METHODOLOGIES FOR ESTIMATING ADVISORY CURVE SPEEDS ON OREGON HIGHWAYS

Final Report

SPR 641

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by

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16. Abstract

This report reviews an Oregon research effort to evaluate the identification and marking of advisory speeds on Oregon highways. In particular, this research effort focused on the implications of modified advisory speed thresholds and identification procedures following the most recent and the upcoming MUTCD and the Traffic Control Devices (TCD) Handbook recommendations. The primary objectives of this research effort were to help identify the basis for the current and proposed advisory speed posting procedures (with specific attention to the horizontal curve location on rural roads and passenger vehicle condition), to evaluate Oregon placement strategies at a variety of locations, and to identify potential criteria for establishing advisory speeds for these curved sections on Oregon highways. Included with this evaluation is an assessment of associated costs for implementation of a modified advisory speed policy in Oregon. Through the use of both manual and digital ball-bank devices, the report identifies compliance of current and future advisory speed thresholds for both State- and county-maintained roads, expected costs for upgrading State-maintained facilities, evaluation of alternative computational methods, and an assessment of the differences observed between the two different ball-bank devices.

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SI* (MODERN METRIC) CONVERSION FACTORS

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
NOTE: Volumes greater than 1000 L shall be shown in 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

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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METHODOLOGIES FOR ESTIMATING ADVISORY CURVE SPEEDS ON OREGON HIGHWAYS

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EXECUTIVE SUMMARY

The use and placement of advisory speed signs at horizontal curve locations in the state of Oregon is determined by guidance in the Oregon Department of Transportation (ODOT) *Traffic Manual and the ODOT Sign Policy and Guidelines*. These regional guidelines are supplemented by the *Manual of Uniform Traffic Control Devices* (*MUTCD*).

The 2003 *MUTCD*, however, included a change in recommended guidance for establishing advisory speeds on Exit, Ramp, and Curve Speed Signs. Traditionally, advisory speeds have been established by driving a vehicle equipped with a ball-bank indicator around a curve at a specified speed and noting the ball-bank indicator reading. The *MUTCD* notes that a 10-degree ball-bank indicator reading was formerly used in determining advisory speeds, based on research from the 1930's. The 2003 Edition of the *MUTCD* (*FHWA 2003*) changed the 10-degree reading to a 16-degree ball-bank indicator reading, based on perceived performance of modern vehicles and speeds at which most drivers' judgment recognizes "incipient instability" along a ramp or curve.

Subsequent to the publication of the 2003 Edition of the *MUTCD*, the Advisory Speed Task Force of the National Committee on Uniform Traffic Control Devices Regulatory and Warning Signs Technical Committee identified inconsistencies in the *MUTCD* text regarding the advisory speed issue and began re-evaluating this modified advisory speed posting guidance. The Committee has recommended that the criteria for advisory speed engineering studies can be based on ball-bank criteria, accelerometer readings, or calculations using side friction factors. Included in the proposed procedures is a modification to the required ball-bank indicator reading (using a 16-, 14-, and 12-degree threshold based on curve speed).

This report reviews an Oregon research effort to evaluate the identification and marking of advisory speeds on Oregon highways. In particular, this research effort focused on the implications of modified advisory speed thresholds and identification procedures following the most recent and the upcoming *MUTCD* and the *Traffic Control Devices (TCD) Handbook* recommendations. The primary objectives of this research effort were to help identify the basis for the current and proposed advisory speed posting procedures (with specific attention to the horizontal curve location on rural roads and passenger vehicle condition), to evaluate Oregon placement strategies at a variety of locations, and to identify potential criteria for establishing advisory speeds for these curved sections on Oregon highways. Included with this evaluation is an assessment of associated costs for implementation of a modified advisory speed policy in Oregon. Through the use of both manual and digital ball-bank devices, the report identifies compliance of current and future advisory speed thresholds for both State- and county-maintained roads, expected costs for upgrading State-maintained facilities, evaluation of alternative computational methods, and an assessment of the differences observed between the two different ball-bank devices.

1.0 INTRODUCTION

The use and placement of advisory speed signs at horizontal curve locations in the state of Oregon is determined by guidance in the Oregon Department of Transportation (ODOT) *Traffic Manual and the ODOT Sign Policy and Guidelines*. These guidelines are supplemented by the *Manual of Uniform Traffic Control Devices* (*MUTCD*).

The 2003 *MUTCD*, however, included a change in recommended guidance for establishing advisory speeds on Exit, Ramp, and Curve Speed Signs. These changes occurred in Section 2C.36 and 2C.46 of the *MUTCD*. Traditionally, advisory speeds have been established by driving a vehicle equipped with a ball-bank indicator around a curve at a specified speed and noting the ball-bank indicator reading. The *MUTCD* notes that a 10-degree ball-bank indicator reading was formerly used in determining advisory speeds, based on research from the 1930's. The 2003 Edition of the *MUTCD* (*FHWA 2003*) changed the 10-degree reading to a 16-degree ball-bank indicator reading, based on perceived performance of modern vehicles and speeds at which most drivers' judgment recognizes "incipient instability" along a ramp or curve.

Subsequent to the publication of the 2003 Edition of the *MUTCD*, the Advisory Speed Task Force of the National Committee on Uniform Traffic Control Devices Regulatory and Warning Signs Technical Committee identified inconsistencies in the *MUTCD* text regarding the advisory speed issue and began re-evaluating this modified advisory speed posting guidance. Included in this subsequent evaluation is a recommendation by the Committee that the identification of advisory speed locations should be based on an engineering study. The Committee has further recommended that the criteria for these engineering studies can be based on ball-bank criteria, accelerometer readings, or calculations using side friction factors.

Included in the proposed procedures are the following provisions:

- A modification to the required ball-bank indicator reading (using a 16-, 14-, and 12-degree threshold, based on curve speed, rather than solely a 16-degree value, a 10-degree value, or the 14-, 12-, 10-degree procedures of previous editions of the *MUTCD* or the *TCD Handbook*);
- Advisory speeds for trucks versus cars;
- Engineering studies as a requirement to validate advisory speed signage at unique locations; and
- Placement and location of the speed sign.

They have also recommended that Sections 2C.36 and 2C.46 be removed from the next edition of the *MUTCD* and all advisory speed information be contained in updated Sections 2C.06 through 2C.14 with subsequent sections renumbered to accommodate this request. The proposed revised text for these sections of the next edition of the *MUTCD* is included in Appendix C of this report.[1]

This report documents an Oregon research effort to evaluate the identification and marking of advisory speeds on Oregon highways. In particular, this research effort focused on the implications of modified advisory speed thresholds and identification procedures following the most recent and the upcoming *MUTCD* and the *Traffic Control Devices (TCD) Handbook* recommendations. Included in this research effort was an assessment of how these modifications directly impact Oregon's own policies and guidelines for advisory speeds. The primary objectives of this research effort were as follows:

- To help identify the basis for the current and proposed advisory speed posting procedures (with specific attention to the horizontal curve location on rural roads and passenger vehicle condition);
- To evaluate Oregon placement strategies at a variety of locations; and
- To identify potential criteria for establishing advisory speeds for these curved sections on Oregon highways. Included with this evaluation is an assessment of associated costs for implementation of a modified advisory speed policy in Oregon.

The organization of this report is as follows: Chapter 2 reviews the available literature for advisory speed practices. Chapter 3 identifies state-of-the-art advisory speed practices across the United States as well as within the State of Oregon. Chapter 4 summarizes the data collection procedures, including the site selection approach as well as physical data collection methods. Chapter 5 summarizes the observed data, evaluation of the data, and a comprehensive review of the findings. The report ends with study conclusions (Chapter 6), references, and Appendix items.

[1] This information was provided by Mr. James Pline, chair of the Advisory Speed Task Force for the National Committee.

2.0 ADVISORY SPEED PRACTICES – LITERATURE REVIEW

In the United States, the placement of advisory signs at potentially hazardous horizontal curve locations may vary based on the methodology utilized to identify a need for the signs. Upon determination of the need for advisory curve signs, exact sign selection, placement, and location can also vary. This literature review provides a background on the advisory speed literature, followed by a summary of the various need assessment techniques commonly used in the United States. The chapter concludes with a review of appropriate signage placement strategies as identified in the literature.

2.1 BACKGROUND

Guidance for identifying the configuration and need for advisory signage at sharp horizontal curve locations in the United States has historically been based on direction presented in the *MUTCD* (*FHWA 2003*), predecessors of the *MUTCD*, procedures outlined in the *TCD Handbook* (*ITE 2001; FHWA 1983*), or per regional guidelines or manuals unique to specific jurisdictions.

The body of literature regarding the development of advisory speed warning criteria dates back to an early work performed by Moyer and Berry (*1940*). At that time, Moyer and Berry conducted a survey, asking representatives of the various states to determine when or if each state marked advisory speeds, how many of these warning curve conditions were present in each state, and how the state agency determined the proper speed to post. Approximately 50% of the states indicated that they did mark advisory speeds at some locations; and of these states, the methods used for identifying a need included computational techniques, ball-bank indicator readings using trial runs, and spot speed studies. The authors then proceeded to analytically evaluate advisory speed procedures to identify the best available methods for these speed warning needs. They determined that the safe speed on curves is a factor of several interacting forces including those resulting from vehicle design, tire condition, side friction factor, road surface condition and cross-slope, and steering angles and forces. Included in their evaluation were the approximate side friction factors for various speed conditions.

For over 50 years little subsequent advisory speed research occurred. Though a jurisdiction occasionally re-evaluated their specific procedures for posting advisory speeds, the basic methodologies and values defined in the Moyer and Berry study were not tested again until it became apparent that vehicle technologies, driver performance, and road construction methods of more modern times indicated that earlier findings were no longer entirely applicable. In 1999 Carlson and Mason studied the use of ball-bank indicators, assessed traditionally accepted values of side friction factors, and recommended modifications to these traditional values (*Carlson and Mason 1999*). The side friction factor represents the lateral acceleration acting on a moving vehicle.

In 2000, Bonneson performed a study re-evaluating superelevation strategies, and this report included updated friction factors per his observations (*Bonneson 2000*). Work performed by the Midwest Research Institute (*Harwood, et al. 2003*) further recommended side friction factors for passenger cars and separate values for heavy vehicles. The traditionally assumed friction factors for low-speed urban streets as well as rural highways or high-speed urban roadways were revisited in the 2004 Edition of the *AASHTO Policy on Geometric Design of Highways and Streets* (referred to as the *Green Book* from this point forward), and slight modifications to these values were introduced. Table 2.1 depicts the various side friction factors identified in the literature.

Table 2.1: Side friction factor values

Speed (mph)	Moyer & Berry (*1940*) *f* values	Carlson & Mason (*1999*)		AASHTO 1990 & 2001 Max. *f* values		Bonneson (*2000*) (Interpolated)	MRI (*2003*) Values shown are max. demand *f*		AASHTO (*2004*) Max. *f* values (All Roads)
		Adjusted Moyer & Berry Values	Proposed Values	Low Speed	High Speed or Rural		Car	Truck	
20	0.21	0.24	0.28	0.300	0.170	0.223	0.17	0.19	0.27
25	0.18	0.21	0.21	0.252	0.165	0.209	---	---	0.23
30	0.18	0.21	0.21	0.221	0.160	0.193	0.16	0.18	0.20
35	0.15	0.17	0.15	0.197	0.155	0.178	---	---	0.18
40	0.15	0.17	0.15	0.178	0.150	0.164	0.15	0.17	0.16
45	0.15	0.17	0.15	0.163	0.145	0.145	---	---	0.15
50	0.15	0.17	0.15	---	0.140	0.134	0.14	0.15	0.14
60	---	---	---	---	0.120	0.103	0.12	0.13	0.12
70	---	---	---	---	0.100	0.075	0.10	0.11	0.10
80	---	---	---	---	0.080	---	0.08	0.09	0.08

Carlson & Mason (*1999*) further evaluated the use of the ball-bank indicator and companion lateral acceleration and vehicular body-roll rates. They found that the body-roll angle, which causes a body to lean in a horizontal direction at higher speeds, was different than values identified in the earlier work by Moyer and Berry (1940). They suggested that these observed differences were probably due to improvements in vehicle technologies during a period of more than 50 years.

Since side friction factor and vehicle design are two of the fundamental influences on perceived safe speed conditions at horizontal curves, there is compelling evidence that the re-evaluation of curve posting procedures merits additional investigation. The following sections review the various methods used for determining these appropriate speeds as presented in the literature.

2.2 NEED ASSESSMENT TECHNIQUES

The literature summarizes three common techniques in use for the estimation of the maximum safe speed at sharp horizontal curves. The most frequently cited method is the ball-bank indicator method. Two additional advisory speed procedures often recommended are the analytical method and the design curve procedure. In addition, a few less common methods are presented in the literature and are briefly summarized in Section 2.2.4 Other cited techniques.

2.2.1 Ball-bank indicator

The use of a ball-bank indicator (also known as a slope meter) as a tool for determining safe operating speeds on curves in the United States occurred as early as 1937 when this device was employed by the Missouri State Highway Department (*Moyer and Berry 1940*). This simple tool is a curved level that is mounted in a test vehicle. The ball-bank reading, in degree units, represents the combined influences of vehicle body-roll, lateral acceleration angle, and superelevation. Figure 2.1 depicts the various values represented by a ball-bank angle reading.

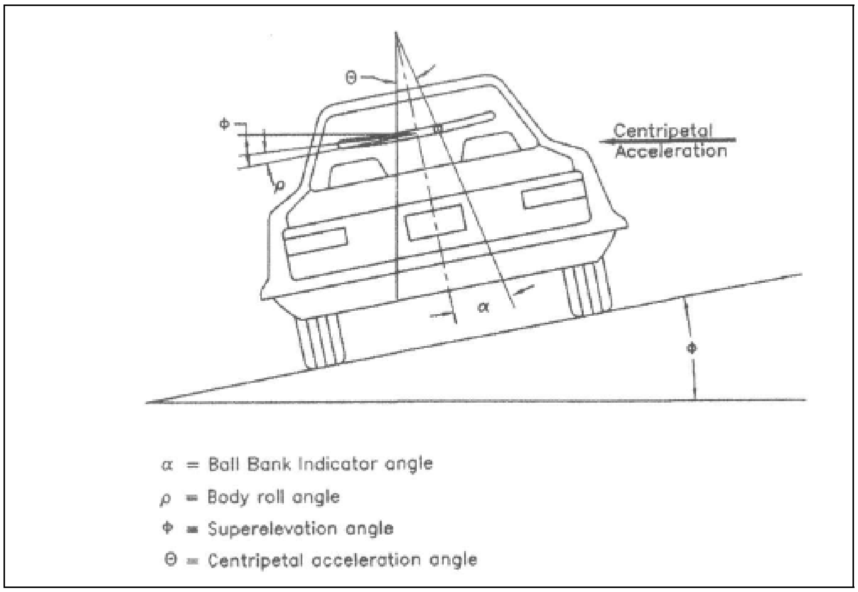

Figure 2.1: Geometry for the ball-bank (Source: *AASHTO 2004*)

The ball-bank indicator displays an angular reading that represents the measurement from the vehicle centerline (perpendicular to the road) to a value representative of the forces acting on a vehicle in motion as it traverses a curve. For a vehicle parked on a level surface, the ball-bank indicator would display a 0-degree value. To assess a curve condition, a vehicle equipped with a ball-bank indicator traverses the curve at 5 mph intervals. For each test run the ball-bank value is recorded. The advisory speed is then defined as the maximum speed for which the ball-bank value does not exceed some predetermined threshold.

Moyer and Berry (*1940*) suggested that a maximum safe speed ball-bank reading is the sum of the centrifugal force angle plus the body-roll angle minus the superelevation angle. Though later studies suggest the force is actually the centripetal acceleration force (*Carlson and Mason 1999*), the relationship identified in this early work and depicted in Figure 2.1 is used today. This relationship is expressed by the following equation:

$$\alpha = \theta + \rho - \phi \quad \textbf{(2-1)}$$

where:

$\alpha \equiv$ Ball-bank indicator angle (degrees),
$\theta \equiv$ Centripetal acceleration angle (degrees),
$\rho \equiv$ Vehicle body-roll angle (degrees), and
$\phi \equiv$ Pavement superelevation angle at curved location (degrees).

Moyer and Berry (*1940*) performed several evaluations using 1936, 1937, 1939, and 1940 cars to determine variations in the influence of vehicle design and its associated vehicle roll angle. For example, for a 10-degree ball-bank reading the maximum roll angle with some vehicles was 2 degrees, 25 minutes, while for other vehicles it was 1 degree, 25 minutes, resulting in a maximum 1-degree difference for the observed vehicles. They suggested this difference could easily be attributed to tire inflation levels for the various study vehicles. Moyer and Berry further suggested that these body-roll angle differences were unlikely to affect speed choices for drivers. They hypothesized that the tire inflation was the primary contributing factor to variations in the roll angle of the cars. Following evaluations of various pavement conditions, a wide variety of curve radii, and a wide range of operating speeds, they ultimately proposed that the maximum safe speed at horizontal curves could be determined using the following ball-bank readings:

- 10 degrees (30 mph $<$ Speed $\leq$ 60 mph),
- 12 degrees (20 mph $<$ Speed $\leq$ 30 mph), and
- 14 degrees (Speed $\leq$ 20 mph).

The 10-, 12-, and 14-degree ball-bank recommendation by Moyer and Berry (*1940*) became one of the common threshold values for signing curves in the United States. For example, the *TCD Handbook* (*ITE 2001; FHWA 1983*) suggests this threshold for advisory speed signage; however, both versions of this document indicate that many states simply use the 10-degree reading to represent the maximum safe speed, as this single threshold provides a conservative value.

In 1991, Chowdhury, et al. evaluated prevailing traffic speeds at sharp horizontal curves and encouraged the use of uniform speed assessment procedures to help create a consistent roadway environment (*Chowdhury, et al. 1991*). They compared the prevailing speeds with companion ball-bank readings and recommended the following thresholds:

- 12 degrees (40 mph $<$ Speed),
- 16 degrees (30 mph $\leq$ Speed $\leq$ 40 mph), and
- 20 degrees (Speed $<$ 30 mph).

In 1999, Carlson and Mason revisited the fundamental assumptions for advisory speed selection (*Carlson and Mason 1999*). They pointed out that various researchers and jurisdictions suggested that advisory speeds on curves were generally posted at too low of a speed and also noted inconsistent posting procedures within and between states. Carlson and Mason evaluated the relationship between the ball-bank readings and lateral accelerations. They also cited the one-degree variation in body-roll angle first noted by Moyer and Berry (*1940*) and evaluated the body-roll angle to determine if this relationship existed for modern vehicles and to what extent this value influenced safe speed choice.

Carlson and Mason used a 1992 Ford Taurus on the Pennsylvania Transportation Institute test track. The Pennsylvania research team evaluated the relationship of the unbalanced lateral acceleration and the ball-bank indicator reading. The unbalanced lateral acceleration included lateral acceleration and superelevation. By isolating these two variables, they could directly assess the body-roll influence as previously shown in Equation 2-1. Carlson and Mason determined the ranges of body-roll angle shown in Table 2.2 and compared their observed values to the 1940 values determined by Moyer and Berry. Carlson and Mason hypothesized that the observed reduction in error was due to improvements in vehicle technology such as a lower center of gravity and improved vehicle suspension systems.

Table 2.2: Body-roll error values

Ball-Bank Reading	Error Due to Body-Roll of Passenger Car	
	Carlson & Mason, 1999	**Moyer & Berry, 1940**
10 degrees	0.5 to 1.2 degrees	1.5 to 2.5 degrees
14 degrees	0.7 to 1.7 degrees	---

Carlson and Mason concluded that the body-roll of a vehicle did not significantly influence the safe speed choice; however, they did identify comfortable lateral acceleration levels that resulted in the following ball-bank indicator value thresholds:

- 9 degrees (Speed $>$ 30 mph),
- 12 degrees (20 mph $\leq$ Speed $\leq$ 30 mph), and
- 16 degrees (Speed $<$ 20 mph).

In 1999, Brudis & Associates, Inc. (BAI) evaluated advisory speed applications for Maryland Highways (*Brudis & Associates 1999*). They determined that drivers have a relatively consistent tolerance for “lean angle” (a value they equated to ball-bank angle) while traveling around a curve. BAI evaluated a variety of test runs in three different test vehicles – the Escort, Lumina, and Explorer. Using an accelerometer and an inclinometer (an electronic version of a ball-bank indicator), BAI tabulated the average gravitational forces and companion lean angles. They then presented results for 42 rural state road horizontal curve locations with a variety of posted advisory speeds. Summary statistics of the 42 locations are depicted in Table 2.3.

BAI also evaluated curves on ramps, and they provided a combined recommendation that an appropriate g-force value (value depicted by an accelerometer) was 0.28 ft/sec^2 and the inclinometer or lean angle value was 16 degrees. As shown in Table 2.3, the observed lean angles for the 42 rural highway horizontal curves ranged from 8.9 degrees up to 24.0 degrees in the BAI study with an average lean angle of 15.3 degrees. The lean angles do not appear to have a consistent relationship to the 85th percentile speed. The average 85th percentile speed was generally 10 mph or more above the posted advisory speed.

Table 2.3: Summary of speed evaluation for 42 Maryland curves on rural roads

Posted Advisory Speed, mph	Number of Sites	g-Force, ft/sec^2		Lean Angle, degrees		85th Percentile, mph	
		Average	Range	Average	Range	Average	Range
15	2	0.26	0.26 to 0.26	15.5	14.8 to 16.1	26	18 to 33
20	2	0.33	0.29 to 0.36	18.3	14.4 to 22.3	30	27 to 33
25	7	0.29	0.22 to 0.34	16.0	8.9 to 21.0	36	32 to 44
30	10	0.27	0.22 to 0.34	15.0	10.1 to 22.1	45	41 to 58
35	13	0.30	0.23 to 0.47	15.6	11.8 to 24.0	45	37 to 54
40	6	0.24	0.20 to 0.29	13.2	10.8 to 16.5	52	48 to 56
45	2	0.27	0.25 to 0.28	16.3	11.5 to 21.1	55	53 to 56
	Average:	0.28		15.3			

Source: Based on *BAI 1999*

The 2003 Edition of the *MUTCD* references the older 10 degree ball-bank reading but also indicates that current advisory speed posting procedures may be based on the 16 degree ball-bank value as one method for identifying advisory speeds. This 16 degree reference appears to be primarily based on the BAI (*1999*) Maryland study previously described.

Finally, the Regulatory and Warning Signs Technical (RWST) Committee for the National Committee on Uniform Traffic Control Devices issued a recommendation in March of 2006 to remove advisory speed posting recommendations, such as ball-bank values, from future versions of the *MUTCD* and simply recommend the use of engineering judgment. Actual procedures would then be outlined in future versions of the *TCD Handbook*. In the next edition of the *TCD Handbook*, the RWST recommended ball-bank criteria should be modified from the 14-, 12-, and 10-degree thresholds to a new 16-, 14-, and 12-degree threshold. These new values are outlined as follows:

- 12 degrees (30 mph $<$ Speed $\leq$ 60 mph),
- 14 degrees (20 mph $<$ Speed $\leq$ 30 mph), and
- 16 degrees (Speed $\leq$ 20 mph).

2.2.2 Computational Approach

During the design phase, an engineer evaluates minimum radii based on a known design speed and an associated minimum radius value. When unavoidable sharp horizontal curvature is required, the engineer can evaluate the maximum safe speed using simple physics principles. In particular, the basic principles of centripetal acceleration combined with Newton's Second Law results in Equation 2-2 below, where the superelevation plays a role in offsetting the centripetal (or lateral) acceleration (*AASHTO 2004*).

$$\frac{0.01e+f}{1-0.01ef}=\frac{V^2}{15R} \qquad \textbf{(2-2)}$$

where:

$e \equiv$ Superelevation of road surface (percent),
$f \equiv$ Lateral or Side Friction Factor,
$V \equiv$ Velocity (mph), and
$R \equiv$ Horizontal curve radius (feet).

Assuming the value of *ef* is quite small, the approximate value of 1-0.01*ef* is approximately equal to a value of one. This results in the simplified curve formula as follows:

$$f = \frac{V^2}{15R} - 0.01e \quad \textbf{(2-3)}$$

Higher values of the lateral or side friction factor represent a condition when a tire is likely to skid; smaller target side friction factor values are assumed to assure conservative results. Table 2.1 shows sample side friction factor values.

The simplified curve formula can be used to evaluate existing facilities with a known radius. The *TCD Handbook* (*FHWA 1983; ITE 2001*) presents the simplified curve formula depicted by Equation 2-3 as an alternative advisory speed analysis procedure. This method was evaluated for comparison purposes by Moyer and Berry (*1940*) and again by Carlson and Mason (*1999*) and found to be dependent on the selected side friction factor value. Many jurisdictions recommend the use of a ball-bank indicator or an engineering study. The simplified curve formula procedure is one common method used for this engineering study evaluation.

2.2.3 Safe Speed Curves

The 1983 edition of the *TCD Handbook* (*FHWA 1983*) included Figure 2.2 that identifies recommended safe speeds when the radius and superelevation values are known. The figure incorporates the simplified curve formula with estimated side friction factors to identify the appropriate speed. As a result, this procedure will provide similar values as the analytical procedure, assuming that the same friction factors are used. The *TCD Handbook*, however, did not publish these friction factor thresholds. This safe speed curve method is another common procedure included in the engineering study evaluation and is still recommended by the current version of the *TCD Handbook* (*ITE 2001*). It is also provided as a supplemental procedure in many of the state guidelines. Both the analytical procedure and the safe speed curves method are commonly used for both the design of new facilities and evaluation of existing facilities.

