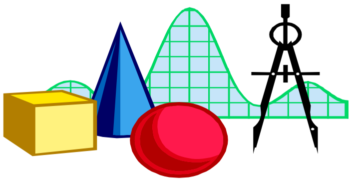
Texas Department of Transportation

Texas Transportation Institute

Procedures for Setting Curve Advisory Speed

Horizontal Curve Signing Workshop



Course Notes

Product 5-5439-01-P1
http://tti.tamu.edu/documents/5-5439-01-P1.pdf

June 2009
Published: August 2009

HORIZONTAL CURVE SIGNING WORKSHOP:
PROCEDURES FOR SETTING CURVE ADVISORY SPEED

Date:
Location:
Contacts: Jim Bonneson, (979) 845-9906, j-bonneson@tamu.edu
Mike Pratt, (979) 845-1907, m-pratt@ttimail.tamu.edu
Jeff Miles, (979) 845-9880, jeff-m@tamu.edu

Agenda

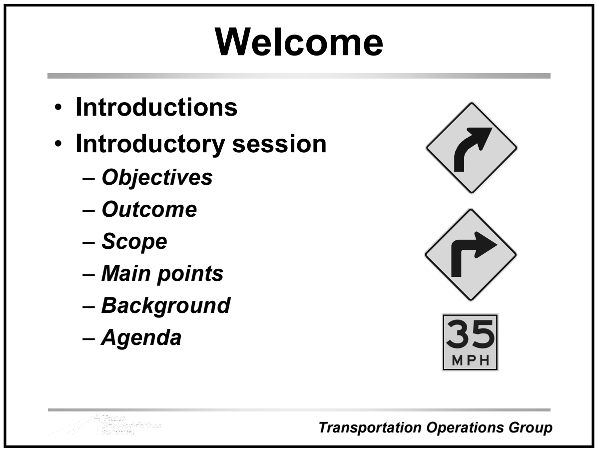
8:30	Training Exercise 1: Hands-on training for three participants for 40-min.
9:10	Training Exercise 2: Hands-on training for three participants for 40-min.
9:50	Introduction
10:05	Session 1: Communicating Changes in Horizontal Alignment
10:40	>Break<
10:55	Session 2: Texas Curve Advisory Speed (TCAS) Software
11:25	Session 3: GPS Method for Setting Advisory Speed
12:00	>Lunch<
1:15	Session 4: Advisory Speed Setting Procedure
1:40	Session 5: Curve Signing Guidelines
2:10	>Break<
2:25	Session 6: Engineering Principles
2:40	Wrap-Up, Complete Course Review Form
2:50	Training Exercise 3: Hands-on training for three participants for 40-min.
3:30	Training Exercise 4: Hands-on training for three participants for 40-min.

Course Materials: Course Notes, Horizontal Curve Signing Handbook, CD-ROM

Horizontal Curve Signing Workshop

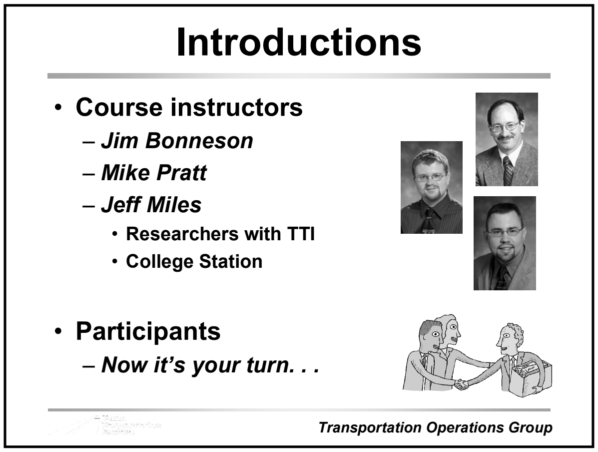
Procedures for Setting Curve Advisory Speed

Texas Department of Transportation



Welcome

- Introductions
- Introductory session
  - *Objectives*
  - *Outcome*
  - *Scope*
  - *Main points*
  - *Background*
  - *Agenda*



Introductions

- Course instructors
  - *Jim Bonneson*
  - *Mike Pratt*
  - *Jeff Miles*
    - Researchers with TTI
    - College Station
- Participants
  - *Now it's your turn. . .*

Objectives & Outcome

- Objectives
  - *To inform participants about. . .*
    - Challenges associated with curve signing
    - Availability of tools to determine appropriate signs
  - *To demonstrate how to apply these tools*
- Outcome
  - *Participants should be able to. . .*
    - Apply the tools and. . .
    - Determine the advisory speed
    - Determine which signs are needed

Objectives & Outcome

- Course Elements
  - *Guidelines for curve signing*

  - *Criteria and methods for setting advisory speed*

Scope

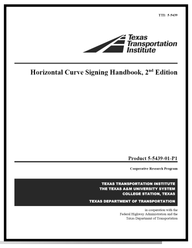
- Workshop Scope
  - *Intended for engineers and technicians that want information about curve signing issues, procedures, and practices*
- Handbook Scope
  - *Intended for engineers and technicians responsible for evaluating and maintaining curve signing and delineation devices*
  - *Horizontal curves on rural highways*

Main Points

- Points to Remember
  - *Objective of curve signing is a consistent display of devices and advisory speed*
  - *Devices should be uniform among curves of similar geometry, character, and road condition*
  - *Advisory speed should be consistent with driver expectation*
  - *85th percentile speed usually exceeds the posted speed*
  - *Selection of devices should be based on an engineering study that considers...*
    - 85th percentile speed
    - Sight distance
    - Intersections
    - Adjacent curves

Background

- Project 5-5439
  - *"Workshops on Identifying and Testing Advisory Speed Setting Procedures"*
  - *Project Director:*
    - Darren McDaniel
  - *Product:*
    - *Horizontal Curve Signing Handbook, 2nd Edition* (5-5439-01-P1)



TTI: 5-5439

Texas Transportation Institute

Horizontal Curve Signing Handbook, 2nd Edition

Product 5-5439-01-P1

Cooperative Research Program

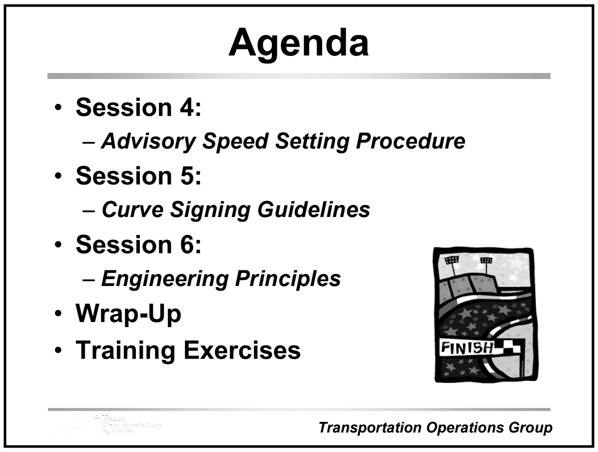
TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation

Agenda

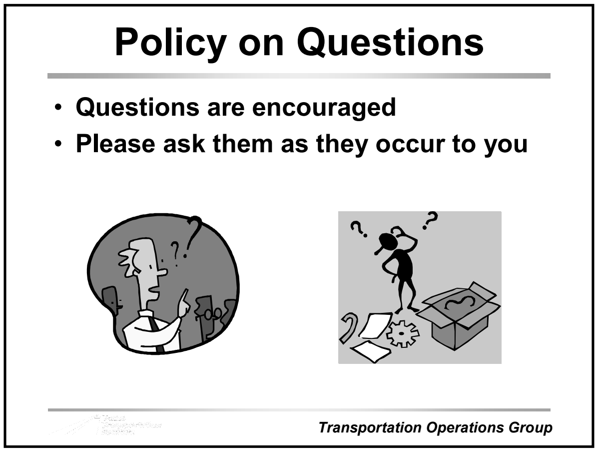
- Session 1:
  - *Communicating Changes in Horizontal Alignment*
- Session 2:
  - *Texas Curve Advisory Speed Software*
- Session 3:
  - *GPS Method for Setting Advisory Speed*
- Lunch Break



Agenda

- Session 4:
  - *Advisory Speed Setting Procedure*
- Session 5:
  - *Curve Signing Guidelines*
- Session 6:
  - *Engineering Principles*
- Wrap-Up
- Training Exercises

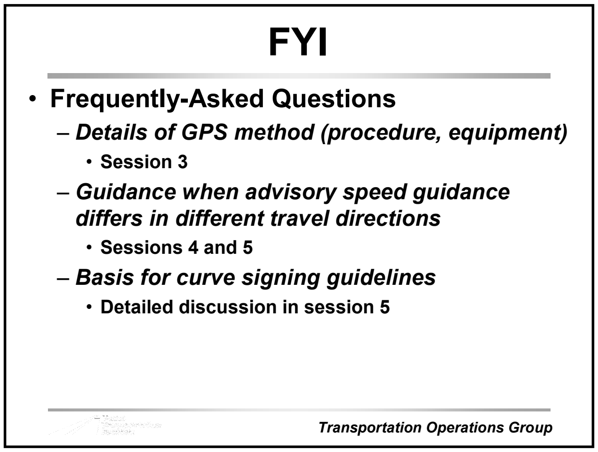
Transportation Operations Group



Policy on Questions

- Questions are encouraged
- Please ask them as they occur to you

Transportation Operations Group



FYI

- Frequently-Asked Questions
  - *Details of GPS method (procedure, equipment)*
    - Session 3
  - *Guidance when advisory speed guidance differs in different travel directions*
    - Sessions 4 and 5
  - *Basis for curve signing guidelines*
    - Detailed discussion in session 5

Transportation Operations Group

1. Communicating Changes

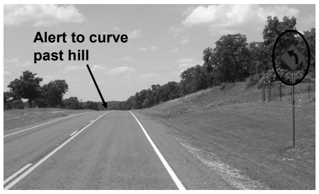
- Curve Signing Objectives
- Current Practice
- Issues with Current Practice
- New Procedure

Curve Signing Objectives

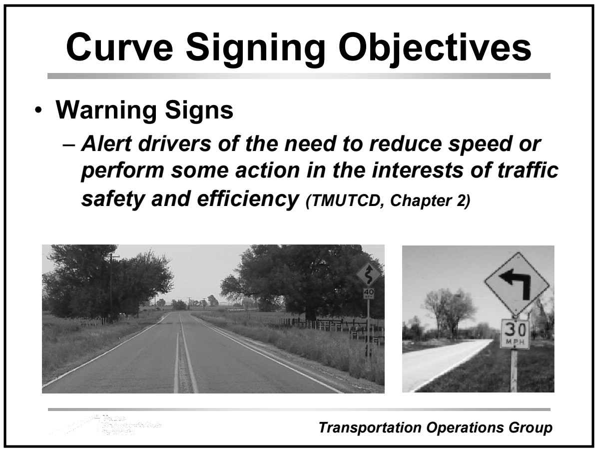
- Warning Signs
  - *Display devices consistently*
    - Similar message displayed in similar situations
    - Consistent display of traffic control devices on curves of similar geometry, character, and condition
  - *Benefit of consistency*
    - Uniformity of devices simplifies the task of the road user
    - "Uniformity of the meaning of traffic control devices is vital to their effectiveness" (*MUTCD*)

Curve Signing Objectives

- Warning Signs
  - *Call attention to unexpected conditions* *(TMUTCD, Chapter 2)*


Alert to curve past hill


Emphasize sharpness of curve



Curve Signing Objectives

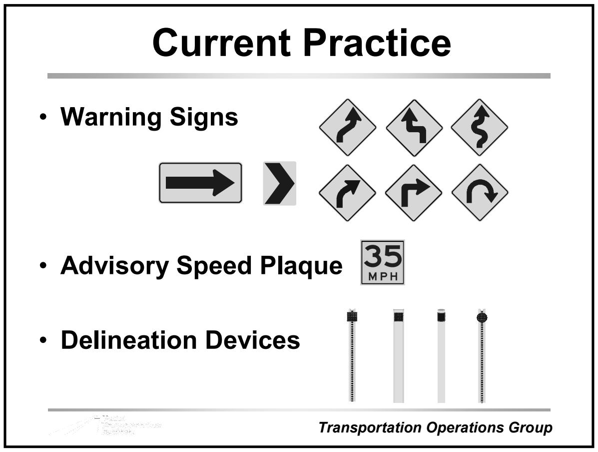
- **Warning Signs**
  - ***Alert drivers of the need to reduce speed or perform some action in the interests of traffic safety and efficiency*** *(TMUTCD, Chapter 2)*

Transportation Operations Group

1. Communicating Changes

- **Curve Signing Objectives** ✓
- **Current Practice**
- **Issues with Current Practice**
- **New Procedure**

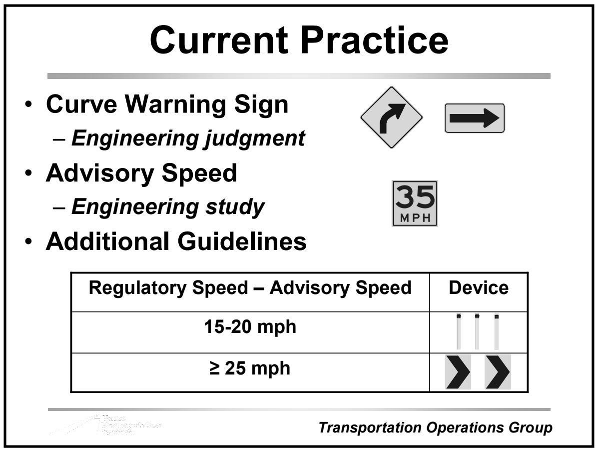
Transportation Operations Group



Current Practice

- **Warning Signs**
- **Advisory Speed Plaque**
- **Delineation Devices**

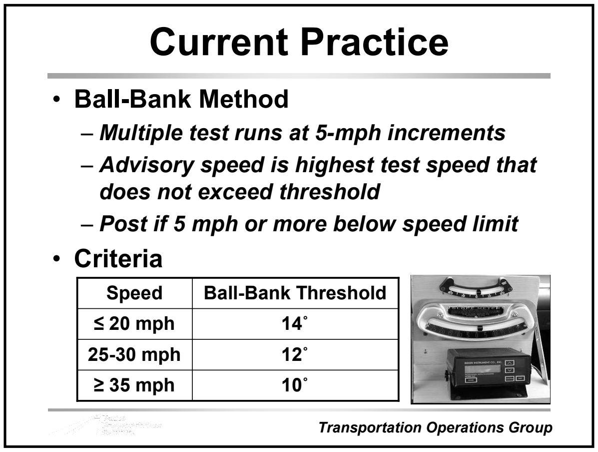
Transportation Operations Group



Current Practice

- **Curve Warning Sign**
  - – ***Engineering judgment***
- **Advisory Speed**
  - – ***Engineering study***
- **Additional Guidelines**

Regulatory Speed – Advisory Speed	**Device**
15-20 mph	╿ ╿ ╿
≥ 25 mph	❯ ❯



Current Practice

- **Ball-Bank Method**
  - – ***Multiple test runs at 5-mph increments***
  - – ***Advisory speed is highest test speed that does not exceed threshold***
  - – ***Post if 5 mph or more below speed limit***
- **Criteria**

Speed	**Ball-Bank Threshold**
≤ 20 mph	**14˚**
25-30 mph	**12˚**
≥ 35 mph	**10˚**

1. Communicating Changes

- **Curve Signing Objectives** ✓
- **Current Practice** ✓
- **Issues with Current Practice**
- **New Procedure**

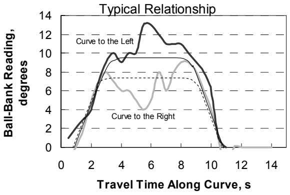
Issues with Current Practice

- **Ball-Bank Method Variability**
  - *Video 1*
  - *Video 2*

Transportation Operations Group

Issues with Current Practice

- **Ball-Bank Method Variability**
  - *Expectation of constant reading along curve*
  - *May differ by direction based on superelevation*
  - *Found wide variation in reading along curve*



Issues with Current Practice

- **Sources of Variability**
  - *Use of different test vehicles*
  - *Personnel training*
  - *Instrument calibration quality*
  - *Steering corrections*
    - Tire slip
  - *Pavement variability*
    - Roughness
    - Superelevation
    - Friction supply

Can control

Difficult to control

Cannot control

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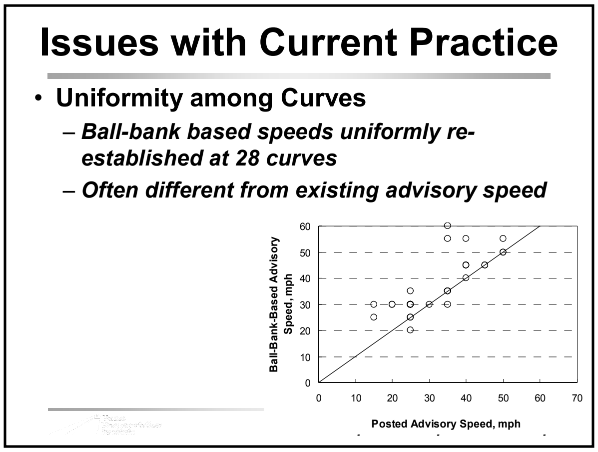
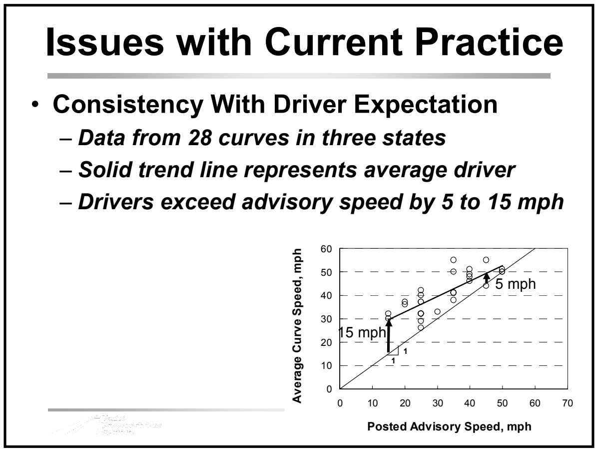


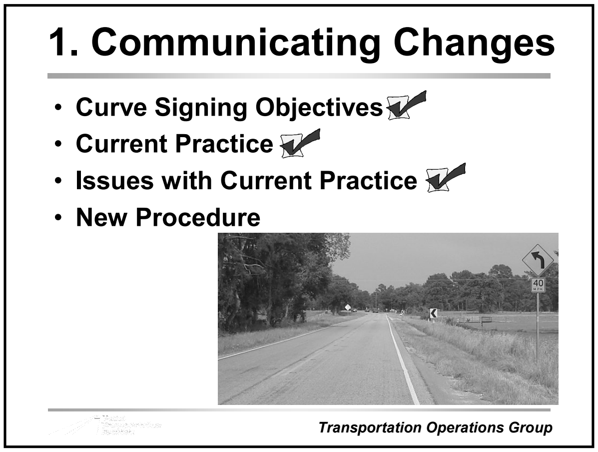
Issues with Current Practice

- **Uniformity among Curves**
  - ***Ball-bank based speeds uniformly re-established at 28 curves***
  - ***Often different from existing advisory speed***



Issues with Current Practice

- **Consistency With Driver Expectation**
  - ***Data from 28 curves in three states***
  - ***Solid trend line represents average driver***
  - ***Drivers exceed advisory speed by 5 to 15 mph***



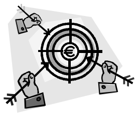
1. Communicating Changes

- Curve Signing Objectives ✓
- Current Practice ✓
- Issues with Current Practice ✓
- New Procedure

Transportation Operations Group

New Procedure

- Goals
  - – *Promote uniform use of curve signs*
  - – *Based guidelines for devices on curve severity*
  - – *Avoid overuse of devices*
  - – *Limit number of devices used at a given curve*
- Components
  - – *Advisory speed criteria*
  - – *Engineering study method*
  - – *Curve signing guidelines*



New Procedure

- Advisory Speed Criteria
  - – *Considerations*
    - Car vs. truck speed
    - Average vs. 85th percentile vs. BBI reading
    - Curves are inherently unsafe, so advisory speed should be conservatively low
    - Drivers should feel advisory speed is reasonable
    - On sharp curves, 85th percentile driver tends to adopt a speed that may be borderline unsafe

New Procedure

- Advisory Speed Criteria
  - – *Recommend using average truck speed*
    - Roughly equivalent to 40th percentile car
    - Truck speed is generally 97% of car speed
    - Round to 5-mph increment

New Procedure

- **Engineering Study Methods**
  - *Direct method*

  - *GPS method*

  - *Design method*

Direct Method

- **Field Measurements**
  - *Measure speed of 125 free-flow cars*
    - Stop after 2 hours (radar)
    - Stop after 4 hours (classifier)

  - *Compute average and 85th percentile*

- **Determine Advisory Speed**
  - *Average truck speed = 0.97 x average car speed*
  - *Add one and drop down*
    - 34, 35, 36, 37, 38 → 35 mph

- **Confirm Speed for Conditions**

Direct Method

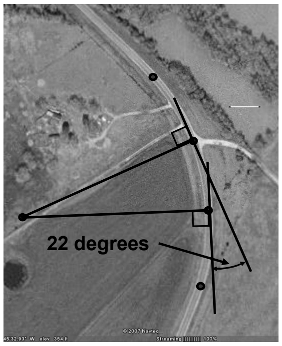
- **Example – Curve 65**
  - *Curve speed data*
    - Average (125 cars): 46.1 mph
  - *What is the advisory speed?*
    - Average truck speed = 0.97 x 46.1 mph = 44.7 mph
    - Advisory speed = 45 mph

GPS Method

- **Field Measurements**
  - *Drive through curve with instruments*
    - GPS receiver (provided through 5-5439)
    - Electronic ball-bank indicator
    - Laptop computer with TRAMS program
- **Determine Advisory Speed**
  - *Based on sharpest part of curve*
- **Confirm Speed for Conditions**

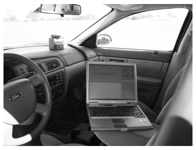
GPS Method

- **Data Needs**
  - *Curve geometry*
    - Sharpest part of curve
      - Radius
      - Superelevation rate
      - Deflection angle
    - Entire curve
      - Deflection angle



GPS Method

- **Advisory Speed Calculation**
  - *Texas Curve Advisory Speed (TCAS)*
    - Excel® spreadsheet
  - *Available from Traffic Operations Division*
  - *Steps*
    - Enter geometry data
    - Enter tangent speed
    - Read advisory speed



GPS Method

- Tangent Speed
  - *A speed that is representative of the 85th percentile speed on the tangent sections of the highway where the subject curve is located*
    - General descriptor of highway
    - Precise measurement not needed at every curve
    - Can estimate using regulatory limit and curve radius

Design Method

- Obtain Curve Geometry
  - *Get curve data from plans*
    - Good for newly constructed or reconstructed curves
- Determine Advisory Speed
  - *Estimate curve and tangent speed*
- Confirm Speed for Conditions

New Procedure

- Guidelines for Curve Signing
  - *Based on curve severity index*
  - *Index is similar to speed reduction*
  - *Device selection is dependent on severity category*
    - Category A: slight speed reduction
    - Category E: exceptional speed reduction

Curve Severity	Typical Traffic Control Device Treatments
A	Curve or Turn sign and raised pavement markers
B	Curve warning sign with Advisory Speed plaque
C	Redundant curve warning sign and Advisory Speed plaque and delineators
D	Redundant curve warning sign, Adv. Speed plaque, and Chevrons (or Large Arrow sign)
E	Special treatments

Questions?

