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Curve Evaluations using Rieker's CARS Shakedown and Development of Methodology	December 15, 2014 Report No. TDE-2014-02

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Executive Summary

The Oregon Department of Transportation (ODOT) is exploring a method of ball-banking highway curves that promises to be more time and cost effective and safer for investigators than the current method of ball-banking.

In recent years, ODOT has produced spreadsheet software to aid ball-bank data collection, but the data collection process has largely remained the same. Investigators still need to drive through curves multiple times to determine maximum recommended speeds. For experienced investigators, this process can take 30 to 90 minutes per curve. A method to streamline the data collection process would greatly reduce labor costs and safety risks associated with curve evaluations.

The Rieker Curve Advisory Reporting System (CARS) promotes successful data collection with one pass in each direction, with traffic, at any speed. Before replacing traditional data collection statewide with CARS, ODOT Traffic-Roadway and Region 2 Traffic conducted basic shakedown testing of the Rieker system in the summer of 2014. This technical white paper documents the shakedown testing and helps inform how curves should be analyzed on ODOT highways using CARS.

Based on the analysis and findings of this investigation, the following can be concluded and recommended:

- The CARS methodology uses best-fit models and common design equations from the *Green Book* and is an acceptable method to determine curve advisory speed.
- CARS and the ODOT spreadsheet recommended advisory speeds are generally within 5 mph of each other. When different, CARS tends to recommend advisory speeds greater than the ODOT spreadsheet, within 5 mph.
- For statewide consistency, all Oregon highways should be evaluated using the CARS methodology.
- An inexperienced investigator can achieve similar results to an experienced investigator if properly trained and with some practice.
- Speed from run to run on the same curve does not need to be constant.
- When driving through a curve, speed should be kept relatively constant to avoid unnecessary spikes in lateral acceleration.
- Greater model fits generally result in more precise estimates of advisory speed. When building curves, strive for a fit of 99% or better; 96% or better is sufficient.
- The average calculated advisory speed of 3 runs should be used when determining the final advisory speed. If data are collected properly, this average should be within ±3.5% of the true average at the 95% confidence level.
- A training class for traffic investigators and sign designers should be developed for statewide consistency.

Keywords

Curve Advisory Speed, Ball-Banking, Rieker CARS, Curve Signing

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Curve Evaluations using Rieker's CARS

Shakedown and Development of Methodology

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December 15, 2014

Contents

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Introduction

In an effort to be more consistent determining curve advisory speeds, the Oregon Department of Transportation (ODOT) is exploring a method of ball-banking highway curves that promises to be more time and cost effective and safer for investigators than the current method of ball-banking.

The current accepted curve advisory speed evaluation method is ball-banking [1]. In recent years, ODOT has produced spreadsheet software to aid ball-bank data collection, but the basic ball-banking method has largely remained the same. Investigators still need to drive through the curve multiple times to determine the maximum advisory speed. If that speed is different than the current advisory speed, the investigator needs to drive through the curve 3 times in each direction at that speed in order to change the advisory speed. For experienced investigators, this process can take 30 to 90 minutes per curve, depending on availability of safe turn-around points, accuracy of existing signing, and traffic volumes during the investigation, among other variables. Because of this duration, remote locations can require overnight accommodations for investigators. A method to streamline the data collection process would greatly reduce labor costs and safety risks associated with curve evaluations.

Rieker, Inc. approached ODOT in the spring of 2014 with their new Curve Advisory Reporting System (CARS), promoting successful data collection with one pass in each direction, with traffic, at any speed using the accepted ball-banking method. Before replacing data collection strategies statewide with CARS, ODOT Traffic-Roadway and Region 2 Traffic conducted basic shakedown testing of the Rieker system in the summer of 2014; more statistically relevant results can be achieved by examining a larger, more diverse dataset. This technical white paper documents the shakedown testing and helps inform how curves should be investigated on ODOT highways using CARS.

Scope

The scope of this white paper was to:

- determine how the Rieker tool calculates curve advisory speeds,
- test sensitivity of results based on different driving methods and number of runs,
- compare advisory speed recommendations from the ODOT Spreadsheet to CARS, and
- develop recommendations on if and how ODOT will use the CARS tool.

Recommendations needed to be completed by fall 2014 to allow investigators to begin collecting data and curves analyzed as soon as practical for project development and delivery, pursuant the December 31, 2019 MUTCD compliance date for horizontal alignment signs [2]. More statistically relevant results can be achieved by examining a larger, more diverse dataset. This could be achieved through a more formalized research project.

MUTCD Advisory Speeds

Ball-banking limits used by ODOT in the past were lower than the 2009 MUTCD limits. Limits currently accepted for use in Oregon are found in the 2009 MUTCD [1]. These higher limits better meet expected driver performance through horizontal curves as research has shown drivers often exceed curve advisory speeds by 7 to 10 mph [2]. Dixon and Rohani [3] and Dixon and Avelar [4] provide some history of this transition in Oregon in their reports.

Section 2C.08 of the 2009 MUTCD [2] says "the advisory speed shall be determined by an engineering study that follows established engineering practices." Among the engineering practices listed as appropriate for the determination of the recommended advisory speed for a horizontal curve is a traditional ball-bank indicator using the following criteria:

1. 16 degrees of ball-bank for speeds of 20 mph or less
2. 14 degrees of ball-bank for speeds of 25 to 30 mph
3. 12 degrees of ball-bank for speeds of 35 mph and higher.

Section 2C.08 goes on to say "the 16, 14, and 12 degrees of ball-bank criteria are comparable to the current AASHTO horizontal curve design guidance. Research has shown that drivers often exceed existing posted advisory curve speeds by 7 to 10 mph."

Currently, the curve reports generated through the CARS Portal will default the MUTCD limit corresponding to the *posted regulatory speed* entered by the user. Ball-banking practice published in Oregon, several other states, FHWA's Safety Website, and ITE's *Traffic Control Devices Handbook* ([5], [6], [7], [8], [9], [10], [11]) use the MUTCD limit corresponding to the speed of the test run during investigation. In the absence of a regulatory speed, the system will default to 12 degrees. The MUTCD limits need to be manually entered on slower curves (<35 mph calculated advisory speed) to make sure the correct limit is being used.

Kinematics

An analysis of the forces acting on a vehicle traveling through a curve is shown in Figure 1 [12]. This analysis ignores the small effects of body-roll (see Body Roll Rate discussion) and assumes the digital inclinometer instrument is properly mounted in the vehicle and properly leveled.

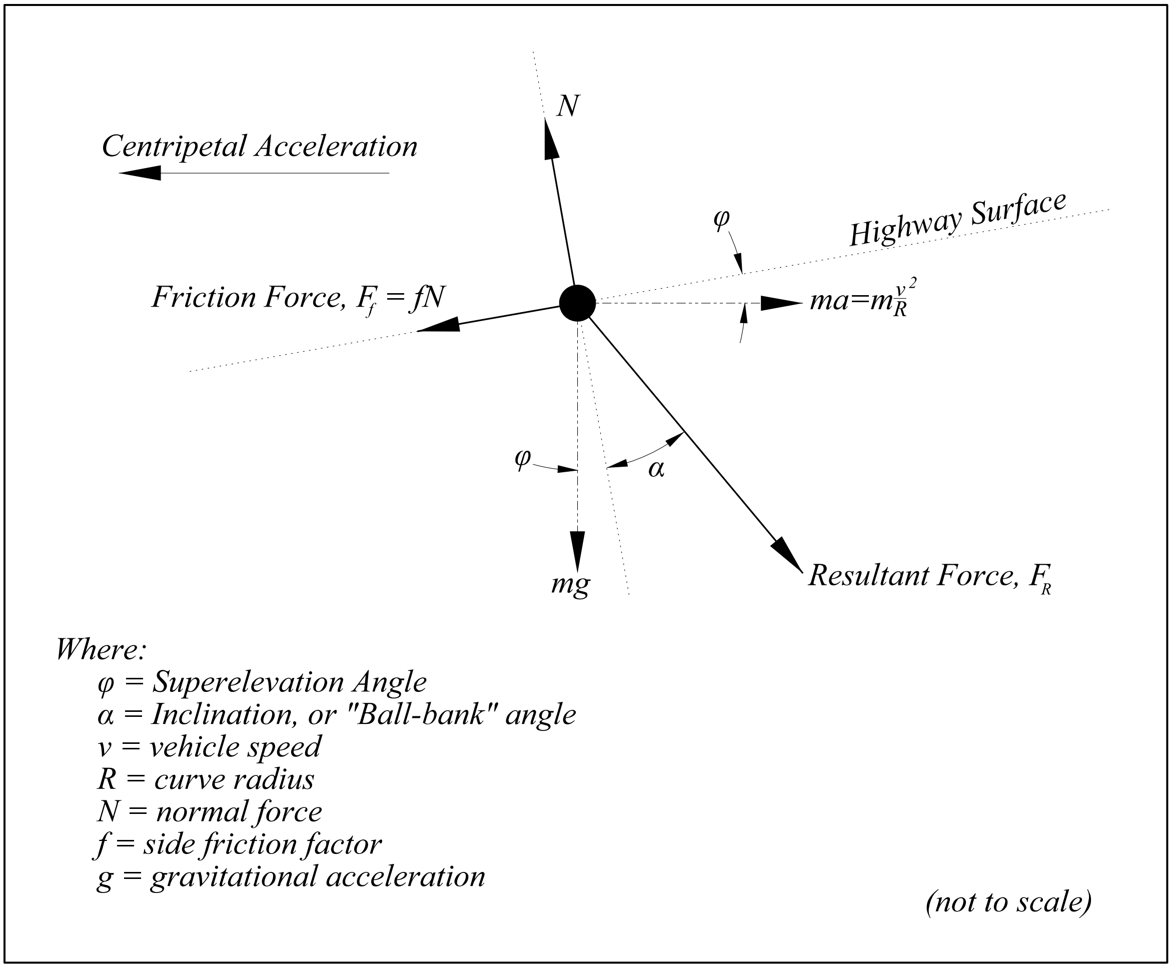


Figure 1 | Geometry of Forces Acting on Vehicle
(ignoring the effects of body roll)

Inclination

The RDS7-GPS-PRO is an accelerometer built to display degrees of inclination. The angle displayed on the instrument is the angle of the Resultant Force F_R the accelerometer is measuring relative to itself (theoretically, relative to the highway surface). When traversing a curve, this is the force that results from adding the gravitational force vector and the “centrifugal force” vector.

For example, when the instrument is not moving and on a level pad, the only force acting on it is gravity. This force is perpendicular to the instrument, so zero degrees is displayed. When the instrument is moving around a curve, the instrument is measuring the resultant force of gravity and centripetal acceleration. The angle of this resultant force relative to the instrument is the inclination angle displayed by the instrument.

Note the "centrifugal force" is not a real force – it's actually the feeling of a force resulting from inertia because the vehicle wants to continue moving in a straight line tangent to the curve. "Centrifugal force" and centrepital force are calculated using the same formula, $F=ma_c=m(v^2/R)$.

Body Roll Rate

Body roll rate is calculated:

$$R_{\Phi} = \frac{m_s g h_1}{K_s - m_s g h_1}$$

Where:

- R_{Φ} = roll rate of body (rad/g)
- m_s = mass of sprung vehicle including suspension members
- g = gravitational acceleration (32.2 ft/s^2)
- h_1 = vertical difference between the roll axis and the center of mass of sprung mass
- K_s = suspension roll stiffness (N-m/rad)

Carlson and Mason [13] investigated the effect body roll rate has on ball-bank indicator readings and resulting advisory speeds. Typical passenger vehicles at the time of the report (1992) had a body roll rate that ranged between 3 and 7 degrees/g (7 degrees being typical of a 1992 Ford Taurus). At a 10 degree ball bank indicator angle, the error due to body roll would range between 0.5 and 1.2 degrees. At a 14 degree reading, the error would be 0.7 to 1.7 degrees.