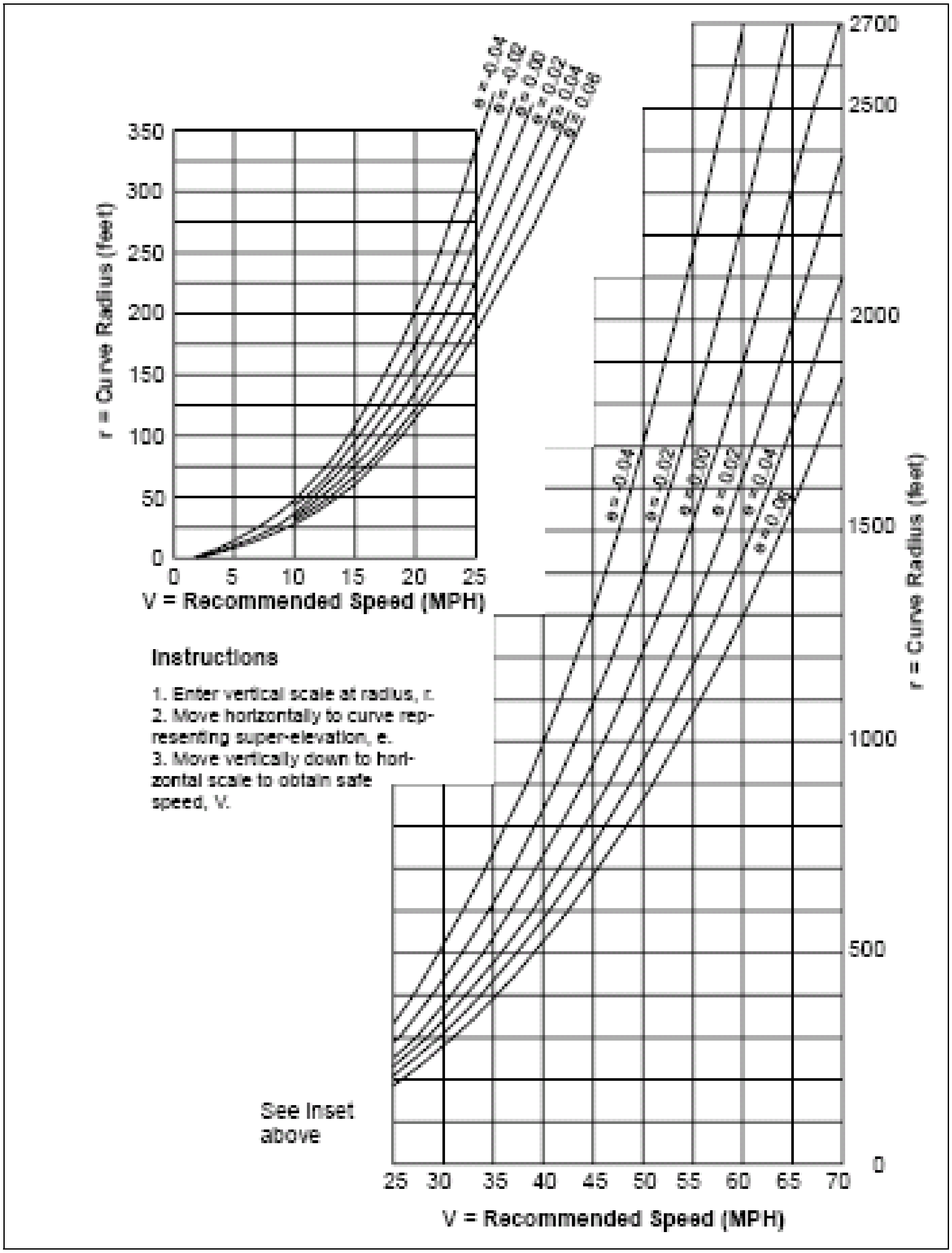

Figure 2.2: Safe speed curve (Source: *FHWA 1983*)

2.2.4 Other cited techniques

In addition to the ball-bank method, the analytical procedure, and the safe speed curves approach, the literature also cites a few alternative techniques for determining the maximum safe speed at horizontal curve locations. The most commonly referenced alternative technique is driver perception. A second common technique is that of engineering judgment. A third approach is posting the speed at the 85th percentile operating speed.

For the driver perception approach, an analyst will perform several test runs traversing through the curve. The advisory speed is then posted at the “most comfortable” speed as perceived by the driver. This subjective analysis can be largely influenced by the type of vehicle used for this procedure as well as the experience level of the driver.

The engineering judgment approach has no definitive requirements but was often cited by various jurisdictions during the email survey (see Chapter 3) as their best practice for determining advisory speeds. There are many references in the literature to engineering studies; however, these do not specify a procedure for using engineering judgment.

The advisory speed can be established based on the 85th percentile operating speed. Several state guidelines and the *MUTCD (*FHWA *2003)* specify this advisory speed approach as an acceptable alternative to the more common procedures cited. This method requires evaluating the existing speeds at the horizontal curve over a period of time and assigning the advisory speed based on these observations.

The *Wisconsin Transportation Bulletin*, Number 21 (*1999*) recommends that supplemental engineering studies may include crash history; roadside development and access studies; sight distance evaluations at intersections and curves; evaluation of general road geometrics; parking, pedestrian, and bicycle activities and conflicts analysis; pavement and shoulder surface condition assessments; and evaluation of current enforcement levels.

2.3 SIGN TYPE SELECTION

The literature provides surprisingly sparse data about advisory sign type and placement. This section specifically addresses the selection of sign types, while Section 2.4 of this report reviews sign placement.

Many advisory speed sign critics suggest that drivers do not heed the warnings presented by advisory signs at curves. Ritchie (*1972*) found that at advisory speed locations with proposed speeds less than 40 mph, these speeds were exceeded by at least two standard deviations greater than the posted advisory speed. He also found that when advisory speeds were posted at 45 or 50 mph, the observed operating speed closely mirrored the advisory speed. Chrysler and Schrock (*2005*) evaluated rural curve warning signs and observed only modest speed reductions when both a curve sign and an advisory speed plaque were present. At locations with curve signs only (no speed plaques), they observed less definitive speed influences.

The *MUTCD* (*FHWA 2003*) offers several potential horizontal alignment signs. Examples of available advisory speed signs are depicted on the Video Data Collection Form in Appendix A of this report. The most common horizontal alignment signs are shown with their associated posting conditions in Table 2.4. The *MUTCD* suggests that a supplemental advisory speed plaque may be appropriate at locations where an engineering study recommends their use to inform road users about the appropriate speed for available conditions. The *South Dakota Local Government Roads Signing Reference* (*SDLTAP 2004*) recommends consistent use of advisory speed plaques at locations where the usual operating speed exceeds the safe speed by more than 10 mph.

Table 2.4: Horizontal alignment sign type

Number of Alignment Changes	**Advisory Speed**	
	≤ 30 mph	**> 30 mph**
1	Turn (W1-1) 	Curve (W1-2) 
2	Reverse Turn (W1-3) 	Reverse Curve (W1-4) 
3 or more	Winding Road (W1-5) 	

Source: Based on MUTCD (*FHWA 2003*)

2.4 SIGN PLACEMENT

Sign placement is primarily based on sign visibility and estimated values for perception-response time (PRT) and the total distance required for Perception, Identification (to understand message), Emotion (to make a decision), and Volition (execute the decision). This combined time is referred to as PIEV and originated in early human factor applications to traffic engineering (*ITE 2003*). Table 2.5 demonstrates the minimum longitudinal placement for warning signs based on the initial speed condition and the reduced speed condition. Prior to 2001, the minimum longitudinal sign placement was considerably longer than those values shown in Table 2.5. The reduction in these distances was due to revised AASHTO stopping and decision sight distance recommendations.

The specific distance values for minimum longitudinal sign placement are based on a PIEV time of 2.5 seconds combined with vehicle deceleration of 10 ft/sec^2 minus the assumed sign legibility distance of 250 feet.

Table 2.5: Advance placement of advisory speed warning signs

Speed (mph): Posted or 85th Percentile	Deceleration to the listed Advisory Speed (mph)						
	10	20	30	40	50	60	70
20	N/A*						
25	N/A*	N/A*					
30	N/A*	N/A*					
35	N/A*	N/A*	N/A*				
40	N/A*	N/A*	N/A*				
45	125	N/A*	N/A*	N/A*			
50	200	150	100	N/A*			
55	275	225	175	100	N/A*		
60	350	300	250	175	N/A*		
65	425	400	350	275	175	N/A*	
70	525	500	425	350	250	150	N/A*
75	625	600	525	450	350	250	100

*There is no suggested minimum value for these conditions. Placement should be based on conditions at the site and other signs so as to provide adequate advance warning for the driver.

Source: Based on MUTCD (*FHWA 2003*) and *ITE 2001*

2.5 SUMMARY OF FINDINGS

Until recently, advisory speed procedures were largely based on research performed in the 1930s and published around 1940. Vehicle performance, road construction techniques, and driver characteristics have changed during the elapsed period of time. In the 1990s, researchers again evaluated the procedures for advisory speed identification to determine if these perceived driving environment changes of the modern road and vehicle fleet have resulted in substantial differences to the appropriate maximum safe speed at horizontal curve locations.

In general, identification of a maximum safe speed is most frequently determined using a ball-bank indicator; however, the thresholds used for selection of the companion advisory speed vary dramatically between states and within states. The three most common advisory speed procedures as cited in the literature are the ball-bank method, the analytical procedure, and the safe speed curve approach. Other procedures include use of the 85^{th} percentile speed, driver perception, various engineering studies, and simple engineering judgment.

Sign type selection and placement are largely based on recommendations in the *MUTCD* (*FHWA 2003*), distances provided in the *Green Book* (*AASHTO 2004*), and supplemental guidance provided in the *TCD Handbook* (*ITE 2001*). Very little additional research has focused on sign type and placement for advisory speed conditions.

3.0 STATE-OF-THE-PRACTICE

As summarized in Chapter 2 of this document, a variety of techniques are used for determining the maximum safe speed at horizontal curves throughout the United States. These strategies range from computational procedures to simple engineering judgment; however, one of the simplest and most common methods is the use of a ball-bank indicator in conjunction with field test runs. This chapter summarizes sample procedures used by states in the United States and local jurisdictions in Oregon including the various ball-bank indicator thresholds. The objectives of this chapter are as follows:

- Provide results of a website assessment of available state procedures;
- Provide results of an email survey for all Oregon counties;
- Provide results of an email survey for a sample of Oregon cities; and
- Summarize an Iowa advisory speed survey published in the literature and not previously identified in the Chapter 2 literature review.

3.1 STATES

One of the tasks for this research project was to inspect the various web sites for state departments of transportations and determine (when available) what criteria is used by each state to determine advisory speeds at horizontal curve locations. Table 3.1 summarizes the results of this investigation. A total of 33 states were found to have criteria posted on the internet. As indicated in the literature review, a common concern within the transportation community is the inconsistency in establishing advisory speeds between states. This table demonstrates that at least five advisory speed scenarios are currently in use. They include the historic speed recommendations from research in the 1930s and 1940s as well as more recent recommendations from the 1990s and beyond. For higher speed locations (greater than 60 mph), the ball-bank indicator criteria can range from 7 degrees up to 16 degrees. For lower speed locations (less than 20 mph), the ball-bank indicator criteria can range from 10 degrees up to 16 degrees. These wide ranges of criteria result in a large variation in posted advisory speeds.

Many states do not have ball-bank criteria; instead they recommend alternative methods such as a variety of engineering study methods consistent with those outlined in the Chapter 2 literature review. Also, a few states distinguish *proposed* facility procedures from *existing* facility procedures and encourage the use of design curves for the proposed locations.

Table 3.1: Summary of state advisory speed ball-bank indicator criteria

Summary of Scenario Definitions					
	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Ball-Bank Reading Units: [degrees (speed in mph)]	14 ($\leq$ 20 mph) 12 (25-30 mph), 10 ($\geq$ 35 mph)	10 (All Speeds)	16 (All Speeds)	15 ($\leq$ 20 mph) 12.5 (25-30 mph), 10 ($\geq$ 35 mph)	13 ($\leq$ 30 mph) 10 (35-55 mph), 7 ($\geq$ 60 mph)

State	DOT Website Link	Scenario Used*	Notations
Alabama	--	--	Not Specified
Alaska	http://www.dot.state.ak.us/stwddes/dcstraffic/assets/pdf/atm/05/entiremanual_05.pdf	D	Scenario D for existing curves, Figure 2C-100 on design projects (based on curve radius and superelevation)
Arizona	http://www.azdot.gov/Highways/Traffic/standards/PGP/TM321.pdf	A	--
Arkansas	--	--	Not Specified
California	http://www.dot.ca.gov/hq/traffops/signtech/mutcdsupp/pdf/CA-Chap2C.pdf http://www.dot.ca.gov/hq/traffops/signtech/mutcdsupp/pdf/camutcd/part2C-032706-draft.pdf	C	DRAFT(March 2006) recommends modifying standard to Scenario D
Colorado	http://www.dot.state.co.us/Traffic_Manuals_Guidelines/MUTCD_2003/index.cfm	C	MUTCD 2003 Edition
Connecticut	--	--	Not Specified
Delaware	http://www.deldot.net/static/pubs_forms/manuals/safety_manual_2000/toc.shtml	--	Engineering Study
Florida	http://www.dot.state.fl.us/trafficoperations/Operations/MUTCD.htm	A or C	Operating Manual shows Scenario A, but the MUTCD 2003 Edition scenario will be phased in
Georgia	--	--	Not Specified
Hawaii	--	--	Not Specified
Idaho	http://itd.idaho.gov/manuals/Online_Manuals/Current_Manuals/Traffic/150Signs.pdf	D	--
Illinois	http://www.dot.state.il.us/mutcd/MUTCD2003ILSupplement.pdf	C	MUTCD 2003 Edition
Indiana	http://www.in.gov/dot/div/contracts/design/mutcd/mutcd.html	B	MUTCD 2000 Edition & Engineering Study
Iowa	--	--	Not Specified
Kansas	http://www.ksdot.org/offtransinfo/Presentations/KDOT_Traffic_Engineering_files/frame.htm	C	MUTCD 2003 Edition
Kentucky	http://transportation.ky.gov/traffic/links.htm	--	MUTCD 2000 Edition Linked – Advisory Speed Not specifically indicated

Table 3.2 (continued): Summary of state advisory speed ball-bank indicator criteria

Summary of Scenario Definitions					
	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Ball-Bank Reading Units: [degrees (speed in mph)]	14 (≤ 20 mph) 12 (25-30 mph), 10 (≥ 35 mph)	10 (All Speeds)	16 (All Speeds)	15 (≤ 20 mph) 12.5 (25-30 mph), 10 (≥ 35 mph)	13 (≤ 30 mph) 10 (35-55 mph), 7 (≥ 60 mph)

State	DOT Website Link	Scenario Used*	Notations
Louisiana	http://www.dps.state.la.us/tiger/ SMSNewsSpring2004.pdf	B	MUTCD 2000 Edition Adopted
Maine	http://www.maine.gov/mdot/mlrc/trafficissues/ localspeed_mutcdstd.php	B	MUTCD 2000 Edition Adopted
Maryland	http://www.sha.state.md.us/businesswithsha/ permits/ohd/15.asp	C	MUTCD 2003 Edition
Massachusetts	http://www.mhd.state.ma.us/default.asp?pgid=content/ publicationmanuals&sid=about	A, B, or C	MUTCD 2003 Edition with supplemental recommendations
Michigan	http://mdotwas1.mdot.state.mi.us/public/tands/ Details_Web/mmutcdcompleteinteractive.pdf	C	MUTCD 2003 Edition
Minnesota	http://www.dot.state.mn.us/trafficeng/otepubl/tem/ Chap-6-2003-pict.pdf	A	--
Mississippi	--	--	Not Specified
Missouri	--	--	Not Specified
Montana	--	--	Not Specified
Nebraska	http://www.dor.state.ne.us/traffeng/mutcd.htm	C	MUTCD 2003 Edition
Nevada	--	--	Not Specified
New Hampshire	--	--	Not Specified
New Jersey	http://www.state.nj.us/transportation/refdata/ traffic_orders/ http://www.state.nj.us/transportation/eng/documents/ dexception/demanual_2004.shtm	C	MUTCD 2003 Edition Design Exceptions based on Scenario B
New Mexico	--	--	Not Specified
New York	http://www.dot.state.ny.us/pubs/mutcd-summarychanges.pdf	C	MUTCD 2003 Edition
North Carolina	http://www.ncdot.org/doh/preconstruct/traffic/mutcd/ docs/part2c.pdf	B or C	Conflicting information available.
North Dakota	--	--	Not Specified
Ohio	http://www.dot.state.oh.us/traffic/ Publication%20Manuals/omutcd/2005OMUTCD/ 03_Part%2002_111705_final.pdf	C	MUTCD 2003 Edition
Oklahoma	http://www.okladot.state.ok.us/traffic/mutcd2003/ pdfVersion/pdfs/Ch2C.pdf	C	MUTCD 2003 Edition

Table 3.3 (continued): Summary of state advisory speed ball-bank indicator criteria

Summary of Scenario Definitions					
	Scenario A	**Scenario B**	**Scenario C**	**Scenario D**	**Scenario E**
Ball-Bank Reading Units: [degrees (speed in mph)]	14 ($\leq$ 20 mph) 12 (25-30 mph), 10 ($\geq$ 35 mph)	10 (All Speeds)	16 (All Speeds)	15 ($\leq$ 20 mph) 12.5 (25-30 mph), 10 ($\geq$ 35 mph)	13 ($\leq$ 30 mph) 10 (35-55 mph), 7 ($\geq$ 60 mph)

State	DOT Website Link	Scenario Used*	Notations
Oregon	http://www.oregon.gov/ODOT/HWY/TRAFFIC/ SIGINING/PDF/english_chapter_4.pdf	E	--
Pennsylvania	Source: (Hood, 2001)	A	--
Rhode Island	--	--	Not Specified
South Carolina	http://www.scdot.org/doing/trafficengineering.shtml	C	MUTCD 2003 Edition
South Dakota	http://www.sddot.com/pub.asp?mode=list&TypeID=2	B	DOT site references the South Dakota Local Government Roads Signing Reference
Tennessee	http://www.tdot.state.tn.us/Chief_Engineer/ assistant_engineer_design/design/DGpdf/ ENGLISH%20GUIDELINES.pdf	C	MUTCD 2003 Edition
Texas	http://www.dot.state.tx.us/publications/traffic/ 2006part2c.pdf ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/ manuals/szn.pdf	A	Engineering Judgment cited
Utah	http://www.udot.utah.gov/index.php/m=c/tid=110/ item=6141/d=full/type=1	C	MUTCD 2003 Edition
Vermont	--	--	Not Specified
Virginia	http://www.virginiadot.org/business/ bu-mutcd-disclaim.asp	C	MUTCD 2003 Edition
Washington	http://www.wsdot.wa.gov/biz/trafficoperations/ mutcd.htm	--	MUTCD - State modifications remove the 16-degree criteria and defer to Engineering Judgment
West Virginia	--	--	Not Specified
Wisconsin	http://www.dot.wisconsin.gov/business/engrserv/ wmutcd.htm	--	Wisconsin Manual stipulates 3 engineering study methods, therefore requiring Engineering Judgment
Wyoming	http://www.dot.state.wy.us/Default.jsp?sCode=infma	B	MUTCD 2000 Edition & Engineering Study

3.2 LOCAL JURISDICTIONS

For the purposes of this study, local jurisdictions within the state of Oregon include cities or counties. Though the local agency structure and responsibility can vary dramatically in Oregon as well as within the United States, in general a city maintains roads with lower urban-condition speeds while a county maintains a variety of roads ranging from low-speed local roads to higher speed rural highways.

Via an email request, the research team collected information on advisory speed practices of counties throughout Oregon. Out of a total of 36 counties in the state, 22 responded to the email request. Figure 3.1 shows a summary of the information collected. Table 3.4 lists the advisory speed practices for the counties.

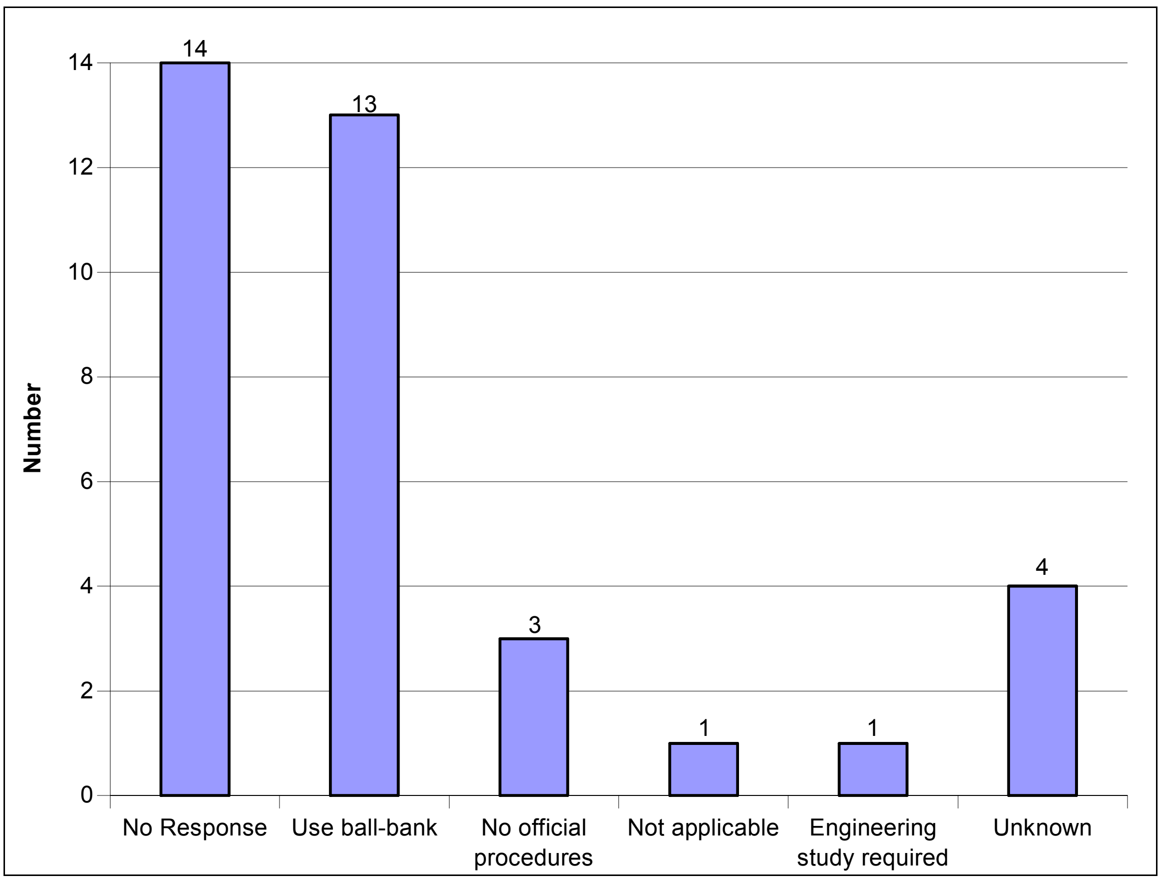

Figure 3.1: Oregon county advisory speed practices

Table 3.4: Oregon county advisory speed procedures

Oregon County	Advisory Speed Practice
Baker	*No Response*
Benton	*No Response*
Clackamas	14, 12, & 10-degree scenario previously identified, no official written policy
Clatsop	Adhere to ODOT requirements
Columbia	AASHTO 2001, page 135
Coos	*No Response*
Crook	Ball-bank indicator (no degree thresholds identified)
Curry	10-degree ball-bank indicator threshold
Deschutes	Adhere to ODOT requirements
Douglas	No official procedures
Gilliam	*No Response*
Grant	*No Response*
Harney	*No Response*
Hood River	Adhere to the MUTCD requirements
Jackson	*No Response*
Jefferson	*No Response*
Josephine	None – do not place advisory speed signs
Klamath	Ball-bank indicator (no degree thresholds identified)
Lake	*No Response*
Lane	*No Response*
Lincoln	*No Response*
Linn	Adhere to ODOT requirements
Malheur	Varies for the four rural road assessment districts, generally based on judgment but a few are based on ODOT requirements
Marion	Used ODOT requirements, 14, 12, & 10-degree thresholds previously identified, 85^{th} percentile, or engineering judgment. Current direction is to adhere to ODOT requirements.
Morrow	*No Response*
Multnomah	*No Response*
Polk	Engineering Study
Sherman	*No Response*
Tillamook	*No Response*
Umatilla	*No Response*
Union	Use the *TCD Handbook* recommendations (recommends the 14, 12, & 10-degree as well as the more conservative 10-degree thresholds)
Wallowa	*No Response*
Wasco	Adhere to ODOT or MUTCD guidelines
Washington	Unknown
Wheeler	*No Response*
Yamhill	Ball-bank indicator (no degree thresholds identified)

The research team also contacted a sample of 31 Oregon cities via email to determine their common advisory speed practices. Though this exercise did not include all Oregon cities, it is a good indication of differences between the city practices and those at the county or state level. The results of the sample of city procedures are summarized in Figure 3.2 and detailed in Table 3.5.

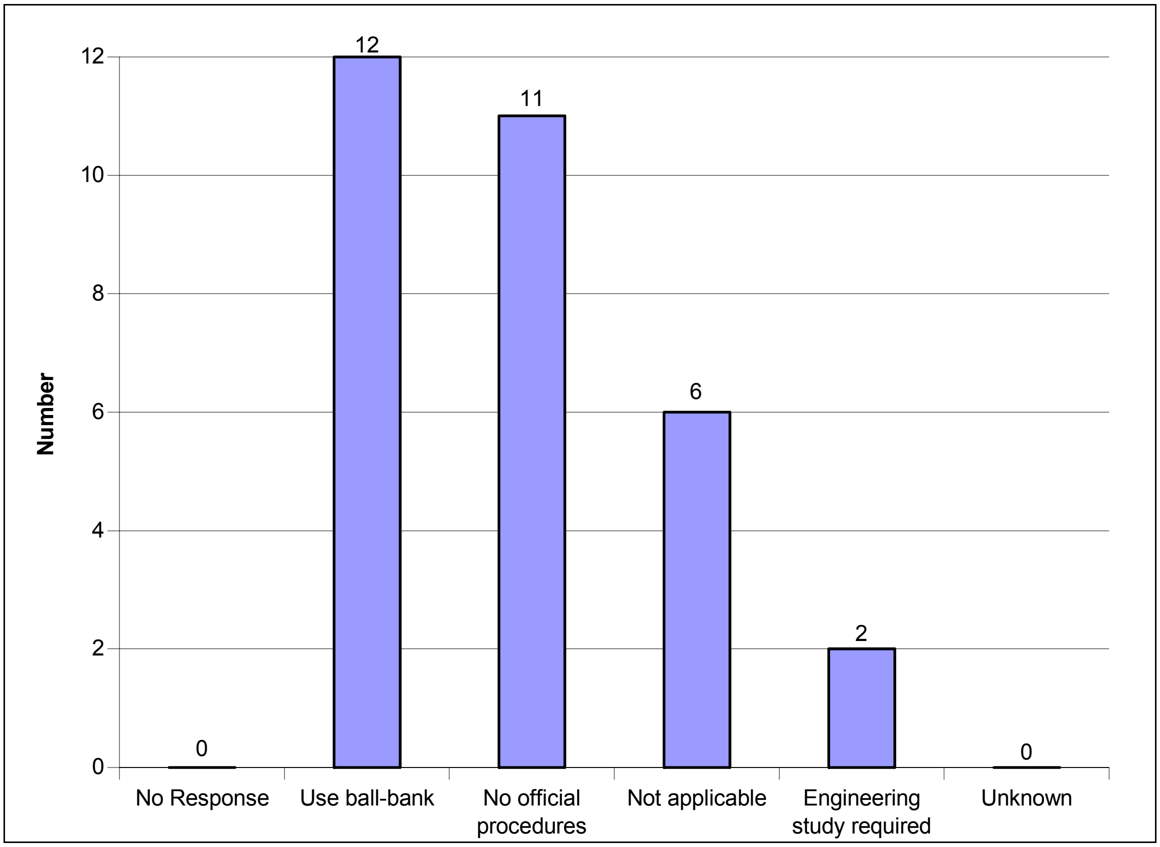

Figure 3.2: Sample Oregon city advisory speed practices

Table 3.5: Sample Oregon city advisory speed procedures

Oregon City or Town	Advisory Speed Practice
Albany	No official procedures
Astoria	None – do not place new advisory speed signs
Baker City	Rely on ODOT for direction
Beaverton	Adhere to ODOT requirements
Bend	Adhere to ODOT requirements
Cannon Beach	No official procedures
Cascade Locks	Rely on ODOT for direction
Coos Bay	No advisory speeds
Coquille	No official procedures
Corvallis	14, 12, & 10-degree scenario previous identified
Eagle Point	Adhere to ODOT requirements
Eugene	14, 12, & 10-degree scenario previous identified
Joseph	None – do not place advisory speed signs
La Grande	Rely on ODOT for direction
Lake Oswego	2003 MUTCD Criteria (16-degree ball-bank)
McMinnville	None – do not place advisory speed signs
Medford	Rarely use advisory speeds, but if required base them on crash history or known special conditions
Monmouth	Adhere to ODOT requirements but do not use a ball-bank indicator
Newport	No official procedures
Ontario	Rely on ODOT or Malheur County for direction
Oregon City	Engineering study
Redmond	AASHTO guidelines based on stopping sight distance
Salem	Adhere to ODOT requirements & MUTCD
Seaside	Adhere to ODOT requirements & MUTCD
Silverton	None – do not place advisory speed signs
St. Helens	No official procedures
Stayton	Adhere to the MUTCD requirements
Troutdale	No official procedures
Tualatin	Generally use a 12-degree ball-bank indicator reading
West Linn	None – do not place advisory speed signs
Wilsonville	Adhere to the MUTCD requirements

Researchers at Iowa State University (*Andrle, et al. 2001*) conducted a survey of cities and counties within Iowa to determine common traffic control device procedures. In their survey, the research team asked each local agency a variety of questions. One of their questions asked the jurisdiction to define their current standard procedures for placing curve or turn signs. Figure 3.3 shows the wide variety of responses within Iowa, ranging from very informal procedures up to formal criteria.