Break

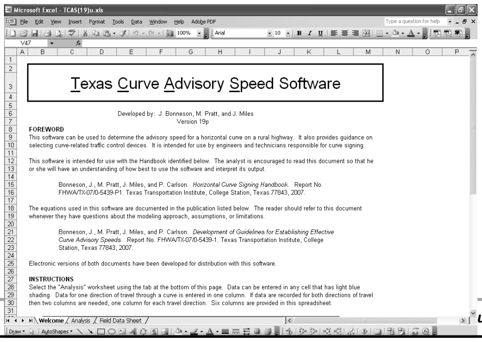
- 15 minutes

2. Texas Curve Advisory Speed

- Texas Curve Advisory Speed (TCAS) Software
- Participant Exercise

TCAS Software

- **Welcome**



Texas Curve Advisory Speed Software

Developed by: J. Bonneson, M. Pratt, and J. Miles
Version 19p

FOREWORD

This software can be used to determine the advisory speed for a horizontal curve on a rural highway. It also provides guidance on selecting curve-related traffic control devices. It is intended for use by engineers and technicians responsible for curve signing.

This software is intended for use with the Handbook identified below. The analyst is encouraged to read this document so that he or she will have an understanding of how best to use the software and interpret its output.

Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Horizontal Curve Signing Handbook*. Report No. FHWA/TX-07/0-5439-P1. Texas Transportation Institute, College Station, Texas 77843, 2007.

The equations used in this software are documented in the publication listed below. The reader should refer to this document whenever they have questions about the modeling approach, assumptions, or limitations.

Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Development of Guidelines for Establishing Effective Curve Advisory Speeds*. Report No. FHWA/TX-07/0-5439-1. Texas Transportation Institute, College Station, Texas 77843, 2007.

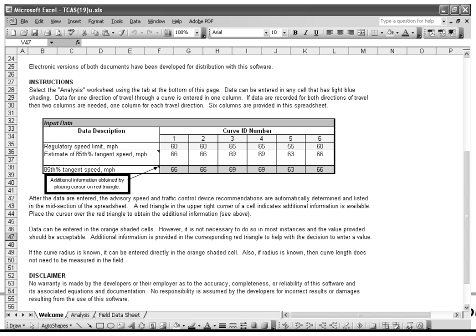
Electronic versions of both documents have been developed for distribution with this software.

INSTRUCTIONS

Select the "Analysis" worksheet using the tab at the bottom of this page. Data can be entered in any cell that has light blue shading. Data for one direction of travel through a curve is entered in one column. If data are recorded for both directions of travel then two columns are needed, one column for each travel direction. Six columns are provided in this spreadsheet.

TCAS Software

- **Instructions**



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Input Data

Data Description	Curve ID Number					
	1	2	3	4	5	6
Regulatory speed limit, mph	60	60	65	65	55	60
Estimate of 85th% tangent speed, mph	66	66	69	69	63	66
85th% tangent speed, mph	66	66	69	69	63	66

After the data are entered, the advisory speed and traffic control device recommendations are automatically determined and listed in the mid-section of the spreadsheet. A red triangle in the upper right corner of a cell indicates additional information is available. Place the cursor over the red triangle to obtain the additional information (see above).

Data can be entered in the orange shaded cells. However, it is not necessary to do so in most instances and the value provided should be acceptable. Additional information is provided in the corresponding red triangle to help with the decision to enter a value.

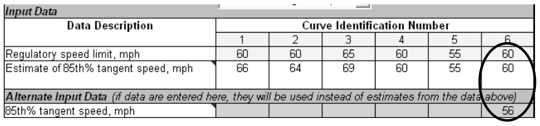
If the curve radius is known, it can be entered directly in the orange shaded cell. Also, if radius is known, then curve length does not need to be measured in the field.

DISCLAIMER

No warranty is made by the developers or their employer as to the accuracy, completeness, or reliability of this software and its associated equations and documentation. No responsibility is assumed by the developers for incorrect results or damages resulting from the use of this software.

TCAS Software

- **Instructions**
  - *One curve per column, six curves per sheet*
  - *Enter data in blue cells*
  - *Speed can be entered in orange cells*
    - If estimated 85th% speed shown is not correct

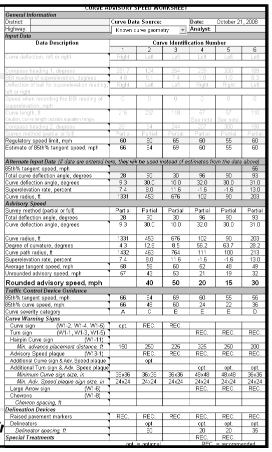


Input Data

Data Description	Curve Identification Number					
	1	2	3	4	5	6
Regulatory speed limit, mph	60	60	65	60	55	60
Estimate of 85th% tangent speed, mph	66	64	69	60	55	60
Alternate Input Data *(if data are entered here, they will be used instead of estimates from the data above)*						
85th% tangent speed, mph						56

TCAS Software

- Analysis
  - *General Info.*
  - *Input Data*
  - *Alternate Input Data*
  - *Advisory Speed*
  - *Device Guidance*



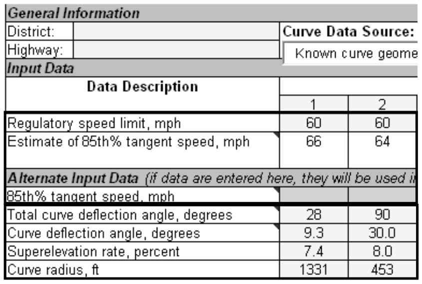
CURVE ADVISORY SPEED WORKSHEET						
General Information						
District:		Curve Data Source:		Date:	October 21, 2008	
Highway:		Known curve geometry		Analyst:		
Input Data						
Data Description	Curve Identification Number					
	1	2	3	4	5	6
Curve deflection, left or right	Right	Left	Left	Left	Left	Left
Compass heading 1, degrees	251.7	124	254	239	330	189
BBI reading of superelevation, degrees	4.8	5.1	7.4	1.0	1.0	8.3
Deflection of ball for superelevation reading, left or right	Right	Left	Left	Right	Right	Left
Speed when recording the BBI reading of superelevation, mph	0	0	0	0	0	0
Curve length, ft Caution, curve length outside equation range.	216	237	118	57 See note.	57 See note.	110
Compass heading 2, degrees	261	94	244	207	300	158
Survey method (partial or full)	Partial	Partial	Partial	Partial	Partial	Partial
Regulatory speed limit, mph	60	60	65	60	55	60
Estimate of 85th% tangent speed, mph	66	64	69	60	55	60
Alternate Input Data *(if data are entered here, they will be used instead of estimates from the data above)*						
85th% tangent speed, mph						56
Total curve deflection angle, degrees	28	90	30	96	90	93
Curve deflection angle, degrees	9.3	30.0	10.0	32.0	30.0	31.0
Superelevation rate, percent	7.4	8.0	11.6	-1.6	-1.6	13.0
Curve radius, ft	1331	453	676	102	90	203
Advisory Speed						
Survey method (partial or full)	Partial	Partial	Partial	Partial	Partial	Partial
Total deflection angle, degrees	28	90	30	96	90	93
Curve deflection angle, degrees	9.3	30.0	10.0	32.0	30.0	31.0
Curve radius, ft	1331	453	676	102	90	203
Degree of curvature, degrees	4.3	12.6	8.5	56.2	63.7	28.2
Curve path radius, ft	1432	463	764	111	100	213
Superelevation rate, percent	7.4	8.0	11.6	-1.6	-1.6	13.0
Average tangent speed, mph	58	56	60	52	48	49
Unrounded advisory speed, mph	57	43	53	21	19	32
Rounded advisory speed, mph		**40**	**50**	**20**	**15**	**30**
Traffic Control Device Guidance						
85th% tangent speed, mph	66	64	69	60	55	56
85th% curve speed, mph:	66	48	60	24	22	36
Curve severity category	A	C	B	E	E	D
Curve Warning Signs						
Curve sign (W1-2, W1-4, W1-5)	opt.	REC.	REC.			
Turn sign (W1-1, W1-3, W1-5)				REC.	REC.	REC.
Hairpin Curve sign (W1-11)						
Min. advance placement distance, ft	150	250	225	325	250	200
Advisory Speed plaque (W13-1)		REC.	REC.	REC.	REC.	REC.
Additional Curve sign & Adv. Speed plaque		opt.				
Additional Turn sign & Adv. Speed plaque				opt.	opt.	opt.
Minimum Curve sign size, in	36x36	36x36	36x36	48x48	48x48	36x36
Min. Adv. Speed plaque sign size, in	24x24	24x24	24x24	24x24	24x24	24x24
Large Arrow sign (W1-6)				REC.	REC.	REC.
Chevrons (W1-8)						
Chevron spacing, ft						
Delineation Devices						
Raised pavement markers	REC.	REC.	REC.	REC.	REC.	REC.
Delineators		opt.		opt.	opt.	opt.
Delineator spacing, ft		60		20	20	35
Special Treatments				REC.	REC.	
		opt. = optional			REC. = recommended	

TCAS Software

- **General Information and Input Data**

Tangent speed →

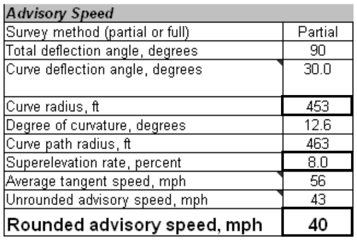
Curve geometry →



General Information			
District:		Curve Data Source:	
Highway:		Known curve geome	
Input Data			
Data Description			
		1	2
Regulatory speed limit, mph		60	60
Estimate of 85th% tangent speed, mph		66	64
Alternate Input Data *(if data are entered here, they will be used i*			
85th% tangent speed, mph			
Total curve deflection angle, degrees		28	90
Curve deflection angle, degrees		9.3	30.0
Superelevation rate, percent		7.4	8.0
Curve radius, ft		1331	453

TCAS Software

- **Advisory Speed**



Advisory Speed	
Survey method (partial or full)	Partial
Total deflection angle, degrees	90
Curve deflection angle, degrees	30.0
Curve radius, ft	453
Degree of curvature, degrees	12.6
Curve path radius, ft	463
Superelevation rate, percent	8.0
Average tangent speed, mph	56
Unrounded advisory speed, mph	43
Rounded advisory speed, mph	**40**

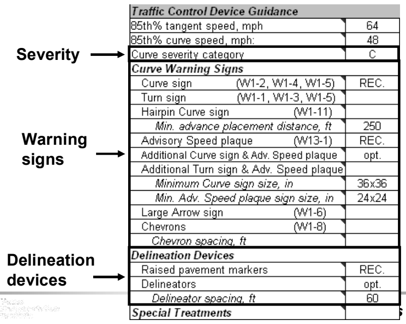
← **Curve radius**

← **Superelevation rate**

← **Advisory speed**

TCAS Software

- **Traffic Control Device Guidance**



Traffic Control Device Guidance	
85th% tangent speed, mph	64
85th% curve speed, mph:	48
Curve severity category	C
Curve Warning Signs	
Curve sign (W1-2, W1-4, W1-5)	REC.
Turn sign (W1-1, W1-3, W1-5)	
Hairpin Curve sign (W1-11)	
Min. advance placement distance, ft	250
Advisory Speed plaque (W13-1)	REC.
Additional Curve sign & Adv. Speed plaque	opt.
Additional Turn sign & Adv. Speed plaque	
Minimum Curve sign size, in	36x36
Min. Adv. Speed plaque sign size, in	24x24
Large Arrow sign (W1-6)	
Chevrons (W1-8)	
Chevron spacing, ft	
Delineation Devices	
Raised pavement markers	REC.
Delineators	opt.
Delineator spacing, ft	60
Special Treatments	

Questions – Comments?

Exercise 1

- **Objective**
  - ***Determine needed devices and advisory speed***
    - **Record answers on page 49**

Exercise 1

- **Data**
  - *Speed limit: 60 mph*
  - *Advisory speed: 45 mph*

Exercise 1

- **Data**
  - *Lane width: 11.5 ft*
  - *AADT: 1100 veh/d*

Exercise 1

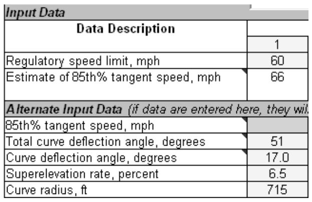
- **Data**
  - *Regulatory speed limit: 60 mph*
  - *Total deflection angle: 51 degrees*
  - *Curve deflection angle: 17 degrees*
  - *Superelevation rate: 6.5 percent*
  - *Curve radius: 715 ft*
- **Question**
  - *What devices are needed?*
  - *What is the advisory speed?*

Transportation Operations Group

Exercise 1

- **Results**

Advisory Speed



Input Data	
Data Description	
	1
Regulatory speed limit, mph	60
Estimate of 85th% tangent speed, mph	66
Alternate Input Data *(if data are entered here, they wil*	
85th% tangent speed, mph	
Total curve deflection angle, degrees	51
Curve deflection angle, degrees	17.0
Superelevation rate, percent	6.5
Curve radius, ft	715

Traffic Control Device Guidance

Tran

Exercise 1

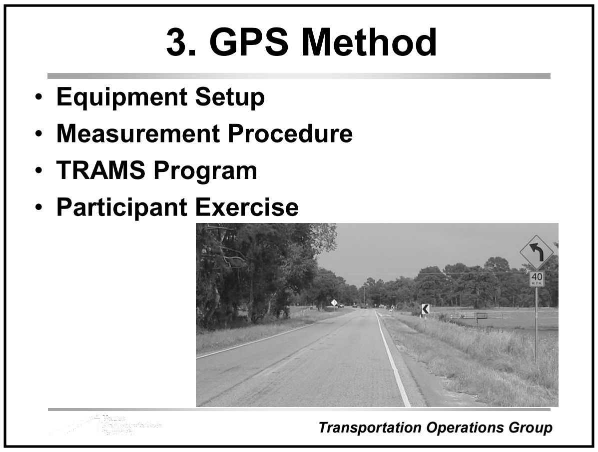
Condition	Existing	Proposed
Advisory Speed		
Delineation		

- **Discussion**

Transportation Operations Group

Questions?

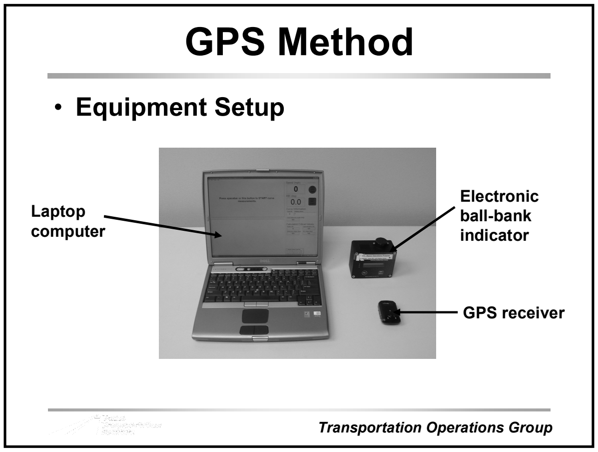
Transportation Operations Group



3. GPS Method

- Equipment Setup
- Measurement Procedure
- TRAMS Program
- Participant Exercise

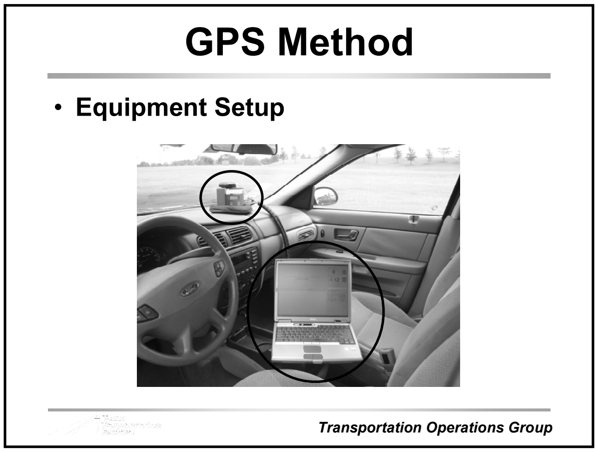
Transportation Operations Group



GPS Method

- Equipment Setup

Transportation Operations Group



GPS Method

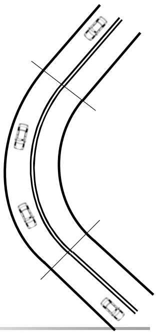
- Equipment Setup

Transportation Operations Group

GPS Method

- **Measurement Procedure**
  - *1-2 seconds before start of curve*
    - Press space bar to start recording

  - *Drive through one curve*
  - *1-2 seconds after end of curve*
    - Press space bar to stop recording

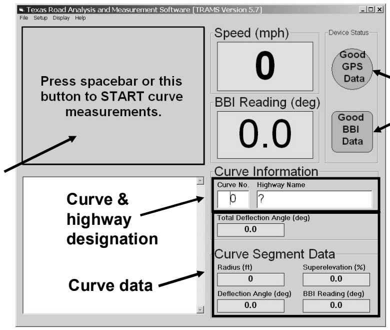


GPS Method

- **Measurement Procedure**
  - *Track the centerline carefully*
  - *Choose slow but reasonable speed*
    - Rule of thumb: 10 mph below existing advisory speed
    - No less than 15 mph
    - No greater than 45 mph if superelevation is being measured

---

TRAMS Program



Press spacebar or this button to START curve measurements.

Speed (mph): 0

BBI Reading (deg): 0.0

Curve Information

Curve No.: 0

Highway Name: ?

