these higher speed locations.

1.2.1.3.1 Enhanced Warning or Speed Limit Signs

A wide variety of warning or speed "count down" signs for speed limit reductions may be used at rural-to-urban transition locations to help reduce operating speed. The use of stop signs is not suitable for the arterial condition; however, enhanced regulatory signs, gateway entry signs, and informational signs can all function as tools to notify a driver of the change in the road environment. Wheeler et al. (*1993*) found that the use of advance warning signing of downstream speed reductions can enhance the reduced speed limit effectiveness by influencing unaware drivers of the impending speed reduction. Stamatiadis et al. (*2006*) performed a study about the safety consequences of design flexibility in rural to urban transitions and observed that simply a change from shoulder to curb accompanied by a lower posted speed limit sign is inadequate for alerting a driver of the upcoming roadway environment changes. In their study, Statmatiadis et al. noticed no speed reductions or only slight speed reductions at locations with this simple transition configuration.

A study by Crowley and MacDermott (*2001*) evaluated traffic calming strategies implemented in Ireland from 1993 to 1996. They found the placement of a "Traffic Calming Ahead" sign at the beginning of the transition zone reduces inbound traffic speeds when they compared the speeds with and without the "Traffic Calming Ahead" sign. With the "Traffic Calming Ahead" sign in place, the 85th percentile speeds varied between 56 and 62 mph (90 and 100 km/h) at the sign location. The 85th percentile speeds at companion "Do Not Pass" signs were reduced by about 4 to 5 mph (6 to 8 km/h). Without traffic calming signs, 85th percentile speeds were observed to be reduced by 1 to 2 mph (2 to 3 km/h) in a before-after evaluation.

In the United Kingdom, researchers tested the use of an interactive sign that was activated when a vehicle exceeded a pre-set acceptable speed threshold (*Davis, 2001*). For locations with a 30 mph (48 km/h) speed limit, the threshold or trigger speed was set to 35 mph (56 km/h). For locations with a 40 mph (64 km/h) speed limit, the threshold speed was 45 mph (72 km/h). When activated, the sign (known as a roundel sign) would light up and two amber lights would flash alternately alerting the driver of the need to reduce speed. When the signs were initially placed at the 40 mph (64 km/h) sites, approximately 20-percent of vehicles exceeded the trigger speed. After one year, only 6-percent of the vehicles at the sites regularly exceeded the trigger speed. For the 30 mph (48 km/h) sites, initially 36-percent of the vehicles exceed the trigger speed. This number was reduced to 7-percent after one year of operation.

The effectiveness of gateway signs that welcome drivers to the community is a common application, particularly at residential neighborhood gateways; however, the influence of these signs on speed in not known.

1.2.1.3.2 Transverse Road Markings

The use of transverse road markings (pavement markings placed perpendicular to the direction of travel) may be used to draw a driver's attention to a change in road environment. The lines are often placed in decreasing intervals across the travel path in an effort to give the illusion of increasing speed (*Ewing, 1999*). Many jurisdictions use rumble strips as these transverse road markings to further alert the driver to the change; however, the use of rumble strips is generally perceived negatively by adjacent land owners who observe increased noise due to their placement. Painted transverse road markings are often used upstream of devices such as speed tables.

There does not appear to be published literature on the field measurement of the influence of painted transverse road markings on operating speeds; however, one Australian study evaluated transverse markings using a driving simulator. Studies that have looked at transverse markings generally focus on their placement upstream of an intersection where ultimately the vehicle is required to stop. Australian researchers Godley et al. (*1999*) evaluated "perceptual countermeasures" using a driving simulator. Godley et al. evaluated transverse lines with decreasing spacing and constant spacing for normal driving and extensive driving conditions. The researchers also evaluated peripheral transverse lines (shorter lines that do not extend complete across the travelway). The transverse lines were positioned upstream of simulated intersections. The research team used mean speeds across the length of the treatment as a measure of effectiveness. They concluded that full length transverse lines (when compared to a control road condition) reduced the simulated vehicle speed by approximately 5 mph (8 km/h) for normal driving conditions and by 7 mph (11 km/h) for extended driving conditions. For peripheral lines, speed reductions were 4 mph (6.6 km/h) and 3 mph (5 km/h) respectively. The speed reduction did not appear to be influenced by the different spacing of the transverse lines. The results of this Australian study were specifically for transverse lines preceding intersections and may not be directly applicable to mid-block conditions.

1.2.1.3.3 Colored or Textured Pavement

The use of various pavement treatments is one technique suggested for speed reduction or gateway definition conditions. The use of textured or rough pavement may help raise a driver's awareness that he or she is traversing a road segment with different physical conditions. An extreme change in pavement texture such as the use of brick or cobblestones to define low-speed conditions is known to have a direct influence on speed reduction; however, these rough pavement conditions are not appropriate for arterial roadways with higher traffic volumes. Rough pavement surfaces also make conditions difficult for pedestrians (particularly the elderly) and bicycles to navigate. The use of less abrupt textured pavement treatments can be an attractive addition to a road and can provide a visual cue to motorists of a change in street function (*Zegeer et al., 2001; Oregon*, *1999*).

The use of colored pavement can provide a clear delineation of roadway functional space. A location where colored pavement may be appropriate is at corridors that benefit from enhanced functional space delineation such as bicycle lanes (*Harkey & Zegeer*, *2004*). This can have the added benefit of making the actual roadway appear narrower (see Figure 1.13). Textured pavement can also be used to delineate the boundaries of crosswalks or as transverse pavement markings (see Figure 1.14).

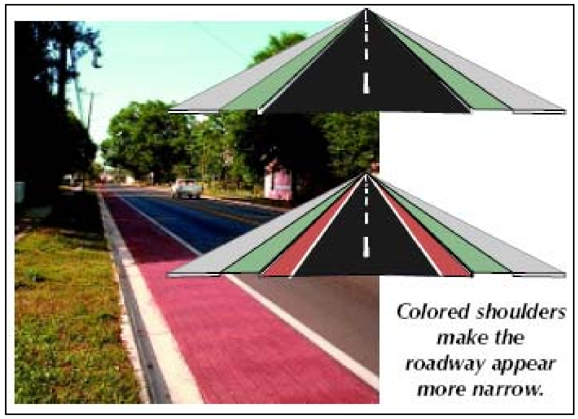

Figure 1.13: Colored Shoulders (*Oregon, 1999)*

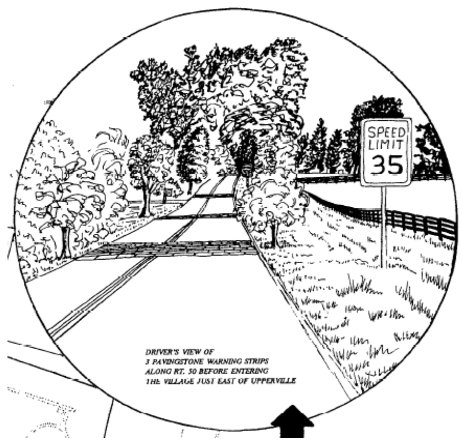

Figure 1.14: Striped Cobble Stone (*Route 50 Corridor Coalition, 1996*)

The speed reduction capability of pavement treatments is largely anecdotal as this treatment is often used in conjunction with other strategies such as gateway islands or raised intersections (*Oregon, 1999*). Kennedy (*2005*) performed a simulator trial using colored pavement alone and found that no matter how elaborate the design, this pavement treatment did not slow traffic. Kennedy did find, in both simulator and actual speed tests, that the use of colored or textured edge markings (to visually narrow the road) did have some speed reduction influences, particularly when textured edging did not appear to be a suitable driving surface.

1.2.1.3.4 Photo-Radar Enforcement

The Boulder, Colorado traffic calming toolbox (*Boulder, undated*) recommends the use of a photo-radar speed enforcement system for streets with high traffic volumes that exceed the speed limit by at least 10 mph (16 km/h). Though this strategy is not a common recommendation in the traffic calming literature, the technology is relatively new and is not generally perceived in a positive manner by the public. Anecdotal information regarding the use of photo radar speed systems in countries that have been using the technology for corridor speed enforcement suggests that the systems are effective at the specific location of placement; however, in locations where the exact photo radar system is fixed, downstream speeds do not reflect the speed reduction that occurs adjacent to the system.

1.2.2 Landscaping Treatments

Several types of roadside landscaping are commonly employed to enhance the aesthetics of the roadside environments. These treatments may include the placement of shrubbery, street trees, or alternative treatments such as landscape berms.

The Oregon guide "*Main Street-When a Highway Runs Through It: A Handbook for Oregon Communities*" (*ODOT, 1999*) recommends that trees should be spaced so that mature tree canopies grow within 10 ft (3 m) of each other to help provide shade. This placement results in tree spacing from 25 to 50 ft (7.6 to 15.2 m), depending on the tree type. The presence of roadside landscaping or street trees is perceived by many to have a calming effect on drivers that may result in reduced driving speeds. The C*anadian Guide to Neighbourhood Traffic Calming* (*TAC, 1998*) further suggests that well designed aesthetic landscaping treatments can increase drivers' awareness as well as result in lower driving speeds. A study by Cackowski and Nasar (*2003*) required participants (primarily college students) to evaluate video tapes of several corridors with a variety of landscaping treatments. The researchers concluded that roadside vegetation appears to have a calming influence on driver frustration levels; however, they also noted that these findings may not extend to locations with heavier traffic. There are many references in psychology journals that support these findings of the restorative effect of landscaping on driver perception and performance.

One Denmark report (*Herrstedt et al., 1993*) suggests that the traffic-related feature of roadside plantings may be due to the visual narrowing of the driver's field of view resulting in speed reductions. This speed reduction hypothesis is echoed in other literature, but it has not yet been empirically substantiated.

The New Zealand Guidelines for Highway Landscaping (*Transit New Zealand, 2003*) recommend plant layering where plants are grouped according to height as depicted in Figure 1.15. This plant layering approach permits the use of roadside landscaping and, as indicated in the guide, will:

- Allow wider clear zones to rigid objects
- Permit the inclusion of large trees into the roadside design
- Allow appropriate sight distance
- Permit visually appealing plant compositions

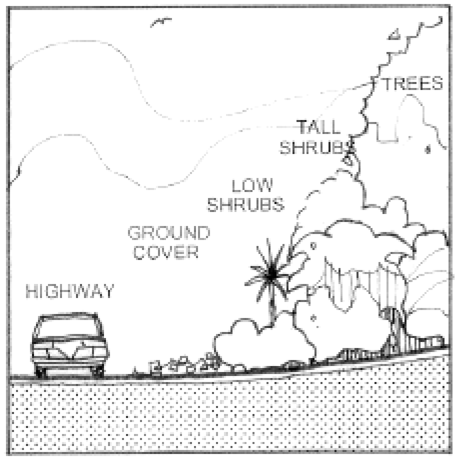

Figure 1.15: Example of Plant Layering
(Transit New Zealand, 2003)

In New Zealand, landscaping treatments are also recommended as treatments that can give the perception of an "enclosed" environment resulting in potential vehicle operating speed reductions. This *vertical elements* technique encourages the use of roadside features where the height of these vertical features is designed to be greater than the street width. This relationship is graphically depicted in Figure 1.16 where ideally the value of "w" (width of road) would be less than the value of "h" (object height). This technique provides an optical appearance of a narrow street (*Land Transport Safety Authority, 2002*). In addition to street trees, these vertical elements can also include light poles or and other elements as long as the man-made objects are frangible, and trees or shrubs do not interfere with sight lines and have narrower trunks.

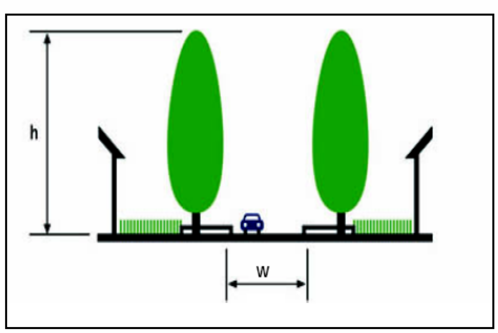

Figure 1.16: Vertical Element Scenario
(Land Transport Safety Authority, 2002)

Naderi et al. (*2006*) used a mid-level simulator (see Appendix A for simulator categories) to evaluate the influence of curb-side trees on driver behavior. They evaluated simulated urban and suburban sites with and without street trees to determine the influence of the trees on driver perceptions of safety. The researchers did note that study participants included many transportation professionals who may have entered the study with pre-conceived notions of the influence of trees on road safety. Drivers perceived suburban streets with trees as the safest streets evaluated and urban streets without trees as the least safe. The researchers also evaluated the influence of street trees on speed reduction for the suburban scenarios. They determined that participants driving at a cruising speed in the suburban landscapes typically reduced their speeds as much as 4 mph (6 km/h) for some of the simulated landscape locations. There are several studies that evaluate the perceived safety tradeoffs between street trees as rigid objects versus street trees as calming roadside influences. Studies that attempt to quantify the safety impacts have been inconclusive to date.

1.2.3 Additional Traffic Calming Strategies

The literature included several additional traffic calming strategies that may have an influence on reducing operating speed. Example strategies include improving access control, implementing publicity campaigns, and increasing targeted law enforcement. The three strategies that were cited as promising roadway design speed reduction options for transitional corridors were: the use of banners; street furniture and lighting; and higher visibility crosswalks. Each of these strategies is briefly reviewed in the following sections.

1.2.3.1 Banners

The most frequently cited gateway treatments are permanent features that will help to clearly delineate the change in street environment. An interesting concept for gateway definition as presented in the Oregon guide "Main Street … When a Highway Runs Through It" is the use of a banner extended above the roadway (Figure 1.17). This type of gateway treatment helps to clearly depict the entrance into a changing road environment and also narrows the driver's field of view potentially resulting in speed reductions. There does not appear to be any literature on the measured influence of banner placement on operating speeds.

Figure 1.17: Banner as a Gateway Treatment (*Oregon, 1999*)

1.2.3.2 Street Furniture & Lighting

In many urban areas the use of street furniture is a common approach to improving the aesthetic quality of a street. Street furniture includes items placed adjacent to the road that are there to improve the adjacent land use or to improve transportation operations. In some jurisdictions, street lights and signs are included in the category of street furniture. Example street furniture includes items such as benches, public art, trash receptacles, phone booths, fountains, kiosks, transit shelters, bicycle stands, etc. Many street furniture items are placed along the right-of-way by the property-owners themselves, as in the case of the placement of a sidewalk cafe in front of a restaurant, and are thus largely outside the engineer's control. Transit shelters are provided to protect transit riders from inclement weather and must be located close to the curb to facilitate short bus dwell times. There does not appear to be any research regarding the actual influence of street furniture on operating speed; however, the presence of these supplement items can help a driver recognize that the street environment is transitioning and should have a subsequent influence on driver-selected speeds.

1.2.3.3 Higher Visibility Crosswalk

The combination of higher speed conditions and pedestrians in the rural-to-urban regions creates concerns for pedestrian safety. Where crosswalks are critical, enhanced visibility of the crosswalk should serve to improve pedestrian safety and encourage lower vehicle operating speeds. High visibility crosswalks can range from simple painted or textured crosswalks up to crosswalks with imbedded lights for improved nighttime visibility. A common crosswalk treatment is one that includes an alternative pavement treatment and is supplemented by warning signs or lights. The influence of higher visibility crosswalks on operating speed is largely unknown, but is generally perceived to result in reduced vehicle operating speeds.

1.3 COMBINED EFFECTS OF STRATEGIES

Much of the research summarized in the previous sections indicated that individual traffic or speed calming strategies perform better when combined with other calming devices. In fact, a gateway is essentially a combination of several other calming strategies. In many cases, researchers were not able to separate the specific influence of a traffic calming device on operating speeds simply because of these combined effects. For example, the use of an entry island, lane narrowing, landscaping, and transverse pavement markings may all be combined to form a single gateway treatment. For studies that evaluated a combination of treatments, specific influences that could be quantified have been included in the summaries for the individual treatments.

1.4 TRANSITION ZONE CONSIDERATIONS

An effective method for delineating changing road environments is to divide the road into segments and apply speed reduction strategies to these individual segments. This segmentation approach permits a gradual change and allows adequate sight distance for drivers to reduce speeds appropriately. Figure 1.18 demonstrates one segmentation method as proposed by Pates (*1998*). Garrod et al. (*2002*) suggest this transition zone should be divided into two discrete segments. The first segment is the approach to the actual change in environment and should be used to warn drivers of the downstream environment and encourage driver behavior changes. The second segment is then at the changed environment and would then use measures that ensure speed reductions. Figure 1.19 shows a similar two-part transition as proposed by the Vermont Agency of Transportation.

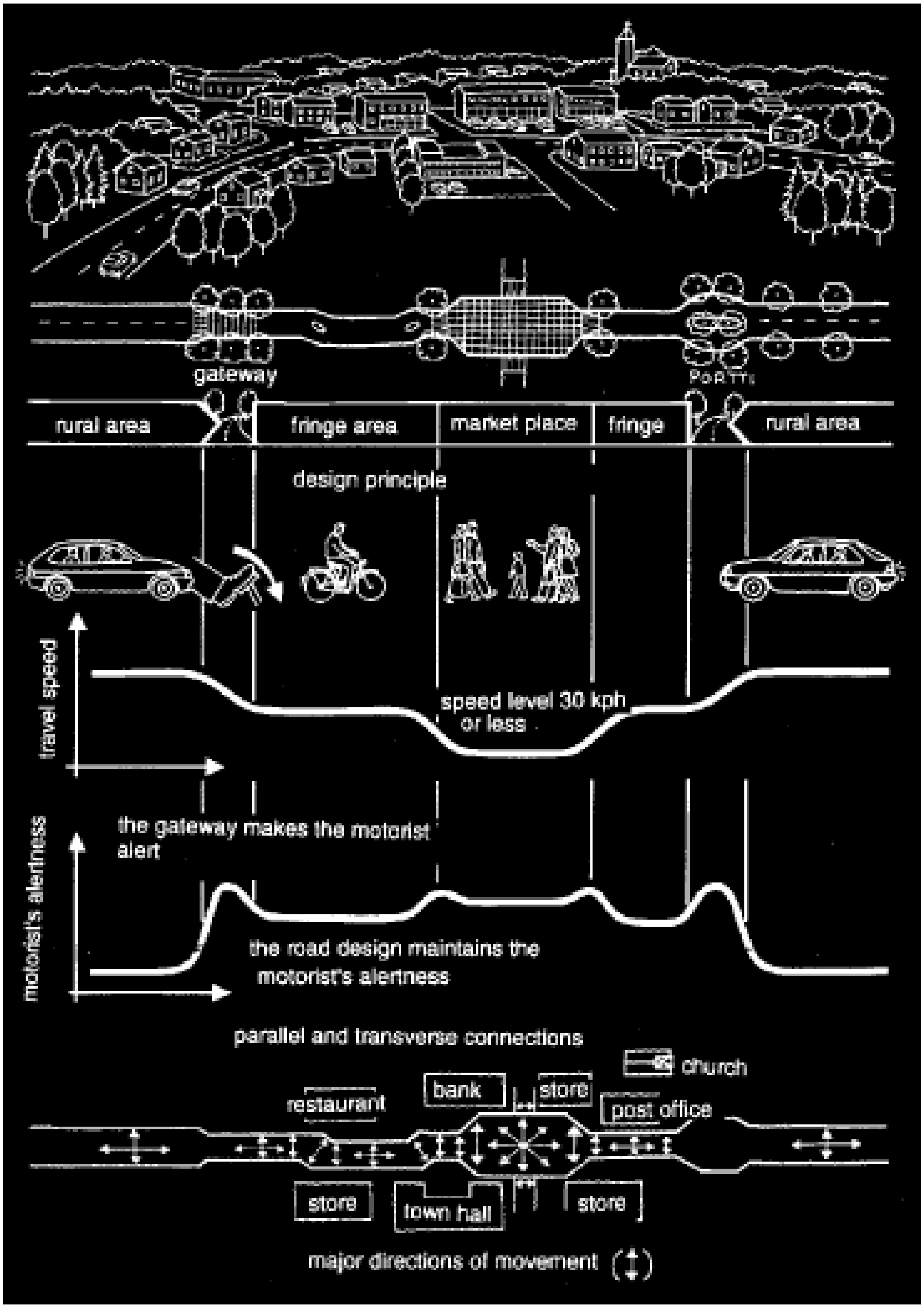

Figure 1.18: Roadway Segmentation (Pates, 1998)

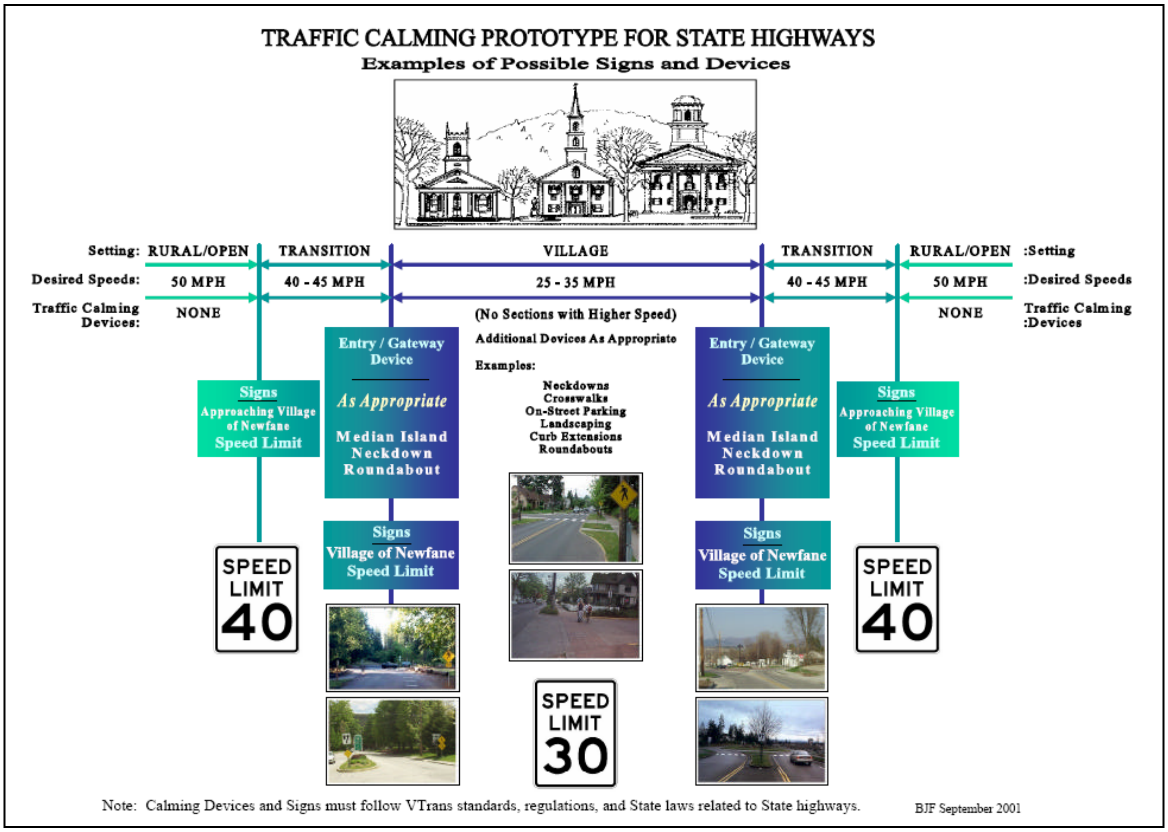

Figure 1.19: Traffic Calming Prototype for State Highways (*The Vermont Agency of Transportation, 2003*)

1.5 OVERVIEW OF TREATMENT ESTIMATED COSTS

The various candidate treatments reviewed in this chapter for potential speed reduction in the rural-to-urban transition corridor have a wide range of costs. Table 1.3 shows expected cost information depicted in the literature (when available) and also presents cost categories of low, moderate, and high cost. Since the literature included a wide variety of estimated costs, often for the same treatment, the cost values shown in the table are consistent with the more frequently cited cost estimates. For some treatments, actual cost information was not available in the published literature. In general, the “low” cost category represents deployment costs of $10,000 or less; the “moderate” category represents deployment costs of $10,000 to $20,000; and the “high” cost category is for construction costs greater than $20,000.

Table 1.3: Potential Traffic Calming Treatments for Rural-to-Urban Transitions

Treatment	Estimated Treatment Cost	Cost Category
Physical Treatments:		
Horizontal Displacement:		
Gateway	$10,000 to $20,000	Moderate
Center Island / Raised Median	$6,000 to $15,000 (Island), $15,000 to $30,000 per 100 feet (Median)	Low to Moderate
Reducing Number of Lanes	$15 to $25 per linear foot	Moderate to High
Roadway Narrowing	$50 per foot (physical narrowing), $0.20 per foot (re-striping)	Low (re-striping), High (physical)
Roundabout	$25,000 to $150,000 (On Major highway as much as $500,000)	High
Vertical Displacement:		
Raised Intersection	$25,000 to $120,000	High
Speed Cushions	$1000 to $3000 each	Low
Traffic Control Signs & Pavement Marking:		
Enhanced Warning or Speed Limit Signs	Varies per design ($2,000 to $15,000 for speed display boards, $100 to $200 for static signs, for example)	Low to Moderate
Transverse Road Markings	$1,000 to $5,000	Low
Colored or Textured Pavement	Varies	Moderate
Photo-Radar Enforcement	$85,000 to $190,000 (generates revenue to offset cost)	High
Landscaping	$1,000 to $10,000 typical	Low to Moderate
Other Treatments		
Banners	Not in published literature	Low
Street Furniture & Lighting	Varies	Low to Moderate
Higher Visibility Crosswalk	$300 (painted) up to $5,000 (patterned concrete)	Low

Source: Burden, 2000; Ewing, 1999; Harkey & Zegeer, 2004; Pat Noyes, 1998; Saffel, 1998; TAC, 1998

1.6 SIMULATION SPEED STUDIES

While there is a great deal of research focusing on the effects of specific roadway treatments in specific locations, it is difficult to compare these results as the studies have been conducted in various environments involving different driver characteristics. Moreover, it is difficult to conduct such comparative research in the field. More importantly, field studies may create a potential safety risk for drivers unfamiliar with the conditions of the driving environment being tested. Such studies can also be expensive to construct in the field and time-consuming to assess.

One alternative way to test multiple treatment effects is by using a driving simulator study, a conclusion supported by Godley et al. (*2001*) who found the advantages of their simulator study, over a real world evaluation, to be "experimental control, efficiency, expense, safety, and ease of data collection." The 2005 European technology scan for Roadway Human Factors and Behavioral Safety in Europe also identified support for using driving simulators as a key tool in developing appropriate roadway designs (*Keith et al.*). Similar to Godley, this technology scan concluded that major benefits to simulator roadway design studies include the ability to fix design errors with ease and at limited relative expense. For example, the French National Institute for Transport and Safety Research (Institut National de Recherche sur les Transports et leur Sécurité (INRETS)) owns a driving simulator investigated in the technology scan. INRETS has been involved in several speed studies looking at driver behavior and modifying roadway environments based on the results. One such speed study analyzed the effects of narrow lanes on lane-keeping, finding that speeds decrease up to 15 percent when lanes are narrow (*Keith et al, 2005*).

Simulator studies have been conducted to validate the simulation results relative to those of the real world. Table 1.4 outlines the benefits and costs of both low and high fidelity simulators studied in the technology scan with those of field studies. As this table shows, high fidelity simulators that are characterized by high audio quality are more advantageous than field studies in all areas except for relative cost where the two options are comparable and for degree of realism where the high fidelity simulator, though rated as medium to high, does not compare with the realism of on-the-road studies. Similarly, low fidelity simulators are more advantageous than field studies in all aspects except for the degree of realism and the ability to study a range of highway geometrics.

A considerable amount of simulator research has also been conducted to establish the absolute and relative validity of simulators. The study reported here uses these terms referenced in repeated studies (*Godley et al., 2001; Keith et al., 2005*). **Absolute validity** is referred to by Godley as "the numerical similarity between the speeds of an instrumented car and speeds in the simulator," while **relative validity** is established when the "differences between two speed results are in the same direction and of the same magnitude." The European technology scan found that an important factor in using simulators is that simulator behavior can predict road behavior (*Keith et al., 2005*).

Table 1.4: Benefits and Costs of Simulation and Road Studies *(Keith et al., 2005)*

Benefits/Costs	Low-Fidelity Simulation	High-Fidelity Simulation	On-the-Road Studies
Ability to study relevant driver behaviors	Medium-High	High	Medium
Ability to study range of highway geometrics	High	High	Medium
Ability to study range of traffic conditions	Medium	High	Medium
Control over experimental conditions	Medium-High	High	Medium
Degree of realism	Medium	Medium-High	Very High
Relative cost	Medium	High	High
Risk to driver	Very Low	Very Low	Low-Medium

To test the simulator validity, the 2001 study by Godley, Triggs, and Fildes used a three-dimensional sound system in conjunction with a vertical motion-based simulator projecting computer graphics onto three front screen panels providing a 180 degree field of view, 60 degrees of rear vision, and 45 degrees of vertical vision. They compared a control roadway with a roadway containing rumble strips under three conditions: approach to a stop sign controlled intersection; approach to a right curve; and approach to a left curve. These same conditions were then tested in the field using an instrumented vehicle. All sites were two-lane suburban roads with speed limits of 36 mph (60km/h).

For the stop sign controlled approach, the treatment case in both the simulator and the instrumented vehicle showed significantly lower speeds than the control. The findings for the stop approach exhibited similar behavioral patterns for both the simulator and the instrumented vehicle. This indicates absolute and relative validity for the straight road scenario. For the right curve approach as well as the left curve approach, the instrumented vehicle experiments showed insignificant speed differences between the treatment and the control, while the simulator showed a significantly slower speed in the treatment scenario than for the control. Therefore, they did not establish absolute validity for the curve approaches, but did establish relative validity as the speed trends from the simulated results were similar. While this experiment established relative validity for both straight and curved approaches, it analyzed only one treatment, rumble strips. The lane widths also differed between the simulator and the field conditions, emphasizing one problem with comparing results: difficulty in matching the conditions.

Expanding on Godley et al.'s 2001 study, researchers in Minnesota conducted an investigation comparing the absolute and relative validity of simulator and field results using several different treatments on residential roads (*Corkle et al., 2001*). One aspect of the field study involved a combination of lane width reduction, choker, and plantings indicating a significant speed reduction in only one direction; however, it did not determine the precise role of each of the three treatments in this reduction. This site was re-created in two simulated environments-- one prior to treatment and one including the treatments. These results indicated a significant reduction at the treatment location, finding speeds similar to those collected in the field. However, a comparison of the speeds between the field and the simulated environment away from the treatment found higher speeds in the simulator than in the field. Therefore, the study did not determine absolute validity between the simulated and the field results.

In determining the relative validity of the simulator, the Corkle et al. study (*2001*) tested different combinations of medians, chokers and landscaping. In the simulated environment, both the median and choker were individually successful at reducing speeds as seen in Figure 1.20. In addition, the combination of median and choker indicated a significant decrease in mean speed, though only slightly more so than the decrease due to the median alone.

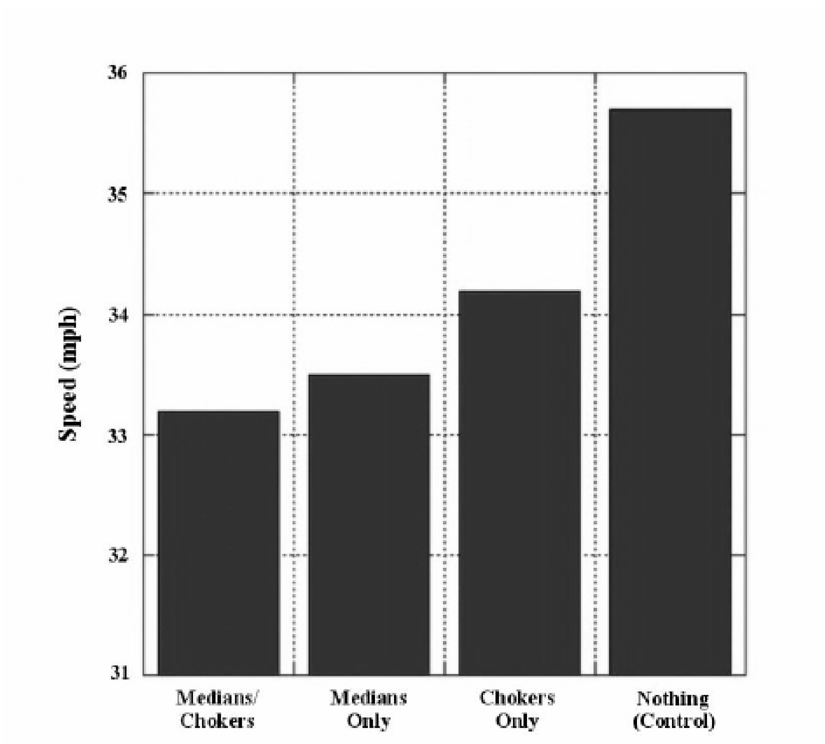

Figure 1.20: Effects of Curb Treatments on Speeds

In addition, the Corkle et al. study (*2001*) compared the simulated effects of adding plants in all treated and control scenarios. Although not significant, the plantings resulted in speeds comparable to the no-planting condition in all cases but the control as shown in Figure 1.21. On the other hand, the plantings in the control scenario resulted in higher speeds. These results indicate similar speed trends for both the individual and combination treatments, signifying both relative validity and the ability to compare accurately relative speed changes across different treatments. The results did not achieve absolute validity, possibly caused by the fact that the simulated environment did not provide an exact portrayal of the roadside, omitting other key influences such as vehicles, landscaping, and pedestrians.

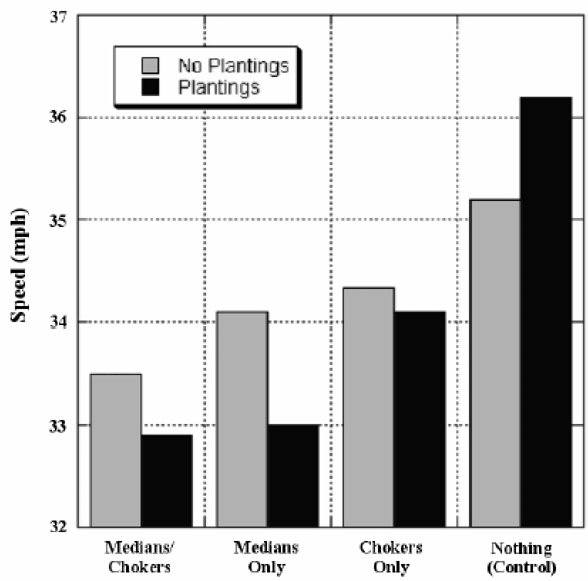

Figure 1.21: Effect of Plantings on Speeds

A United Kingdom study conducted by Uzzell and Muckle (*2005*) used a photographic simulation technique to determine absolute and relative validity of perceived driver speeds. Their study involved surveying the public to determine expected driving speeds using original and altered photographs of an existing roadway. The treatments Uzzell and Muckle tested included a grass center dividing the opposing travel directions, white edge lines to narrow the road, narrowed lanes, and cattle grids. Their results indicated that the mean perceived speed on the experimental road compared to the actual speed on the road were "well within the confidence interval" corresponding "very closely with the average 85th percentile speed" (*Uzzell and Muckle, 2005*). Respondents to the survey also indicated that while the hypothetical addition of white lines would cause them to increase their speeds significantly over the experimental condition, the addition of grass in the center of the travel lanes would cause the greatest speed reduction, approximately five mph. The findings of this study indicate similar trends between the conditions, providing relative validity. In addition, Uzzell and Muckle indicated they would expect absolute validity for the control scenario, but since they did not have actual driving data for the treated conditions they could not definitively establish absolute validity for the simulation.

Previous driving simulator studies have often focused on specific location needs to alter existing designs rather than providing solutions for overall design guidelines. For example, a study conducted using the VTI simulator examined the best lighting for the Laerdal Tunnel in Norway (*Keith et al, 2005*). Other studies, such as those conducted using the National Advanced Driving Simulator (NADS) at the University of Iowa have looked at driver distractions, driver impairment, and other aspects of driver behavior. The driver behavior studies executed using the NADS simulator have focused on young driver risk and validating simulation driving performance with actual driving performance. Throughout simulator research there has been little focus on the effects of altering engineering aspects of roadway design.

2.0 RESEARCH METHODOLOGY

The purpose of this research effort was to determine the effectiveness of roadway treatments in reducing speeds as vehicles travel through a rural-to-urban transition area. This "transition area" is assumed to be the location on a rural road prior to entering a rural town or suburban community where speed limits are reduced to accommodate the changed environment. Based on potential treatment strategies identified in the literature review portion of this project and perceived suitability for such treatments to be reasonably assessed using a driver simulator study, the research team identified 13 candidate roadway treatments for evaluation in an initial simulator pilot study. The primary purpose of this initial pilot study was to develop sample environments and determine how closely they resembled a realistic depiction of the candidate treatment. These 13 treatment configurations are summarized as follows and further reviewed in the Pilot Study I discussion, Section 2.3.

1. Median with Tall Shrubs
2. Layered Landscaping
3. Lane and Shoulder Narrowing
4. Gateway Treatment
5. Traversable Lines Perpendicular to the Road
6. Traversable Lines Parallel to the Road
7. Roadside Trees Only
8. Banner Across Road
9. Roadside Billboard
10. Median with Small Shrubs
11. Median with Medium Shrubs
12. "Speed Enforced By Radar" Sign
13. Transverse Lines with Decreasing Spacing

Following evaluation of the 13 treatments, the research team further refined the candidate treatment list and reduced the list of potential treatment strategies to six treatment configurations for the second pilot study (Pilot Study II). This pilot study included preliminary simulator testing with college students to determine scenario realism and refinement needs. Pilot Study II incorporated the following six configurations:

1. No Treatment – Control section with two-lane highway
2. Layered Landscape
3. Gateway with Lane Narrowing
4. Gateway with Median
5. Medians in Series with Pedestrian Walks
6. Median with Small Shrubs

Based on observations resulting from Pilot Study II and following additional treatment refinement, the research team initiated a full scale simulator study.

As a result, the simulation study included five different phases:

1) Procedure Identification and acquisition of Institution Review Board (IRB) for Human Subjects approval
2) Pilot Study I
3) Pilot Study II,
4) Full Scale Test
5) Data Analysis.

The next two sections of this chapter briefly outline the materials required for the study as well as descriptions of the participant training. These are followed by discussions of the various simulator tests and analysis procedures.

2.1 MATERIALS

The research team elected to perform the simulator tests at the Clemson University driving simulator lab located in Clemson, South Carolina. The driving simulator consists of four projector screens -- three forward screens that provide a 120-degree field of view, and one rear screen that provides a 40-degree rear field of view. The software used in the simulator was developed by Drive Safety, while the program to run the simulation is known as Vection. The Drive Safety software allows for programmable traffic, signal settings, road type, development type, density, and roadside elements. The software can acquire data for velocity, acceleration (both latitudinal and longitudinal), lane position, and numerous additional variables.

The simulator equipment includes an authoring computer and the actual driving simulator vehicle. The car is a 1989 Mitsubishi Galant with functional steering, acceleration, braking, automatic transmission, and turn signals. The authoring station is an independent Dell Pentium running the program Hyperdrive to create and transfer the scenarios to the simulator. The simulator also has an audio system that outputs engine noise, wind noise, tire squeal, and traffic noises.