The Iowa survey also asked if a ball-bank indicator or similar device is commonly used for identifying safe speeds at curves. Figure 3.4 shows that this procedure was not common for cities, but very common for counties and the state. Finally, the Iowa survey asked if each agency routinely used advisory speed signs in conjunction with curve signs. As shown in Figure 3.5, the smaller cities did not use speed plaques while it was common practice for counties and the state to use advisory speed plaques as companions to curve signs.

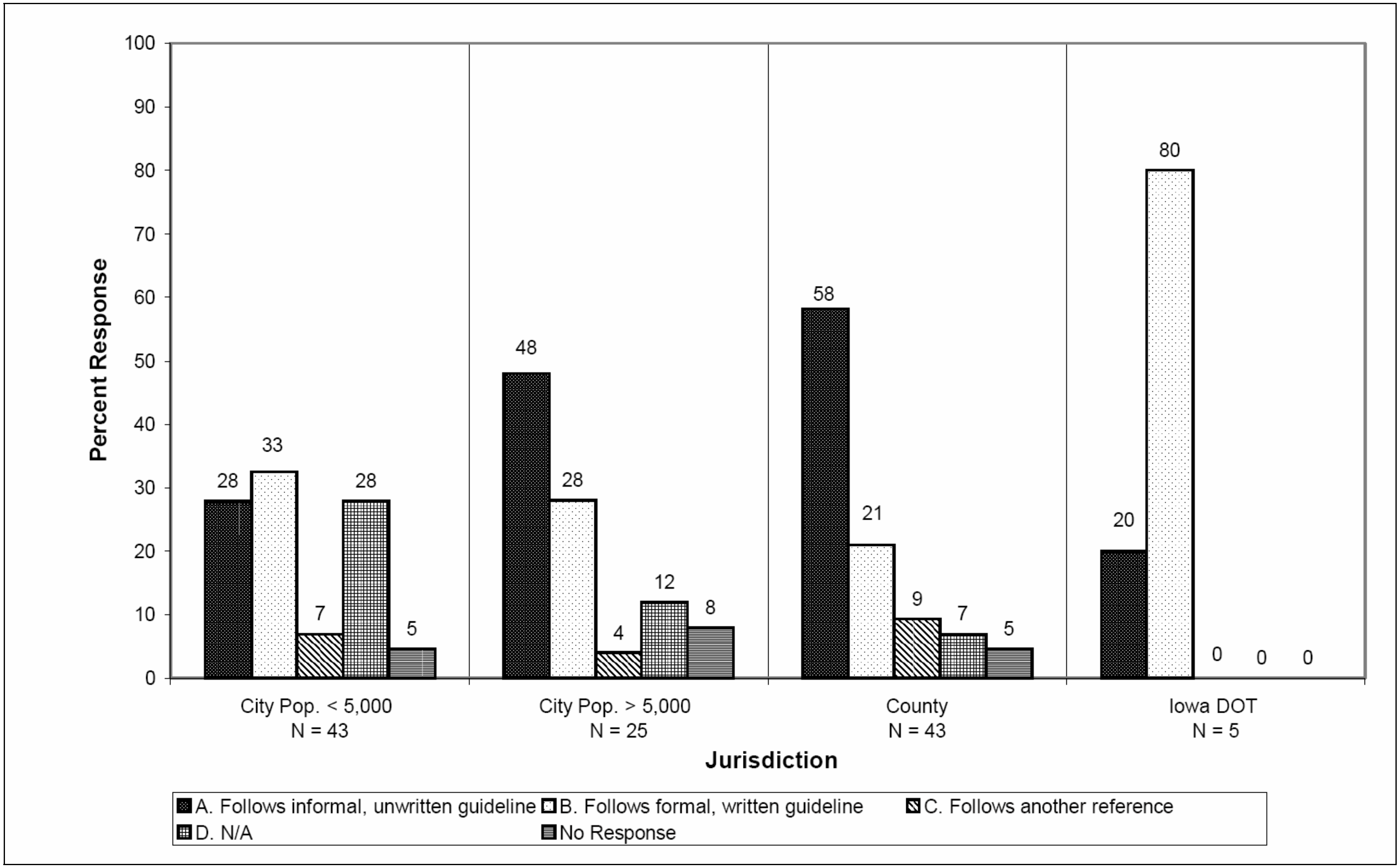

Figure 3.3: Iowa supplements to the MUTCD for curve or turn sign placement (Source: *Andrle, et al. 2001*)

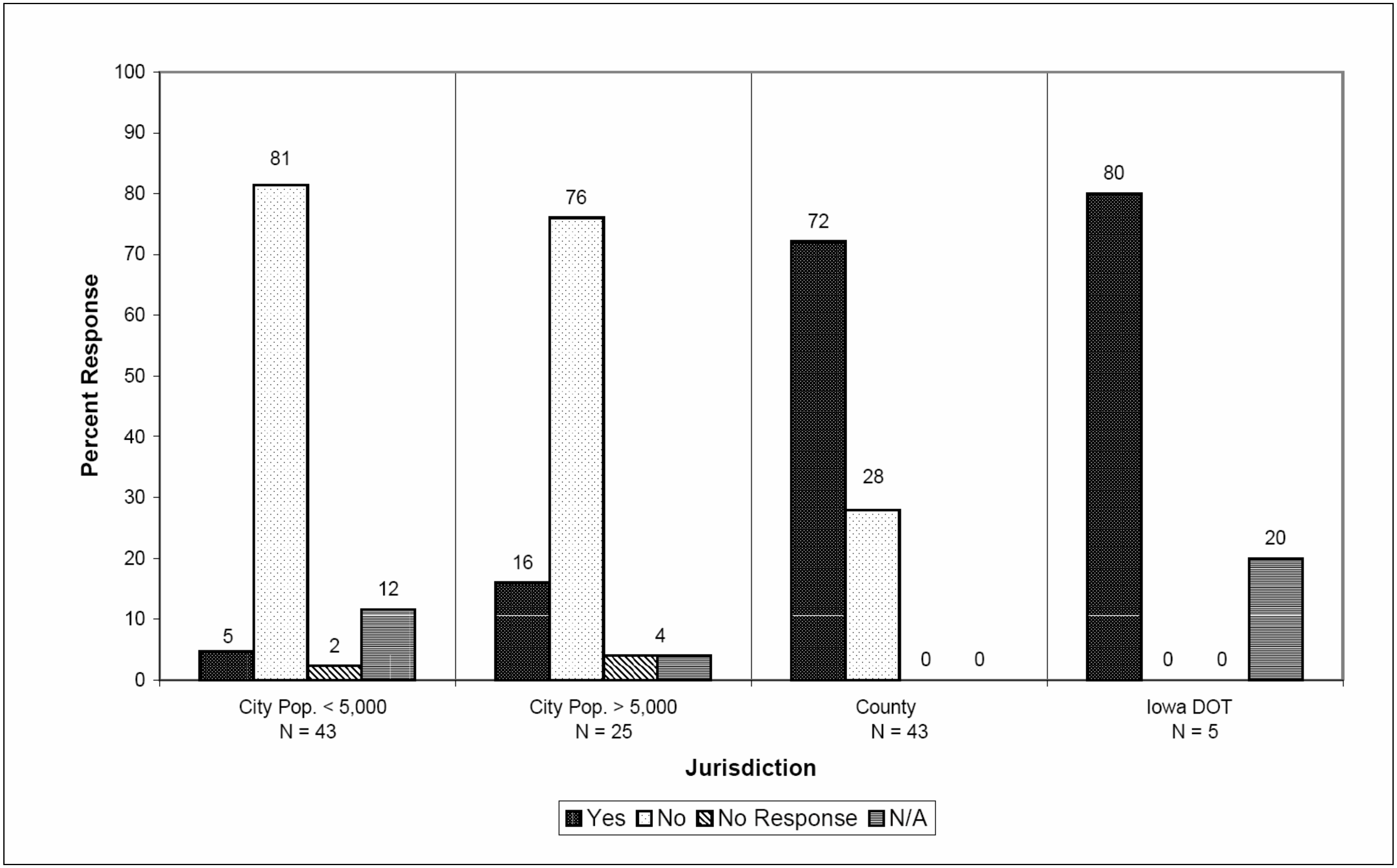

Figure 3.4: Iowa use of ball-bank indicator to determine safe operating speed (Source: *Andrle, et al. 2001*)

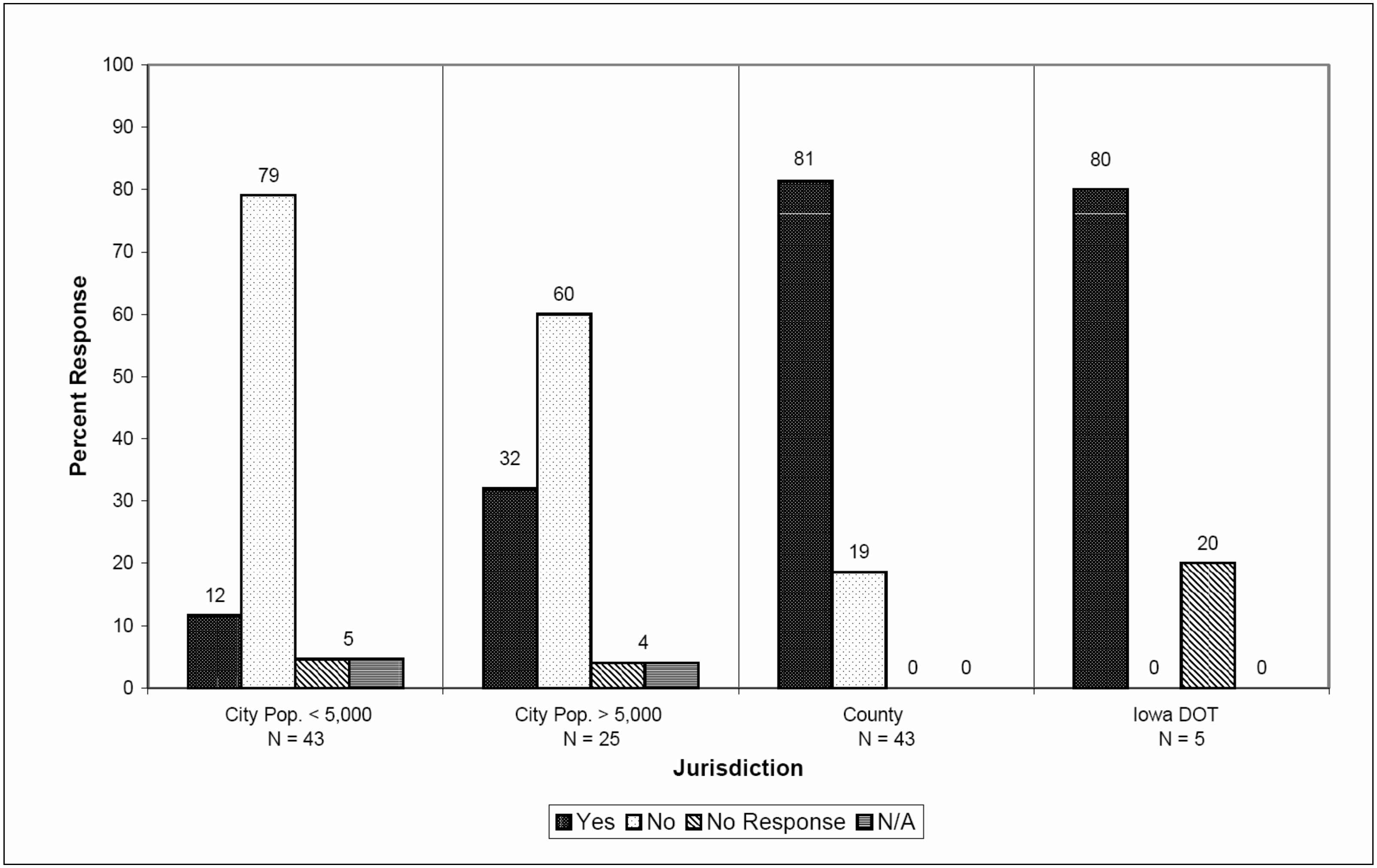

Figure 3.5: Iowa use of advisory speed plaques with curve signs (Source: *Andrle, et al. 2001*)

3.3 SUMMARY OF FINDINGS

The determination of maximum safe speeds at horizontal curve locations for various states in the United States is inconsistent. In general, five common ball-bank indicator thresholds are used as well as a variety of alternative procedures including engineering studies, engineering judgment, and analytical procedures.

In Oregon, many counties use ball-bank indicators with varying threshold levels; however, several of the responding counties indicated they did not post advisory speeds; did not have official procedures; or required engineering studies for determination of advisory speed needs. In a sampling of Oregon cities, a larger number of cities had no official procedures established for advisory speed determination or did not post advisory speeds within their jurisdictions. By comparison, a 2001 Iowa study found that Iowa counties and the state of Iowa used uniform advisory speed procedures (ball-bank indicator with advisory speed plaques) more than their companion cities.

This review of current practices reinforces the perception that advisory speed procedures are variable across the United States, resulting in inconsistent posting of these speeds.

4.0 DATA COLLECTION AND REDUCTION

This project includes data collected from 166 randomly selected sites. Eighty of the sites were located on state highways, and 86 were located on county roadways. Out of those 166 sites, the research team evaluated approximately 232 horizontal curves with a target of 34 descriptive variables recorded for each. In keeping with this project's focus, the majority were on roadways with a functional classification of major collector or above – all within the rural setting. The following sections describe the data collected, data collection methods, field equipment unique to this project, and data reduction.

4.1 VARIABLES COLLECTED FOR ANALYSIS

It is important to have a comprehensive list of variables that summarize the physical, operational, and descriptive characteristics of each candidate curve. These data help illustrate the current signing practices throughout the state of Oregon so that any policy modifications to the Oregon advisory speed practices are based on observed practices and vehicle performance, including identification of the major factors that influence the maximum safe speed for horizontal curves. Table 4.1 provides a list of variables included in this analysis.

Table 4.1: Variables identified or measured during data collection

• Region Number	• Functional Class
• Highway Number	• National Highway System (NHS)
• Highway Name	• Road Surface Type
• Route Number	• Road Condition
• Approximate Curve Radius	• Pavement Width
• Direction of Travel	• Shoulder Width
• Speed Limit	• Section Mile Points
• Advisory Speed Sign (Yes/No)	• Curve Direction (Left or Right)
• Advisory Speed (MPH)	• Curve Mile Points (PC & PT)
• Advisory Curve Sign (Yes/No)	• Curve Isolation (miles)
• Advisory Curve Sign Type	• Curve Latitude/Longitude
• Advisory Sign Color/Reflectivity	• Sign Latitude/Longitude
• Advisory Sign Visibility	• Number of Travel Lanes
• Advisory Sign Dist. From Curve (PC & PT)	• Width of Travel Lanes
• Advisory Sign Height	• Superelevation
• Advisory Sign Dist. From Outer Travel Lane	• Vertical Grade
• Manual & Digital Ball-Bank Readings	• Pavement Edge Drop Off

4.2 SITE SELECTION

Often a research study can inadvertently introduce bias by the method of selecting study sites. For example, safety evaluations often focus on improvements at unsafe locations only. If crash statistics are then evaluated in a before-after analysis, the results will be misrepresentative of safety implications at all locations since all the "before" locations had known hazards. For this reason, the selection of candidate corridors requires a sampling procedure that reduces the opportunity for such bias. This study targeted 160 curve "sites" (corridors of approximately two miles in length), which provided a geographic representation of the state of Oregon. The Oregon DOT is divided into five administrative regions, so these regions served as an initial cluster level for site identification. The research team developed several general steps for an unbiased identification of candidate sites. These steps are shown in Figure 4.1.

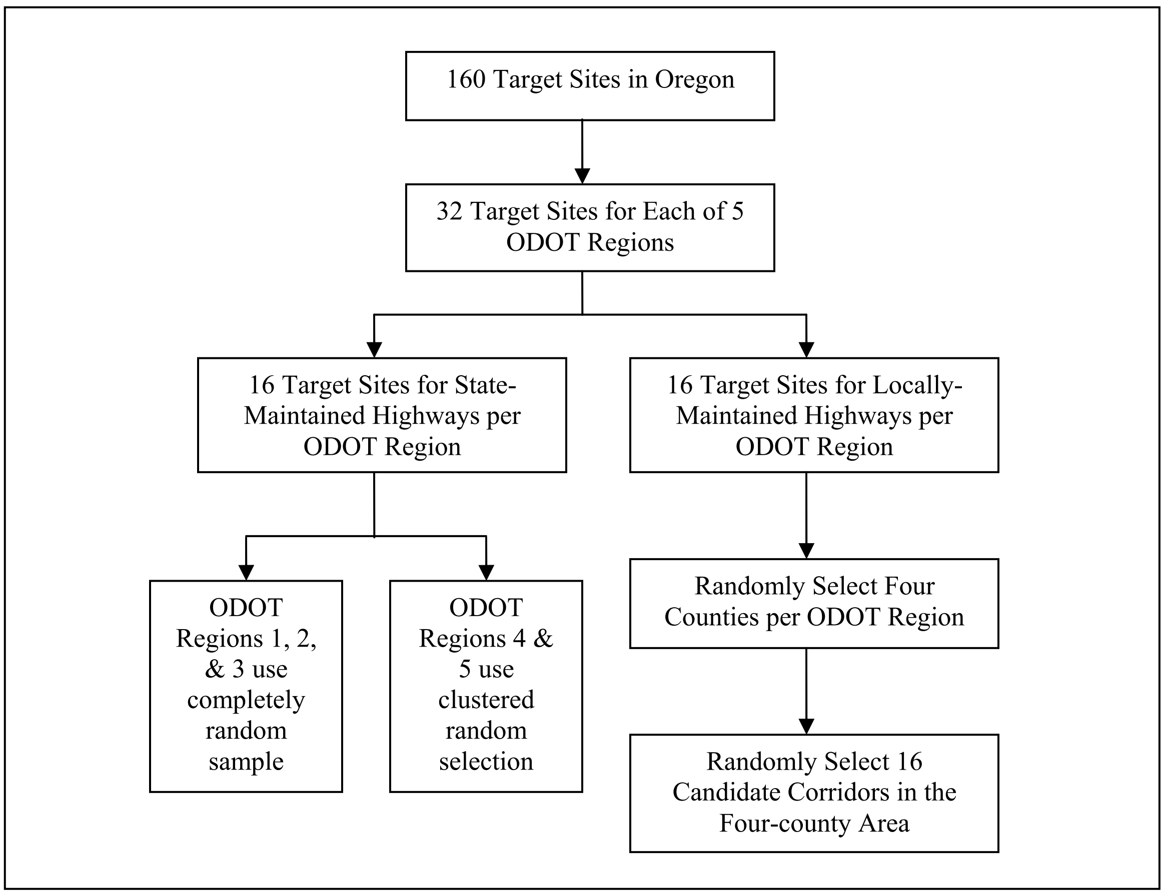

Figure 4.1: Data sampling approach

For State-maintained roads, the research team selected rural highways with approximate segment lengths of two miles. For example, a road that was eight miles long was segmented into approximately four potential study corridors. A member of the team assigned random numbers to all of the State-maintained rural highway two-mile segments and ranked them by ODOT region using a random number selection. Due to the large, somewhat remote geographic area in ODOT Regions 4 and 5, the research team then inspected this larger list of candidate sites for geographic proximity and identified clustered random samples for analysis.

For locally-maintained highways, the OSU team first assigned random numbers to each county in an ODOT region. Following this random number assignment to the counties, the research team then randomly selected four candidate counties within each of the five ODOT regions. Though the team sought to target three of the randomly selected counties per region, a fourth alternate county provided an option, should data quality issues or problems with data collection occur for any of the other three counties. This procedure also included the random clustering of counties for Regions 4 and 5. The corridor identification procedure used the ODOT summary list of roads to identify the State-maintained corridors. For the locally-maintained roads, the research team compiled a list by acquiring road summary lists from the various randomly selected Oregon counties.

Upon creation of the candidate site lists, the OSU team then sought to verify that the candidate sites actually included horizontal curvature suitable for an advisory speed study. To perform this evaluation, a combination of aerial photos (all sites) and video logs (State-maintained sites) provided an evaluation of site horizontal curvature prior to physical site visits. These data sources also provided a mechanism for horizontal curve radius estimation.

In the event that a randomly selected corridor did not include horizontal curvature, the data collection team removed that site from the target sites list and added the next randomly selected alternate site to the proposed data set. As a result, the data collection team was armed with a list of study corridors that included horizontal curvature suitable for advisory speed evaluations. This filtering technique optimized the data collection effort. It is important to note that southeastern Oregon roads were often very straight due to the flat topography of the region, so candidate sites from Region 5 tended to be located in the northern part of that ODOT Region.

4.3 STUDY LOCATIONS

The data collection procedure targeted approximately half of the sites for State-maintained corridors and the other half as locally-maintained (usually by a county). While the data collection team originally intended to only investigate major collectors and above, the data collection included several minor classifications due to variations in maps and discrepancies in functional classification information or definition. The summary of functional classifications by roadway type is shown in Table 4.2.

Table 4.2: Selected classifications

State-Maintained Highways					
Local	Minor Collector	Major Collector	Minor Arterial	Principal Arterial	Total Sites
0	0	11	38	31	80
County-Maintained Highways					
Local	Minor Collector	Major Collector	Minor Arterial	Principal Arterial	Total Sites
1	11	64	10	0	86

Figure 4.2 shows the ODOT regions as well as study county locations. Regions 1, 2, and 3 are located in western Oregon, while Regions 4 and 5 are large geographic regions extending across the central and eastern portions of Oregon respectively.

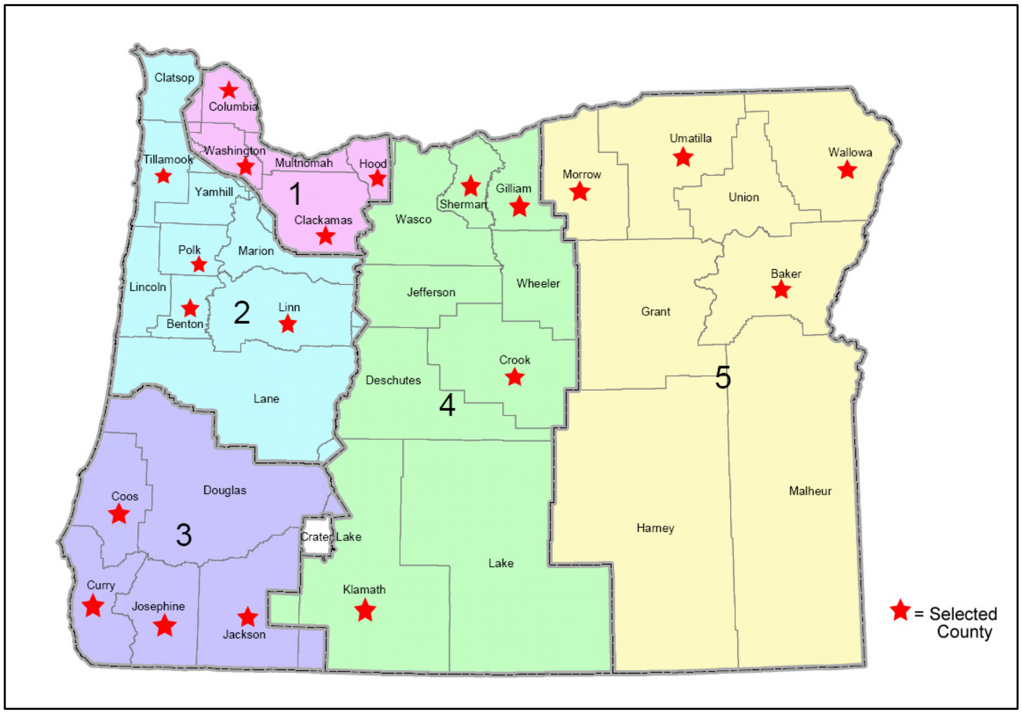

Figure 4.2: Statewide ODOT region and study counties

The top four randomly selected counties from each ODOT region are shown in Table 4.3. The data collection team used these counties for identifying the candidate county-maintained roads. The counties shown in boldface text in Table 4.3 represent the top four randomly ranked counties for that region, while the counties depicted with grayscale text represent the remaining counties in the region.

Table 4.3: Candidate study counties by region

REGION	RANK	COUNTY	REGION	RANK	COUNTY
Region 1:	**1**	**Columbia**	**Region 4:**	**1**	**Sherman**
	2	**Hood River**		**2**	**Klamath**
	3	**Washington**		**3**	**Gilliam**
	4	**Clackamas**		**4**	**Crook**
	5	Multnomah		5	Wasco
				6	Lake
Region 2:	**1**	**Tillamook**		7	Jefferson
	2	**Polk**		8	Deschutes
	3	**Linn**		9	Wheeler
	4	**Benton**			
	5	Yamhill	**Region 5:**	**1**	**Morrow**
	6	Clatsop		**2**	**Umatilla**
	7	Lincoln		**3**	**Baker**
	8	Marion		**4**	**Wallowa**
	9	Lane		5	Malheur
				6	Grant
Region 3:	**1**	**Jackson**		7	Union
	2	**Coos**		8	Harney
	3	**Curry**			
	4	**Josephine**			
	5	Douglas			

Note: **Bold text** represents the "Top Four" randomly selected counties within an ODOT Region. The grayscale text represents counties within each region that were not randomly selected in "Top Four" target category.

4.4 DATA COLLECTION EQUIPMENT

Understanding the specific devices used in this research project is important towards evaluating data and comparing the results with various standards and research results. The key data collection equipment used by the OSU team for this study included ball-bank indicators, an electronic level, and the research vehicle. Each of these data collection instruments is further described in the following sections.