The error due to body roll increases the reading of the ball bank indicator (that is, the more the vehicle rolls, the greater the ball bank reading). If the body roll is neglected, then the determined advisory speed would be slightly lower than the theoretically correct comfortable speed. The magnitude of the difference would depend on the roll rate of the test vehicle, the unbalanced lateral acceleration acting on the vehicle, the radius, and the superelevation. Carlson and Mason found if a vehicle with a roll rate of 7 degrees/g were used to determine safe speed on a horizontal curve and that roll rate were neglected, the estimated safe speed would be 5 to 7 percent less than intended. For cars with a roll rate less than 7 degrees/g, the difference would be even less. Carlson and Mason concluded that although the body-roll influences the reading of the ball-bank indicator somewhat, it does not greatly affect the posting of comfortable horizontal curve speeds.

For example, if the estimated advisory speed were 55 mph, the theoretically correct advisory speed would be approximately 3.9 mph higher, assuming a 7 percent difference.

Based on Carlson's and Mason's findings, if a typical passenger vehicle is used to investigate curve advisory speeds, the effect of body roll may be neglected. In the 20+ years since this study, passenger vehicle body roll rates have likely decreased as vehicle handling performance has improved, such as Electronic Stability Control systems. Therefore, neglecting the body roll effect while using passenger vehicles is still likely appropriate for traditional ball-banking.

Equations

From the geometry of the forces shown in Figure 1, the following can be defined:

$$Resultant\ Force, F_R = \sqrt{(mg)^2 + \left(m\frac{v^2}{R}\right)^2} \qquad \textbf{Equation 1}$$

$$Normal\ Force, N = F_R \cos(\alpha) \qquad \textbf{Equation 2}$$

$$Friction\ Force, F_f = fN$$
$$(f = side\ friction\ demand\ factor, f_D) \qquad \textbf{Equation 3}$$

In order for the vehicle's tires to resist skidding, the "centrifugal force" must be resisted by the available friction between the tires and the road surface. This friction force is the normal force multiplied by the side friction demand factor, f_D. If the highway surface is the x-axis, and the tires are not skidding to the outside of the curve, the forces along the x-axis must balance. Equation 4 results when the forces along the x-axis are solved for side friction demand (Equation 4 is an approximation due to ignoring the effects of body roll):

$$\sum F_x = 0 = F_R \sin(\alpha) - f_D N$$

$$F_R \sin(\alpha) = f_D F_R \cos(\alpha)$$

$$f_D = \frac{\sin(\alpha)}{\cos(\alpha)}$$

$$f_D \approx \tan(\alpha) \qquad \textbf{Equation 4}$$

Note the RDS7-BB-PRO differentiates between left and right directionality by assigning positive and negative inclination. At normal run speeds, where the resultant force shown in Figure 1 is towards the outside of the curve, friction demand is keeping the vehicle from sliding to the outside of the curve. The way the following equations are set up assumes this is positive friction demand.

When run speeds are very slow, resulting in nominal centrepital acceleration, and if superelevation is present, side friction acts in an opposite direction to keep the vehicle from sliding to the inside of the curve. The resultant force in Figure 1 is then towards the center of the curve. This inward direction is opposite that shown in Figure 1 and represents a negative value for friction demand. The sign of the inclination angle used in Equation 4 is determined using the following rules [12]:

- Inclination is negative (-) if the inclination angle is:
    - To the right of 0.0 degrees on a right-hand curve
    - To the left of 0.0 degrees on a left-hand curve
- Inclination is positive (+) if the inclination angle is:
    - To the left of 0.0 degrees on a right-hand curve
    - To the right of 0.0 degrees on a left-hand curve

The resulting side friction demand factor limits set by the MUTCD are given in Table 1, calculated using Equation 4, rounded down to the nearest 0.01 ft/ft.

Table 1 | MUTCD Side Friction Limits

MUTCD Ball-Bank Angle Limit	Side Friction Demand Limit
12 degrees	0.21
14 degrees	0.24
16 degrees	0.28

From the *AASHTO Green Book*, the simplified curve formula solved for side friction is:

$$f_D = \frac{(1.47V_c)^2}{gR} - \frac{e}{100}$$ **Equation 5**

where,

f_D = side friction demand factor (or lateral acceleration);
e = superelevation rate, percent;
V_c = curve speed, mph;
g = gravitational acceleration (=32.2 ft/s^2); and
R = radius of curve, ft.

In order to estimate the speed at a side friction limit, ball-bank angle, vehicle speed, and vehicle position must be known. The vehicle position over time can be used to estimate curve radius. With these known variables, superelevation can be calculated by solving Equation 5 for superelevation:

$$e = 100\left[\frac{(1.47V_c)^2}{gR} - f_D\right]$$ **Equation 6**

Once superelevation is known, the MUTCD side friction limits from Table 1 can be entered as f_D to determine the speed the limits will be reached. Equation 5 can be solved for vehicle speed:

$$V_c = \frac{\sqrt{gR\left(f_D + \frac{e}{100}\right)}}{1.47}$$ **Equation 7**

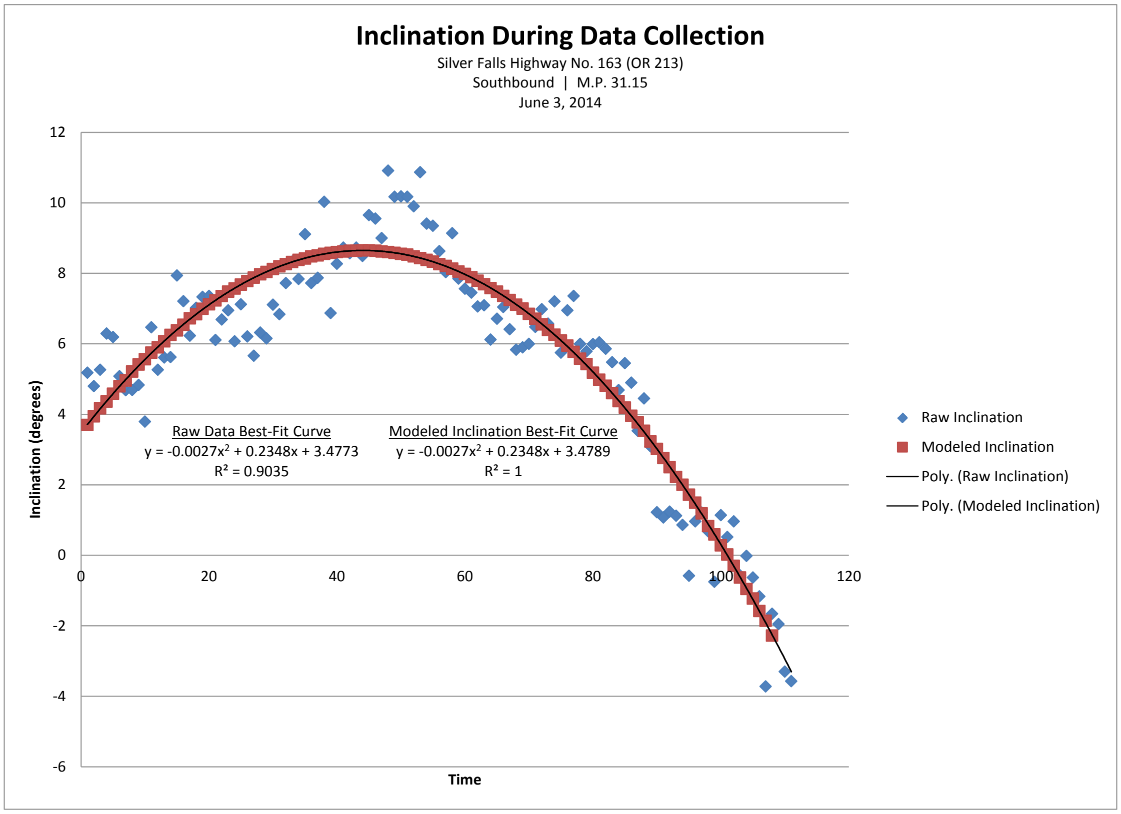
Variables

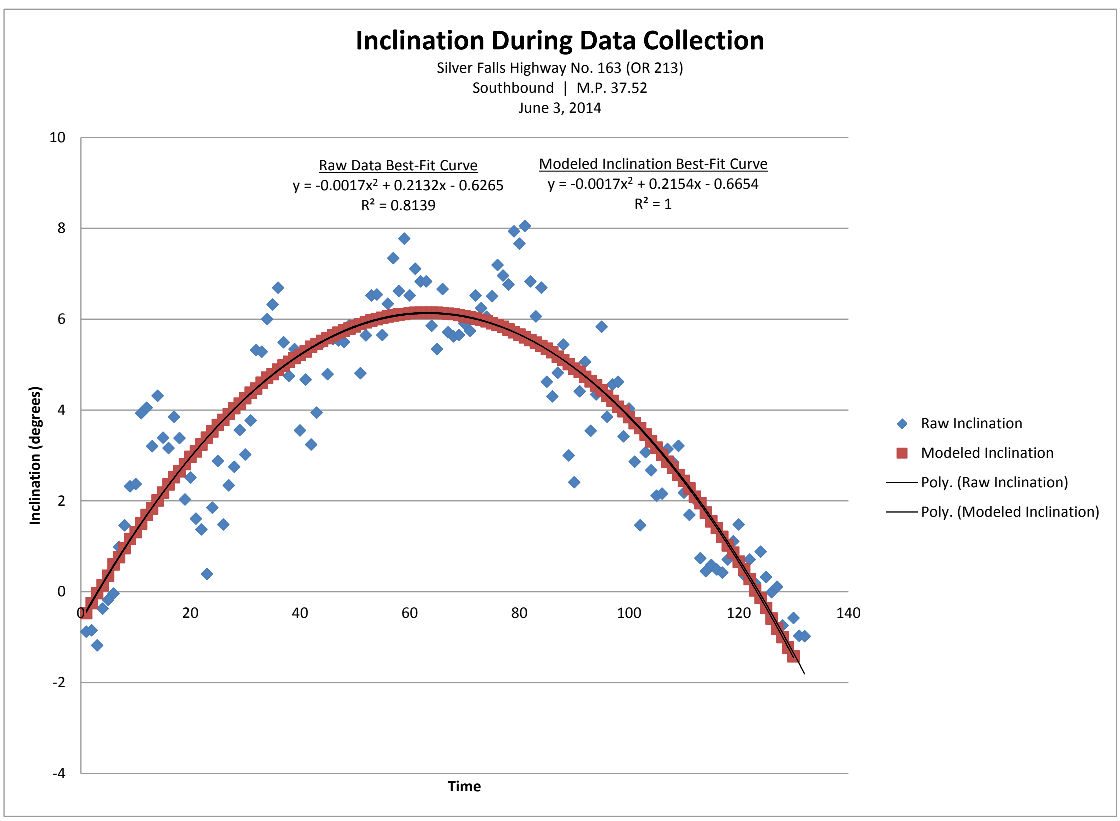
The Kinematics section discussed which variables are needed and how those variables are used to calculate an advisory speed. This section discusses how CARS calculates each variable. An example calculation walk-through is available at the end of the Appendix.