2.2 TRAINING SESSIONS

Prior to allowing a human subject to participate in the experimental data portion of the simulator study, the potential candidate participated in mandatory training sessions. In the first portion of the training session, the “driver” traversed a straight road with a speed limit of 55 mph and an “Out of Lane” message periodically appeared on the screen if the driver exceeded the lane boundaries. There was also a warning voice indicating the driver should “slow down” if he or she drove over 60 mph. The second portion of the training session presented the participant with a curvilinear road with a speed limit of 55 mph. This scenario also included an “Out of Lane” message displayed on the screen and a warning voice if he or she drove over 60 mph. In the first two portions of the practice session, the driver was encouraged to maneuver “side to side” in order to get comfortable with the boundaries of the lane. The third and final portion of the practice session also included a curvilinear road. This part of the training session lasted for five minutes and drivers did not receive warning regarding speed or lane position. The research team recorded data for this practice session and evaluated the baseline requirements to ensure the driver’s capabilities in the simulator prior to collecting experimental data for subsequent simulator studies. If the participant did not pass the basic session requirements, he or she was asked to repeat the scenario.

The baseline assessment requirements were as follows: 1) the driver maintained an average speed of 45 mph or higher, and 2) the driver was within the lane at least 85-percent of the time. Once the participant proved capable of simulator driving, he or she was then given a break to rest prior to participating in the experimental data simulation study.

2.3 PILOT STUDY I

As previously indicated, Pilot Study I included 13 simulated roadway treatments. The scenarios consisted of driving through a rural environment, then entering a transition zone, and finally a town. Each scenario contained only one treatment and lasted approximately five minutes. Twenty university students participated, with each student “driving” through approximately 50-percent of the scenarios. The order of and specific scenarios reviewed by each participant were randomly assigned. Each test scenario in the study consisted of a “driver” traversing a curvilinear section that has a speed limit of 55 mph followed by a straight section of road. The “driver” then entered a straight transition area (with the specific study treatment) followed by a small town. The simulated towns appeared consistent as far as building density, access control, and roadway environment. Snapshots of the 13 Pilot Study I treatments are depicted in Figure 2.1 through Figure 2.13.

__Treatment #1:__ Median with Tall Shrubs as shown in -- A center-island median shown as the driver entered town with tall shrubs blocking visibility to the other side of the road

Figure 2.1: Median with Tall Shrubs for Pilot Study I

__Treatment #2:__ Layered Landscaping as shown in Figure 2.2 -- Shrubs and Trees perpendicular to the road with shorter landscaping positioned laterally closer to the road and taller landscaping located further from the road

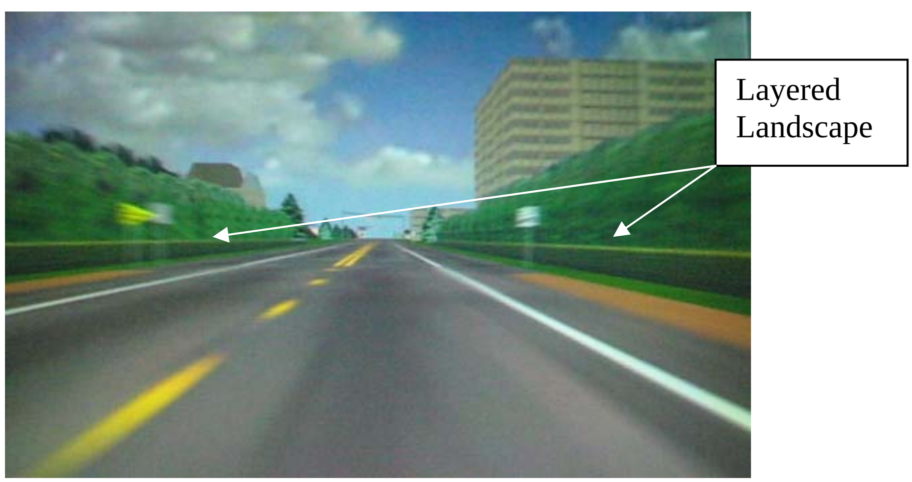

Figure 2.2: Roadside Layered Landscape for Pilot Study I

Treatment #3: Lane and Shoulder Narrowing as shown in Figure 2.3 -- Shoulder narrows to edge of lane and the lane width decreases from 12 feet to 11 feet

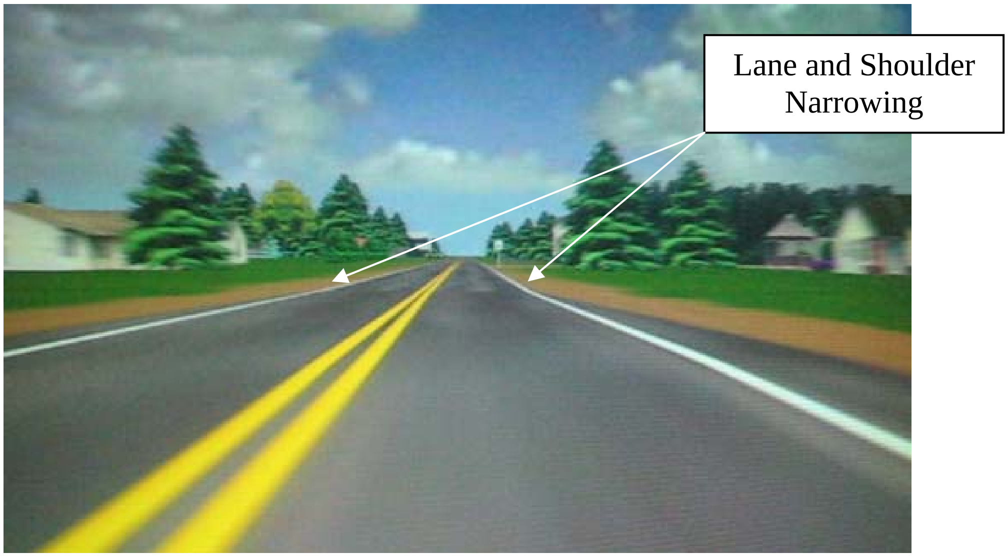

Figure 2.3: Lane and Shoulder Narrowing for Pilot Study I

Treatment #4: Gateway as shown in Figure 2.4-- A welcome sign surrounded by landscaping that helps to demarcate an entrance to the town

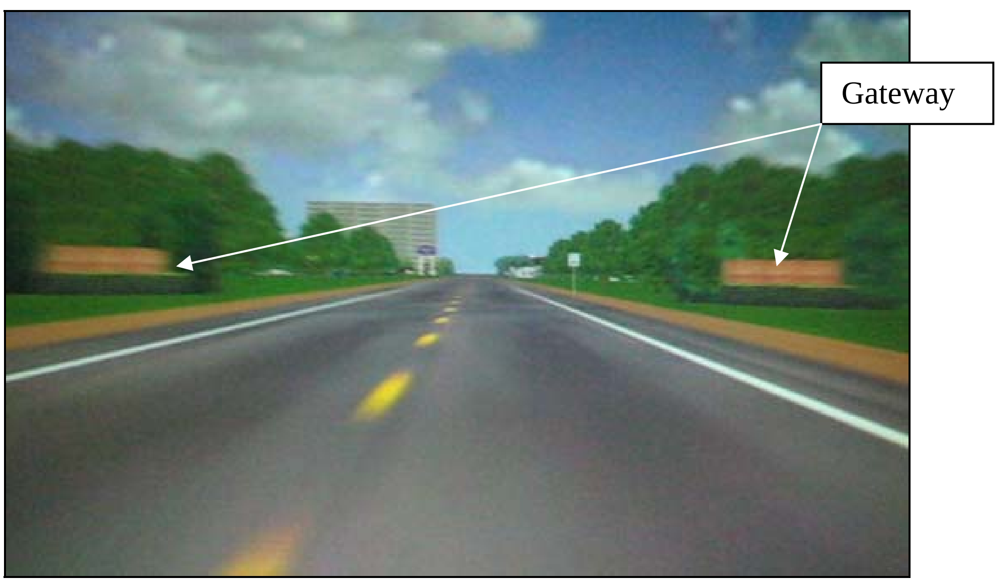

Figure 2.4: Gateway Treatment for Pilot Study I

Treatment #5: Traversable Lines Perpendicular to the Road as shown in Figure 2.5 -- 1.5 feet thick (similar thickness to a stop bar) white lines spanning the roadway in sets of five with decreasing spacing to give the sensation of an increase in speed

Figure 2.5: Traversable Lines Perpendicular to Road for Pilot Study I

Treatment #6: Traversable Lines Parallel to the Road as shown in Figure 2.6 -- 1.5 feet thick and 14.5 feet long white lines along the travel path and constructed in sets of five

Figure 2.6: Traversable Lines Parallel to Road for Pilot Study I

<u>Treatment #7:</u> Roadside Trees as shown in Figure 2.7 – Numerous roadside trees along the side of the road so that they help demarcate an entrance to the town

Figure 2.7: Roadside Trees for Pilot Study I

<u>Treatment #8:</u> Banner as shown in Figure 2.8 -- Large sign positioned above the road welcoming the driver to the town

Figure 2.8: Banner across Road for Pilot Study I

Treatment #9: Billboard as shown in Figure 2.9 -- A large sign on the roadside (similar to the shape of an advertising billboard) that welcomes the driver to the town

Figure 2.9: Roadside Billboard for Pilot Study I

Treatment #10: Median with Small Shrubs as shown in Figure 2.10 – A center-island median treatment with small shrubs that the driver can easily see over

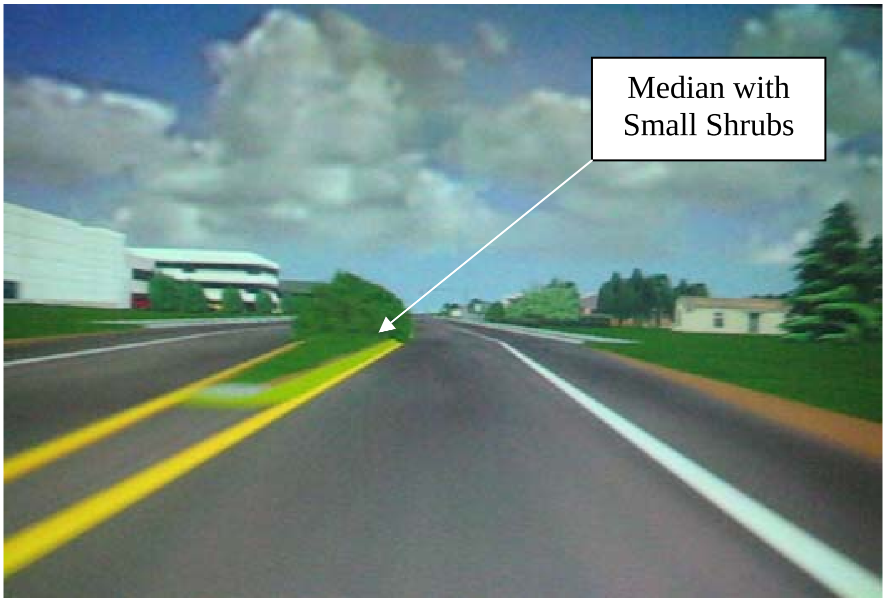

Figure 2.10: Median with Small Shrubs for Pilot Study I

Treatment #11: Median with Medium Shrubs as shown in Figure 2.11 – A center-island median treatment with shrubs at a height in which the driver can barely see over

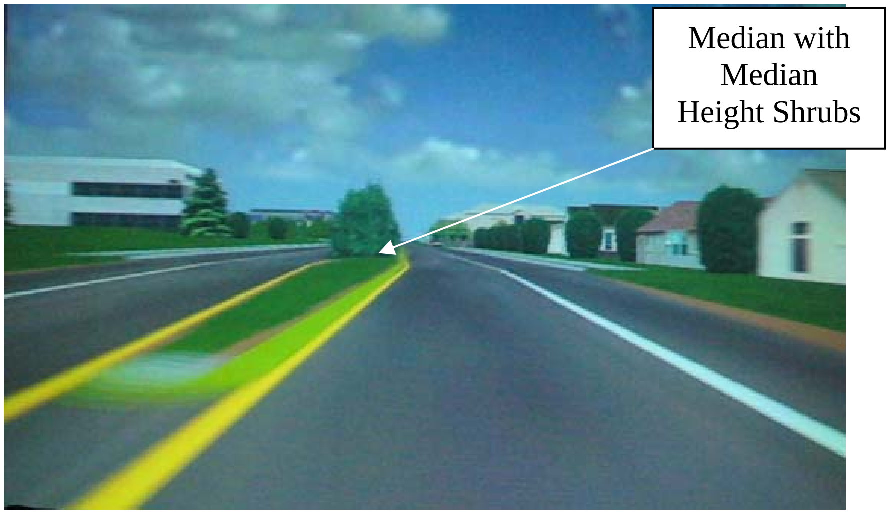

Figure 2.11: Median with Median Shrubs for Pilot Study I

Treatment #12: "Speed Enforced by Radar" Sign as shown in Figure 2.12 -- A sign the size of two standard speed limit signs that reminds drivers that speeds are enforcement within this jurisdiction

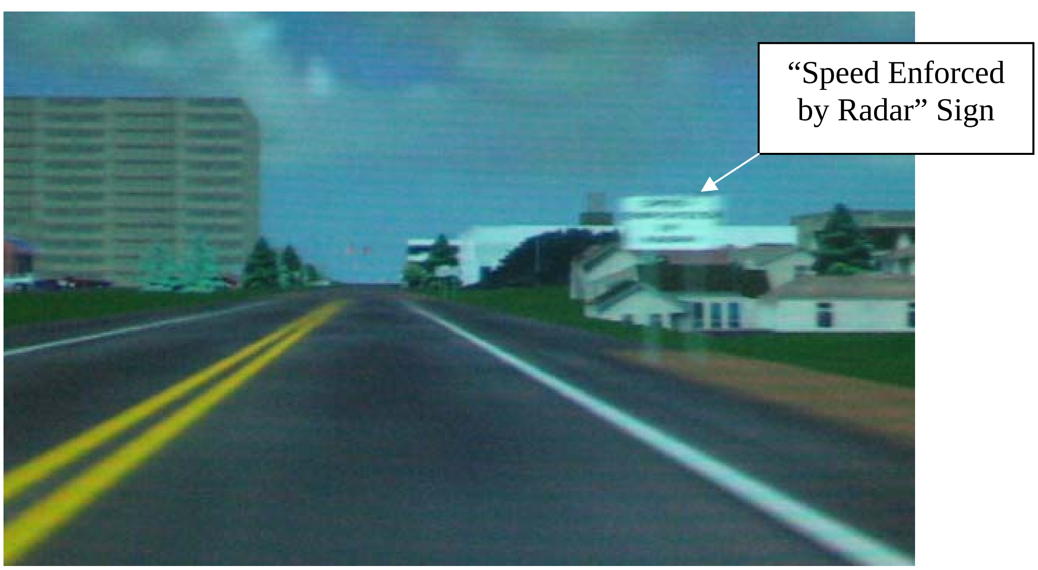

Figure 2.12: "Speed Enforced by Radar" Sign for Pilot Study I

Treatment #13: Transverse Lines with Progressive Decreasing Longitudinal Spacing as shown in Figure 2.13 -- One set of white lines spanning the width of the road entering town with decreasing spacing between each to give the sense of increasing speed

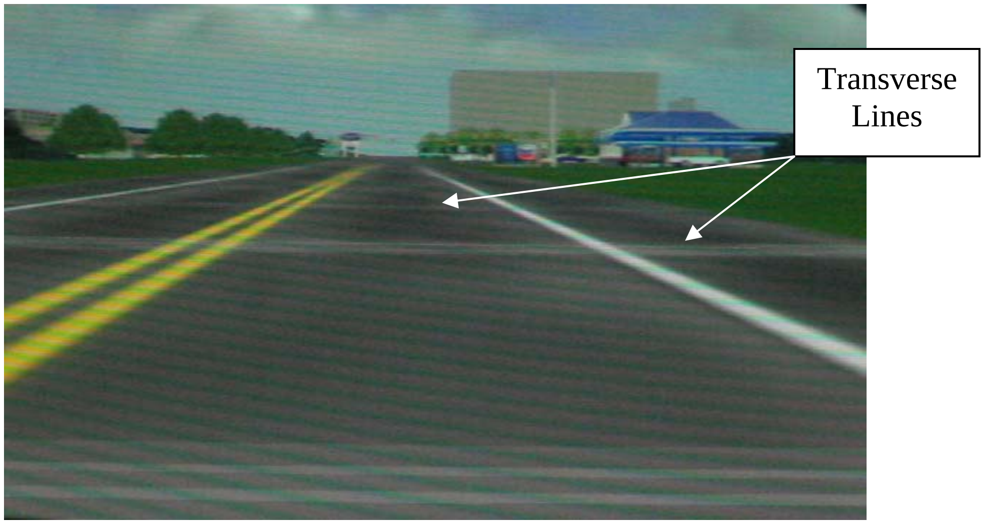

Figure 2.13: Transverse Lines with Progressively Decreasing Longitudinal Spacing for Pilot Study I

The simulation monitoring team recorded data samples at specific coordinates upstream of the treatment, within the treatment area, and downstream of the treatment at each town entrance. This analysis included the display of points of interest with dimensioned distances to show the speed related signs and the locations of the treatments. The research team also analyzed the data for the physical location of the signs. For each scenario, members of the research team plotted and compared the associated speed data. The data provided consistent indications that drivers were slowing at the treatments; however, the researchers did not conduct further statistical analysis for the Pilot Study I treatments. They observed confounding variables that appeared to influence driver speed choice; one such variable was a traffic signal visible from the treatment area. The researchers hypothesized that a visible downstream red traffic signal could affect speed results at the study treatment locations. An example plot of speed data from the first pilot study is shown in Figure 2.14. Appendix H (see Figure H1.1 through Figure H1.13) includes speed and dimension plots for the simulations included in Pilot Study I.

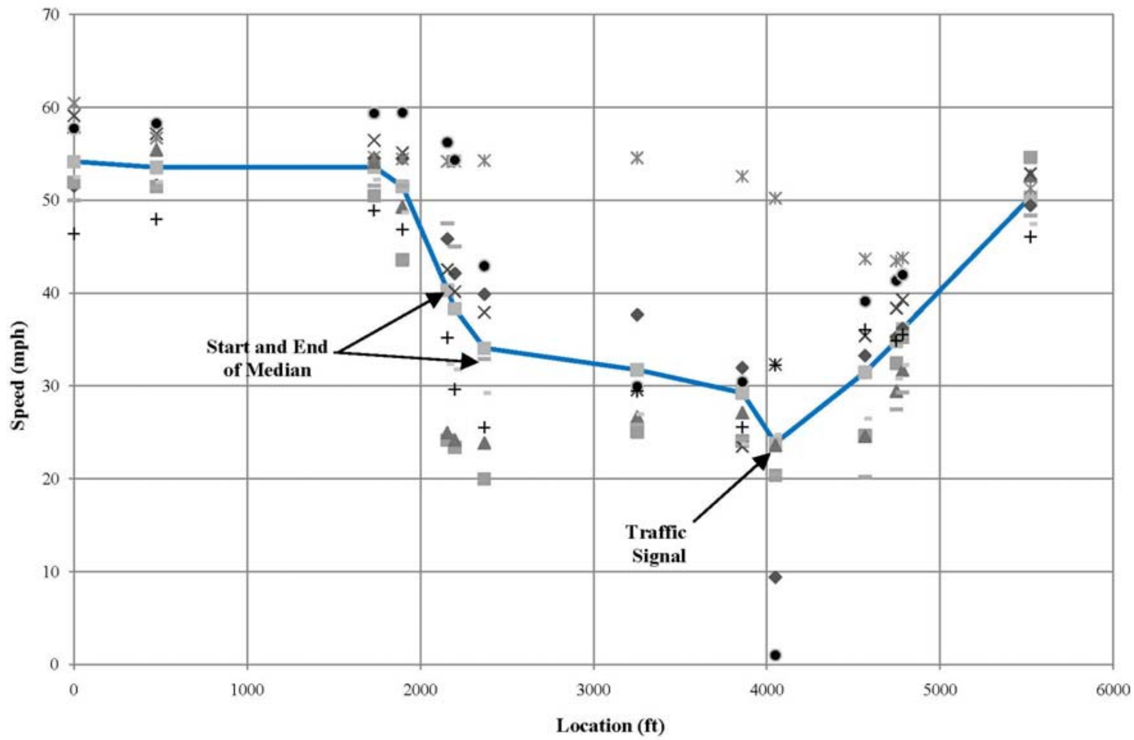

Figure 2.14: Example of Mean Speed Results of Median Treatment for Pilot Study I

Data from Pilot Study I provided insight into the capabilities and limitations of the simulator as well as future considerations for the design of the scenarios. This study also provided data from which the researchers could determine the effectiveness and realistic nature of the treatments. This allowed the research team to eliminate ineffective treatments before Pilot Study II. In this process, the pavement markings were eliminated as the fixed based simulator did not give the full effect of pavement markings with the sounds and feel of the change in texture. The banner, billboard, and ‘Speed Enforced’ sign were also eliminated as the simulated environment did not provide realistic versions of the signs as would be found in an entrance to a small rural town. Only the median option with small shrubs was carried forward for further research. Other median designs with larger shrubs and trees were abandoned due to issues related to sight distance and fixed object hazards associated with actual implementation. In addition, the research team retained the layered landscape treatment for further analysis. The researchers also decided to combine several of the individual treatments from the Pilot Study I into a variety of combinations such as a gateway with lane narrowing, gateway with median, and four medians in a series. The literature indicated that individual treatments have limited influence on speed, but a combination of treatments can be effective. The Pilot Study II scenarios included this assumption for analysis.

The researchers decided to change several components of the driving environment following Pilot Study I. These included:

- Incorporated a “Control” scenario that does not have any traffic calming treatments. This scenario could then be used as a baseline comparison to other treatment configurations.
- Removed traffic signals that were visible from the transition area
- Modified any remaining downstream traffic signals to be set to green so they would not affect speed data.

Another consideration resulting from Pilot Study I was the consistency of the transition areas as far as speed limit and location relative to the town. For control in the future scenarios the speed limit would be consistent between the scenarios. The speed limits drop from 55 mph in the rural settings to 45 mph in the transition area (where the treatments are located) and to 35 mph in the town area. The most appropriate location for the transition area is prior to entering the town, as previously discussed. Another minor adjustment to the simulated driving environment included the addition of oncoming traffic to make the scenarios more realistic. Finally, the research team narrowed down the 13 treatments to six treatments to be tested in Pilot Study II.

2.4 PILOT STUDY II

Following the identification of both limitations and strengths for the various treatments evaluated in Pilot Study I, the research team conducted Pilot Study II. For this pilot study, 14 previously untested university students participated. The purpose of this Pilot Study II was to further refine the strategies and validate potential treatments identified in Pilot Study I. At the conclusion of Pilot Study II, the research team would proceed to full-scale testing, so any lingering questions regarding treatments were targeted during Pilot Study II. As previously indicated, all participants were required to participate in practice scenarios and to pass the baseline requirements prior to entering the data evaluation stages of Pilot Study II. The treatments included in Pilot Study II were:

Treatment #1: Control section for baseline purposes -- This scenario included the standard 55-45-35 mph speed reduction but did not have any additional speed reduction treatments.

Treatment #2: Layered Landscape as shown in Figure 2.15 – Shrubs and Trees perpendicular to the road with shorter landscaping positioned laterally closer to the road and taller landscaping located further from the road.

Figure 2.15: Roadside Layered Landscape for Pilot Study II

Treatment #3: Gateway with Lane and Shoulder Narrowed – Shoulder narrowed to edge of lane and the lane width decreased from 12 feet to 11 feet (see Figure 2.16). This transition is followed by a roadside gateway welcome sign (see Figure 2.17). The gateway treatments included combinations of roadside signage and landscaping.

Figure 2.16: Lane Narrowing for Pilot Study II

Figure 2.17: Gateway Treatment for Pilot Study II

Treatment #4: Gateway with Median – This treatment was characterized by a roadside gateway welcome sign placed in the vicinity of median treatments. The gateway treatments included combinations of roadside signage and landscaping. Figure 2.17 depicts the gateway sign configuration used for both treatments #3 and #4.

Treatment #5: Short Medians in Series with Pedestrian Crosswalks as shown in Figure 2.18 – This treatment included the placement of a group of medians where the first median does not include a crosswalk but subsequent medians do provide a pedestrian crossing facility. The medians in series included four successive median treatments. The pedestrian crosswalks included pavement markings and signage alerting the driver of the pedestrian crosswalk.

Figure 2.18: Pedestrian Crosswalk for Pilot Study II

__Treatment #6:__ Linear Median with Small Shrubs as shown in Figure 2.19 – The use of a linear median with small shrubs planted that do not impede sight distance requirements.

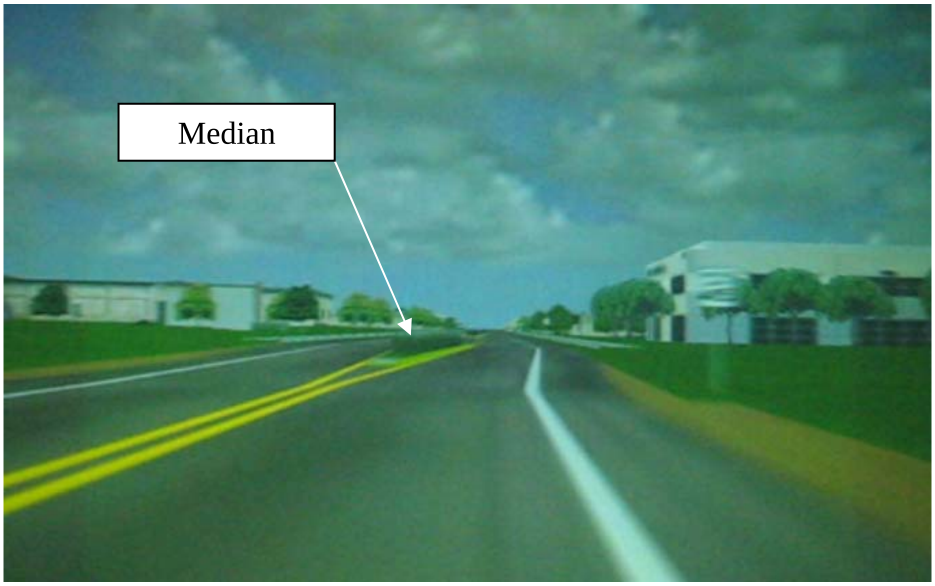

Figure 2.19: Median Treatment for Pilot Study II

In Pilot Study I, each participant traversed a five minute simulator world for the individual study treatments. For Pilot Study II, the research team combined the six treatments into two simulator worlds. Each "world" included three test treatments, and required approximately twenty minutes for participants to drive in the simulator. Within the simulator worlds, the participants would drive through rural curvilinear road segments into small towns with treatments positioned at the entrance to the towns. Three rural driving segments were separated in each world with three small towns located after the transition areas.

Pilot Study II generated data similar to that resulting from Pilot Study I. This data included both speed and speed variability at specific coordinates for each treatment configuration. The research team evaluated speed data at critical points of interest (locations of posted speed signs and treatment locations) and then visually and quantitatively compared data for the various subjects (participants) to determine average speed reductions through the transition areas. An example plot of the speed data is shown in Figure 2.20. Standard deviation speed results are shown in Figure 2.21.

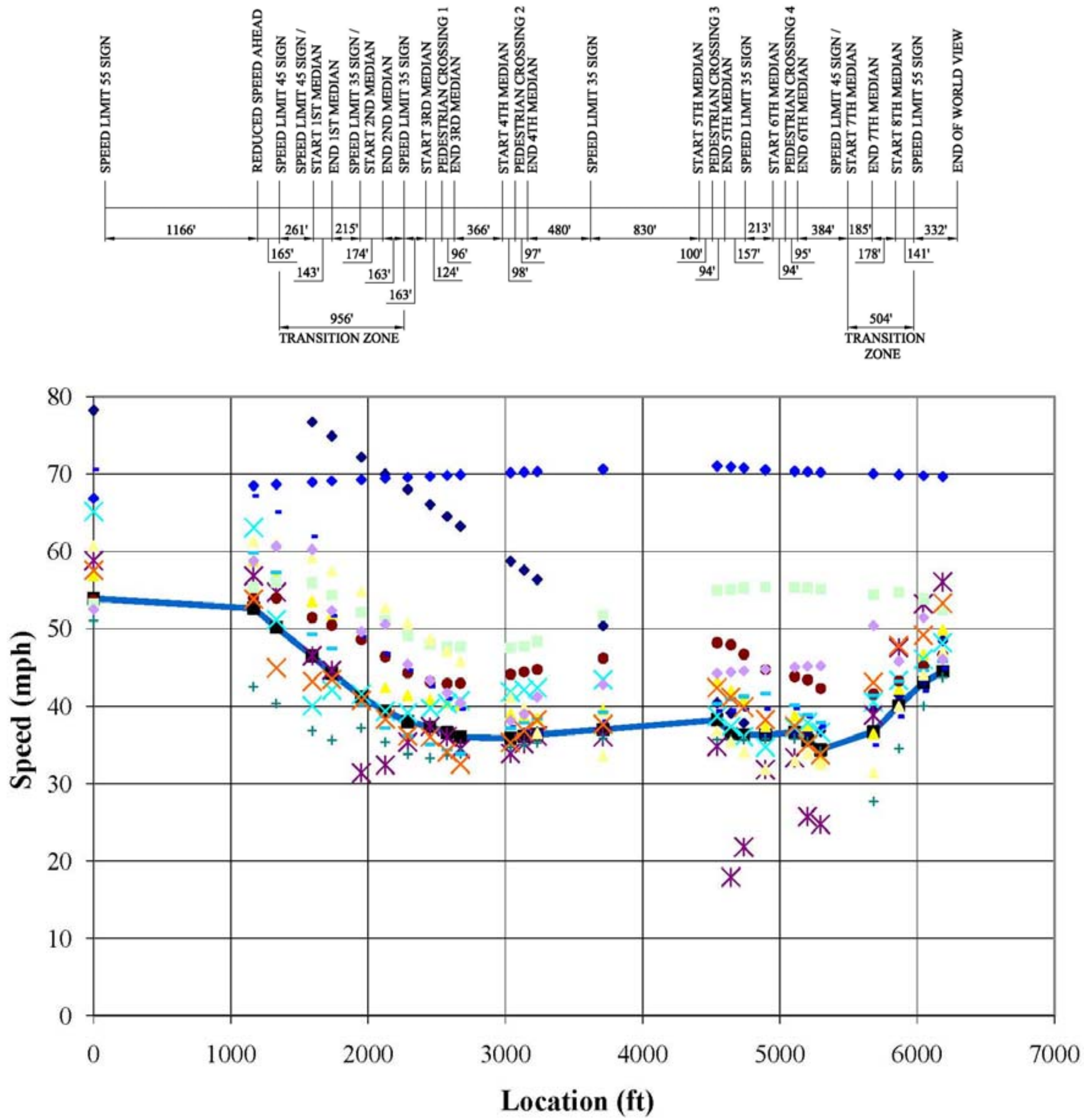

Figure 2.20: Individual Speed Data for Medians in Series -- Pilot Study II

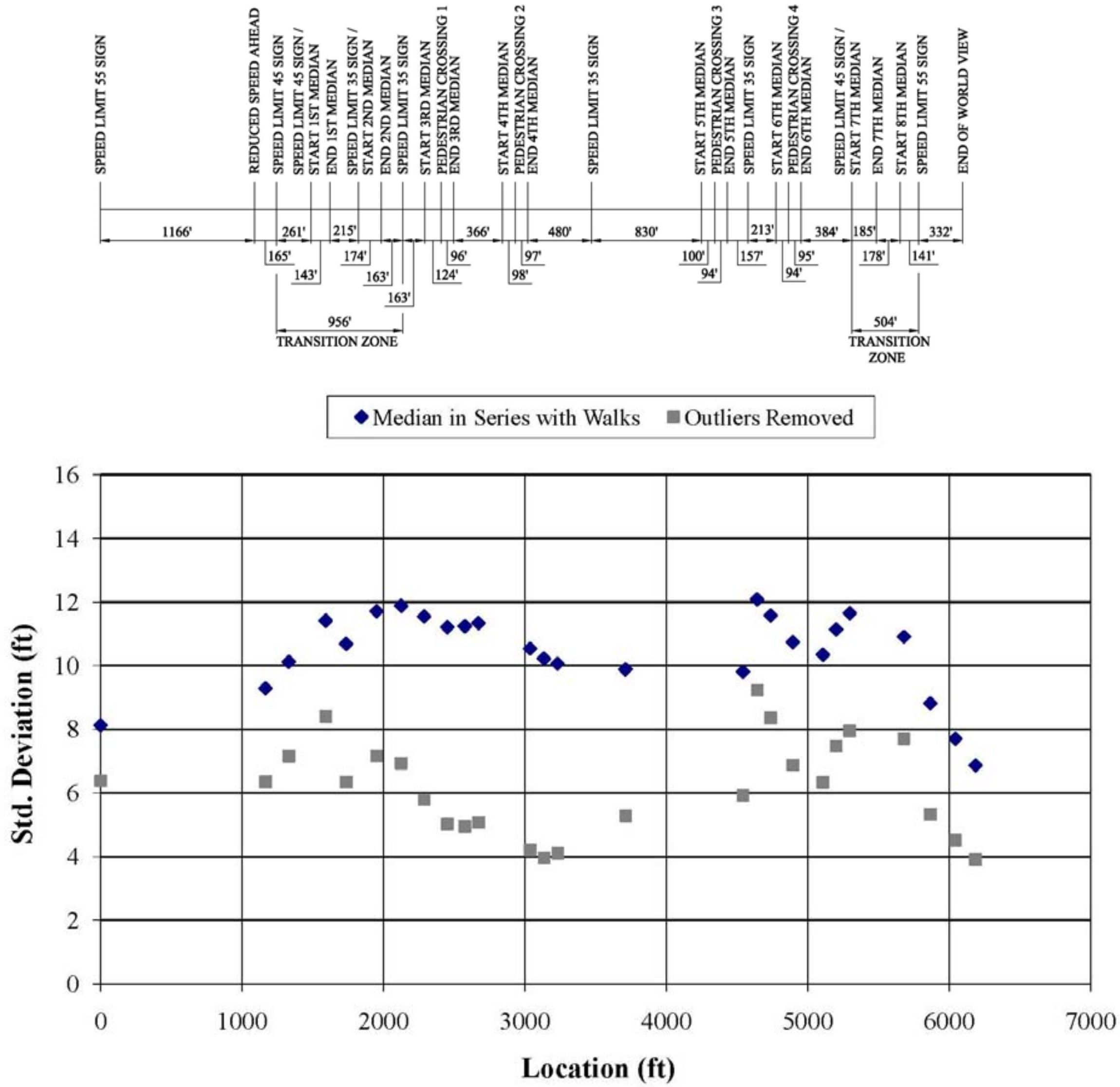

Figure 2.21: Standard Deviation Results for Medians in Series Treatment – Pilot Study II

The research team simplified the data analysis used for Pilot Study I by maintaining consistent speed limits ranging from a rural 55mph speed limit to 45 mph in the transition zone and ultimately to 35 mph in the town. The speeds were then increased in a similar manner at the town exit. In addition to evaluating individual speed data, the research team also considered the variability of speed between participants. Figure 2.21 depicts the standard deviation of speeds throughout the simulator world. The diamond symbols represent the standard deviation of the mean speed with the outliers included, and the rectangular symbols represent the standard deviation of the mean speed with the outliers removed. As shown on Figure 2.20, certain drivers appeared to consistently represent outlier speeds. Based on the standard deviation assessment and the speed observations, the research team determined that removing the outliers would provide a more accurate account of speed trends. As a result, data analysis in the Full Scale study excluded speed outliers and the research team attempted to collect additional replacement data to help address this limitation. Appendix H (see Figure H1.14 through Figure H1.19) includes dimension, speed, and standard deviation plots for the Pilot Study II simulation scenarios.

One significant observation resulting from Pilot Study II was that the length of the transition areas should be standardized to control the distances between the speed limit sign changes and the placement of the treatments so that drivers have equal opportunities (both time and space) to respond to each treatment. As noted previously, the research team determined that speed outliers should be excluded in the final analysis. Subjects whose speeds were greater than two standard deviations away from the mean were considered outliers. Those subjects who made no attempt to change their speed throughout the town environment were disregarding both the speed limit signs and the surrounding environment indicating driving that would hopefully not be seen in the real world. Though some drivers may follow the same trends as most drivers, their speeds are much higher which would not be realistic for the roadway environment. Lastly, the Pilot Study II demonstrated the effects of having participants drive in the simulator for longer periods. The group determined that it would be best to incorporate a distracter game into the scenarios in order to disguise the purpose of the study. In addition several participants mentioned feeling fatigued because of the length of drive time, so the game would also help keep the drivers engaged and add some effect of the distractions that could exist in their own vehicle.

The ultimate result of Pilot Study II was the identification of candidate treatments to be continued in the full scale experiment. The research team selected all of the Pilot Study II treatments for continued evaluation. In addition they elected to add two additional controls as well as one treatment resulting in a total of nine test treatments. The group decided to add a third simulator world, and each world would test three treatments, one of which would be a control. The added treatment included a set of medians in a series without pedestrian walks.

The purpose of Pilot Study I and Pilot Study II was to help resolve problems that could affect the data in determining the effectiveness of candidate treatments during a full scale study. The researchers addressed the issues noted in Pilot Study I before collecting Pilot Study II experimental data. This pilot study approach provided some basic data as well as helped to define potential problems prior to deploying the full scale study.

2.5 FULL SCALE STUDY

The full scale study included three "simulated worlds." Within each of these worlds were two test treatments and one control treatment. To adequately evaluate these environments the research team recruited participants of varying age and driving experience. The participant pool, experimental design, and data collection are reviewed in the following sections.

2.5.1 Participants

The full scale study included three groups of 18 participants each. The first groups of participants were young drivers from age 17 to 25, the second group of participants had ages ranging from 35 to 50 years old, and the third participant groups were adults over the age of 65. For half of the participants in each age group, the simulation experiment included the use of a word game during the rural driving only (not in the transitions or towns) which consisted of a letter presented orally by the simulator prompting the subject to respond by saying a word starting with that letter. This word game, known as the distracter, helped keep the drivers engaged during the rural driving task and is thought to more realistically depict a driver's actual behavior when subjected to minor distractions such as talking to passengers or adjusting a car radio.

The young drivers voluntarily signed up through a subject pool website at the Clemson University Psychology department. Most of the students who participated received extra credit for their university classes while others were paid for the time they spent on the study. The pay rate for the participants was ten dollars per hour of time spent on the study. The middle age group and the older citizen group were recruited through advertising in local papers, flyers, and word of mouth. All participants read and signed a consent form prior to participating in the study.

The simulation study occurred at Clemson University in Clemson, South Carolina; therefore the participants were local to that region. Clemson is a rural/ suburban town with a population of approximately 12,000. All participants had a valid United States driver's license. They were all tested for motion sickness during the practice sessions in order to ensure all drivers were capable of simulator driving.

Table 2.1 demonstrates the participants evaluated for the study. This summary includes candidates who did not complete the study or whose data was not used. The lower portion of the table summarizes the reasoning for participants who were not included in the full scale study. The most common reasons for excluding a candidate or for discarding data were simulator sickness, “driving” speeds greater than 100 mph, or the inability to run experiments due to simulator malfunctions.

Table 2.1: Participant Data

	Male	Female	Total
Total Number of Participants	40	35	75
Number of Participants for Whom Data is Studied	33	21	54
Reasons Data Discarded for Remaining Participants:			
Simulator Malfunction		12	
Simulator Sickness		6	
Unrealistic Driving		3	

Please see Appendix C for the participant instructions, Appendix D for the participant data sheets, Appendix E for a summary of participants, and Appendix F for a summary of responses to the driver behavior questions asked after each participant completed this study.