4.4.1 Ball-Bank Indicators

The OSU research team used ball-bank indicators for this data collection effort. Ball-bank indicators in some form have been used for advisory speed assessment dating back to the late 1930s. The ball-bank readings obtained in this study can provide a good baseline for comparing conditions at specific sites with other sites, posting practices, and regional or national posting standards. In recent years, digital ball-bank devices have become readily available but are also considerably more expensive than the manual devices. The research team used both manual and digital ball-bank devices at each site. This combined use of the two different ball-bank indicator devices allowed the research team the opportunity to evaluate the compatibility of the devices and to make informed recommendations regarding future measurement techniques using similar devices.

The manual ball-bank indicator used for this research effort was the Rieker Electronics[2] 1023W1 shown in Figure 4.3. This instrument has been widely implemented, and is useful for comparing our results with those found in past research. It has a range of ±20º, with indicated accuracy to 1º (*Rieker 2006*). Although this device is not as user friendly as its electronic counterpart, it appears to give consistent readings and was favored by the OSU research team. Because a passenger in the test vehicle must observe it closely, any spikes in the readings due to road conditions or a slight jerk of the wheel can be recognized and discounted by the observer. The manual ball-bank indicator also is less reactive to minor fluctuations in the pavement and, therefore, tends to provide more consistent results along the length of a corridor.

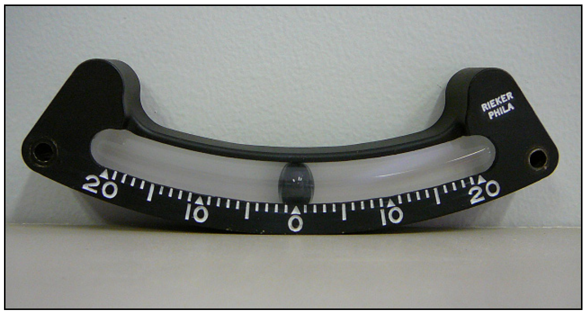

Figure 4.3: Manual ball-bank indicator

The electronic "ball-bank" indicator is called a digital inclinometer. The device used for this research effort was the Rieker Electronics[2] RDS7-BB shown in Figure 4.4. This device has a range of ±25º and a reported accuracy to 0.01º. The research team observed that this device is prone to high variability of results under certain conditions such as uneven pavement surfaces or abrupt superelevation transitions. The device does, however, have the ability to record maximum readings in both positive and negative directions (right and left curves), which can be read off the digital display after the test run is finished. This feature simplifies the data collection process in the field but also reduces the ability of those conducting field trials to monitor any spikes in readings due to road conditions or a slight jerk of the wheel.

[2] Rieker Incorporated, Aston, Pennsylvania 19014

Figure 4.4: Electronic "ball-bank" indicator

The OSU data collection team chose to record readings from both devices during the same field test trial run. This combined data collection maximized the use of the time available. The research team combined the manual and electronic devices into a single instrument assembly to facilitate these combined data collection efforts. This instrument assembly required minor hardware connections not provided with the individual devices. Figure 4.5 shows the complete ball-bank instrument assembly configuration with and without the adjustable support brackets. To provide extra stability, two adjustable suction devices mounted the assembly to the vehicle windshield. These suction devices provided lateral and torsional resistance for increased consistency and eliminated the need to place adhesive Velcro® onto the vehicle's dashboard (which the commonly recommended method for ball-bank indicator installation).

As part of the data collection procedure, each device had to be calibrated before each use to verify that a zero-degree reading occurred at level static locations. To accomplish this calibration, the data collection team used several techniques. First, they placed both instruments on a known level surface (e.g., table, countertop, etc.) and compared their readings to those of a digital level. Next, the data collection team mounted the devices together and compared the readings to that of the digital level.

After adjusting the two devices to provide a consistent and accurate reading, the research team then calibrated the device assembly in the data collection vehicle provided by ODOT. The analyst parked the vehicle on a level surface and measured the cross-slope of the roadway beneath the vehicle to verify this value was very close to zero. The analyst then compared the readings on both instruments to that measured on the roadway. If the vehicle's dashboard was not perfectly level at the center of the vehicle, the analyst simply installed a wedge to "level" the data collection device. The data collection team marked the exact calibrated location on the dashboard of the research vehicle to allow for a simple installation each day. The OSU team repeated this calibration process on multiple surfaces with a variety of slope conditions. Once these values were consistent over repeated tests, the team deemed the combined vehicle-mounted instruments as ready for use. Even after this rigorous process, the research team always checked the instruments for calibration before each use. Figure 4.6 shows the instruments mounted in the research vehicle.

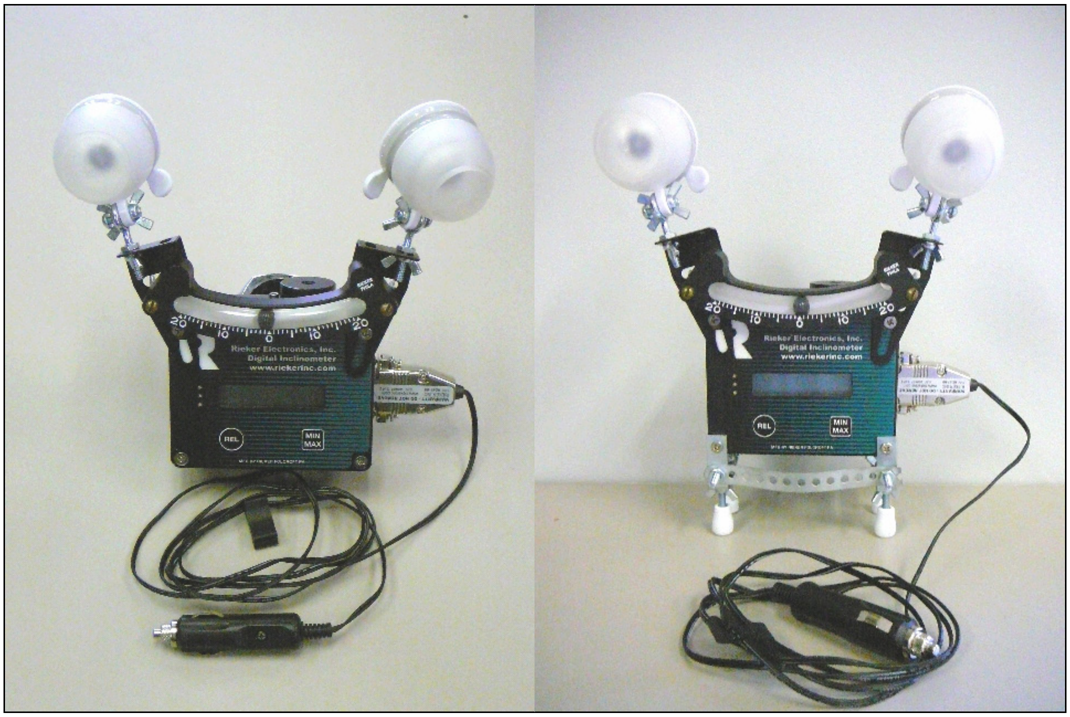

Figure 4.5: Ball-bank indicators without and with mounting brackets

Figure 4.6: Ball-bank indicators mounted in test vehicle

4.4.2 Other Data Collection Equipment

ODOT provided a 2001 Jeep Cherokee for use in this study. Since this vehicle was once the ODOT traffic operations vehicle, the research team assumed that it was likely to be representative of a typical vehicle that may be used for this type of study.

To measure superelevation rates and vertical grade at the study sites, the OSU research team used a digital level. The level the team used for this project was a 48-inch SmartTool™ digital level made by M-D Building Products.[3] This tool provides a digital reading in a percent format as shown in Figure 4.7. This four-foot level is long enough to give a reasonably accurate average reading even over slightly uneven terrain.

Figure 4.7: Automatic level with digital reading

4.5 FIELD PROCEDURE

After arriving at each site, the research team traveled the selected two-mile section of roadway and observed the curves within that segment. They generally chose the controlling curve to study, based on its ball-bank reading. However, other factors influenced their choice of study curves as well. Since poor roadway conditions led to a high variance in readings, especially in the electronic ball-bank readings, they selected the curve(s) with the least obvious damage (e.g., potholes, ruts, etc.) when that option was available. In addition, they selected a representative sampling of curve and signage types for each area (single curve, reverse curve, s-curve, etc.).

[3] M-D Building Products, Gainesville, GA 30504

Once the data collection team identified the study curve(s) within the roadway segment, they recorded that site's information on the data collection forms. (See Appendix A for sample data collection forms, and Appendix B for data collection instructions). They then conducted the test runs by adhering to the following steps:

Test Runs - Instructions:

1. While maintaining a consistent speed, steering smoothly, and driving parallel to the centerline of the road, the data collection team should drive down the travel lane at an obviously safe speed. After two or three trials at this speed, (depending on consistency of data) repeat the trials while increasing the speed of the automobile by 5 mph in each of the following sets of passes. Continue doing so until the appropriate ball-bank reading, averaged over each trial speed, is exceeded. This will indicate that the previous trial run speed is likely to be the appropriate one.

2. If the driver or any of the passengers feel abnormal discomfort, note this issue and engineering judgment shall be used.

3. If multiple travel lanes exist in the travel direction, the conservative travel lane (often the lane with the sharpest radius), shall always be used for ball-bank testing procedures. The conservative lane refers to the lane which yields the highest ball-bank readings. This can be affected by differing superelevation from one lane to the other, and can be determined by preliminary test runs in each lane at equal speeds.

4. There shall always be at least two persons conducting these tests, one focusing on driving, and the other on ball-bank readings. This should provide consistent speeds and steady steering.

During the data collection, the OSU team conducted an adequate number of test runs to evaluate each of the five common ball-bank threshold values identified during the literature review stage of the project. These threshold values, plus a sixth future *MUTCD* threshold assessment, are shown in Table 4.4. The ball-bank value used for this evaluation was the average ball-bank value determined from one five-mph speed increment below each threshold. This average value approach minimized one difference between the two ball-bank devices -- their different maximum outputs. As previously indicated, the manual indicator had a range of ±20º, while the electronic indicator had a higher range of ±25º. This could cause problems when comparing values greater than 20º between devices (*BAI 1999*).

Table 4.4: Tested advisory speed thresholds

Speeds (mph)	Ball-bank Indicator Readings (degrees) for Possible Ball-Bank Threshold					
	1	2	3	4	5	6
30 mph or less	13 º	14 º	15 º	10 º	16 º	16 º
35 mph to 55 mph	10 º	12 º	12.5 º	10 º	16 º	14 º
60 mph or more	7 º	10 º	10 º	10 º	16 º	12 º

Superelevation (roadway cross-slope) was a key variable the OSU team recorded at three locations for each curve. This superelevation was an important site characteristic because it had a high level of influence on ball-bank readings. For this project's convention, if a curve was towards the left, the superelevation of the travel lane was recorded as a negative value. Similarly, if a curve was towards the right, the superelevation of the travel lane was recorded as a positive value. Figure 4.8 provides a simple schematic of this relationship.

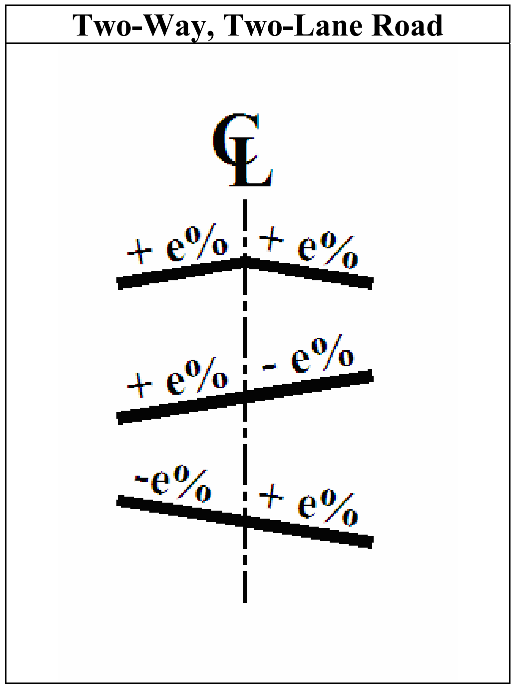

Figure 4.8: Superelevation convention

The data collection team recorded superelevation values at the curve approach, the middle of the curve, and the departure of each curve in both directions of travel. If multiple travel lanes existed, the data collection team collected values at all three points for each travel lane. The OSU team noted that superelevation was also a key factor in determining which of the multiple travel lanes (if present) controlled ball-bank readings for the curve.

While investigating each site, the research team also observed the condition of the roadway. Using the numbering convention outlined in the supplemental directions (see Appendix B), the OSU team classified the roadway condition at each site. This value represented the system as a whole, and was determined by examining the roadway both on foot and in the research vehicle. The numbering convention for roadway condition is as follows:

1. Relatively new pavement without any noticeable cracking, potholes, dips, or vibrations when passed over in a vehicle;

2. Relatively new pavement with minor cracking or dips that cause minor vibrations when passed over in a vehicle;

3. Somewhat fatigued pavement with any combination of cracking, potholes, or dips that cause vibrations when passed over in a vehicle;

4. Fatigued pavement with any combination of major cracking, potholes, or dips that cause some instability when passed over in a vehicle; and

5. Severely fatigued pavement with major structural issues including cracking, potholes, or dips that cause serious instability when passed over in a vehicle.

The OSU team determined that pavement condition is an important variable for a variety of reasons. First, severely fatigued pavement could lead to a vehicle's instability on the roadway, thus increasing the chances of a crash at that location. Second, uneven roadway conditions can help explain variances in the observed ball-bank readings. Third, road condition may specifically address the observed relationship between roadway condition and variations among manual and digital ball-bank readings. Figure 4.9 shows an example of condition "5," a severely fatigued pavement. In this figure, there are multiple forms of damage to the pavement (e.g., rutting, fatigue cracking, potholes, etc.).

Figure 4.9: Poor roadway conditions

The data collection team observed that the visibility of advisory signs present at the candidate study sites was also an important issue. Even with the highest level of consideration put towards each advisory speed posted, if the sign visibility/placement is poor, the potential benefit as a result of the sign may be negligible. The data collection team classified sign visibility at each location using the numbering convention outlined in the supplemental directions (see Appendix B). The numbering convention for sign visibility was as follows:

1. Clear visibility – the sign was clean, had reasonable placement, and had no obstructions that could inhibit a driver's view of the sign;

2. Mediocre visibility – the sign was either very dirty, had awkward placement, or had obstructions that could inhibit a driver's view of the sign; and

3. Poor visibility – the sign had poor placement or had obstructions that could inhibit a driver's view of the sign.

Figure 4.10 shows an example of poor visibility. The advisory curve and speed sign are located behind shrubbery and adjacent to tree foliage. This natural screening hindered sign visibility from any point on the roadway. While the general sign visibility was noted, the OSU team recorded specific details such as sign color/reflectivity and placement (height, distance from travel lane, and distance upstream of the point of curvature). Additional specifics regarding these variables are cited in the supplemental form information/directions in Appendix A and B.

Figure 4.10: Poor sign visibility

4.6 RADII CALCULATIONS

After collecting the field data for each site, the research team calculated the radius for each of the selected curves. For the State-maintained roadways the OSU team evaluated the radius using two methods. One method used the ODOT horizontal curve information provided on their website (http://highway.odot.state.or.us/cf/highwayreports/horizontal_curves_parms.cfm). This site provided the length and central angle of curves based on the highway name and range of mile points. After these values were known, the OSU team calculated the radius for each curve location using a commonly accepted highway circular curve equation shown below (*Wright & Dixon 2005*):

$$R = \frac{360L}{2\Delta\pi} \tag{4}$$

where:

R = Horizontal curve radius (feet).
L = Length of curve – PC to PT (feet).
Δ = Central Angle (degrees).

It is quite possible that many of the sites included transitional spirals; however, the research team could not cleanly identify the limits of these spirals and so used the assumption of a best-fit horizontal curve. While this method was straightforward, it also had its drawbacks. The data provided could have been approximate or labeled incorrectly for a specific roadway. Also, the research team observed frequent variation in mile point information provided online versus based on field observation. At locations with multiple horizontal curves and questionable mile points in the state database, the research team encountered difficulty determining the correct curve data.

The OSU team used a second method for estimating the radius for a specific horizontal curve when they noted discrepancies using the online data source. This second method involved downloading aerial images of the selected roadway sections, and importing them into a CAD program. The OSU team identified the appropriate location using geo-codes (latitude and longitude) recorded in the field with a handheld GPS unit. The source of the aerial images was the TerraServer-USA website located at: http://terraserver.microsoft.com/. Any scaled online mapping sources are suitable for this analysis approach.

Following location of the candidate horizontal curve and importing of the image into a CAD program, the OSU team used the following radius estimation procedure. First, the research team compared the scale from the imported image against the CAD scale. Next, they used the circle command (preferably by 3 points), and drew a circle that represented the curve as accurately as possible. Then they computed the actual radius (in feet) by scaling the CAD radius according to the difference in drawing scales. When spiral curves were in place, this method still served as a relatively accurate measurement. Figure 4.11 shows an example of the image processing procedure just described.

Figure 4.11: Sample radius calculation

Finally, the OSU team performed a comparison between Method #1 (the ODOT database source) and Method #2 (CAD aerial estimation) for the 21 curves investigated at 16 sites within Region 4. This comparison provided a relative prediction of accuracy for the county sites, and other State roadways for which only Method 2 could be used. As discussed previously, there was a certain amount of error expected between design and as-built measurements. Method #1, which appeared to use design values, had very high radii listed for both curves at Site No. 1 shown in Table 4.5 below, while Method #2, which measured as-built conditions, had values that were more representative of the actual road and curve conditions. These two curves provided the only unexplained outliers noticed in the radii calculations. When the data from Site No. 1 were included in the analysis there was an average difference between calculated values of approximately 10.7%. However, upon removal of these two outliers, the average difference between methods appeared to be approximately 6%. Table 4.5 shows these differences. In either case, this relative difference between estimated values is within a tolerable level for this analysis, since radii with similar values should experience similar superelevation designs.

Table 4.5: Differences in radii estimations

Test Location Number (sites with multiple curves listed multiple times)	Milepoint at Point of Curvature	Method #1 Radii (ft)	Method #2 Radii (ft)	Difference (%)
1a	5.9	1150	775	32.6
1b	6.1	1275	300	76.5
2a	6.6	775	775	0
2b	6.9	475	450	5.3
3	58.6	950	1375	44.7
4	46.7	1900	1900	0
5	10.6	1425	1350	5.3
6a	40.4	575	625	8.7
6b	40.6	575	550	4.3
7	87.5	1200	1225	2.1
8	44.6	350	375	7.1
9a	7.3	1275	1300	2.0
9b	7.6	625	650	4.0
10	12.1	1900	1825	3.9
11	6.2	950	1025	7.9
12	48.6	725	700	3.4
13	35.3	1425	1350	5.3
14	46.3	1425	1425	0
15a	37.3	1425	1500	5.3
15b	37.5	575	550	4.3
16	29.1	100	100	0
Average Difference With Location #1:				10.6 %
Average Differences Without Location #1:				6.0 %

4.7 OTHER DATA CONSIDERATIONS

Though the OSU team developed a system for selection of candidate curve sites designed to minimize the bias and improve the quality of data, there are always special cases that arise during field data collection. For this reason, engineering judgment was always used when conducting such procedures. Several unique instances identified by the OSU team are summarized in the following paragraphs.

The research team initially expected that the selection of the "critical lane" for ball-bank trials would logically be the lane with the sharpest radius when multiple lanes in one direction of travel were present. After testing this hypothesis at multiple locations, the data collection team determined that this assumption was not always true. The controlling lane would often be the adjacent lane with a slightly larger radius due to differing superelevation. At some locations this adjacent lane was superelevated at a greater slope than the lane with the sharpest radius resulting in a lower reading on the ball-bank indicator. Because of this, the OSU team always conducted test trials to reveal the controlling lane at each site before they initiated full data collection efforts.

Another unexpected problem encountered by the OSU team involved site selections. After following all procedures outlined in Section 4.2, there were circumstances that caused many of the sites to be removed from the ranking. In the eastern regions of Oregon, the data collection team had to remove several roads due to issues with the roadway surface. Often the research team traveled to sites, only to see a "major roadway" on the map was actually a gravel road. When this occurred, the data collection team removed these roadway sections from the candidate site list and substituted the next appropriate site (from the random ranking). In a few occasions, the data collection team could not locate a site due to ambiguities in maps. Following a rigorous search for the site, the data collection team removed the candidate corridor and substituted the next site on the random list. In two cases, the data collection team later discovered they had made mistakes in site identity and investigated sections before a highway merge rather than after a highway merge as originally intended. For both sites, the research team accepted the error and used the sites, assuming them to still be based on a "random" selection.

At locations where a speed limit was not posted at a site, the OSU research team typically assumed a limit of 55 mph for advisory speed evaluation.

In a few instances, the data collection team encountered locations for which trial runs above a certain speed threshold were either not safe or not attainable due to conditions in one direction but not the other. This unique condition often occurred when a curve with a very sharp radius followed a curve with a large radius. In this case, trial speeds were limited on the flatter curve in at least one direction. The OSU team evaluated the flatter curves based on an assumption that it is often easier to decelerate to an appropriate speed in a short distance than it is to accelerate in the opposite direction. When the OSU team investigated back-to-back curves such as these, they indicated the field limitations by having missing information in the resulting database. Other conditions such as stop signs and poor pavement conditions also led to this issue.

Another major issue the OSU team encountered during data collection efforts was variations between manual and digital ball-bank readings. In general, these differences between devices appeared to be more significant for poor pavement conditions and at locations with sharp back-to-back curves. At poor pavement condition locations, the digital ball-bank devices appeared quite sensitive, resulting in higher readings when compared to the manual ball-bank values. However, this high-sensitivity, or lack of dampening, seemed to be a benefit when testing sharp back-to-back curves, as the device could easily shift from positive to negative values in a short time period. This was not the case with the manual ball-bank, which had difficulties in these sharp curve-reversal situations due to a higher level of dampening. In general, the research team reported more variations in the electronic readings than it did with the manual indicator's readings, due to the high sensitivity of the electronic device. For this reason, the data collection team often conducted test runs for the various standard's thresholds based on the manual readings rather than the electronic readings (as a basis for when to end the incremental trial runs at a site).

Finally, the data collection team used a unique convention for recording ball-bank values during trial runs at each location. The manual ball-bank indicator had tick marks for every 1º, but it was possible to observe whether the indicator was above or below such marks. For this reason, if the observer believed the reading to be between two tick marks, he reported a "+" after the value. Ultimately the research team rounded a plus sign to a value of 0.5º. For example, if the data collection team observed a value of 9º for the first trial, a value of 10º for the second trial, but a value of 9+ for the third trial, the average reading would still be considered to be 9.5º.

5.0 DATA ANALYSIS

Upon completion of the data collection and reduction efforts, the OSU team entered the data analysis phase of the project. The primary goal of this phase was to evaluate the impacts of modifying the Oregon advisory speed policy for current or future *MUTCD* recommended advisory speed procedures. To address this objective, the OSU research team analyzed the extent to which modifying the approach for establishing advisory speed sign placement at horizontal curve locations to match the *MUTCD* procedures may directly impact Oregon. This effort included a comparison of the more conservative ball-bank threshold approach found in the ODOT *Sign Policy and Guidelines* with the methods recommended for the current *MUTCD* and those in the upcoming *MUTCD* (likely to be detailed in the companion ITE *TCD Handbook* rather than in the *MUTCD*). The current *MUTCD* recommendation is a 16-degree ball-bank threshold for all speeds. The proposed future advisory speed procedure is the use of a 16-degree threshold (30 mph or less), a 14-degree threshold (35 to 55 mph), and a 12-degree threshold (60 mph or more). At this writing, it is expected that the *MUTCD* will recommend an engineering study and point the reader to the *TCD Handbook* or other traffic engineering study resources where the new advisory speed thresholds will be stipulated.

The evaluation procedures in this report include an estimate of how the Oregon advisory speed signs would change under a modified threshold for advisory speed and the approximate financial impact of changing the advisory speed signs throughout the state if such a change were deemed appropriate.

The research team divided this analysis into several evaluation tasks. These included the following:

- Assessment of the current and consistent use of the Oregon policy for posting advisory speeds and how its application may differ for State-maintained roads versus county-maintained roads;
- Evaluation of how many of the advisory speeds on State and county roads conform to the current and future *MUTCD* thresholds; and
- Estimation of the cost of implementation of the proposed *MUTCD* procedures for State and county roads in Oregon.

In addition to the three tasks identified above, the research team also evaluated the differences in using a manual versus electronic ball-bank device and identified computational methods for determining appropriate advisory speeds. Finally, general sign lateral placement descriptive statistics are included for informational purposes.

The following section describes the compliance categories and advisory speed plaque criteria followed by the proposed analysis procedures for the assessment of the advisory speed data.

5.1 SPEED PLAQUE CRITERIA AND COMPLIANCE DEFINITIONS

The assessment of advisory speed thresholds for this research project first included determining the appropriate advisory speed based on ball-bank readings, followed by evaluating this recommended advisory speed to determine if an advisory speed plaque was warranted at the site. When the recommended advisory speed was greater than 5 mph below the speed limit, an advisory speed plaque was warranted. (It was not warranted when equal to or less than 5 mph below the speed limit.) Because ball-bank thresholds are tested in 5 mph intervals, this is equivalent to saying a speed plaque was warranted when the recommended advisory speed was less than or equal to 10 mph below the speed limit.

In this report, the method for determining compliance of advisory speeds is presented as "Equal To" or "Equal To or Less Than" categories. These categories are defined as follows:

- "Equal To" compliance: posted advisory speeds equal to recommended advisory speeds, based on field ball-bank evaluations;
- "Equal To or Less Than" compliance: posted advisory speeds equal to or less than recommended advisory speeds, based on field ball-bank evaluations.

This second category is included because in some instances, current advisory speeds may be posted less than the recommended advisory speed values. Though these speeds are less than those warranted, and having speeds below the appropriate level may compromise the creditability of all advisory speed signs, it is also clear that these advisory speeds do not exceed warranted advisory speed values. Hence this may be useful information when gradually changing signage to achieve compliance, as sites without advisory speed signs or speeds posted too high would likely receive priority. Table 5.1 is included as an aid to help clarify the various compliance category assignments based on example speed posting scenarios.

Table 5.1: Example advisory speed compliance assignments

Speed Posting Scenario			Comply using "Equal To"		Comply using "Equal To or Less Than"	
Speed Limit	Warranted Advisory Speed	Posted Advisory Speed	Yes	No	Yes	No
45	45	None	X		X	
45	40	None	X		X	
45	40	40	X		X	
45	40	35		X	X	
45	35	None		X		X
45	35	40		X		X
45	35	35	X		X	
45	35	30		X	X	

5.2 ANALYSIS FOR CURRENT OREGON ADVISORY SPEED POLICY

To assess the current level of consistency and compliance within the state of Oregon, the OSU research team evaluated whether the field study advisory speed requirements were consistent with the current Oregon policy.

During the literature review phase of this project, the research team contacted several Oregon local jurisdictions (primarily counties) to determine their procedures for posting advisory speeds. Though the current Oregon policy is required, many jurisdictions indicated they were unaware of this policy and used alternative methods or thresholds for posting advisory speeds. The current Oregon policy for posting advisory speeds includes the following thresholds:

- 13-degree ball-bank value for speeds equal to or less than 30 mph,
- 10-degree ball-bank value for speeds from 35 to 55 mph, and
- 7-degree ball-bank value for speeds equal to or greater than 60 mph.