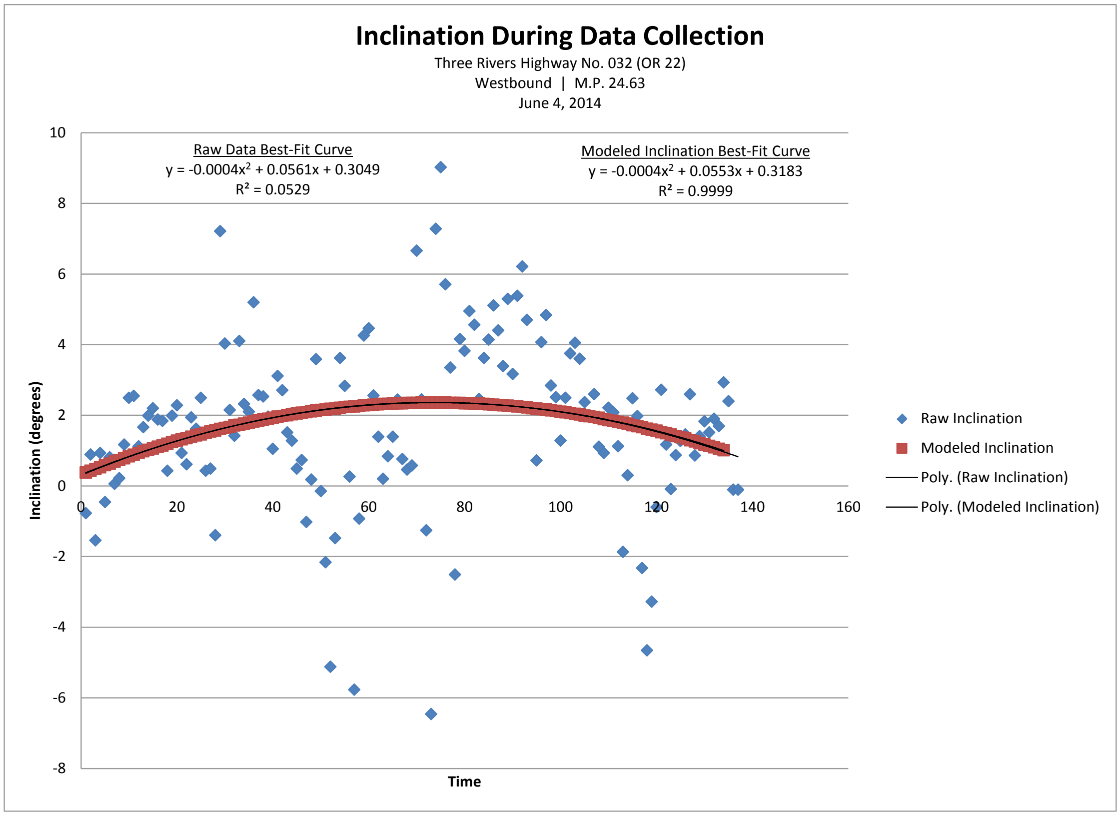
Inclination

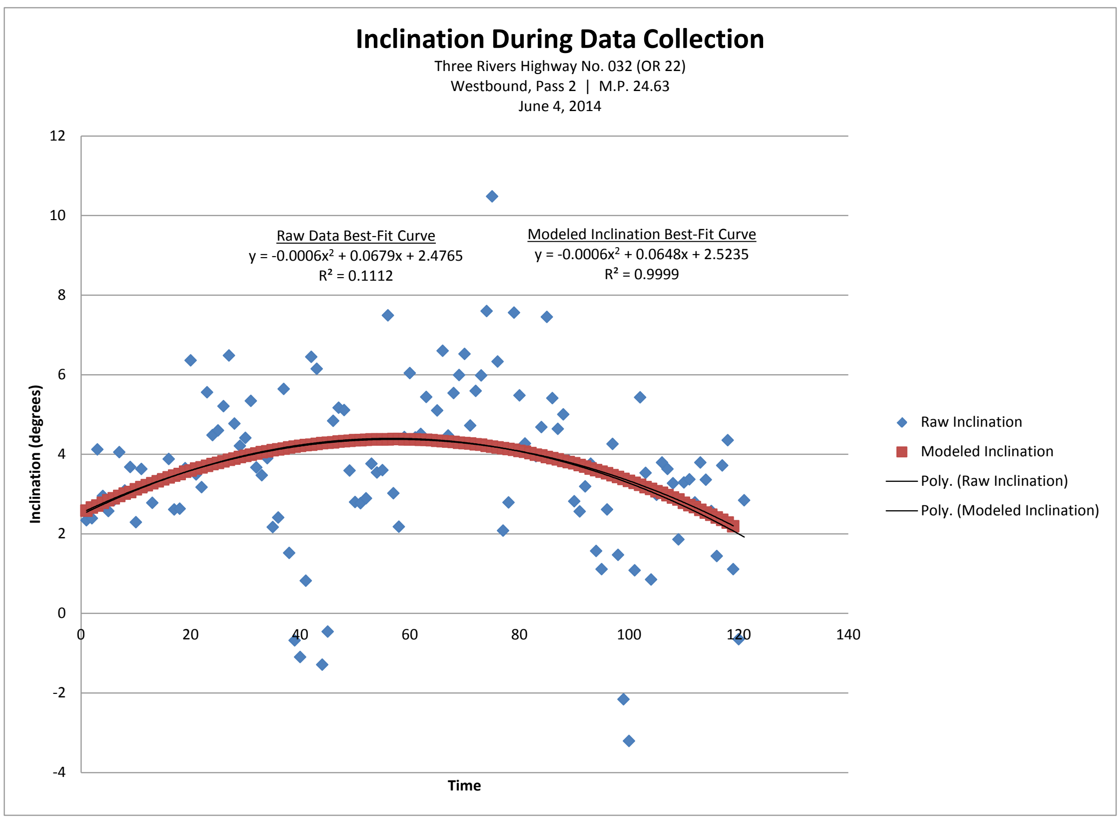
The RDS7-GPS-PRO measures inclination several times each second. Because of the frequency and precision of measurement, these data can be “noisy” and must be post-processed to give a meaningful inclination measurement for advisory speed calculation.

Below are comparisons of raw inclination data and the normalized data from a CARS report. These data were collected by ODOT Region 2’s Weldon Ryan on Silver Falls Highway on June 3, 2014 and Three Rivers Highway on June 4, 2014. The blue diamonds are the reported inclination in the raw run data reported directly from the inclinometer. The red squares are the modeled data reported in the curve evaluation report. Both of these datasets were fit with a best-fit model in Excel to confirm the model CARS is using is a best-fit parabola.


Inclination During Data Collection
Silver Falls Highway No. 163 (OR 213)
Southbound | M.P. 31.15
June 3, 2014
Raw Data Best-Fit Curve
y = -0.0027x² + 0.2348x + 3.4773
R² = 0.9035
Modeled Inclination Best-Fit Curve
y = -0.0027x² + 0.2348x + 3.4789
R² = 1
Inclination (degrees)
Time
Raw Inclination
Modeled Inclination
Poly. (Raw Inclination)
Poly. (Modeled Inclination)


Inclination During Data Collection
Silver Falls Highway No. 163 (OR 213)
Southbound | M.P. 37.52
June 3, 2014
Raw Data Best-Fit Curve
y = -0.0017x² + 0.2132x - 0.6265
R² = 0.8139
Modeled Inclination Best-Fit Curve
y = -0.0017x² + 0.2154x - 0.6654
R² = 1
Inclination (degrees)
Time
Raw Inclination
Modeled Inclination
Poly. (Raw Inclination)
Poly. (Modeled Inclination)


Inclination During Data Collection
Three Rivers Highway No. 032 (OR 22)
Westbound | M.P. 24.63
June 4, 2014
Raw Data Best-Fit Curve
y = -0.0004x² + 0.0561x + 0.3049
R² = 0.0529
Modeled Inclination Best-Fit Curve
y = -0.0004x² + 0.0553x + 0.3183
R² = 0.9999
Inclination (degrees)
Time
Raw Inclination
Modeled Inclination
Poly. (Raw Inclination)
Poly. (Modeled Inclination)


Inclination During Data Collection
Three Rivers Highway No. 032 (OR 22)
Westbound, Pass 2 | M.P. 24.63
June 4, 2014
Raw Data Best-Fit Curve
y = -0.0006x² + 0.0679x + 2.4765
R² = 0.1112
Modeled Inclination Best-Fit Curve
y = -0.0006x² + 0.0648x + 2.5235
R² = 0.9999
Inclination (degrees)
Time
Raw Inclination
Modeled Inclination
Poly. (Raw Inclination)
Poly. (Modeled Inclination)

From these results, the modeled inclination, or "measured side friction," reported by CARS are normalized inclination data using a second-order polynomial best fit curve (parabola) through the raw inclination readings. The resulting normalized inclination curve is used to calculate demanded side friction to calculate superelevation (see Kinematics section).

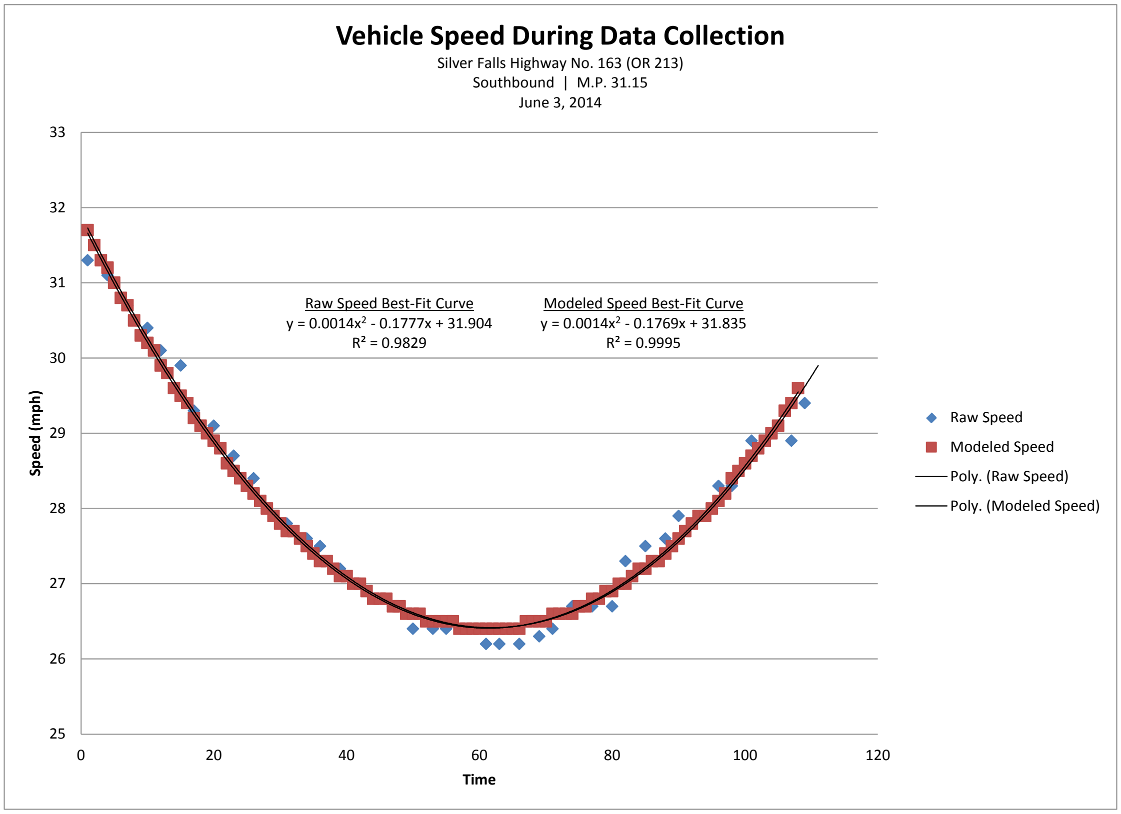
It is important to check the curve report to make sure the inclination curve is a parabola with a clear maximum or minimum that is not at either end, even if the report "fit" is very good. If the inclination curve does not show a maximum or minimum, the critical area of the curve probably has not been included in the "net"; increasing the dataset usually results in a clear maximum or minimum.