2.5.2 Design and Procedure

The simulation experiment included participants with varying age, simulated environments with varying transition designs, and a simulator test that may have included a distracter word game. As a result, the independent variables included in this study were transition type, driver age, and distracter versus no distracter. The three analysis variables were distributed based on their respective options, so there were nine simulation configurations (three per environment with a total of three environments), three age test categories, and two distracter categories.

The research team defined the transition scenarios by the nine different treatments tested, all of which included a transition area into a town, the town itself, and the transition area out of the town. The towns are all similar but not exactly the same to avoid recognition within the towns. The signage was also standardized for each treatment condition as the signs appeared in the following order as the driver entered the town setting: Speed Limit 55, Reduced Speed Ahead, Speed Limit 45, and Speed Limit 35. The rural settings all had a speed limit of 55 mph. The speed limit reduced to 45 mph through the transition areas, and then ultimately to 35 mph through the towns. The transitions were controlled by making the length of the transition area as standardized as possible at approximately 1,000 feet. Additionally, each of the three driving scenarios contained one “no treatment” (control) section in which the transition area was only indicated by the change in Speed limit signs.

The age variable included young drivers, middle, and older drivers. The transition and age group were counterbalanced so that each age group had three participants starting at each scenario to reduce the effects of driver fatigue and driver recognition. Half of the drivers were exposed to the distracter game. The distracter task is a word game in which a simulator generated voice presents a letter and the participant responds with a word. The letters are presented at specified time intervals only while participants were viewing the rural settings so as to limit the effect of distractions during the transition. The distracter game also helped to mask the purpose of the simulations study so that participants did not focus on how the driving environments differed at each transition.

A proctor conducted the experiment by reading from a set script which can be found in Appendix C. The script provided a controlled experiment so as to provide consistent testing with different proctors administering the exam. The participants were first asked to sign a consent form agreeing to allow the results of the experiment to be used for research. Next, participants were asked questions about their demographics including age, driver's license ownership, gender, and seat belt usage, the last two for informational purposes only. This information was recorded on the participant data sheet as shown in Appendix D. This information also helped the research team keep records of the tested scenarios so that additional participants would be appropriately assigned to alternative scenarios (to ensure a balanced test).

The participants were asked to sit in the car and were instructed on the operation of the vehicle. Prior to traversing the experimental scenarios, participants drove through a series of training sessions to introduce them to the simulator and ensure they did not get motion sick. Throughout both the practice scenarios and the experimental scenarios, the proctor conducted a motion sickness survey at the end of each driving session where the participant was asked to rate the severity of specific conditions, such as drowsy, nauseated, or tired. This data was recorded using the Motion Sickness Questionnaire also included in Appendix D.

The experimental conditions consisted of three scenarios that were approximately thirty minutes each. The time each participant drove varied based on how long it took to drive through the three towns in each of the scenarios. As previously stated, each scenario had three scenarios (two treatments and one control) located in close proximity to the transition areas from the rural settings to the urban settings. The overall length of the experiment for each participant ranged from two and a half to three and a half hours.

The three control scenarios replicate different lane configurations seen in the six treatment scenarios. “Control Two Lane (1)” and “Control Two Lane (2)” were two-way two lane roads with no changes in the lane configuration during the transition or the town, replicating the configuration of the Layered Landscape scenario and similar to the configuration of Gateway with Lane Narrowing scenario. “Control Two Lane with Center Lane” was a two lane road that widened to provide a center lane through the transition area and the town. This control section provided a base condition for the treatment scenarios involving medians. The following is a list of the treatments tested in this study followed by visuals (screen shots shown in Figure 2.22 through Figure 2.29) of each treatment (plan view drawings of each treatment can be found in Appendix G):

A. Control Two Lanes (1)
B. Control Two Lanes (2)
C. Layered Landscape
D. Gateway with Lane Narrowing
E. Control Two Lanes with Center Lane
F. Median with Short Landscape
G. Median with Gateway
H. Medians in Series with No Pedestrian Crosswalks
I. Medians in Series with Pedestrian Crosswalks

The participant completed the initial tests and then received a break. After the break, each participant drove through the first test scenario. The participant was instructed to drive as he or she would in his or her own vehicle, and continue driving until a timer beeped to signal completion of the simulation. The first scenario consisted of a rural road with a speed limit of 55 mph, which transitioned into three different towns throughout the test with one control and two treatments located on the fringes of each town. The rural portions of each scenario included combinations of curvy and straight roads while the transition areas and the towns for each scenario located at straight roads. To make the simulated driving more realistic, with no effect of traffic on speed choices, all scenarios had traffic in oncoming lanes only. After the first scenario the driver received a break and was offered a snack before starting the second scenario. The second and third scenario had the same conditions as the first but with different treatments.

Figure 2.22: Control Two Lanes (1)

Figure 2.23: Layered Landscape Treatment

Figure 2.24: Gateway with Lane Narrowing Treatment

Figure 2.25: Control Two Lane with Center

Figure 2.26: Median Treatment

Figure 2.27: Median with Gateway Treatment

Figure 2.28: Medians in Series with No Pedestrian Crosswalks

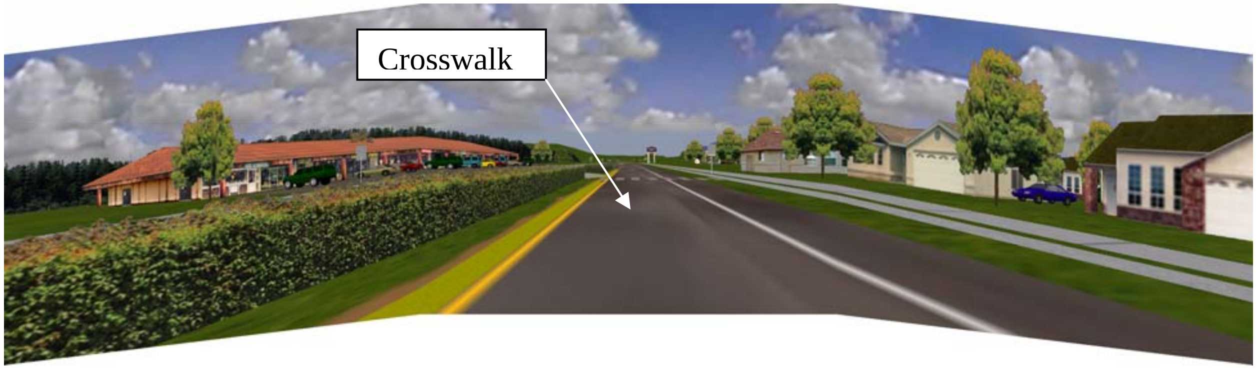

Figure 2.29: Medians in Series with Pedestrian Crosswalks

2.5.3 Procedure for Data Analysis

The simulator authoring computer collected the data for the speed, lane position, and acceleration at specified frequencies or specified locations. The software acquired periodic speed data at previously determined locations. For control configurations, these data collection locations included seven standard configurations as depicted in Table 2.2. The study also included an eighth common data analysis location for non-control scenarios. This location was located immediately adjacent to the treatment and is indicated as site L8 in Table 2.2.

Table 2.2: Data Analysis Locations

L1	Speed Limit 55 Sign (immediately prior to transition)
L2	300 feet Upstream of Speed Limit 45 Sign
L3	Reduced Speed Ahead Sign
L4	Speed Limit 45 Sign
L5	300 feet Downstream of Speed Limit 45 Sign
L6	Speed Limit 35 Sign
L7	300 feet Downstream of Speed Limit 35 Sign
L8	Physical Location of Beginning of Treatment

Following selection of critical data analysis locations, the research team evaluated speed at this locations as well as speed comparisons between locations to determine resulting speed reductions due to the treatments. Where appropriate, the research team used statistical comparisons to determine level of speed reduction between treatments.

2.5.4 Imputed Data

Prior to initiating analysis, the team members visually examined the data to determine outliers or missing data. Two participants were added to ensure proper counterbalancing and a complete data set where feasible. Upon further examination, certain data points were not collected for several of the selected participants. It is not clear why some critical locations did not have companion data but when this occurred the research team followed a simple procedure. First, if the missing data point was located within 20 feet of another collected data point, the analyst inserted the speed value at that proximate location. If there was a gap in data that was less than 100 feet but the speeds at the two boundary locations were similar, the analyst interpolated between the two speeds. If, however, the gap in data exceeded 100 feet the analyst did not use a speed value for that location and the sample size was subsequently reduced.

3.0 RESULTS

The comprehensive evaluation of the simulator data and assessment of the speed reduction influences of the various transition treatments are reviewed in this chapter. To provide an initial overview of the evaluated strategies, this chapter first includes graphics that represent descriptive data at the transition locations. This overview is followed by summary data at key locations and comparison of that data. Finally, this chapter provides statistical inferences regarding the various treatments, age groups, and distracter testing procedures.

3.1 DESCRIPTIVE FIGURES FOR TRANSITION SCENARIOS

Figure 3.1 through Figure 3.9 provide a graphic plan view of the transition region for each of the nine treatment conditions (six treatments and three controls). Shown with each of the plan view drawings is the key location used for additional data analysis (shown above the layout and as described in Table previously). For informational purposes, the mean speed at each key location is shown below the plan view. The full length plan view for each of these simulations is shown in Appendix G (see Figure G1.1 to Figure G1.9).

In addition, speed profiles for individual drivers at each treatment are shown in Figure 3.10 through

. The various age group and distracter test configurations are shown in each figure along with a schematic of the treatment and posted speed limits.

The Reduced Speed Ahead Sign is shown with the label “RSA” in both sets of figures.

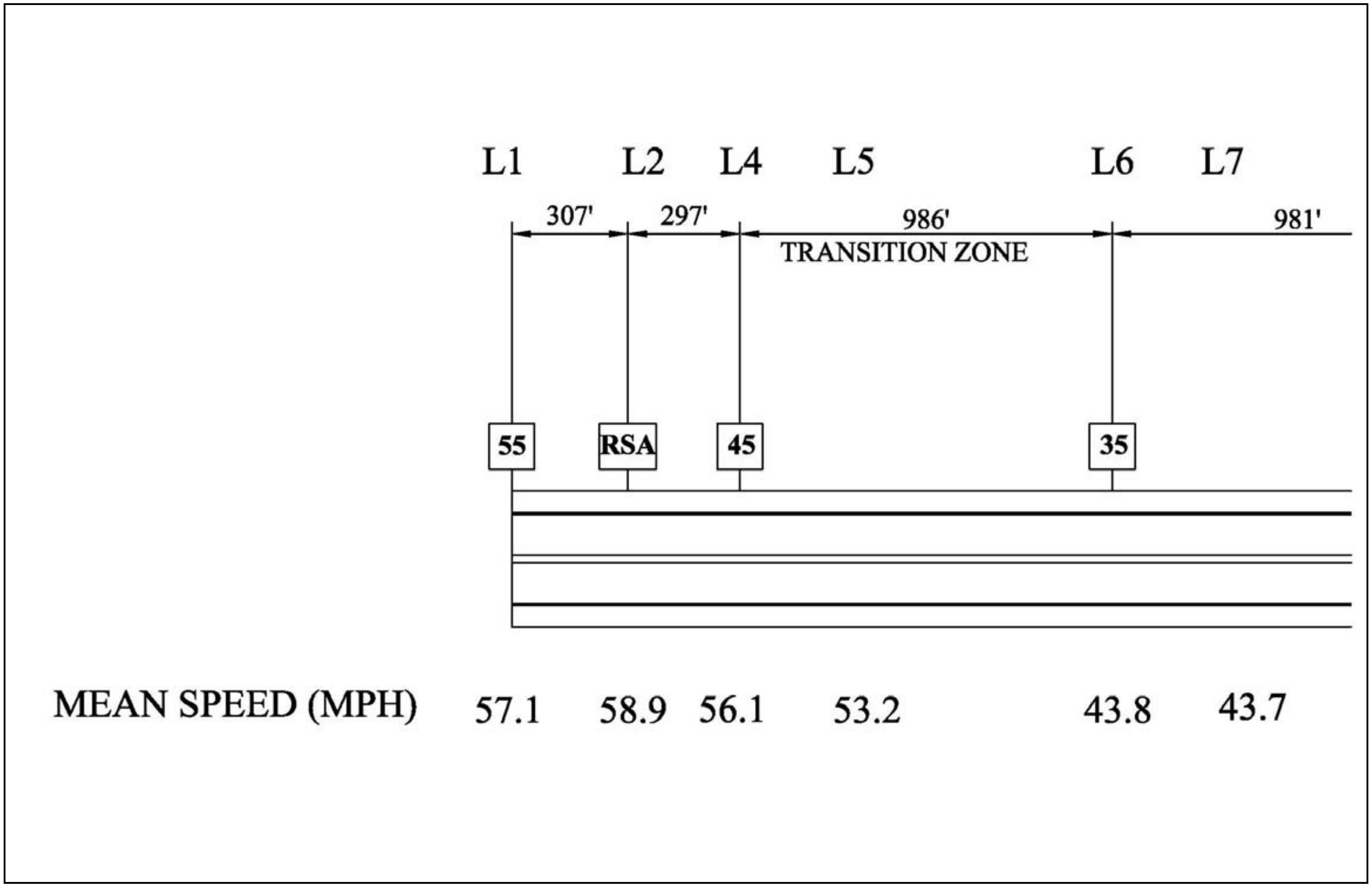

Figure 3.1: Key Location Speed Characteristics for Control Two Lanes (1) Transition and Distracter Test

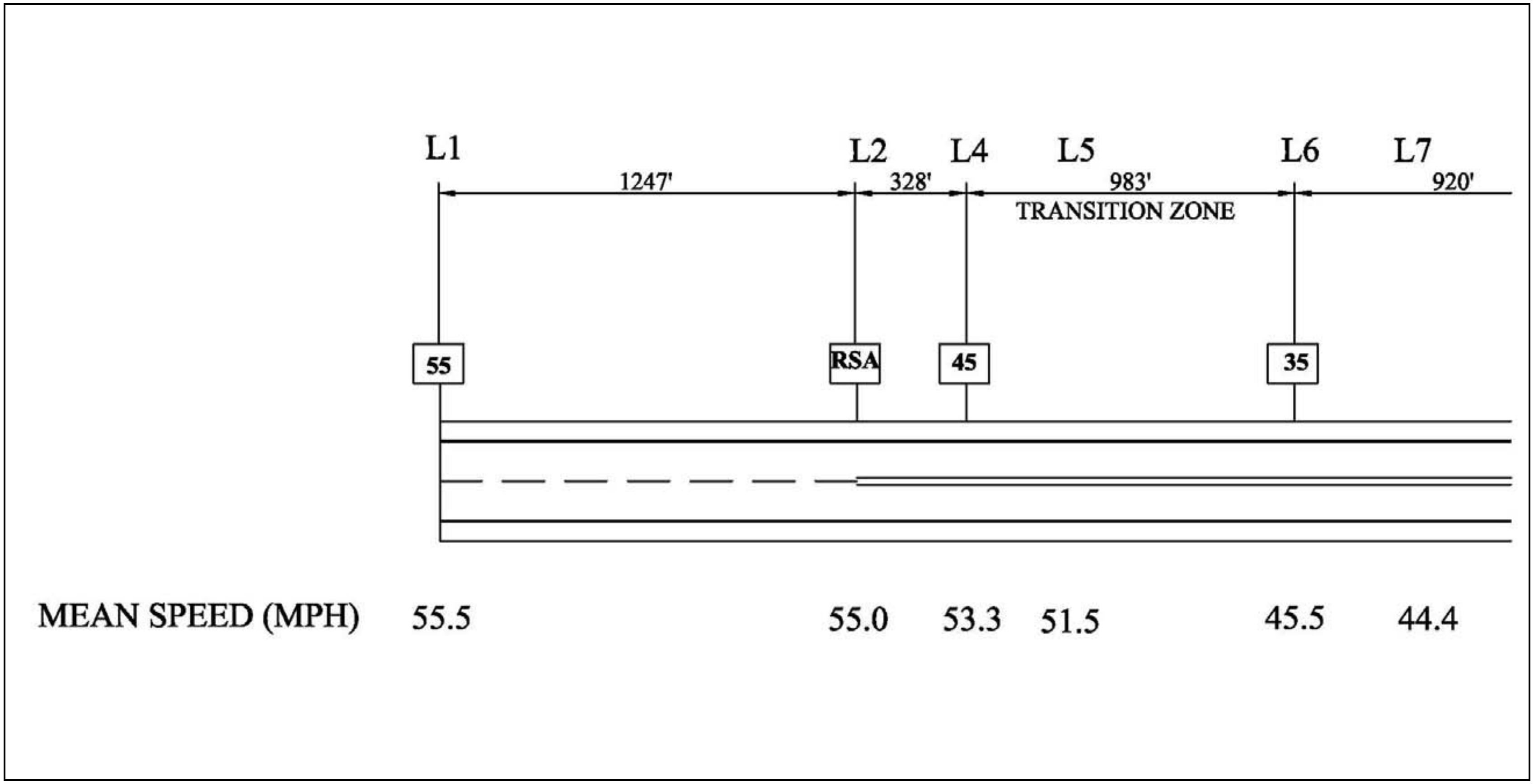

Figure 3.2: Key Location Speed Characteristics for Control Two Lanes (2) Transition and Distracter Test

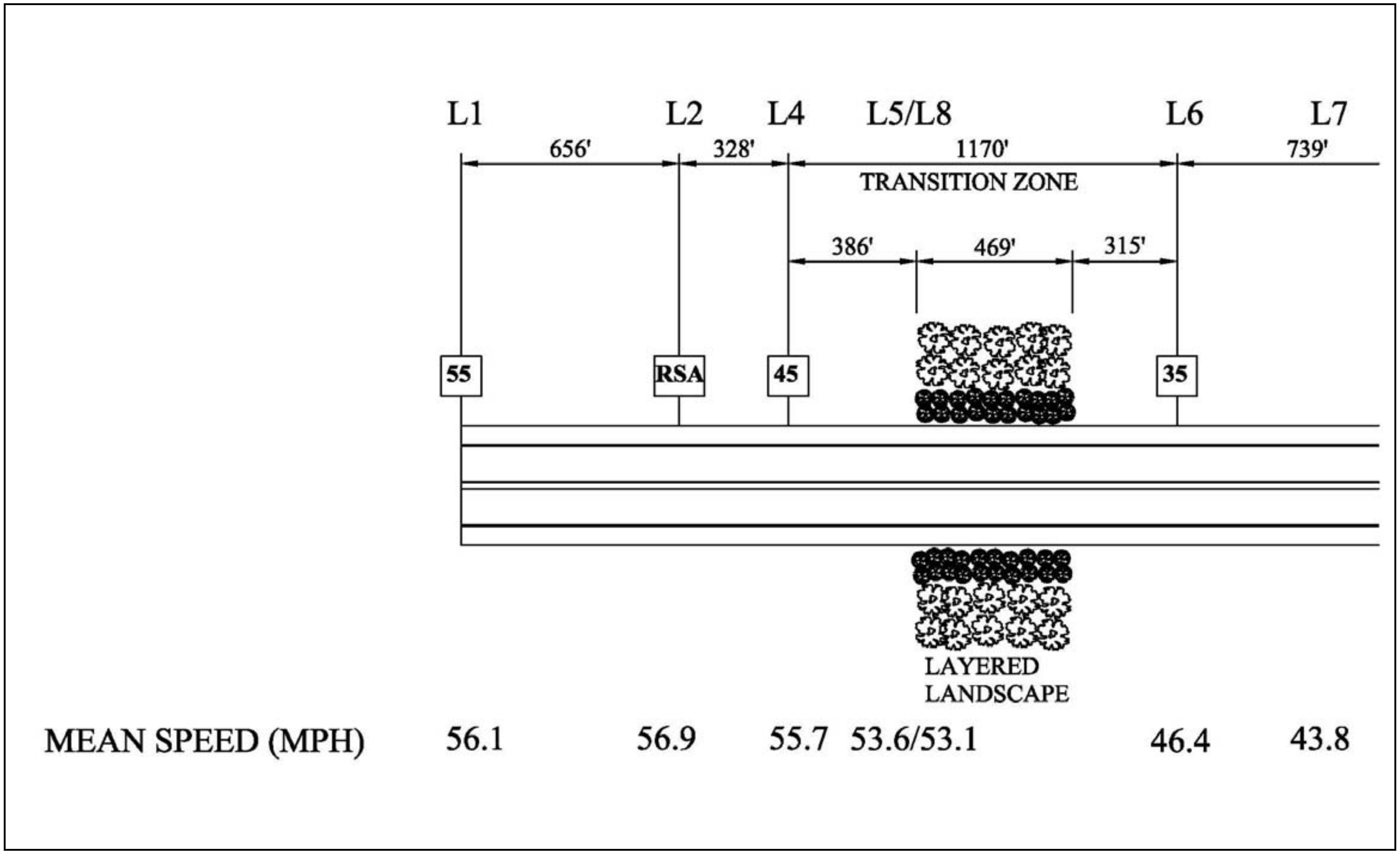

Figure 3.3: Key Location Speed Characteristics for Layered Landscape Treatment and Distracter Test

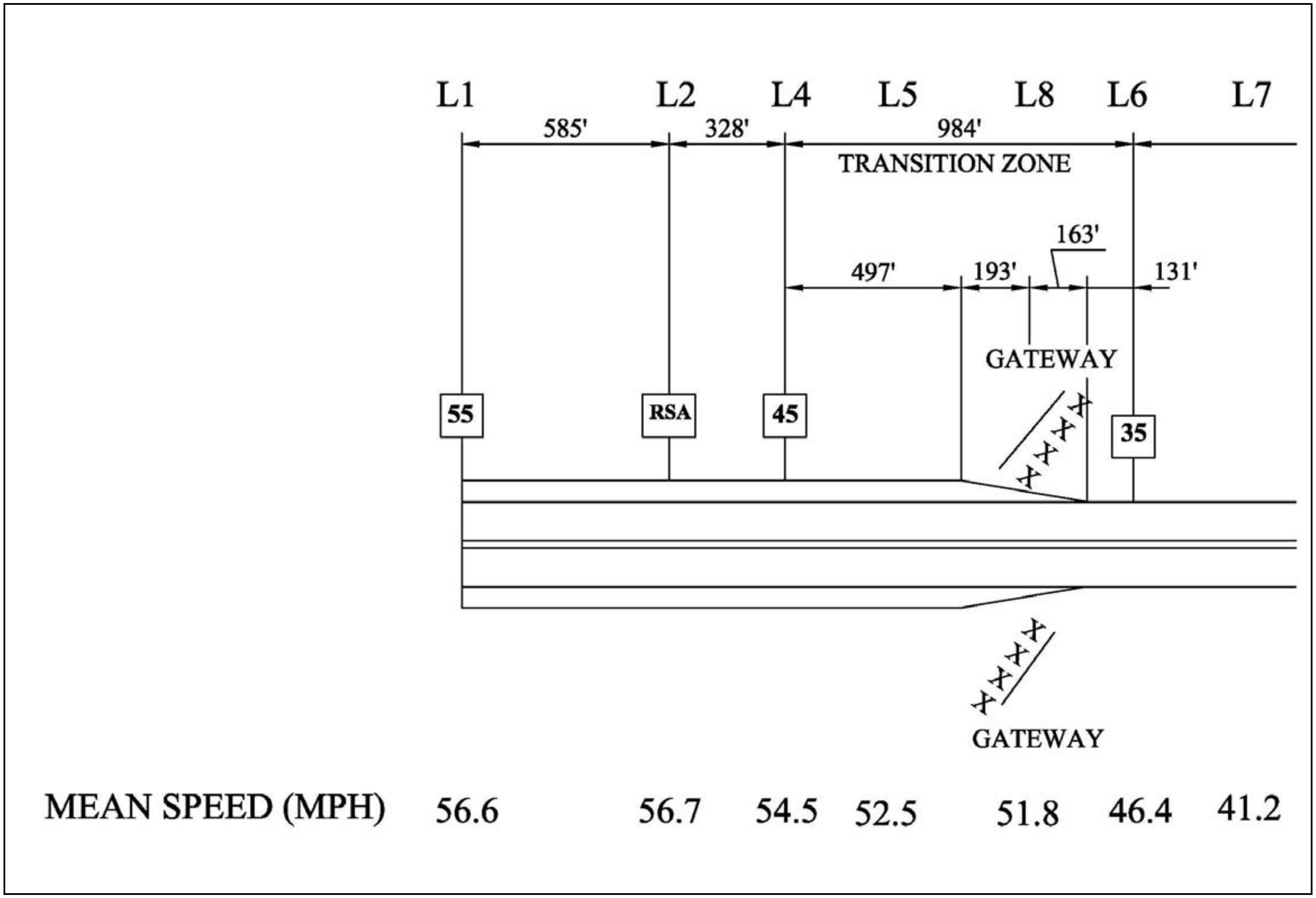

Figure 3.4: Key Location Speed Characteristics for Gateway with Lane Narrowing Treatment and Distracter Test

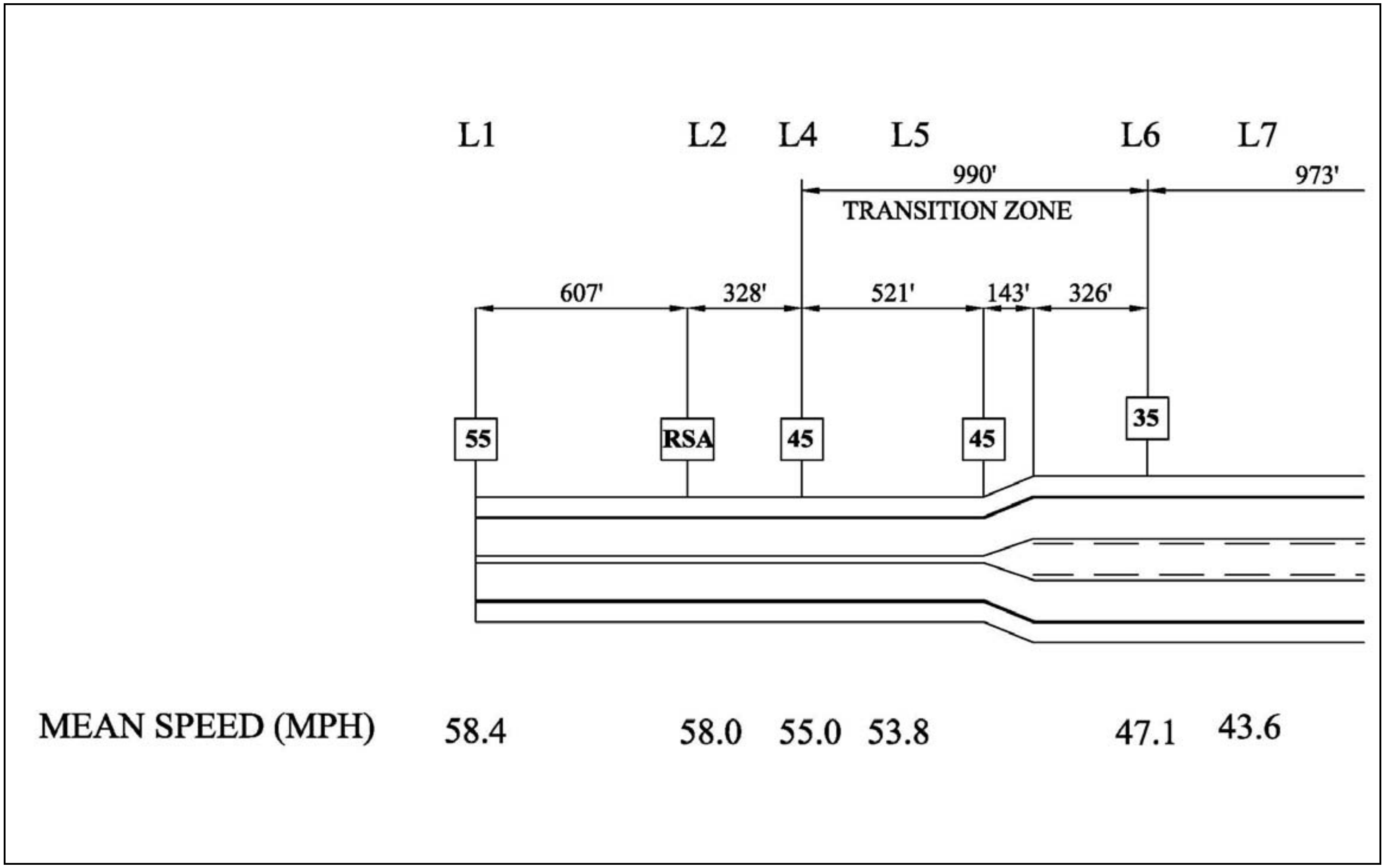

Figure 3.5: Key Location Speed Characteristics for Control Two Lane with Center Lane Transition and Distracter Test

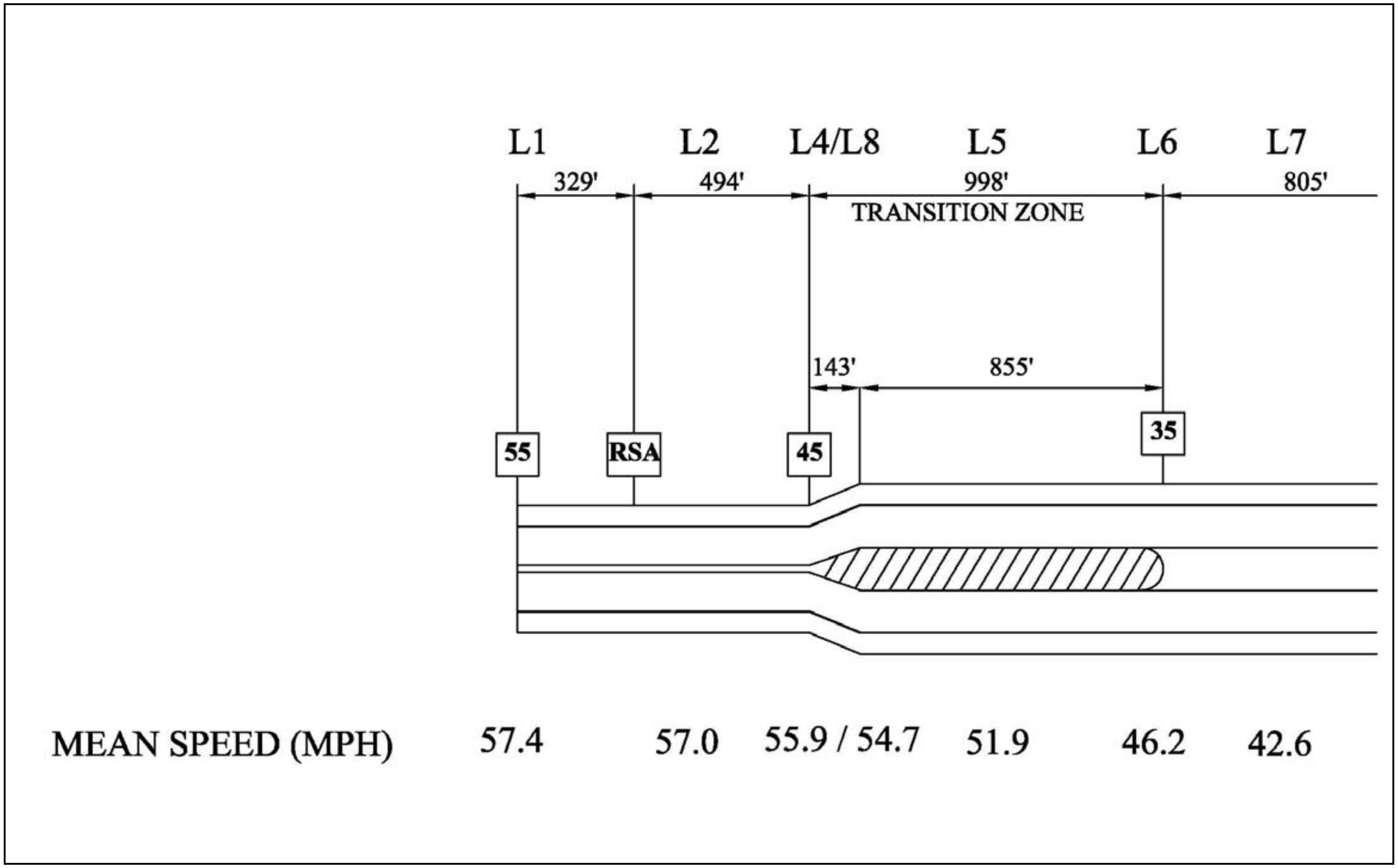

Figure 3.6: Key Location Speed Characteristics for Median Treatment and Distracter Test

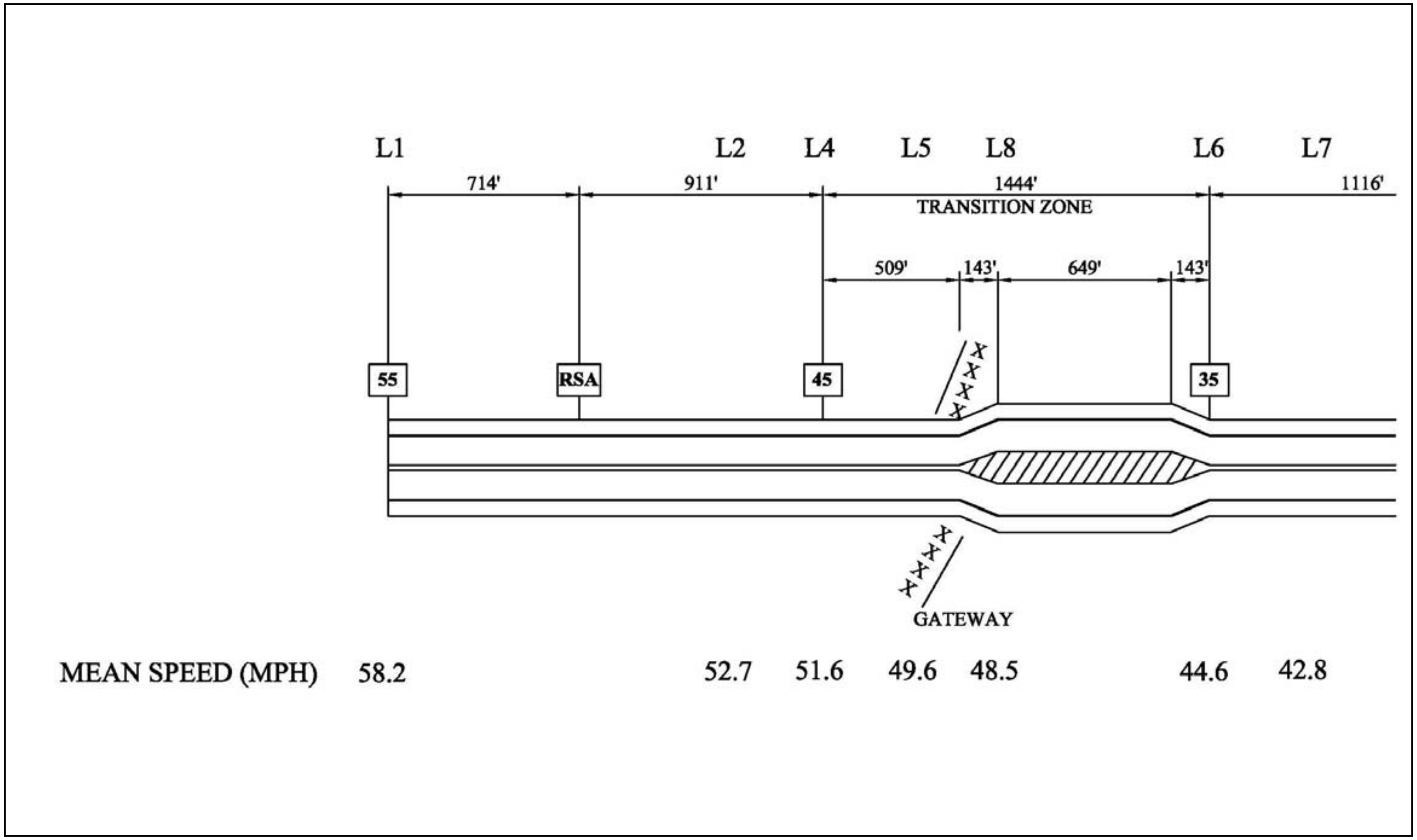

Figure 3.7: Key Location Speed Characteristics for Gateway with Median Treatment and Distracter Test

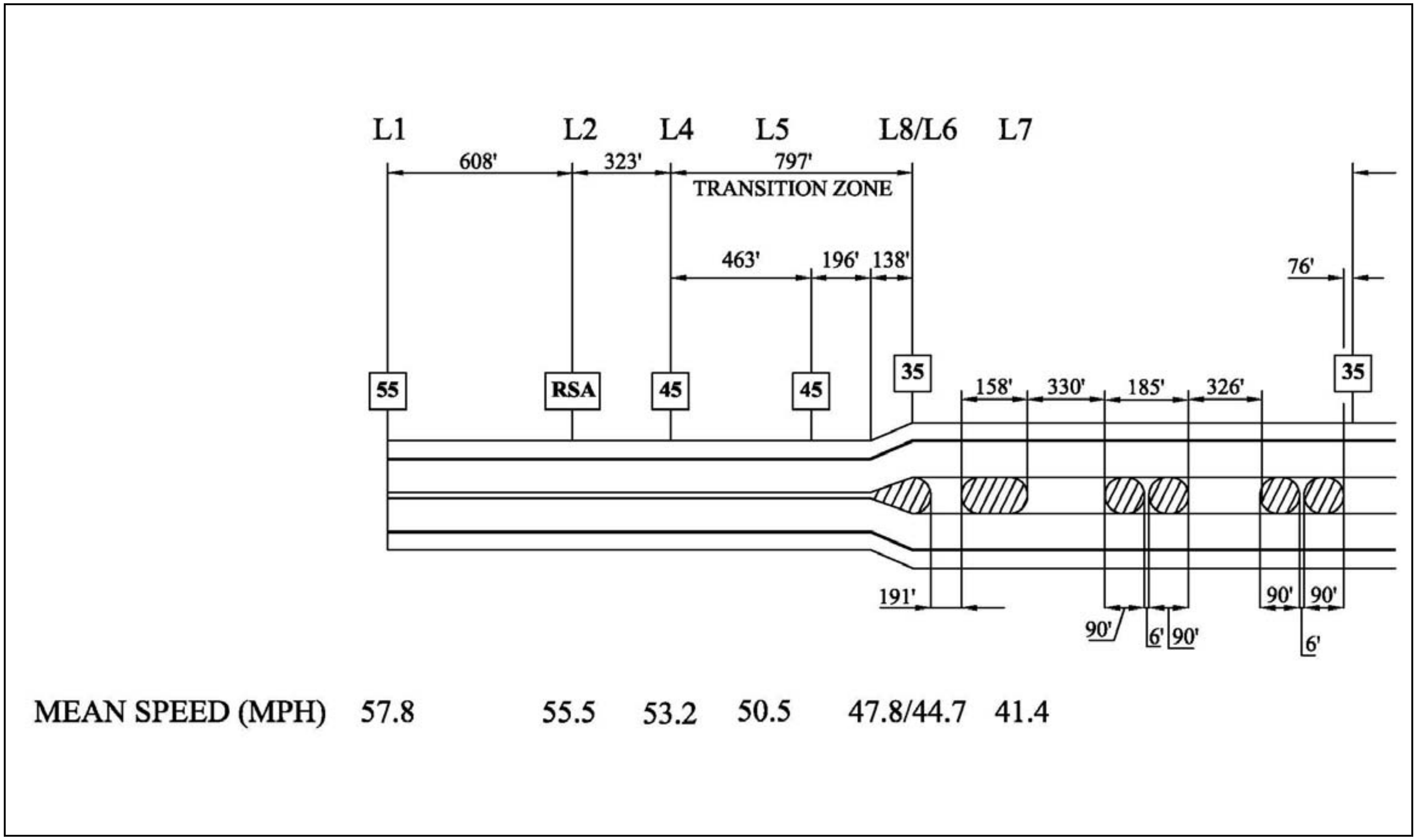

Figure 3.8: Key Location Speed Characteristics for Median in Series No Crosswalks and Distracter Test