Since the research team anticipated different compliance rates for State- versus county-maintained roadways, the OSU team assessed compliance separately for state and county governing jurisdictions. Though the data collection team only collected data for a subset of horizontal curves for the state of Oregon, the nature of the randomly selected sites should adequately represent the statewide trends for the jurisdictions in Oregon.

As a result of the random nature of the site selection process, candidate corridors for field evaluation included curves with and without advisory speed plaques. In addition, the ball-bank thresholds for Oregon identify recommended advisory speeds and compliance with these speeds defined as advisory speeds posted at values exactly equal to the recommended speeds.

Compliance summaries for the various advisory speed conditions based on the Oregon policy are presented in the following formats:

Advisory speeds equal to the recommended speed for all curves studied (see Table 5.2);

- Advisory speeds less than or equal to the recommended speed for all curves studied (see Table 5.3);
- Advisory speed equal to the recommended speed for current speed plaque locations, plus locations where speed plaques are warranted but may or may not be present (see Table 5.4). This summary includes regional fluctuations as well as State- and county-maintained road compliance for each region.
- Advisory speed equal to or less than the recommended speed for current speed plaque locations and locations where speed plaques are warranted but may not be present (see Table 5.5).

At most locations, the research team evaluated curves in both directions of travel. Occasionally the recommended advisory speed could not be evaluated for one travel direction due to physical site constraints. In addition, data from each site included both the manual ball-bank values as well as the electronic ball-bank values. The values depicted in Table 5.2 through Table 5.5

represent the manual ball-bank recommended speeds; however, the ball-bank assessment (later in this chapter) demonstrates the differences based on the manual versus digital ball-bank devices. Appendix D provides companion tables (see Table D.1 through Table D.4) for the compliance rates based on the digital ball-bank values.

Table 5.2: Compliance for advisory speeds "Equal To" Oregon policy (all curves)

Based on Manual Ball-bank Readings	State and County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	4	16	14	23	21	22	19	29	42	192
Total Curve Directions	5	14	33	40	72	62	72	68	42	48	456
% Compliance	40%	29%	48%	35%	32%	34%	31%	28%	69%	87%	42%
	State Roads -- Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	0	0	3	5	10	10	17	19	21	36	121
Total Curve Directions	0	1	5	8	26	21	36	50	26	37	210
% Compliance	NA	0%	60%	63%	38%	48%	47%	38%	81%	97%	58%
	County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	4	13	9	13	11	5	0	8	6	71
Total Curve Directions	5	13	28	32	46	41	36	18	16	11	246
% Compliance	40%	31%	46%	28%	28%	27%	14%	0%	50%	55%	29%

Table 5.2 demonstrates that for all sites evaluated (state and county), advisory speed posting compliance (based on the use of a manual ball-bank device) averaged 29% for county-maintained roads and 58% for State-maintained roads. Since the study sites were randomly selected, advisory speed signs were not always present. At many of these locations, however, advisory speed signs were present but their posted speeds were different than those identified during the field assessment phase of this project. These differences could be due to the use of different ball-bank thresholds or could be due to variations in ball-bank values from using different devices or test vehicles. A common criticism of the ball-bank indicator is how different evaluations of the same location can result in slightly different recommendations.

Table 5.3 demonstrates that if compliance includes speeds posted lower than or equal to recommended values, the overall (state and county) compliance rate would increase from 42% to 54% with higher compliance on State-maintained roads than on county-maintained roads.

Table 5.3: Compliance for advisory speeds "Equal To or Less Than" Oregon policy (all curves)

Based on Manual Ball-bank Readings	State and County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	6	16	17	29	27	36	25	41	48	247
Total Curve Directions	5	14	33	40	72	62	72	68	42	48	456
% Compliance	40%	43%	48%	43%	40%	44%	50%	37%	98%	100%	54%
	State Roads -- Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	0	0	3	7	13	12	20	23	26	37	141
Total Curve Directions	0	1	5	8	26	21	36	50	26	37	210
% Compliance	NA	0%	60%	88%	50%	57%	56%	46%	100%	100%	67%
	County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	6	13	10	16	15	16	2	15	11	106
Total Curve Directions	5	13	28	32	46	41	36	18	16	11	246
% Compliance	40%	46%	46%	31%	35%	37%	44%	11%	94%	100%	43%

Speed plaques should be posted when the recommended advisory speed is greater than 5 mph below the regulatory speed limit. Table 5.4 demonstrates regional compliance for locations that currently have speed plaques as well as locations where plaques are warranted (whether they are present or not). Though many of the sites in both summary columns may be the same, there were several locations where signs were warranted but not present. As shown in Table 5.4, compliance by region dramatically varies.

The observed posted advisory speed values did not appear to vary systematically from those determined using the ball-bank devices. In other words, often about as many posted speeds exceeded the recommendations as did those that were below the recommended values. The actual speed information for each site is not included with this report. The research team performed a matched pairs t-test to determine if there was a statistically significant difference between the observed and recommended speeds and found that the values are statistically similar ($t=0.694$, $df=241$, $P=0.488$). This means that, on average, the posted speeds were about the same as those required using the Oregon policy. Upon individual inspection, however, compliance is approximately 45%; about one-half of the signs actually complied with recommended speeds.

Table 5.5 shows the regional variations in compliance when including speeds posted <u>lower than or equal to</u> the recommended speeds. As was the case before, the compliance rates were greater than the "equal to" compliance in Table 5.4.

Table 5.4: Compliance for advisory speeds "Equal To" Oregon policy at speed plaque locations (current and required)

Based on Manual Ball-Bank Values	Locations with Current Speed Plaques			All Locations where Speed Plaques are Warranted		
	Current Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply	Warranted Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply
Region 1:						
State Roads	26	16	62%	25	15	60%
County Roads	36	13	36%	39	13	33%
All Roads	62	29	47%	64	28	44%
Region 2:						
State Roads	21	9	43%	27	9	33%
County Roads	45	21	47%	43	20	47%
All Roads	66	30	45%	70	29	41%
Region 3:						
State Roads	23	18	78%	35	18	51%
County Roads	20	7	35%	52	7	13%
All Roads	43	25	58%	87	25	28%
Region 4:						
State Roads	20	6	30%	25	6	24%
County Roads	28	5	18%	42	5	12%
All Roads	48	11	23%	67	11	16%
Region 5:						
State Roads	24	13	54%	32	13	41%
County Roads	13	8	62%	34	8	24%
All Roads	37	21	57%	66	21	32%
Total:						
State Roads	114	62	54%	144	61	42%
County Roads	142	54	38%	210	53	25%
All Roads	256	116	45%	354	114	32%

Table 5.5: Compliance for advisory speeds "Equal To or Less Than" Oregon policy at speed plaque locations (current and required)

Based on Manual Ball-Bank Values	Locations with Current Speed Plaques			All Locations where Speed Plaques are Warranted		
	Current Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply	Warranted Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply
Region 1:						
State Roads	26	22	85%	25	18	72%
County Roads	36	22	61%	39	21	54%
All Roads	62	44	71%	64	39	61%
Region 2:						
State Roads	21	17	81%	27	14	52%
County Roads	45	30	67%	43	23	53%
All Roads	66	47	71%	70	37	54%
Region 3:						
State Roads	23	19	83%	35	19	54%
County Roads	20	7	35%	52	7	13%
All Roads	43	26	60%	87	26	30%
Region 4:						
State Roads	20	8	40%	25	8	32%
County Roads	28	16	57%	42	11	26%
All Roads	48	24	50%	67	19	28%
Region 5:						
State Roads	24	17	71%	32	17	53%
County Roads	13	13	100%	34	13	38%
All Roads	37	30	81%	66	30	45%
Total:						
State Roads	114	83	73%	144	76	53%
County Roads	142	88	62%	210	75	36%
All Roads	256	171	67%	354	151	43%

5.3 ANALYSIS FOR MUTCD ADVISORY SPEED RECOMMENDATIONS

The current *MUTCD* recommends the use of a 16-degree ball-bank threshold for all speed categories; however, this threshold recommendation will be modified to a 16-14-12-degree recommendation with the next release of the *MUTCD*.[4] As a result, this project included an evaluation of compliance with the current Oregon policy (previously reviewed) as well as the two *MUTCD* thresholds. Figure 5.1 shows compliance with the three thresholds for State-maintained roads based on the "equal to" compliance category. These values are also based on the manual ball-bank indicator. Similarly, Figure 5.2 depicts compliance for county-maintained roads. The improved compliance for these county roads (based on *MUTCD* criteria) may imply that many of the jurisdictions are already using thresholds other than currently required.

[4] The source of this information is the chair of the Advisory Speed Task Force for the MUTCD, Mr. James Pline.

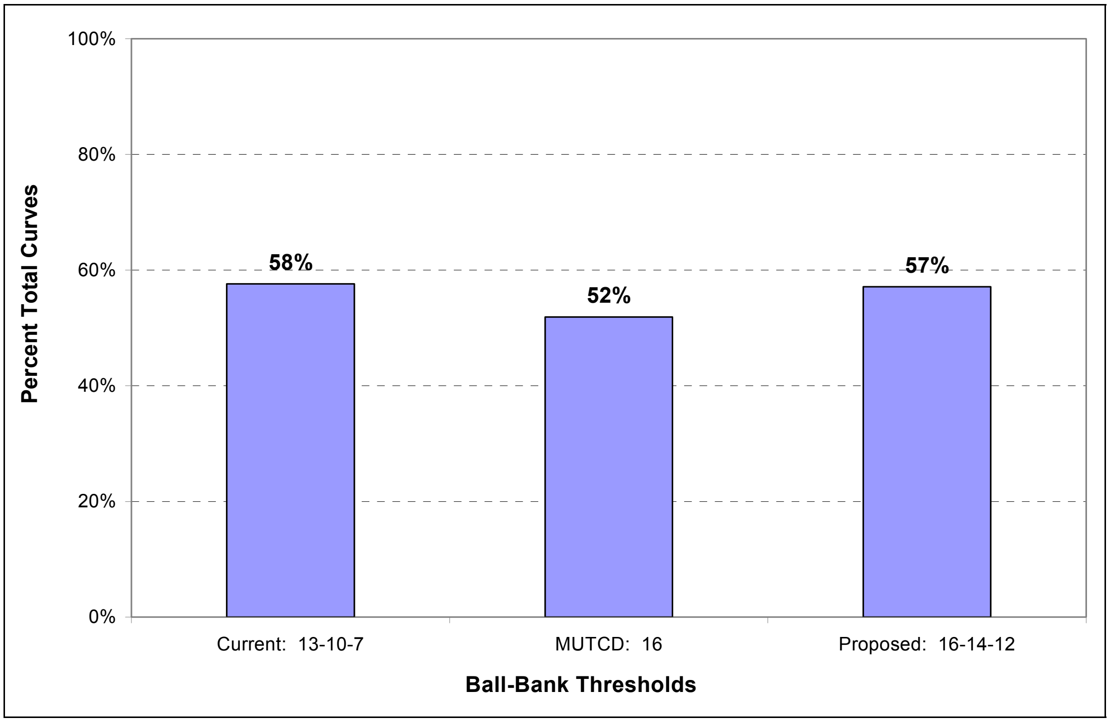

Figure 5.1: Percentage State-maintained road advisory speed compliance for key ball-bank thresholds

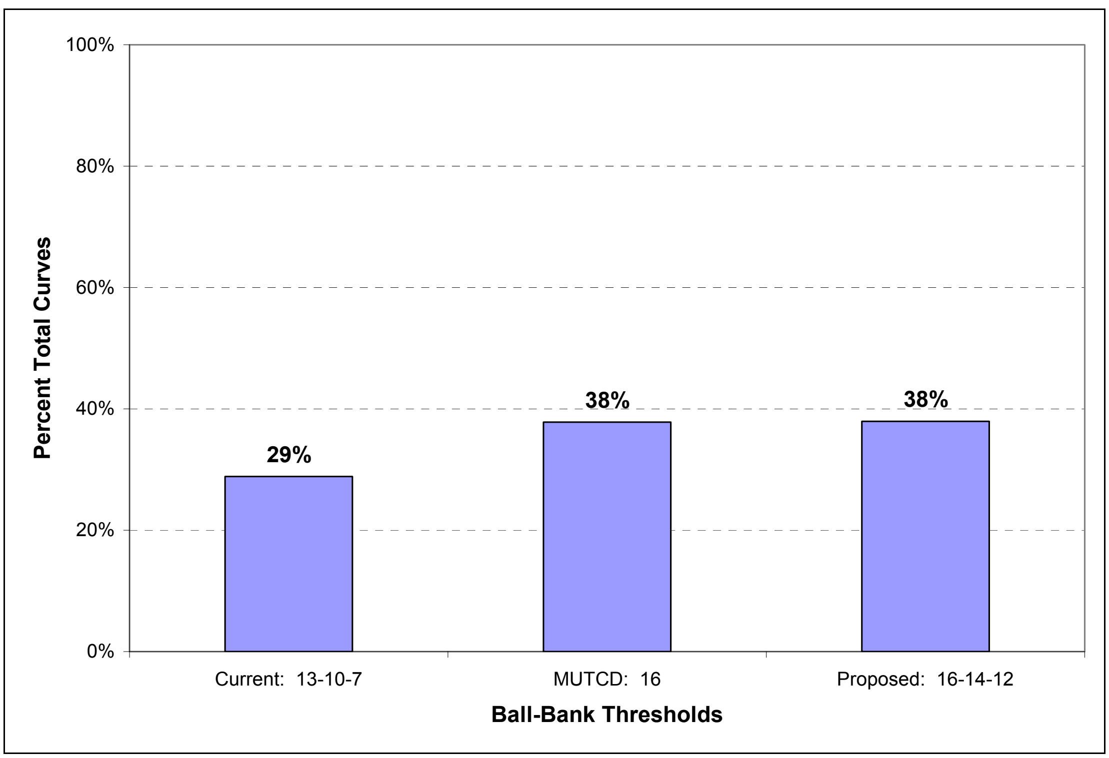

Figure 5.2: Percentage county-maintained road advisory speed compliance for key ball-bank thresholds

The values shown in Table 5.6 depict the specific "equal to" compliance regionally for the State-maintained roads and all three advisory speed thresholds. Table 5.7 similarly demonstrates the "equal to" speed category compliance for county-maintained roads. These tables are the source of information for Figure 5.1 and Figure 5.2. Table 5.8 and Table 5.9 provide information similar to those in Table 5.6 and Table 5.7 but for the "equal to or less than" category. As previously indicated, this compliance category is provided for informational purposes; however, maintaining advisory speed signs posted below the warranted value can undermine the credibility of the sign messages to the driving public.

Table 5.6: "Equal To" threshold compliance for State-maintained roads

Based on Manual Ball-Bank Values	**Advisory Speed Ball-Bank Threshold**		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	27	17	15
Region 2	25	23	26
Region 3	29	27	28
Region 4	23	25	31
Region 5	17	17	20
Statewide Total	121	109	120
	Number of Sites Evaluated		
Region 1	40	40	40
Region 2	46	46	46
Region 3	46	46	46
Region 4	42	42	42
Region 5	36	36	36
Statewide Total	210	210	210
	Percent Sites in Compliance		
Region 1	68%	43%	38%
Region 2	54%	50%	57%
Region 3	63%	59%	61%
Region 4	55%	60%	74%
Region 5	47%	47%	56%
Statewide Total	**58%**	**52%**	**57%**

Table 5.7: “Equal To” threshold compliance on county-maintained roads

Based on Manual Ball-Bank Values	Advisory Speed Ball-Bank Threshold		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	15	19	20
Region 2	29	25	27
Region 3	6	18	13
Region 4	11	20	23
Region 5	10	11	10
Statewide Total	71	93	93
	Number of Sites Evaluated		
Region 1	44	44	44
Region 2	58	58	58
Region 3	52	52	52
Region 4	54	54	53
Region 5	38	38	38
Statewide Total	246	246	245
	Percent Sites in Compliance		
Region 1	34%	43%	45%
Region 2	50%	43%	47%
Region 3	12%	35%	25%
Region 4	20%	37%	43%
Region 5	26%	29%	26%
Statewide Total	**29%**	**38%**	**38%**

Table 5.8: "Equal To or Less Than" compliance for State-maintained roads

Based on Manual Ball-Bank Values	Advisory Speed Ball-Bank Threshold		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	32	40	37
Region 2	33	42	41
Region 3	30	45	43
Region 4	25	40	39
Region 5	21	34	34
Statewide Total	141	201	194
	Number of Sites Evaluated		
Region 1	40	40	40
Region 2	46	46	46
Region 3	46	46	46
Region 4	42	42	42
Region 5	36	36	36
Statewide Total	210	210	210
	Percent Sites in Compliance		
Region 1	80%	100%	93%
Region 2	72%	91%	89%
Region 3	65%	98%	93%
Region 4	60%	95%	93%
Region 5	58%	94%	94%
Statewide Total	**67%**	**96%**	**92%**

Table 5.9: "Equal To or Less Than" threshold compliance on county-maintained roads

Based on Manual Ball-Bank Values	Advisory Speed Ball-Bank Threshold		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	25	40	36
Region 2	38	56	55
Region 3	6	24	18
Region 4	22	44	40
Region 5	15	24	23
Statewide Total	106	188	172
	Number of Sites Evaluated		
Region 1	44	44	44
Region 2	58	58	58
Region 3	52	52	52
Region 4	54	54	53
Region 5	38	38	38
Statewide Total	246	246	245
	Percent Sites in Compliance		
Region 1	57%	91%	82%
Region 2	66%	97%	95%
Region 3	12%	46%	35%
Region 4	41%	81%	75%
Region 5	39%	63%	61%
Statewide Total	**43%**	**76%**	**70%**

As indicated in Section 5.1, at many curve locations advisory speed plaques may not be required if the recommended speed is within 5 mph of the posted speed. Table 5.4 demonstrates that while a total of 256 advisory speed plaque locations occur that the Oregon policy actually merits 354 plaques. In a few instances, plaques are present where they are not required; however, in other locations plaques are not posted where warranted. Table 5.10 and Table 5.11 each provide similar speed plaque compliance information for the proposed *MUTCD* 16-14-12 threshold. As the current Oregon posting procedures are generally more conservative than the recommended future *MUTCD* procedures, many locations that currently have speed plaques may no longer need them. For State-maintained roads, the appropriate locations for speed plaques using this future threshold would require complete removal of some signs (114 current and only 88 needed in future). For county-maintained roads there were 140 signs observed but 183 would be warranted, requiring the addition of signs for these roads.

Table 5.10: Compliance for advisory speeds "Equal To" future 16-14-12 *MUTCD* thresholds at speed plaque locations (current and required)

Based on Manual Ball-Bank Values	Locations with Current Speed Plaques			Locations where Speed Plaques are Warranted		
	Current Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply	Warranted Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply
Region 1:						
State Roads	26	3	12%	18	3	17%
County Roads	36	17	47%	37	17	46%
All Roads	62	20	32%	55	20	35%
Region 2:						
State Roads	21	6	29%	17	6	35%
County Roads	45	16	36%	38	16	42%
All Roads	66	22	33%	55	22	40%
Region 3:						
State Roads	23	6	26%	19	6	32%
County Roads	20	13	65%	52	13	25%
All Roads	43	19	44%	71	19	27%
Region 4:						
State Roads	20	10	50%	16	8	50%
County Roads	26	8	31%	30	8	27%
All Roads	46	18	39%	46	16	35%
Region 5:						
State Roads	24	8	33%	18	8	44%
County Roads	13	0	0%	26	0	0%
All Roads	37	8	22%	44	8	18%
Total:						
State Roads	114	33	29%	88	31	35%
County Roads	140	54	39%	183	54	30%
All Roads	254	87	34%	271	85	31%

Table 5.11: Compliance for advisory speeds "Equal To or Less Than" future 16-14-12 MUTCD thresholds at speed plaque locations (current and required)

Based on Manual Ball-Bank Values	Locations with Current Speed Plaques			All Locations where Speed Plaques are Warranted		
	Current Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply	Warranted Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply
Region 1:						
State Roads	26	25	96%	18	15	83%
County Roads	36	33	92%	37	29	78%
All Roads	62	58	94%	55	44	80%
Region 2:						
State Roads	21	21	100%	17	13	76%
County Roads	45	44	98%	38	35	92%
All Roads	66	65	98%	55	48	87%
Region 3:						
State Roads	23	21	91%	19	16	84%
County Roads	20	18	90%	52	18	35%
All Roads	43	39	91%	71	34	48%
Region 4:						
State Roads	20	18	90%	16	13	81%
County Roads	26	25	96%	30	17	57%
All Roads	46	43	93%	46	30	65%
Region 5:						
State Roads	24	22	92%	18	16	89%
County Roads	13	13	100%	26	11	42%
All Roads	37	35	95%	44	27	61%
Total:						
State Roads	114	107	94%	88	73	83%
County Roads	140	133	95%	183	110	60%
All Roads	254	240	94%	271	183	68%

5.4 COST ESTIMATE TO CONFORM TO FUTURE MUTCD RECOMMENDATIONS

The Oregon Department of Transportation will be faced with a decision of whether to modify current advisory speed posting procedures so that they align with the proposed 16-14-12 threshold recommended for the next *MUTCD* release. Based on the field assessment, there is considerable variation between current advisory speed posting procedures within the state (as evidenced by the minimal compliance to the current Oregon policy). This lack of compliance could be due to jurisdictions that are not informed about Oregon policy, restricted sign and maintenance budgets, or ball-bank equipment variability for posting procedures. Regardless of these factors, as Oregon officials weigh how best to consider the implications of modifying these procedures to match the future recommendations in the *MUTCD* and companion documents, the financial implications of such a change must be considered.

To evaluate this task, the OSU research team acquired general sign costs from ODOT. In addition, in the early stages of this project the research team performed a sign inventory using video records for rural non-freeway State-maintained roads. A few sites were not available for analysis in the statewide video log, but a total of approximately 6,190 miles of rural roads were reviewed for advisory sign placement and location. These roads were not evaluated for advisory sign need, however, so the smaller random sample of State roads generally represents all State-maintained sign needs. The research team was not able to perform a similar video inventory for roads maintained by other jurisdictions.

The randomly sampled State roads were selected in approximately 2-mile segments with a target of 16 sites per ODOT region. This equates to an advisory speed evaluation of approximately 160 miles of State-maintained roads. At several of the 2-mile long corridor locations, more than one curve was evaluated, resulting in a total of 104 curves evaluated for 160 miles studied. Table 5.12 summarizes the total number of common advisory speed signs observed on State-maintained rural roads in Oregon (per the video inventory). To evaluate an approximate distribution of sign types, the final rows in the table depict the percent of signs per speed plaques observed and the average number of signs for every 100 miles, respectively. A total of 7,818 alternative signs occur in conjunction with the 5,940 speed signs, resulting in a state-wide ratio of 1.3 alternative signs for every one speed plaque sign, or on average 2.3 signs (1.3 alternative signs + 1 speed plaque sign) for each plaque location.

Table 5.12: Advisory speed signs on State-maintained rural roads (per video)

Rural Road Type	Length of Roads (miles)	 W1-1	 W1-2	 W1-3	 W1-4	 W1-5	 W1-6	 W1-8	 W13-1
Principal Arterial - Other (Not NHS)	152.84	17	74	9	27	23	0	47	147
Principal Arterial - Other (NHS)	2661.77	69	803	32	288	137	17	427	1080
Minor Arterial	1924.59	233	1103	84	338	252	22	428	1812
Major Collector	1412.47	519	1223	275	435	511	39	294	2811
Minor Collector	34.88	30	13	15	7	20	2	0	88
Local	2.89	2	0	0	0	0	0	3	2
Total:	6189.44	870	3216	415	1095	943	80	1199	5940
Percent Signs Compared to W13-1	--	15%	54%	7%	18%	16%	1.4%	20%	100%
Number Signs per 100 Miles:	--	14	52	7	18	15	1.3	19	96

The cost for replacement of signs will vary dramatically depending on when this replacement occurs, as the price of steel in the United States continues to escalate. As a result, the cost estimate included in this summary is for the year 2007 and should be projected to future year dollars as appropriate. Also, the cost assessment is for State-maintained rural roads only and does not address the county roads and the additional costs that will be associated with any changes in policy.

Table 5.13 shows the summary of the video sign inventory for State-maintained roads (as computed in Table 5.12) followed by the video inventory of the randomly selected State sites used for field analysis in this study. The number of speed plaques (W13-1) in this table represents those observed for the entire corridor length; thus these numbers are larger than the observed speed plaques for the studied curves (as shown in Table 5.4 and Table 5.10). Since corridors were selected in approximate 2-mile segments, many began or ended in a horizontal curve, so this entire curve was not included in the field assessments but any signs in this region are included in the video summary.

Table 5.13 also shows the percentage of various signs compared to the number of W13-1 signs. In general these percentages are similar to those observed statewide. There are approximately 1.45 alternative signs for every one W13-1 sign in the study corridors. On average, therefore, there are approximately 2.5 signs for every speed plaque. This value compares to the 2.3 signs estimated for the statewide values. Since the research team for this project evaluated appropriate advisory speed values but did not evaluate the companion placement of alternative signs, a crude estimate of 2.5 signs per every speed plaque sign will be used to estimate costs for future Oregon compliance on State-maintained roads.

Table 5.13: Advisory speed signs on State-maintained study corridors (per video)

	Length (miles)	W1-1	W1-2	W1-3	W1-4	W1-5	W1-6	W1-8	W13-1
Rural Roads Inventoried with Video:									
Total Signs	6189.44 miles	870	3216	415	1095	943	80	1199	5940
Percent Signs Compared to W13-1	--	15%	54%	7%	18%	16%	1.4%	20%	100%
Video Inventory for Randomly Selected Study Sites (also included in total sign list above):									
Region 1	34.1	21	39	3	7	3	2	61	67
Region 2	30.0	10	22	3	0	6	2	0	40
Region 3	32.8	5	31	1	5	14	1	12	52
Region 4	32.3	4	28	2	6	1	0	0	33
Region 5	32.5	5	36	1	7	9	1	8	51
Total:	161.7	45	156	10	25	33	6	81	243
Percent Signs Compared to W13-1	--	19%	64%	4%	10%	14%	2.5%	33%	100%

An approximate cost can be determined based on the following three general cost categories:

- Complete removal of all signs;
- Re-use posts but replace signs; and
- New sign placement.

Table 5.14 summarizes costs for these three general signing categories. These costs range from $140 per site for complete removal of signs up to $500 per site for new sign placement. For the State-maintained locations, the "New Sign Placement" category will be rare since the State road sites that warrant advisory speed plaques will decrease with the new thresholds. This category is provided as a guide for potential additional costs for the county road locations not included in this cost summary.

Table 5.14: Estimated cost of improvements

Category	Item	Unit Cost	Quantity	Total Item Cost	Total Category Cost
Removal of Signs					
	Labor	$35/hour	4 hours*	$140	
				Estimated Cost for Sign Removal:	***$140***
Re-use Posts but Replace Signs					
	Sign Cost	$70/sign	2.5 signs	$175	
	Labor	$35/hour	4 hours*	$140	
				Estimated Cost to Replace Signs on Existing Posts:	***$315***
New Sign Placement					
	Sign Cost	$70/sign	2.5 signs	$175	
	Posts	$46/post	2.5 posts	$115	
	Labor	$35/hour	6 hours*	$210	
				Estimated Cost for New Sign Placement:	***$500***

*Labor costs assume a 2-person crew; 4 hours would be 2 hours for each person.