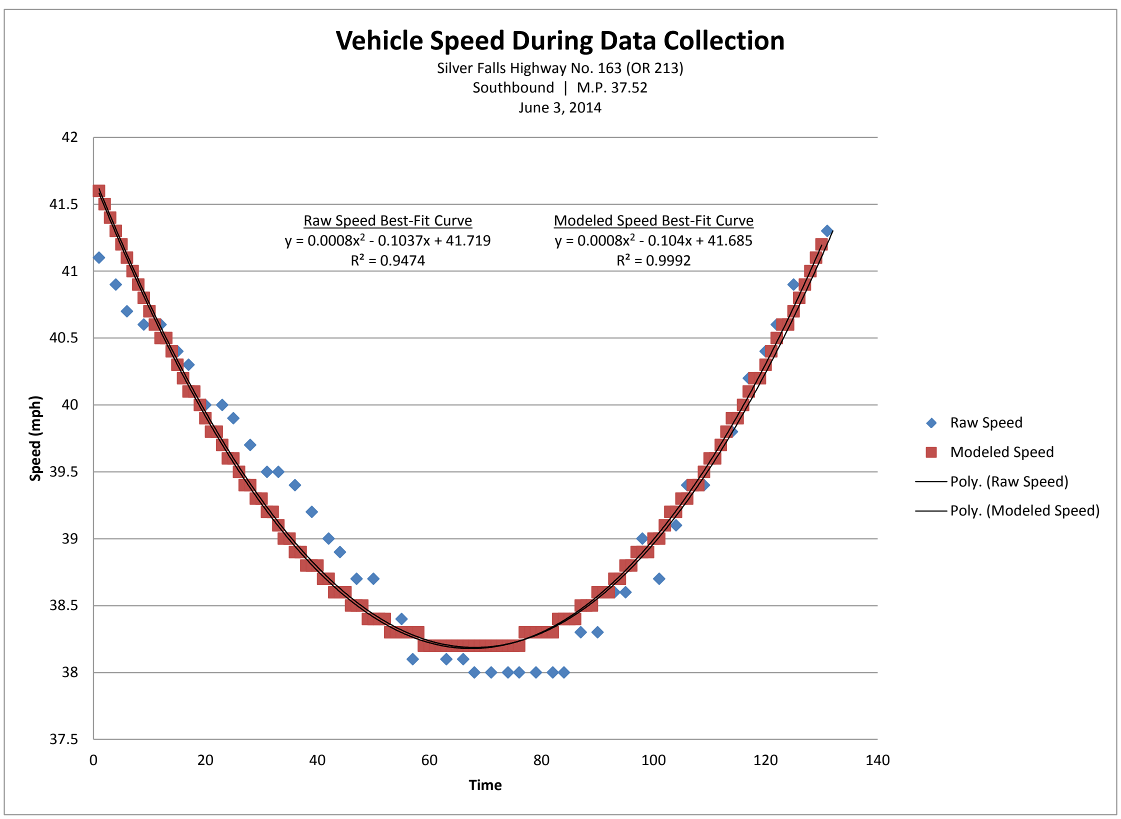
Speed

CARS measures vehicle speed from the GPS roughly every 0.3 seconds [14]. Because of the frequency of measurement, and because the GPS unit is not survey-grade, driving speed through the curve is post processed to give a meaningful speed measurement for advisory speed calculation.

Below are comparisons of raw speed data and the normalized data reported by the CARS curve report. These data were collected by ODOT Region 2's Weldon Ryan on Silver Falls Highway and Three Rivers Highway. The curve reports are available upon request.

The blue diamonds are the reported speed in the raw run data, reported directly from the GPS. The red squares are the modeled data reported in the curve evaluation report. Both of these datasets were fit with a best-fit model to confirm the model CARS is using is a best-fit parabola.


Vehicle Speed During Data Collection
Silver Falls Highway No. 163 (OR 213)
Southbound | M.P. 31.15
June 3, 2014
Raw Speed Best-Fit Curve
y = 0.0014x² - 0.1777x + 31.904
R² = 0.9829
Modeled Speed Best-Fit Curve
y = 0.0014x² - 0.1769x + 31.835
R² = 0.9995
Speed (mph)
Time
Raw Speed
Modeled Speed
Poly. (Raw Speed)
Poly. (Modeled Speed)


Vehicle Speed During Data Collection
Silver Falls Highway No. 163 (OR 213)
Southbound | M.P. 37.52
June 3, 2014
Raw Speed Best-Fit Curve
y = 0.0008x² - 0.1037x + 41.719
R² = 0.9474
Modeled Speed Best-Fit Curve
y = 0.0008x² - 0.104x + 41.685
R² = 0.9992
Speed (mph)
Time
Raw Speed
Modeled Speed
Poly. (Raw Speed)
Poly. (Modeled Speed)

From these results, the modeled speed, or "test speed," reported by CARS are normalized speed data using a second-order polynomial best fit curve (parabola) through the raw vehicle speed readings. The resulting normalized speed curve is used to calculate superelevation (see Kinematics section).

Radius

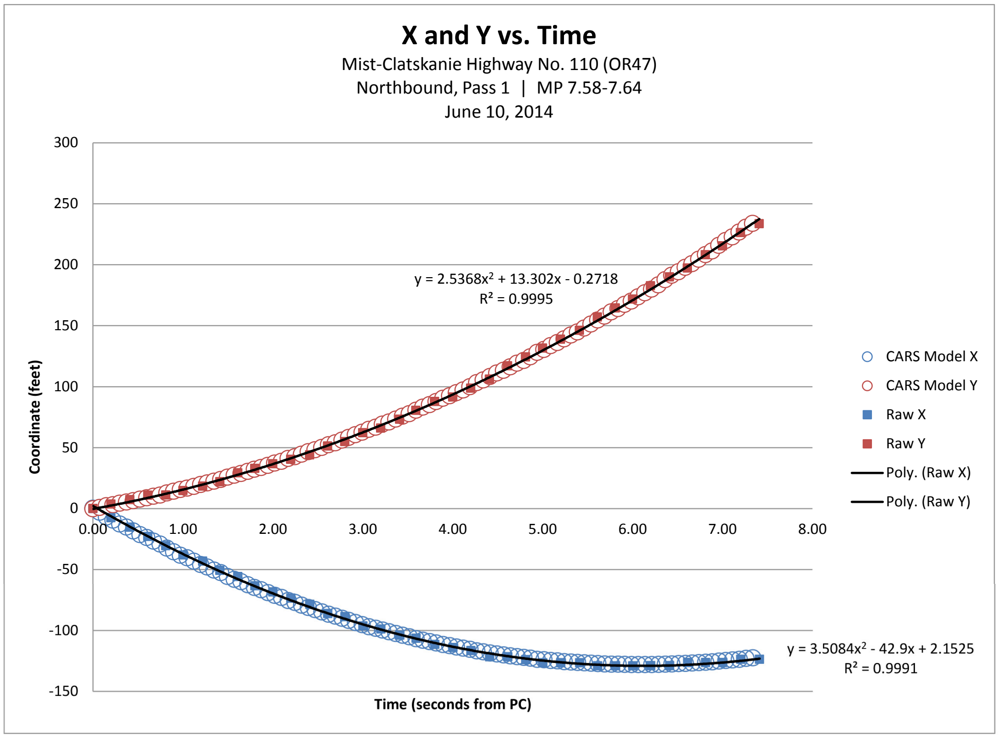
CARS records location (lat/long) from the GPS roughly every 0.3 seconds [14]. These data are used to calculate the curve radius used to calculate advisory speed. Because of the frequency of measurement, and because the GPS unit is not survey-grade, location data are post processed to give a meaningful radius estimate for advisory speed calculation.

During post processing, individual location points are plotted relative to the Point of Curvature, PC (i.e., the PC is at (0,0)) by converting latitude and longitude into Cartesian (x,y) coordinates using the Universal Transverse Mercator geographic coordinate system [14]. The Defense Mapping Agency (now called the National Geospatial-Intelligence Agency) discusses the calculations required to complete this conversion in their report *The Universal Grids: Universal Transverse Mercator (UTM) and Universal Polar Stereographic (UPS)* [15]. There are many online applications that complete these calculations with mapping features.

Once individual location points are plotted, parabolic models are fit to the change in latitude over time and longitude over time to estimate the path the investigation vehicle traveled around the curve. This results in two dependent variables – x and y – and one independent variable – time. When these points are combined, it results in a parabola oriented to match the investigation vehicle's path.

To confirm this, raw lat/long data were plotted from data collected by Weldon Ryan on Mist-Clatskanie Highway and compared to the *Modeled x* and *y* points given in the curve report. The *Modeled x* and *y* points matched the parabola fit to the raw lat/long data when the PC was set to coordinates (0,0).

When these data were laid over a Google aerial view of the curve, the best-fit line and CARS modeled coordinates matched the vehicle path through the curve very well ($r^2 > 0.99$), shown in Figure 2. The black points are the raw lat/long coordinates, white points are the CARS *Modeled x* and *y* coordinates, and the red points are the calculated coordinates based on the best-fit x and y models shown in the graph. The calculated radius at the modeled apex was 147 feet, very close to the ODOT Horizontal Curve Report radius of 143 feet (40 degree curve). The calculated radius was the same as the reported minimum radius in the CARS report.



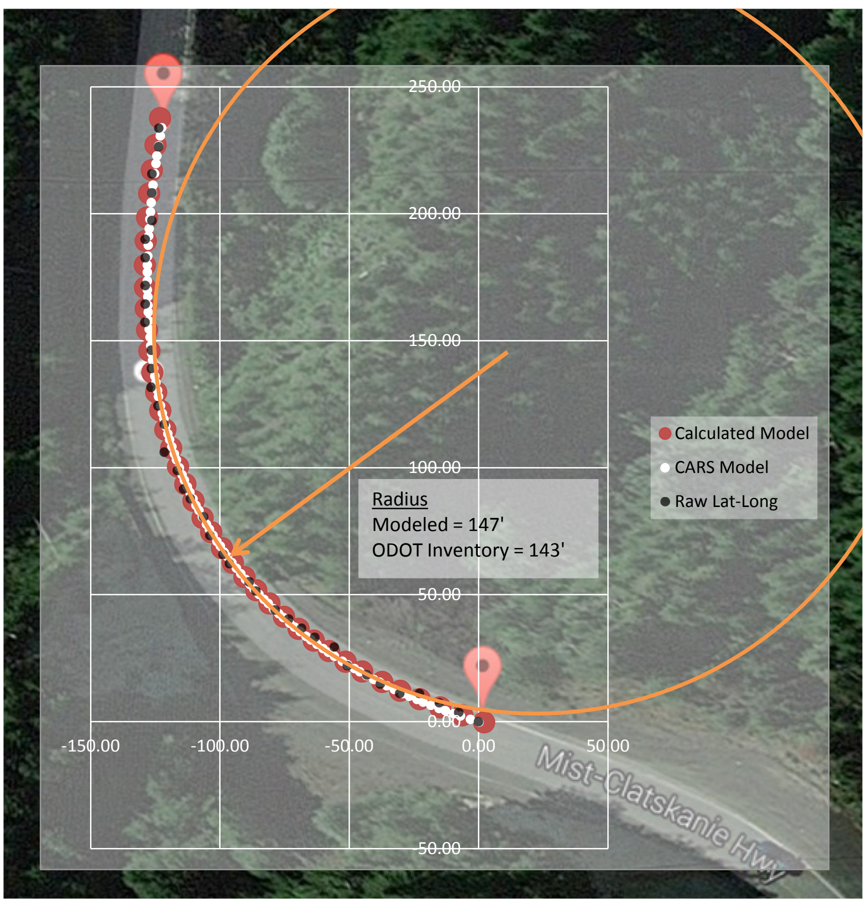


Figure 2 | Raw and Modeled Location Data over Aerial Map

It is important to note horizontal curves are circular curves, usually with spiral curves on the ends – not a parabola. For the purpose of estimating curve shape for advisory speeds, a parabolic model fits the vehicle path data well (if the data are selected appropriately, R^2 >0.96), so curve shape estimates should be close to real-world vehicle path shape.