Total Deflection Angle (deg): 0.0

Curve Segment Data

Radius (ft): 0

Superelevation (%): 0.0

Deflection Angle (deg): 0.0

BBI Reading (deg): 0.0

Control button

Curve & highway designation

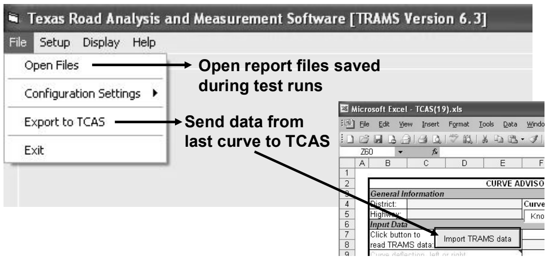
Curve data

Device status

GPS Method

TRAMS Program

- **Data File Management**

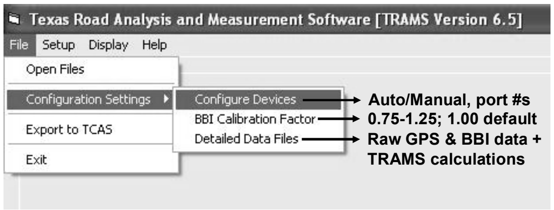


Open Files → Open report files saved during test runs

Export to TCAS → Send data from last curve to TCAS

TRAMS Program

- **Configuration Settings**



Configure Devices → Auto/Manual, port #s

BBI Calibration Factor → 0.75-1.25; 1.00 default

Detailed Data Files → Raw GPS & BBI data + TRAMS calculations

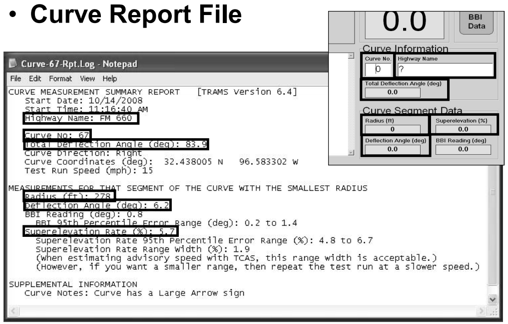
TRAMS Program

- Other Controls
  - *Setup – Curve Information*
    - Curve Number
    - Highway Name
    - Curve Notes

    Also on main panel (Curve Number, Highway Name)
  - *Display – Status Information*
    - Echo of all status messages displayed on main panel since start of TRAMS
  - *Display – GPS Message Form*
    - Shows all GPS data in real time

TRAMS Program

- Curve Report File



Curve-67-Rpt.Log - Notepad

```
CURVE MEASUREMENT SUMMARY REPORT   [TRAMS Version 6.4]
   Start Date: 10/14/2008
   Start Time: 11:16:40 AM
   Highway Name: FM 660

   Curve No: 67
   Total Deflection Angle (deg): 83.9
   Curve Direction: Right
   Curve Coordinates (deg):  32.438005 N   96.583302 W
   Test Run Speed (mph): 15

MEASUREMENTS FOR THAT SEGMENT OF THE CURVE WITH THE SMALLEST RADIUS
   Radius (ft): 278
   Deflection Angle (deg): 6.2
   BBI Reading (deg): 0.8
     BBI 95th Percentile Error Range (deg): 0.2 to 1.4
   Superelevation Rate (%): 5.7
     Superelevation Rate 95th Percentile Error Range (%): 4.8 to 6.7
     Superelevation Rate Range Width (%): 1.9
     (When estimating advisory speed with TCAS, this range width is acceptable.)
     (However, if you want a smaller range, then repeat the test run at a slower speed.)

SUPPLEMENTAL INFORMATION
   Curve Notes: Curve has a Large Arrow sign
```

Curve Information

Curve No.: 0

Highway Name: ?

Total Deflection Angle (deg): 0.0

Curve Segment Data

Radius (ft): 0

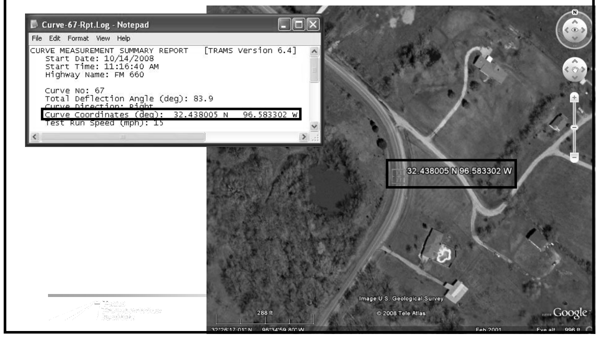
Superelevation (%): 0.0

Deflection Angle (deg): 0.0

BBI Reading (deg): 0.0

TRAMS Program

- Curve Report File



Curve-67-Rpt.Log - Notepad

```
CURVE MEASUREMENT SUMMARY REPORT   [TRAMS Version 6.4]
   Start Date: 10/14/2008
   Start Time: 11:16:40 AM
   Highway Name: FM 660

   Curve No: 67
   Total Deflection Angle (deg): 83.9
   Curve Direction: Right
   Curve Coordinates (deg):  32.438005 N   96.583302 W
   Test Run Speed (mph): 15
```

GPS Method

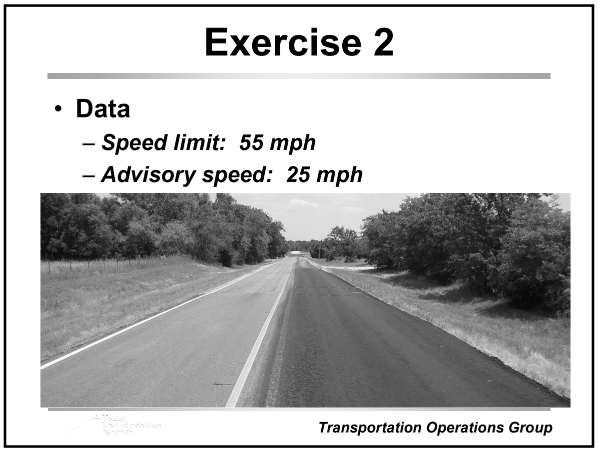
- Determine Advisory Speed and Curve Sign Selection
  - *Save report file for each curve*
  - *Review files in office or field*

GPS Method

- Confirm Advisory Speed and Curve Sign Selection
  - *Drive through curve at recommended advisory speed*
  - *Compare suggested devices with field conditions*

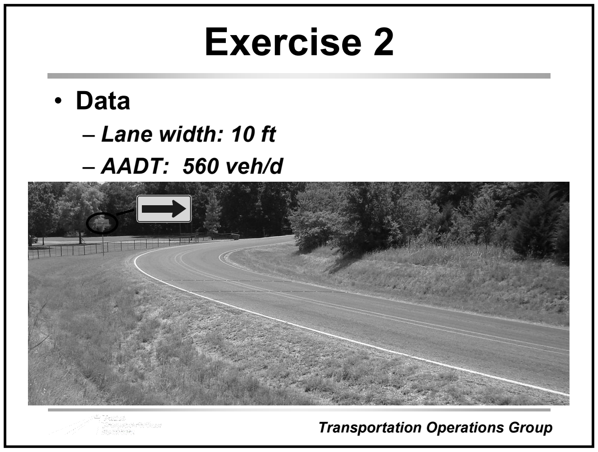
Exercise 2

- Objectives
  - *Determine needed devices and advisory speed*
    - Record answers on page 49



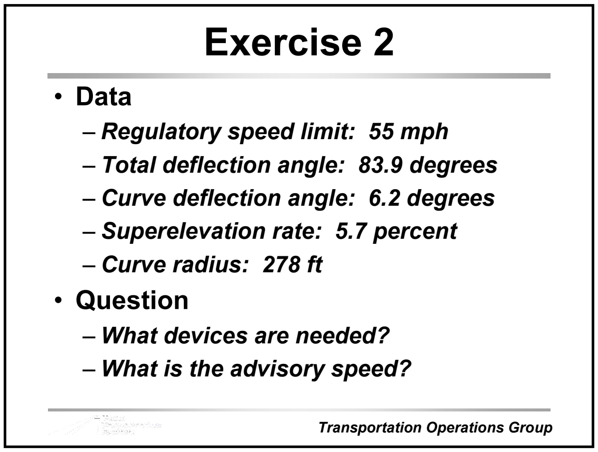
Exercise 2

- Data
  - *Speed limit: 55 mph*
  - *Advisory speed: 25 mph*



Exercise 2

- Data
  - *Lane width: 10 ft*
  - *AADT: 560 veh/d*



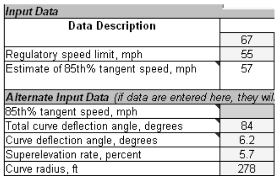
Exercise 2

- Data
  - *Regulatory speed limit: 55 mph*
  - *Total deflection angle: 83.9 degrees*
  - *Curve deflection angle: 6.2 degrees*
  - *Superelevation rate: 5.7 percent*
  - *Curve radius: 278 ft*
- Question
  - *What devices are needed?*
  - *What is the advisory speed?*

Exercise 2

- **Results**

Advisory Speed



Input Data	
Data Description	
	67
Regulatory speed limit, mph	55
Estimate of 85th% tangent speed, mph	57
Alternate Input Data *(if data are entered here, they wil*	
85th% tangent speed, mph	
Total curve deflection angle, degrees	84
Curve deflection angle, degrees	6.2
Superelevation rate, percent	5.7
Curve radius, ft	278

Traffic Control Device Guidance

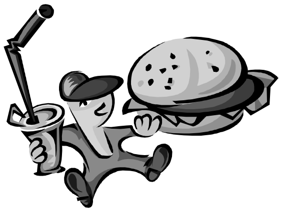
Exercise 2

Condition	Existing	Proposed
Advisory Speed		
Delineation		

- **Discussion**

Questions – Comments?

Lunch Break



Transportation Operations Group

Horizontal Curve Signing Workshop

Procedures for Setting Curve Advisory Speed

Texas Department of Transportation

Transportation Operations Group

Agenda

- Session 4:
  - *Advisory Speed Setting Procedure*
- Session 5:
  - *Curve Signing Guidelines*
- Session 6:
  - *Engineering Principles*
- Wrap-Up
- Training Exercises

Transportation Operations Group

4. Advisory Speed Procedure

- Determine Advisory Speed
- Confirm Speed for Conditions
- Participant Exercise

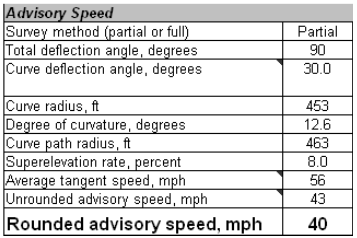
Determine Advisory Speed

- Criteria
  - *Average truck speed*
  - *Add 1.0 mph to average and drop down to nearest 5 mph increment*
- Note on Rounding
  - *Break points at _4.0 and _9.0*
  - *If unrounded speed is 54.0 → 55 mph*
  - *If unrounded speed is 53.9 → 50 mph*

45					50					55				
44	45	46	47	48	49	50	51	52	53	54	55	56	57	58

Determine Advisory Speed

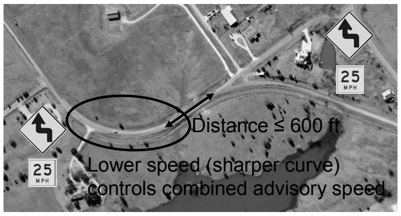
- TCAS Software
  - *In the office*
  - *In the field*



Advisory Speed	
Survey method (partial or full)	Partial
Total deflection angle, degrees	90
Curve deflection angle, degrees	30.0
Curve radius, ft	453
Degree of curvature, degrees	12.6
Curve path radius, ft	463
Superelevation rate, percent	8.0
Average tangent speed, mph	56
Unrounded advisory speed, mph	43
Rounded advisory speed, mph	**40**

Determine Advisory Speed

- TxDOT Guidance
  - *Procedures for Establishing Speed Zones*

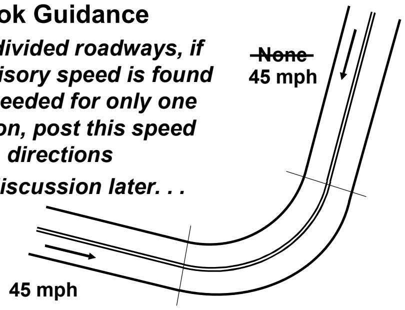


Distance ≤ 600 ft

Lower speed (sharper curve) controls combined advisory speed

Determine Advisory Speed

- **Handbook Guidance**
  - *On undivided roadways, if an advisory speed is found to be needed for only one direction, post this speed in both directions*
  - *More discussion later. . .*



4. Advisory Speed Procedure

- Determine Advisory Speed ✓
- Confirm Speed for Conditions
- Participant Exercise

Confirm Speed for Conditions

- Engineering Study
  - *Site-specific examination*
  - *Issues <u>not</u> considered by TCAS include:*
    - Approach sight distance
    - Visibility around curve
    - Intersections in curve
    - Proximity to other curves
    - Crash history
  - *Test run at the advisory speed*
    - Does the advisory speed “feel” right?
  - *Adjust guidance from TCAS if appropriate*

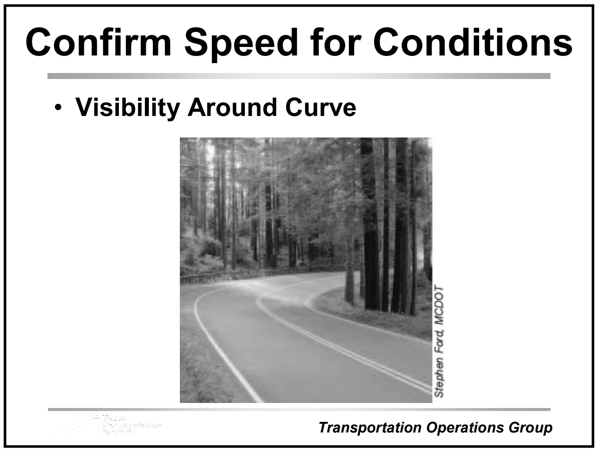
Confirm Speed for Conditions

- Approach Sight Distance

Confirm Speed for Conditions

- Approach Sight Distance

MoDOT

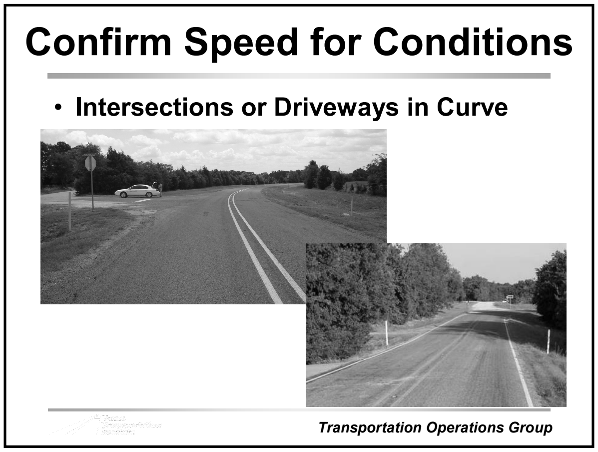


Confirm Speed for Conditions

- Visibility Around Curve

Stephen Ford, MCDOT

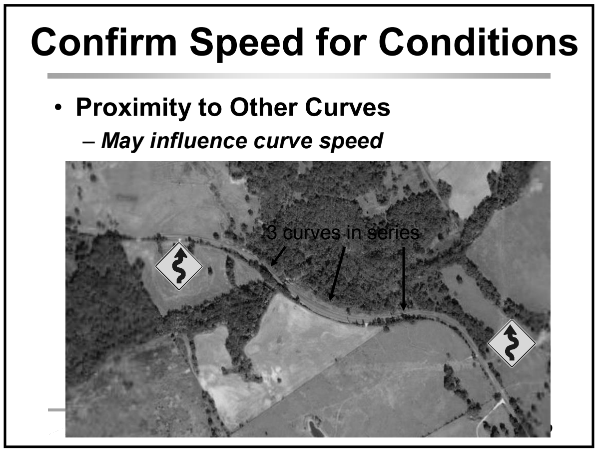
Transportation Operations Group



Confirm Speed for Conditions

- Intersections or Driveways in Curve

Transportation Operations Group

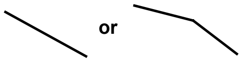


Confirm Speed for Conditions

- Proximity to Other Curves
  - *May influence curve speed*

Confirm Speed for Conditions

- Check Data Consistency
  - *Consistent between opposing directions?*
    - Superelevation
      - Differ by 0 - 4%



    - Radius
      - Within 10% in opposing directions
    - Deflection angle
      - Within 2 degrees in opposing directions
    - Smooth curve tracking is important
  - *Consistent with judgment?*
    - 85th percentile tangent speed

Confirm Speed for Conditions

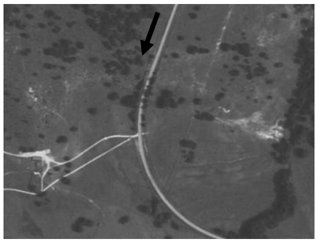
- Example
  - *Radius and deflection angle are consistent*
  - *Superelevation differs by 7%*
  - *Consider re-driving the curve*

Direction	Left	Right
Radius (ft)	1040	1105
Deflection angle (deg)	38	38
Superelevation (%)	2	9

Questions?

Exercise 3

- **Objectives**
  - *Determine needed devices and advisory speed*
    - Record answers on page 50



Exercise 3

- **Data**
  - *Speed limit: 60 mph*
  - *Advisory speed: 50 mph*

Exercise 3

- **Data**
  - *Lane width: 10.5 ft*
  - *AADT: 310 veh/d*

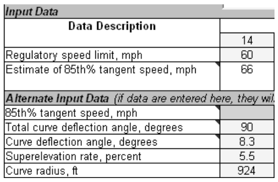
Exercise 3

- Data
  - *Regulatory speed limit: 60 mph*
  - *Total deflection angle: 90 degrees*
  - *Curve deflection angle: 8.3 degrees*
  - *Superelevation rate: 5.5 percent*
  - *Radius: 924 ft*
- Question
  - *What devices are needed?*
  - *What is the advisory speed?*

Transportation Operations Group

Exercise 3

- Results



Input Data

Data Description	
	14
Regulatory speed limit, mph	60
Estimate of 85th% tangent speed, mph	66
Alternate Input Data *(if data are entered here, they wil*	
85th% tangent speed, mph	
Total curve deflection angle, degrees	90
Curve deflection angle, degrees	8.3
Superelevation rate, percent	5.5
Curve radius, ft	924

Advisory Speed

Traffic Control Device Guidance

Trans

Exercise 3

Condition	Existing	Proposed
Advisory Speed		
Delineation		

- Discussion

Transportation Operations Group

Exercise 3

- Discussion
  - *Southbound approach has 5.5 percent downhill grade*
  - *Review of crash data reveals crash problem on this approach (run-off-road near PC)*
  - *May consider adding delineators (usually reserved for category C or worse)*

Questions – Comments?

5. Curve Signing Guidelines

- Curve Severity Categories
- Guidelines
- Participant Exercise

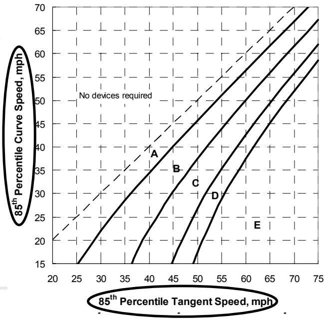
Curve Severity Categories

- Curve Severity
  - *Based on energy required to slow*
  - *Similar to speed reduction (but based on speed squared)*
  - *Concept embodied in other guidance*
    - TMUTCD Table 2C- 4
      - Sign placement based on speed squared
      - 70 to 50 mph → sign 250 ft ahead of curve
      - 60 to 40 mph → sign 175 ft ahead of curve
      - 40 to 20 mph → sign at curve PC
- Categories
  - *A, B, C, D, E*

Transportation Operations Group

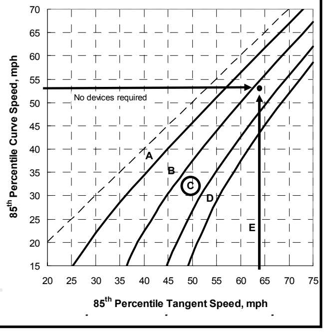
Severity Evaluation

- Methods
  - *Equation in TCAS*
  - *Chart in Handbook*
  - *Based on 85th percentile speeds*
  - *Note*
    - Category D is unlikely when 85th% speed is less than 45 mph



Severity Evaluation

- Example – Curve 65
  - *85th% tangent speed is 64 mph*
  - *85th% curve speed is 53 mph*
  - *Category is C*



5. Curve Signing Guidelines

- Curve Severity Categories ✓
- Guidelines
- Participant Exercise

Guidelines

- Guidelines for Selection of Devices
  - *Warning signs*
  - *Delineation devices*
  - *Special treatments*
    - Oversize curve warning signs
    - Flashers added to signs
    - Wider edge lines
    - Profiled edge lines
    - Increase superelevation rate
    - Flatten curve

Special Treatments

- Pavement Markings
- Flashers w/ Signs

Guidelines

- **Advisory Speed of 35 mph or More**
  - ✔ *= Recommended*
  - ✓ *= Optional*
  - *Recognizes option for 2nd sign at curve PC (TMUTCD Section 2C.06)*

Device Type	Device Name	Device Number	Curve Severity Category				
			A	B	C	D	E
Warning Signs	Curve, Reverse Curve, Winding Road, Hairpin Curve	W1-2, W1-4, W1-5, W1-11	✓	✔	✔	✔	✔
	Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
	Additional Curve, Hairpin Curve	W1-2, W1-11	▨	▨	✓	✓	✓
	Chevrons	W1-8	▨	▨	▨	✔	✔

Guidelines

- **Advisory Speed of 30 mph or Less**
  - *Use of "Turn" vs. "Curve"*
  - *Use of Large Arrow sign vs. Chevron*

Device Type	Device Name	Device Number	Curve Severity Category				
			A	B	C	D	E
Warning Signs	Turn, Reverse Turn, Winding Road, Hairpin Curve	W1-1, W1-3, W1-5, W1-11	✓	✔	✔	✔	✔
	Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
	Additional Turn, Hairpin Curve	W1-1, W1-11	▨	▨	✓	✓	✓
	Large Arrow sign	W1-6	▨	▨	▨	✔	✔

Guidelines

- **Delineation Devices**
- **Special Treatments**

Device Type	Device Name	Device Number	Curve Severity Category				
			A	B	C	D	E
Delineation Devices	Raised pavement markers		✔	✔	✔	✔	✔
	Delineators		▨	▨	✓	✓	✓
Special Treatments			▨	▨	▨	▨	✔