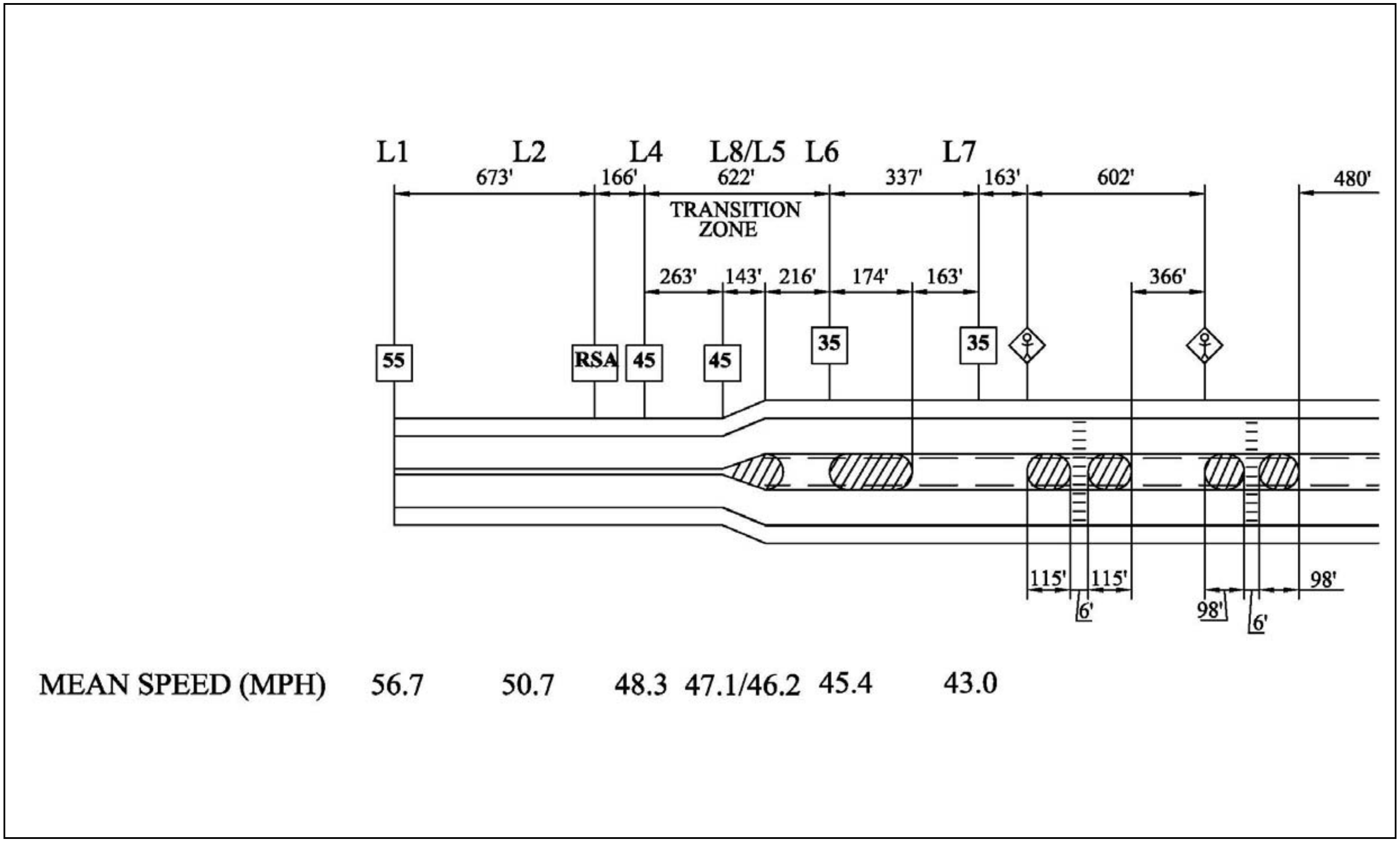

Figure 3.9: Key Location Speed Characteristics for Medians in Series with Crosswalks and Distracter Test

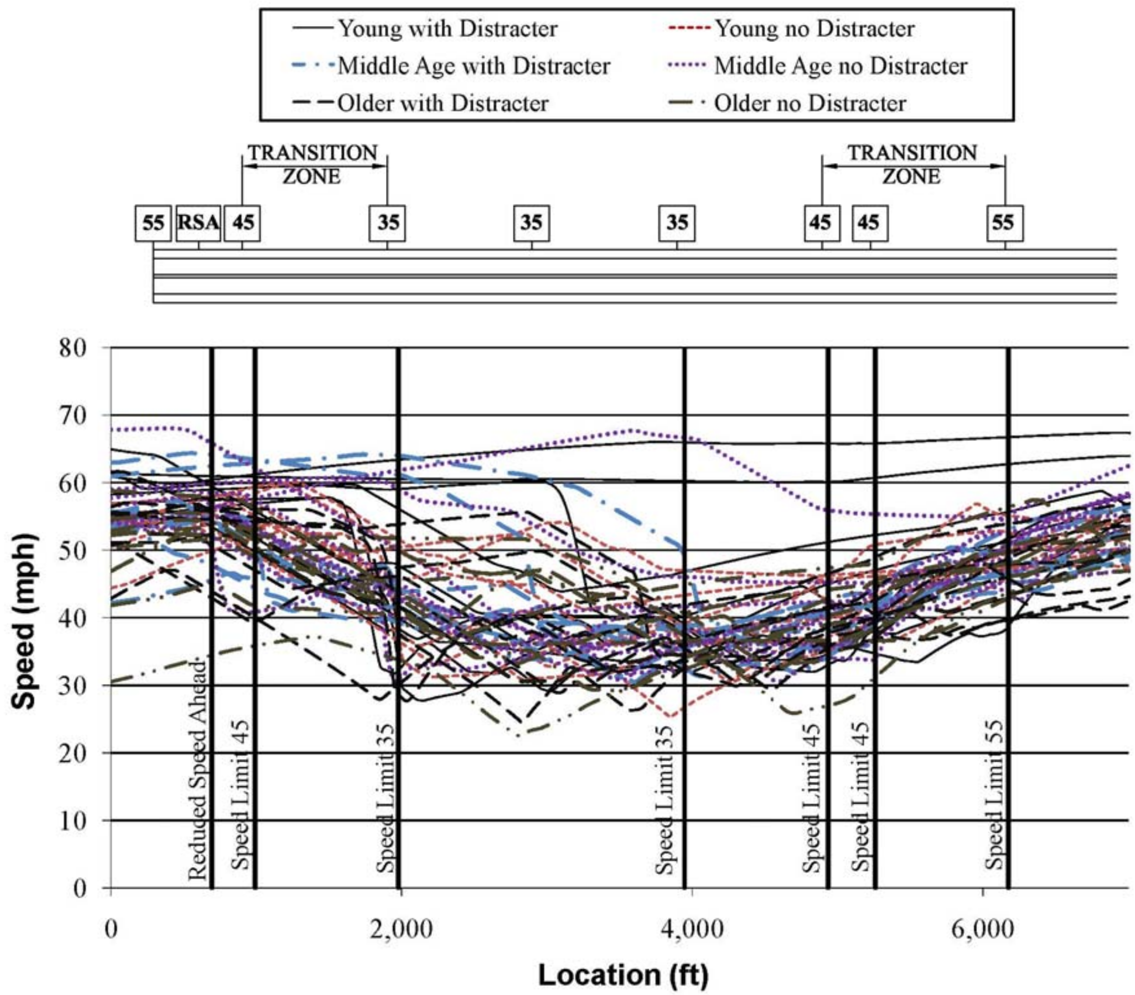

Figure 3.10: Individual's Speed at Control Two Lanes (1)

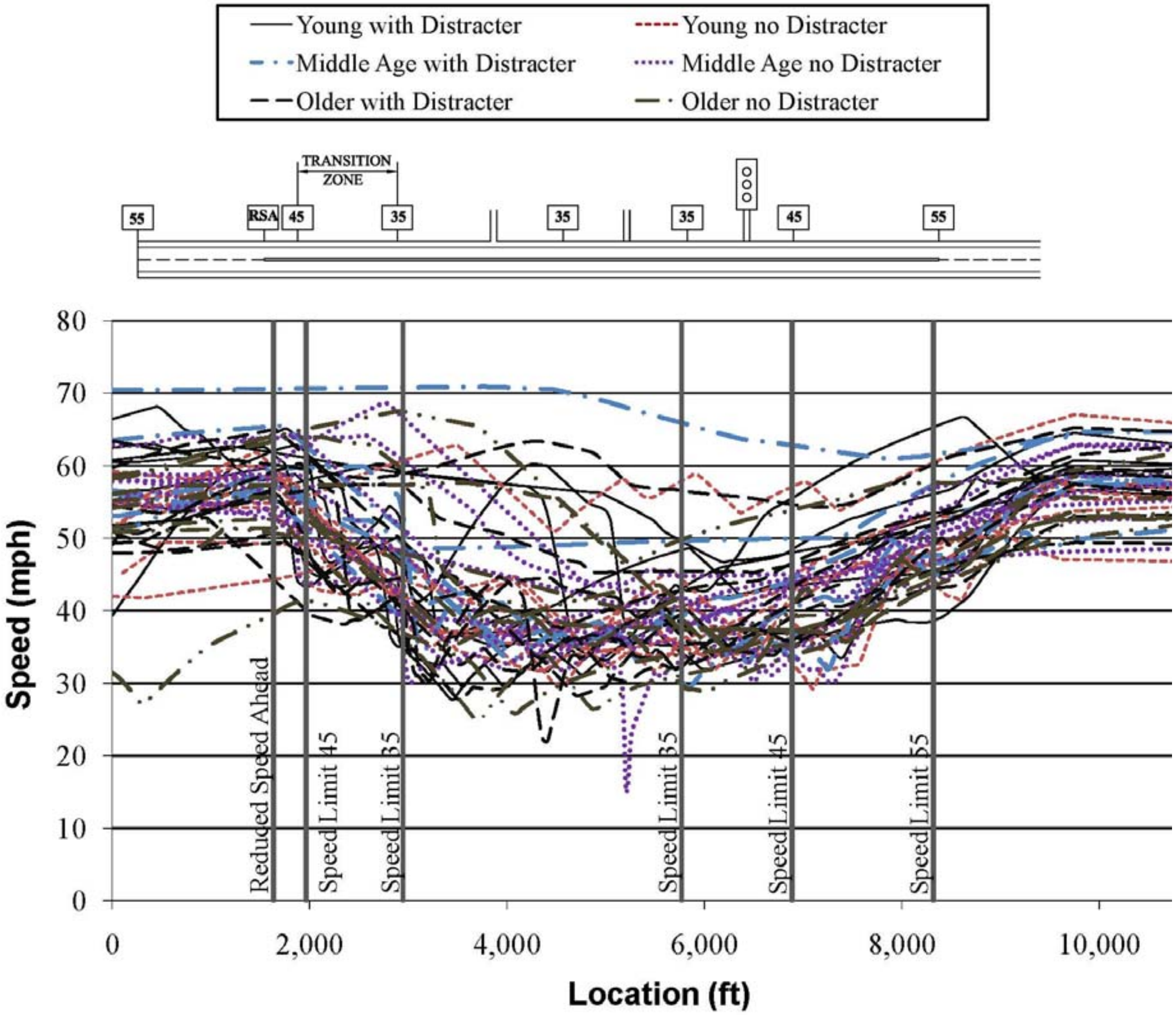

Figure 3.11: Individual's Speed at Control Two Lane (2)

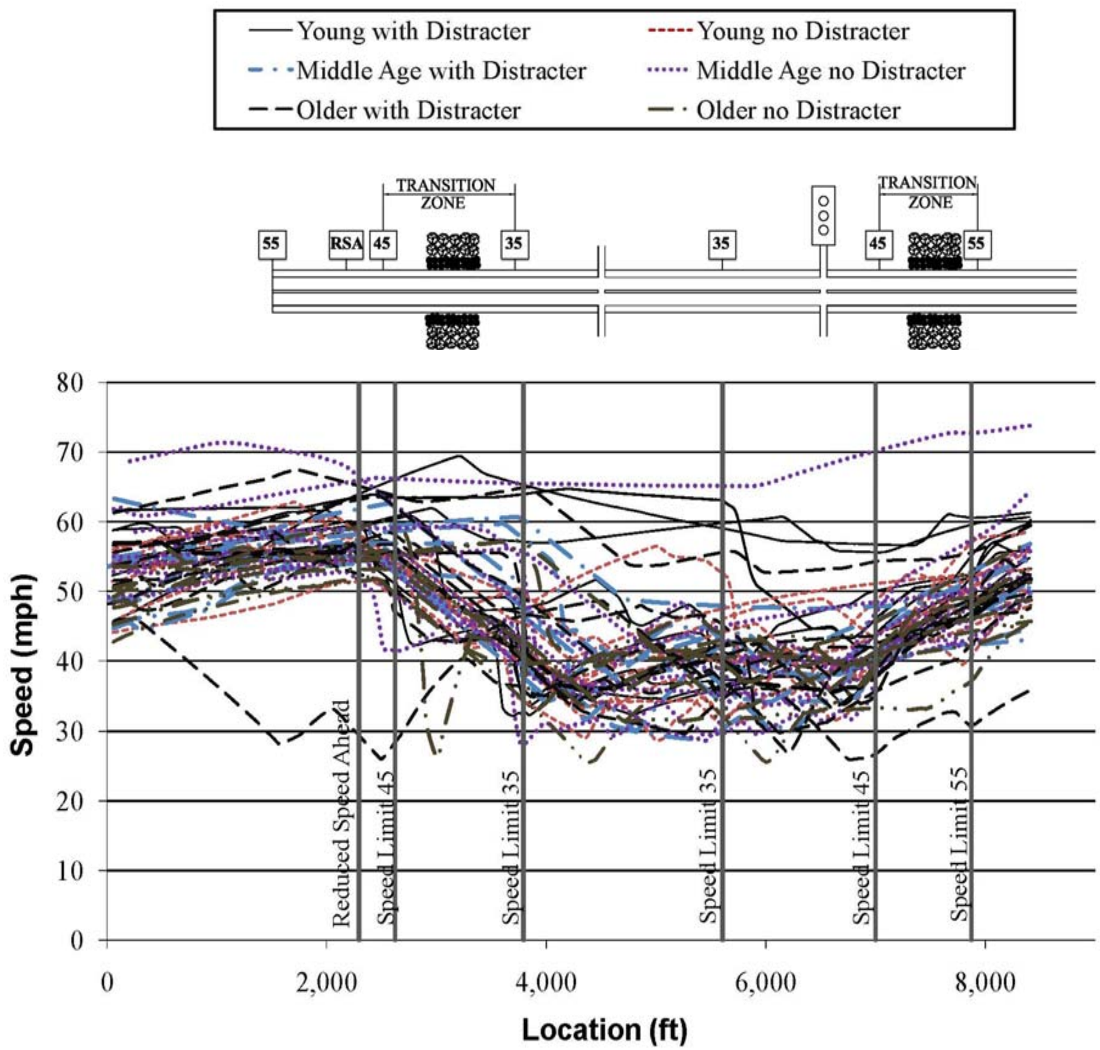

Figure 3.12: Individual's Speed at Layered Landscape Treatment

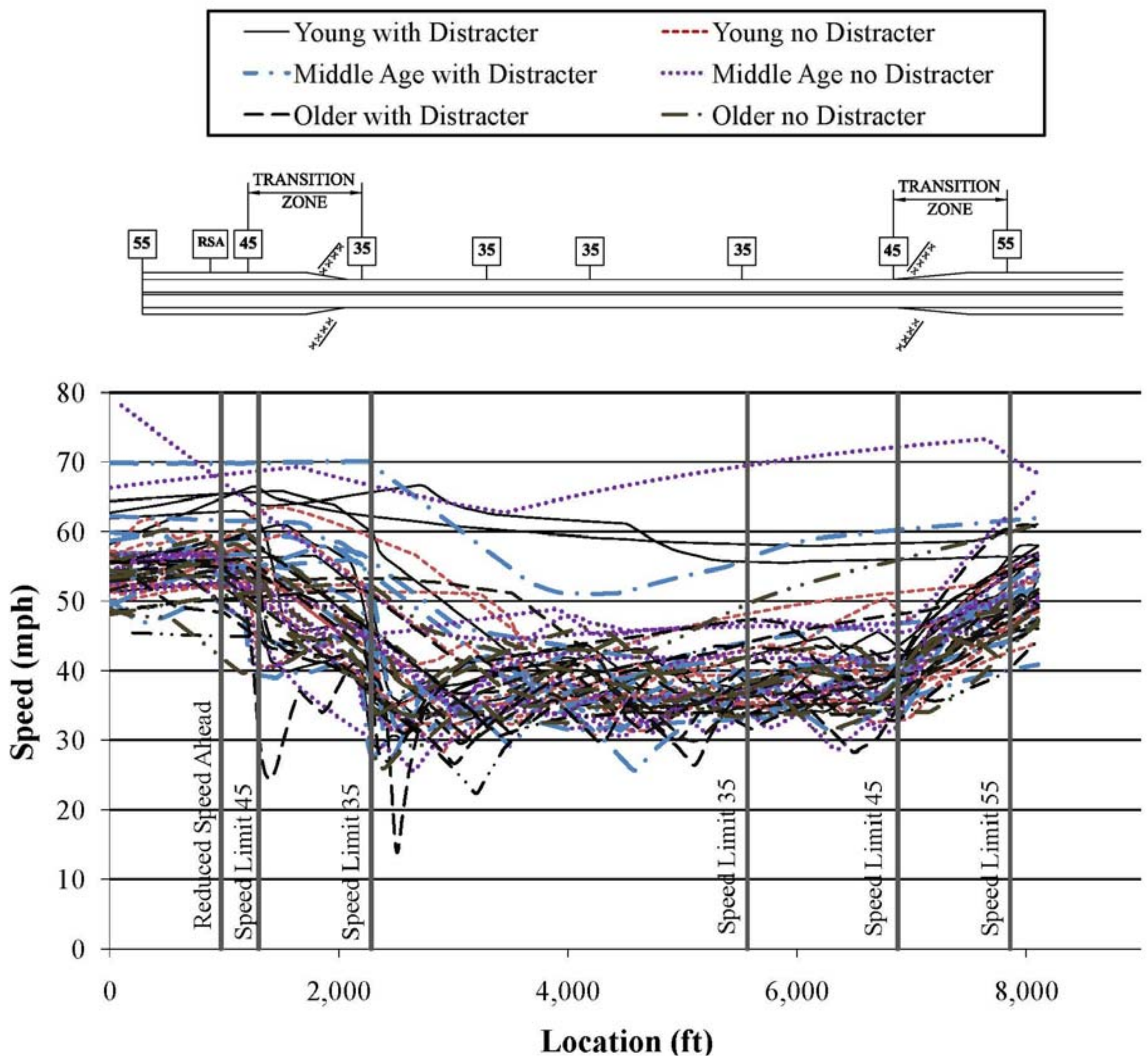

Figure 3.13: Individual's Speed at Gateway with Lane Narrowing Treatment

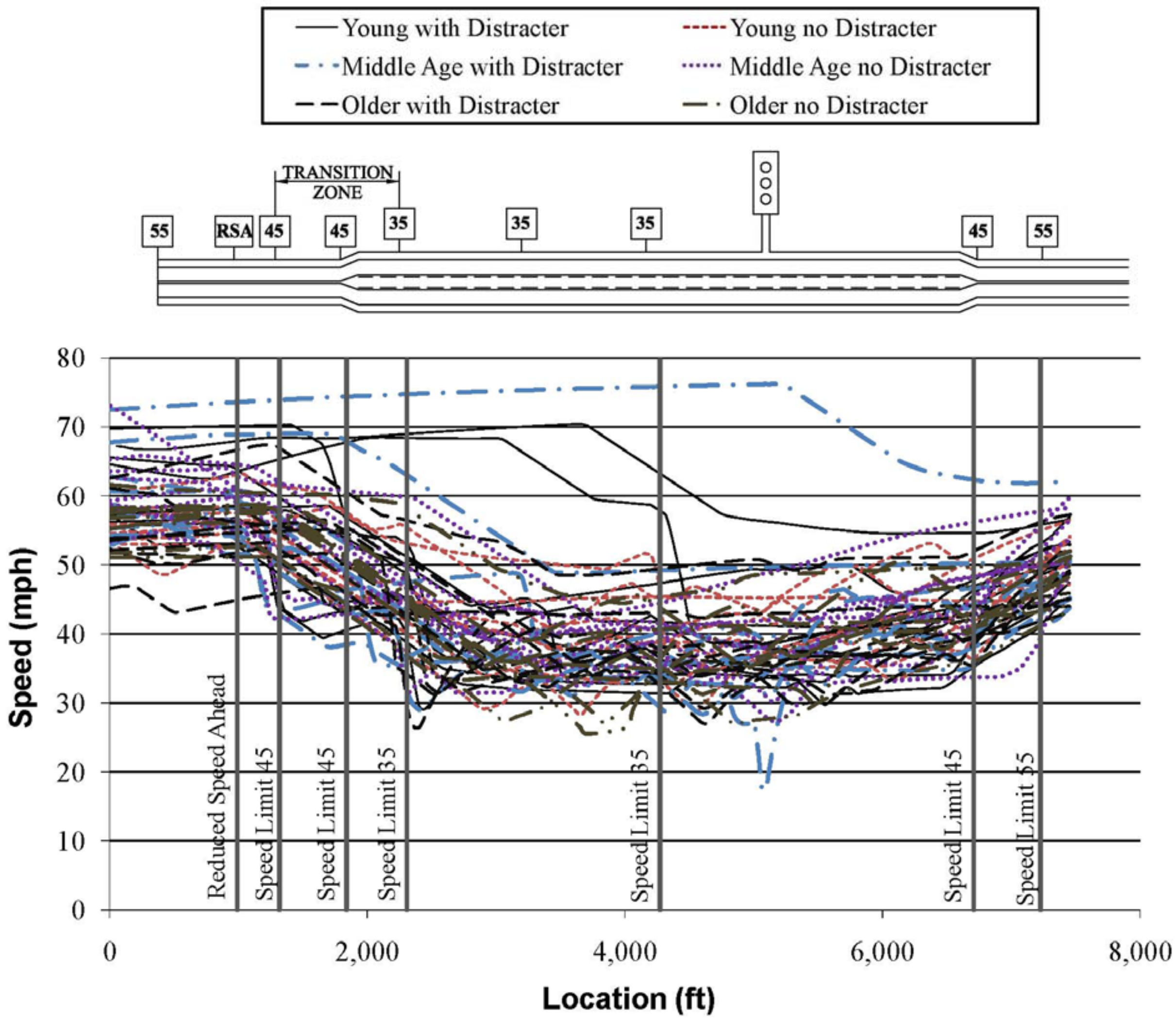

Figure 3.14: Individual's Speed at Control Two Lanes with Center Lane

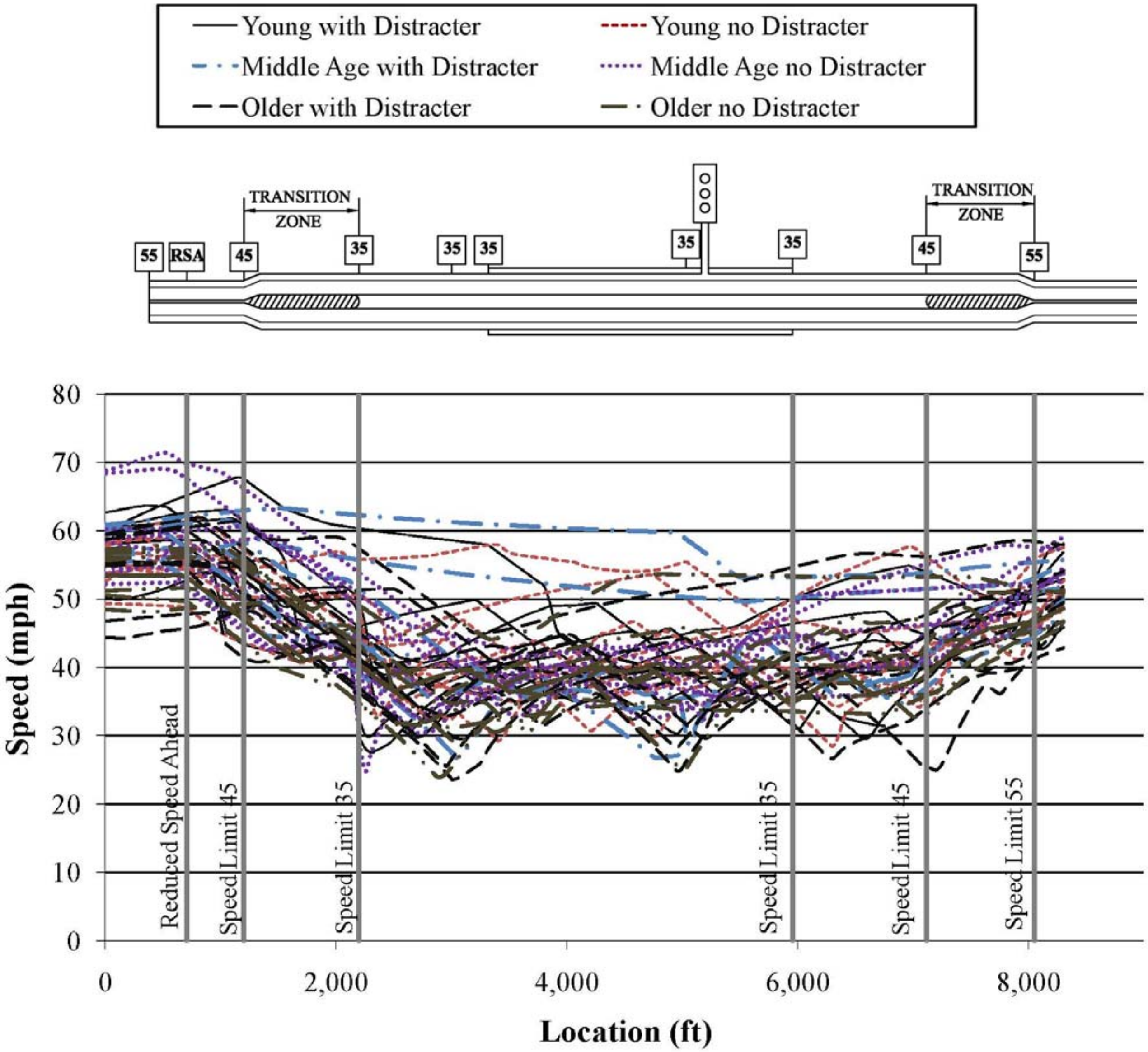

Figure 3.15: Individual's Speed at Median Treatment

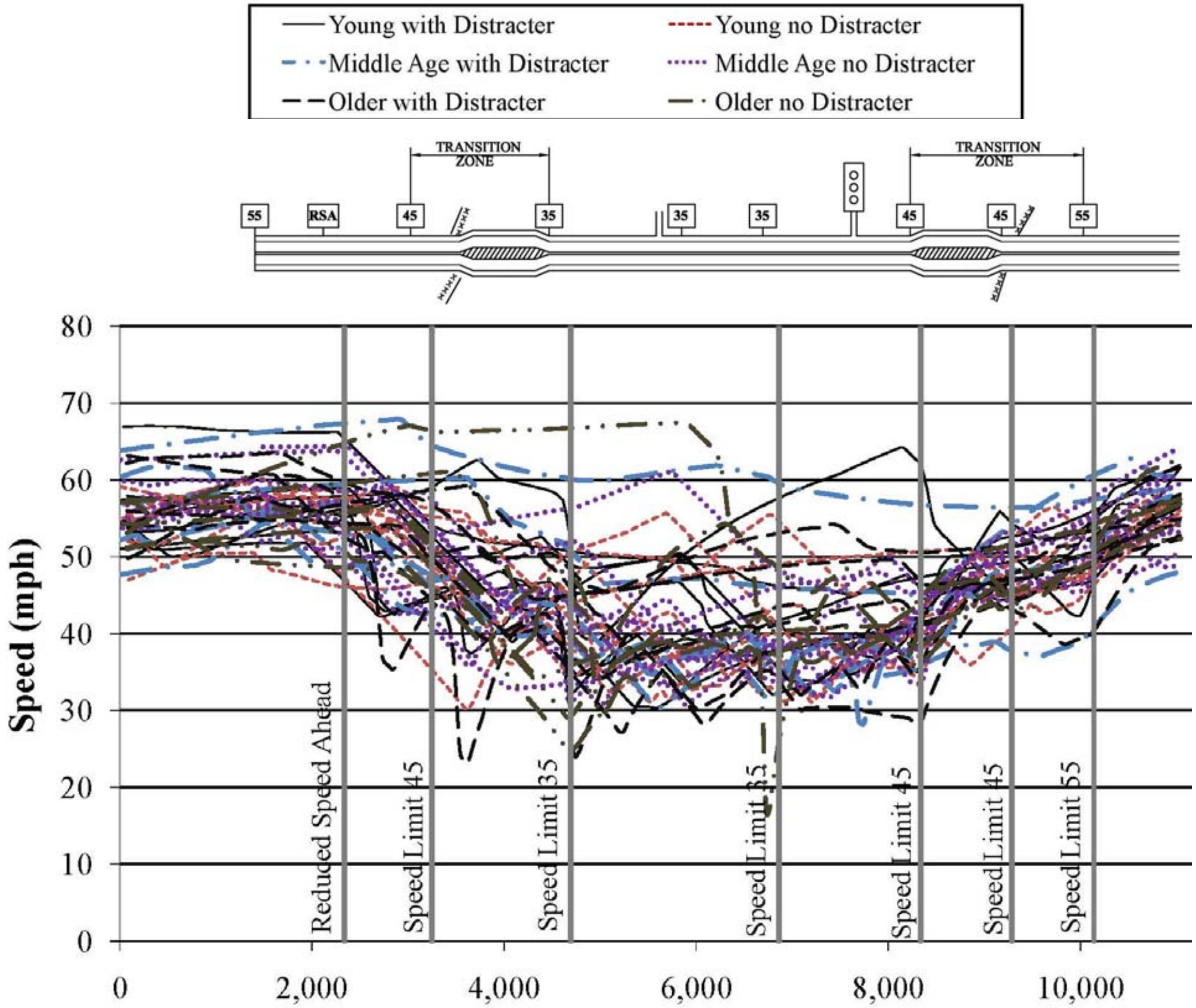

Figure 3.16: Individual's Speed at Gateway with Median Treatment

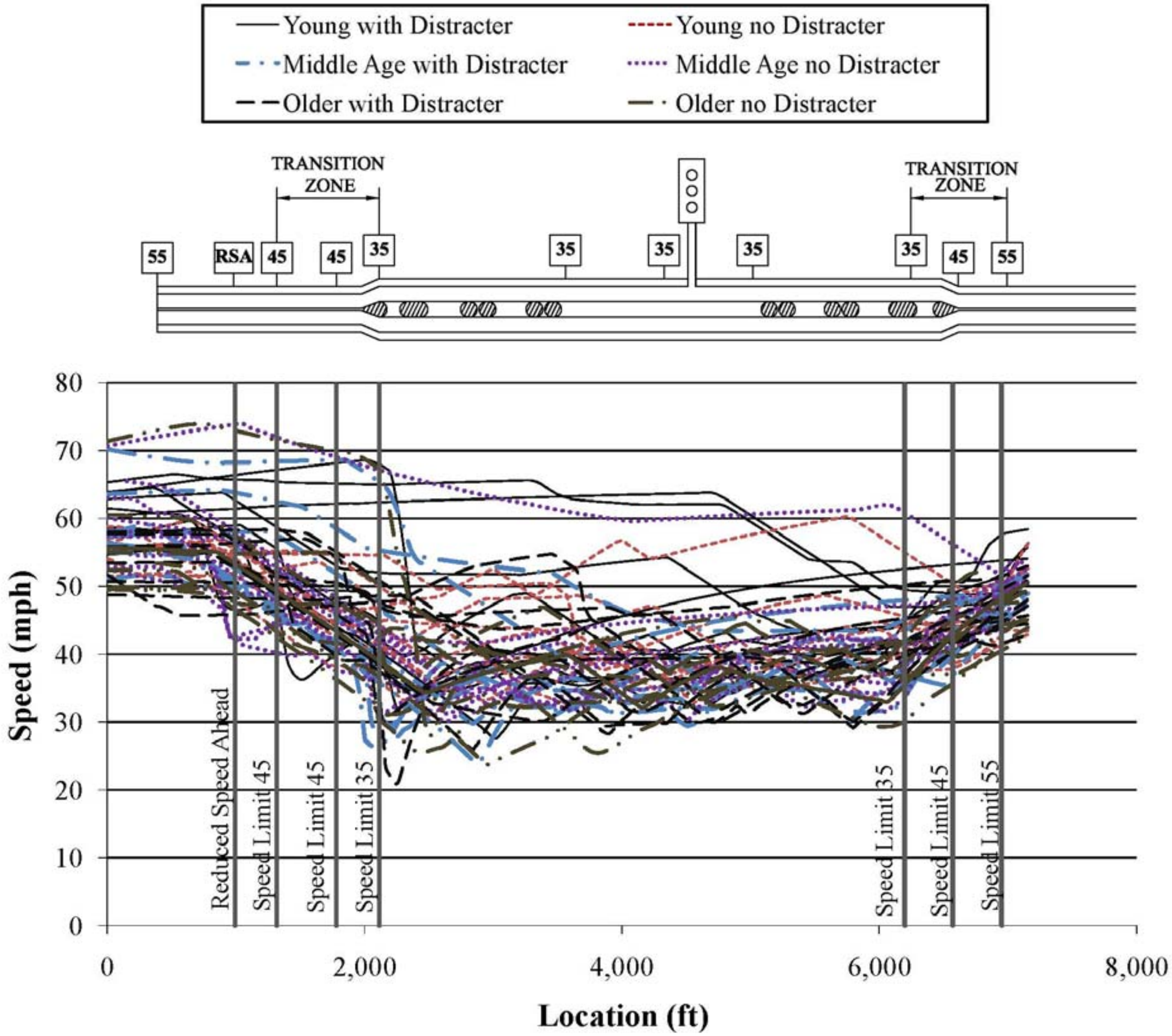

Figure 3.17: Individual's Speed at Medians in Series with No Walks Treatment

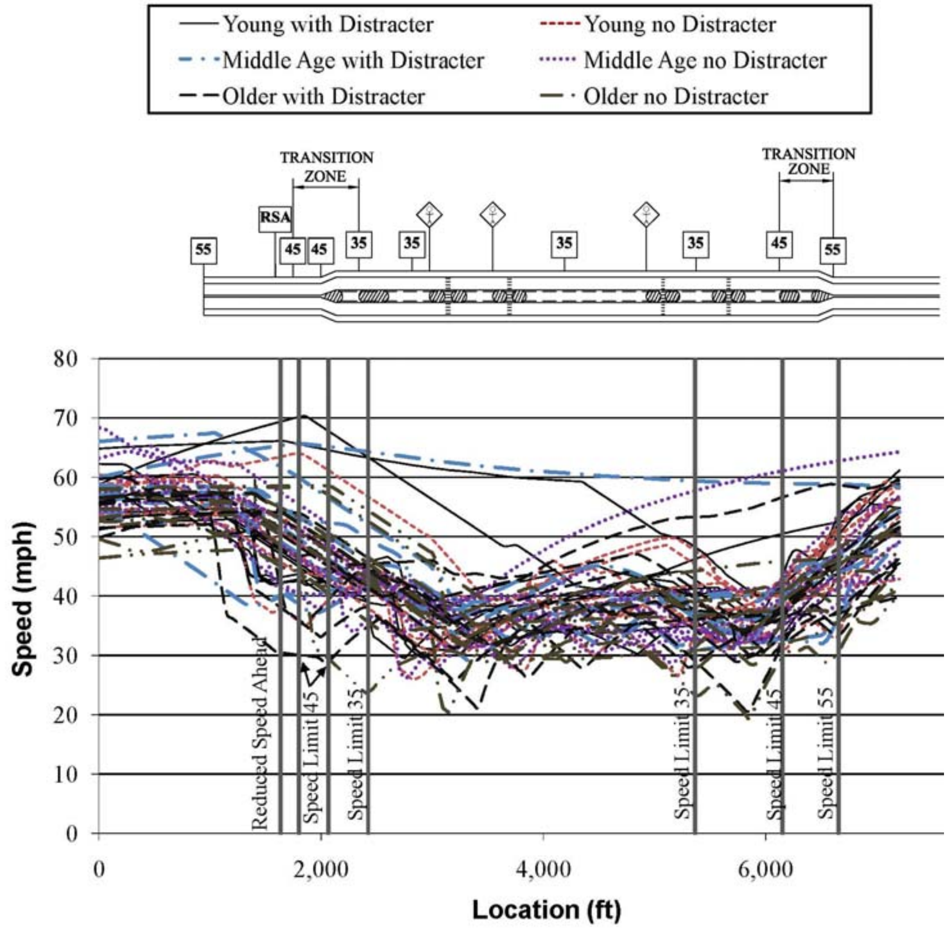

Figure 3.18: Individual's Speed at Medians in Series with Pedestrian Walks Treatment

3.2 OBSERVED DATA FOR THE TRANSITIONS

The research team acquired speed data at several critical locations as previously indicated in Table 2.2. Examination of this data can provide valuable insight into speed trends for both the mean and 85th percentile speeds. For example, speed characteristics at the "Speed Limit 55 mph" sign, as shown in Table 3.1, demonstrate the variability of speeds at the upstream end of the transition for both simulated driving experiences with and without the distracter game. Similar summary speed data are included for the region adjacent to the "Speed Limit 35 mph" sign (see Table 3.2) as well as the location 300 feet downstream of the first 35 mph speed limit sign (see Table 3.3). Tables for the other key analysis locations are included in Appendix B (Table B1.1 through Table B1.5). In addition to the mean speed and 85th percentile speed for each design treatment, these tables provide a ranking for all participant mean speeds (from the lowest to the highest). This ranking is one indicator of how effective a treatment appears to be for speed reduction; however, the actual speed reduction is also an important variable since overall influence on reducing speed is the ultimate objective of the candidate treatments.

Table 3.1: Speed Characteristics at 55 mph Speed Limit Sign (L1)

	With Distracter		No Distracter		All			
Treatment	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Mean Speed mph)**	**85thPercentile Speed (mph)**	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Sample Size**	**Rank (lowest to highest mean)**
A - Control 2 Lanes (1)	57.1	63.7	54.1	58.7	55.6	61.6	47	2
B - Control 2 Lanes (2)	55.5	60.1	53.9	58.1	54.7	59.0	53	1
C - Layered Landscape	56.1	59.8	55.8	58.8	56.0	59.5	53	3
D - Gateway with Lane Narrowing	56.6	62.0	55.4	58.3	56.0	60.8	54	3
E - Control 2 Lane with Center Lane	58.4	65.1	57.5	61.5	58.0	63.7	54	9
F – Median Only	57.4	61.5	56.5	59.5	56.9	60.8	51	6
G – Median with Gateway	58.2	63.5	56.3	59.1	57.2	60.9	46	8
H - Medians in Series No Crosswalks	57.8	63.9	56.5	60.3	57.1	63.3	54	7
I - Medians in Series with Crosswalks	56.7	60.6	56.5	59.7	56.6	60.0	53	5

Table 3.4 and Table 3.5 demonstrate the observed speed reduction for mean speed and 85th percentile speed respectively between the 55 mph sign and the 35 mph sign location based on driver age and distracter test. Similarly Table 3.6 and Table 3.7 demonstrate the observed reductions in mean speed and 85th percentile speed respectively between a variety of the key analysis locations. These values are further separated based on whether the proctor administered the distracter test. Table 3.8 shows total speed reductions for all participants between these key locations.