In order to estimate the radius of the curve along the path of travel, CARS calculates the radius of curvature along the parabolic shape of the modeled curve. For each point along a parabola, the radius of curvature can be calculated to determine the radius of the approximating circle at that point. The formula for radius of curvature at any point *x* for the curve *y=f(x)* is given in Equation 8. Another method to determine radius at a point is the 3-Point Method. For clarity, the following discussion will use the radius of curvature equation.

$$Radius\ of\ Curvature, R = \frac{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}{\left|\frac{d^2y}{dx^2}\right|}$$

Equation 8

A good explanation and interactive exercise on the concept of Radius of Curvature can be found at intmath.com. Since the curve model is a parabola, finding the first and second derivative for the curve is simple. In order to verify reported radii using Excel's graphing functions, the modeled parabola must be rotated so the directrix is parallel with the x-axis (i.e.: so the parabola is symmetrical about the y-axis to determine the curve's equation). Parabolas can be rotated if any 4 points *P, Q, R, S* along the curve are known [16], shown in Figure 3.

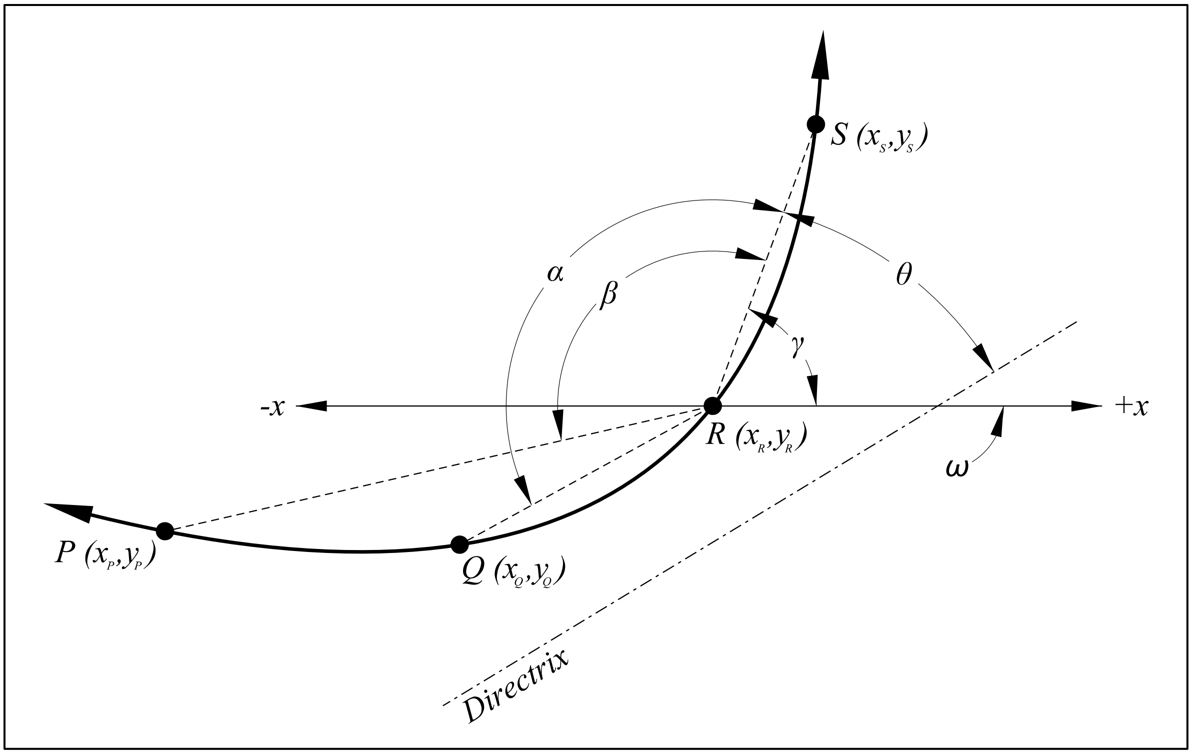


Figure 3 | Parabola through Four Points

From the geometry shown in Figure 3, the following properties can be defined:

r_1 = length of ray PR

r_2 = length of ray QR

r_4 = Length of ray SR

α = angle between rays RQ and RS

β = angle between rays PR and SR

γ = counter-clockwise angle between ray SR and the positive x-axis

θ = angle between ray SR and the directrix

ω = parabola rotation angle

The angle between the ray SR and the directrix, θ can be determined by solving Equation 9 for θ:

$$A\tan(\theta)^2 + B\tan(\theta) + C = 0 \qquad \textbf{Equation 9}$$

Where:

$A = \sin\alpha\sin\beta(\sin\alpha\, r_2 - \sin\beta\, r_1)$

$B = 2\sin\alpha\sin\beta\,(\cos\beta\, r_1 - \cos\alpha\, r_2)$

$C = \sin\alpha\cos\beta\,(r_4 - \cos\beta\, r_1) - \sin\beta\cos\alpha\,(r_4 - \cos\alpha\, r_2)$

$\theta = \tan^{-1}\left[\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}\right]$

Because θ is determined with a quadratic equation, there will be two values of θ. One value of θ rotates the parabola so it is symmetrical about the x-axis; the other so it is symmetrical about the y-axis. The required rotation can then be calculated using Equation 10.

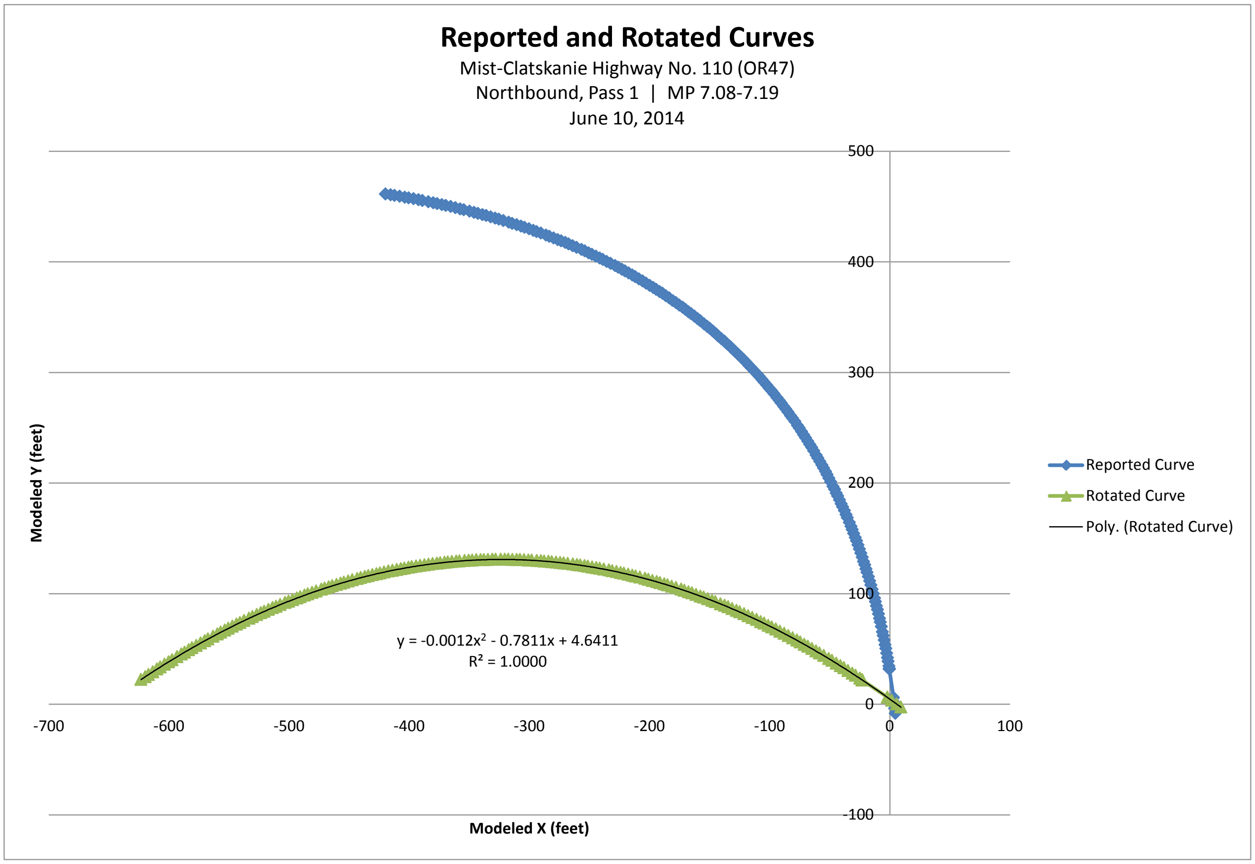
$$\omega = \theta - \gamma \qquad \textbf{Equation 10}$$

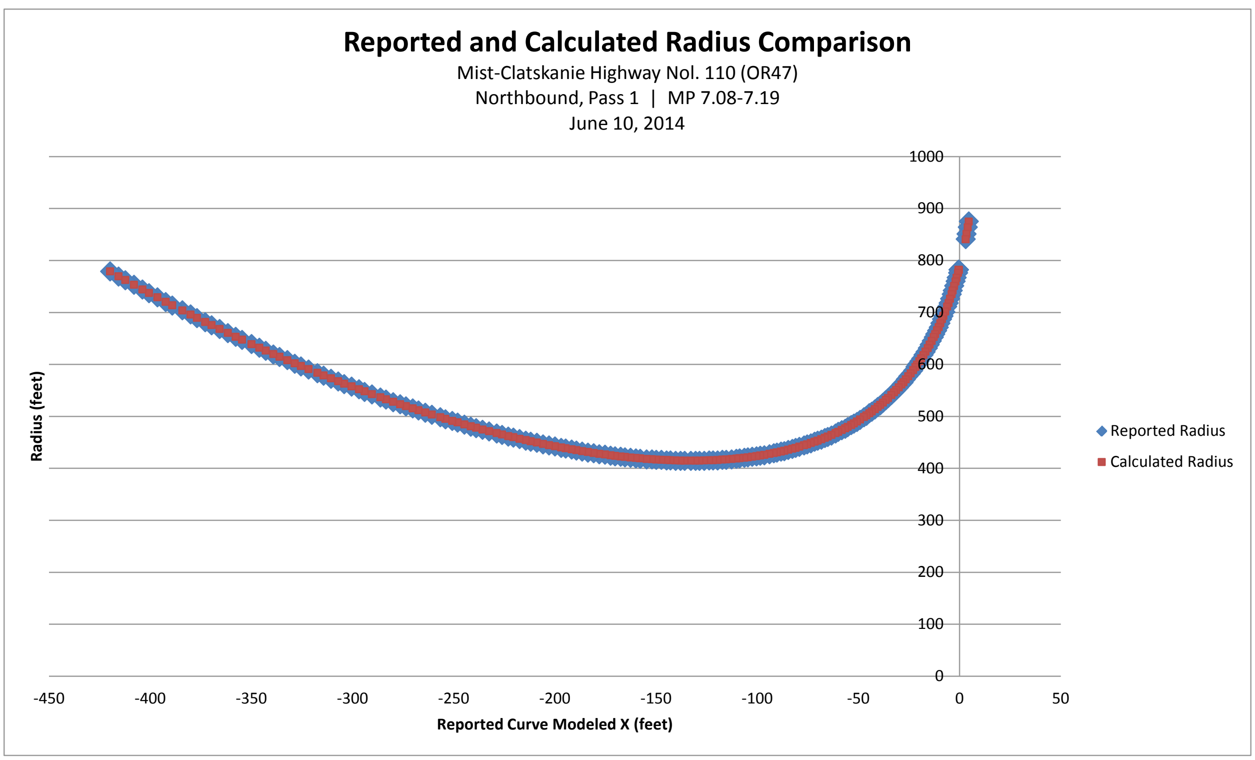
Once the rotation angle is determined, each *Modeled x* and *y* point given in the CARS report can then be rotated to the proper alignment using Equation 11. Excel can then plot a best-fit line to the rotated data and give the equation, making the radius of curvature calculation possible.