Guidelines

- **Table 1 in Handbook**

Advisory Speed, mph	Device Type	Device Name	Device Number	Curve Severity Category				
				A	B	C	D	E
35 mph or more	Warning Signs	Curve, Reverse Curve, Winding Road, Hairpin Curve	W1-2, W1-4, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
		Additional Curve, Hairpin Curve	W1-2, W1-11	▨	▨	✓	✓	✓
		Chevrons	W1-8	▨	▨	▨	✔	✔
30 mph or less	Warning Signs	Turn, Reverse Turn, Winding Road, Hairpin Curve	W1-1, W1-3, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
		Additional Turn, Hairpin Curve	W1-1, W1-11	▨	▨	✓	✓	✓
		Large Arrow sign	W1-6	▨	▨	▨	✔	✔
Any	Delineation Devices	Raised pavement markers		✔	✔	✔	✔	✔
		Delineators		▨	▨	✓	✓	✓
	Special Treatments			▨	▨	▨	▨	✔

Guidelines

- **Example**
  - ***Curve category B and adv. speed of 40 mph***

Advisory Speed, mph	Device Type	Device Name	Device Number	Curve Severity Category				
				A	B	C	D	E
35 mph or more	Warning Signs	Curve, Reverse Curve, Winding Road, Hairpin Curve	W1-2, W1-4, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
		Additional Curve, Hairpin Curve	W1-2, W1-11	▨	▨	✓	✓	✓
		Chevrons	W1-8	▨	▨	▨	✔	✔
30 mph or less	Warning Signs	Turn, Reverse Turn, Winding Road, Hairpin Curve	W1-1, W1-3, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
		Additional Turn, Hairpin Curve	W1-1, W1-11	▨	▨	✓	✓	✓
		Large Arrow sign	W1-6	▨	▨	▨	✔	✔
Any	Delineation Devices	Raised pavement markers		✔	✔	✔	✔	✔
		Delineators		▨	▨	✓	✓	✓
	Special Treatments			▨	▨	▨	▨	✔

Guideline Comparison

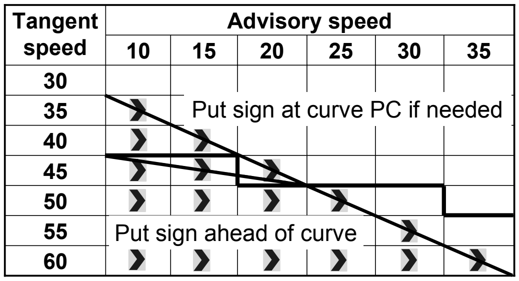
- **TMUTCD Table 3D-3**

Amount by which Advisory Speed is less than Posted Speed	Warning Devices needed
0 to 14 MPH 15 to 24 MPH 25 MPH or greater	RPM's RPM's and Delineators RPM's and Chevron

  - ***Based on <u>speed</u> reduction***
  - ***Use <u>posted</u> regulatory and advisory speeds***
- **TMUTCD Table 2C-4**
  - ***Based on <u>energy</u> reduction (speed <u>squared</u>)***
  - ***Use regulatory <u>or</u> 85th percentile speed***

Guideline Comparison

- **Comparison (TMUTCD & New Guidance)**



Tangent speed	Advisory speed					
	10	15	20	25	30	35
30						
35	❯	Put sign at curve PC if needed				
40	❯	❯				
45	❯	❯	❯			
50	❯	❯	❯	❯		
55	Put sign ahead of curve				❯	
60	❯	❯	❯	❯	❯	❯

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5. Curve Signing Guidelines

- **Curve Severity Categories** ✓
- **Guidelines** ✓
- **Participant Exercise**

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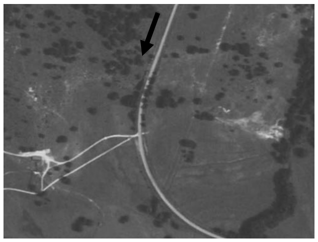
Exercise 4

- **Objectives**
  - ***Assess robustness of guidance from Exercise 3***
    - **Record answers on page 50**



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Exercise 4

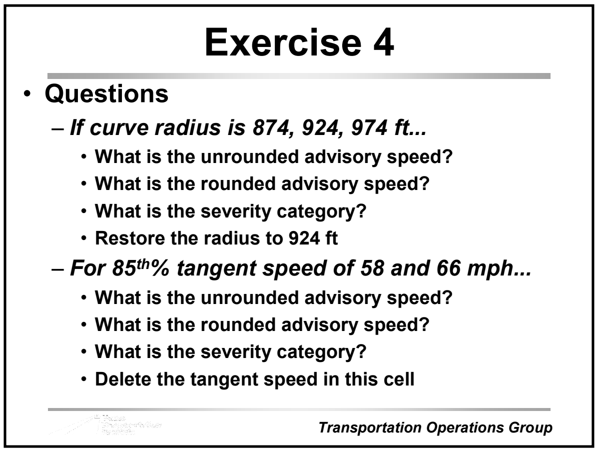
- **Data**
  - *Speed limit: 60 mph*
  - *Advisory speed: 50 mph*

Exercise 4

- **Data**
  - *Regulatory speed limit: 60 mph*
  - *Total deflection angle: 90 degrees*
  - *Curve deflection angle: 8.3 degrees*
  - *Superelevation rate: 5.5 percent*
  - *Radius: 924 ft*

Exercise 4

- **Questions**
  - *For total deflection angles of 80, 90, 100 deg...*
    - What is the unrounded advisory speed?
    - What is the rounded advisory speed?
    - What is the severity category?
    - Restore the total deflection angle to 90 degrees
  - *If the superelevation rate is 4, 5.5, 7 percent...*
    - What is the unrounded advisory speed?
    - What is the rounded advisory speed?
    - What is the severity category?
    - Restore the superelevation rate to 5.5 percent



Exercise 4

- **Questions**
  - ***If curve radius is 874, 924, 974 ft...***
    - **What is the unrounded advisory speed?**
    - **What is the rounded advisory speed?**
    - **What is the severity category?**
    - **Restore the radius to 924 ft**
  - ***For 85th% tangent speed of 58 and 66 mph...***
    - **What is the unrounded advisory speed?**
    - **What is the rounded advisory speed?**
    - **What is the severity category?**
    - **Delete the tangent speed in this cell**

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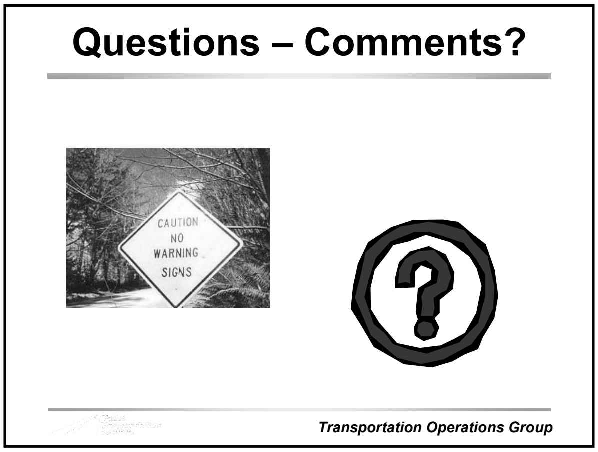
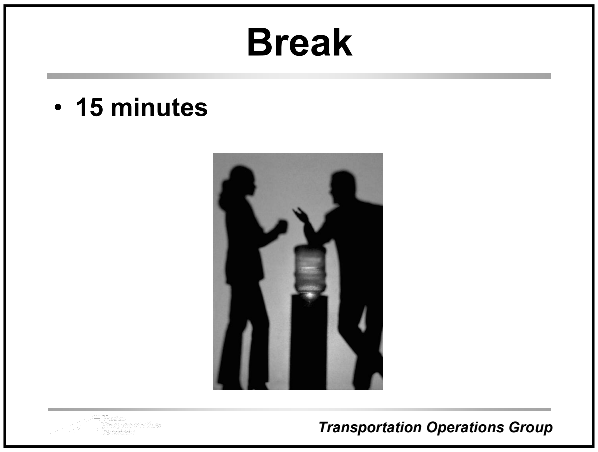


Questions – Comments?

Transportation Operations Group



Break

- **15 minutes**

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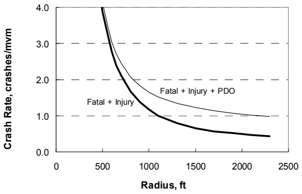
6. Engineering Principles

- Curve Safety
- Curve Speed
- Driver Speed vs. Speed Limit

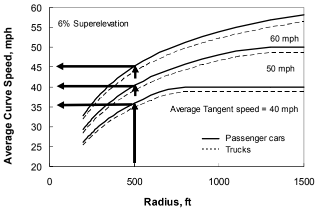
Curve Safety

- **Curve Crashes**
  - *Crash risk increases rapidly with decreasing radius*
  - *Likely to be severe*
- **Causes**
  - *Distracted driver*
  - *Poor judgment*



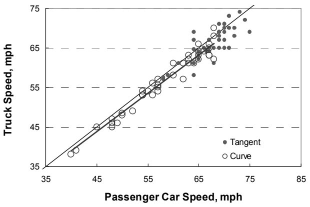
Curve Speed

- **Effect of Radius & Tangent Speed**
  - *Drivers accept slower speed on sharper radii*
  - *Drivers reduce speed to safely traverse curve*
  - *Reduction is influenced by tangent speed*



Curve Speed

- **Other Factors Affecting Curve Speed**
  - ***Vehicle type***
    - **Trucks are generally slower than cars by 2-3%**

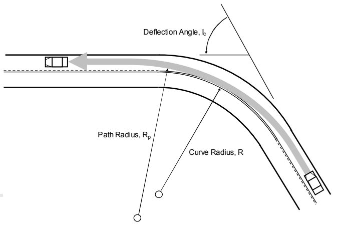


Curve Speed

- **Other Factors Affecting Curve Speed**
  - ***Superelevation rate***
    - **1 mph increase for each 2% increase**
  - ***Tangent length***
    - **Higher speeds when tangents are “long”**

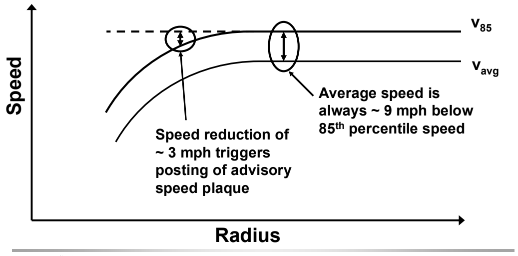
Curve Speed

- **Path Radius**
  - ***Drivers tend to flatten curve***
  - ***Most significant on curves with small deflection angles***



Curve Speed

- Severity Thresholds
  - *70-mph roadway*



Average speed is always ~ 9 mph below 85th percentile speed

Speed reduction of ~ 3 mph triggers posting of advisory speed plaque

Curve Speed

- Meaning of Thresholds
  - *Indicate sufficient severity to suggest need for devices (i.e., "trigger")*
  - *Based on a <u>given driver's</u> speed reduction (85th%), <u>not</u> speed distribution*

Curve Number	85th% speeds		Average speeds	
	Tangent	Curve	Tangent	Curve *
1	72	72	63	63
2	72	68	63	58

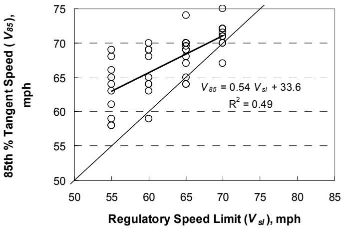
* "Unrounded advisory speed" in TCAS

Driver Speed vs. Speed Limit

- Guidelines Often Based on Speed Limit
  - *TMUTCD*
    - Advance Placement of Warning Signs (Table 2C-4)
    - RPMs, Delineators, and Chevrons (Table 3D-3)
- Assumption
  - *Speed limit is surrogate for actual traffic speed*
- Benefit
  - *Speed limit is readily available information*

Driver Speed vs. Speed Limit

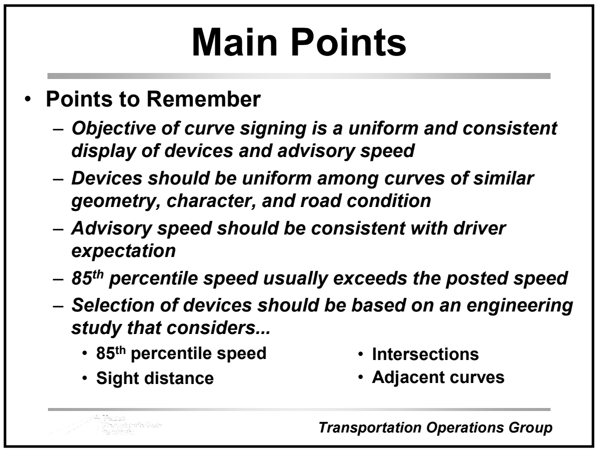
- **Measurement of Highway Tangent Speed**
  - *40 two-lane rural highways in Texas*
- **Conclusion**
  - *85th% speed exceeds the speed limit*
  - *Amount varies*
  - *Some unexplained variation*



Driver Speed vs. Speed Limit

- **Conclusion**
  - *Signing decisions should be based on 85th percentile speed*
    - This practice will promote consistency
  - *If speed limit is used, be sure it represents the 85th percentile speed*
    - Highways with a notably low speed limit should be addressed
    - In no case, should the advisory speed exceed the speed limit

Questions?



Main Points

- **Points to Remember**
  - ***Objective of curve signing is a uniform and consistent display of devices and advisory speed***
  - ***Devices should be uniform among curves of similar geometry, character, and road condition***
  - ***Advisory speed should be consistent with driver expectation***
  - ***85th percentile speed usually exceeds the posted speed***
  - ***Selection of devices should be based on an engineering study that considers...***
    - **85th percentile speed**
    - **Sight distance**
    - **Intersections**
    - **Adjacent curves**

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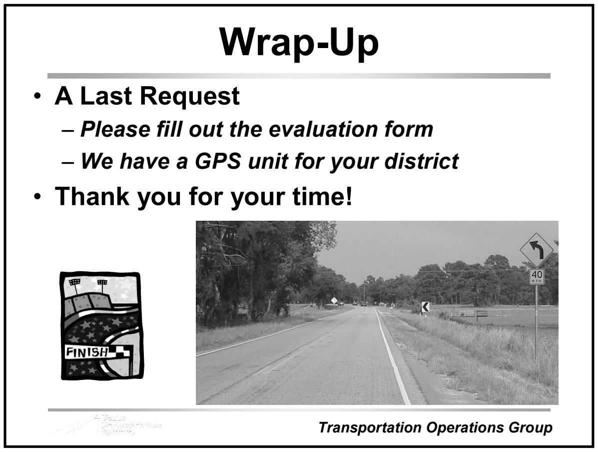

Wrap-Up

- **A Last Request**
  - ***Please fill out the evaluation form***
  - ***We have a GPS unit for your district***
- **Thank you for your time!**

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EXERCISE 1

INPUT DATA

Regulatory speed limit: 60 mph
Total deflection angle: 51 degrees
Curve deflection angle: 17 degrees
Superelevation rate: 6.5 percent
Curve radius: 715 ft

OUTPUT SUMMARY

What devices are needed? ____

____

What is the advisory speed? ______________

EXERCISE 2

INPUT DATA

Regulatory speed limit: 55 mph
Total deflection angle: 83.9 degrees
Curve deflection angle: 6.2 degrees
Superelevation rate: 5.7 percent
Curve radius: 278 ft

OUTPUT SUMMARY

What devices are needed? ____

____

What is the advisory speed? ______________

EXERCISES 3 & 4

INPUT DATA

Regulatory speed limit: 60 mph
Total deflection angle: 90 degrees
Curve deflection angle: 8.3 degrees
Superelevation rate: 5.5 percent
Curve radius: 924 ft

OUTPUT SUMMARY

Exercise 3

What devices are needed? ____

____

What is the advisory speed? ____________

Exercise 4

What happens if the input data are changed?

Total deflection angle	**80 degrees**	**90 degrees**	**100 degrees**
Unrounded advisory speed			
Rounded advisory speed			
Severity category			

Superelevation rate	**4 percent**	**5.5 percent**	**7 percent**
Unrounded advisory speed			
Rounded advisory speed			
Severity category			

Curve radius	**874 ft**	**924 ft**	**974 ft**
Unrounded advisory speed			
Rounded advisory speed			
Severity category			

85th percentile tangent speed	**58 mph**	**66 mph**
Unrounded advisory speed		
Rounded advisory speed		
Severity category		

HORIZONTAL CURVE SIGNING WORKSHOP:
PROCEDURES FOR SETTING CURVE ADVISORY SPEED

Date:
Location:

Your
Agency:____

Your Position:______________________________________

Course Content (circle one)

	Yes				No
1. Did the course meet your expectations? Comments:	1	2	3	4	5
2. Was the material presented at the correct level of difficulty? Comments:	1	2	3	4	5
3. Was the topic of the course covered adequately (nothing left out, no one topic overemphasized)? Comments:	1	2	3	4	5
4. Was the software easy to use? Comments:	1	2	3	4	5

General Observations

5. What did you like most about the course?

6. What did you like the least about the course?

7. What can we do to improve this workshop?

8. Other Comments:

Thank you for taking the time to complete this course evaluation form. Please make sure the course instructor receives it before you leave.

WORKSHOP HANDOUTS

A. HORIZONTAL CURVE SIGNING HANDBOOK, 2nd EDITION
B. SELECTED TABLES FROM THE *TMUTCD*
C. DATA COLLECTION SHEET

APPENDIX A

HORIZONTAL CURVE SIGNING HANDBOOK, 2nd EDITION

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

OVERVIEW

Horizontal curves are a necessary component of the highway alignment; however, they tend to be associated with a disproportionate number of severe crashes. Each year in the United States, about 38,000 fatal crashes occur on the highway system with 25 percent of the fatalities found to occur on horizontal curves (*1*). Texas accounts for about 3200 of these fatal crashes, with about 44 percent of Texas' crashes occurring on horizontal curves. Hence, Texas is over-represented in terms of its proportion of fatal curve-related crashes, relative to the national average.

Warning signs are intended to improve curve safety by alerting the driver to a change in geometry that may not be apparent or expected. These signs notify drivers of the change through the use of one or more of the curve warning signs identified in the *Manual on Uniform Traffic Control Devices* (*MUTCD*) (*2*). These drivers may also be notified of the need to reduce their speed through the use of an Advisory Speed plaque.

Several research projects conducted in the last 20 years have consistently shown that drivers are not responding to curve warning signs nor complying with the Advisory Speed plaque. Evidence of this non-responsiveness is evidenced by the aforementioned curve crash statistics. Chowdhury et al. (*3*) suggest that current practice in the U.S. for setting advisory speeds is contributing to this lack of compliance and the poor safety record. They advocate the need for a procedure that can be used to: (1) identify when a curve warning sign and advisory speed are needed, and (2) select an advisory speed that is consistent with driver expectation. They also recommend the uniform use of this procedure on a nationwide basis, such that driver respect for curve warning signs is restored and curve safety records are improved.

PURPOSE AND SCOPE

The procedures described in this handbook are intended to improve consistency in curve signing and driver compliance with the advisory speed. The handbook describes guidelines for determining when an advisory speed is needed, criteria for identifying the appropriate advisory speed, an engineering study method for determining the advisory speed, and guidelines for selecting other curve-related traffic control devices.

The handbook is intended for use by traffic engineers and technicians who have been given the responsible charge of evaluating and maintaining horizontal curve signing and delineation devices. The procedures described in this handbook are applicable to rural highways. However, they may be useful for establishing advisory speeds for urban streets.

The curve advisory speed and other curve-related traffic control devices should be checked periodically to ensure that they are appropriate for the prevailing conditions. Changes in the regulatory speed limit, curve geometry, or crash history may justify the conduct of an engineering study to re-evaluate the appropriateness of the existing signs and the need for additional signs.

CHAPTER 2. COMMUNICATING CHANGES IN HORIZONTAL ALIGNMENT

OVERVIEW

This chapter provides a brief overview of topics related to horizontal curve safety, operation, and curve warning signs. It consists of three parts. The first part examines the safety and operation of horizontal curves. The second part reviews the various warning signs that are used to sign horizontal curves. The last part provides an overview of the Texas Curve Advisory Speed (TCAS) software that was developed to automate the procedures and guidelines described in Chapters 3 and 4, respectively.

Additional background information about curve advisory speed is provided in Reference *4*. The information in this report examines the objectives of curve signing and the challenges associated with establishing advisory speeds that are uniform among curves and consistent with driver expectation. This report also reviews the various criteria that have been used to set advisory speeds.