Table 3.2: Speed Characteristics at Speed Limit 35 Sign (L6)

	With Distracter		No Distracter		All			
Treatment	Mean Speed (mph)	85th Percentile Speed (mph)	Mean Speed (mph)	85thPercentile Speed (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Sample Size	Rank (lowest to highest mean)
A - Control 2 Lanes (1)	43.8	56.0	42.0	55.7	42.8	57.5	48	1
B - Control 2 Lanes (2)	45.5	59.4	45.1	51.3	45.3	55.7	49	8
C - Layered Landscape	46.4	58.2	44.1	52.7	45.2	55.9	53	7
D - Gateway with Lane Narrowing	46.4	56.4	43.5	49.0	45.0	53.5	51	6
E - Control 2 Lane with Center Lane	47.1	57.1	45.4	51.6	46.3	54.3	51	9
F – Median Only	46.2	56.6	43.4	49.3	44.7	51.4	51	5
G – Median with Gateway	44.6	50.7	42.2	50.5	43.3	50.7	46	2
H - Medians in Series No Crosswalks	44.7	56.0	43.3	49.9	44.0	52.1	54	3
I - Medians in Series with Crosswalks	45.4	51.6	42.8	45.9	44.1	48.5	50	4

Table 3.3: Speed Characteristics 300 Feet Downstream of Speed Limit 35 Sign (L7)

	With Distracter		No Distracter		All			
Treatment	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Mean Speed (mph)**	**85thPercentile Speed (mph)**	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Sample Size**	**Rank (lowest to highest mean)**
A - Control 2 Lanes (1)	43.7	57.2	41.1	51.7	42.4	56.5	46	7
B - Control 2 Lanes (2)	44.1	59.1	42.6	50.5	43.4	54.1	49	9
C - Layered Landscape	43.8	56.5	39.9	45.4	41.9	50.4	51	6
D - Gateway with Lane Narrowing	41.2	53.8	40.2	47.2	40.7	51.5	51	1
E - Control 2 Lane with Center Lane	43.6	55.3	41.9	49.1	42.8	51.9	51	8
F – Median Only	42.6	54.4	39.8	45.3	41.1	48.8	51	4
G – Median with Gateway	42.8	48.6	40.9	49.8	41.8	49.5	45	5
H - Medians in Series No Crosswalks	41.4	52.1	39.9	46.4	40.7	48.5	53	1
I - Medians in Series with Crosswalks	43.0	49.3	38.8	42.7	40.9	45.5	50	3

Table 3.4: Mean Speed Differences by Age for 55 mph to 35 mph Locations

Treatment	Mean Speed (mph)											
	Young Drivers			Mid-Age Drivers			Older Drivers			All Drivers		
	55 mph Sign	35 mph Sign	Speed Reduction	55 mph Sign	35 mph Sign	Speed Reduction	55 mph Sign	35 mph Sign	Speed Reduction	55 mph Sign	35 mph Sign	Speed Reduction
With Distracter Test												
A - Control: 2 Lanes (1)	59.2	43.2	16.0	58.7	46.6	12.1	53.5	42.4	11.1	57.1	43.8	13.3
B - Control: 2 Lanes (2)	58.2	47.8	10.4	55.0	47.5	7.5	53.3	41.2	12.1	55.5	45.5	10.0
C - Layered Landscape	57.9	46.5	11.4	56.3	47.5	8.8	54.1	45.2	8.9	56.1	46.4	9.7
D - Gateway with Lane Narrowing	59.1	49.4	9.7	57.1	47.5	9.6	53.6	42.2	11.4	56.6	46.4	10.2
E - Control 2 Lane with Center Lane	60.7	51.5	9.2	60.2	46.3	13.9	54.3	43.5	10.8	58.4	47.1	11.3
F – Median Only	59.1	46.7	12.4	58.6	49.1	9.5	54.8	43.7	11.1	57.4	46.2	11.2
G – Median with Gateway	58.3	47.1	11.2	57.5	45.6	11.9	58.6	39.9	18.7	58.2	44.6	13.6
H - Medians in Series No Crosswalks	61.7	50.6	11.1	58.2	40.9	17.3	53.6	42.6	11.0	57.8	44.7	13.1
I - Medians in Series with Crosswalks	57.8	47.9	9.9	57.3	46.7	10.6	55.0	42.0	13.0	56.7	45.4	11.3
No Distracter Test												
A - Control: 2 Lanes (1)	53.2	41.4	11.8	57.7	42.3	15.4	52.0	42.3	9.7	54.1	42.0	12.1
B - Control: 2 Lanes (2)	54.1	44.3	9.8	57.5	47.2	10.3	50.2	44.4	5.8	53.9	45.1	8.8
C - Layered Landscape	56.2	42.3	13.9	57.7	46.2	11.5	53.6	43.9	9.7	55.8	44.1	11.7
D - Gateway with Lane Narrowing	54.9	44.6	10.3	58.4	45.2	13.2	52.9	41.2	11.7	55.4	43.5	11.9
E - Control 2 Lane with Center Lane	55.4	45.3	10.1	60.8	46.3	14.5	56.4	44.9	11.5	57.5	45.4	12.1
F – Median Only	55.7	46.0	9.7	59.8	42.6	17.2	54.0	41.7	12.3	56.5	43.4	13.1
G – Median with Gateway	55.8	43.4	12.4	58.0	41.7	16.3	55.0	41.2	13.8	56.3	42.2	14.1
H - Medians in Series No Crosswalks	55.2	44.5	10.7	58.9	42.8	16.1	55.4	42.7	12.7	56.5	43.3	13.2
I - Medians in Series with Crosswalks	56.4	43.5	12.9	59.5	41.6	17.9	53.6	43.1	10.5	56.5	42.8	13.7

Table 3.5: 85th Percentile Speed Differences by Age for 55 mph to 35 mph Locations

Treatment	85th Percentile Speed (mph)											
	Young Drivers			Mid-Age Drivers			Older Drivers			All Drivers		
	55 mph Sign	35 mph Sign	Speed Reduction	55 mph Sign	35 mph Sign	Speed Reduction	55 mph Sign	35 mph Sign	Speed Reduction	55 mph Sign	35 mph Sign	Speed Reduction
With Distracter Test												
A - Control: 2 Lanes (1)	66.9	56.5	10.4	65.6	54.2	11.4	61.1	51.2	9.9	63.7	56.0	7.7
B - Control: 2 Lanes (2)	60.8	60.2	0.6	61.6	60.3	1.3	56.6	47.2	9.4	60.1	59.4	0.7
C - Layered Landscape	60.8	62.6	-1.8	58.2	57.0	1.2	60.1	48.7	11.4	59.8	58.2	1.6
D - Gateway with Lane Narrowing	63.4	61.7	1.7	61.5	55.3	6.2	55.4	49.8	5.6	62.0	56.4	5.6
E - Control 2 Lane with Center Lane	66.4	65.3	1.1	67.0	59.9	7.1	59.5	50.6	8.9	65.1	57.1	8.0
F – Median Only	62.7	57.0	5.7	60.8	57.3	3.5	59.8	50.0	9.8	61.5	56.6	4.9
G – Median with Gateway	64.6	51.2	13.4	60.7	53.0	7.7	61.4	46.1	15.3	63.5	50.7	12.8
H - Medians in Series No Crosswalks	64.7	64.4	0.3	62.8	53.7	9.1	57.3	48.4	8.9	63.9	56.0	7.9
I - Medians in Series with Crosswalks	62.0	61.5	0.5	61.6	51.0	10.6	57.3	45.3	12.0	60.6	51.6	9.0
No Distracter Test												
A - Control: 2 Lanes (1)	56.0	42.9	13.1	59.2	53.8	5.4	59.1	56.8	2.3	58.7	55.7	3.0
B - Control: 2 Lanes (2)	55.7	50.4	5.3	59.3	59.7	-0.4	55.1	49.8	5.3	58.1	51.3	6.8
C - Layered Landscape	59.4	48.1	11.3	63.1	55.0	8.1	55.3	52.6	2.7	58.8	52.7	6.1
D - Gateway with Lane Narrowing	57.9	51.0	6.9	65.0	47.5	17.5	56.9	46.1	10.8	58.3	49.0	9.3
E - Control 2 Lane with Center Lane	58.1	52.8	5.3	65.2	50.7	14.5	58.3	47.8	10.5	61.5	51.6	9.9
F – Median Only	58.7	50.2	8.5	67.2	50.4	16.8	57.1	44.5	12.6	59.5	49.3	10.2
G – Median with Gateway	58.1	49.8	8.3	62.7	50.2	12.5	59.1	49.3	9.7	59.1	50.5	8.6
H - Medians in Series No Crosswalks	56.4	49.3	7.1	64.1	44.0	20.1	59.3	49.1	10.2	60.3	49.9	10.4
I - Medians in Series with Crosswalks	59.3	44.2	15.1	63.9	43.3	20.6	57.9	51.5	6.3	59.7	45.9	13.8

Table 3.6: Mean Speed Reduction Between Select Key Locations (Separated by Distracter Test)

Treatment	Reduction in Mean Speed (mph)							
	55 to 35 mph Sign	55 to 45 mph Sign	45 to 35 mph Sign	55 to 300' Downstream of 45 mph Sign	300' Upstream to 300' Downstream of 45 mph Sign	55 mph Sign to 300' Downstream of 35 mph Sign	45 mph Sign to 300' Downstream of 35 mph Sign	55 mph Sign to Treatment Location
With Distracter Test								
A – Control 2 Lanes (1)	13.3	0.9	12.3	3.0	5.8	13.3	12.4	--
B – Control 2 Lanes (2)	10.1	2.2	7.8	2.0	3.7	11.4	9.2	--
C - Layered Landscape	9.7	0.4	9.3	2.1	3.3	12.3	11.8	3.0
D - Gateway with Lane Narrowing	10.2	2.1	8.1	1.9	4.1	**15.4**	13.3	4.8
E - Control 2 Lane with Center Lane	11.3	3.4	7.9	1.2	4.1	14.7	11.4	--
F – Median Only	11.2	2.6	8.6	2.9	5.1	14.8	12.2	2.6
G – Median with Gateway	**13.5**	6.6	6.9	1.9	3.1	**15.3**	8.7	9.6
H - Medians in Series No Crosswalks	**13.1**	4.6	8.4	2.7	5.0	**16.4**	11.7	10.0
I - Medians in Series with Crosswalks	11.3	8.4	2.8	2.1	4.5	11.3	5.3	9.6
No Distracter Test								
A – Control 2 Lanes (1)	12.1	0.2	11.9	1.9	4.4	13.1	12.9	--
B - Control 2 Lanes (2)	8.8	1.5	7.4	2.0	4.3	11.4	9.9	--
C - Layered Landscape	11.7	1.6	10.1	3.5	5.1	**16.0**	14.4	6.0
D - Gateway with Lane Narrowing	11.9	3.6	8.3	1.9	5.0	**15.2**	11.6	6.5
E - Control 2 Lane with Center Lane	12.1	2.7	9.4	2.6	5.0	15.7	13.0	--
F – Median Only	**13.1**	4.2	8.9	2.9	5.3	**16.7**	12.6	4.2
G – Median with Gateway	**14.2**	6.4	7.8	2.8	5.5	15.4	9.0	10.8
H - Medians in Series No Crosswalks	**13.1**	5.9	7.2	2.3	4.5	**16.6**	10.6	11.3
I - Medians in Series with Crosswalks	**13.7**	7.7	6.0	3.7	6.5	13.7	10.0	10.6

Table 3.7: 85th Percentile Speed Reduction Between Select Key Locations (Separated by Distracter Test)

Treatment	Reduction in 85th Percentile Speed (mph)							
	55 to 35 mph Sign	55 to 45 mph Sign	45 to 35 mph Sign	55 to 300' Downstream of 45 mph Sign	300' Upstream to 300' Down-stream of 45 mph Sign	55 mph Sign to 300' Downstream of 35 mph Sign	45 mph Sign to 300' Downstream of 35 mph Sign	55 mph Sign to Treatment Location
With Distracter Test								
A – Control 2 Lanes (1)	7.7	1.2	6.5	2.9	5.2	6.5	5.3	--
B – Control 2 Lanes (2)	0.7	0.0	0.7	0.2	-0.1	1.0	1.0	--
C - Layered Landscape	1.7	-2.2	3.9	1.8	1.9	3.3	5.6	-0.5
D - Gateway with Lane Narrowing	5.6	0.3	5.3	0.1	1.6	**8.2**	7.9	1.8
E - Control 2 Lane with Center Lane	8.0	-0.6	8.6	-1.1	-2.5	9.8	10.4	--
F – Median Only	4.9	0.3	4.6	2.9	3.8	7.2	6.8	0.3
G – Median with Gateway	**12.9**	4.5	8.3	-1.2	-2.1	**15.0**	10.4	5.0
H - Medians in Series No Crosswalks	7.9	2.0	6.0	1.6	1.9	**11.8**	9.9	7.2
I - Medians in Series with Crosswalks	**9.0**	4.6	4.4	4.7	6.2	9.0	6.7	3.7
No Distracter Test								
A – Control 2 Lanes (1)	3.0	-2.7	5.8	2.3	1.1	7.0	9.7	--
B - Control 2 Lanes (2)	6.8	0.2	6.6	-0.7	-0.7	7.5	7.4	--
C - Layered Landscape	6.0	2.9	3.1	0.0	2.6	**13.4**	10.4	2.8
D - Gateway with Lane Narrowing	**9.3**	2.6	6.7	3.3	5.8	**11.1**	8.5	6.0
E - Control 2 Lane with Center Lane	9.9	1.6	8.3	2.1	2.9	12.3	10.8	--
F – Median Only	**10.2**	2.2	8.0	1.9	2.9	**14.2**	12.0	2.2
G – Median with Gateway	8.6	3.6	5.0	1.9	4.4	9.3	5.8	5.8
H - Medians in Series No Crosswalks	**10.4**	5.5	4.9	0.0	1.6	**14.0**	8.5	8.6
I - Medians in Series with Crosswalks	**13.8**	5.0	8.9	5.5	8.0	**13.8**	12.0	8.9

Table 3.8: Speed Reduction Between Select Key Locations (All Participants)

Treatment	Reduction in Speed (mph)							
	55 to 35 mph Sign	55 to 45 mph Sign	45 to 35 mph Sign	55 to 300' Downstream of 45 mph Sign	300' Upstream to 300' Down-stream of 45 mph Sign	55 mph Sign to 300' Down-stream of 35 mph Sign	45 mph Sign to 300' Down-stream of 35 mph Sign	55 mph Sign to Treatment Location
Mean Speed -- All								
A – Control 2 Lanes (1)	12.7	0.5	12.2	2.4	5.1	13.2	12.6	--
B – Control 2 Lanes (2)	9.4	1.8	7.6	2.0	4.0	11.3	9.5	--
C - Layered Landscape	10.7	1.0	9.7	2.8	4.2	**14.1**	13.1	4.6
D - Gateway with Lane Narrowing	11.0	2.8	8.2	1.9	4.5	**15.3**	12.5	5.5
E - Control 2 Lane with Center Lane	11.7	3.0	8.6	1.9	4.6	15.2	12.1	--
F – Median Only	**12.2**	3.4	8.8	2.9	5.2	**15.8**	12.4	3.4
G – Median with Gateway	**13.9**	6.5	7.4	2.4	4.3	**15.4**	8.9	10.2
H - Medians in Series No Crosswalks	**13.1**	5.3	7.8	2.5	4.7	**16.5**	11.2	10.7
I - Medians in Series with Crosswalks	**12.5**	8.1	4.4	2.9	5.5	12.5	7.6	10.0
85^{th} Percentile Speed -- All								
A – Control 2 Lanes (1)	4.1	-1.2	5.3	2.9	3.7	5.1	6.3	--
B - Control 2 Lanes (2)	3.3	-0.3	3.6	-0.1	-0.1	4.9	5.2	--
C - Layered Landscape	3.6	-0.9	4.5	1.5	0.4	**9.1**	10.1	1.2
D - Gateway with Lane Narrowing	**7.3**	1.0	6.3	0.2	0.7	**9.3**	8.3	3.0
E - Control 2 Lane with Center Lane	9.4	3.2	6.3	0.3	2.6	11.8	8.6	--
F – Median Only	9.4	0.1	9.3	3.0	3.4	**12.0**	11.9	0.1
G – Median with Gateway	**10.2**	2.8	7.4	-0.1	0.1	11.4	8.6	5.6
H - Medians in Series No Crosswalks	**11.2**	4.9	6.2	2.2	3.4	**14.8**	9.9	10.7
I - Medians in Series with Crosswalks	**11.5**	4.7	6.8	5.3	8.0	11.5	9.8	5.6

By inspection of the data, it appears that the gateway with lane narrowing (Scenario D) results in additional mean speed reductions of approximately 2 to 4 mph over those normally expected without this treatment. This value is based on the speed difference between the 55 mph sign location to 300' downstream of the first 35 mph sign. Similarly, 85^{th} percentile speed reductions of approximately 2 to 4 mph can be expected for this treatment. The layered landscape scenario resulted in additional mean speed reductions of 1 to 3 mph and 85^{th} percentile speed reductions of approximately 4 mph.

The four median configurations provided mixed results. For the median only treatment (Scenario F), mean speeds reduced less than 1 mph while 85^{th} percentile speeds reduced approximately 0 to 3 mph. The median with gateway treatment (Scenario G) resulted in negligible speed reductions. For medians in a series (Scenarios H and I), there was a mean speed reduction of an additional 4 mph; however, the 85^{th} percentile speed reductions ranged from no additional speed reduction up to approximately 3 mph of speed reduction. To determine if these observed speed differences were statistically significant, the research team performed a series of significance tests. The results of these tests are included in the following section.

3.3 STATISTICAL INFERENCES

The purpose of this research is to determine the effectiveness of physical treatments at rural to urban transitions. As a result, one hypothesis that must be explored is that speeds adjacent to and downstream of the transitions are expected to be statistically different than the control configurations that did not incorporate similar treatments. A secondary hypothesis that should be explored is whether the distracter test created significantly different speed results for the various driving populations. Though the goal of speed reduction applies to the entire driving population, it is also worth noting whether the various age groups behaved differently towards the various speed reduction strategies during the distracter tests. As a result, this section explores whether these two hypotheses will identify any additional insights into the observed simulator data.

3.3.1 Hypothesis Testing for Reduced Speeds

Statistical testing enables an analyst to compare mean speeds for two scenarios to determine if the speed observed for one configuration is equivalent to the speed observed at the same location for an alternative scenario. The study included two two-lane controls (Scenario A and B) and one two-lane with center turn-lane control (Scenario E). The analysts could then use the speeds observed at these locations for comparison to similar locations where additional "speed reduction" strategies have been tested. Scenario C (layered landscape) and Scenario D (gateway with lane narrowing) should be directly compared to Scenarios A and B since they have similar baseline conditions. Alternatively, Scenarios F, G, H, and I should be directly compared to Scenarios A, B, and E to determine significant speed differences for the median treatment scenarios. Table 3.9 depicts the results of the average (mean) speed comparison between the treatments and the control runs. Since the objective of the treatments is to reduce speed in the rural to urban transition area, five key analysis locations are included in the table. P-values less than 0.05 (or 95% significance) indicate a scenario and location with statistically different speeds than the control site. As shown in the table, values that meet the 95% criteria are shaded and the text is bold. In addition, values that exceeded the 95% criteria but are within the 90% significance are indicated with bold text and no shading.

Table 3.9: Significant Speed Difference at Five Key Locations

	P-Value for T-Test		
Test Treatment	A -- Control 2 Lanes (1)	B – Control 2 Lanes (2)	E – Control 2 Lane with Center Lane
C – Layered Landscape			
300' Upstream of Speed Limit 45 Sign	0.124	0.930	NA
Speed Limit 45 Sign	0.478	0.958	NA
300' Downstream of Speed Limit 45 Sign	0.395	0.836	NA
Speed Limit 35 Sign	0.893	0.487	NA
300' Downstream of Speed Limit 35 Sign	0.398	0.207	NA
D – Gateway with Lane Narrowing			
300' Upstream of Speed Limit 45 Sign	**0.051**	0.809	NA
Speed Limit 45 Sign	0.109	0.588	NA
300' Downstream of Speed Limit 45 Sign	0.202	0.618	NA
Speed Limit 35 Sign	0.864	0.441	NA
300' Downstream of Speed Limit 35 Sign	0.205	**0.085**	NA
F – Median Only			
300' Upstream of Speed Limit 45 Sign	**0.050**	0.829	**0.041**
Speed Limit 45 Sign	0.422	0.943	0.446
300' Downstream of Speed Limit 45 Sign	**0.075**	0.422	**0.036**
Speed Limit 35 Sign	0.851	0.362	0.171
300' Downstream of Speed Limit 35 Sign	0.236	**0.090**	0.162
G – Median with Gateway			
300' Upstream of Speed Limit 45 Sign	**<0.001**	**0.004**	**<0.001**
Speed Limit 45 Sign	**0.003**	**0.061**	**0.002**
300' Downstream of Speed Limit 45 Sign	**0.008**	**0.063**	**0.003**
Speed Limit 35 Sign	0.584	0.143	**0.059**
300' Downstream of Speed Limit 35 Sign	0.390	0.210	0.308
H – Medians in Series No Crosswalks			
300' Upstream of Speed Limit 45 Sign	**0.004**	0.262	**0.002**
Speed Limit 45 Sign	**0.017**	0.231	**0.015**
300' Downstream of Speed Limit 45 Sign	**0.025**	0.173	**0.011**
Speed Limit 35 Sign	0.720	0.253	0.119
300' Downstream of Speed Limit 35 Sign	0.186	**0.068**	0.124
I – Medians in Series with Crosswalks			
300' Upstream of Speed Limit 45 Sign	**<0.001**	**0.002**	**<0.001**
Speed Limit 45 Sign	**<0.001**	**0.002**	**<0.001**
300' Downstream of Speed Limit 45 Sign	**<0.001**	**<0.001**	**<0.001**
Speed Limit 35 Sign	0.763	0.238	**0.098**
300' Downstream of Speed Limit 35 Sign	0.204	**0.073**	0.137

Note: NA = Not Applicable

As shown in Table 3.9, Scenarios C and D had little significant affect on systemic speed reductions at the key locations. All four median treatments, however, appeared to influence speed reductions in the area adjacent to the transition (primarily 300 feet upstream to 300 feet downstream of the 45 mph Speed Limit sign). These speed reductions did not consistently extend beyond the transition region. As indicated in Section 4.2, the actual speed reductions at these locations varied.

3.3.2 Hypothesis Testing for Distracter Tests

As previously indicated, the goal of a simulator distracter test is to keep the participant engaged and to help mask the objective of the simulation so as to reduce anticipatory behavior by the participant. Though the proctor administered the distracter "game" in the rural 55 mph region of each "distracter test" simulation run, it is possible that any influence on driver's response to the environment could extend into the transition area. Since a distracter is an actual expectation for the driving task (similar to talking to a passenger or perhaps changing the station on the radio), the extended influence on speed, if present, may realistically capture the driving characteristics of a driver when faced with "multi-tasking" activities.

To determine if the distracter tests influenced the driver's selected speed choices, the research team performed a t-test comparison for the 95% significance level. This test incorporated the variance in the data to determine if the average differences in speeds between the simulator runs with the distracter test, and those without, are comparable. The tested hypothesis was that the speeds during the distracter test runs were equal to the speeds for no distracter tests and that observed differences between the values are insignificant. Table 3.10 demonstrates the result of this significance test. Interestingly, the distracter significantly influenced the speed choice for younger drivers while the speed choice for middle and older aged drivers was not influenced at all. A similar significance test for the compiled data across age groups resulted in very little statistically significant locations for speed difference. The two identified locations (layered landscape at the treatment location and medians in a series with crosswalks 300 feet downstream of the 35 mph sign) were right at the 95% threshold value used for analysis. The findings of this distracter test assessment indicate that younger, generally less experienced drivers are more easily influenced by distractions during the driving task than are the older, more experienced drivers.

Table 3.10: Significance of Distracter Test on Speed Choice

	Statistically Significant Speed Difference Key Locations			
Treatment	**Young**	**Middle**	**Older**	**All Ages**
A - Control 2 Lanes (1)	L1 - L4	--	--	--
B - Control 2 Lanes (2)	L1 – L3	--	--	--
C - Layered Landscape	L2 – L4	--	--	L8
D - Gateway with Lane Narrowing	L1 – L4, L8	--	--	--
E - Control 2 Lane with Center Lane	L1	--	--	--
F – Median Only	L1 – L4, L8	--	--	--
G – Median with Gateway	L1 – L5, L6 – L7	--	--	--
H - Medians in Series No Crosswalks	L1 – L5	--	--	--
I - Medians in Series with Crosswalks	--	--	--	L7

3.4 ANALYSIS OVERVIEW

This chapter summarized the individual transition scenarios evaluated in the simulator study. Six treatment strategies and three control conditions made up the driving environments. Though results are mixed, the use of median treatments with gateways, in a series, and with crosswalks all resulted in greater speed reductions. The layered landscape and gateway with lane narrowing, which at some locations resulted in minor speed reductions, also included substantial variability and results were not determined to be statistically significant.

The distracter game provided a surprising finding that young drivers are primarily influenced while older, more experienced drivers did not demonstrate significant speed changes.

Finally, observed speed reductions generally occurred in the vicinity of the candidate transition treatments. They generally did not have significant downstream speed reduction affects.

4.0 CONCLUSIONS

This study determined the speed effects of roadway treatments implemented to slow drivers transitioning from rural environments to suburban communities. The study incorporated nine transition areas using a driving simulator where six of the transitions included treatments and three of the transitions were untreated (control sections). The selected treatments were based on individual treatments or combinations of treatments previously tested in the driving simulator during the two pilot study phases of the project. The treatments tested were as follows:

A) Control Two Lanes (1)
B) Control Two Lanes (2)
C) Layered Landscaping
D) Gateway with Lane Narrowing
E) Control Two Lanes with Center Lane
F) Median with Short Landscaping
G) Median with Gateway
H) Medians in Series with No Pedestrian Crosswalks
I) Medians in Series with Pedestrian Crosswalks

The simulated resulting speeds were similar to speed trends observed in the published literature regarding similar field studies. This study found that four treatments had the greatest speed reducing effects: 1) Medians in Series with Pedestrian Walks, 2) Medians in Series with No Pedestrian Walks, 3) Median with Gateway, and 4) Gateway with Lane Narrowing; however, this observed speed results for this final treatment were not statistically significant at a 95% level.

These treatments all resulted in mean speeds slower than the control scenarios. The treatments that were most effective had the most impact on the driver, either by forcing a horizontal maneuver, positioning the driver in closer lateral proximity to roadside or median objects, or by drawing their attention visually with signs. Particularly, the medians in a series with and without pedestrian crosswalks treatment slowed drivers down adjacent to the treatment, though observed speeds remained marginally higher than the posted speed limit at these locations.

The “Median with Gateway” treatment also proved effective at consistently reducing speeds during and after the treatment as the combination treatment helped improve the conspicuity of the change in driving environment. The “Median Only” treatment had modest speed reductions as well.

Though minor speed reductions also occurred at the “Gateway with Lane Narrowing” treatment and to some extent at the “Layered Landscape” treatment, these perceived improvements were extremely small and generally not statistically significant.

Approximately one-half of the simulations included the use of a distracter word game during the rural portion of the simulation. Though this game was suspended as a driver approached a simulated “town” with a control or transition segment, a residual effect of the word game on driver speeds occurred for the initial segment of the transition for young drivers. This observation is interesting when compared to statistically insignificant speed changes for middle or older aged drivers also tested with and without the distracter. One possible reason for this observation is that the more experienced drivers (presumably the middle and older aged drivers) are not as easily distracted from the driving task as younger, less experienced drivers.

Further studies could be conducted to compare these simulated results with field results using before and after case studies at specific locations. Additionally, further studies can analyze the effects of these treatment options on speeds throughout the towns instead of only around the transition area.

The study also concluded that there is an age effect between the young drivers compared to the middle and older aged drivers at specific locations. The only locations where an age effect was evident were on the fringes of the transition areas and appeared most often to correspond to a concurrent distracter word game as indicated previously. Therefore, additional research seems prudent to determine if the observed speed variations were in fact due to the distracter game or some other feature unique to a rural road environment.

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APPENDIX A:
DRIVING SIMULATOR OVERVIEW

A.1 SIMULATOR INTRODUCTION

Driving simulators date back to the early 1970s with early work performed by automobile manufactures and universities, such as General Motors and Virginia Polytechnic Institute. This technology has continued to mature. Examples of such simulators include (*Gruening et al., 1998*):

- Highway Driving Simulator (HYSIM), developed by the Federal Highway Administration of the USA. It is a fix-based simulator used primarily for human factor studies.
- VTI, the first generation, developed by Swedish Road and Traffic Research Institute. It is a motion-based simulator with a vibration table that connects to a hydraulic motion platform.
- Daimler-Benz driving simulator, developed by Daimler-Benz. It is a motion-based driving simulator.
- Iowa driving simulator, developed by the University of Iowa. It is a motion-based driving simulator with a hexapod support system.

Driving simulators have been used in a wide variety of studies related to drivers, vehicles and roadways. Various influence factors tested for “drivers” in simulation experiments include alcohol or drugs, age, fatigue, and disabilities. Vehicle variables include vehicle dynamic properties, in-vehicle environment, and various communication devices. Roadway factors include roadway geometry layout, road surface properties, traffic control devices, roadside environment features, and other roadway users.

By employing driving simulators, researchers can perform experiments at a relatively low cost that they may not be able to easily perform on the actual road. Simulators also enable researchers to repeat the experiments and obtain results with certain measurements of confidence. Some of the advantages of driving simulator studies include:

- Well designed study experiments with more flexibility and repeatability;
- Less expensive studies with no physical risk when compared to a real driving test;
- Hazardous condition studies that may be impossible or difficult to field test can be performed with little or no risk; and
- Simulators provide extensive data collection capabilities.

Meanwhile, driving simulator experimental studies also have known disadvantages including:

- Motion sickness occurs frequently in many driving simulator tests. Some research reports have detailed discussions of the causes and how to reduce driving sickness (*Kennedy, 1997*).
- Misleading experimental results could occur due to inappropriate experimental design, inadequate calibration of the employed driving simulator, or minimal assurance of repeatable, dependable results.

A.2 SIMULATOR CATEGORIES

Saluäär et al. (*2000*) categorized driving simulators into three levels of sophistication: low-level, mid-level and high-level. This categorization is based on the level of technology and functionality as well as the required financial support of the system development (*Stärnevall, 2003*). The general features and examples of these driving simulator categories are summarized in Table A1.1.

A.3 IMPORTANT ASPECTS OF SIMULATORS

A driving simulator and accompanying experiment must be constructed with recognition of common simulator conditions that can influence "real world" calibration of the study findings. The most common aspects that should be considered for speed studies are delay, speed, and the force and motion feedback. Each of these is briefly discussed in the following section.

Table A1.1: Features of Driver Simulator Levels

	Low-level	Mid-level	High-level
Motion System	Fix-based, no motion supply	Most of them are fix-based, some are motion-based Provide pitch, roll, and heave motion based on servo system or small hexapod support system	Motion-based Provide 6 degree of freedom, based on large hexapod support and also allow longitudinal translation movement Provide better physical reaction force feedback
Display System	Standard monitors with limited field of view	Projection screen system, providing front view, side view, or rear view Horizontal Field of View(FOV): 60-240 degrees Vertical FOV: 30-40 degrees	Projection screen system, providing front view, side view, and rear view Horizontal FOV 120-360 degrees
Vehicle Model	Equipped with a steering wheel (full size or smaller) and pedal control devices, without steering force feedback	Mockup vehicle or cab, providing steering wheel force feedback	Mockup vehicle or cab, providing steering wheel force feedback and braking, gear shifting force reaction as well
Example	• STISIM • GlobalSim DriveSafty DS-100c	• GlobalSim DriveSafety DS-600c • Illusion Technologies • AutoSim • STS • LADS	• NADS • VTI-III

- *Delay.* Generally, a driving simulator is made up of several subsystems including sound, force feedback, visual image, vehicle model, and scenario generation. Good system synchronization is the key to producing good system performance. The system delay from a driver's action to simulator's reaction should not be more than 60 milliseconds (ms). Larger delays may cause the "driver" to feel dizzy. This is one of the potential causes of simulator motion sickness (*Johansson & Nordin, 2002*).

- *Speed.* Without a speedometer, drivers acquire a speed sensation from the edge of their general field of vision instead of from their direct view. Therefore, a projection screen with at least a 120-degree horizontal field of view by 30-degree vertical field of view will provide a better sense of speed for drivers than a screen with 60-degree horizontal field of view by 30-degree vertical field of view, which only covers the forward field of view (*Johansson & Nordin, 2002; Saluäär et al. 2000; Weir & Clark, 1995*). Driving simulator research also shows that real world speeds are generally **higher** than the speeds obtained from simulator experiments when testing identical roadways and environments (*Johansson & Nordin, 2002*). This means that drivers tend to drive slower in simulators than the real world.

- *Force Feedback and Motion System.* The force feedback system includes two types of forces:

    1. Forces produced from driving control: steering wheel, brake pedal, gear shifting, etc.; and
    2. Forces produced from motion changes of the car and road surface variation.

The first type of force significantly contributes to the sense of driving. The torque feedback from the steering column should be included in the simulator. This feedback will help to reduce the steering variance and increase the fidelity of the driving simulator (*Gruening et al., 1998*). Steering force feedback can give drivers the steering sensation similar to what they would experience in real world driving. Without the steering force feedback, drivers will turn (over-steer) more than they would in the real world. When drivers realize they have steered too far in one direction, they will attempt to straighten the car's path. As a result, they often have a hard time maintaining the path of the vehicle on the simulated road (*Johansson & Nordin, 2002*). This type of unrealistic maneuver tends to eventually reduce the test fidelity.

A motion system can produce a second type of motion force that includes a vibration table and a motion platform. The vibration table can create the vertical forces the drivers expect to feel. Some researchers suggest that the fix-based driving simulator will accommodate maneuvers below 0.3g (*Gruening et al., 1998*). Most of the motion platforms employ a hexapod to provide pitch, yaw, roll, and heave. Hydraulic translation equipment produces the lateral and longitudinal translational movement. Researchers compared the validation tests of driving simulators with and without motion-bases for standard road driving situations. The simulators with motion-bases produced good validation results using the standard deviation of the relative vehicle position within the lane. The simulators in both categories produced good validation results of the average speeds and lane positions. Both simulator types produced poor validation results using the standard deviation of vehicle speeds (*Törnros et al., 1997*).

A.4 OVERVIEW OF SELECT SIMULATORS

A.4.1 Low-level Simulators

As previously indicated in Table A1.1, low-level driving simulators are often simple, fix-based devices that do not incorporate motion feedback. Examples of these devices include STISIM, and the GlobalSim DriveSafety DS-100c. The characteristics of these are briefly reviewed in the following sections.

A.4.1.1 STISIM Drive, System Technology, Inc. USA.

STISIM Drive is a low-cost, personal computer based, interactive driving simulator. Figure A1.1 through Figure A1.4 depict a variety of hardware configurations that can be used for STISIM Drive evaluation.

Figure A1.1: Scaled Model Vehicle Cab *(STI website, 2005)*

Figure A1.2: Simulated Vehicle Cab *(STI website, 2005)*

Figure A1.3: Modular Desktop Controls *(STI website, 2005)*

Figure A1.4: Laptop PC-based Configuration *(STI website, 2005)*

The past and current research applications evaluated using a STISIM include:

- Sleep, drug, disease, age, and fatigue studies;
- Training, rehabilitation, and cognitive factor studies; and
- Vehicle dynamics, tires, roadway design, and driver modeling.

In a speed related study, researchers used the desktop based STISIM driving simulator to assess the effects of geometric curvature and lane demarcation on drivers' selection of path and speed in double-lane roundabouts. In this study (*Davis et al., 2003*) the speed and lane position were measured at seven simulated roundabout locations. The average speed data indicated the participants drove faster through larger interchange roundabouts than the smaller urban roundabout. In this study, the simulator appeared to be a feasible solution for speed comparison studies for facilities with operating speeds of 40 mph (64 km/h) or lower.

A.4.1.2 DriveSafety DS-100c Desktop Simulator, GlobalSim, USA.

GlobalSim developed the DriveSafety DS-100c Desktop Research Simulator for use on a standard desktop computer system. This system includes a single channel audio/visual system, monitor or flat screen, 900-degree steering wheel, accelerator and brake pedal (see Figure A1.5). This low-level driving simulator provides only basic functionality. There does not appear to be any documented speed simulation research performed using this particular simulator.

Figure A1.5: DriveSafety DS-100c Desktop Simulator

A.4.2 Mid-level Simulators

Table A1.1 summarizes a variety of features for a mid-level driving simulator. These devices are more sophisticated that the low-level simulators but do not have the full functionality of the high-level simulators. Examples of these devices include: GlobalSim DriveSafety DS-600c, Illusion Technologies, AutoSim, STS, and LADS. The characteristics of these are briefly reviewed in the following sections.

A.4.2.1 DriveSafety DS-600c Simulator, GlobalSim, USA

The GlobalSim DriveSafety DS-600c simulator is a fix-based, mid-level driving simulator designed for ground vehicle research and training applications. The hardware system includes a vehicle cab, a projection screen system, and system control computers. Figure A1.6 depicts a view of the simulator components. The vehicle cab varies (often a Ford Focus cab is used) and includes steering wheel torque feedback and passive brake and accelerator sensations. Screen projections can range from 180-degrees up to 300-degrees. The simulator also includes a digital audio system with four speakers. This system simulates driving noise and associated environment sounds.

Figure A1.6: DriveSafety DS-600c Simulator

The DriveSafety DS-600c simulator has been used at several universities, research institutions and corporations, such as: Ford, General Motors, Nissan, Texas Transportation Institute, the University of Michigan, Clemson University, the University of Iowa, the University of Illinois, Montana State University, and the University of Calgary.

Research performed at the Texas Transportation Institute driving simulator, for example, evaluated driver distraction due to cell phone use or other in-vehicle devices while driving (*Crawford et al., 2001*). This study investigated the influence on driving performance by using cell phones with various conversation intensity levels and the different modes of cell phone use (handheld or hands-free). The performance measures recorded during the experimental drives included:

- Mean and standard deviation of lane position;
- Mean and standard deviation of steering input;
- Mean and standard deviation of accelerator input; and
- Mean and standard speed.

Researchers at Clemson University used the fix-based DriveSafety simulator to study the influence of cell phones on driving performance (*Rakauskas et al., 2004*). In this study, the dependent variables collected for speed and lane position maintenance measures included accelerator position variability, speed variability, average speed, steering offset, and mean lateral speed.

A.4.2.2 Real Drive Simulator, Illusion Technologies, Inc., USA

The Real Drive Simulator, produced by Illusion Technologies International, Inc. (ITI), is a fixed-base fully interactive dynamic driving simulator. Example ITI simulators are located in Australia, and in the United States in Washington (not currently functional), and Massachusetts. Figure A1.7 shows, as an example, the

University of Massachusetts at Amherst Real Drive simulator. The Real Drive mid-level simulator includes a vehicle cab with steering force feedback, three to four separate images on a semi-circular screen for a 150-degree to 180-degree field of view, a high resolution graphics system, and a Bose surround-sound audio system that introduces realistic road, wind, and environment noises. A rear-view screen with 60-degree projection can also be added for a rear-view mirror option.