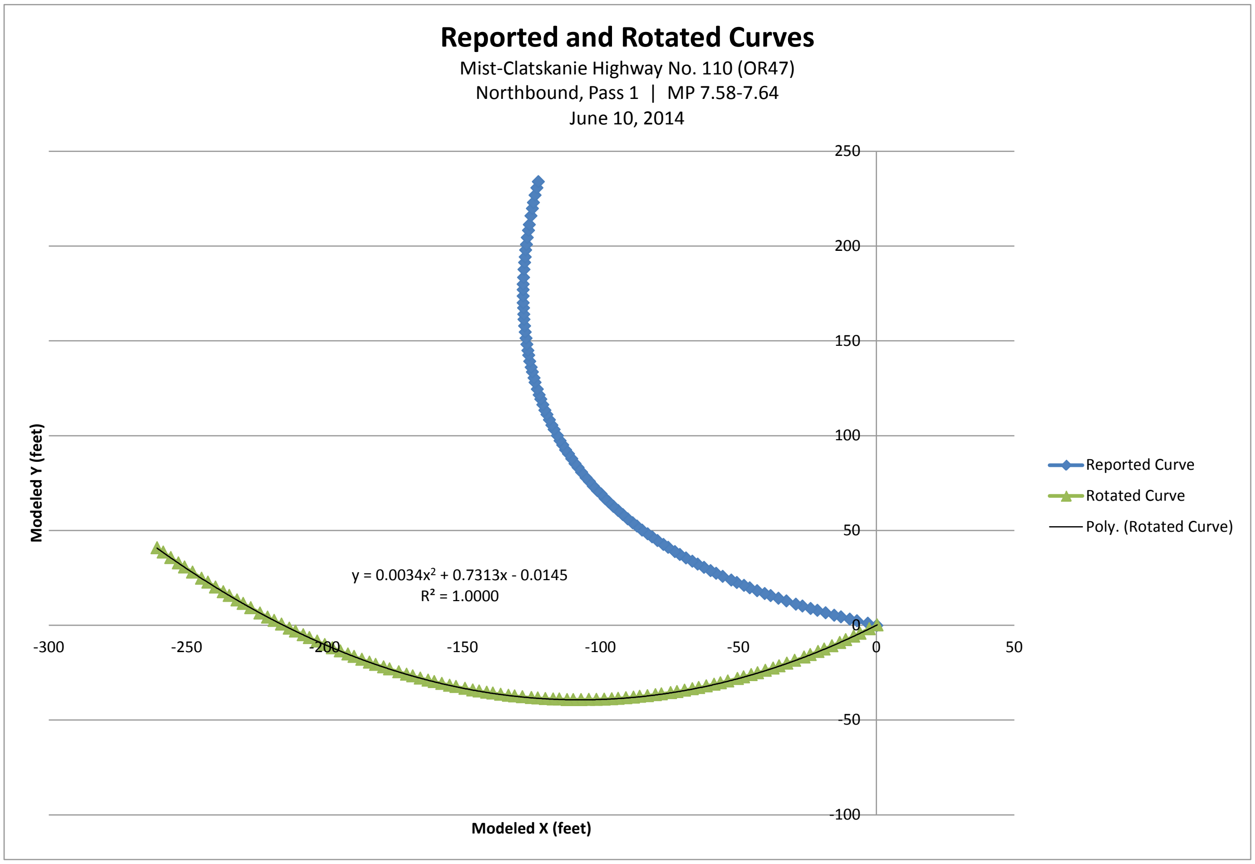
$$\begin{aligned} x' &= x\cos\omega - y\sin\omega \\ y' &= x\sin\omega + y\cos\omega \end{aligned} \qquad \textbf{Equation 11}$$

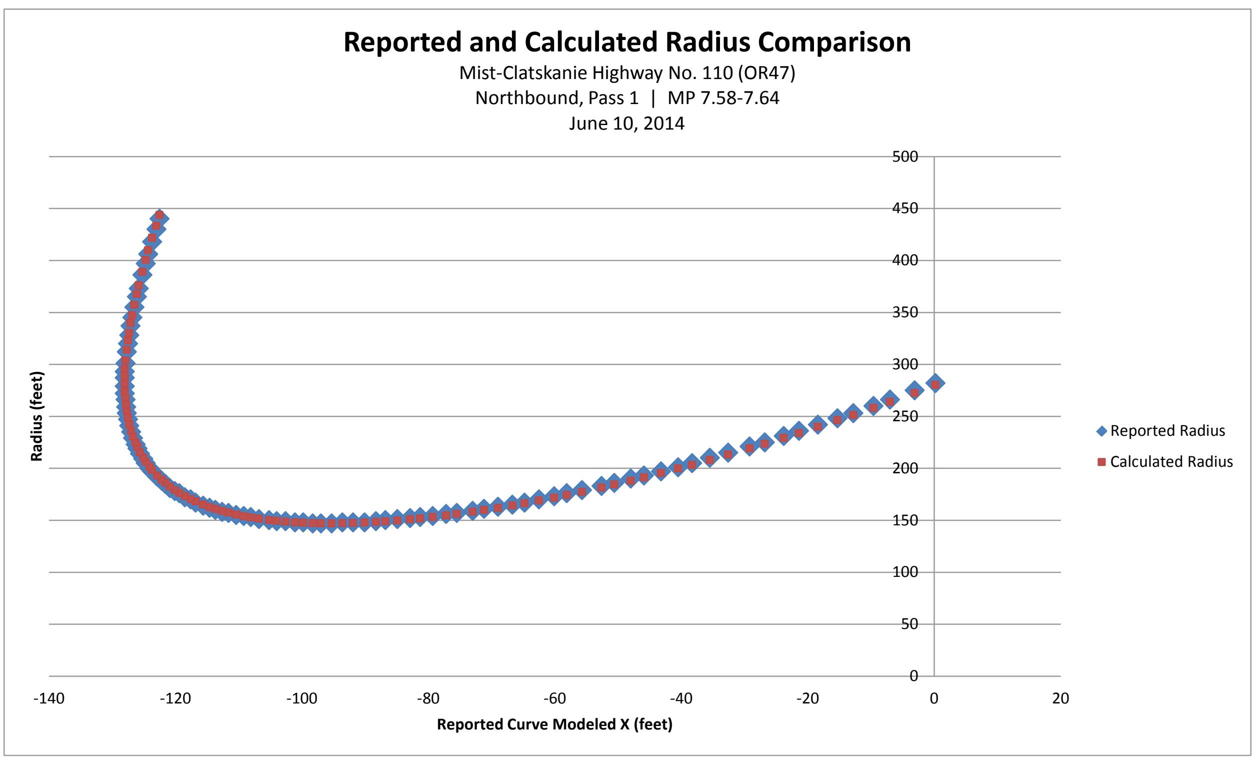
Below are modeled curves and corresponding comparisons of CARS reported radius and radius calculated using the Radius of Curvature equation. These data were collected by ODOT Region 2's Weldon Ryan on Mist-Clatskanie Highway on June 10, 2014. In the first graph of each location, the blue curve is the curve model (*Modeled x* and *y*) given in the CARS report. The green line is the rotated parabola with a best-fit curve and corresponding equation. The second graph shows a comparison between the reported and calculated radius. If the reported radius matches the radius calculated using the radius of curvature equation, these points should form two curves that lay directly on top of each other.

The following results confirm the radius reported by CARS is the radius of curvature at each point *x, y* along the best-fit parabolic curve model.


Reported and Rotated Curves
Mist-Clatskanie Highway No. 110 (OR47)
Northbound, Pass 1 | MP 7.08-7.19
June 10, 2014
Modeled Y (feet)
Modeled X (feet)
y = -0.0012x² - 0.7811x + 4.6411
R² = 1.0000
Reported Curve
Rotated Curve
Poly. (Rotated Curve)
500
400
300
200
100
0
-100
-700
-600
-500
-400
-300
-200
-100
0
100


Reported and Calculated Radius Comparison
Mist-Clatskanie Highway Nol. 110 (OR47)
Northbound, Pass 1 | MP 7.08-7.19
June 10, 2014
Radius (feet)
Reported Curve Modeled X (feet)
Reported Radius
Calculated Radius
1000
900
800
700
600
500
400
300
200
100
0
-450
-400
-350
-300
-250
-200
-150
-100
-50
0
50


Reported and Rotated Curves
Mist-Clatskanie Highway No. 110 (OR47)
Northbound, Pass 1 | MP 7.58-7.64
June 10, 2014
Modeled Y (feet)
Modeled X (feet)
y = 0.0034x² + 0.7313x - 0.0145
R² = 1.0000
250
200
150
100
50
0
-50
-100
-300
-250
-200
-150
-100
-50
0
50
Reported Curve
Rotated Curve
Poly. (Rotated Curve)


Reported and Calculated Radius Comparison
Mist-Clatskanie Highway No. 110 (OR47)
Northbound, Pass 1 | MP 7.58-7.64
June 10, 2014
Radius (feet)
Reported Curve Modeled X (feet)
500
450
400
350
300
250
200
150
100
50
0
-140
-120
-100
-80
-60
-40
-20
0
20
Reported Radius
Calculated Radius

Advisory Speed

With the inclination, speed, and radius modeled through the length of the curve, the speed at which the MUTCD limits will be reached can be calculated for every point on the curve. From the Kinematics section, the superelevation can be calculated using Equation 12 (inclination angle must be converted to radians):

$$e = 100\left[\frac{(1.47V_c)^2}{gR} - f_D\right] \quad \textbf{Equation 12}$$

Once superelevation is known, the MUTCD side friction limits can be entered as f_D *=tan(MUTCD limit)* to determine the speed at which the limits will be reached. From the Kinematics section, vehicle speed can be calculated using Equation 13:

$$V_c = \frac{\sqrt{gR\left(f_D + \frac{e}{100}\right)}}{1.47} \quad \textbf{Equation 13}$$

The minimum calculated advisory speed is the critical speed on the curve – the slowest speed at which the MUTCD limit will be reached. The minimum calculated advisory speed is then rounded down to the nearest 5 mph for posting.

Interpreting Results

When reading CARS curve reports, the critical output is the **average of the minimum calculated advisory speeds**. This is the average speed the side friction limit will be reached. It is important to interpret this speed in the context of MUTCD 2C.08:

> Among the engineering practices listed as appropriate for the determination of the recommended advisory speed for a horizontal curve is a traditional ball-bank indicator using the following criteria:
>
> 1. 16 degrees of ball-bank for speeds of 20 mph or less
> 2. 14 degrees of ball-bank for speeds of 25 to 30 mph
> 3. 12 degrees of ball-bank for speeds of 35 mph and higher.

It is especially important to interpret the average minimum calculated advisory speeds when they are around 30-35 mph and 20-25 mph and choose the MUTCD thresholds appropriately.

In the sample curve report given in Table 2, the minimum calculated advisory speeds for a 12 degree limit are less than 20 mph. For the Northeast direction, the average minimum calculated advisory speed is 19.5 mph. This means if you traveled around the curve at 19.5 mph, the maximum inclination would be 12 degrees. If these results were not checked, this would result in a recommended advisory speed of 15 mph; however, 12 degrees is the limit for test speeds of 35 mph and greater.

Since 12 degrees is reached at a very slow speed, we can estimate the side friction limit needs to be changed to 16 degrees (limit for speeds 20 and less). Table 3 shows the results of changing the side friction limit to 16 degrees.