HORIZONTAL CURVE SAFETY AND OPERATION

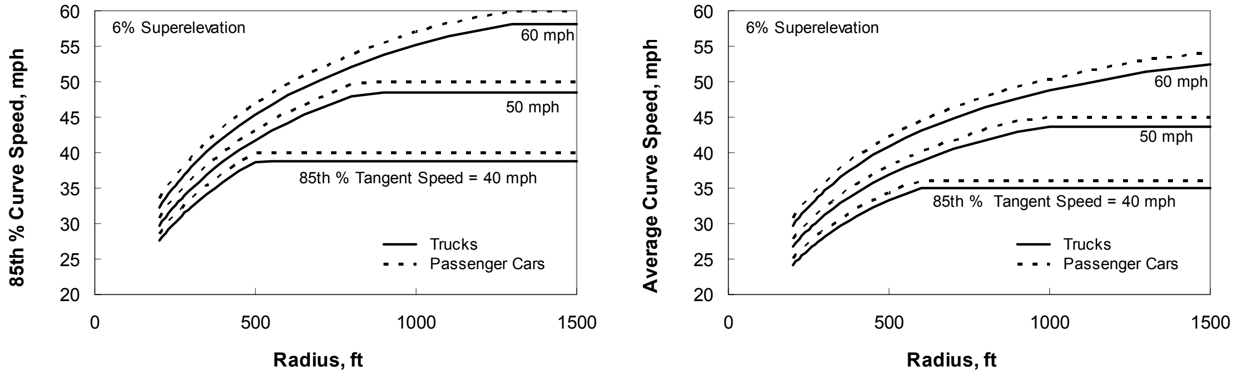
This part of the chapter examines the factors that influence the safety and operation of horizontal curves. The focus of the examination is on factors related to the curve's geometric design. The relationship between curve design and driver speed choice is described in the first section. Then, the relationship between curve design and crash rate is explored in the second section.

Curve Speed

A review of the literature indicates that several variables can have an influence on curve speed. These variables include:

- radius,
- superelevation rate,
- tangent speed,
- vehicle type,
- curve deflection angle,
- tangent length,
- curve length,
- available stopping sight distance,
- grade, and
- vertical curvature.

Of those variables in the aforementioned list, research indicates that the first five variables have the most significant effect on curve speed. Using data collected on rural highways in Texas, Bonneson et al. (*4*) developed a curve speed prediction model that includes a sensitivity to these variables. The speeds predicted by this model are shown in Figure 1. The trends shown indicate that the average truck speed equals about 97 percent of the average passenger car speed.



a. 85th Percentile Speed. **b. Average Speed.**

Figure 1. Effect of Radius, Tangent Speed, and Vehicle Type on Curve Speed.

The trend lines in Figure 1 indicate that drivers on sharper curves slow from the tangent speed to an acceptable curve speed. The amount of speed reduction increases with decreasing radius. For curves with a 500 ft radius and a 60 mph tangent speed, the reduction is about 10 mph. In contrast, for a 1000 ft radius and 60 mph tangent speed, the reduction is only about 5 mph.

The effect of superelevation rate is not shown in Figure 1. However, the model indicates that curve speed increases about 1.0 mph for every 2.0 percent increase in superelevation rate.

Curve Safety

Bonneson et al. (*4*) examined the relationship between curve radius and crash rate using safety relationships documented in the literature (*5, 6*). These relationships are shown in Figure 2. Crash rate is defined in this figure in terms of crashes per million vehicle miles (crashes/mvm). One trend line represents the combination of fatal and injury crashes. The other trend line represents the combination of fatal, injury, and property-damage-only (PDO) crashes.

The two trend lines in Figure 2 are in fairly good agreement. They indicate that the crash rate increases sharply for curves with a radius of less than 1000 ft. They also indicate that most crashes on sharper curves result in an injury or fatality.

Based on the discussion in this and the previous sections, it is likely that the trends in Figure 2 are reflecting driver error while entering or traversing a curve. It is possible that some drivers are distracted or impaired and do not track the curve. It is also possible that some drivers detect the curve but do not correctly judge its sharpness. In both instances, traffic control devices have the potential to improve safety by making it easier for drivers to detect the curve and judge its sharpness.

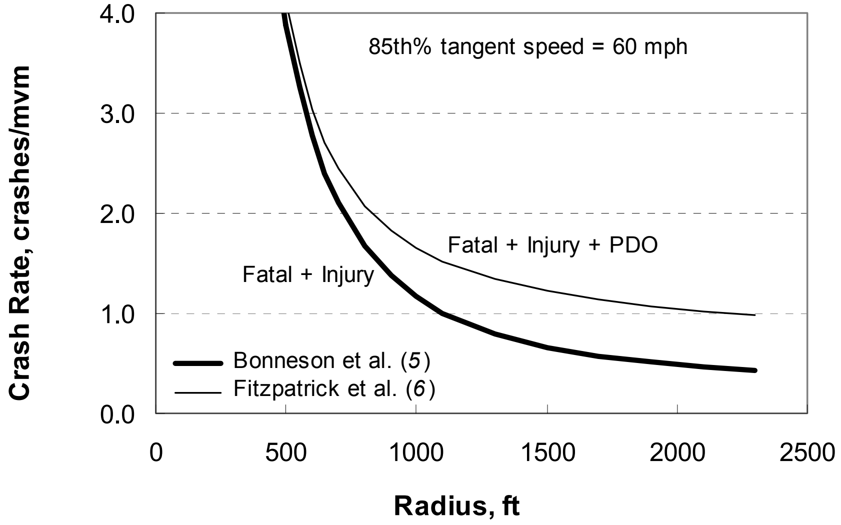


Figure 2. Curve Crash Rate as a Function of Radius.

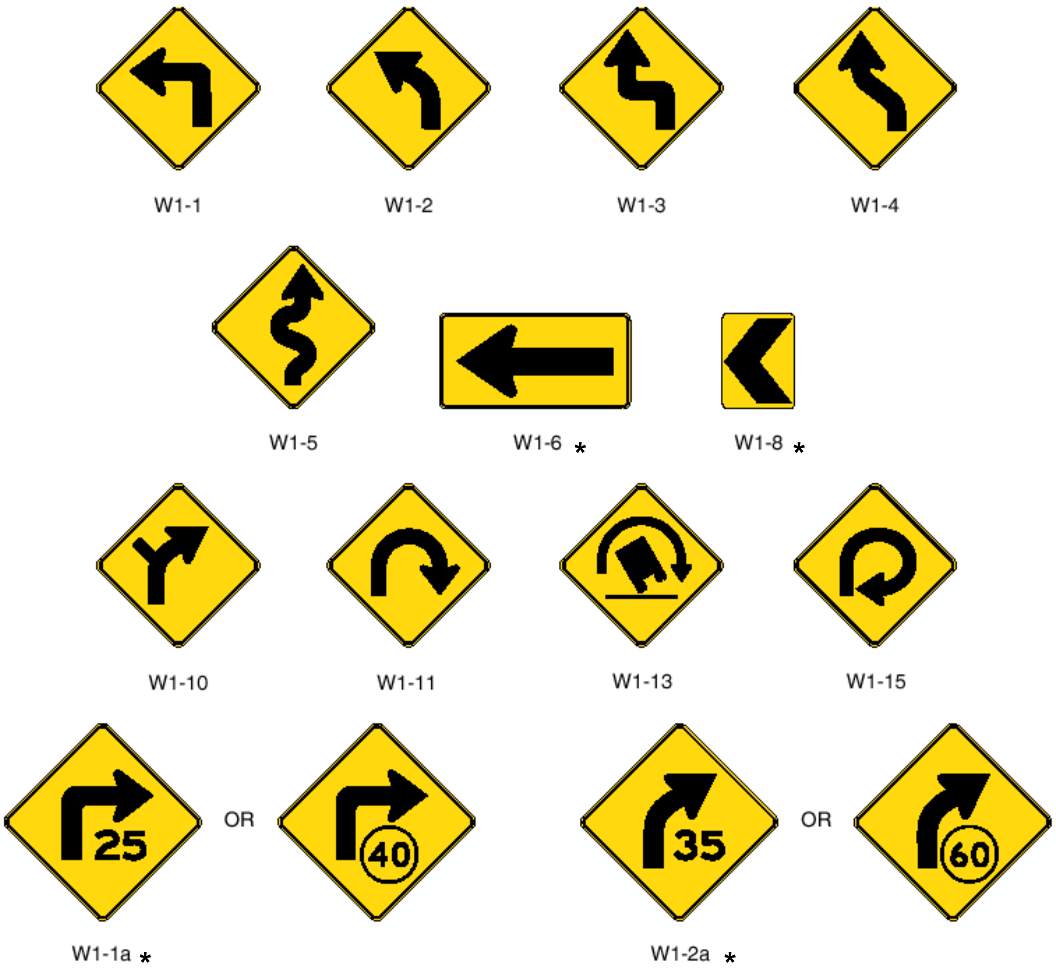
WARNING SIGNS FOR CHANGES IN HORIZONTAL ALIGNMENT

Most transportation agencies use a variety of traffic control devices to inform road users of a change in horizontal alignment. These devices include curve warning signs, delineation devices, and pavement markings. The focus of this part of the chapter is on curve warning signs; however, conditions where other traffic control devices may be helpful are also identified.

Curve Warning Signs

The *MUTCD* (*2*) identifies a variety of warning signs that can be used where the horizontal alignment changes in an unexpected or restrictive manner. These signs are shown in Figure 3a. There are two sign categories shown: advance signs and supplemental signs. Advance signs are located in advance of the curve. Signs in this category include: Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), Hairpin (W1-11), Truck Rollover Warning (W1-13), and 270-degree Loop (W1-15). These signs are recognized in the *Texas Manual on Uniform Traffic Control Devices* (*TMUTCD*) (*7*). In contrast, the Combination Horizontal Alignment/Intersection (W1-10) is not recognized in the *TMUTCD*.

One additional sign that falls in the advance sign category is the Advisory Speed plaque (W13-1). This sign is shown in Figure 3b. It is used to advise drivers of the speed found to be appropriate based on an engineering study. When used, it is combined with one of the advance horizontal alignment signs and mounted on the same sign post.



a. Horizontal Alignment Signs.

* Denotes "supplemental" sign.
Signs without asterisk represent "advance" signs.

b. Advisory Speed Plaques.

Figure 3. Curve Warning Signs.

The second category of sign is the supplemental sign. They are shown in Figures 3a and 3b, and are denoted by an asterisk ("*"). Signs in this category are used with advance signs to amplify or reinforce their message. Supplemental signs are used at, or within, the curve. Supplemental signs include: One-Direction Large Arrow (W1-6), Chevron (W1-8), Turn/Advisory Speed (W1-1a), Curve/Advisory Speed (W1-2a), and Curve Speed (W13-5). The W1-1a and W1-2a signs are not recognized in the *TMUTCD*.

The *MUTCD* guidance regarding the use of curve warning signs can be described as flexible. It encourages engineers to base their signing decisions on engineering studies and judgment. However, this flexibility has the disadvantage of occasionally promoting the inconsistent application of traffic control devices. Inconsistent device application makes it difficult for drivers to develop expectancies and, consequently, promotes disrespect for the device and mistrust of its message. The Advisory Speed plaque is one of most renowned examples of the consequences of inconsistent sign usage. Research has found it to be one of the more disrespected traffic control devices (*8*).

Effectiveness of Curve Warning Signs

Research indicates that the inconsistent use of curve warning signs, especially those with an Advisory Speed plaque, may have lessened the average motorist's respect for the message the signs convey. On familiar highways, drivers come to learn that they can comfortably exceed the advisory speed for most curves. The concern is that these drivers may occasionally travel on roadways that are less familiar to them and where the advisory speed is posted at the maximum safe speed. These drivers may find themselves traveling too fast for conditions and experience a crash.

Only one report was found in the literature that documented the effect of horizontal curve signing on safety. This report documented a before-after study by Hammer (*9*) of the installation of warning signs in advance of several curves. He found that the implementation of advance horizontal alignment signs reduced crashes by 18 percent. He also offered that the combined use of advance signing with an Advisory Speed plaque reduced crashes by 22 percent.

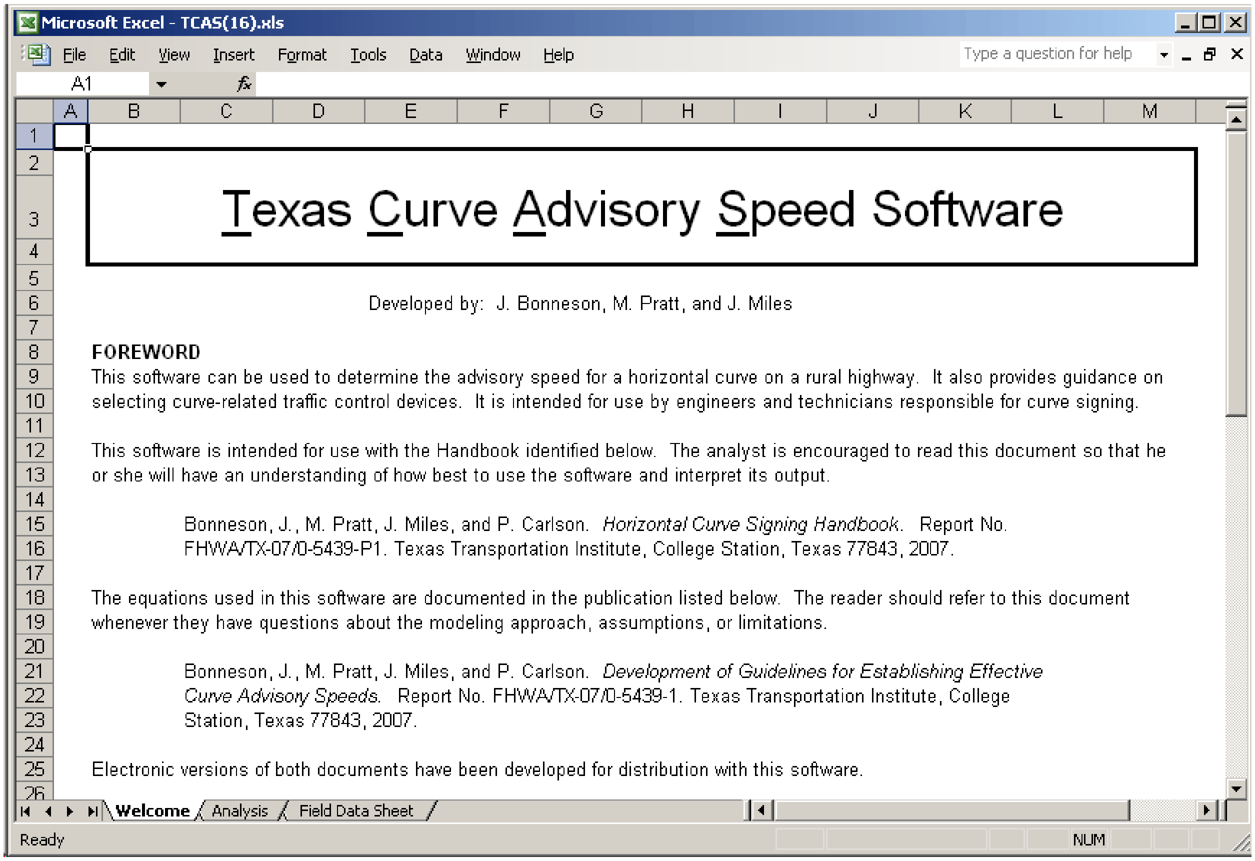
Research by Ritchie (*10*) examined driver response to the Curve sign and the Advisory Speed plaque. He found that average curve speeds exceeded the advisory speed when the advisory speed was less than 45 mph. The amount by which the average speed exceeded the advisory speed increased with decreasing advisory speeds. Thus, for an advisory speed of 40 mph, the average speed exceeded the advisory speed by only 2 mph (i.e., the average speed was 42 mph). However, for an advisory speed of 20 mph, the average speed exceeded the advisory speed by 10 mph.

The findings of this review are consistent with those noted in the previous part of this chapter. Specifically, drivers do not appear to be responding to the Advisory Speed plaque by reducing their speed to the advisory speed. Hence, speed reduction may be of limited value in assessing the effect this sign has on safety. Moreover, these findings suggest that advance information about an upcoming curve, as provided by a curve warning sign, may heighten driver awareness of the curve, but it does not cause them to slow significantly. It is this heightened awareness that likely produced the safety benefit found by Hammer (*9*).

TEXAS CURVE ADVISORY SPEED SOFTWARE

This part of the chapter provides an overview of the TCAS spreadsheet. This spreadsheet was developed to automate the procedures and guidelines described in this handbook. The background for the development of the equations in this spreadsheet is documented in a research report by Bonneson et al. (*4*).

The "Welcome" worksheet for TCAS is shown in Figure 4. This screen provides background information about the software, with reference to the aforementioned research report and this handbook. The tabs at the bottom of the Welcome worksheet can be used to select the other worksheets included in the software. The "Field Data Sheet" tab provides a template for the field data collection sheet. This sheet is also shown in Appendix C. The "Analysis" tab accesses the worksheet containing the curve advisory speed calculations. This worksheet is shown in Figure 5. Six columns are provided in the worksheet. One column is used for each curve being evaluated.



Texas Curve Advisory Speed Software

Developed by: J. Bonneson, M. Pratt, and J. Miles

FOREWORD

This software can be used to determine the advisory speed for a horizontal curve on a rural highway. It also provides guidance on selecting curve-related traffic control devices. It is intended for use by engineers and technicians responsible for curve signing.

This software is intended for use with the Handbook identified below. The analyst is encouraged to read this document so that he or she will have an understanding of how best to use the software and interpret its output.

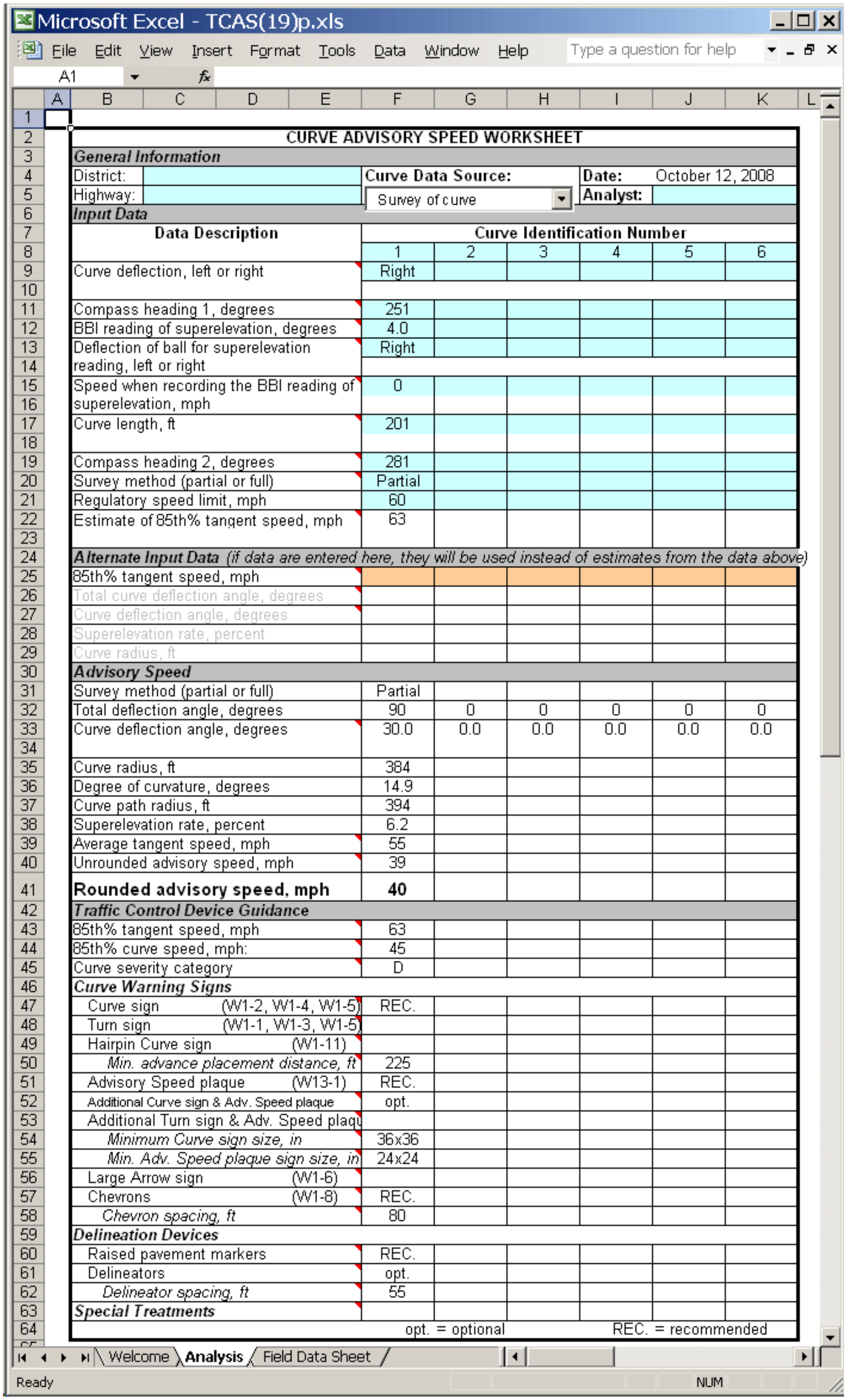
Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Horizontal Curve Signing Handbook*. Report No. FHWA/TX-07/0-5439-P1. Texas Transportation Institute, College Station, Texas 77843, 2007.

The equations used in this software are documented in the publication listed below. The reader should refer to this document whenever they have questions about the modeling approach, assumptions, or limitations.

Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Development of Guidelines for Establishing Effective Curve Advisory Speeds*. Report No. FHWA/TX-07/0-5439-1. Texas Transportation Institute, College Station, Texas 77843, 2007.