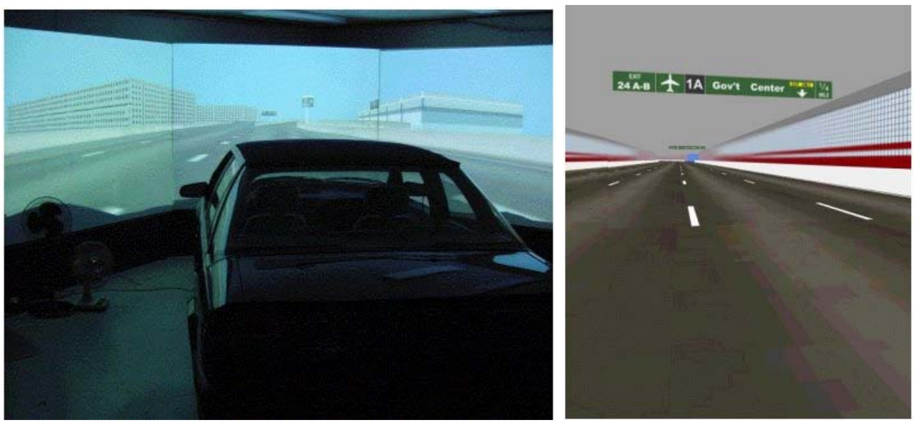

Figure A1.7: Real Drive Simulator at University of Massachusetts

The Australia simulator, located at Monash University, has been used for research projects such as the effects of a restricted field of view from night vision goggles on driving performance, evaluation of the instructional effectiveness of a CD ROM product designed to accelerate the development of critical perceptual and cognitive driving skills, and the evaluation of the effects of a range of road environment-related "perceptual countermeasures" such as edge-line, median and transverse-line treatment (*Godley et al., 1999*). The perceptual countermeasures study used the simulator to test the effects of several new treatments on speed reduction. The speed and lateral position measures were compared at both treated and untreated simulated sites.

A.4.2.3 AutoSim Simulator, AutoSim (AS), Norway

The AutoSim Driving Research Simulator is produced in Norway. The AutoSim is used worldwide in locations such as England, the United States (at the University of Minnesota), Germany, and China.

At the University of Minnesota, the HumanFIRST driving simulator is an AutoSim device. This example simulator is depicted in Figure A1.8.

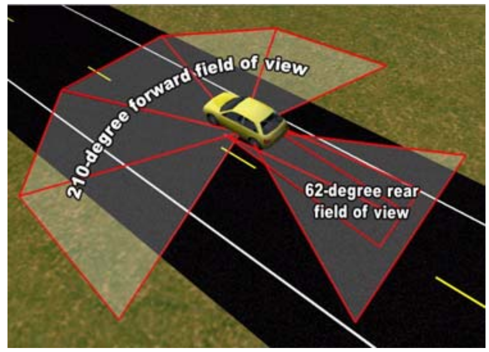

Figure A1.8: HumanFIRST Simulator

The AutoSim mid-level simulators generally include a vehicle cab with force-feedback steering and power-assisted brakes, up to five screen projections for a 210-degree field of view (including images for the rear and side mirrors), and a 3-dimensional surround-sound system that includes natural auditory feedback such as noise generated from inside as well as outside the car. The AutoSim simulators are motion-based and can duplicate sensations consistent with driving over rumble strips, curbs, or speed humps. Video surveillance cameras and intercom systems can be installed inside the vehicle to record the driver's actions and verbal comments during experiments. System measures of effectiveness include the physical vehicle orientation and location, vehicle conditions including steering, braking, and accelerating, and measures derived from these items such as vehicle speed.

Several University of Minnesota studies suggest that the AutoSim simulator can be used for speed related studies. For example, in a study of behavioral effects of driver distraction and alcohol impairment, participant drivers were asked to follow a lead vehicle as it randomly changed speed (between 55 and 70 mph [88 and 112 km/h]) with varied time cycles and fixed speed amplitude. The lead vehicle's taillights were not illuminated during decelerations. This experimental design simulated releasing the accelerator without pressing the brake pedal. The participant drivers were able to perceive the realistic cue of speed variations of the lead vehicle and perform the corresponding maneuver in order to follow the lead vehicle. Even though speed was not one of the selected study performance measures, the experiments showed that the sensation of speed can be adequately represented with the simulator (*Rakauskas & Ward, 2005*).

In the United Kingdom, Lockwood (*1997*) used the AutoSim simulator to evaluate the effectiveness of select traffic calming measures and gateway treatments. This study focused on speed as drivers approached and entered a town. The driving performance measures were recorded for every tenth of a second (10Hz) and included the location (x, y coordinates), speed, time, steering angle, accelerator position, brake pressure, and gear. A video camera system recorded the view of the road ahead, the subject's face, and the speedometer. The researchers validated their results with acceptable thresholds of error.

A.4.2.4 STS Mark-III Simulator, STS L3 Communication, USA

STS L3 Communication also produces a motion-based mid-level simulator. The University of Central Florida, for example, maintains a STS simulator (see Figure A1.9). The STS simulator includes a vehicle cab with steering wheel force feedback (developed for either a truck or a passenger car vehicle cab), vehicle motion, 180-degrees of horizontal field of view and approximately 30-degrees of vertical field of view, a rear-view mirror/window view, realistic (though time-consuming to create) graphic images, and an audio system to replicate a variety of driving noises. Performance measures can include driving speed, acceleration, and deceleration.

Figure A1.9: STS L3 Simulator

Researchers at the University of Central Florida used the STS simulator to study the influence of limited visibility of large size vehicles for red-light running (*Radwan et al., 2005*). Initially they evaluated pavement marking to indicate clearance interval thresholds. Using the simulator, they measured operating speeds at each intersection as the green signal phase ended. For the second part of the study, they collected average cruising velocities while the simulator car followed a passenger car or a school bus just prior to the traffic signal turning amber.

A.4.2.5 Leeds Advanced Simulator (LADS), UK

Leeds Advance Driving Simulator is a fix-based driving simulator suitable for use in performing transport safety and driver behavior related studies. Figure A1.10

depicts two photos of the LADS simulator. This mid-level simulator includes a vehicle cab with steering force feedback, a cylindrical screen in front of the vehicle and a screen behind the vehicle. Forward field of view is 230-degrees horizontal and 39-degrees vertical. The rear-view screen provides a 60-degree image viewed through the rear view and side mirrors. Audio feedback is provided through two speakers that provide engine and roadway environment noises. Performance measures available with the LADS device include driver behavior, vehicle information, and speed or position.

Figure A1.10: LADS Simulator

Blana (*1999*) performed a validation study for the LADS system to evaluate subject's opinions regarding the overall realism. Though realism perception received high ratings, participants indicated that the steering and braking features were un-realistic features.

Merat and Jamson (*2005*) used the LADS to compare the influences on driving performance for a driver talking on a hands-free phone versus talking with an inconsiderate passenger. The performance measures included driving speed, lane position, and headway. The testing route included four "events" such as a straight event, curve event, braking event, and coherence event. Each participant was instructed to drive through the testing route in one of the four driving situations, including silent, talking on a mobile phone, talking with an inconsiderate passenger, and talking with a considerate passenger.

A.4.3 High-level Simulators

Table A1.1 summarizes a variety of features for a high-level driving simulator. These devices are the most sophisticated and realistic of driving simulators. Examples of these devices include the National Advanced Driving Simulator and the VTI Driving Simulator. The characteristics of these are briefly reviewed in the following sections.

A.4.3.1 NADS, University of Iowa, USA

The National Advanced Driving Simulator (NADS), developed by the National Highway Traffic Safety Administration (NHTSA), is the most sophisticated driving simulator in the world and the first driving simulator with a large motion base (Figure A1.11). The NADS facility is located and operated at the University of Iowa. With NADS, researchers can perform real-time driving simulation of various study areas related to drivers, vehicles, and roadways. The system includes a dome mounted on a motion subsystem. The dome provides essentially a 360-degree horizontal field of view. The driver receives feedback that realistically replicates the sense of accelerating, braking, steering cues, and feedback. Entire cars or the cabs of trucks and buses can be mounted inside the dome with four available vehicle cab types (*Chen et al., 2001*).

Figure A1.11: NADS Simulator Dome (Exterior & Interior)

Ranney et al. (*2005*) used NADS to investigate the effects of cell phone use on driving performance and behavior. They examined four simulation events: car-following, lead-vehicle braking, lead-vehicle cut in, and merging. The NADS offered realistic operational maneuvers to the drivers. The variables used in the study included speed in various situations (at merge and before the event), speed changes, maximum deceleration, lane position variability, and time headway for various freeway locations.

A.4.3.2 VTI Simulator, Sweden

The VTI Driving Simulator III at the Swedish National Road and Transport Research Institute is a motion-based, high-level driving simulator. The simulator includes projection systems that can turn 90-degrees. The simulator includes a vibration table positioned under the chassis that simulates the driving contact between the tires and the road surface and also provides limited pitch and rolling angles. The field of view provides a 120-degree horizontal front view and rear view in side and rear mirrors. Simulator research using the VTI system includes road sign and aesthetic design of roadways. Figure A1.12 shows the VTI simulator configuration.

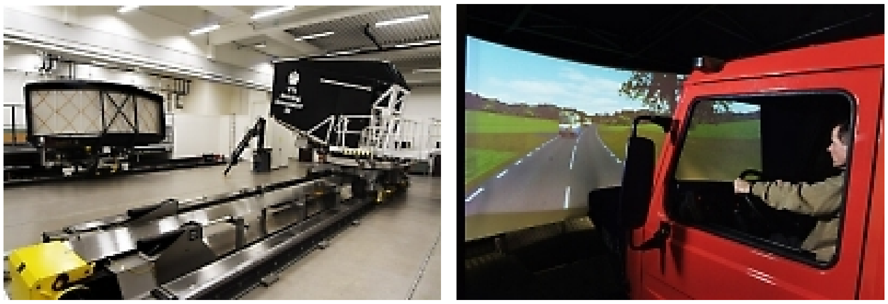

Figure A1.12: VTI Driving Simulator (Outside & Inside View)

A.5 Driving Simulator Pros and Cons

The use of driving simulators for speed-related research varies based on the specific functionality of the system. The advantages and disadvantages of the three simulator levels for speed related research are summarized in Table A1.2. For realistic speed evaluations, the low-level simulators do not appear to provide accurate road environment features that will adequately address driver perception of the road and associated speed. The mid-level simulators address most of the low-level simulator deficiencies and are often used for speed research, provided real-world calibration accompanies the analysis. Finally, the high-level simulators are ideal for all driving experience studies but are also extremely costly to own, operate, and rent. For research that is intended to identify the influence of road features on speed, the mid-level simulator appears to be the minimum device to adequately address these objectives.

Table A1.2: Simulator Level Advantages and Disadvantages

Simulator Level	Advantages	Disadvantages
Low-level Simulator	• Simple equipment • Low cost • Can be used for speed variability studies	• Field of view inferior for speed realistic speed sensation • Marginal quality and realism of display • Minimal vehicle control system features • Restricted options for building study corridors
Mid-level Simulator	• Can be used for speed variability studies as well as calibrated speed measurement studies	• Cost for purchase or rent greater than low-level • System performance less stable than

Simulator Level	Advantages	Disadvantages
	• Field of view adequate • Display seems more realistic than low-level • Vehicle control systems improved over low-level with some motion feedback	the PC-based low-level system
High-level Simulator	• High quality and easily adapted to almost any road environment scenario • Can be used for all speed studies • Complete, realistic field of view and motion feedback	• Expensive to purchase or rent • Realistic scenario development but can be costly and time consuming to generate

APPENDIX B:
FULL SCALE RESULT SUMMARIES FOR SUPPLEMENTAL LOCATIONS

Table B1.1: Speed Characteristics at 300 Feet Upstream of Speed Limit 45 Sign (L2)

	With Distracter		No Distracter		All			
Treatment	Mean Speed (mph)	85th Percentile Speed (mph)	Mean Speed mph)	85thPercentile Speed (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Sample Size	Rank (lowest to highest mean)
A - Control 2 Lanes (1)	58.9	64.8	56.4	60.2	57.7	63.5	46	9
B - Control 2 Lanes (2)	55.0	59.9	54.8	57.9	54.9	59.3	50	4
C - Layered Landscape	56.9	62.2	55.9	58.3	56.4	59.4	52	7
D - Gateway with Lane Narrowing	56.7	63.1	54.8	58.1	55.8	60.3	52	5
E - Control 2 Lane with Center Lane	58.0	64.4	57.3	60.7	57.6	62.9	52	8
F – Median Only	57.0	62.0	54.8	58.3	55.8	61.2	51	5
G – Median with Gateway	52.7	58.2	52.6	58.0	52.6	58.2	44	2
H - Medians in Series No Crosswalks	55.5	62.2	52.8	56.4	54.1	59.5	53	3
I - Medians in Series with Crosswalks	50.7	57.6	51.6	57.3	51.1	58.0	49	1

Table B1.2: Speed Characteristics at Reduced Speed Ahead Sign (L3)

	With Distracter		No Distracter		All			
Treatment	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Mean Speed mph)**	**85thPercentile Speed (mph)**	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Sample Size**	**Rank (lowest to highest mean)**
A - Control 2 Lanes (1)	59.0	64.8	56.6	60.1	57.7	63.5	46	9
B - Control 2 Lanes (2)	55.0	59.9	54.8	57.9	54.9	59.3	50	2
C - Layered Landscape	56.9	62.2	56.0	58.5	56.4	59.4	52	3
D - Gateway with Lane Narrowing	56.7	63.1	55.0	58.2	55.9	60.3	52	6
E - Control 2 Lane with Center Lane	58.0	64.5	57.3	60.8	57.7	62.9	52	8
F – Median Only	57.5	62.0	56.0	58.7	56.7	61.8	51	7
G – Median with Gateway	56.8	59.7	55.1	59.0	55.9	59.6	45	5
H - Medians in Series No Crosswalks	55.8	62.8	53.1	57.0	54.5	59.5	53	4
I - Medians in Series with Crosswalks	49.5	57.7	50.4	55.9	50.0	56.7	50	1

Table B1.3: Speed Characteristics at Speed Limit 45 Sign (L4)

Treatment	With Distracter		No Distracter		All			
	Mean Speed (mph)	85th Percentile Speed (mph)	Mean Speed mph)	85thPercentile Speed (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Sample Size	Rank (lowest to highest mean)
A - Control 2 Lanes (1)	56.1	62.5	53.9	61.4	56.5	63.2	46	9
B - Control 2 Lanes (2)	53.3	60.1	52.5	57.9	52.9	59.3	52	4
C - Layered Landscape	55.7	62.1	54.2	55.8	54.9	60.5	53	7
D - Gateway with Lane Narrowing	54.5	61.7	51.7	55.7	53.2	59.9	51	5
E - Control 2 Lane with Center Lane	55.0	65.7	54.8	59.9	54.9	60.5	53	7
F – Median Only	55.9	62.1	53.8	58.4	54.8	61.4	51	6
G – Median with Gateway	51.6	59.0	50.0	55.5	50.7	58.1	44	2
H - Medians in Series No Crosswalks	53.2	61.9	50.5	54.8	51.9	58.3	53	3
I - Medians in Series with Crosswalks	48.3	56.0	48.8	54.7	48.5	55.3	48	1

Table B1.4 Speed Characteristics 300 Feet Downstream of Speed Limit 45 Sign (L5)

	With Distracter		No Distracter		All			
Treatment	Mean Speed (mph)	85th Percentile Speed (mph)	Mean Speed mph)	85thPercentile Speed (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Sample Size	Rank (lowest to highest mean)
A - Control 2 Lanes (1)	53.2	59.6	52.0	59.1	52.6	59.8	46	8
B - Control 2 Lanes (2)	51.3	60.0	50.4	58.6	50.8	59.4	51	6
C - Layered Landscape	53.6	60.3	50.8	55.8	52.2	59.0	52	5
D - Gateway with Lane Narrowing	52.5	61.5	49.8	52.4	51.3	59.6	50	7
E - Control 2 Lane with Center Lane	53.8	66.8	52.3	57.9	53.1	60.3	53	9
F – Median Only	51.9	58.3	49.4	55.5	50.6	57.8	51	3
G – Median with Gateway	49.6	60.2	47.1	53.7	48.3	58.1	43	4
H - Medians in Series No Crosswalks	50.5	60.3	48.3	54.8	49.4	56.1	52	2
I - Medians in Series with Crosswalks	46.2	51.4	45.1	49.2	45.6	50.0	48	1

Table B1.5: Speed Characteristics Adjacent to Treatment (L8)

	With Distracter		No Distracter		All			
Treatment	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Mean Speed mph)**	**85thPercentile Speed (mph)**	**Mean Speed (mph)**	**85th Percentile Speed (mph)**	**Sample Size**	**Rank (lowest to highest mean)**
A - Control 2 Lanes (1)	--	--	--	--	--	--	--	--
B - Control 2 Lanes (2)	--	--	--	--	--	--	--	--
C - Layered Landscape	53.1	60.3	49.7	56.0	51.4	58.3	51	5
D - Gateway with Lane Narrowing	51.8	60.1	48.9	52.3	50.4	57.8	51	4
E - Control 2 Lane with Center Lane	--	--	--	--	--	--	--	--
F – Median Only	54.7	61.2	52.3	57.3	53.5	60.7	51	6
G – Median with Gateway	48.5	58.5	45.6	53.3	46.9	55.3	45	3
H - Medians in Series No Crosswalks	47.8	56.7	45.2	51.7	46.5	52.6	54	1
I - Medians in Series with Crosswalks	47.1	57.0	45.9	50.8	46.5	54.4	51	1

APPENDIX C:
PARTICIPANT SCRIPT TO CONDUCT EXPERIMENT

Participant Script to Conduct Experiment

Note: During transitions between sessions it is important NOT to say things such as "good job", "bad job", or anything of this reinforcing nature
***make sure speedometer is working before participant arrives. (IVIS computer)

Pre-participant

- Consent Form
- Motion Sickness Forms
- Make sure puke can is by car and empty
- Sim Data Forms
- Reaching task

Welcome—if you have a cell phone please make sure it is turned off before we begin. Please note that I will be reading from a script throughout the experiment, and I may not be able to answer certain questions that pertain to the experiment until after we have completed the study.

- Place experiment in progress sign on door.
- Thank you for choosing to participate in our study. Before we get started please read and sign this consent form. Should you have any questions, please feel free to ask. After you have read it, please initial the bottom of the pages and sign and date the back page. If you would like a copy of the signed consent form for your records, just let me know.
- The purpose of this study is to investigate driving behavior in various settings.
- Before we get started I am going to ask you some motion sickness questions. I will ask you these same questions after each time you drive today. If you feel uncomfortable at any time during the experiment, please let me know immediately.
- Ask Motion Sickness Questionnaire and Demographics questions

For Distracter Participants Only:

- During the time that you spend driving today, you will be playing a simple word game. For this word game, you will be presented with a letter, and your task will be to respond with a word that begins with that letter. If the same letter is presented more than once during a drive, please try not to use the same word for your response. Please practice this game a few times so that you will be familiar with it when it occurs while driving: A, F, C, R.

You may now get into the car.

- Please sit in the vehicle and move the seat forward or backward so that it suits you.
- Show car controls

- The controls work just like a regular automatic transmission vehicle: the gas is on the right, and the brake is on the left. The car should already be in drive, so please do not change gears as the car is already in drive.
- The steering is quite loose and sensitive, meaning the vehicle reacts as if it has too much power steering.
- You will now have several practice sessions to get used to the vehicle and the simulator.
- Once you see the road you may start driving. Your goal for today will be to drive through the scenarios as you would in your own vehicle.
- If you start to feel uncomfortable or uneasy at any time please tell me immediately.

*Load "*ODOT-*straight"*

- ➢ Enter participant number then "odotst"

For your first practice session:

- You will drive on a straight road to familiarize yourself with the vehicle for 2 minutes. If you drive on the shoulder of the road or in the oncoming driver's lane a message will appear on the screen that says "out of lane". A voice will also instruct you to slow down if you drive faster than 60 mph. Please move around inside the lane until you are comfortable with the lane's boundaries.
- Remember you will drive for 2 minutes, I will set a timer for each session, when you hear the timer go off, lift your foot off the gas, and I will turn off the driving simulator.
- You can repeat practice sessions as many times as necessary to feel comfortable.
- Buzz timer after 2 minutes, wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session
- Motion Sickness Questionnaire

Load "ODOT -curvy"

- ➢ Enter participant number then "odotcu"

For your second practice session

- You will drive on a continuously curvy road. It is designed to be difficult for everyone as it is intentionally quite curvy.
- If you go outside of your lane the "out of lane" message will appear. Please move around within your lane until the "out of lane" message appears so you know exactly where the boundaries of your lane are. A voice will also instruct you to slow down if you drive faster than 60 mph.
- This session will last 5 minutes. Remember, when you hear the timer go off, lift your foot off the gas, and I will turn off the driving simulator.
- You can repeat each practice session as many times as necessary to feel comfortable.
- Buzz timer after 5 minutes, wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session
- Motion Sickness Questionnaire

Load "ODOT– *baseline*"

- ➢ Enter participant number then "odotbl"
- ➢ If a participant needs to do this scenario more than once then enter "odotbl2"

Baseline requirements – 85% in lane at 40 mph average speed

This will be your third and final practice session.

- Now that you are a more experienced simulator driver, please continue driving the best you can from now on for each driving session remembering your main goal is to drive as you would in your own vehicle.
- This is the last session in which a voice will tell you to slow down if you drive faster than 60 mph; however, the out of lane message will not appear. The speedometer is located on the dash and will provide feedback as to your speed. This session will last 5 minutes. Remember, when you hear the timer go off, lift your foot off the gas, and I will turn off the driving simulator.

- Buzz timer after 5 minutes, wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session
- Motion Sickness Questionnaire
- Check that participant meets baseline criteria
    - o Under collected data folder for the ODOT_baseline sim world double-click on the quickcheck.exe program.
    - o Type the sim code of the participant into the window and press enter
    - o Confirm that the Time In Lane is >85% and the average speed is > 40 MPH
- LOAD FIRST EXPERIMENTAL CONDITION NOW!!!!!
- Take a break. Get participant out of car. Offer restroom break.
- ****Next they Complete Handedness tasks*****

Handedness task instructions:

In this test you will be seated in front of this table. You should be seated in a position such that your shoulders are parallel to the edges of the arc. Place your palms on the table in a diamond shape with your finger tips on the line of black tape in the center, making sure that you maintain a 90^0 bend in your elbows. This is your starting position for each trial. Please place these wristbands on your wrists, red on your right hand and blue on your left. The starting position for the objects in this test will be on top of these holders. In this task I will give you instructions, for example "pick up 7". In this case, you would simply pick up object number 7 and then set it back down. You will also hear other instructions. For toss, simply pick up the object and toss it to me. For point, point to the object. For knock down, please knock down the appropriate object, holding on to it like this, so it doesn't slide across the table. And finally for place in holder, simply place the object into the holder. After each of these instructions, you or I will set each object back to their original starting location. Do you have any questions? Okay then, let's begin.

- Collect Data
    - o the handedness tasks (you record actions)
    - o the handedness survey (they fill out themselves)

- Make sure to check and see which one is circled to do first

- Bathroom break
- Get back in sim
- Read before the first experimental condition:

CONDITION 1

Now that you have completed the practice sessions, we will begin the actual study. It is important that you drive as you would in your own vehicle. Do your best to remain in the center of your lane. Please drive straight the entire time, do not make any left or right turns on side streets. Remember, there will no longer be a slow down voice or an out of lane notification. The remaining three sessions will each last about 30 minutes. When you hear the timer go off, lift your foot off the gas, and I will turn off the driving simulator.

- Transfer and start condition 1
- Open new Hyperdrive (so 2 hyperdrives are open), load condition 2
  (You DO NOT have to do calibration check!!)

- When participant drives through each town – check off the towns, when participant is completely out of town and in the country for 15 seconds (until you can't see the town on the back screen) beep the timer and stop scenario and say yes to collect data.

Ask Motion Sickness Questions

- Make participant get our of car
- Offer snack

CONDITION 2

Remember, it is important that you drive as you would in your own vehicle. Do your best to remain in the center of your lane. Please drive straight the entire time, do not make any left or right turns on side streets. This session will last about 30 minutes. When you hear the timer go off, lift your foot off the gas, and I will turn off the driving simulator.

- Transfer and start condition 2
- Close Hyperdrive with condition 1 (the one you just stopped)
- Open new Hyperdrive (so 2 hyperdrives are open), load condition 3
  (You DO NOT have to do calibration check!!)

- When participant drives through each town – check off the towns, when participant is completely out of town and in the country for 15 seconds (until you can't see the town on the back screen) beep timer and stop scenario and say yes to collect data.

Ask Motion Sickness Questions

- Make participant get our of car

CONDITION 3

This will be your final driving session. Remember, it is important that you drive as you would in your own vehicle. Do your best to remain in the center of your lane. Please drive straight the entire time, do not make any left or right turns on side streets. This session will last about 30 minutes. When you hear the timer go off, lift your foot off the gas, and I will turn off the driving simulator.

- Transfer and start condition 3
- Close Hyperdrive with condition 2 (the one you just stopped)

- When participant drives through each town – check off the towns, when participant is completely out of town and in the country for 15 seconds (until you can't see the town on the back screen) beep timer and stop scenario and say yes to collect data.

- Ask Motion Sickness Questions
- Have person get out of car and sit at table
    - Ask "what do you think was the purpose of this study?"
    - Ask remaining questions on bottom of motion sickness page
- Pay participant

Thank you for participating in this research study

- Remember that the purpose of the study was to investigate driving behavior in various settings.
- Complete Master subject list "success" column now.
- Email rfwills@gmail.com with attendance/success information.

Backup data to the other computer

APPENDIX D:
PARTICIPANT DATA SHEETS

Participant #______ Age group_____________

Date __________ Experimenter _______________

Valid US liscense: Y / N Gender _______ Age _______ Years driving ______

Motion sickness: _______________________ Migraines: ___________________

Vision problems: ____

Completed	Participant #	ODOT	Scenario	Startpoint	Comments
	Pretest motionsickness questions				
	03	odot	st	[redacted]	
	03	odot	cu	[redacted]	
	03	odot	bl	[redacted]	
	Handedness task & questions				
	03	odot	A	3001	
	03	odot	B	2315	
	03	odot	C	293	
	Ask manipulation check item below				
	Fill out master subject list				
	Email Rebekkah status rfwills@gmail.com				

What do you think was the purpose of this study?

Towns:

Scenario A _____ Gateway & Median _____ Median _____ Control

Scenario B _____ Layered landscape _____ Control _____ Walks

Scenario C _____ Control _____ Gate & Narrow _____ Series - no walks

Answer each question: Yes or no, if yes.... tell me the number that best describes how you feel right now where 0 is "not at all" and 10 is "severely"

	Pre	Straight	Curvy	Baseline	ODOT-A	ODOT-B	ODOT-C
1. sick to my stomach							
2. faint-like							
3. annoyed/ irritated							
4. sweaty							
5. queasy							
6. lightheaded							
7. drowsy							
8. clammy/ cold sweat							
9. disoriented							
10. tired/fatigued							
11. nauseated							
12. hot/warm							
13. dizzy							
14. like I am spinning							
15. as if I might vomit							
16. uneasy							
floating?							
Mental Effort							

How many days to you drive each week? ______
Estimate the number of miles you drive each year _____
Have you been in a crash in the last year while driving? no / yes -if yes, how many_____
Have you been in a crash in the last 5 years while driving? no / yes -if yes, how many_____
Have you received a speeding ticket in the last year? no / yes -if yes, how many_____
Have you received a speeding ticket in the last 5 years? no / yes -if yes, how many_____
How often do you wear your seatbelt? never / sometimes / always
How often do you talk on your cell phone when you drive? never / sometimes / always
How often do you text message when you drive? never / sometimes / always

APPENDIX E:
PARTICIPANT DATA

Table E1.1: Summary of Participant Data

Subject	Age	Dist	Used	Reason Not Used
0	U		N	Gateway sign didn't show up and shoulders too wide
1	U	N	Y	
2	U	N	Y	
3	U	N	N	Sim crash during scenario B
4	U	N	Y	
5	U	N	Y	
6	U	N	N	Sim would not calibrate
7	U	N	Y	
8	U	N	N	Sim crashed and did not collect data
9	U	Y	Y	
10	U	Y	Y	
11	U	Y	N	Speeds too high
12	U	Y	Y	
13	U	Y	Y	
14	U	Y	Y	
15	U	Y	Y	
16	U	Y	Y	
17	U	Y	N	Speeds too high
18	M	N	Y	
19	M	N	N	Started at wrong place
20	M		N	Sim Sick
21	M	N	Y	
22	M	N	Y	
23	M	N	Y	
24	M	N	Y	Missing 3 Treatments
25	M	N	N	Two data sets with same conditions
26	M	N	Y	
27	M	N	Y	
28	M	Y	Y	
29	M		N	Projector Malfunction
30	M		N	Sim Sick
31	M	Y	N	Two data sets with same conditions
32	M	Y	Y	
33	M	Y	Y	
34	M	Y	Y	
35	M	Y	Y	
36	S		N	Sim Sick
37	S	N	N	
38	S	N	Y	
39	S	N	Y	
40	S	N	Y	
41	S		N	Sim Sick
42	S	N	Y	
43	S	N	Y	
44	S	N	Y	

Subject	Age	Dist	Used	Reason Not Used
45	S	Y	Y	
46	?	?	N	Data had been overwritten
47	S	Y	Y	
48	S	Y	N	Missing 3 Treatments
49	S	Y	Y	
50	S	Y	Y	
51	S		N	Sim Sick
52	S	Y	Y	
53	S	Y	Y	
101	U	N	Y	
102	U		N	Sim Sick
103	U		N	Started at wrong location
104	U	N	Y	
105	U	N	Y	
106	U	N	Y	
107	U	Y	Y	
108	U	Y	Y	
109	U	N	N	Went off road a few times
120	S	N	Y	
121	S	N	Y	
122	S	N	Y	
123	S	Y	Y	
124	S	Y	Y	
125	S	Y	N	Out of Age Group- Age 62
130	M	N	Y	
131	M	N	Y	
132	M	Y	Y	
133	M	Y	Y	
134	M	Y	Y	
146	S	Y	Y	

APPENDIX F:
QUESTIONNAIRE RESULTS ON DRIVING BEHAVIOR

Table F1.1: How often do you wear your seat belt?

Seat Belt	Young	Middle	Old
Never	0	0	0
Sometimes	4	2	0
Always	14	16	16

Table F1.2: How often do you talk on your cell phone when you drive?

Cell Phone	Young	Middle	Old
Never	1	14	6
Sometimes	13	4	11
Always	4	0	1

Table F1.3: How often do you text message when you drive?

Text Messaging	Young	Middle	Old
Never	11	18	16
Sometimes	4	0	2
Always	3	0	0

Table F1.4: Estimate the number of miles you drive each year

Age Group	Age	Yrs Driving	Miles/ Yr
Young	20	4.5	8000
Middle	43	27.2	17000
Old	71	55.6	12000

Table F1.5: Have you been in a crash in the last year (5 years) while driving?

Age Group	Crash- 1 yr	Crash-5 yr		
		0	1	2
Young	0	12	4	2
Middle	0	14	4	0
Old	0	17	1	0

Table F1.6: Have you received a speeding ticket in the last year (5 years)?

Age Group	Ticket-1 yr			Ticket-5 yr		
	0	1	2+	0	1	2+
Young	0	3	0	15	1	2
Middle	13	3	2	11	5	2
Old	17	1	0	15	2	1

APPENDIX G:
PLAN VIEW OF FULL SCALE TREATMENTS

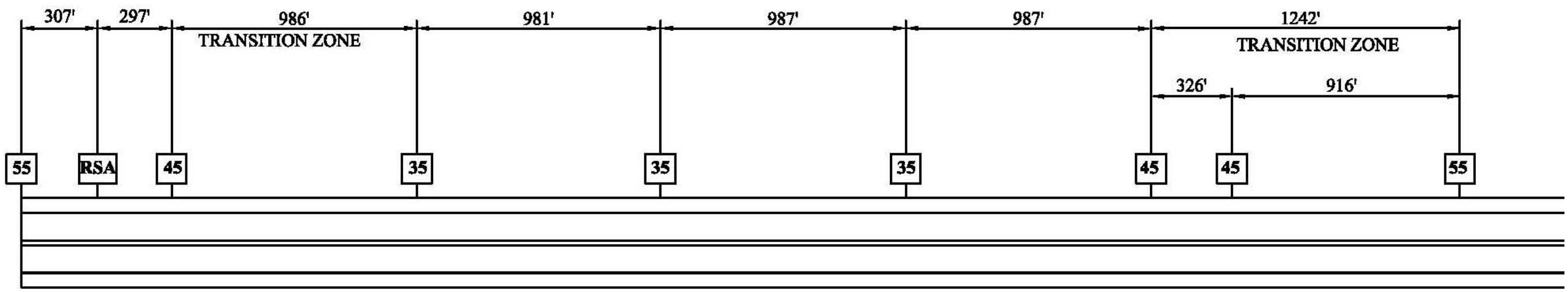

Figure G1.1: Control Two Lanes (1)

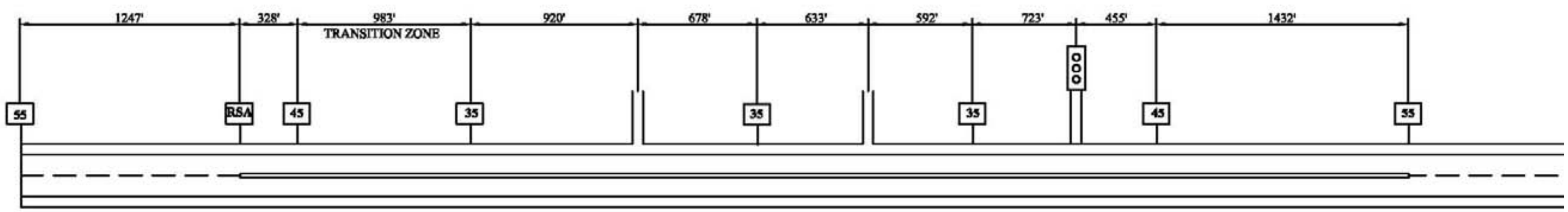

Figure G1.2: Control Two Lanes (2)