Table 2 | Sample Curve Report – 12 Degree Threshold

Pass #	Curve	Travel	Fit	Avg. Test Speed	Curve Radius	Curve Length	Deflection Angle	Elevation at Apex	Minimum Calculated Advisory Speed	Recommended Advisory Speed	Chevron Spacing
1	Left	Northeast	99.30%	20.3 mph	85 ft	249 ft	100°	9.50%	**19.0 mph**	15 mph	40 ft
2	Right	South	99.20%	20.5 mph	78 ft	244 ft	102°	9.80%	**19.0 mph**	15 mph	40 ft
3	Left	Northeast	99.50%	20.9 mph	91 ft	247 ft	97°	8.20%	**19.6 mph**	15 mph	40 ft
4	Right	Southeast	98.60%	20.7 mph	81 ft	247 ft	101°	9.70%	**19.3 mph**	15 mph	40 ft
5	Left	Northeast	99.50%	21.6 mph	97 ft	240 ft	93°	7.30%	**19.8 mph**	15 mph	40 ft
6	Right	South	99.30%	20.8 mph	84 ft	246 ft	100°	9.70%	**19.4 mph**	15 mph	40 ft

Table 3 | Sample Curve Report – 16 Degree Threshold

Pass #	Curve	Travel	Fit	Avg. Test Speed	Curve Radius	Curve Length	Deflection Angle	Elevation at Apex	Minimum Calculated Advisory Speed	Recommended Advisory Speed	Chevron Spacing
1	Left	Northeast	99.3%	20.3 mph	85 ft	249 ft	100°	9.50%	**21.5 mph**	20 mph	40 ft
2	Right	South	99.2%	20.5 mph	78 ft	244 ft	102°	9.80%	**21.0 mph**	20 mph	40 ft
3	Left	Northeast	99.5%	20.9 mph	91 ft	247 ft	97°	8.20%	**22.0 mph**	20 mph	40 ft
4	Right	Southeast	98.6%	20.7 mph	81 ft	247 ft	101°	9.70%	**21.3 mph**	20 mph	40 ft
5	Left	Northeast	99.5%	21.6 mph	97 ft	240 ft	93°	7.30%	**22.4 mph**	20 mph	40 ft
6	Right	South	99.3%	20.8 mph	84 ft	246 ft	100°	9.70%	**21.6 mph**	20 mph	40 ft

Setting the side friction limit to 16 degrees, the average minimum calculated advisory speed for the Northeast direction is 22.0 mph. So at 20 mph, the MUTCD threshold of 16 degrees will not be exceeded; 20 mph would be the recommended advisory speed.

Data Gathering

In order to test differences between CARS and the ODOT digital ball-banking spreadsheet, compare CARS results to existing curve signing, and compare sensitivity of CARS results, CARS data and ODOT spreadsheet data were collected by ODOT Region 2's Weldon Ryan on:

- 3 Rivers Highway No. 032 (OR22),
- Oregon Coast Highway No. 009 (US101),
- Cascade Highway No. 160 (OR213), and
- Yamhill-Newberg Highway No. 151 (OR240).

In order to further test sensitivity of CARS results, Weldon collected CARS data on

- Mist-Clatskanie Highway No. 110 (OR47), and
- Siletz Highway No. 181 (OR229).

Weldon used Region 2's 2007 Chevy 2500 HD pickup to gather all data. Inventory of existing advisory signs on OR 22 and US 101 were based on Google Streetview imagery dated October 2013 for both highways. Data comparison results are tabulated in the Appendix.

These corridors were chosen because:

1. There is a high density of horizontal curves,
2. There are a variety of curve types and advisory speeds,
3. Weldon already collected data using the GPS-enabled ODOT spreadsheet on OR 22, US 101, OR 213, and OR 240, and,
4. There is a variety of terrain and tree coverage where GPS signal could be lost.

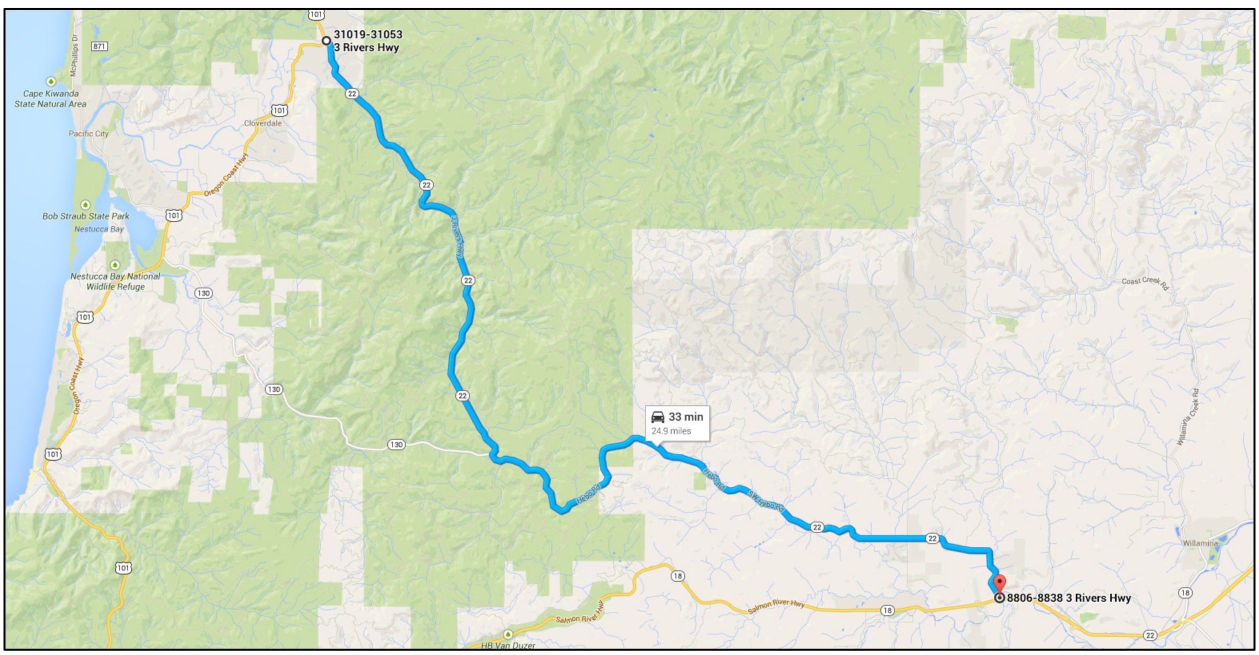
3 Rivers Highway No. 032 (OR 22)

CARS data were collected on the entire length of 3 Rivers Highway on Thursday June 5 and 6, 2014; four passes in each direction. The first three passes were at or below the existing advisory speeds and were on average within 6 mph of each other. The last pass was done faster than the first three (on average 13 mph faster). After data were collected, 18 curves were chosen along the corridor to see whether different test speeds affect the calculated advisory speed and determine differences in recommended advisory speed between CARS, ODOT spreadsheet, and existing signing. CARS curve reports on OR 22 were generated by Eric Leaming.

ODOT Ball-banking spreadsheet data were collected from MP 00 to MP 21 between April 30 and May 27, 2014.

3 Rivers Highway is classified as a Rural Minor Arterial between Valley Junction (Spirit Mountain Casino) and Hebo in the northwest Oregon Coast Range. This section of highway is narrow and winding along the Little Nestucca River and runs against hillsides and in shallow canyons in sections.

Figure 4 | 3 Rivers Highway



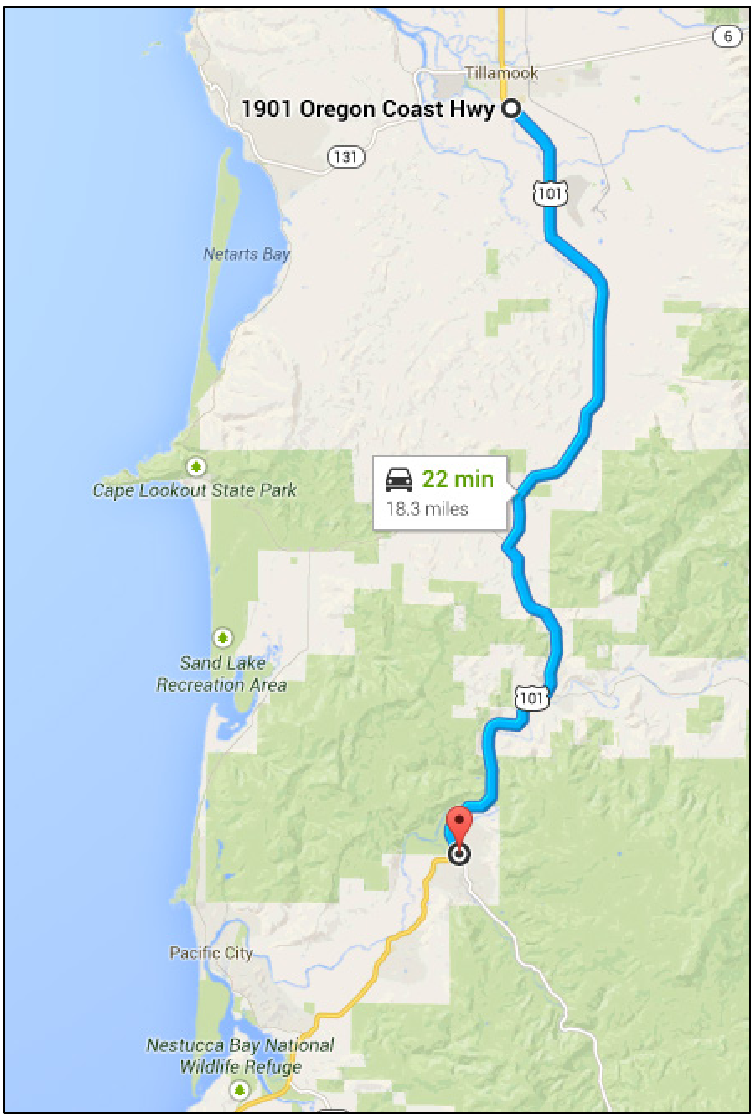
Oregon Coast Highway No. 009 (US 101)

CARS data were collected on June 6, 2014 from MP 84.9 (Hebo, intersection with OR 22) to MP 67.0 (Tillamook); three passes in each direction. Each pass was at or below the existing advisory speed. CARS curve reports were generated by Ian Roholt.

ODOT Ball-banking spreadsheet data were collected from MP 3 in Astoria to MP 129 south of Depoe Bay. The section of US 101 between Tillamook and Hebo was collected March 11-13, 2014.

This section of the Oregon Coast Highway is classified as a Rural Principal Arterial and winds through cow pastures along the Nestucca River.

Figure 5 | Oregon Coast Highway



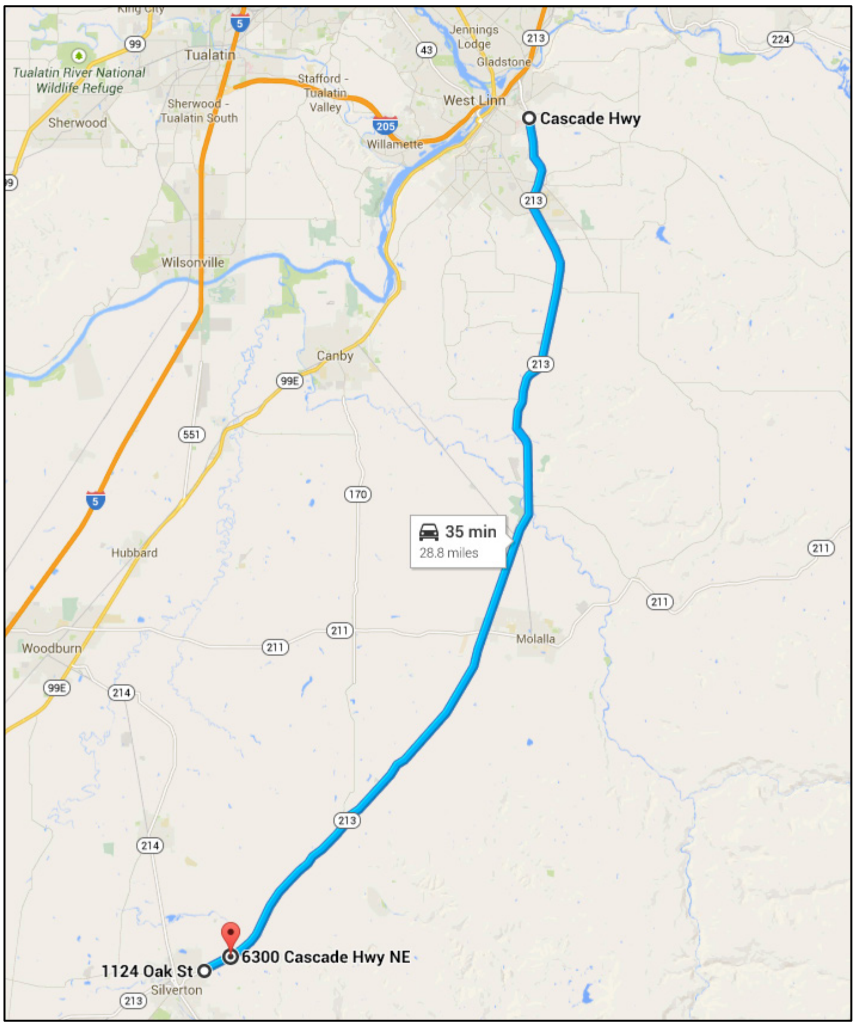
Cascade Highway No. 160 (OR 213)

CARS data were collected on July 17, 2014 along the entire length of Cascade Highway; three passes in each direction. Each pass was at or below the existing advisory speed. CARS curve reports were generated by Ian Roholt.