Electronic versions of both documents have been developed for distribution with this software.

Figure 4. TCAS Welcome Worksheet.



CURVE ADVISORY SPEED WORKSHEET

General Information						
District:		**Curve Data Source:**			**Date:**	October 12, 2008
Highway:		Survey of curve			**Analyst:**	
Input Data						
Data Description	**Curve Identification Number**					
	1	2	3	4	5	6
Curve deflection, left or right	Right					
Compass heading 1, degrees	251					
BBI reading of superelevation, degrees	4.0					
Deflection of ball for superelevation reading, left or right	Right					
Speed when recording the BBI reading of superelevation, mph	0					
Curve length, ft	201					
Compass heading 2, degrees	281					
Survey method (partial or full)	Partial					
Regulatory speed limit, mph	60					
Estimate of 85th% tangent speed, mph	63					
Alternate Input Data *(if data are entered here, they will be used instead of estimates from the data above)*						
85th% tangent speed, mph						
Total curve deflection angle, degrees						
Curve deflection angle, degrees						
Superelevation rate, percent						
Curve radius, ft						
Advisory Speed						
Survey method (partial or full)	Partial					
Total deflection angle, degrees	90	0	0	0	0	0
Curve deflection angle, degrees	30.0	0.0	0.0	0.0	0.0	0.0
Curve radius, ft	384					
Degree of curvature, degrees	14.9					
Curve path radius, ft	394					
Superelevation rate, percent	6.2					
Average tangent speed, mph	55					
Unrounded advisory speed, mph	39					
Rounded advisory speed, mph	**40**					
Traffic Control Device Guidance						
85th% tangent speed, mph	63					
85th% curve speed, mph:	45					
Curve severity category	D					
Curve Warning Signs						
Curve sign (W1-2, W1-4, W1-5)	REC.					
Turn sign (W1-1, W1-3, W1-5)						
Hairpin Curve sign (W1-11)						
Min. advance placement distance, ft	225					
Advisory Speed plaque (W13-1)	REC.					
Additional Curve sign & Adv. Speed plaque	opt.					
Additional Turn sign & Adv. Speed plaqu						
Minimum Curve sign size, in	36x36					
Min. Adv. Speed plaque sign size, in	24x24					
Large Arrow sign (W1-6)						
Chevrons (W1-8)	REC.					
Chevron spacing, ft	80					
Delineation Devices						
Raised pavement markers	REC.					
Delineators	opt.					
Delineator spacing, ft	55					
Special Treatments						
	opt. = optional			REC. = recommended		

Figure 5. TCAS Analysis Worksheet.

The spreadsheet can be used with two types of input data. One method is based on data obtained from a survey of the curve using the Compass Method. This method is described in Chapter 3. The use of this method is specified with the drop-down list located in cell F5 by selecting “Survey of curve,” as shown in Figure 5. The data from the Compass Method are entered in the cells that have a lightly shaded background in rows 9 through 21 are designated “input data” cells.

The second method is based on data describing the curve deflection angle, superelevation rate, and radius. These data can be obtained from the GPS Method or the Design Method, as described in Chapter 3. The use of either of these methods is specified with the drop-down list located in cell F5 by selecting “Known curve geometry.” The data from the GPS Method or the Design Method are entered in the cells in rows 26 through 29.

The cells in rows 31 to 63 that do not have background shading contain equations. The basis for each equation is documented in the aforementioned research report. These equations document the analysis of advisory speed for each of the six curves.

Shown in Figure 5 are the calculations associated with one curve. The speed limit of 60 mph correlates with an 85th percentile tangent speed of 63 mph. The field measurements indicate that the partial curve has a deflection angle of 30 degrees and a length of 201 ft. These two measures are used to compute the curve radius of 384 ft. The ball-bank reading of 4.0 degrees corresponds to a superelevation rate of 6.2 percent. All of these data are used to estimate the curve speed as 39 mph. This estimate is then rounded to 40 mph to obtain the recommended advisory speed.

The bottom third of the spreadsheet documents the traffic control device guidance. The third row in this section indicates the curve severity category. The guidelines described in Chapter 4 and those in the *TMUTCD* are used to calculate the information that is summarized in this section of the spreadsheet. For the example curve shown in Figure 5, a curve severity category D is indicated. For this category, a Curve sign and an Advisory Speed plaque are recommended. The sign and plaque should be posted 225 ft or more from the beginning of the curve.

The worksheet also provides information about other curve-related traffic control devices. For example, the worksheet indicates that the example curve is sufficiently severe that it may benefit from an additional Curve sign and Advisory Speed plaque located at the beginning of the curve. Chevrons are also recommended for this curve. If used, they should be spaced at 80 ft intervals along the curve. Delineators are optional for this curve. However, if they are used, they should be spaced at 55 ft intervals along the curve. Raised pavement markers are recommended if the curve is located in an area where snowfall is not frequent.

CHAPTER 3. METHODS FOR ESTABLISHING ADVISORY SPEED

OVERVIEW

Four methods for establishing curve warning signs and advisory speed are described in this chapter. The methods are based on the same criteria and will provide a uniform and consistent display of curve warning signs and advisory speed among curves, regardless of which method is used. For all methods, the advisory speed is defined as the average speed of free-flowing trucks.

The methods are all based on the premise that the need for various curve warning signs and the selection of an advisory speed should be based on the "critical" portion of the curve. The critical portion of the curve is defined as the section that has a radius and superelevation rate that combine to yield the largest side friction demand. Through this definition, the procedure is applicable to curves that have a constant radius, those that have compound curvature, and those that have spiral transitions.

Any one of the following four methods can be used to determine the curve advisory speed:

- Direct Method,
- Compass Method,
- Global Positioning System (GPS) Method, and
- Design Method.

Steps for implementing each method are described in this chapter. The Direct Method is based on the field measurement of curve speed. The Compass Method is based on a single-pass survey technique using a digital compass and distance measuring instrument to estimate the curve radius and deflection angle. The GPS Method is also based on a single-pass survey using a GPS receiver and software to compute radius and deflection angle. The Design Method is useful when the radius and deflection angle are available from as-built plans.

DIRECT METHOD

The Direct Method is based on the field measurement of vehicle speeds on the subject curve. The procedure for implementing the Direct Method consists of three steps. During the first step, speed measurements are taken in the field. During the second step, the measurements are used to compute the advisory speed. During the last step, the recommended advisory speed is confirmed through a field trial run. Each of these steps is described in the remainder of this section.

Step 1: Field Measurements

Measure the speed of free-flowing passenger cars at about the middle of the curve in one direction of travel. A free-flowing vehicle will be at least 3 s ahead of the next following vehicle and at least 3 s behind the previous vehicle. If a radar speed meter is used, then data collection can be discontinued after the speed of 125 cars has been measured or two hours have elapsed, whichever occurs first. If a traffic counter/classifier is used, then data collection can be discontinued after the speed of 125 cars has been measured or four hours have elapsed, whichever occurs first.

Repeat the measurements for the opposing direction of travel if the road is divided or if conditions suggest the need for separate consideration of each curve travel direction. When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be surveyed separately in this step.

Compute the arithmetic average of the measured speeds for each direction of travel at each curve studied. Also, compute the 85th percentile speed for each direction and curve.

Step 2: Determine Advisory Speed

Multiply each of the average speeds from Step 1 by 0.97 to obtain an estimate of the average truck speed for each direction of travel. The advisory speed for each direction of travel is then computed by first adding 1.0 mph to the corresponding average and then rounding the sum *down* to the nearest 5 mph increment. This technique yields a conservative estimate of the advisory speed by effectively rounding curve speeds that end in 4 or 9 up to the next higher 5 mph increment, while rounding all other speeds down. For example, applying this rounding technique to a curve speed of 54, 55, 56, 57, or 58 mph yields an advisory speed of 55 mph.

When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be evaluated separately in this step. The Advisory Speed plaque should show the value for the curve having the lowest advisory speed in the series.

For undivided roadways, if an advisory speed is determined to be needed for one curve travel direction but not for the opposite curve travel direction, then both directions of the curve should be posted with the advisory speed determined for the one direction.

Step 3: Confirm Speed for Conditions

During this step, the appropriateness of the advisory speed determined in Step 2 and the need for other curve warning signs is evaluated. As an initial task, the need for an Advisory Speed plaque is checked. A representative 85th percentile speed on tangent sections of the roadway is needed for this check. It can be measured using the procedure described in Step 1 or estimated from the regulatory speed limit. If it is measured, the point of measurement should be at least 8 s travel time from any curve in either direction. The 85th percentile tangent speed and the 85th percentile curve speed (from Step 1) are used with the guidelines in Chapter 4 to determine the need for an Advisory Speed plaque and other curve warning signs.

If the 85th percentile tangent speed exceeds the speed limit by a large amount, then it is possible to find that the advisory speed from Step 2 also exceeds the speed limit. In this situation, the disparity between the speed limit and 85th percentile tangent speed should be addressed and in no instance should the posted advisory speed exceed the speed limit.

A second task involves a field evaluation of curve conditions. The evaluation includes consideration of the following factors:

- driver approach sight distance to the beginning of the curve,
- visibility around the curve,
- unexpected geometric features within the curve, and
- position of the most critical curve in a sequence of closely-spaced curves.

The unexpected geometric features noted in the third bullet may include:

- presence of an intersection,
- presence of a sharp crest curve in the middle of the horizontal curve,
- sharp curves with changing radius (including curves with spiral transitions),
- sharp curves after a long tangent section, and
- broken-back curves.

A final task involves a test run through the curve while traveling at the advisory speed determined in Step 2. The engineer may choose to adjust the advisory speed or modify the warning sign layout based on consideration of the aforementioned factors. The advisory speed for one direction of travel through the curve may differ from that for the other direction.

COMPASS METHOD

The Compass Method is based on the field measurement of curve geometry. The geometric data are then used with a speed-prediction model to compute the advisory speed. The procedure for implementing the Compass Method is based on heading and curve length measurements taken at the critical portion of the curve. When spiral transitions or compound curves are present, this critical portion of the curve is typically found in the middle third of the curve, as shown in Figure 6. If the curve is truly circular for its entire length, then measurements made in the middle third will yield the same radius estimate as those made in other portions of the curve.

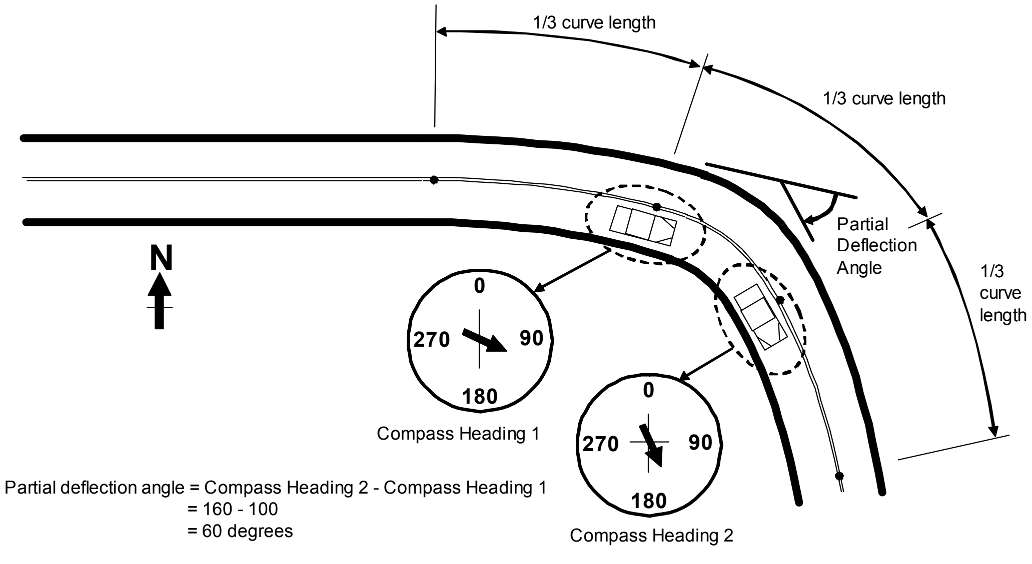


Figure 6. Location of Critical Portion of Curve.

The deflection angle associated with the critical portion is referred to as the "partial deflection angle." The curve length associated with the critical portion is referred to as the "partial curve length."

The procedure for implementing the Compass Method consists of three steps. During the first step, geometry measurements are taken in the field when traveling along the curve. During the second step, the measurements are used to compute the advisory speed. During the last step, the recommended advisory speed is confirmed through a field trial run. Each of these steps is described in more detail in the next three sections.

To ensure reasonable accuracy in the model estimates using this method, the total curve length should be 200 ft or more and the partial curve length should be 70 ft or more. Also, the curve deflection angle should be 12 degrees or more and the partial curve deflection angle should be 4 degrees or more. A curve with a deflection angle less than 12 degrees will rarely justify curve warning signs.

Step 1: Field Measurements

In the first step of the procedure, the technician travels through the subject curve and makes a series of measurements. These measurements include:

- curve deflection in direction of travel (i.e., left or right);
- heading at the "1/3 point" (i.e., a point that is located along the curve at a distance equal to 1/3 of curve length and measured from the beginning of the curve);
- ball-bank reading of curve superelevation rate at the "1/3 point";
- length of curve between the "1/3" and "2/3 points";
- heading at the "2/3 point"; and
- 85th percentile speed (can be estimated using the regulatory speed limit).

These measurements may require two persons in the test vehicle—a driver and a recorder. However, with some practice or through the use of a voice recorder, it is possible that the driver can also serve as the recorder such that a second person is not needed. The next two subsections describe the procedure for making the aforementioned field measurements.

Repeat the measurements for the opposing direction of travel if the road is divided or if conditions suggest the need for separate consideration of each curve travel direction. When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be surveyed separately in this step.

Equipment Setup

The test vehicle will need to be equipped with the following three devices:

- digital compass,
- distance-measuring instrument (DMI), and
- ball-bank indicator (BBI).

The digital compass' heading calculation should be based on global positioning system (GPS) technology with a position accuracy of 10 ft or less 95 percent of the time and a position update interval of 1 s or less. It must also have a precision of 1 degree (i.e., provide readings to the nearest whole degree).

The compass should be installed in the vehicle in a location that is easily accessed and in the recorder's field of view. The type of mounting apparatus needed may vary; however, the compass should be firmly mounted so that it cannot move while the test vehicle is in motion.

The DMI is used to measure the length of the curve. It should have a precision of 1 ft (i.e., provide readings to the nearest whole foot). The DMI can also be used to: (1) locate a specific curve (in terms of travel distance from a known reference point), and (2) verify the accuracy of the test vehicle's speedometer. The DMI can be mounted in the vehicle but should be removable such that it can be hand-held during the test run.

The ball-bank indicator must have a precision of at least 1 degree (i.e., provide readings to the nearest whole degree). Indicators with less precision (e.g., 5 degree increments) cannot be used with this method. The indicator should be installed along the center of the vehicle in a location that is easily accessed and in the recorder's field of view. The center of the dash is the recommended position because it allows the driver to observe both the road and the indicator while traversing the curve. The type of mounting apparatus needed may vary; however, the ball-bank indicator should be firmly mounted so that it cannot move while the test vehicle is in motion.

To ensure proper operation of the devices, it is important that the following steps are taken before conducting the test runs:

- Inflate all tires to a pressure that is consistent with the vehicle manufacturer's specification.
- Calibrate the test vehicle's DMI.
- Calibrate the ball-bank indicator.

The instruction manual for the DMI and the ball-bank indicator should be consulted for specific details of the calibration process.

Measurement Procedure

The following task sequence describes the field measurement procedure as it would be used to evaluate one direction of travel through the subject curve. Measurement error and possible differences in superelevation rate between the two directions of travel typically justify repeating this procedure for the opposing direction. Only one test run should be required in each direction.

a. Record the regulatory speed limit and the curve advisory speed.

b. Stay in the same lane for all measurements. Record the curve deflection (i.e., left or right) relative to the direction of travel. This designation indicates which direction the vehicle turns as it tracks the curve. A turn to the driver's right is designated as a right-hand deflection.

c. Advance the vehicle to the "1/3 point," as shown in Figure 6. This point is about one-third of the way along the curve when measured from the beginning of the curve in the direction of travel. It does not need to be precisely located. The technician's best estimate of this point's location is sufficient. This point is referred to hereafter as the point of partial curvature (PPC).

   Stop the vehicle and complete the following four tasks while at the PPC:

   - Record the vehicle heading (in degrees).
   - Press the Reset button on the DMI to zero the reading.
   - Record the ball-bank indicator reading (in degrees).
   - Record whether the ball has rotated to the left or right of the "0.0 degree" reading.

d. Advance the vehicle to the "2/3 point," as shown in Figure 6. This point is about two-thirds of the way along the curve. This point is referred to hereafter as the point of partial tangency (PPT).

   Stop the vehicle and complete the following two tasks while at the PPT:

   - Record the vehicle heading (in degrees).
   - Press the Display Hold button on the DMI.

   The value shown on the DMI is the partial curve length. With some practice, it may be possible to complete the two tasks listed above while the vehicle is moving slowly (i.e., 15 mph or less). However, if the measurements are taken while the vehicle is moving, is imperative that they represent the heading and length for the same exact point on the roadway. Error will be introduced if the heading is noted at one location and then the length is measured at another location.

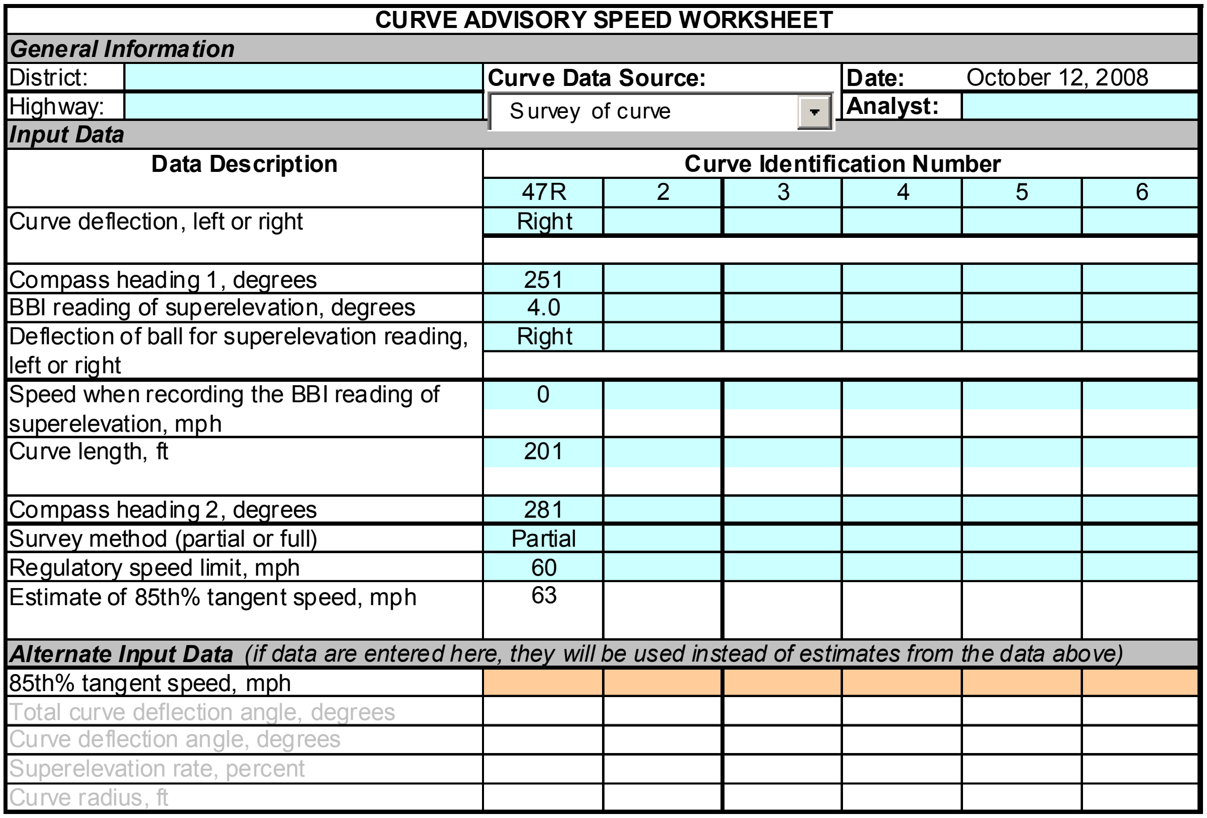
Step 2: Determine Advisory Speed

During this step, the field measurements are used to determine the appropriate advisory speed for a specified travel direction through the subject curve. The calculations are repeated to obtain the advisory speed for a different curve or for the opposing direction of travel through the same curve.

Initially, the data collected in Step 1 are entered in the Analysis worksheet of the TCAS software. The entry of data for example curve "47R" is shown in Figure 7. The measurements taken at this curve are shown in the column headed by the curve's identification number. The curve deflected to the right, relative to the direction of travel during curve measurement.

The compass heading at the first "1/3 point" was 251 degrees. A ball-bank indicator reading of 4.0 degrees was noted at this point. The ball deflected to the right of the "0.0 degrees" tick mark. This direction indicates that a positive (i.e., beneficial) superelevation is provided along the curve. The vehicle was stopped for these two measurements, so "0 mph" was input as the vehicle speed when the ball-bank indicator was read.