The values depicted in Table 5.10 were used as a basis for this cost assessment. For State-maintained roads, sign removal is expected for 23% of the sites ((114 current – 88 required) / 114 current x 100%). This will result in 1,367 locations (5,940 (W13-1 signs per Table 5.12) x 0.23) where signs can be estimated for removal. The associated cost for this category for Oregon State-maintained roads would then be $191,380 (1,367 locations x $140 per site). These estimates do not include transportation costs to and from each site. Following removal of these signs, approximately 4,573 speed plaque locations will remain (5,940 – 1,367).

Locations where signs should be replaced but where posts can be re-used can be estimated based on the number of current advisory speed plaques that do not comply with the future *MUTCD* thresholds. As shown in Table 5.10, 71% (100% - 29%) of the current speed plaque locations do not meet the future *MUTCD* threshold. As a result, 3,247 signs (4,573 remaining sign locations x 0.71) would need to be replaced for a total approximate cost of $1,022,805 (3,247 locations x $315 per site). This cost does not include transportation expenses and assumes the re-use of existing posts.

The total estimated cost, in 2007 dollars, for upgrading the current State-maintained roads to comply with the future *MUTCD* advisory speed posting thresholds would be approximately $1,214,185 ($191,380 + $1,022,805). Fortunately, the compliance period recommended for the new *MUTCD* thresholds is 10 to 15 years, so this cost could be distributed over multiple years. This expected additional investment of $1.214 million applies only to State roads and does not include the cost for upgrading signs on county roads.

5.5 COMPUTATIONAL APPROACH TO ADVISORY SPEED ASSESSMENT

Dating back to the late 1930's, researchers have used Newton's principles as a basis for identifying appropriate advisory speed values. For sites where the actual lateral resistance (friction factor) is unknown, researchers have used the ball-bank indicator as a means for capturing the friction resistance, the vehicle body roll influence, and the superelevation influence on vehicle performance on a horizontal curve. In this study, the research team used the ball-bank indicators to evaluate specific curve locations, but a convenient computational approach for identifying appropriate advisory speeds could significantly simplify the process. A common criticism of the ball-bank approach is variability between multiple runs or multiple test drivers. As observed in this study, road surface imperfections often contribute to unstable ball-bank readings.

Since the use of scaled aerial maps for approximating the radius for existing horizontal curves is now feasible, if the superelevation can be determined then an advisory speed can be estimated using a modified version of Equation 2-3 in Chapter 2. As previously indicated, this referenced equation is based on Newton's Second Law of Motion which assumes a constant mass for the object in motion. The improved suspensions of modern vehicles may redistribute mass as a vehicle traverses a curve, resulting in a computed "maximum safe speed" that may actually be too conservative due to this improved technology and its influence on vehicle handling around the curve.

The modified equation for estimating this maximum safe speed is as follows:

$$V = \sqrt{15R(f + 0.01e)} \qquad \textbf{(5-1)}$$

where:

- e ≡ Superelevation of road surface (percent),
- f ≡ Lateral or Side Friction Factor,
- V ≡ Velocity (mph), and
- R ≡ Horizontal curve radius (feet).

By using the friction factors estimated by Carlson and Mason (*1999*) and shown in Table 2.1, it is possible to develop a set of modified curves similar to those depicted in Figure 2.2. Since advisory speeds should be posted in 5 mph increments, the actual recommended advisory speed would then be the closest speed divisible by 5 mph that does not exceed this computed maximum safe speed. Figure 5.3 shows an example of a curve with a 6% superelevation. The thin curved line in the figure represents the computed "maximum safe speed" using Equation 5-1 while the thicker, stepped line represents the companion advisory speed (in 5 mph intervals) for the same radius. A procedure that automates advisory speed computations is desirable; however, since the vehicle is not rigid, resulting in a re-distribution of its mass, it is important that future research correlate field-observed speeds to those obtained using this computational approach, and this violation of Newton's Second Law should be addressed.

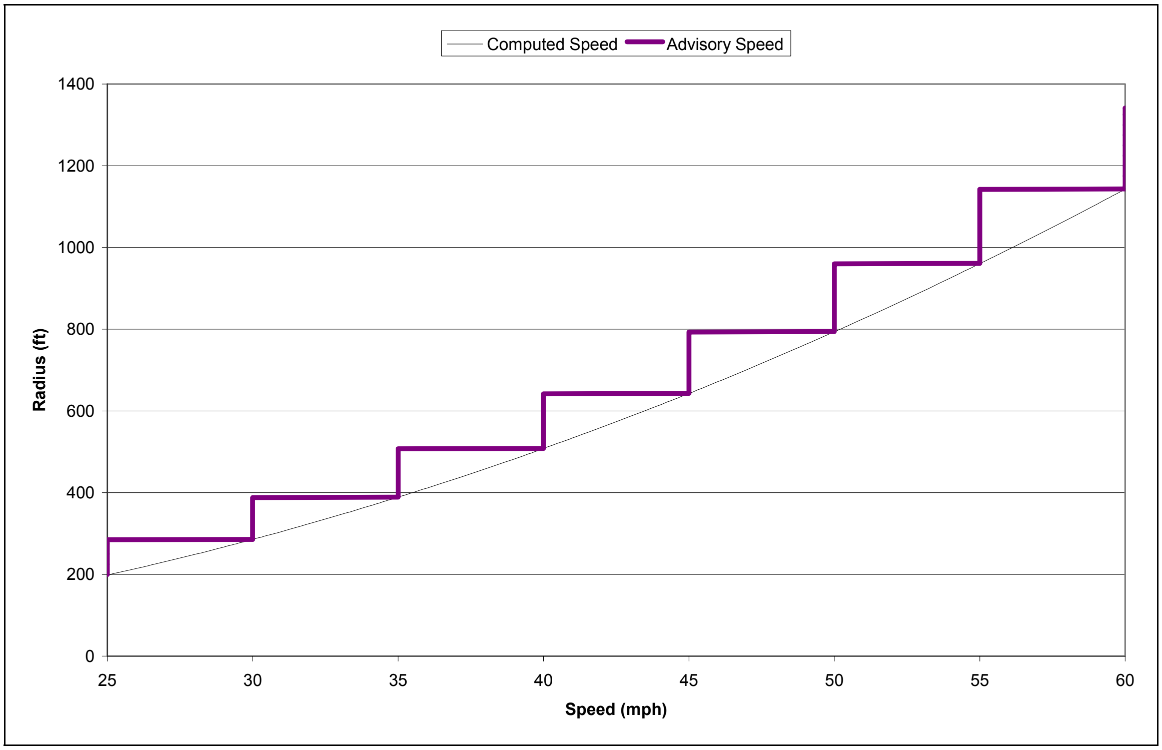

Figure 5.3: Computed and advisory speed for 6% superelevation

The advisory speed task force for the National Committee on Uniform Traffic Control Devices has suggested that the proposed 16-14-12 *MUTCD* threshold represents approximately 8 to 10 mph that the average driver currently travels over existing posted speeds. For this study, the research team performed a matched pairs t-test and determined that the current Oregon policy results in speeds that are statistically larger (by approximately 5 mph) than those determined using the computational method ($t=9.03$, $df=397$, $P<0.005$). Similarly, the proposed 16-14-12 *MUTCD* threshold speeds are statistically larger (by approximately 9 mph) than those determined using the computational method ($t=16.18$, $df=358$, $P<0.005$). This second observation is consistent with the National Committee's observations.

These evaluations suggest that the current computation method provides conservative values; however, it could be modified with a potential additive component, to more closely equate to the current or future thresholds. An advantage to a computational approach is stability of results, as an analyst would get consistent recommendations without having to consider road imperfections and the influence those imperfections have on ball-bank accuracy.

5.6 ASSESSMENT OF MANUAL VERSUS DIGITAL BALL-BANK DEVICE RESULTS

As a general rule, the ball-bank readings obtained by the manual versus the digital ball-bank devices resulted in recommended advisory speeds that were the same or similar (usually within 5 mph). The summary statistics provided throughout this chapter have been based on the manual ball-bank device; however, similar summary statistics were developed for the digital ball-bank device. These summaries are provided in Appendix D of this report. In general, the digital ball-bank device seemed to be slightly more sensitive than the dampened manual ball-bank device. Upon inspection of recommended advisory speeds at individual sites, it is difficult to observe a systematic trend regarding the performance of the two ball-bank devices. Since these devices were mounted together, the vehicle type or driver influences are not factors. The recommended advisory speeds for the manual versus the digital ball-bank devices are plotted for the Oregon Threshold in Figure 5.4. Similarly, the proposed 16-14-12 *MUTCD* threshold recommended advisory speeds are depicted in Figure 5.5. There is considerable scatter among the observed data; however, when a polynomial trend line is plotted it is clear that the digital ball-bank device systematically appears to recommend a slightly lower advisory speed for the same curve radius than that indicated by the manual ball-bank device.

To further determine differences between the manual and digital ball-bank devices, the research team performed two matched pairs t-tests. The first test evaluated whether the digital device provided statistically significant lower advisory speed recommendations than its manual ball-bank counterpart for the Oregon policy speed recommendations. This analysis determined that the lower recommended advisory speeds for the digital device compared to the manual device was statistically significant ($t=8.83$, $df=402$, $P<0.005$). Similarly, a paired t-test for the 16-14-12 *MUTCD* advisory speed recommendations showed that the digital device consistently predicted statistically significant lower advisory speeds than its manual counterpart ($t=6.45$, $df=361$, $P<0.005$).

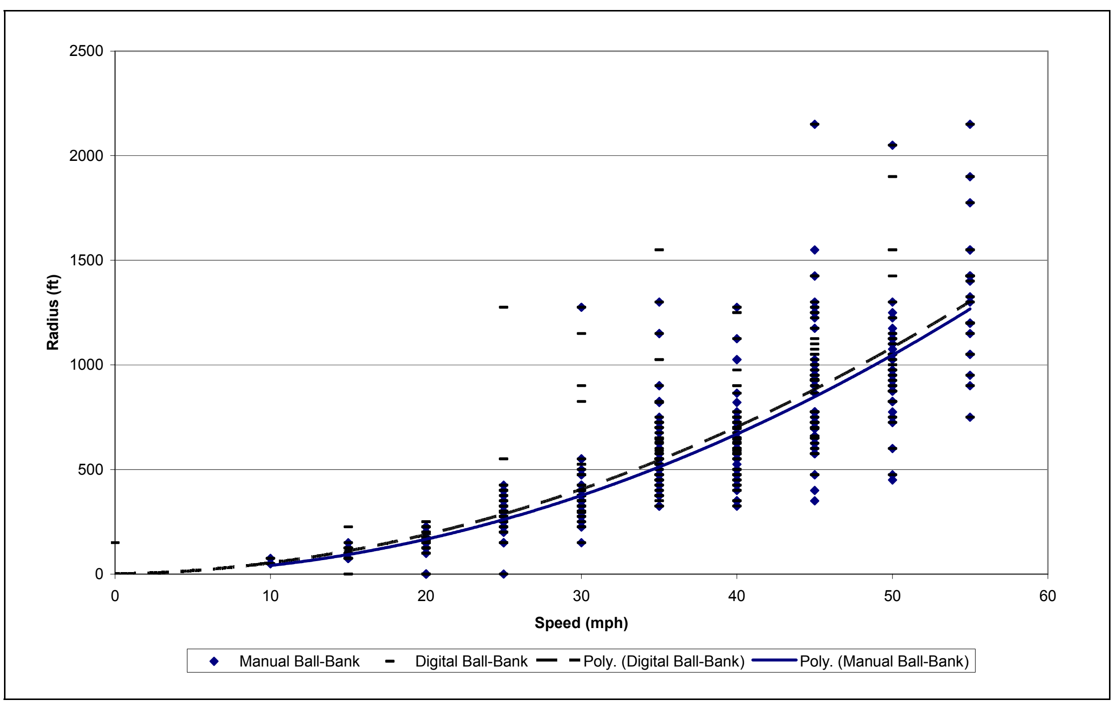

Figure 5.4: Manual vs. digital ball-bank recommended speeds for current Oregon policy

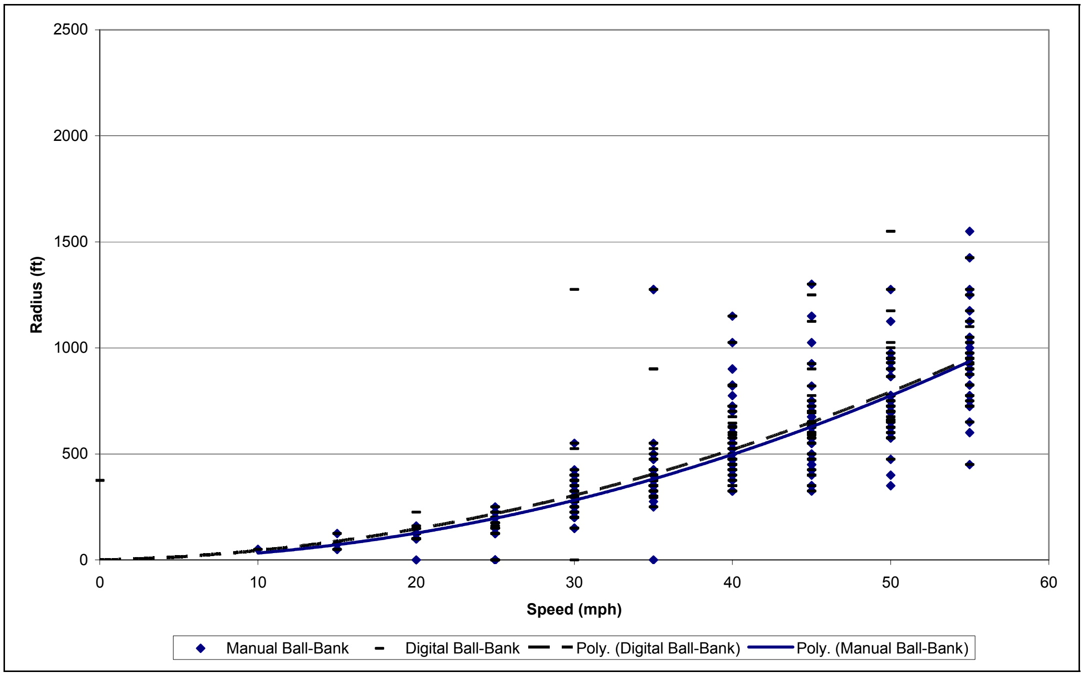

Figure 5.5: Manual vs. digital ball-bank recommended speeds for MUTCD 16-14-12 threshold

5.7 LATERAL SIGN PLACEMENT

Often the correct sign type, message, and sign frequency can be positioned but the sign is not placed in such a way that the driver can see the sign, read it and respond. One common issue is that the lateral placement of the sign may not conform to the recommended offset requirements for roads with and without shoulders. Table 5.15 demonstrates that approximately 35% of the lateral placement for signs does not comply with offset requirements as stipulated in the *MUTCD* 2003 (Revision One). Any relocation of sign posts as a result of inadequate lateral placement was not included in the earlier cost estimate summary for State signs. It is recommended, however, that this lateral placement issue be evaluated at each site when future signs are upgraded and replaced.

Table 5.15: Lateral sign placement and percent non-compliance

	Region 1	Region 2	Region 3	Region 4	Region 5	Total
Signs < 6' offset	15	18	12	5	9	59
**Total Signs	48	60	35	60	44	247
Not Conforming	31%	30%	34%	8%	21%	24%
	Region 1	Region 2	Region 3	Region 4	Region 5	Total
Signs > 12' offset	4	5	3	12	3	27
**Total Signs	48	60	35	60	44	247
Not Conforming	8%	8%	9%	20%	7%	11%
	Region 1	Region 2	Region 3	Region 4	Region 5	Total
Signs <6 or >12'	19	23	15	17	12	86
**Total Signs	48	60	35	60	44	247
Not Conforming	40%	38%	43%	28%	27%	35%

* Measured according to *MUTCD* 2003 revision #1

** Total number of signs tested in this study with values available for both lateral placement and shoulder width.

5.8 SUMMARY OF FINDINGS

This chapter demonstrated that the State-maintained roads included in this study complied with Oregon advisory speed policies at approximately 58% of the sites while county-maintained roads had a much lower observed compliance (29%). For locations with speed plaques present, county-maintained road compliance improved (suggesting many sites need signs that are not currently in place).

The Oregon policy, the 16-degree *MUTCD* guidance, and the 16-14-12 degree *MUTCD* future recommendations were all over 50% compliance for State roads. County road compliance for the *MUTCD* recommendations was 38%, but much lower (29%) for the Oregon policy.

For Oregon to convert to the future 16-14-12 *MUTCD* recommendations, a cost of approximately $1.2 million (in year 2007 dollars) can be expected for State-maintained roads. County cost estimates were not performed but would likely be comparable to or greater than those needed for the State roads.

Other findings in this chapter included a consistent difference in advisory speed recommendations based on ball-bank devices, with digital devices recommending slightly lower advisory speeds than those proposed based on manual ball-bank devices (a statistically significant difference).

This chapter included an evaluation of the current computational approach for advisory speeds and found that it provides conservative estimates of maximum safe speeds but appears promising as a tool if modified for vehicle suspension assumptions.

Finally, this chapter reviewed lateral sign placement at the study sites where both shoulder width and sign offset information was available. Approximately 35% of the reviewed signs did not conform to current lateral sign placement criteria. This non-conformance may render these signs ineffective, as their visibility may be restricted.

6.0 SUMMARY AND CONCLUSIONS

6.1 SUMMARY

This report has identified common issues regarding the identification of appropriate advisory speed values at horizontal curve locations in the United States. Chapter 2 reviewed the literature leading up to current advisory speed assumptions and practices. The most common methods for estimating the maximum safe speed in a horizontal curve are the ball-bank indicator approach, the analytical approach, or the safe speed curves approach. The relevant literature also included supplemental methods such as use of the 85^{th} percentile speed, various engineering studies, driver perception, or simple engineering judgment. The specific sign types and placement of the signs have been historically based on human factor research in traffic engineering.

Chapter 3 of this report summarizes a state-of-the-practice based on an inventory of state department of transportation web sites, email correspondence with each Oregon County, and a sample email correspondence with several Oregon cities. Across the United States, at least five different ball-bank threshold scenarios are actively in use for determination of the maximum safe speed at horizontal curves. These thresholds range from values as low as 7 degrees on the ball-bank indicator to values as high as 16 degrees. This observation confirms the perception expressed frequently in the literature that the advisory speed posting procedures in the United States are inconsistent. Within the state of Oregon, there remains considerable variability on posting procedures, even though the ODOT procedure is a legal requirement.

Chapter 4 of this report provides an overview of the data collection efforts. This summary includes the sampling procedure, video inventory of State-maintained rural highways, field data collection efforts, data collection challenges, and the horizontal curve radius estimation technique.

Chapter 5 summarized the data analysis and included an assessment of compliance to the current Oregon advisory speed policy for both State and county roads. This chapter further separates the compliance assessment into sites that currently display speed plaques and sites where speed plaques are warranted (and may or may not be present). Compliance varies dramatically across ODOT regions and among agencies.

Chapter 5 further evaluated *MUTCD* current and future thresholds and compliance for these target values. Finally, Chapter 5 includes a projected cost estimate, evaluation of a computational approach, assessment of the ball-bank devices, and summary of lateral placement of signs.

6.2 CONCLUSIONS

The analysis showed that under the current Oregon policy State-maintained roads performed better (58%) than county roads (29%), with an overall statewide compliance of 42%. Speed plaques were present for most State-maintained roads where warranted, but several county roads did not have these required signs. This compliance also varied dramatically by geographic region.

Approximately $1.2 million (in year 2007 dollars) is the estimated amount needed to bring State roads into compliance with the future *MUTCD* recommendations. A cost estimate for county roads could not be performed but is likely to meet or exceed that required for the State roads.

6.3 FUTURE RESEARCH NEEDS

The findings of this study verified that the posting of advisory speeds is not always consistent across Oregon. Many locations have signs, but the recommended speed or sign placement is suspect. As a result, several future research needs are apparent as a result of this study.

Many locations have signs missing or with incorrect advisory speed values (based on the ball-bank readings of this study). What this research project could not determine is if these signing issues directly affect safety. A research study that includes an evaluation of crash history at these corridors to determine if posting procedures are directly associated with crashes is strongly recommended. In addition, it would be helpful at a subset of the advisory speed sites to perform speed studies to determine the extent to which drivers comply with the recommended speeds.

This research effort also evaluated curves located within two-mile corridor segments, but it did not assess curve position relative to the overall road geometry. For example, are conditions at sharp curves more dangerous if the curve is isolated or if it is positioned following a long tangent? Do curves located in a series of sharp horizontal curves have better compliance or safety records? This additional research effort would entail field speed compliance studies as well as historic crash analysis.

Specific lateral and longitudinal sign placement is required in the *MUTCD*, yet assessment of sign lateral placement in this study found approximately 35% of the advisory speed signs were placed with the required lateral offset criteria. Further evaluation of placement for all advisory signs is therefore recommended.

Finally, the use of the ball-bank indicator demonstrated considerable variation based on road surface conditions, type of indicator used, and road cross-slope. The authors briefly evaluated how the advisory speed recommendations obtained using the computational approach commonly used for advisory speeds compared to the ball-bank values. It appears that such a computational approach will provide more consistent results; however, the historic approach merits improvement. Further evaluation of a computational method could lead to an evaluation procedure that is less time-consuming and with potentially greater reliability. In addition, researchers at the Texas Transportation Institute have recently completed a project evaluating this issue for Texas roads. It could be very useful to evaluate their procedure and compare how their recommended method would determine advisory speeds for Oregon roads.

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APPENDICES

APPENDIX A: SAMPLE DATA COLLECTION FORMS

Figure A.1: Video Data Collection Form

Advisory Speed and Warning Sign Location Investigation. Functional Classification: Major Arterial Non-NHS
Date Captured:
Data Collected By:
Data Collection Date:
Highway No:
Highway Name:
Route No.:
Direction:
Speed Limit:
Segment Length: Beginning M.P.: Ending M.P.:

Mile Point (miles)	Warning Signs																				Advisory
	W1-1		W1-1a		W1-2		W1-2a		W1-3		W1-4		W1-5		W1-6		W1-8		Slow	Others	speed (mph) W13-1
0	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R			
0.00																					

Observations/Comments:

Figure A.2: Blank Field Data Collection Form

Oregon State University / Oregon Department of Transportation
Advisory Speed and Warning Sign Data Collection Form:

Date Captured:		**Functional Class (1-5):**[1]	
Data Collected By:		**Road Surface Type (1-3):**[2]	
Climate/weather:		**Road condition (1-5):**[3]	
Highway No:		**Pavement Width (ft.):**[4]	
Highway Name:		**Shoulder Width (ft.):**[5]	
Route No.:		**Beginning M.P.:**	
Direction (N-S or E-W):		**Ending M.P.:**	
Speed Limit (mph):		**Segment Length:**	

P.C. & P.T. Milepoints - Traveling East/South:[6]				**Start Time:**	
P.C. & P.T. Waypoints - Traveling East/South:[7]				**End Time:**	
		Radius (ft.):[8]		**Duration:**	

Direction #1:			
Curve # (e.g. 1/1, 1/2, etc.):		Curve Direction (L/R):	
P.C. Latitude/Longitude - Traveling East/South:[9]			
POSTED Advisory Speed? (If yes, mph):		Isolated? (If yes, miles):	
Warning/Advisory Curve Sign? (If yes, describe):[10]		Addl Signs?[10]	
Color/Reflectivity (1-3):[11]		Sign Height WRT Paved Edge (ft.):[14]	
Sign Visibility (1-3):[12]		Sign Dist. From Outer Travel Lane (ft.):	
Sign Dist. from P.C.:[13]		Sign - Waypoint:	
Number of Travel Lanes in Direction #1:		Latitude (N):	
Width of Travel Lanes in Direction #1 (ft.):		Longitude(W):	

Test Runs - Direction #1[15]			Ball-bank reading (°)	
Direction:	Trial No.	Trial Speed	Manual:	Digital:
	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			

CL[16] Sketch	Superelevation[16]	
	Location	Slope (%)
	Approach:	
	In curve:	
	Departure:	

Avg. Vertical Grade (%)[17]	
Approach:	
In curve:	
Departure:	

Suggested Advisory Speeds[18]				
Poss. Standards:	Speed:	Avg. Manual (°):	Speed:	Avg. Dig. (°):
1				
2				
3				
4				
5				

Ball Bank Standards (#/°/MPH):				
1	7,**10**,13	30	35-55	60
2	10,**12**,14	30	35-55	60
3	10,**12.5**,15	30	35-55	60
4	**10**	30	35-55	60
5	**16**	30	35-55	60

= Further directions available, see supplemental information sheet

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Direction #2:					
Curve # (e.g. 1/1, 1/2, etc.):		Curve Direction (L/R):			
P.T. Latitude/Longitude - Traveling East/South:[9]					
POSTED Advisory Speed? (If yes, mph):			Isolated? (If yes, miles):		
Warning/Advisory Curve Sign? (If yes, describe):[10]			Addl Signs?[10]		
Color/Reflectivity (1-3):[11]		Sign Height WRT Paved Edge (ft.):[14]			
Sign Visibility (1-3):[12]		Sign Dist. From Outer Travel Lane (ft.):			
Sign Dist. from P.C.:[13]		Sign - Waypoint:			
Number of Travel Lanes in Direction #2:			Latitude (N):		
Width of Travel Lanes in Direction #2 (ft.):			Longitude(W):		

Test Runs - Direction #2[15]			Ball-bank reading (°)	
Direction:	Trial No.	Trial Speed	Manual:	Digital:
	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			

CL[16] Sketch	Superelevation[16]	
	Location	Slope (%)
	Approach:	
	In curve:	
	Departure:	

Avg. Vertical Grade (%)[17]	
Approach:	
In curve:	
Departure:	

Suggested Advisory Speeds[18]				
Poss. Standards:	Speed:	Avg. Manual (°):	Speed:	Avg. Dig. (°):
1				
2				
3				
4				
5				

Ball Bank Standards (#/°/MPH):				
1	7,**10**,13	30	35-55	60
2	10,**12**,14	30	35-55	60
3	10,**12.5**,15	30	35-55	60
4	**10**	30	35-55	60
5	**16**	30	35-55	60

Instructions, Notes, or Comments:[20]

Vert. Pavement Edge Drop-Off (in):[19]	

= Further directions available, see supplemental information sheet

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Figure A.3: Completed Data Collection Form

Oregon State University / Oregon Department of Transportation
Advisory Speed and Warning Sign Data Collection Form:

Date Captured:	September 21, 2006	**Functional Class (1-5):**[1]	4
Data Collected By:	Joshan Rohani/Nick Richards	**Road Surface Type (1-3):**[2]	1
Climate/weather:	40/Overcast	**Road condition (1-5):**[3]	2
Highway No:	*Intentionally Blank*	**Pavement Width (ft.):**[4]	28.0 ft
Highway Name:		**Shoulder Width (ft.):**[5]	0 ft
Route No.:		**Beginning M.P.:**	28.70
Direction (N-S or E-W):	N-S	**Ending M.P.:**	30.80
Speed Limit (mph):	55 MPH	**Segment Length:**	2.10 miles