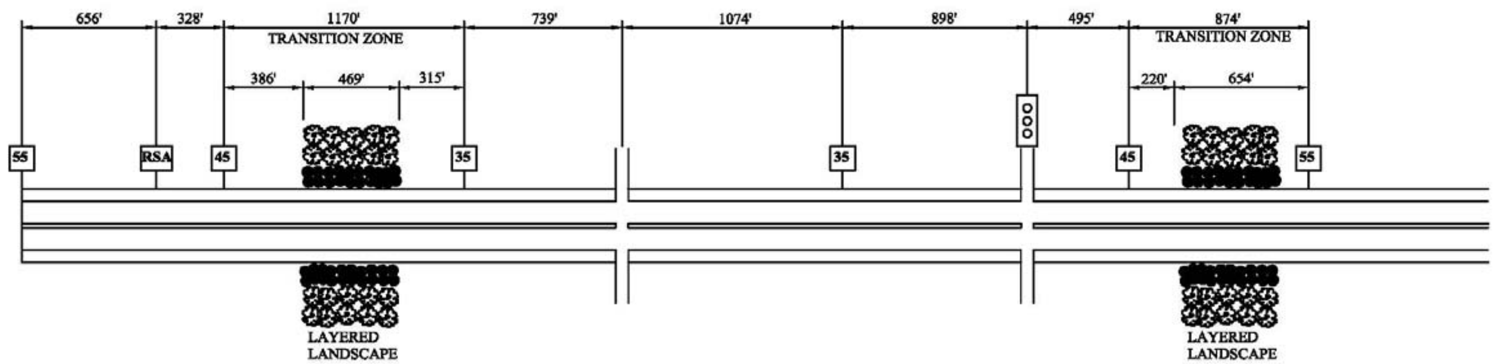

Figure G1.3: Layered Landscape

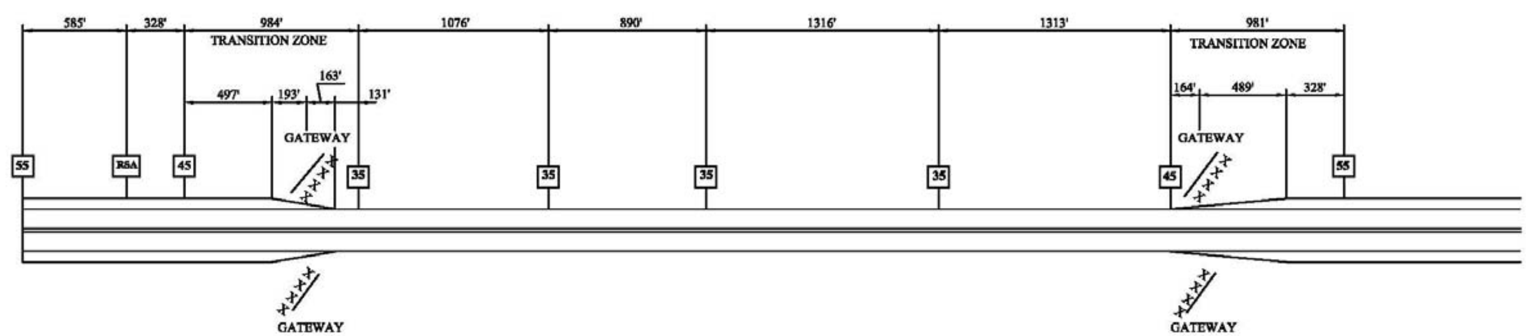

Figure G1.4: Gateway with Lane Narrowing

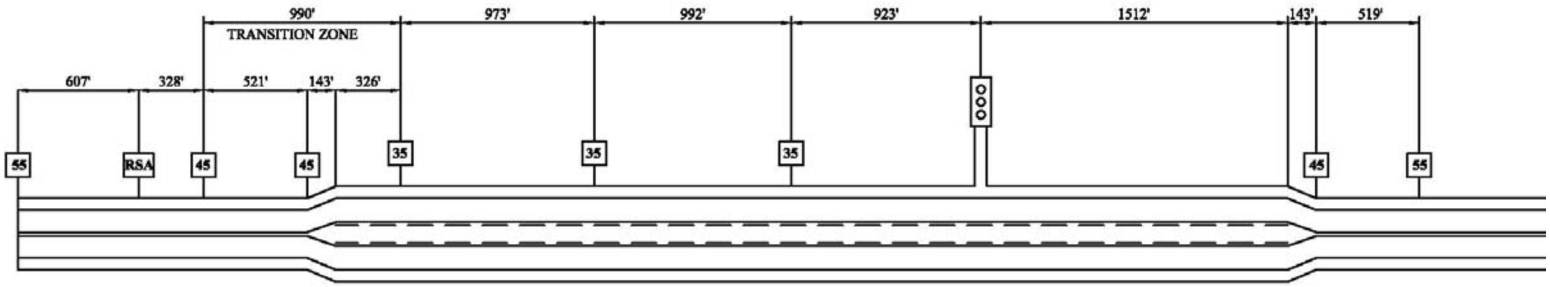

Figure G1.5: Control Two Lane with Center Lane

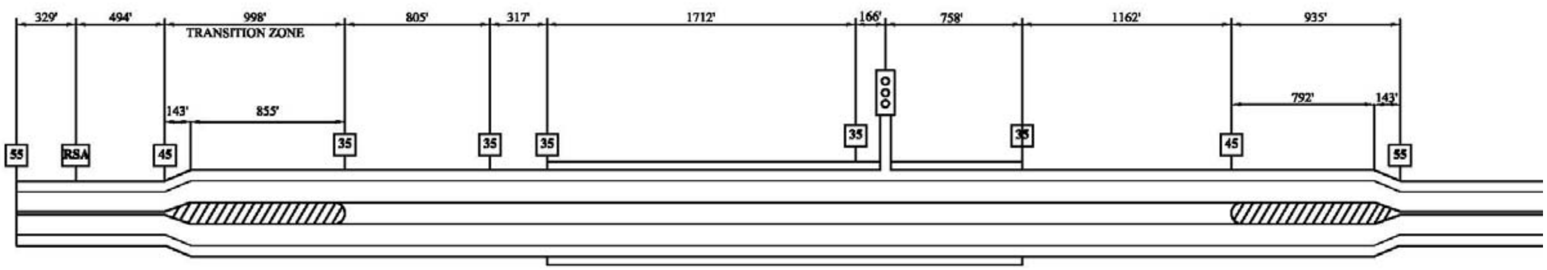

Figure G1.6: Median

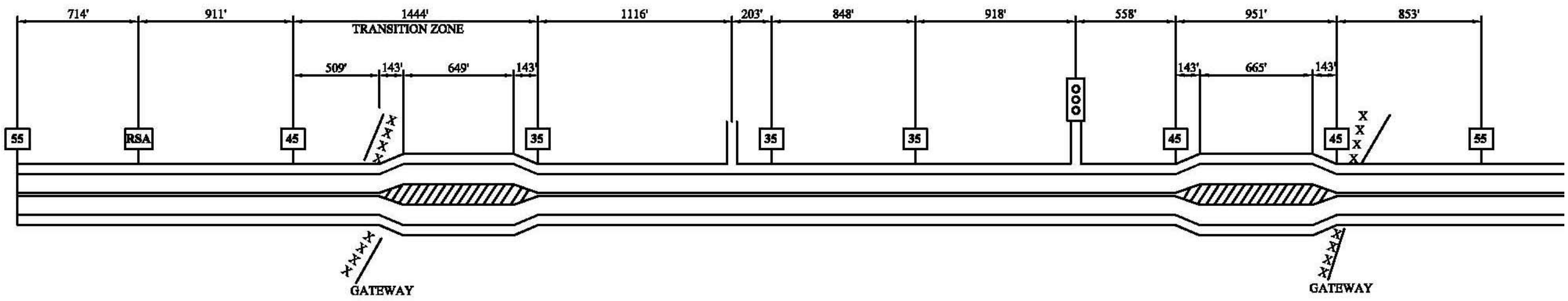

Figure G1.7: Median with Gateway

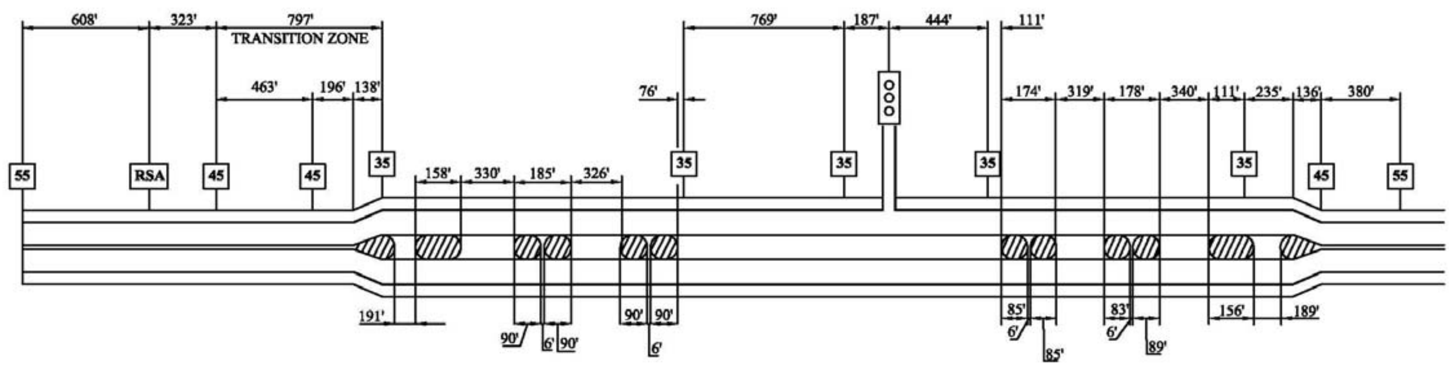

Figure G1.8: Medians in Series -- No Crosswalks

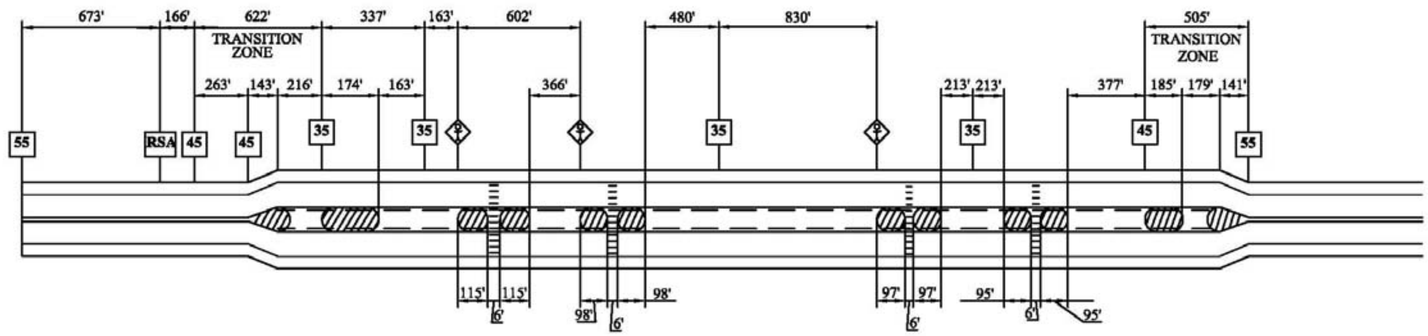

Figure G1.9: Medians in Series -- With Crosswalks

APPENDIX H:
PILOT STUDY RESULTS

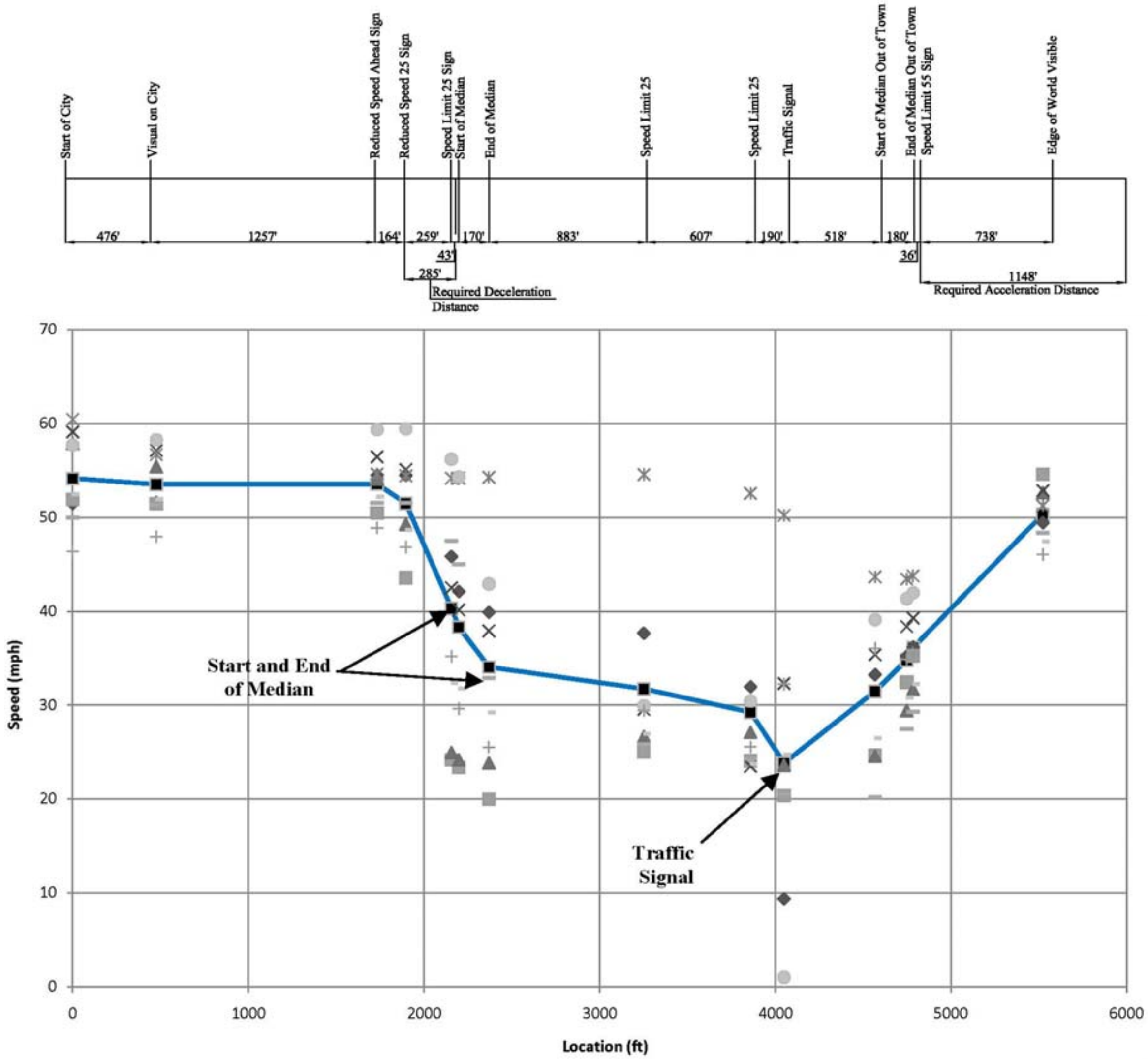

Figure H1.1: Pilot Study 1 - Transition 1 -- Raised Median with Trees

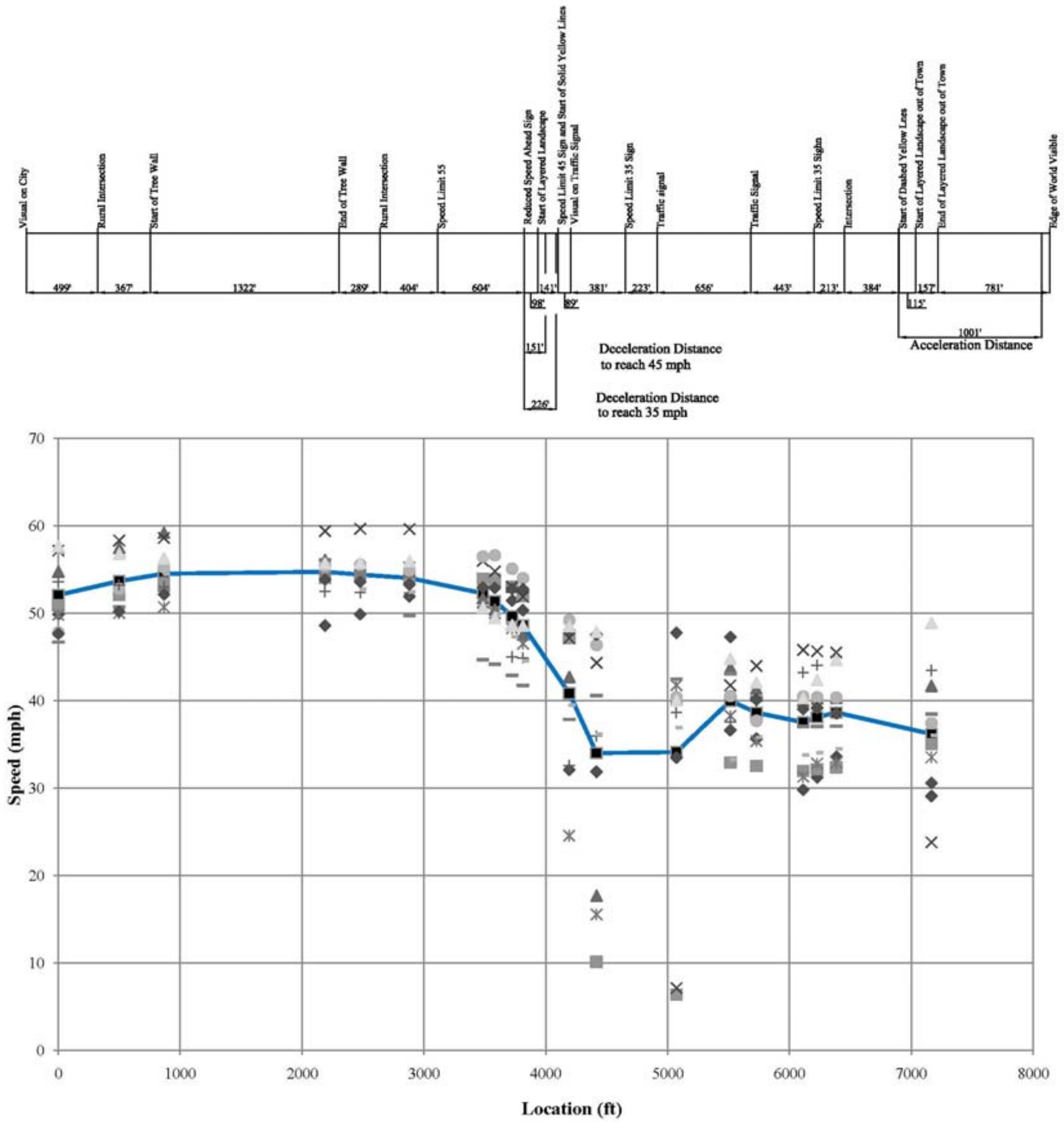

Figure H1.2: Pilot Study 1 - Transition 2 -- Layered Landscape

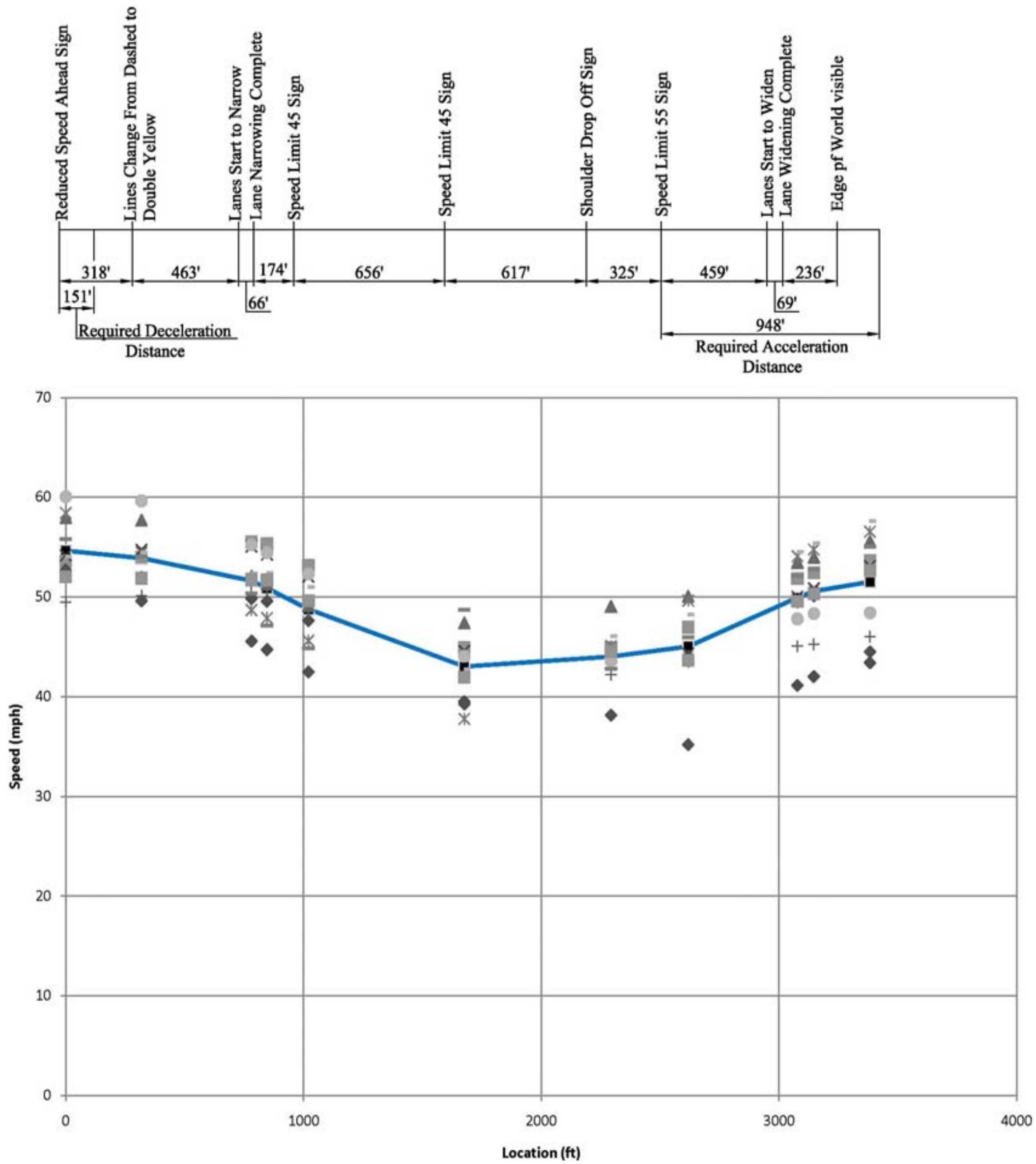

Figure H1.3: Pilot Study 1 - Transition 3 -- Lane Narrowing

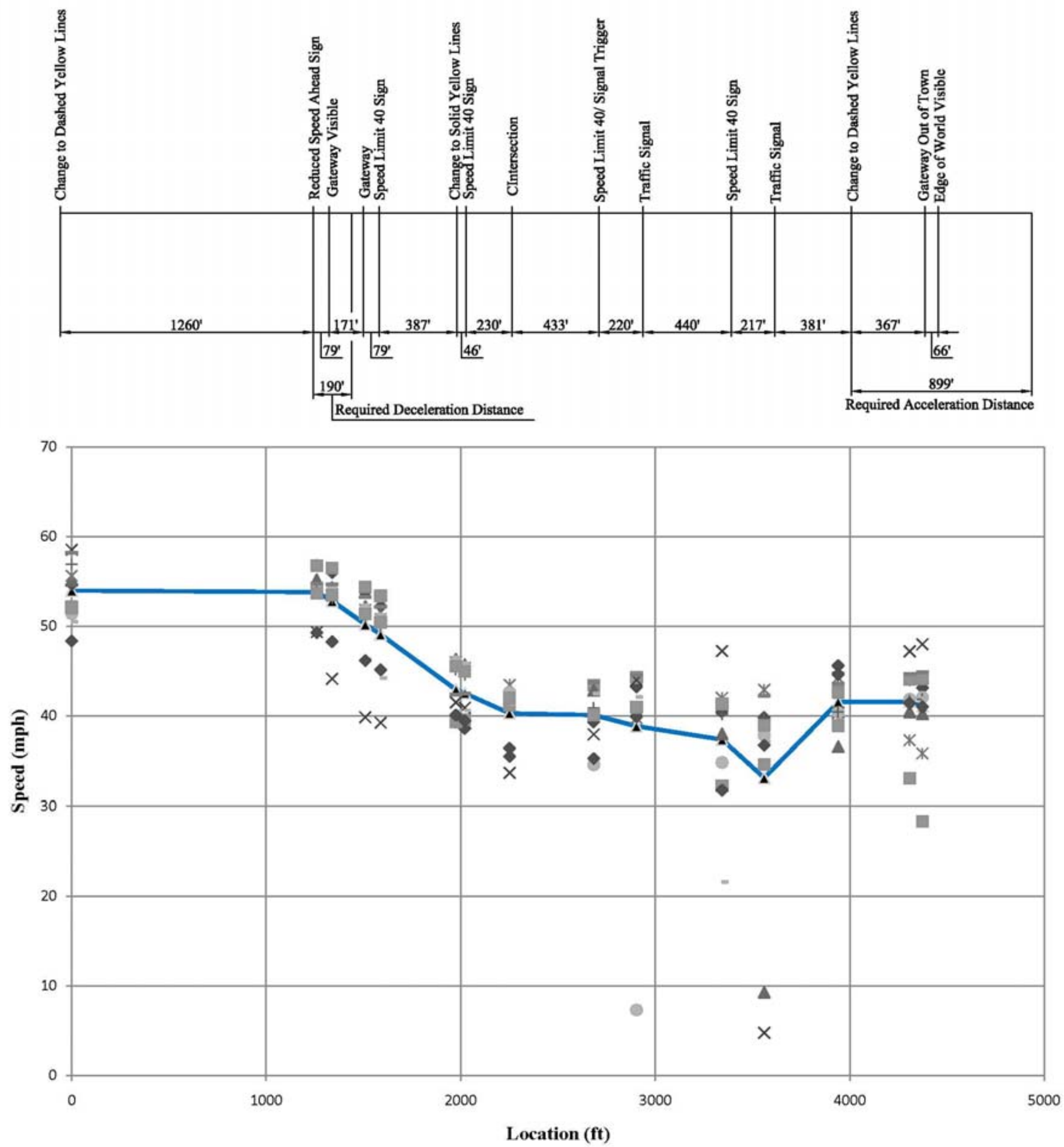

Figure H1.4: Pilot Study 1 - Transition 4 – Gateway

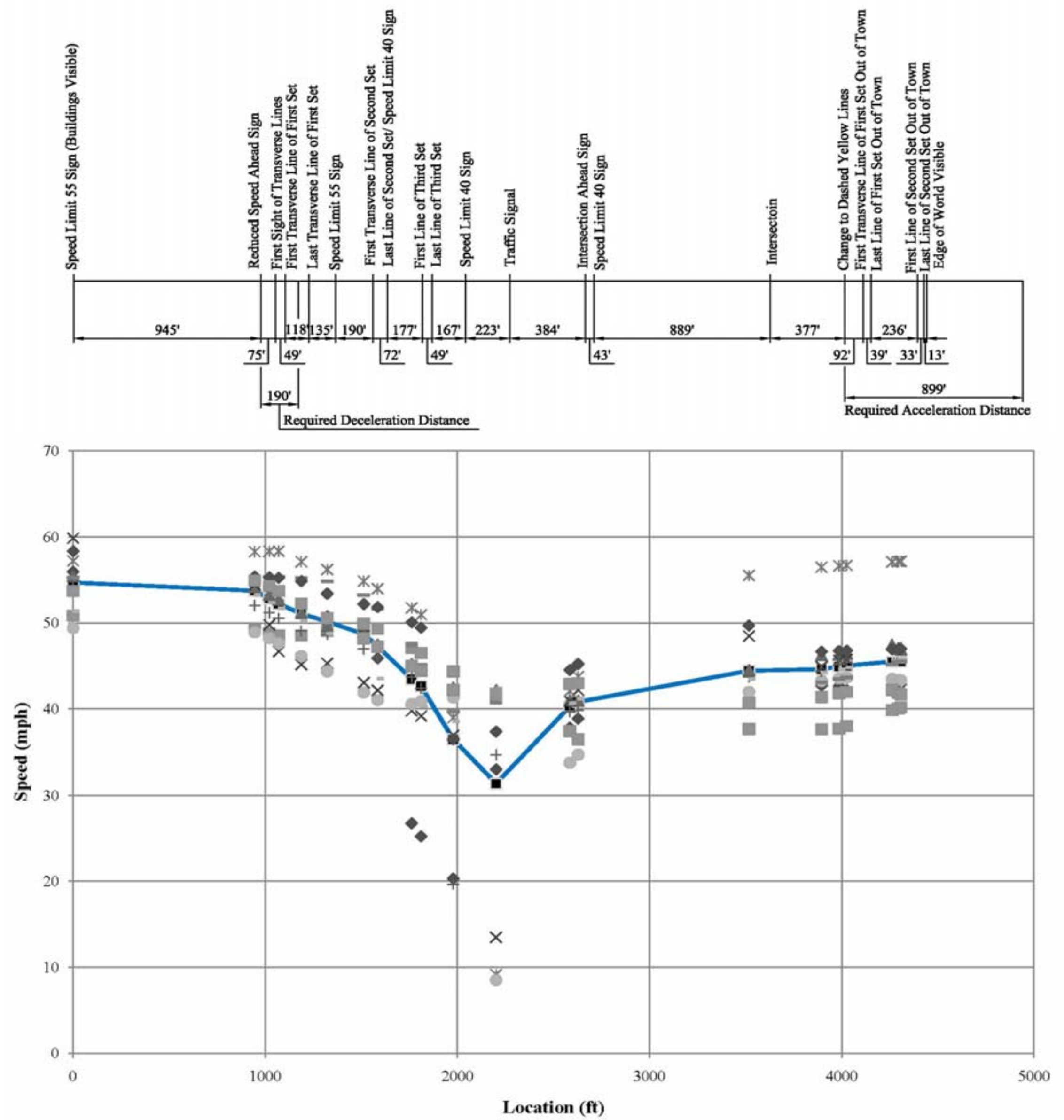

Figure H1.5: Pilot Study 1 - Transition 5 -- Transverse Lines Perpendicular to Road