A curve length of 201 ft was measured at the "2/3 point." The compass heading at this point was 281 degrees. Finally, the regulatory speed limit of 60 mph is entered into the spreadsheet.



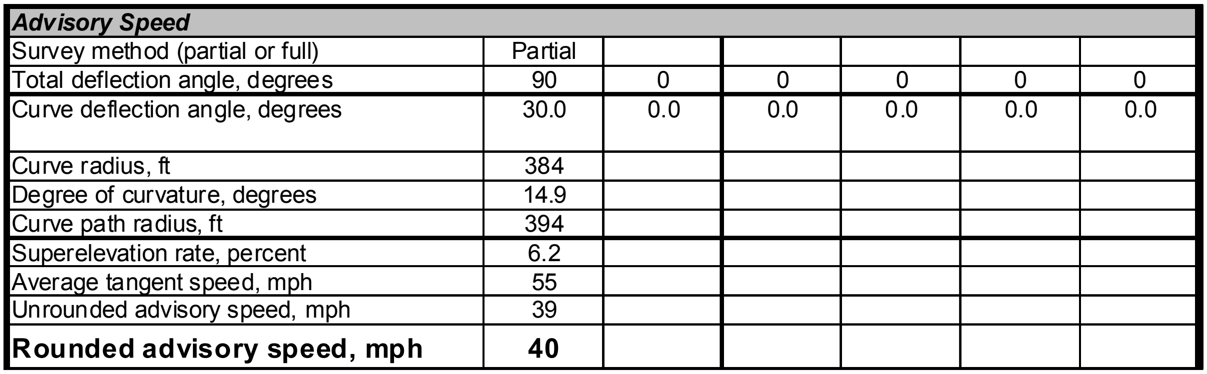
CURVE ADVISORY SPEED WORKSHEET						
General Information						
District:		**Curve Data Source:**		**Date:**	October 12, 2008	
Highway:		Survey of curve ▾		**Analyst:**		
Input Data						
Data Description	**Curve Identification Number**					
	47R	2	3	4	5	6
Curve deflection, left or right	Right					
Compass heading 1, degrees	251					
BBI reading of superelevation, degrees	4.0					
Deflection of ball for superelevation reading, left or right	Right					
Speed when recording the BBI reading of superelevation, mph	0					
Curve length, ft	201					
Compass heading 2, degrees	281					
Survey method (partial or full)	Partial					
Regulatory speed limit, mph	60					
Estimate of 85th% tangent speed, mph	63					
Alternate Input Data *(if data are entered here, they will be used instead of estimates from the data above)*						
85th% tangent speed, mph						
Total curve deflection angle, degrees						
Curve deflection angle, degrees						
Superelevation rate, percent						
Curve radius, ft						

Figure 7. TCAS Input Data.

The speed limit is used to estimate the 85th percentile speed on the highway tangents in the vicinity of the curve. If the 85th percentile tangent speed is known, then it can be directly entered in the first row of the Alternate Input Data section of the worksheet (i.e., the fifth row from the bottom, in Figure 7). If a value is entered in the Alternate Input Data section, then it will be used instead of the value estimated using the field measurements entered in the Input Data section. This priority is extended to the direct entry of 85th percentile tangent speed, curve deflection angle, superelevation rate, curve radius, or any combination of these data.

The advisory speed is computed using the estimated (or directly input) curve radius, deflection angle, and superelevation rate. A curve-speed prediction model is used for this purpose. The estimate obtained from this model represents the "unrounded advisory speed" and is shown in the second row from the bottom of Figure 8. The advisory speed is computed by first adding 1.0 mph to the unrounded speed and then rounding the sum *down* to the nearest 5 mph increment. The rationale for this rounding technique is discussed in Step 2 of the Direct Method. The rounded advisory speed is shown in the last row of Figure 8.

It should be noted that the computed advisory speed is based on the estimated radius of the vehicle travel path, as opposed to that of the curve. When traveling through a curve, drivers shift their vehicle laterally in the traffic lane such that they flatten the curve slightly. This behavior allows them to limit the speed reduction required by the curve. The difference between the radius of the curve and the travel path radius is shown in Figure 9. The estimated path radius for the subject curve is listed in the Advisory Speed section of the Analysis worksheet, as shown in Figure 8. It will always equal or exceed that of the curve radius. The path radius will be notably larger than the curve radius on curves with a smaller deflection angle.



Advisory Speed						
Survey method (partial or full)	Partial					
Total deflection angle, degrees	90	0	0	0	0	0
Curve deflection angle, degrees	30.0	0.0	0.0	0.0	0.0	0.0
Curve radius, ft	384					
Degree of curvature, degrees	14.9					
Curve path radius, ft	394					
Superelevation rate, percent	6.2					
Average tangent speed, mph	55					
Unrounded advisory speed, mph	39					
Rounded advisory speed, mph	**40**					

Figure 8. TCAS Advisory Speed Calculation.

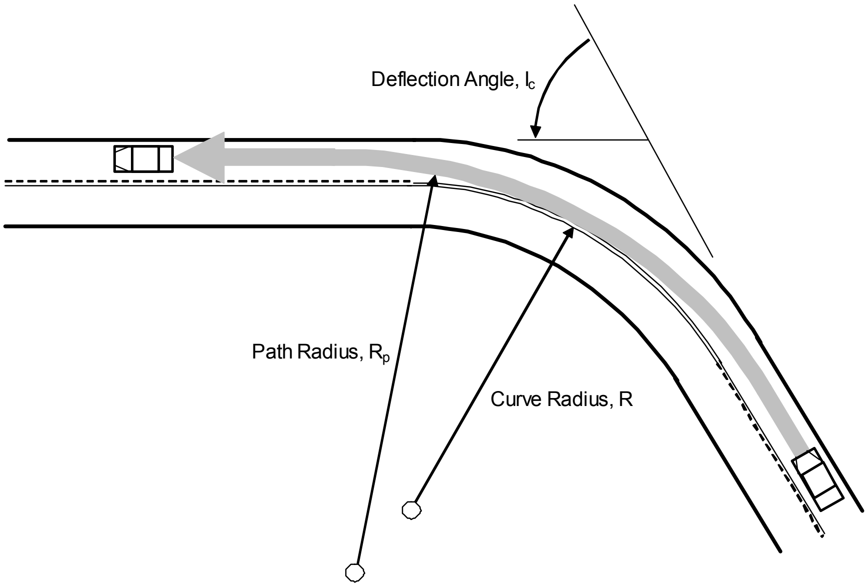


Figure 9. Effect of Lateral Shift on Travel Path Radius.

When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be evaluated separately in this step. The Advisory Speed plaque should show the value for the curve having the lowest advisory speed in the series.

For undivided roadways, if an advisory speed is determined to be needed for one curve travel direction but not for the opposite curve travel direction, then both directions of the curve should be posted with the advisory speed determined for the one direction.

Step 3: Confirm Speed for Conditions

During this step, the appropriateness of the advisory speed determined in Step 2 and the need for other curve warning signs is evaluated. The activities conducted during this step are the same as those discussed in Step 3 of the Direct Method, except that the need for an Advisory Speed plaque is checked using the information in the Traffic Control Device Guidance section of TCAS.

GPS METHOD

The GPS Method is based on the field measurement of curve geometry. The geometric data are then used with a speed-prediction model to compute the average speed of trucks. This speed then becomes the basis for establishing the advisory speed.

The procedure for implementing the GPS Method consists of three steps. During the first step, measurements are taken in the field while traveling along the curve. During the second step, the measurements are used to compute the advisory speed. During the last step, the recommended advisory speed is confirmed through a field trial run. Each of these steps is described in the remainder of this section.

To ensure reasonable accuracy in the model estimates using this method, the total curve deflection angle should be 6 degrees or more. A curve with a smaller deflection angle will rarely justify curve warning signs or an advisory speed plaque.

Equipment

The equipment used includes the following:

- GPS receiver,
- electronic ball-bank indicator (optional), and
- laptop computer.

The GPS receiver is used to estimate curve radius and deflection angle. The electronic ball-bank indicator is optional. It is used to estimate superelevation rate. If an electronic ball-bank indicator is not used, then superelevation rate will need to be estimated using other means.

The computer is used to run the Texas Roadway Analysis and Measurement Software (TRAMS) program. This program is designed to monitor the GPS receiver and the electronic ball-bank indicator while the test vehicle is driven along the curve. After the curve is traversed, TRAMS calculates curve radius and superelevation rate from the data streams. Advisory speed and traffic control device selection guidelines can be determined using the radius and superelevation rate estimates with the Texas Curve Advisory Speed (TCAS) spreadsheet.

Installation

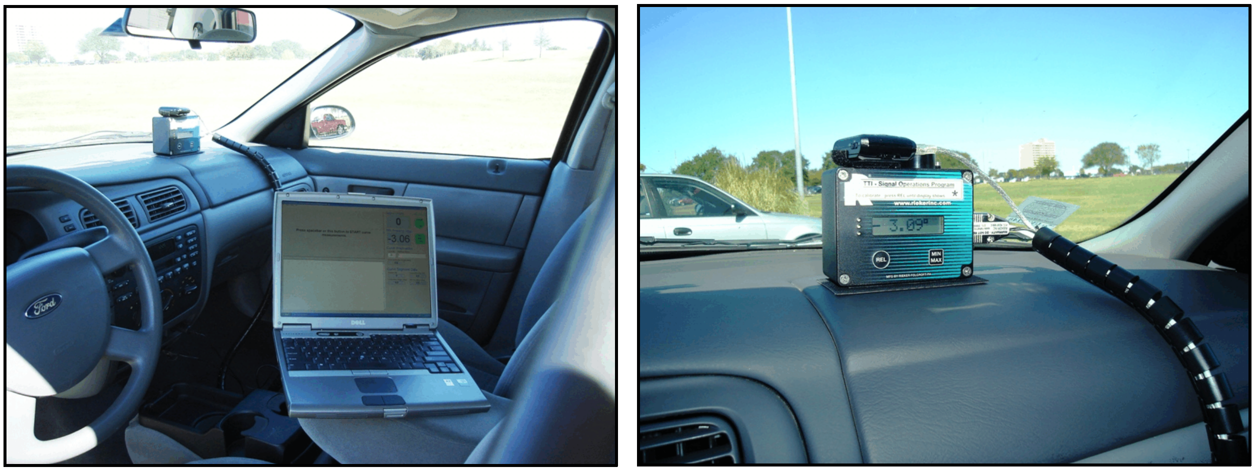
The following activities must be completed the first time TRAMS is installed on the computer. More details are provided in the TRAMS Installation Manual.

- Install the driver for the GPS receiver.
- If the electronic ball-bank indicator is used, an adapter may be needed to convert its RS-232 connection into a USB connection. Install the driver for this adapter.
- Install TRAMS (a copy of TCAS will also be installed in the TRAMS file directory).

Equipment Setup

The following activities must be completed prior to using the equipment to establish the advisory speed for one or more curves.

- Mount the GPS receiver and electronic ball-bank indicator (if used) on the dashboard in a fixed position. These devices should not be able to move during the test runs. Figure 10 shows the devices mounted on the dashboard and secured using Velcro® adhesive tape.

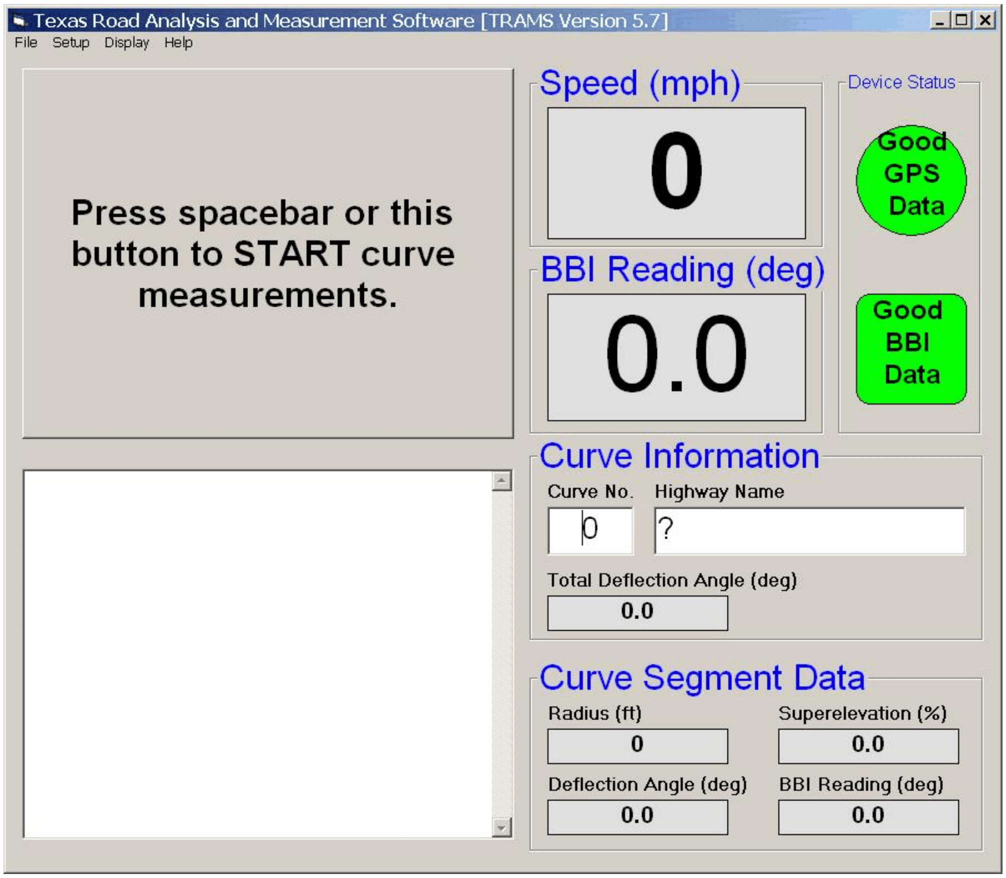


a. Equipment Setup. b. Measurement Devices.

Figure 10. Equipment Setup in Test Vehicle.

- If an electronic ball-bank indicator is used, activate its auto leveling feature with the test vehicle parked on level pavement. Do this under the same vehicle loading and tire inflation conditions that will be present during the test runs.
- With the laptop on, click on the TRAMS icon to launch TRAMS. TRAMS will initially connect with the two devices. It will then present the main panel, as shown in Figure 11.
- Verify that TRAMS is receiving valid data from the GPS receiver. Information about the status of this device is located in the upper right corner of the main panel, as shown in Figure 11. A red circle indicates invalid (bad) data. A green circle indicates valid (good) data.
- If the electronic ball-bank indicator (BBI) is used, verify that TRAMS is receiving valid data from it. A red square indicates invalid (bad) data. A green square indicates valid (good) data.

- If valid data are not being received by one or both of the devices, check the following conditions:
    - ○ Are the devices turned on and properly connected to the laptop computer?
    - ○ Is the GPS receiver blocked from obtaining good satellite reception? Structures (bridges, garage roofs, buildings, etc.) or dense tree coverage may make it difficult to maintain GPS reception.
    - ○ Has TRAMS been configured with the proper port numbers for the devices? This can usually be accomplished by selecting the "Automatic" mode in the Configure Devices panel (from the main panel, select File, Configuration Settings, Configure Devices). If used, the electronic ball-bank indicator ("Rieker Device") must also be enabled in this panel (i.e., select Enabled in the Rieker box).
    - ○ If any settings are changed in the Configure Devices panel, the Save Configuration File option should be selected to save all settings to file (in which case they will be loaded and used each time TRAMS is launched).



Speed (mph): 0

BBI Reading (deg): 0.0

Curve No.: 0

Highway Name: ?

Total Deflection Angle (deg): 0.0

Radius (ft): 0

Superelevation (%): 0.0

Deflection Angle (deg): 0.0

BBI Reading (deg): 0.0

Figure 11. TRAMS Main Panel.

Step 1: Field Measurements

Before beginning a test run, enter the curve number and highway name in their respective fields provided on the main panel (see Figure 11).

Repeat the measurements for the opposing direction of travel if the road is divided or if conditions suggest the need for separate consideration of each curve travel direction. When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be surveyed separately in this step.

Speed Limit

If the 85th percentile tangent speed is not known, note the regulatory speed limit on the roadway where the curve is located. The speed limit can subsequently be used in TCAS to estimate the 85th percentile tangent speed.

Test Run Speed

The following rules-of-thumb should be considered when selecting the test run speed:

- The test run speed should be at least 10 mph below the existing curve advisory speed provided that the resulting test run speed is not less than 15 mph.
- If superelevation rate is being measured, test runs should be conducted at 45 mph or less, with slower speeds considered desirable in terms of yielding more accurate estimates of superelevation.

In general, a slower test run speed will improve accuracy in measurement by minimizing tire slip and allowing the driver to track the curve accurately.

Measurement Procedure

The following task sequence describes the field measurement procedure as it would be used to evaluate one direction of travel through the subject curve. Measurement error and possible differences in superelevation rate between the two directions of travel typically justify repeating this procedure for the opposing direction. Only one test run should be required in each direction.

a. When the test vehicle is 1 or 2 s travel time *in advance* of the beginning of the curve, press the space bar or click the large button on the TRAMS main panel. This action will start the data collection process. Precise location of the beginning of the curve is *not* required. A reasonable estimate of its location, based on the analyst’s judgment, will suffice.

b. While driving through the curve, track the centerline of the roadway as carefully as possible. This process will provide an accurate survey of the intended travel path. The analyst should avoid “cutting the corner” of sharp curves. The analyst should also avoid letting the vehicle drift to the outside of the lane while traveling along the curve.

c. When the test vehicle is 1 or 2 s travel time *beyond* the end of the curve, press the space bar or click the large button a second time to stop recording curve data. Precise location of the end of the curve is *not* required. A reasonable estimate of its location, based on the analyst’s judgment, will suffice.

Save the File

When asked whether a curve report file should be saved, indicate "Yes" by pressing Enter (or clicking on the Yes button). Alternatively, indicate "No" if it is believed that the curve was not accurately measured during the test run (e.g., the driver did not accurately track the curve, or the data recording was not started and stopped at the appropriate times). CAUTION: If the curve has the same number as a curve that was previously evaluated, the new file will overwrite the file from the previous curve.

Optional Check When Superelevation Rate is Measured

At the conclusion of the test run, the 95th percentile error range for superelevation rate is provided in the curve report file. It can be checked to confirm that the estimated value is reasonably precise. If this range exceeds 3 percent, repeat the test run at a lower speed. If the aforementioned test-run-speed rules-of-thumb were followed, then this check should not be needed.

The curve report file can be accessed from the main panel by selecting File, Open Curve Report, and selecting the appropriate "log" file. The file will be named "Curve-XX-Rpt.Log," where XX will be replaced by the curve number entered on the main panel before the start of the test run. Once the file is selected, select Open and the file will be opened in Notepad, a text editor provided with Windows®.

Step 2: Determine Advisory Speed

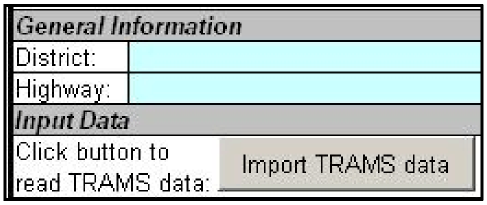
Two options are available for determining the advisory speed. One option is based on a review of the survey data in the field. The second option is based on a review of the survey data in the office, following the survey of all curves of interest.

When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be evaluated separately in this step. The Advisory Speed plaque should show the value for the curve having the lowest advisory speed in the series.

For undivided roadways, if an advisory speed is determined to be needed for one curve travel direction but not for the opposite curve travel direction, then both directions of the curve should be posted with the advisory speed determined for the one direction.

Option 1: In-Field Determination

This option is performed in the field. The data from the most recent test run is exported directly to TCAS. This action is accomplished from the main panel by selecting File, Export to TCAS. At this point, TCAS will load. The analyst will need to click on the "Import TRAMS Data" button in TCAS to import the test run data into TCAS. The



General Information	
District:	
Highway:	
Input Data	
Click button to read TRAMS data:	

analyst will also need to enter the 85th percentile speed. Alternatively, the analyst can enter the speed limit and let TCAS compute an estimate of the 85th percentile speed.

The imported data are always placed in the same TCAS column (i.e., column F). If the analyst wants to save any data in this column, then he or she should copy and paste the data to another column in TCAS (or another spreadsheet) and save the file. Exit TCAS (and Excel) after importing and evaluating the data for a given curve.

Option 2: In-Office Determination

This option is performed back in the office. The curve report file for each curve is opened in Notepad and printed by selecting File, Print. There is one report for each unique curve number entered in TRAMS. The data on a report are typed into TCAS and the appropriate advisory speed determined. Instructions for opening a curve report file were provided in the previous step.

Step 3: Confirm Speed for Conditions.

During this step, the appropriateness of the advisory speed determined in Step 2 and the need for other curve warning signs is evaluated. The activities conducted during this step are the same as those discussed in Step 3 of the Direct Method, except that the need for an Advisory Speed plaque is checked using the information in the Traffic Control Device Guidance section of TCAS.