P.C. & P.T. Milepoints - Traveling East/South:[6]	PC = 29.1	PT = 29.2		**Start Time:**	5:20
P.C. & P.T. Waypoints - Traveling East/South:[7]	# 101	# 102		**End Time:**	6:00
		Radius (ft.):[8]	100 ft	**Duration:**	0:40

Direction #1:	**SOUTH**				
Curve # (e.g. 1/1, 1/2, etc.):	1/1	Curve Direction (L/R):		R	
P.C. Latitude/Longitude - Traveling East/South:[9]					
POSTED Advisory Speed? (If yes, mph):	Y	20 MPH	Isolated? (If yes, miles):		N
Warning/Advisory Curve Sign? (If yes, describe):[10]	Y	W1-1	Addl signs?[10]		
Color/Reflectivity (1-3):[11]	2	Sign Height WRT Paved Edge (ft.):[14]			6. ft
Sign Visibility (1-3):[12]	1	Sign Dist. From Outer Travel Lane (ft.):			11. ft
Sign Dist. from P.C.:[13]	210 ft	Sign - Waypoint:		# 103	
Number of Travel Lanes in Direction #1:	1		Latitude (N):		
Width of Travel Lanes in Direction #1 (ft.):	13.0 ft		Longitude(W):		

Test Runs - Direction #1[15]

Direction:	Trial No.	Trial Speed	Ball-bank reading (°) Manual:	Digital:
S	1	20 MPH	13.5 °	13.95 °
S	2	20 MPH	13. °	12.64 °
S	3	20 MPH	12.5 °	12.52 °
S	4	25 MPH	20.5 °	20.40 °
S	5	15 MPH	5.5 °	5.32 °
S	6	15 MPH	5. °	4.98 °

CL[16] Sketch

Superelevation[16]	
Location	Slope (%)
Approach:	-1.5%
In curve:	13.0%
Departure:	2.0%

Avg. Vertical Grade (%)[17]	
Approach:	-5.0%
In curve:	-5.5%
Departure:	-4.0%

Suggested Advisory Speeds[18]

Poss. Standards:	Speed:	Avg. Manual (°):	Speed:	Avg. Dig. (°):
1	15 MPH	5.3 °	15MPH	5.15 °
2	15 MPH	5.3 °	15MPH	5.15 °
3	15 MPH	5.3 °	15MPH	5.15 °
4	15 MPH	5.3 °	15MPH	5.15 °
5	20 MPH	13. °	20MPH	13.04 °

Ball Bank Standards (#/°/MPH):

1	7,**10**,13	30	35-55	60
2	10,**12**,14	30	35-55	60
3	10,**12.5**,15	30	35-55	60
4	**10**	30	35-55	60
5	**16**	30	35-55	60

= Further directions available, see supplemental information sheet

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Direction #2:	NORTH				
Curve # (e.g. 1/1, 1/2, etc.):	1/1	Curve Direction (L/R):		L	
P.T. Latitude/Longitude - Traveling East/South:[9]					
POSTED Advisory Speed? (If yes, mph):		Y	20 MPH	Isolated? (If yes, miles):	N
Warning/Advisory Curve Sign? (If yes, describe):[10]		Y	W1-1	Addl signs?[10]	
Color/Reflectivity (1-3):[11]	2		Sign Height WRT Paved Edge (ft.):[14]		7 ft
Sign Visibility (1-3):[12]	1		Sign Dist. From Outer Travel Lane (ft.):		9 ft
Sign Dist. from P.C.:[13]	230 ft		Sign - Waypoint:	# 104	
Number of Travel Lanes in Direction #2:		1		Latitude (N):	
Width of Travel Lanes in Direction #2 (ft.):		13.0 ft		Longitude(W):	

Test Runs - Direction #2[15]			Ball-bank reading (°)	
Direction:	Trial No.	Trial Speed	Manual:	Digital:
N	1	20 MPH	10.5 °	11.38 °
N	2	20 MPH	11. °	12.31 °
N	3	20 MPH	11. °	11.84 °
N	4	25 MPH	18. °	18.60 °
N	5	15 MPH	5. °	4.23 °
N	6	15 MPH	5. °	6.36 °

CL[16] Sketch

Superelevation[16]	
Location	Slope (%)
Approach:	2.0%
In curve:	-12.5%
Departure:	2.0%

Avg. Vertical Grade (%)[17]	
Approach:	4.0%
In curve:	5.5%
Departure:	5.0%

Suggested Advisory Speeds[18]				
Poss. Standards:	Speed:	Avg. Manual (°):	Speed:	Avg. Dig. (°):
1	15 MPH	5. °	15MPH	5.30 °
2	20 MPH	10.8 °	20MPH	11.84 °
3	20 MPH	10.8 °	20MPH	11.84 °
4	15 MPH	5. °	15MPH	5.30 °
5	20 MPH	10.8 °	20MPH	11.84 °

Ball Bank Standards (#/°/MPH):				
1	7,**10**,13	30	35-55	60
2	10,**12**,14	30	35-55	60
3	10,**12.5**,15	30	35-55	60
4	**10**	30	35-55	60
5	**16**	30	35-55	60

Instructions, Notes, or Comments:[20]

Vert. Pavement Edge Drop-Off (in):[19] 0.0 in

THIS USE OF A W1-1 CURVE SIGN DOES NOT SEEM ADEQUATE FOR THIS 180 DEG. CURVE.

13' IS THE ROADWAY WIDTH FOR THE CURVE ONLY.

TYPICAL LANE WIDTH = 11'

= Further directions available, see supplemental information sheet

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APPENDIX B: DATA COLLECTION INSTRUCTIONS

Data Collection Form – Supplemental Information

Advisory Speed Data Collection Form – Supplemental Information:

6. **Functional Class:** The functional classification for each site should be recorded on the data collection form. For county roadways, these classifications shall be determined by review of county roadway maps, which are provided on the ODOT website. For State highways, these classifications shall be found in the ODOT road inventories. The codes for each classification should be noted on the data collection form as follows:
   4. Local Road
   5. Minor Collector
   6. Major Collector
   7. Minor Arterial
   8. Principal/Major Arterial

7. **Road Surface Type:** The roadway surface type for each site should be recorded on the data collection form. The codes for each surface type should be noted as follows:
   9. Asphalt Cement
   10. Concrete Cement
   11. Other Pavement (oil, tar, etc.)

8. **Road Condition:** The road condition for each site should be recorded on the data collection form. The codes which correspond to the condition of the surface and overall roadway structure should be noted as follows:
   12. Relatively new pavement without any noticeable cracking, potholes, dips, or vibrations when passed over in a vehicle
   13. Relatively new pavement with minor cracking or dips that cause minor vibrations when passed over in a vehicle
   14. Somewhat fatigued pavement with any combination of cracking, potholes, or dips that cause vibrations when passed over in a vehicle
   15. Fatigued pavement with any combination of major cracking, potholes, or dips that cause some instability when passed over in a vehicle
   16. Severely fatigued pavement with major structural issues including cracking, potholes, or dips that cause serious instability when passed over in a vehicle.

9. **Pavement Width:** The value provided for pavement width is the overall dimension (in feet) from one edge of the roadway to the other, including all lanes and shoulders in-between.

10. **Shoulder Width:** The value provided for shoulder width (in feet) is representative of both sides of the roadway, unless specified differently.

11. **P.C. & P.T. Mile Points-Traveling East/South:** The mile points shall be recorded for the point of curvature (P.C.) entering each curve and the point of tangent (P.T.) exiting each curve involved in the study. These values can be obtained simply by using the vehicle's odometer or trip-set function.

12. **P.C. & P.T. Waypoints – Traveling East/South:** Whenever possible, waypoints (data points stored on a GPS unit, that can be accessed at a later time, and provide information such as latitude and longitude) should be stored on a GPS unit, and the ID number should be recorded on the data collection sheet. These points should be provided for the point of curvature (P.C.) entering each curve and the point of tangent (P.T.) exiting each curve involved in the study.

13. **Radius:** After site data collection is complete, follow the radius calculation directions and record the radius for each curve to the nearest 25 feet.

14. **P.C. & P.T. Latitude/Longitude – Traveling East/South:** Whenever possible, the latitude and longitude shall be provided for the point of curvature (P.C.) entering each curve and the point of tangent (P.T.) exiting each curve involved in the study. These values can be found using a GPS unit, or other means available. It is acceptable for waypoints to be stored on the GPS unit for later review instead of listing latitude and longitude for each curve.

15. **Warning/Advisory Curve Sign? (If yes, describe):** If a warning/advisory curve sign is present at the sight, it should be recorded on the data collection form and described by their associated MUTCD reference code. Some standard signs are shown below with their reference codes. If the sign present at the sight is not on this list, give a brief description of the sign with a quick sketch.

									
W1-1	**W1-1a**	**W1-2**	**W1-2a**	**W1-3**	**W1-4**	**W1-5**	**W1-6**	**W1-8**	**W42-8**

16. **Color/Reflectivity:** If a warning/advisory curve sign is present at the sight, the color and reflectivity should be recorded on the data sheet. Use the codes below to describe the sign(s) at the sight:
    17. Standard yellow
    18. Standard yellow with a retro-reflective Finish
    19. Other – please provide a description

17. **Sign Visibility:** If a warning/advisory curve sign is present at the sight, its visibility should be recorded on the data sheet. Use the codes below to describe the condition of the sign's visibility:
    20. Clear visibility – the sign is clean, has reasonable placement, and has no obstructions that may inhibit driver's view of it
    21. Mediocre visibility – the sign is either very dirty, has awkward placement, or has obstructions that may inhibit driver's view of it
    22. Poor visibility – the sign has poor placement, or has obstructions that inhibit driver's view of it

18. **Sign Distance From P.C.:** If a warning/advisory curve sign is present at the sight, its distance should be recorded (in feet) from the noticeable point of curvature (or P.T. from opposite direction) of the roadways curve.

19. **Sign Height WRT Paved Edge:** If a warning/advisory curve sign is present at the sight, its distance (in feet) between the bottom of the lowest sign (e.g., the curve sign or speed plaque) and the top of the pavement edge.

20. **Test Runs:**
    a) Keeping the speed consistent, steering smooth, and driving parallel to the centerline of the road, drive down the travel lane at an obviously safe speed. After two or three trials at this speed, (depending on consistency of data) repeat the trials while increasing the speed of the automobile by 5 mph in each of the following sets of passes. Continue doing so until the appropriate ball-bank reading is exceeded. This will indicate that the previous pass's speed is likely the appropriate one.

    b) If abnormal discomfort to the driver or any of the passengers is felt, it should be noted, and engineering judgment shall be used.

    c) If multiple travel lanes exist in the travel direction, the conservative travel lane (often the inside lane), shall always be used for ball-bank testing procedures. The conservative lane refers to the lane which yields the highest ball-bank readings. This can be affected by differing superelevation from one lane to the other, and can be determined by preliminary test runs in each lane at equal speeds.

d) There shall always be at least two persons conducting such tests, one focusing on driving, and the other on ball-bank readings. This should provide consistent speeds and steady steering.

21. **Superelevation (cross-slope):** The cross-slope (%) of the roadway shall be recorded at the approach, in the middle of, and at the departure of each curve in both directions. This means that both directions of travel will have separate values recorded for each section of the curve. While recording this data, sketch a simple profile of the roadway in the space provided. In the direction of travel, a positive value indicates a slope down to the right, and a negative value indicates a slope down to the left.

Note:

The reading at the approach should be taken on the tangent section near the advisory sign, if one is present, or approximately 250 ft. before the P.C. of the curve.

The reading at the center of the curve should be taken at what is perceivably the sharpest section of the curve, which will likely have the largest superelevation. If trials indicate that the highest ball-bank reading is not at the sharpest section of the curve, record the superelevation of the roadway where the highest ball-bank reading was observed.

The reading at the departure should be taken on the tangent section near the advisory sign for the opposite direction, if one is present, or approximately 250 ft. after the P.T. of the curve.

22. **Average Vertical Grade:** Roadway grade (%) shall be recorded at the approach, in the middle of, and at the departure of each curve. The reading should be taken on the centerline of the roadway at each location. In the direction of travel, a positive value indicates a slope in the upward direction, and a negative value indicates a slope in the downward direction. This means that the readings will have opposite signs in each direction.

Note:

The same convention used for cross-slope readings at the approach, in the center of, and at the departure of each curve should be used for all other readings, including the vertical grade.

23. **Suggested Advisory Speeds:** After completing all trial runs through each curve, determine and record the recommended advisory speeds, based on each of the five standards provided. The average value's for each speed should be recorded.

Note:

There are many standards for determining advisory speeds. Therefore, it is difficult, if not impossible to suggest one individual advisory speed for a curve without knowing what standards will be implemented in the future. This is why five popular standards are provided on the data collection form.

Speeds (mph)	**Ball-bank Indicator Readings (°) for Possible Standard #:**				
	1	**2**	**3**	**4**	**5**
30mph or less	13°	14°	15°	10°	16°
35mph-55mph	10°	12°	12.5°	10°	16°
60mph or more	7°	10°	10°	10°	16°

24. **Vertical Pavement Edge Drop-Off:** The average vertical pavement edge drop-off shall be measured and recorded for the site. If a drop-off occurs on one side of the roadway and not the other, the value for one side should be recorded and indicated in the notes. If a significant drop-off is present that has a non-vertical edge (less than a 45 degree angle), provide the total drop-off height and approximate sloping angle.

20.) **Notes:** Any additional concerns not addressed by the data collection form should be noted here.

APPENDIX C: RECOMMENDED WORDING CHANGES FOR THE MUTCD

National Committee on Uniform Traffic Control Devices
TECHNICAL COMMITTEE RECOMMENDATIONS TO SPONSORS

RECOMMENDED WORDING:

Replace Sections 2C.06 through 2C.11 with the following revised Sections 2C.06 through 2C.14, delete existing Sections 2C.36 and 2C.46, and renumber the remaining existing Chapter 2C Sections consecutively starting with Section 2C.15.

Changes to the MUTCD shown in red (new text underlined) Revisions made to text based on latest Sponsor comments and RWSTC consideration.

Section 2C.06 Horizontal Alignment Warning Signs

Support:

A variety of traffic control signs (See Figure 2C-1), pavement markings (See Chapter3B) and delineation (See Chapter 3D) can be used to advise motorists of a change in the roadway alignment. Uniform applications of these traffic control devices with respect to the amount of change in the roadway alignment conveys a consistent message establishing driver expectancy and promoting effective roadway operations. The design and application of warning signs to meet those requirements are addressed below.

Standard:

Horizontal Alignment Warning signs on freeways, expressways and roadways functionally classified as arterial or collector with more than 1,000 AADT shall be in accordance with Table 2C-5 based on the speed differential between the roadway posted or statutory speed limit and the horizontal curve advisory speed.

Option:

Horizontal Alignment Warning signs may be used on other roadways or on arterial and collector roadways with less than 1,000 AADT based on engineering judgment.

Replace Table 2C-5 Horizontal Alignment Sign Usage with the following Table.

Table 2C-5. Selection of Horizontal Alignment Traffic Control Signs

Traffic Control Signs	<10 km/h (≤5 mph)	10 km/h (10 mph)	20 km/h (15 mph)	30 km/h (20 mph)	≥ 40 km/h (≥ 25 mph)
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), or Winding Road (W1-5)	Option	Guidance	Standard	Standard	Standard
Advisory Speed (W13-1) Plaque	Option	Guidance	Standard	Standard	Standard
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6)	Option	Option	Guidance	Guidance	Standard
Combination Horizontal Alignment/Advisory Speed (W1-1a, W1-2a)	N/A	N/A	Option	Option	Guidance
~~One Direction Large Arrow (W1-6)~~	~~Option~~	~~Option~~	~~Option~~	~~Option~~	~~Option~~
INTERCHANGE RAMP SIGNING					
Truck Rollover Warning (W1-13) & Advisory Speed (W13-1) Plaque	N/A	Option	Guidance	Guidance	Standard
Advisory Exit Speed (W13-2) & Ramp Speed (W13-3)	N/A	Option	Guidance	~~Standard~~ Guidance	Standard

NOTE: References to Standard, Guidance, and Option in the above Table shall have the same meanings as contained in the Introduction for this publication.

Section ~~2C.06.~~ 2C.07 Horizontal Alignment Signs (W1-1 through W1-5, W1-11, W1-15)

Standard:

A Curve (W1-2) sign (See Figure 2C-1) shall be used in accordance with Table 2C-5 to advise road users of a change in roadway alignment except as specified below.

~~Option~~

~~The horizontal alignment Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), or Winding Road (W1-5) signs (see Figure 2C-1) may be used in advance of situations where the horizontal roadway alignment changes. A One Direction Large Arrow (W1-6) sign (see Figure 2C-1) and Section 2C.09) may be used on the outside of the turn or curve.~~

~~If the change in horizontal alignment is 135 degrees or more, the Hairpin Curve (W1-11) sign (see Figure 2C-1) may be used.~~

~~If the change in horizontal alignment is approximately 270 degrees, such as on a cloverleaf interchange ramp, the 270-degree Loop0 (W!-15) sign (see Figure 2C-1) may be used.~~

Guidance:

A Turn (W1-1) sign (See Figure 2C-1 and 2C-X) should be used in advance of curves with a change in roadway alignment of approximately 90 degrees and an Advisory Speed (W13-1) of 50 km/h (30 mph) or less.

The Reverse Turn (W1-3) or Reverse Curve (W1-4) sign (See Figure 2C-1) should be used in place of multiple Turn (W1-1) or Curve (W1-3) signs where there are two changes in roadway alignment that are separated by a tangent distance less than 180 m (600 ft.).

Option:

A Winding Road (W1-5) sign (See Figure 2C-1) is used where there are three or more changes in roadway alignment separated by a tangent distance less than 180 m (600 ft.).The supplemental distance plaque NEXT XX km (NEXT XX MILES) (W7-3a) may be installed below the Winding Road sign where continuous roadway curves exist (see Section 2C.45).

The Hairpin Curve (W1-11) sign (see Figure 2C-1) may be used in advance of the curve if the curve has a change of direction of 135 degrees or more.

The 270-Degree Loop (W1-15) sign (see Figure 2C-1) may be used in advance of the curve if the curve has a change of direction of approximately 270 degrees such as on a cloverleaf interchange ramp.

Guidance:

~~The application of these signs should conform to Table 2C-5.~~

When the Hairpin Curve sign or the 270-degree Loop sign is installed, either a One-Direction Large Arrow (W1-6) sign or Chevron Alignment (W1-8) signs (See Figure 2C-1) should be installed on the outside of the turn or curve.

~~Option:~~

~~An Advisory Speed (W13-1) plaque (see Section 2C.46) may be used to indicate the speed for the change in horizontal alignment. The combination Horizontal Alignment/Advisory Speed sign (see Section 2C.07), combination Horizontal Alignment/Intersection sign (see Section 2C.08), or the Curve Speed sign (see Section 2C.36) may also be used.~~

~~Standard:~~

~~When engineering judgment determines the need for a horizontal alignment sign, one of the W1-1 through W1-5, W1-10, W1-11, or W1-15 signs shall be used.~~

~~Option:~~

~~If the reduction in speed is 20 km/h (15 mph) or greater, a supplemental combination Horizontal Alignment/Advisory Speed sign or Curve Speed (W13-5) sign may be installed as near as practical to the point of curvature. If the reduction in speed is 40 km/h (25 mph) or greater, one or more additional Curve Speed signs may be installed along the curve.~~

Section ~~2C.46~~ 2C.08 Advisory Speed Plaque (W13-1)

Option:

The Advisory Speed (W13-1) plaque (see Figure ~~2C-5~~2C-1) may be used to supplement any warning sign to indicate the advisory speed for a condition.

Standard:

The Advisory Speed plaque shall be used where an engineering study indicates a need to advise road users of the advisory speed for horizontal alignment signing in accordance with Table 2C-5 ~~and a~~ or other roadway conditions

~~If~~ Where used, the Advisory Speed plaque shall carry the message XX km/h (XXMPH). The speed shown shall be a multiple of 10 km/h or 5 mph.

Except in emergencies or when the condition is temporary, an Advisory Speed plaque shall not be installed until the advisory speed has been determined by an engineering study.

The Advisory Speed plaque shall only be used to supplement a warning sign and shall not be installed as a separate sign installation.

Guidance:

The advisory speed should be determined for free-flowing traffic conditions.

Because changes in conditions, such as roadway geometrics, surface characteristics, or sight distance might affect the advisory speed, each location should be periodically evaluated when the conditions change. and the Advisory Speed plaque changed if necessary.

Option:

The advisory speed may be the 85th-percentile speed of free-flowing traffic, the speed corresponding to a 16-degree ball bank indicator reading, or the speed otherwise determined by an engineering study because of unusual circumstances.

Support:

A 10-degree ball bank indicator reading, formerly used in determining advisory speeds, is based on research from the 1930's. In modern vehicles, the 85th-percentile speed on curves approximates a 16-degree reading. This is the speed at which most drivers' judgment recognizes incipient instability along a ramp or curve.

Section 2C.10 2C.09 Chevron Alignment Sign (W1-8)

Option: Standard:

The Chevron Alignment (W1-8) sign (see Figure 2C-1 and Figure 2C-X) may shall be used in accordance with Table 2C-5 used to provide additional emphasis and guidance for a change in horizontal alignment.

Option:

A Chevron Alignment sign may be used as an alternate or supplement to standard delineators and pavement markings (See Part 3) on curves. or to the One-Direction Large Arrow (W1-6) sign.

Standard:

The Chevron Alignment sign shall be a vertical rectangle. No border shall be used on the Chevron Alignment sign. If Where used, Chevron Alignment signs shall be installed on the outside of a turn or curve, in line with and at approximately a right angle to approaching traffic. Chevron Alignment signs shall be installed at not less than 1.2 m (4 feet) mounting height measured from the bottom of the sign to the nearest edge of pavement.

Option:

A Chevron Alignment sign may be used on the far side of an intersection to inform drivers of a change of horizontal alignment for through traffic.

Guidance:

Spacing of Chevron Alignment signs should be such that the road user always has at least two in view, until the change in alignment eliminates the need for the signs.

The Chevron Alignment sign approximate spacing on the turn or curve measured from the point of curvature (PC) should be as shown in Table 2C-6.

Table 2C-6. Approximate Spacing for Chevron Alignment Signs on Horizontal Curves

Curve Advisory Speed (km/h)	Curve Radii	Approximate Chevron Alignment Sign

Curve Advisory Speed	Curve Radii	Approximate Chevron Alignment Sign

	(Meters)	Spacing (meters)
≤ 20	< 60	12
30 to 50	60 – 120	24
60 to 70	120 – 210	36
80 to 100	210 – 380	48
> 100	> 380	60

(mph)	(feet)	Spacing (feet)
≤ 15	< 200	40
20 to 30	200 – 400	80
35 to 45	400 – 700	120
50 to 60	700 – 1250	160
> 60	> 1250	200

Note: The curve radii criteria shown in this table should not be used to set Advisory Speeds.

Chevron Alignment signs should be visible for a sufficient distance to provide the road user with adequate time to react to the change in alignment.

Section ~~2C.07~~ 2C.10 Combination Horizontal Alignment/Advisory Speed Signs (W1-1a, W1-2a)
Option:
The Turn (W1-1) sign or the Curve (W1-2) may be combined with the Advisory Speed (W13-1) plaque (see Section ~~2C.46~~ 2C.08) to create a Combination Turn/Advisory Speed (W1-1a) sign ~~(see Figure 2C-1)~~ or Combination Curve/Advisory Speed (W1-2a) sign (see Figure 2C-1).
Standard:
~~When used,~~ The combination Horizontal Alignment/ Advisory Speed sign shall be used to supplement other advance horizontal alignment warning signs in accordance with Table 2C-5. The sign shall not be used alone. ~~supplement other advance~~ . ~~warning signs~~. ~~and~~ Where used, the sign shall be installed at the beginning of the turn or curve (See Figure 2C-X).

Section ~~2C.08~~ 2C.11 Combination Horizontal Alignment/Intersection Sign (W1-9, W1-10)
Option:
The Turn (W1-1) sign or the Curve (W1-2) sign may be combined with the Cross Road (W2-1) sign or the Side Road (W2-2 or W2-3) sign to create a combination Horizontal Alignment/Intersection (W1-9 or W1-10) sign (see Figure 2C-1) that depicts the condition where an intersection occurs within or immediately adjacent to a turn or curve.
Guidance:
Elements of the combination Horizontal Alignment/Intersection sign related to horizontal alignment should conform to Section ~~2C.06~~ 2C. 07 and elements related to intersection configuration should conform to Section 2C.37. The ~~sign~~ symbol design should approximate the configuration of the roadway. No more than one Cross Road or two Side Road symbols should be shown on any one combination Horizontal Alignment/Intersection sign.

Section ~~2C.09~~ 2C.12 One-Direction Large Arrow Sign (W1-6)
~~Option:~~
~~A One-Direction Large Arrow (W1-6) sign (see Figure 2C-1) may be used to delineate a change in horizontal alignment.~~
Standard:
The One-Direction Large Arrow sign shall be a horizontal rectangle with an arrow pointing to the left or right.
Option:

A One-Direction Large Arrow (W1-6) sign (see Figure 2C-1) may be used either as a supplement or an alternate to Chevron Alignment signs in order to delineate a change in horizontal alignment of approximately 90 degrees or more. (See Figures 2C-X and 2C-7).

Guidance:

The One-Direction Large Arrow sign should may be used to supplement a Turn or Reverse Turn sign (See Figure 2C-X) to emphasize the abrupt curvature.

Guidance:

The One-Direction Large Arrow sign should be visible for a sufficient distance to provide the road user with adequate time to react to the change in alignment.

Standard:

If Where used, the One-Direction Large Arrow sign shall be installed on the outside of a turn or curve in line with and at approximately a right angle to approaching traffic.

The One-Direction Large Arrow shall not be used where there is no alignment change in the direction of travel, such as at the beginning and ends of medians or at center piers.

Section 2C.11 2C.13 Truck Rollover Warning Sign (W1-13)

Standard:

The use of the Truck Rollover Warning sign (W1-13) shall be used on Freeway and Expressway ramps in accordance with Table 2C-5.

Option Guidance:

A Truck Rollover Warning (W1-13) sign (see Figure 2C-1 and 2C-7) may should be used to warn drivers of vehicles with a high center of gravity, such as trucks, tankers, and recreational vehicles, of a curve or turn having geometric conditions that are prone to cause such vehicles to lose control and overturn. may contribute to loss of control and rollover. Such locations may include Interchange ramps, turn lanes or other separate turning roadways.

The engineering study to determine the truck advisory speed should use recommended established traffic engineering practices for truck advisory speeds

Standard:

When The Truck Rollover Warning (W1-13) sign is used, it shall be accompanied by an Advisory Speed (W13-1) plaque indicating the recommended speed for vehicles with a higher center of gravity.

Option:

The Truck Rollover Warning sign may be displayed either as a static sign, a static sign supplemented by a flashing beacon, or as a changeable message sign activated by the detection of an approaching vehicle with a high center of gravity that is traveling in excess of the recommended speed for the condition.

Support:

The curved arrow on the Truck Rollover Warning sign shows the direction of roadway curvature. The truck tips in the opposite direction.