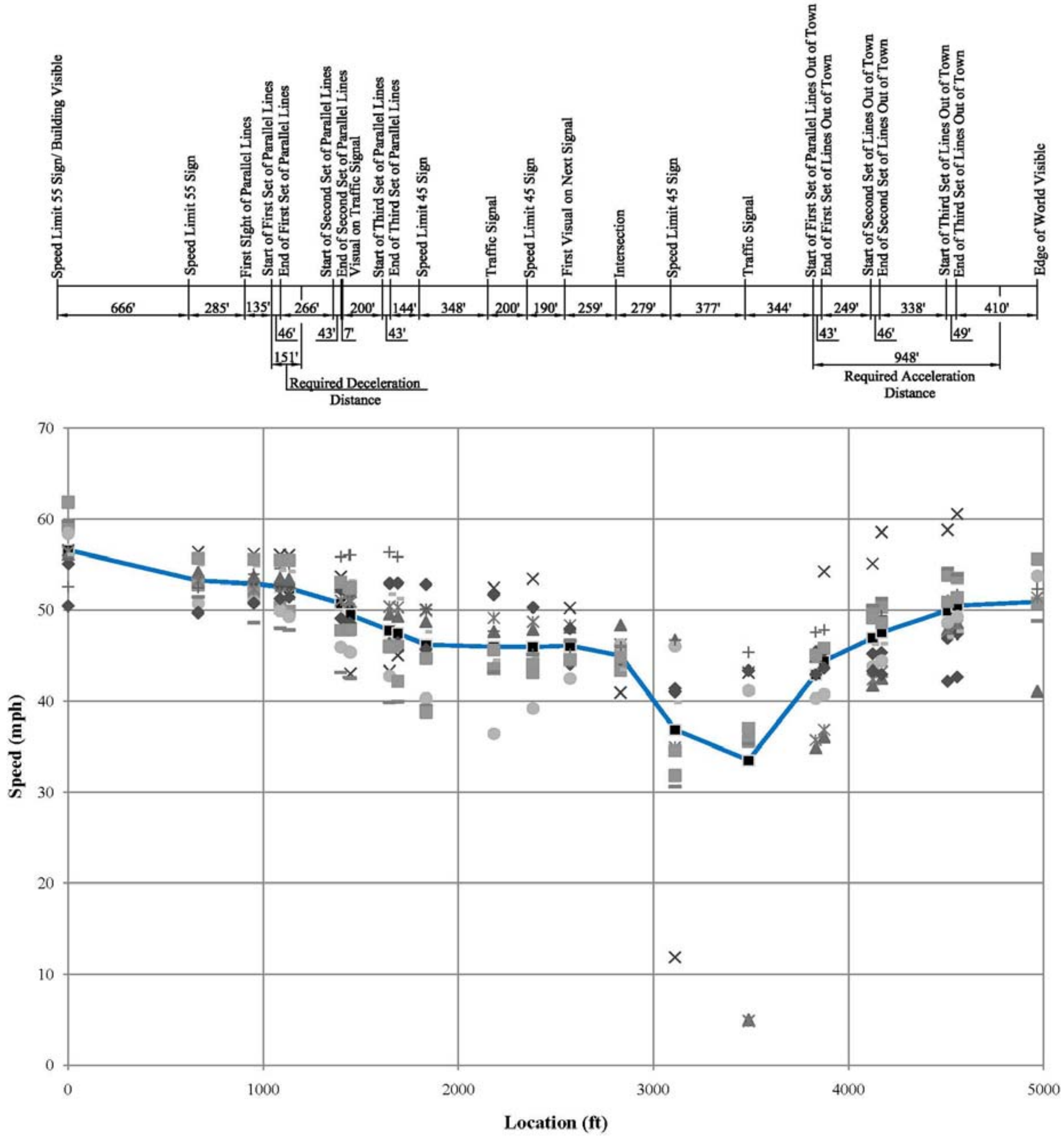

Figure H1.6: Pilot Study 1 - Transition 6 -- Parallel Lines

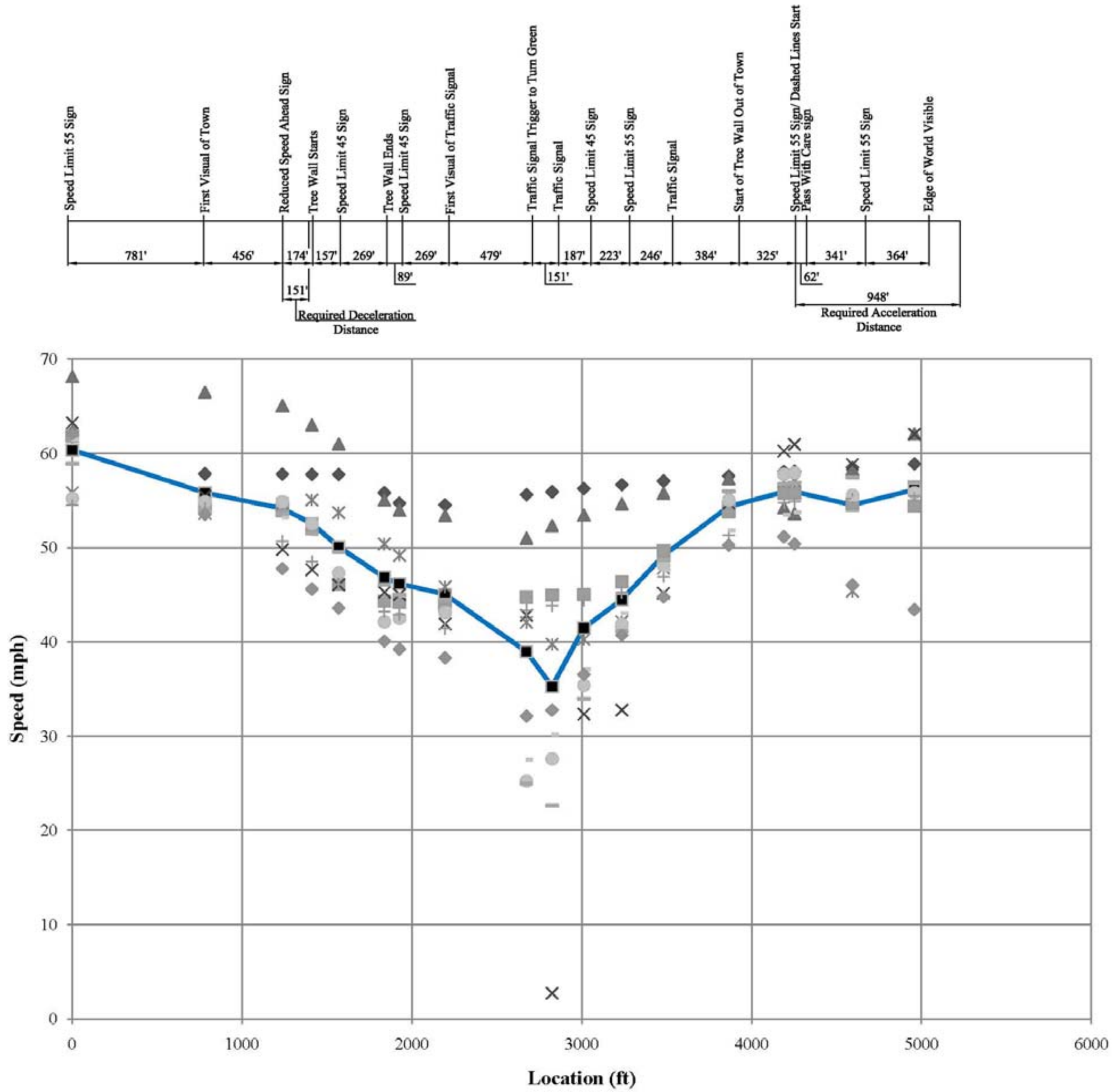

Figure H1.7: Pilot Study 1 - Transition 7 -- Trees Alone

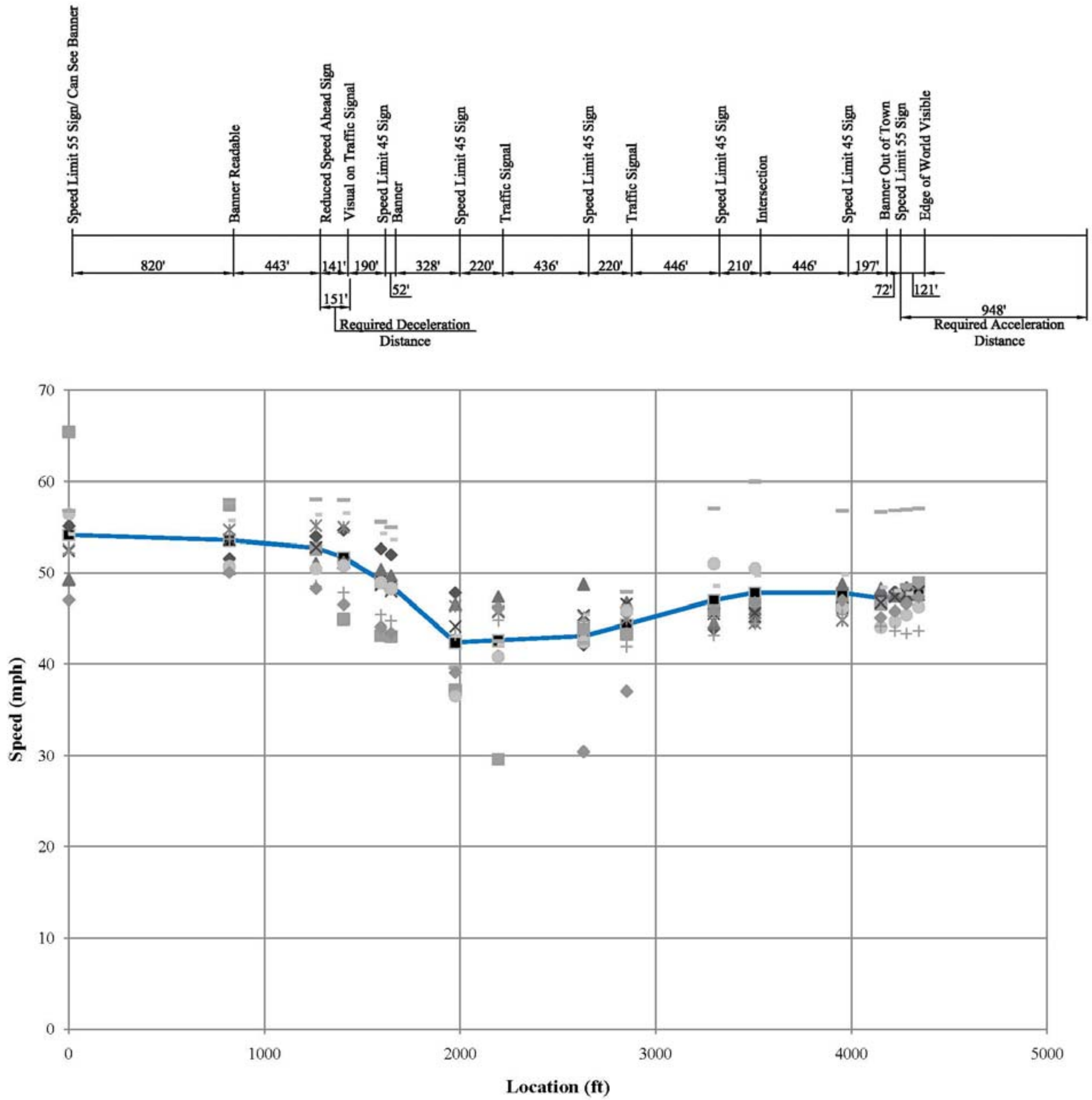

Figure H1.8: Pilot Study 1 - Transition 8 -- Banner

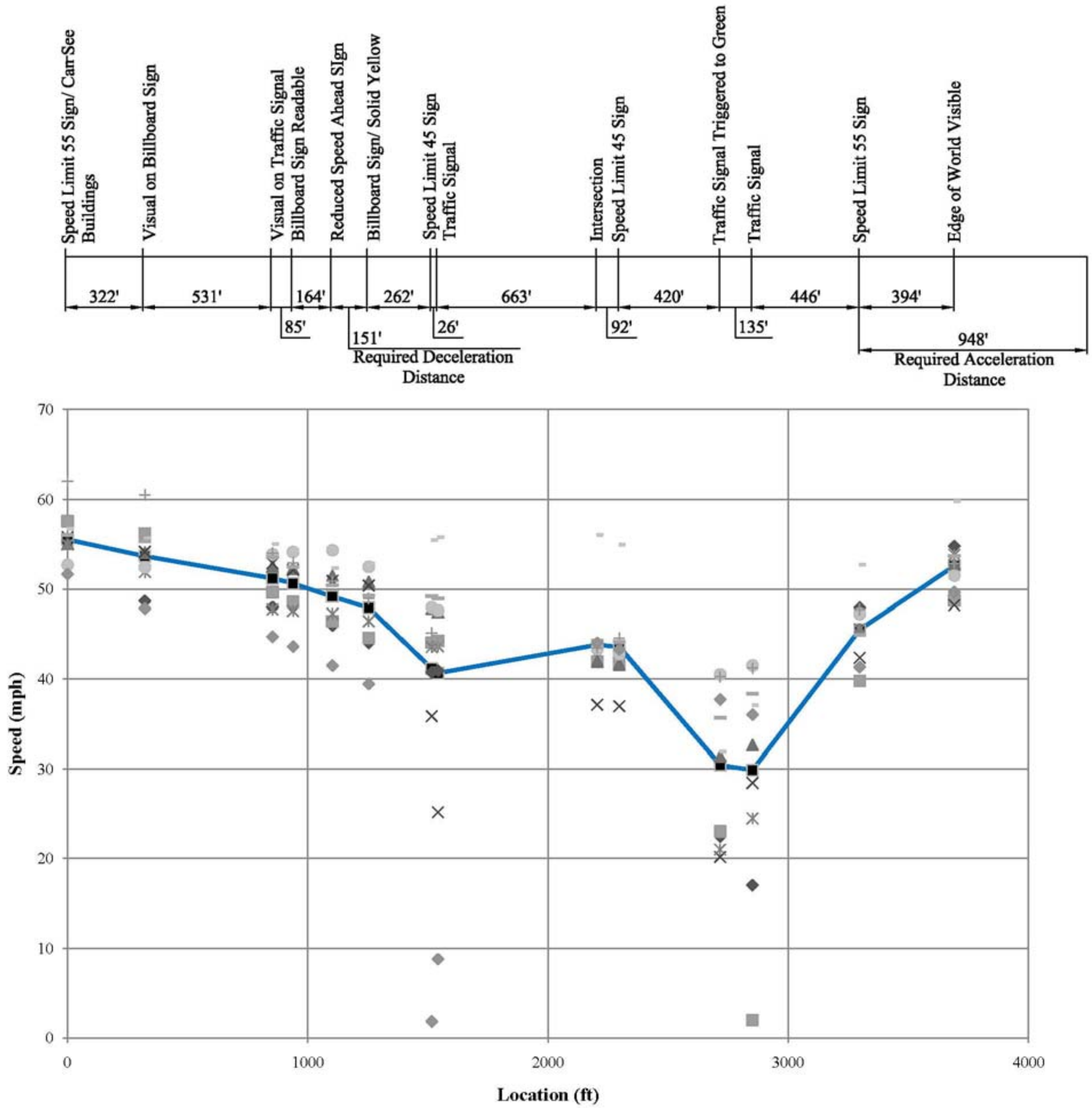

Figure H1.9: Pilot Study 1 - Transition 9 – Billboard

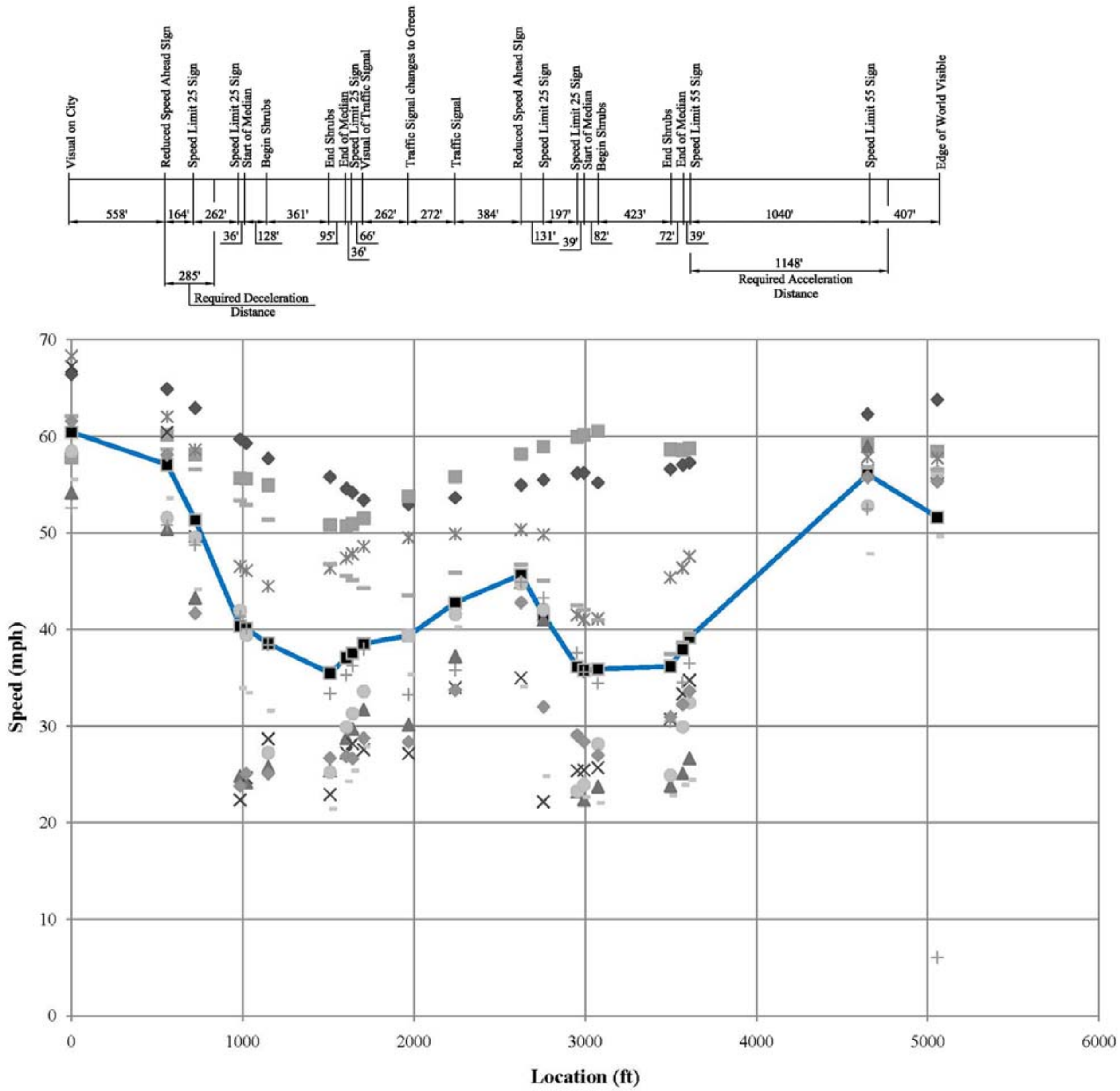

Figure H1.10: Pilot Study 1 - Transition 10 -- Raised Median with Medium Shrubs

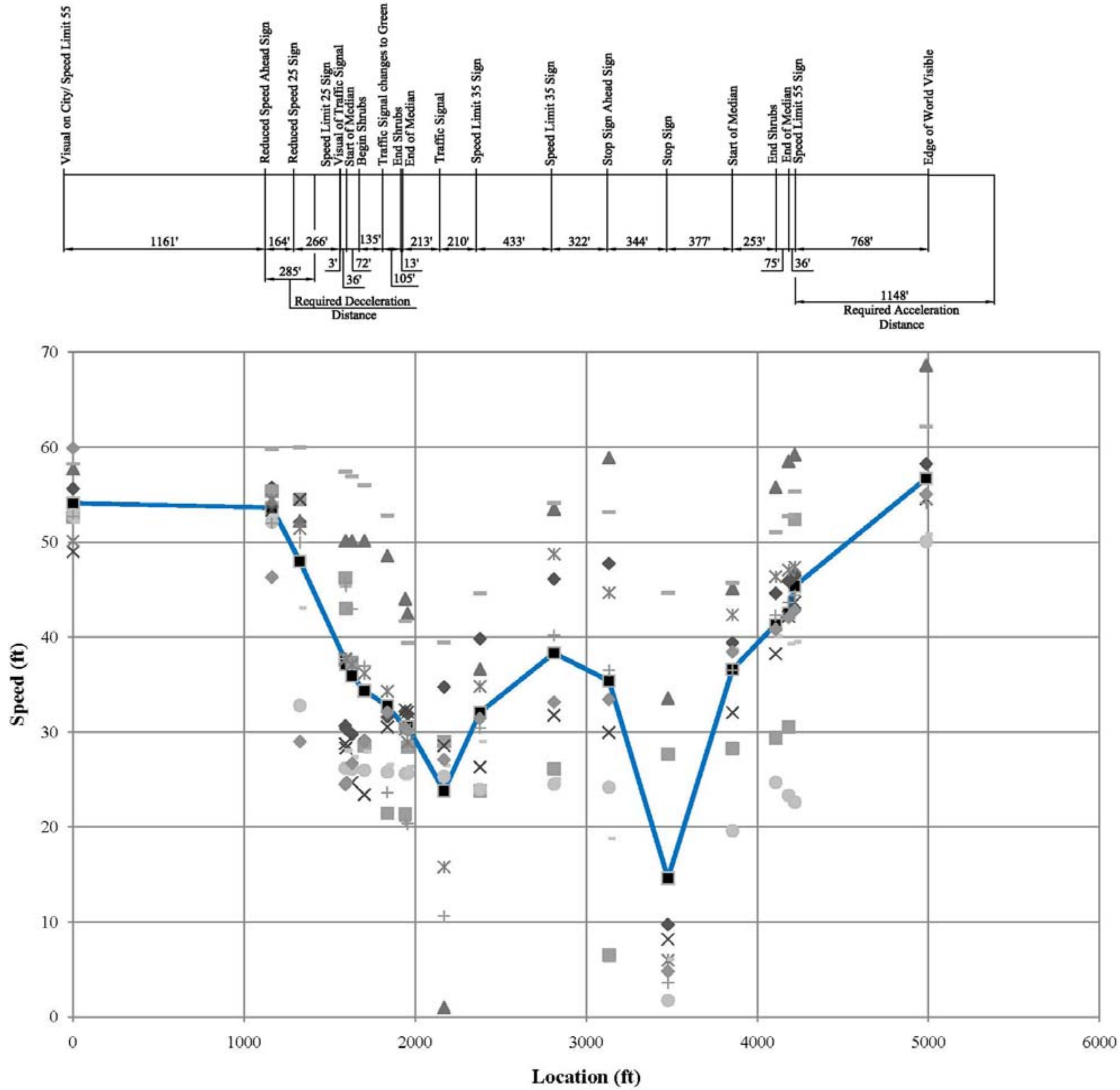

Figure H1.11: Pilot Study 1 - Transition 11 -- Raised Median with Small Shrubs

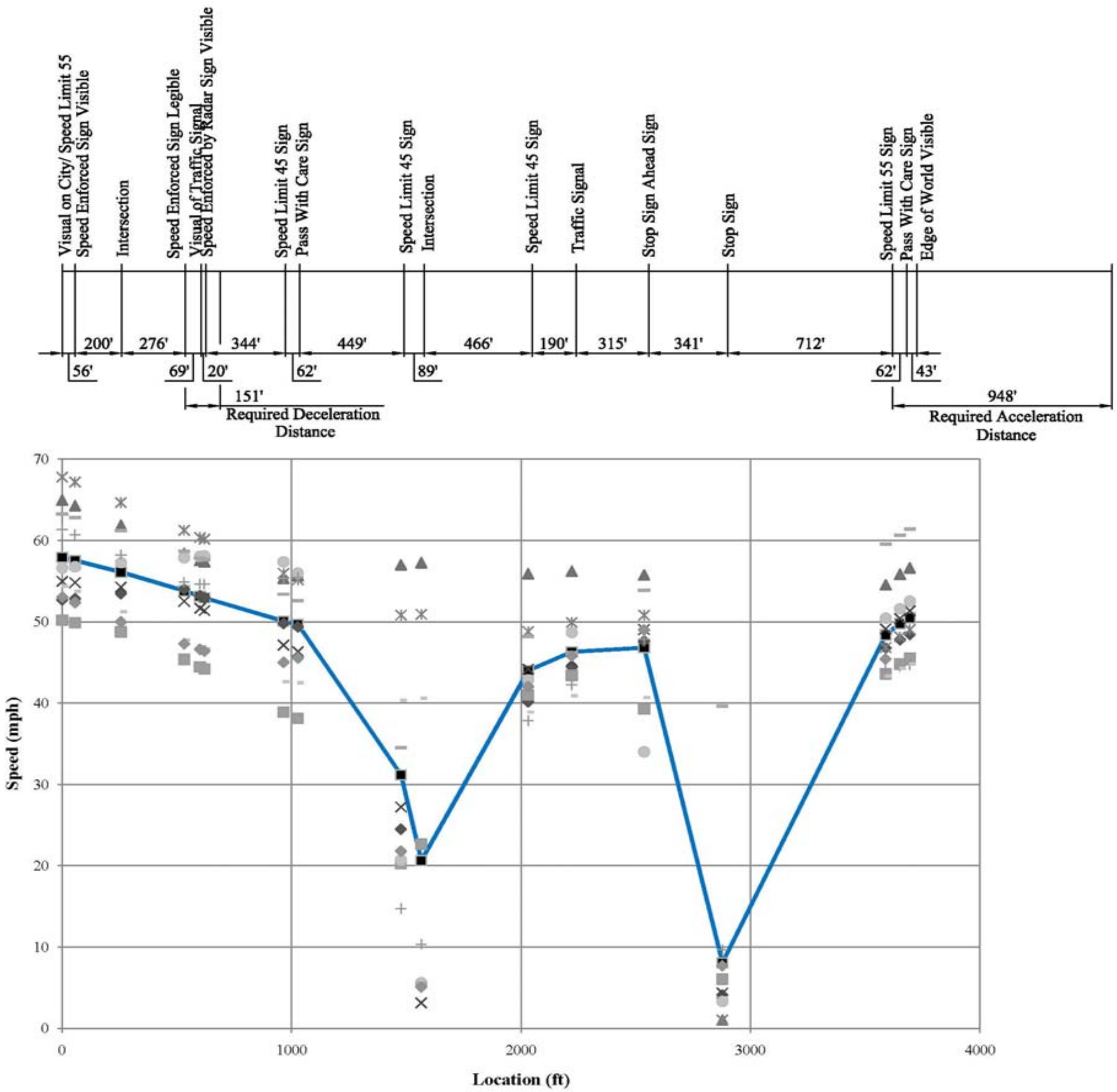

Figure H1.12: Pilot Study 1 - Transition 12 -- Speed Enforced by Radar Sign

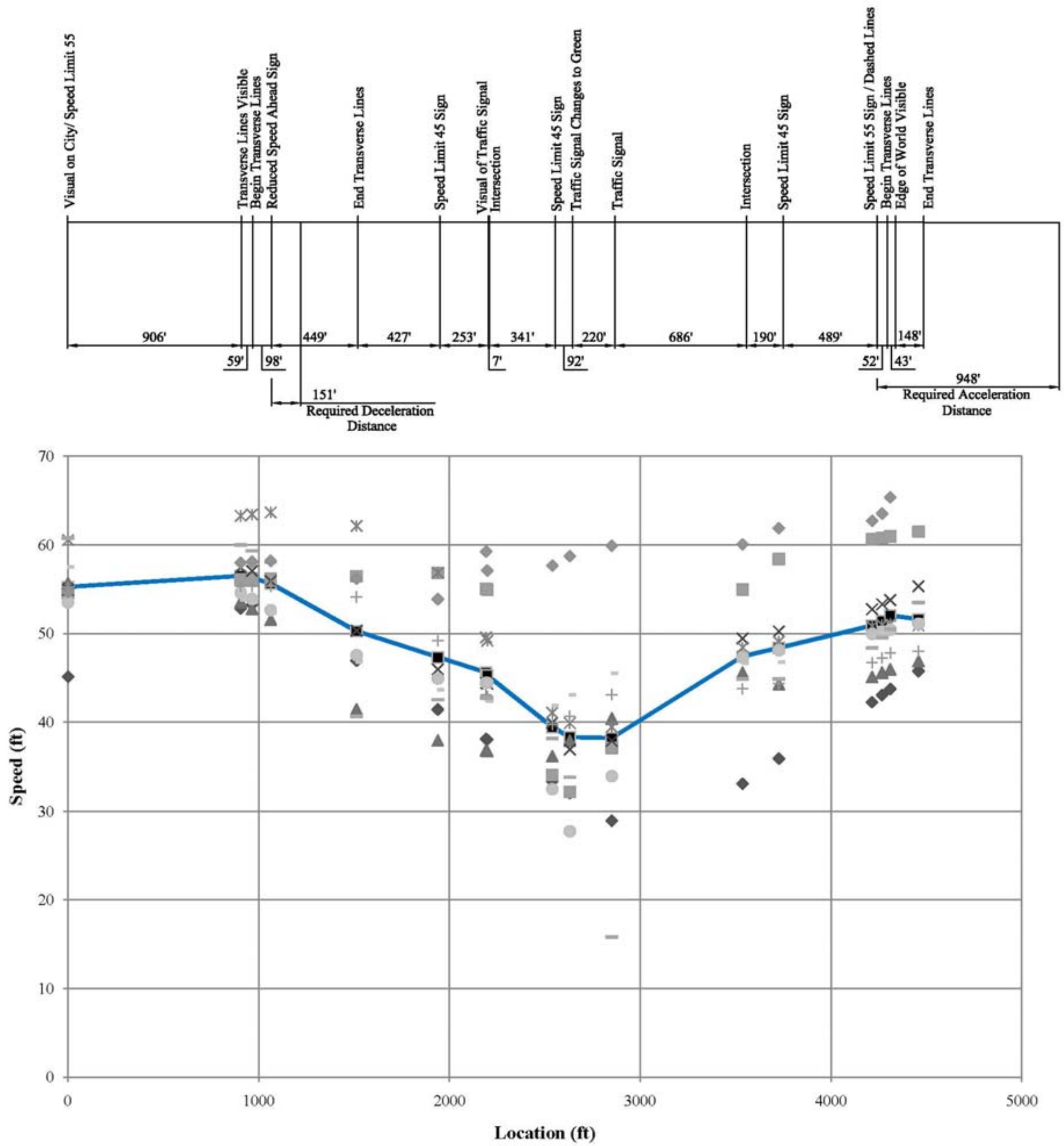

Figure H1.13: Pilot Study 1 - Transition 13 -- Transverse Lines Decreasing Spacing

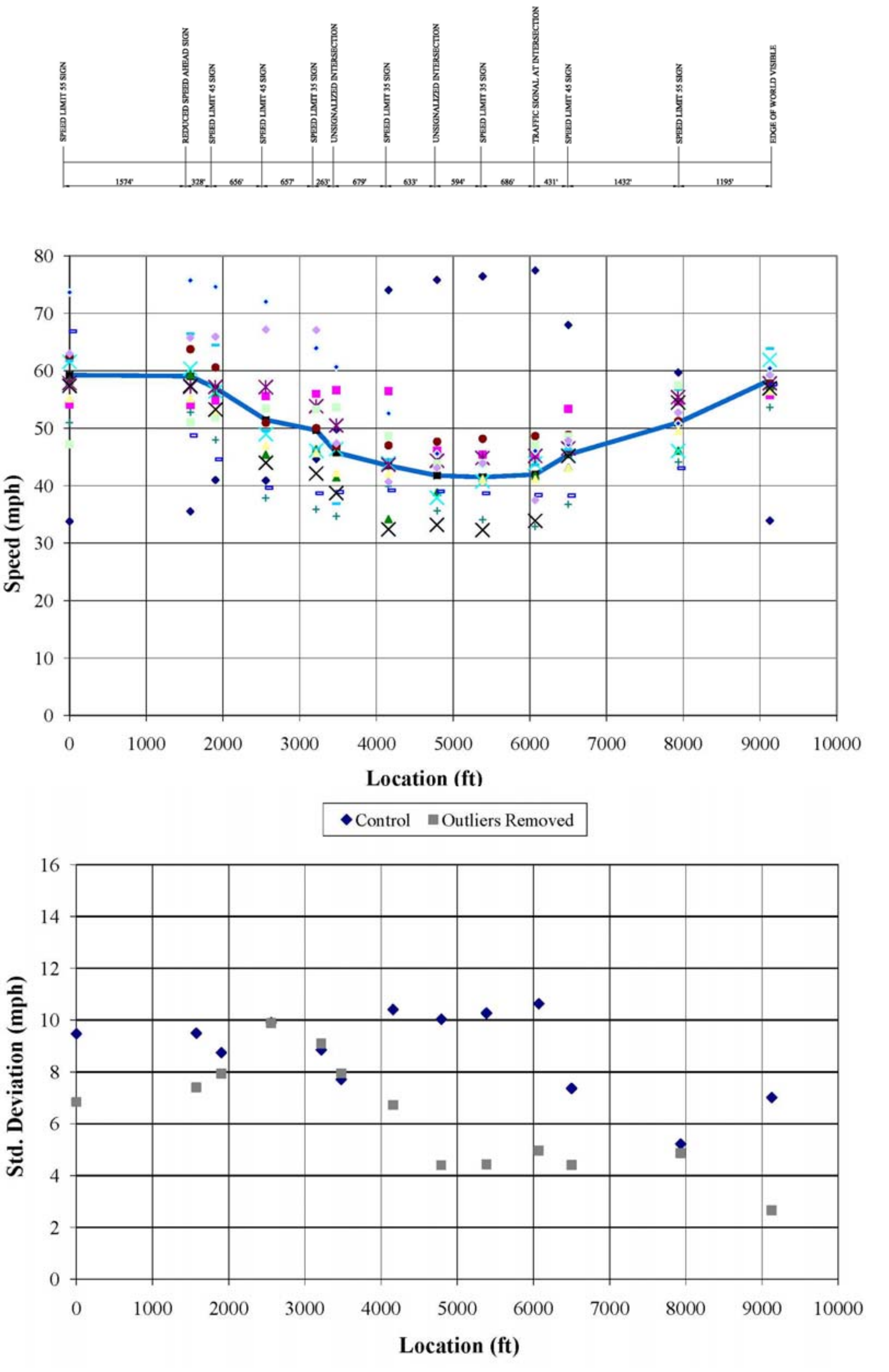

Figure H1.14: Pilot Study II -- Speed Characteristics with No Treatment

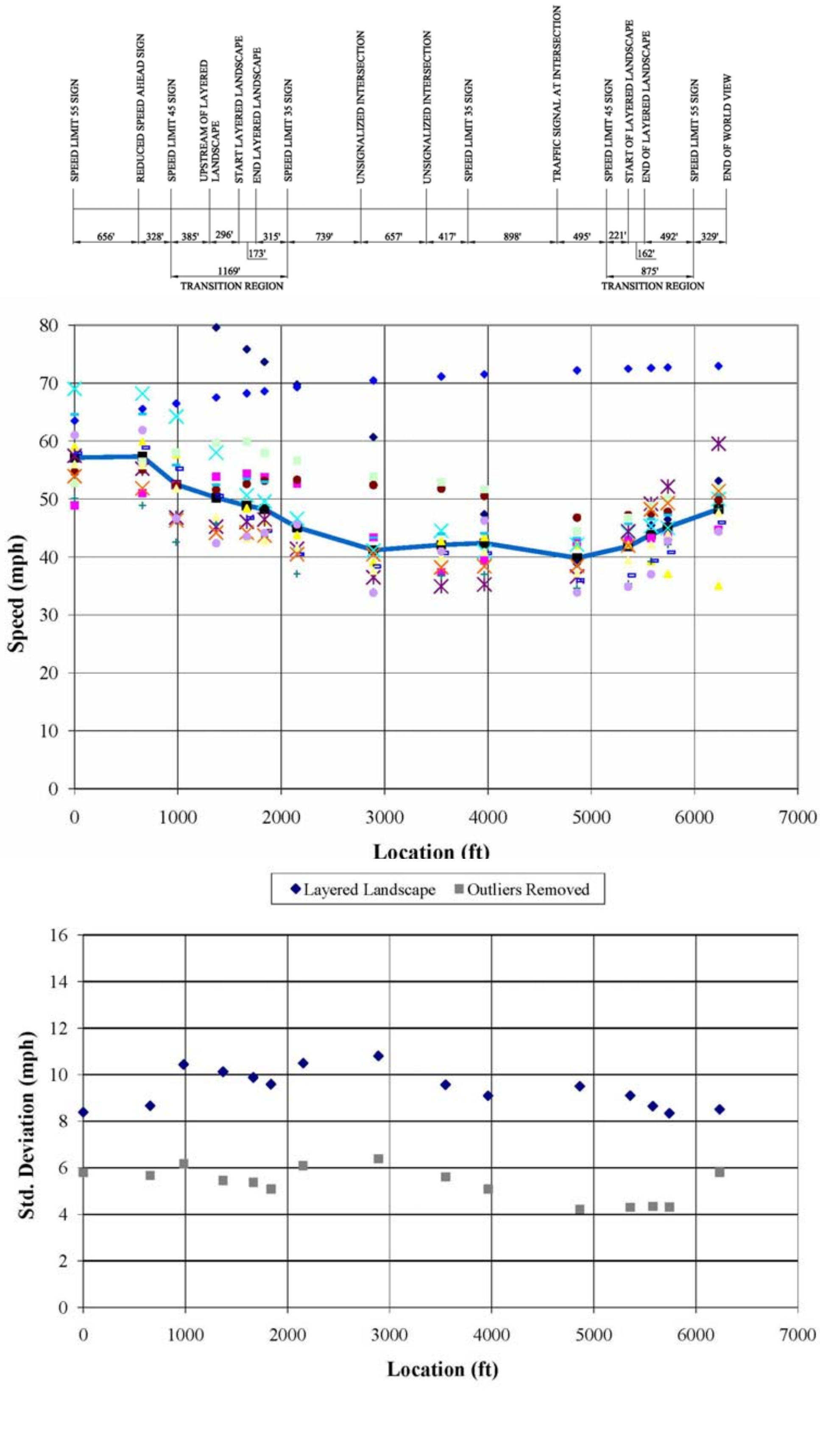

Figure H1.15: Pilot Study II -- Speed Characteristics with Layered Landscaping

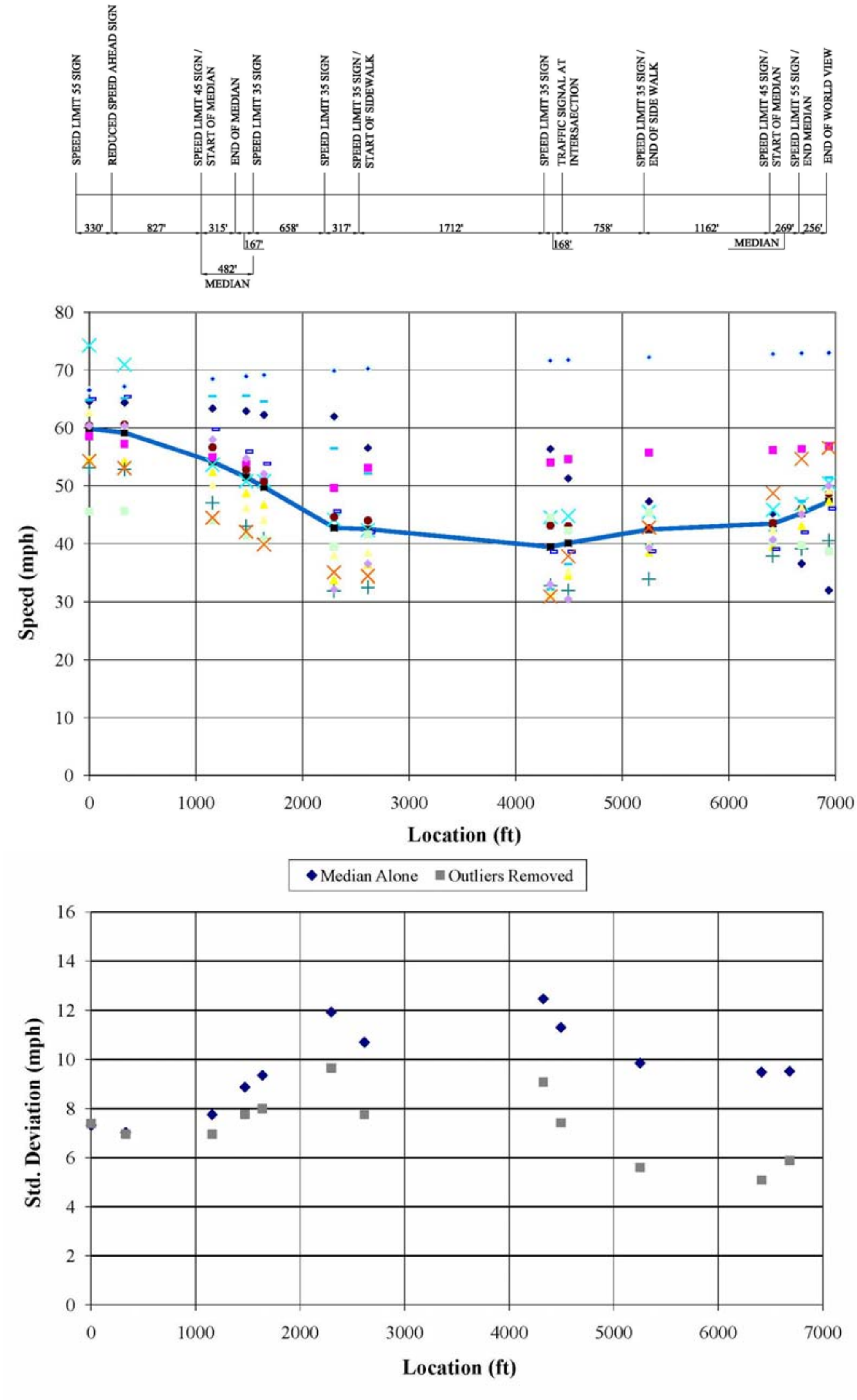

Figure H1.16: Pilot Study II -- Speed Characteristics with Median Only

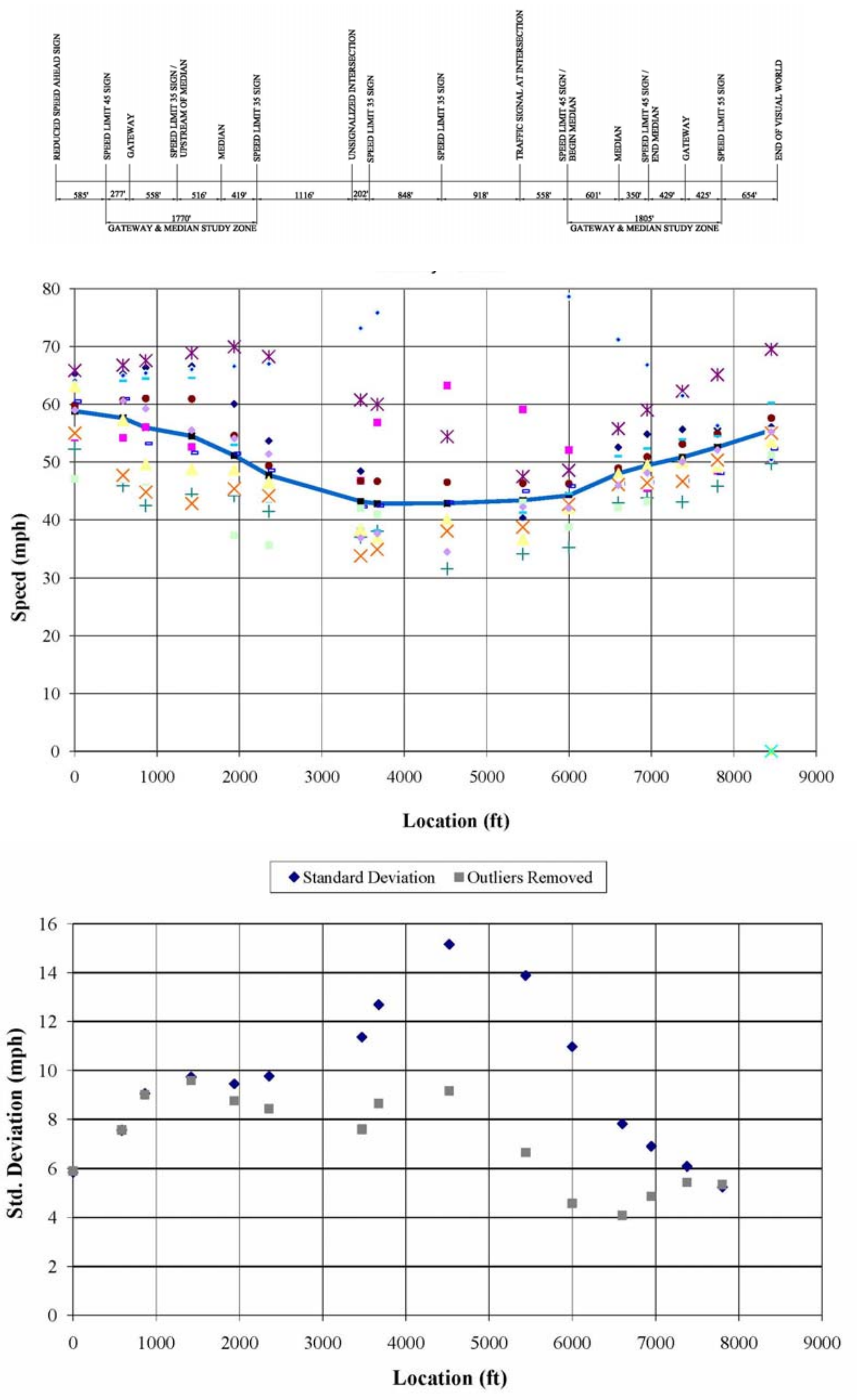

Figure H1.17: Pilot Study II -- Speed Characteristics with Median & Gateway

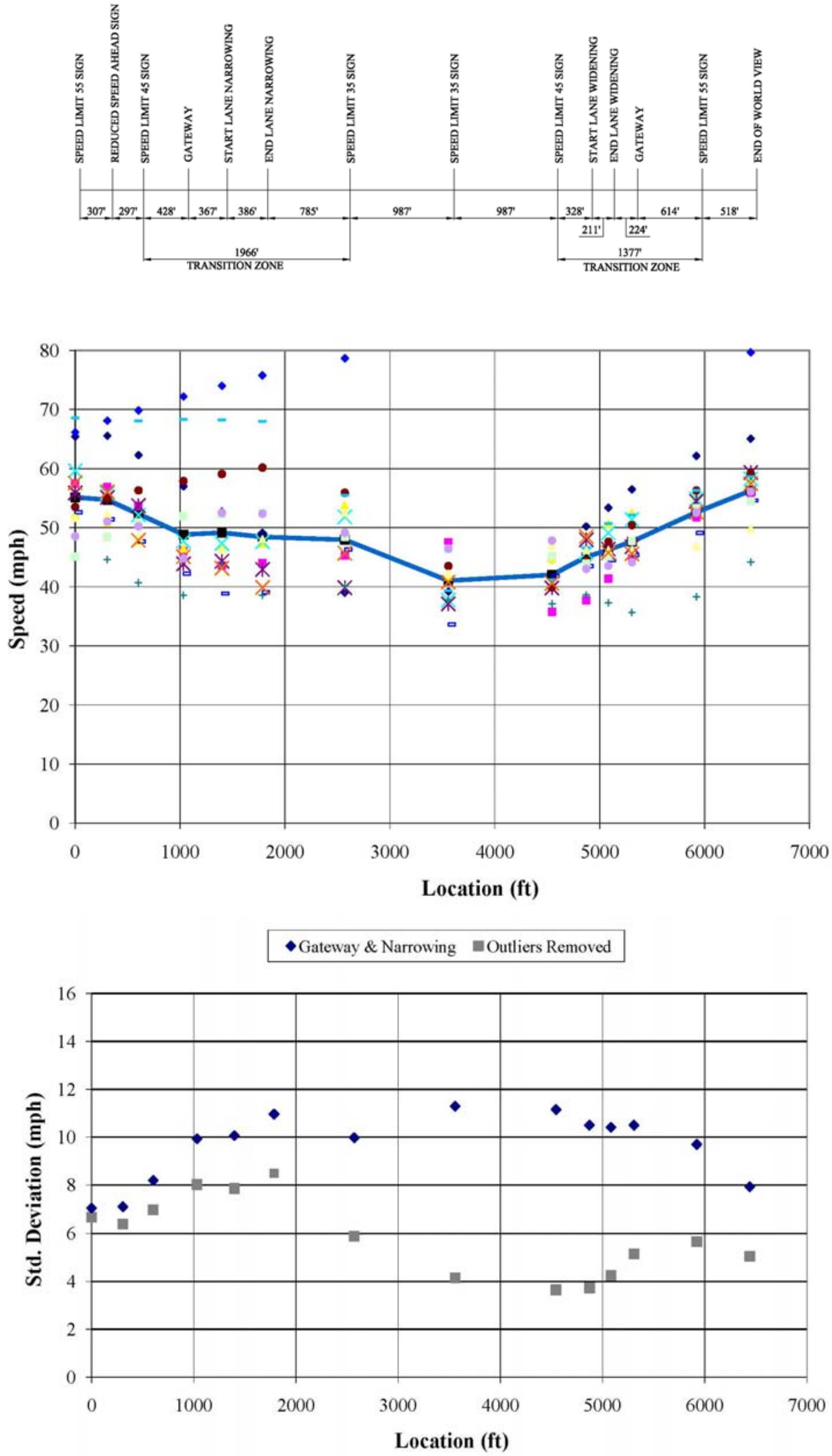

Figure H1.18: Pilot Study II -- Speed Characteristics with Gateway and Lane Narrowing

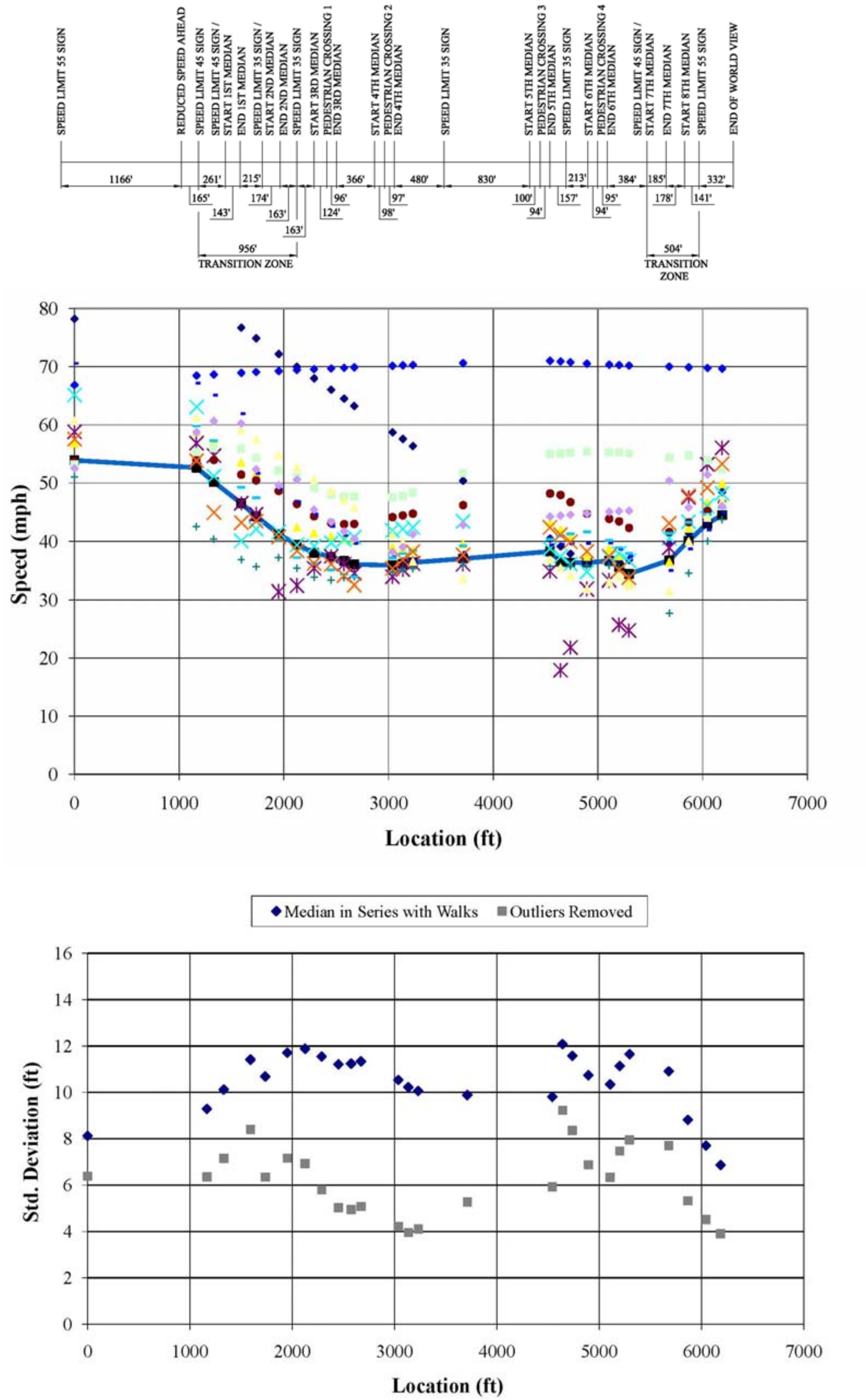

Figure H1.19: Pilot Study II -- Speed Characteristics with Median in Series and Crosswalks