DESIGN METHOD

The Design Method is based on the use of curve geometry data obtained from files or as-built plans. This method is suitable for evaluating newly constructed or reconstructed curves because the data are available from construction plans.

The procedure for implementing the Design Method consists of three steps. During the first step, curve geometry data are obtained from files or plans. During the second step, the measurements are used to compute the advisory speed. During the last step, the recommended advisory speed is confirmed through a field trial run, if or when the curve exists. Each of these steps is described in the remainder of this section.

Step 1: Obtain Curve Geometry

Consult the appropriate files to obtain the radius, deflection angle, and superelevation rate for the curve. If the curve is circular, the "total curve deflection angle" is equivalent to the "curve deflection angle," as used in TCAS. The total curve deflection angle equals the deflection angle in the two intersecting tangents.

If spiral transition curves are included in the design, obtain the radius and superelevation rate data for the central circular curve. The total curve deflection angle is the same as defined in the previous paragraph. The curve deflection angle represents the deflection angle of the central circular curve, defined previously as the partial deflection angle.

If compound curvature is used in the design, obtain the radius and superelevation rate data for the sharpest component curve. The total curve deflection angle is the same as defined in the first paragraph. The curve deflection angle represents the deflection angle of the sharpest component curve.

Obtain the aforementioned data for both directions of travel if the road is divided or if conditions suggest the need for separate consideration of each curve travel direction. When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, data for each curve should be obtained in this step.

Step 2: Determine Advisory Speed

The data obtained in Step 1 are entered in TCAS in the section titled Alternate Input Data. If a reasonable estimate of the 85th percentile tangent speed is not available, the speed limit can be used in TCAS to estimate the 85th percentile tangent speed. Note: the drop-down list at the top of the spreadsheet should be set to “Known curve geometry.”

When two or more curves are separated by a tangent of 600 ft or less, one sign should apply for all curves. However, each curve should be evaluated separately in this step. The Advisory Speed plaque should show the value for the curve having the lowest advisory speed in the series.

For undivided roadways, if an advisory speed is determined to be needed for one curve travel direction but not for the opposite curve travel direction, then both directions of the curve should be posted with the advisory speed determined for the one direction.

Step 3: Confirm Speed for Conditions

During this step, the appropriateness of the advisory speed determined in Step 2 and the need for other curve warning signs is evaluated. The activities conducted during this step are the same as those discussed in Step 3 of the Direct Method, except that the need for an Advisory Speed plaque is checked using the information in the Traffic Control Device Guidance section of TCAS.

CHAPTER 4. CURVE SIGNING GUIDELINES

OVERVIEW

This chapter describes guidelines for the signing of horizontal curves on rural highways. These guidelines were derived largely through a review and synthesis of guidelines offered in the literature. They are intended to complement the procedure for establishing the advisory speed that is described in Chapter 3. Together, the procedure and guidelines provide a rational basis for establishing uniform signing for rural highway curves.

GUIDELINES

Guidelines for selecting curve-related traffic control devices are described in this section. The guidelines are based largely on the existing practices of many transportation agencies. They consist of recommended combinations of traffic control devices associated with a specified curve severity category. The guidelines were developed to reflect a balance of the following goals:

- Promote the uniform and consistent use of traffic control devices.
- Base guidance for these devices on curve severity.
- Avoid overuse of devices.
- Limit the number of devices used at a given curve.

Application of the guidelines begins with a determination of the curve's severity category. This assessment can be obtained using Figure 12. The curve's severity category is based on consideration of the 85th percentile tangent speed and the 85th percentile curve speed. Category A represents curves that are just sharp enough that drivers tend to reduce speed slightly. They accomplish the necessary speed reduction by lifting their foot slightly off the accelerator at the start of the curve. At the other extreme, category E represents the sharpest curves. Drivers will have to begin braking well before they reach the curve, and the degree of braking will be very notable to the vehicle's occupants. These curves can require special treatments such as oversize curve warning signs, flashers added to curve warning signs, wider edge lines approaching (and along) the curve, and profiled edge lines and center lines. Additional information on special treatments is provided in Reference *11*.

Application of Figure 12 requires knowledge of the 85th percentile tangent speed for passenger cars. This speed can be obtained from a survey of speeds on a tangent section of highway in the vicinity of the curve. The location at which tangent speed data are collected should be sufficiently distant from the curve that it does not influence the observed speeds. The TxDOT document *Procedures for Establishing Speed Zones* describes the survey procedure (*12*). If the 85th percentile tangent speed is not available, an equation is provided in the TCAS software for estimating this speed.

To illustrate the use of Figure 12, consider a curve with an 85th percentile tangent speed of 55 mph and an 85th percentile curve speed of 45 mph. Proceeding upward from the 55-mph tick mark on the x-axis of Figure 12 and over from the 45-mph tick mark on the y-axis, find their intersection point in severity category B.

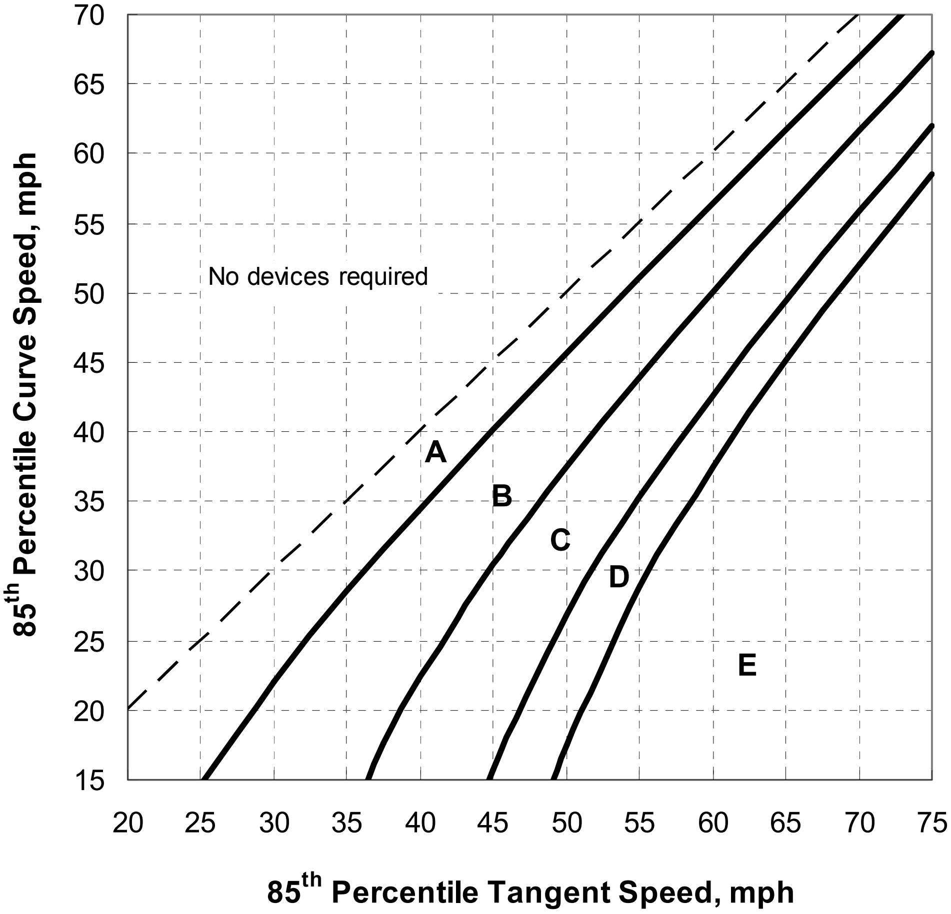


Figure 12. Guidelines for the Selection of Curve-Related Traffic Control Devices.

Table 1 shows the recommended traffic control device treatment for each severity category. The treatments have been categorized into two groups: warning signs and delineation devices. For each category, a combination of devices from both groups is offered. The guidance differentiates between recommended and optional treatments. This approach is intended to provide some flexibility in the selection of devices used at a given curve. An optional device is indicated by an outlined check (✓), and a recommended device is indicated by a solid check (✔).

To illustrate the use of Table 1, consider a curve associated with severity category B and an advisory speed of 40 mph. The solid check marks in Table 1 for this category indicate that a curve warning sign (e.g., Curve sign), Advisory Speed plaque, and raised pavement markers are recommended for this curve.

The curve warning signs listed in Table 1 include: Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Hairpin Curve (W1-11). Guidance on selecting the appropriate sign from this group is specified in Table 2C-5 of the *TMUTCD* (*7*). This guidance is repeated in Appendix B. It is based on the number of alignment changes and the advisory speed. The placement of advance signs, relative to the point of curvature, is described in Table 2C-4 of the *TMUTCD* (and repeated in Appendix B). The delineator and Chevron spacing at a given curve is provided in Table 3D-2 of the *TMUTCD*. This table is shown in Appendix B.

Table 1. Guidelines for the Selection of Curve-Related Traffic Control Devices.

Advisory Speed, mph	Device Type	Device Name	Device Number	Curve Severity Category [7]				
				A	B	C	D	E
35 mph or more	Warning Signs	Curve, Reverse Curve, Winding Road, Hairpin Curve [1]	W1-2, W1-4, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
		Additional Curve, Hairpin Curve [1,2]	W1-2, W1-11	▨	▨	✓	✓	✓
		Chevrons [3]	W1-8	▨	▨	▨	✔	✔
30 mph or less	Warning Signs	Turn, Reverse Turn, Winding Road, Hairpin Curve [1]	W1-1, W1-3, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1	▨	✔	✔	✔	✔
		Additional Turn, Hairpin Curve [1,2]	W1-1, W1-11	▨	▨	✓	✓	✓
		Large Arrow sign	W1-6	▨	▨	▨	✔	✔
Any	Delineation Devices	Raised pavement markers [4]		✔	✔	✔	✔	✔
		Delineators [5]		▨	▨	✓	✓	✓
	Special Treatments [6]			▨	▨	▨	▨	✔

Notes:

1 - Use the Curve, Reverse Curve, Turn, Reverse Turn, or Winding Road sign if the deflection angle is less than 135 degrees. Use the Hairpin Curve sign if the deflection angle is 135 degrees or more.

2 - Use with Advisory Speed plaque. The *MUTCD* indicates that the Combination Horizontal Alignment/Advisory Speed signs (W1-2a and W1-1a) can be also used to supplement other advance warning signs. However, these signs are not recognized in the *TMUTCD*.

3 - A Large Arrow sign may be used on curves where roadside obstacles prevent the installation of Chevrons.

4 - Raised pavement markers are optional in northern regions that experience frequent snowfall.

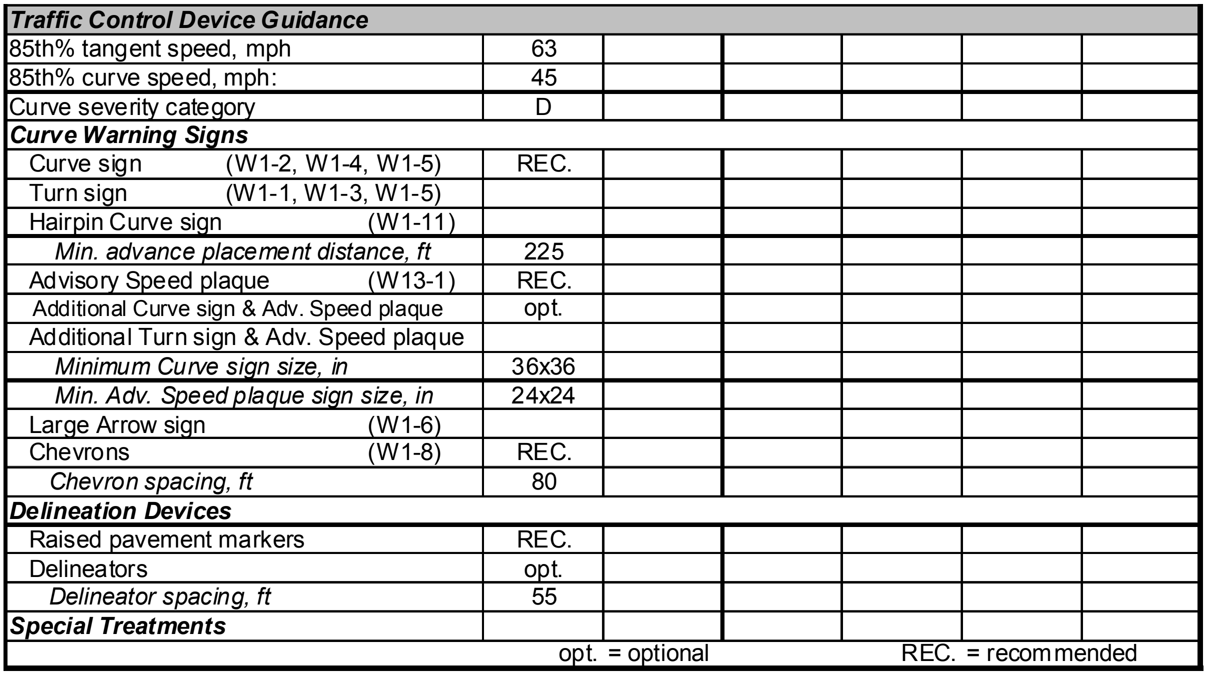
5 - Delineators do not need to be used if Chevrons are used.

6 - Special treatments could include oversize curve warning signs, flashers added to curve warning signs, wider edge lines approaching (and along) the curve, and profiled edge lines and center lines (*11*).

7 - ✓: optional; ✔: recommended.

Figure 13 illustrates the how the guidelines represented in Table 1 and the *TMUTCD* are shown in the TCAS software. The values shown in column two of this figure correspond to the example curve discussed previously for Figures 7 and 8. The speed prediction model indicates that the 85th percentile driver will travel at 63 mph on the highway tangent but slow to 45 mph to negotiate the curve. This 18 mph speed reduction is associated with curve severity category "D." Figure 8 previously indicated that the recommended advisory speed for this curve is 40 mph (which is representative of the average speed of trucks).

As shown in Figure 13 (and confirmed with Table 1), a Curve sign, Advisory Speed plaque, and Chevrons are recommended for the example curve. An additional Curve sign and Advisory Speed plaque located at the beginning of the curve are optional. Engineering judgment should be used to determine whether the additional signs would be beneficial. The Curve sign and Advisory Speed plaque should be located at least 225 ft in advance of the beginning of the curve. The Chevrons should be spaced at 80 ft along the curve. Raised pavement markers are recommended, provided that the curve is not located in a northern region with frequent snowfall. Delineators are also optional, and judgment should be used to determine whether they would be beneficial. If delineators are used, they should be spaced at 55 ft along the curve.



Traffic Control Device Guidance						
85th% tangent speed, mph	63					
85th% curve speed, mph:	45					
Curve severity category	D					
Curve Warning Signs						
Curve sign (W1-2, W1-4, W1-5)	REC.					
Turn sign (W1-1, W1-3, W1-5)						
Hairpin Curve sign (W1-11)						
Min. advance placement distance, ft	225					
Advisory Speed plaque (W13-1)	REC.					
Additional Curve sign & Adv. Speed plaque	opt.					
Additional Turn sign & Adv. Speed plaque						
Minimum Curve sign size, in	36x36					
Min. Adv. Speed plaque sign size, in	24x24					
Large Arrow sign (W1-6)						
Chevrons (W1-8)	REC.					
Chevron spacing, ft	80					
Delineation Devices						
Raised pavement markers	REC.					
Delineators	opt.					
Delineator spacing, ft	55					
Special Treatments						
	opt. = optional			REC. = recommended		

Figure 13. TCAS Traffic Control Device Guidance.

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12. *Procedures for Establishing Speed Zones.* Texas Department of Transportation, Austin, Texas, November 2003.

APPENDIX B. SELECTED TABLES FROM THE *TMUTCD*

Table 2. Guidelines for Advance Placement of Warning Signs.

(Table 2C-4 of the *TMUTCD*)

Posted or 85th Percentile Speed, mph	Advance Placement Distance, ft[1]									
	Condition A: Speed reduction and lane changing in heavy traffic[2]	Condition B: Stop Condition[3]	Condition C: Deceleration to the listed advisory speed (mph) for the condition[4]							
			10	20	30	40	50	60	70	75
20	225	N/A[5]	N/A[5]	-	-	-	-	-	-	-
25	325	N/A[5]	N/A[5]	N/A[5]	-	-	-	-	-	-
30	450	N/A[5]	N/A[5]	N/A[5]	-	-	-	-	-	-
35	550	N/A[5]	N/A[5]	N/A[5]	N/A[5]	-	-	-	-	-
40	650	125	N/A[5]	N/A[5]	N/A[5]	-	-	-	-	-
45	750	175	125	N/A[5]	N/A[5]	N/A[5]	-	-	-	-
50	850	250	200	150	100	N/A[5]	-	-	-	-
55	950	325	275	225	175	100	N/A[5]	-	-	-
60	1100	400	350	300	250	175	N/A[5]	-	-	-
65	1200	475	425	400	350	275	175	N/A[5]	-	-
70	1250	550	525	500	425	350	250	150	-	-
75	1350	650	625	600	525	450	350	250	100	-
80	1475	725	725	700	625	550	475	350	200	125

Notes:

1 - The distances are adjusted for a sign legibility distance of 175 ft for Condition A and B. The distances for Condition C have been adjusted for a sign legibility distance of 250 ft, which is appropriate for an alignment warning symbol sign.

2 - Typical conditions are locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation. Typical signs are Merge and Right Lane Ends. The distances are determined by providing the driver a perception-reaction time (PRT) of 14.0 to 14.5 s for vehicle maneuvers (2004 AASHTO Policy, Exhibit 3-3, Decision Sight Distance, Avoidance Maneuver E) minus the legibility distance of 175 ft for the appropriate sign.

3 - Typical condition is the warning of a potential stop situation. Typical signs are Stop Ahead, Yield Ahead, Signal Ahead, and Intersection Warning signs. The distances are based on the 2001 AASHTO Policy, Stopping Sight Distance, Exhibit 3-1, providing a PRT of 2.5 s, a deceleration rate of 11.2 ft/s^2 minus the sign legibility distance of 175 ft.

4 - Typical conditions are locations where the road user must decrease speed to maneuver through the warned condition. Typical signs are Turn, Curve, Reverse Turn, or Reverse Curve. The distance is determined by providing a 2.5 s PRT, a vehicle deceleration rate of 10 ft/s^2, minus the sign legibility distance of 250 ft.

5 - No suggested distances are provided for these speeds, as the placement location is dependent on site conditions and other signing to provide an adequate advance warning for the driver.

Table 3. Horizontal Alignment Sign Usage.

(Table 2C-5 of the *TMUTCD*)

Number of Alignment Changes	**Advisory Speed**	
	30 mph or Less	**35 mph or more**
1	Turn (W1-1)[1]	Curve (W1-2)[1]
2[2]	Reverse Turn (W1-3)[3]	Reverse Curve (W1-4)[3]
3 or more[2]	Winding road (W1-5)[3]	

Notes:

1 - Engineering judgment should be used to determine whether the Turn or Curve sign should be used.

2 - Alignment changes are in opposite directions and are separated by a tangent distance of 600 ft or less.

3 - A Right Reverse Turn (W1-3R), Right Reverse Curve (W1-4R), or Right Winding Road (W1-5R) sign is used if the first change in alignment is to the right; a Left Reverse Turn (W1-3L), Left Reverse Curve (W1-4L), or Left Winding Road (W1-5L) sign is used if the first change in alignment is to the left.

Table 4. Delineator and Chevron Sign Spacing.

(Table 3D-2 of the *TMUTCD*).

Degree of Curve	**Radius, ft**	**Delineator Spacing (S_d) in Curve, ft**[1]	**Chevron Spacing (S_c) in Curve, ft**[2]
5	1146	100	160
6	955	90	160
7	819	85	160
8	716	75	160
9	637	75	120
10	573	70	120
11	521	65	120
12	478	60	120
13	441	60	120
14	409	55	80
15	382	55	80
16	358	55	80
19	302	50	80
23	249	40	80
29	198	35	40
38	151	30	40
57	101	20	40

Notes:

1 - Delineator spacing refers to the spacing for specific radii computed from the equation: $S_d = 3\ (R - 50)^{0.5}$

2 - Chevron spacing refers to the spacing for specific radii computed from the equation: $S_d = 5.3\ (R - 70)^{0.5}$

APPENDIX C. DATA COLLECTION SHEET

Version 6 7/21/2007

Horizontal Curve Advisory Speed Field Data Sheet Texas Department of Transportation Traffic Operations Division

Date: **Analyst:**

District: **County:** **Roadway:** **Reference Roadway:**

		Field Measurements												Recommendations			
Curve ID Number	Mileage from Reference Roadway	Posted Speed (mph)		Curve Deflection (Left, Right)	Entry Heading (deg)	Cross Slope			Curve Length (ft)	Exit Heading (deg)	Sight Distance OK? (yes,no)	Intersection in Curve (yes, no)	Adjacent Curve < 600 ft (yes,no)	Curve Warning Sign Needed (Yes, No)	Recommended Advisory Speed (mph)	Additional Devices	Comments
		Regulatory Limit	Advisory			Ball-Bank Reading	Ball-Bank Deflection (Left, Right)	Speed During Measurement (mph)									
1																	
2																	
3																	
4																	
5																	
6																	
7																	
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