Section 2C.36 2C.14 Advisory Exit, and Ramp, and Curve Speed Signs (W13-2, W13-3, W13-5)

Standard:

Advisory Exit, and Ramp, and Curve Speed signs (See Figure 2C-1) shall be vertical rectangles.

The advisory Exit Speed (W13-2), Ramp Speed (W13-3), or Curve Speed (W13-5) signs (see Figure 2C-5) shall be used where engineering judgement indicates the need to advise road users of the recommended speed on an exit, a ramp, or a curve. The use of the Advisory Exit (W13-2) and Ramp Speed (W13-3) signs shall be in accordance with Table 2C-5.

Guidance:

When Where used, the Advisory Exit Speed (W13-2) sign should be installed along the deceleration lane and the advisory exit speed should be based on an engineering study. When a Truck Rollover (W1-13) sign (Section 2C.13) is installed, the Advisory Exit speed should be based on the truck advisory speed for the horizontal alignment using recommended engineering practices

The Advisory Exit Speed sign should be visible in time for the road user to make a reasonably safe slowing slow and make an exiting maneuver.

The Ramp Speed sign should be visible in time for the road user to reduce to the recommended speed.

The Ramp Speed (W13-3) sign should be used on a ramp to confirm the ramp advisory speed.

Chevron Alignment (W1-6) signs and/or One-Direction Large Arrow (W1-6) signs should be used on the outside of the exit curve in accordance with the applications noted in Sections 2C.09 and 2C.12.

Option:

A Combination Horizontal Alignment/Advisory Speed (W1-1a) or Hairpin Curve (W1-11) sign with Advisory Speed plaque or a Loop (W1-15) sign with Advisory Speed plaque may be installed at or beyond the beginning of the exit curve or on the outside of the curve, provided that it is apparent that the sign applies only to the exit curve or where there is a need to remind road users of the recommended advisory speed. These signs may also be used at intermediate points along the ramp if the ramp curvature changes and for any second curve on the ramp where the advisory speed is different from that on than the initial ramp curve.

One or more Ramp Speed signs may be used along the deceleration lane, beyond the gore, or along the ramp (see Figure 2C-7). Based on engineering judgment, the Ramp Speed sign may be installed on the inside or outside of the curve to enhance its visibility.

A Turn (W1-1) or Curve (W1-2) sign with an Advisory Speed (W13-1) plaque may be used in place of a Ramp Speed sign if it is located such that it clearly does not apply to drivers on the main roadway.

A Curve Speed sign may be used at and beyond the beginning of a curve following a Horizontal Alignment and Advisory Speed sign combination, or when there is need to remind road users of the recommended speed, or where the recommended speed changes because of a change in curvature (see Section 2C.06). Based on engineering judgment, the Curve Speed sign may be installed on the inside or outside of the curve to enhance its visibility.

The advisory speed may be the 85th percentile of free flowing traffic, the speed corresponding to a 16-degree ballbank indicator reading, or the speed otherwise determined by an engineering study because of unusual circumstances.

Support:

A 10-degree ball-bank indicator reading, formerly used in determining advisory speeds, is based on research from the 1930s. In modern vehicles, the 85th percentile speed on curves approximates a 16-degree reading. This is the speed at which most drivers' judgment recognizes incipient instability along a ramp or curve.

Change Section 5C.02 as follows:

Section 5C.02 Horizontal Alignment Signs (W1-1 through W1-8)
Support
Horizontal Alignment signs (see Figure 5C-1) include turn, curve, reverse turn, reverse curve, winding road, large arrow, and chevron alignment signs. For guidance in the design and application of horizontal alignment warning signs refer to Section 2C.06 through Section 2C.12.
Option:
Horizontal Alignment signs may be used where engineering judgment indicates a need to inform the road user of a change in the horizontal alignment of the roadway.

Section 1A.13 Definition of Words and Phrases in This Manual.

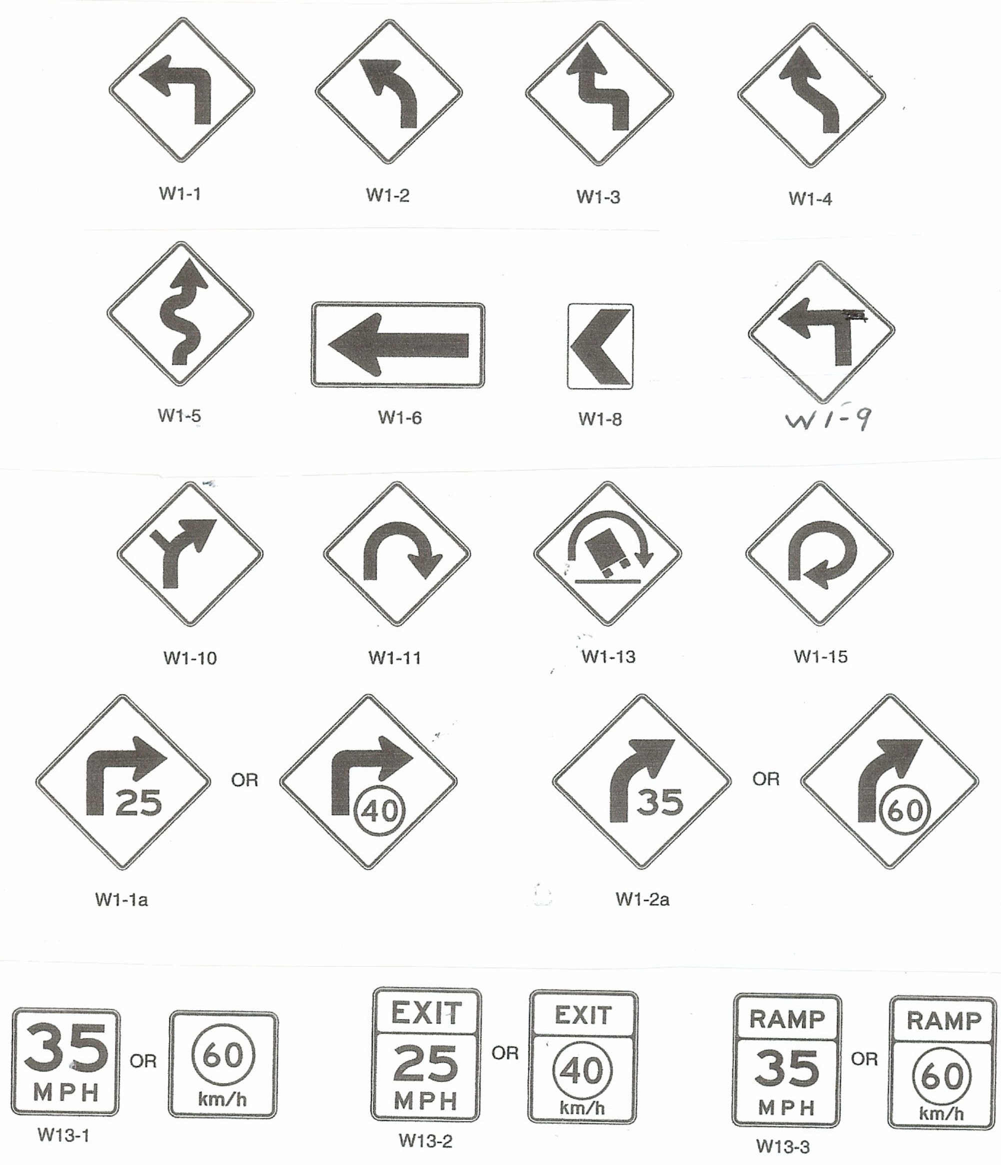
Add the following definition:
Average Annual Daily Traffic (AADT) – The total volume of traffic passing a point or segment of a highway facility in both directions for one year divided by the number of days in the year. Normally, periodic daily traffic volume figures are adjusted for hours of the day counted, days of the week and seasons of the year to arrive at average annual daily traffic.

Revise Figure 2C-1, Horizontal Alignment Signs, page 2C-7, by adding the Combination Turn/ Intersection (W1-9) sign and relocating the Advisory Speed (W13-1) plaque, Exit Speed (W13-2), and Ramp Speed (W13-3) from Figure 2C-5 to Figure 2C-1 so that all the Horizontal Alignment signs are shown in one figure. (Also change the name of the figure)

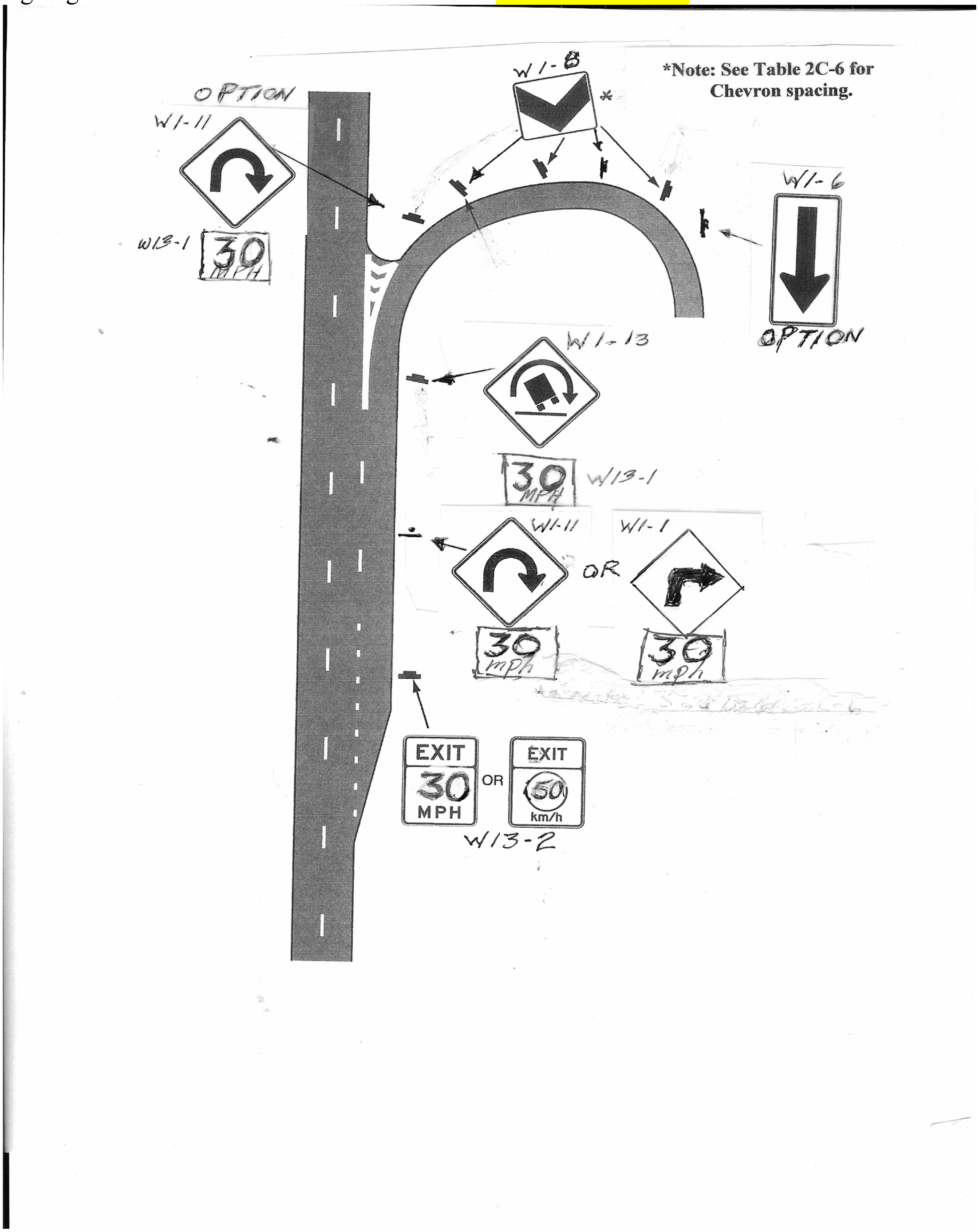
Revise Figure 2C-5, ~~Advisory Speed and~~ Speed Reduction Signs, by relocating the Advisory Speed signs to Figure 2C-1. Note that the Advisory Curve Speed (W13-5) sign has been deleted.

Revised Figure 2C-5. Speed Reduction Signs

Revised Figure 2C-1. Horizontal Alignment Signs



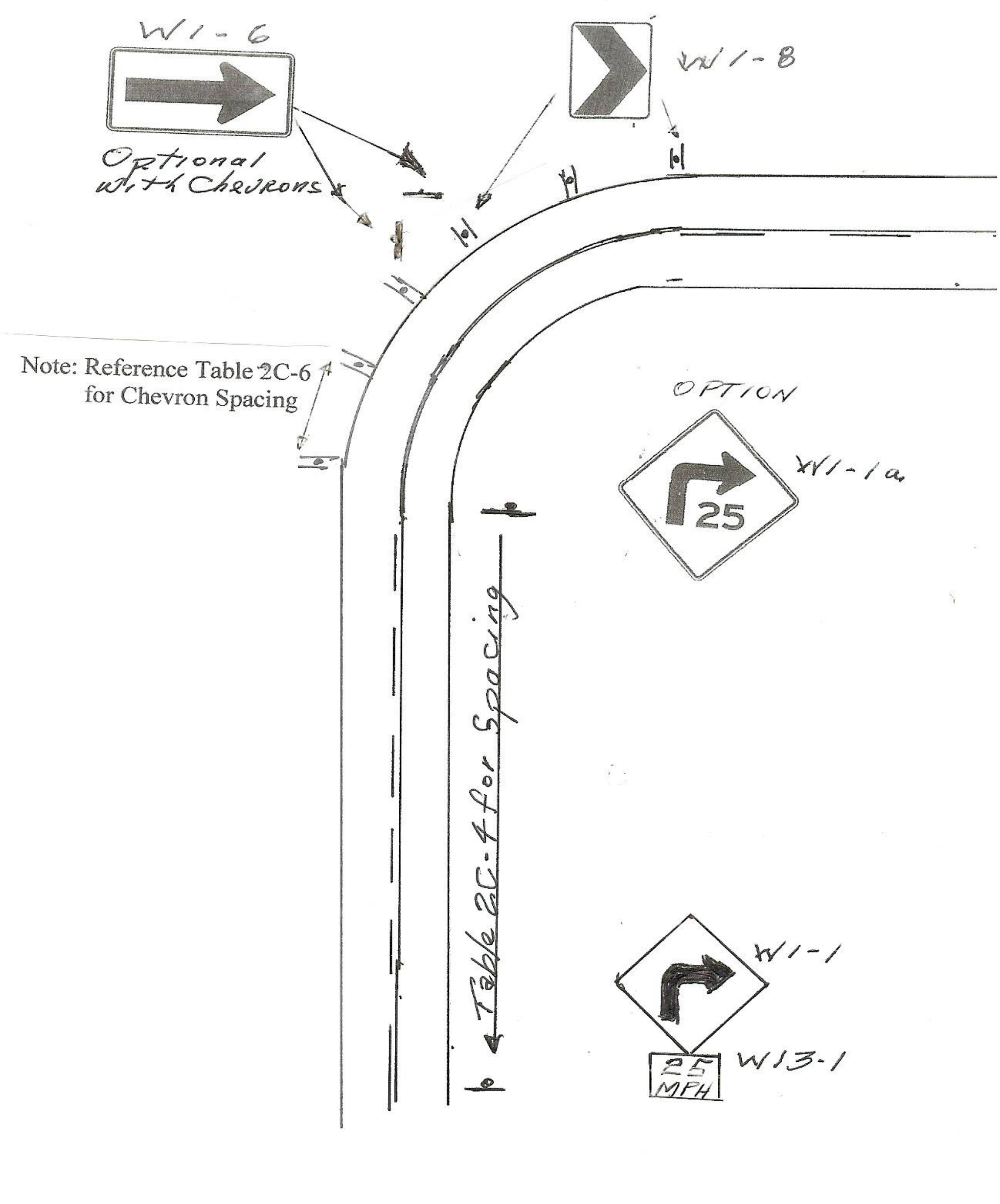
Revise Figure 2C-7. Example of Advisory Speed Signing for an Exit Ramp, to illustrate the signing addressed in Section 2C.13 and 2C.14. Revised 12/18/06.



Add a new Figure 2C-X. Example of Signing for a Turn to illustrate the application of optional signing addressed in Sections 2C. 07, 2C.09, 2C.10 and 2C.12.

Figure 2C-X. Example of Warning Signs for a Turn

Replace with Revised Fig



APPENDIX D: SUMMARY TABLES FOR DATA ANALYSIS PHASE OF PROJECT

Table D.1: Compliance for Advisory Speeds "Equal To" Oregon Policy (All Curves) – Digital Ball-Bank Values

Based on Digital Ball-bank Readings	State and County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	4	14	13	19	22	21	17	23	41	176
Total Curve Directions	6	16	33	45	73	69	69	64	33	45	453
% Compliance	33%	24%	42%	29%	26%	32%	30%	27%	70%	91%	39%
	State Roads -- Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	0	0	3	6	9	9	17	16	17	36	113
Total Curve Directions	0	1	5	9	29	22	39	46	23	36	210
% Compliance	NA	0%	60%	67%	31%	41%	44%	35%	74%	100%	54%
	County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	4	11	7	10	13	4	1	6	5	63
Total Curve Directions	6	15	28	36	44	47	30	18	10	9	243
% Compliance	33%	27%	39%	19%	23%	28%	13%	6%	60%	56%	26%

Table D.2: Compliance for Advisory Speeds "Equal To or Less Than" Oregon Policy (All Curves) – Digital Ball-Bank Values

Based on Digital Ball-bank Readings	State and County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	6	14	17	24	29	31	23	33	45	224
Total Curve Directions	6	16	33	45	73	69	69	64	33	45	453
% Compliance	33%	38%	42%	38%	33%	42%	45%	36%	100%	100%	49%
	State Roads -- Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	0	0	3	8	12	10	21	18	23	36	131
Total Curve Directions	0	1	5	9	29	22	39	46	23	36	210
% Compliance	NA	0%	60%	89%	41%	45%	54%	39%	100%	100%	62%
	County Roads – Oregon Policy Advisory Speed (mph)										
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**Total**
Compliance Sites	2	6	11	9	12	19	10	5	10	9	93
Total Curve Directions	6	15	28	36	44	47	30	18	10	9	243
% Compliance	33%	40%	39%	25%	27%	40%	33%	28%	100%	100%	38%

Table D.3: Compliance for Advisory Speeds "Equal To" Oregon Policy at Speed Plaque Locations (Current and Required) – Digital Ball-Bank Values

Based on Digital Ball-Bank Values	**Locations with Current Speed Plaques**			**All Locations where Speed Plaques are Warranted**		
	Current Speed Plaque Locations	**Comply With Advisory Speed**	**Percent that Comply**	**Warranted Speed Plaque Locations**	**Comply With Advisory Speed**	**Percent that Comply**
Region 1:						
State Roads	26	13	50%	27	12	44%
County Roads	36	11	31%	41	11	27%
All Roads	62	24	39%	68	23	34%
Region 2:						
State Roads	21	9	43%	29	9	31%
County Roads	45	17	38%	49	17	35%
All Roads	66	26	39%	78	26	33%
Region 3:						
State Roads	23	16	70%	35	16	46%
County Roads	20	6	30%	52	6	12%
All Roads	43	22	51%	87	22	25%
Region 4:						
State Roads	20	7	35%	25	7	28%
County Roads	28	5	18%	43	5	12%
All Roads	48	12	25%	68	12	18%
Region 5:						
State Roads	24	11	46%	33	11	33%
County Roads	13	9	69%	34	9	26%
All Roads	37	20	54%	67	20	30%
Total:						
State Roads	114	56	49%	149	55	37%
County Roads	142	48	34%	219	48	22%
All Roads	256	104	41%	368	103	28%

Table D.4: Compliance for Advisory Speeds "Equal To or Less Than" Oregon Policy at Speed Plaque Locations (Current and Required) -- Digital Ball-Bank Values

Based on Digital Ball-Bank Values	**Locations with Current Speed Plaques**			**All Locations where Speed Plaques are Warranted**		
	Current Speed Plaque Locations	**Comply With Advisory Speed**	**Percent that Comply**	**Warranted Speed Plaque Locations**	**Comply With Advisory Speed**	**Percent that Comply**
Region 1:						
State Roads	26	19	73%	27	15	56%
County Roads	36	19	53%	41	19	46%
All Roads	62	38	61%	68	34	50%
Region 2:						
State Roads	21	16	76%	29	13	45%
County Roads	45	25	56%	49	24	49%
All Roads	66	41	62%	78	37	47%
Region 3:						
State Roads	23	17	74%	35	17	49%
County Roads	20	6	30%	52	6	12%
All Roads	43	23	53%	87	23	26%
Region 4:						
State Roads	20	8	40%	25	8	32%
County Roads	28	16	57%	43	12	28%
All Roads	48	24	50%	68	20	29%
Region 5:						
State Roads	24	14	58%	33	14	42%
County Roads	13	12	92%	34	10	29%
All Roads	37	26	70%	67	24	36%
Total:						
State Roads	114	74	65%	149	67	45%
County Roads	142	78	55%	219	71	32%
All Roads	256	152	59%	368	138	38%

Table D.5: "Equal To" Threshold Compliance for State-Maintained Roads – Digital Ball-Bank Values

Based on Digital Ball-Bank Values	**Advisory Speed Ball-Bank Threshold**		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	23	17	16
Region 2	24	23	26
Region 3	27	27	29
Region 4	24	26	33
Region 5	14	17	22
Statewide Total	113	110	126
	Number of Sites Evaluated		
Region 1	40	40	40
Region 2	46	46	46
Region 3	46	46	46
Region 4	42	42	42
Region 5	36	36	36
Statewide Total	210	210	210
	Percent Sites in Compliance		
Region 1	58%	43%	40%
Region 2	52%	50%	57%
Region 3	59%	59%	63%
Region 4	57%	62%	79%
Region 5	39%	47%	61%
Statewide Total	**54%**	**52%**	**60%**

Table D.6: "Equal To or Less Than" Threshold Compliance for State-Maintained Roads -- Digital Ball-Bank Values

Based on Digital Ball-Bank Values	**Advisory Speed Ball-Bank Threshold**		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	29	38	36
Region 2	31	42	40
Region 3	28	45	43
Region 4	25	40	39
Region 5	17	34	34
Statewide Total	130	199	192
	Number of Sites Evaluated		
Region 1	40	40	40
Region 2	46	46	46
Region 3	46	46	46
Region 4	42	42	42
Region 5	36	36	36
Statewide Total	210	210	210
	Percent Sites in Compliance		
Region 1	73%	95%	90%
Region 2	67%	91%	87%
Region 3	61%	98%	93%
Region 4	60%	95%	93%
Region 5	47%	94%	94%
Statewide Total	**62%**	**95%**	**91%**

Table D.7: Summary of "Equal to" Threshold Compliance on County-Maintained Roads -- Digital Ball-Bank Values

Based on Digital Ball-Bank Values	**Advisory Speed Ball-Bank Threshold**		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	13	19	19
Region 2	24	23	23
Region 3	6	15	13
Region 4	11	22	25
Region 5	9	12	13
Statewide Total	63	91	93
	Number of Sites Evaluated		
Region 1	43	44	44
Region 2	58	58	58
Region 3	52	52	52
Region 4	54	54	52
Region 5	36	38	38
Statewide Total	243	246	244
	Percent Sites in Compliance		
Region 1	30%	43%	43%
Region 2	41%	40%	40%
Region 3	12%	29%	25%
Region 4	20%	41%	48%
Region 5	25%	32%	34%
Statewide Total	**26%**	**37%**	**38%**

Table D.8: Summary of "Equal To or Less Than" Threshold Compliance on County-Maintained Roads -- Digital Ball-Bank Values

Based on Digital Ball-Bank Values	Advisory Speed Ball-Bank Threshold		
	Oregon Policy: 13-10-7	**2003 MUTCD: 16**	**Future MUTCD: 16-14-12**
	Number of Sites in Compliance Regionally		
Region 1	21	38	26
Region 2	32	51	49
Region 3	6	18	18
Region 4	22	43	37
Region 5	12	24	23
Statewide Total	93	174	153
	Number of Sites Evaluated		
Region 1	43	44	44
Region 2	58	58	58
Region 3	52	52	52
Region 4	54	54	52
Region 5	36	38	38
Statewide Total	243	246	244
	Percent Sites in Compliance		
Region 1	49%	86%	59%
Region 2	55%	88%	84%
Region 3	12%	35%	35%
Region 4	41%	80%	71%
Region 5	33%	63%	61%
Statewide Total	**38%**	**71%**	**63%**

Table D.9: Compliance for Advisory Speeds "Equal To" Future 16-14-12 *MUTCD* Thresholds at Speed Plaque Locations (Current and Required) -- Digital Ball-Bank Values

Based on Digital Ball-Bank Values	Locations with Current Speed Plaques			Locations where Speed Plaques are Warranted		
	Current Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply	Appropriate Speed Plaque Locations	Comply With Advisory Speed	Percent that Comply
Region 1:						
State Roads	26	4	15%	19	4	21%
County Roads	36	16	44%	39	16	41%
All Roads	62	20	32%	58	20	34%
Region 2:						
State Roads	21	6	29%	14	3	21%
County Roads	45	12	27%	39	12	31%
All Roads	66	18	27%	53	19	36%
Region 3:						
State Roads	23	6	26%	19	6	32%
County Roads	20	13	65%	52	13	25%
All Roads	43	20	47%	71	19	27%
Region 4:						
State Roads	20	12	60%	18	4	12%
County Roads	25	8	32%	29	8	28%
All Roads	45	23	51%	47	22	47%
Region 5:						
State Roads	24	10	42%	21	10	48%
County Roads	13	3	23%	26	3	12%
All Roads	37	13	35%	47	15	32%
Total:						
State Roads	114	38	33%	91	27	30%
County Roads	139	52	37%	185	52	28%
All Roads	253	90	36%	276	79	29%

Table D.10: Compliance for Advisory Speeds "Equal To or Less Than" Future 16-14-12 MUTCD Thresholds at Speed Plaque Locations (Current and Required) -- Digital Ball-Bank Values

Based on Digital Ball-Bank Values	**Locations with Current Speed Plaques**			**All Locations where Speed Plaques are Warranted**		
	Current Speed Plaque Locations	**Comply With Advisory Speed**	**Percent that Comply**	**Warranted Speed Plaque Locations**	**Comply With Advisory Speed**	**Percent that Comply**
Region 1:						
State Roads	26	24	92%	19	15	79%
County Roads	36	30	83%	39	28	72%
All Roads	62	54	87%	58	43	74%
Region 2:						
State Roads	21	20	95%	14	8	57%
County Roads	45	38	84%	39	30	77%
All Roads	66	58	88%	53	38	72%
Region 3:						
State Roads	23	21	91%	19	16	84%
County Roads	20	18	90%	52	18	35%
All Roads	43	39	91%	71	34	48%
Region 4:						
State Roads	20	18	90%	18	7	39%
County Roads	25	23	92%	29	15	52%
All Roads	45	41	91%	47	22	47%
Region 5:						
State Roads	24	22	92%	21	17	81%
County Roads	13	13	100%	26	11	42%
All Roads	37	35	95%	47	28	60%
Total:						
State Roads	114	105	92%	91	63	69%
County Roads	139	122	88%	185	102	55%
All Roads	253	227	90%	276	165	60%