ODOT Ball-banking spreadsheet data were collected from MP 18.3 to MP 26.1 on April 7, 2014.

Cascade Highway is classified as a Rural Minor Arterial running from Silverton to Oregon City through farm areas in the northern Willamette Valley.

Figure 6 | Cascade Highway



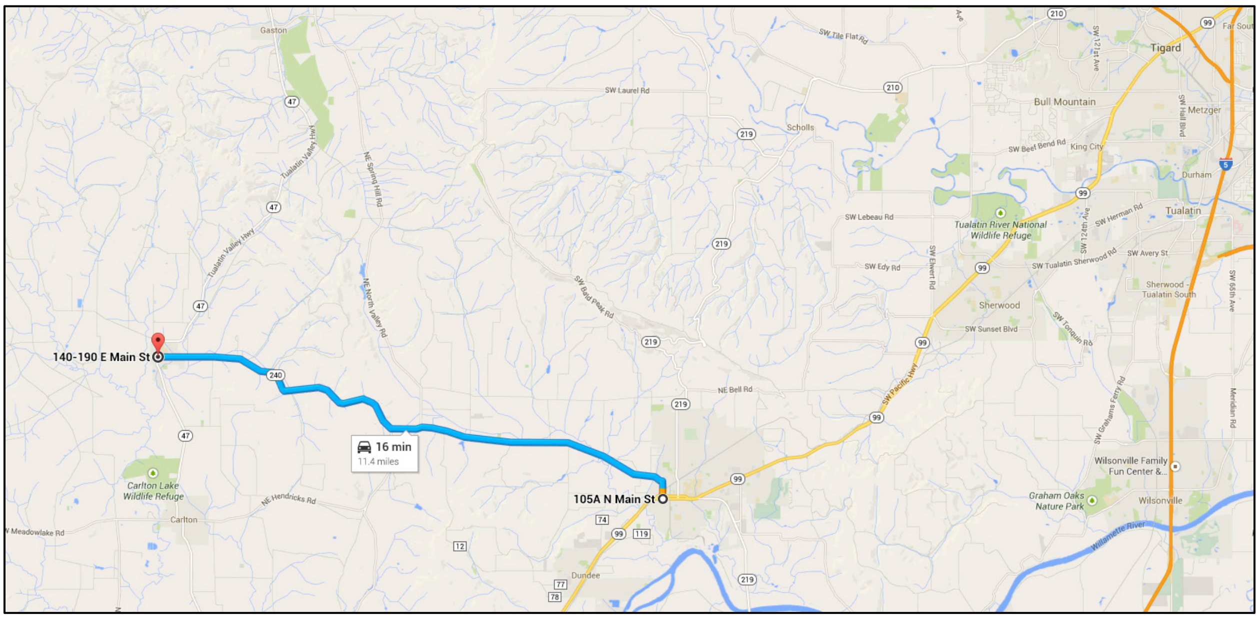
Yamhill-Newberg Highway No. 151 (OR 240)

CARS data were collected on July 28, 2014 along the entire length of the Yamhill-Newberg Highway; three passes in each direction. Each pass was at or below the existing advisory speed. CARS curve reports were generated by Ian Roholt.

ODOT Ball-banking spreadsheet data were collected from MP 1.6 to MP 11.2 on April 8-9, 2014.

Yamhill-Newberg Highway is a short section classified as a Rural Minor Arterial running about 11 miles from Newberg to Yamhill through farm areas in the northern Willamette Valley.

Figure 7 | Yamhill-Newberg Highway

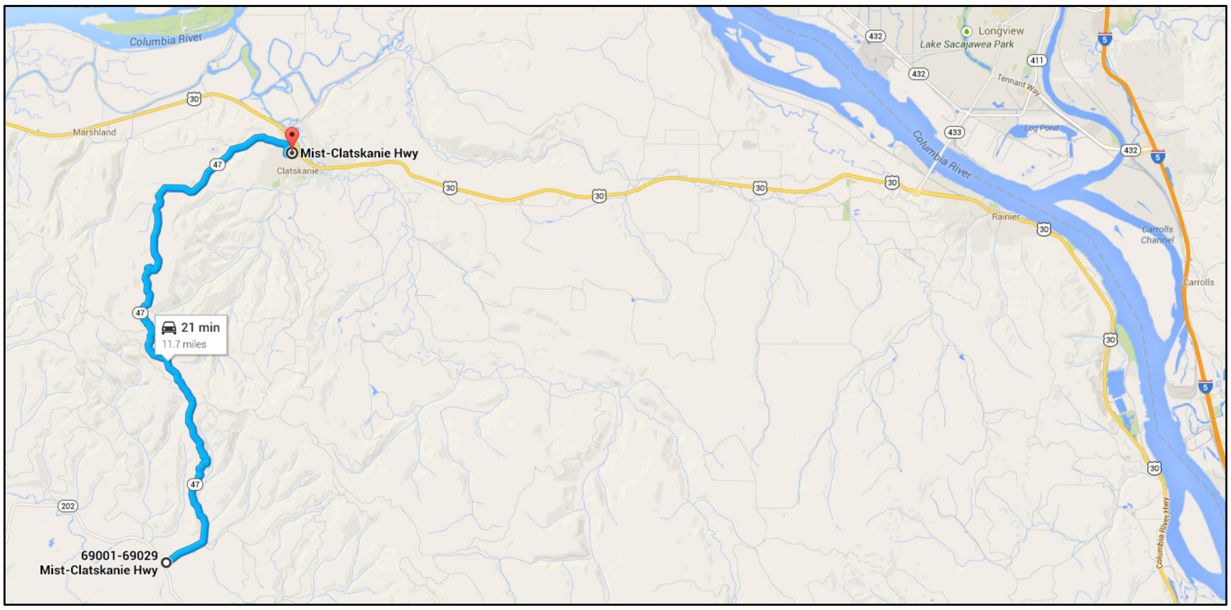


Mist-Clatskanie Highway No. 110 (OR 47)

CARS data were collected on June 10, 2014 along the entire length of the Mist-Clatskanie Highway; three passes in each direction. Each pass was at or below the existing advisory speed. CARS curve reports were generated by Ian Roholt.

Mist-Clatskanie Highway is classified as a Rural Major Collector between Mist and Clatskanie in the northwest Oregon Coast Range. This section of highway is mountainous with many sharp turns and steep grades, descending out of the coast range to the Columbia River.

Figure 8 | Mist-Clatskanie Highway

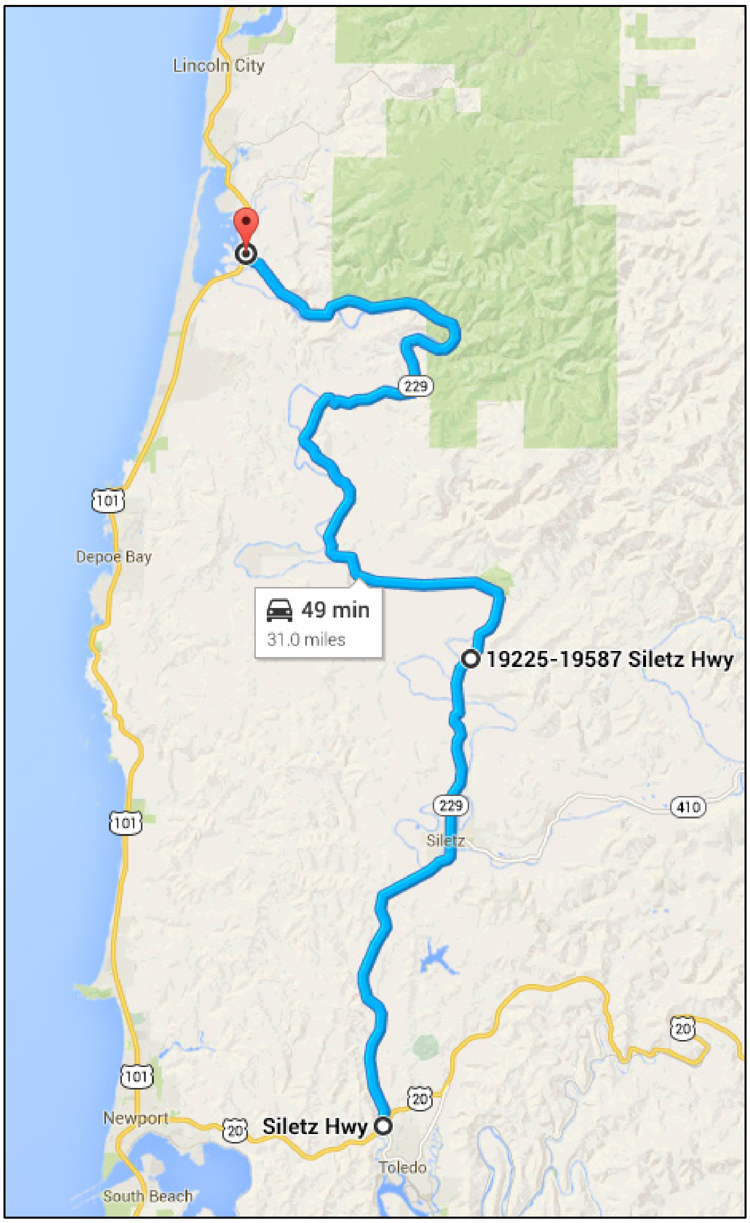


Siletz Highway No. 181 (OR 229)

CARS data were collected on June 30 and July 1, 2014 along the entire length of the Siletz Highway; three passes in each direction. Each pass was at or below the existing advisory speed. CARS curve reports were generated by Ian Roholt.

Siletz Highway is classified as a Rural Major Collector between Toledo and Lincoln City through the Coast Range and along the Siletz River. There is little to no shoulder the length of the highway with many horizontal curves in small valleys and on hillsides.

Figure 9 | Siletz Highway



Driving Method

The CARS Instruction Manual [17] says driving should be done as smooth as possible, with the test vehicle in the center of the driving lane. Erratic steering will result in lower recommended curve advisory speeds. Driving should be done at or below the posted speed, and slower is better.

Because momentary jerks of the wheel cause spikes in inclination, the smoother the data are collected the more reliable the data will be, resulting in greater confidence in the correct resulting advisory speed. Driving at slower speeds results in a denser dataset for each curve, which also increases confidence in the calculated results.

Speed

The CARS Instruction Manual gives the following directions related to speed during data collection:

- Gather data at or below the posted speed limit. Data can be collected at any speed, but more accurate data will be recorded at slower speeds.
- It is not necessary to drive at a speed to achieve the side friction limit, as is the case with the classic Ball Banking technique; slower is better.
- The investigator can come to a stop during the test, but prolonged stops on a curve should be avoided.

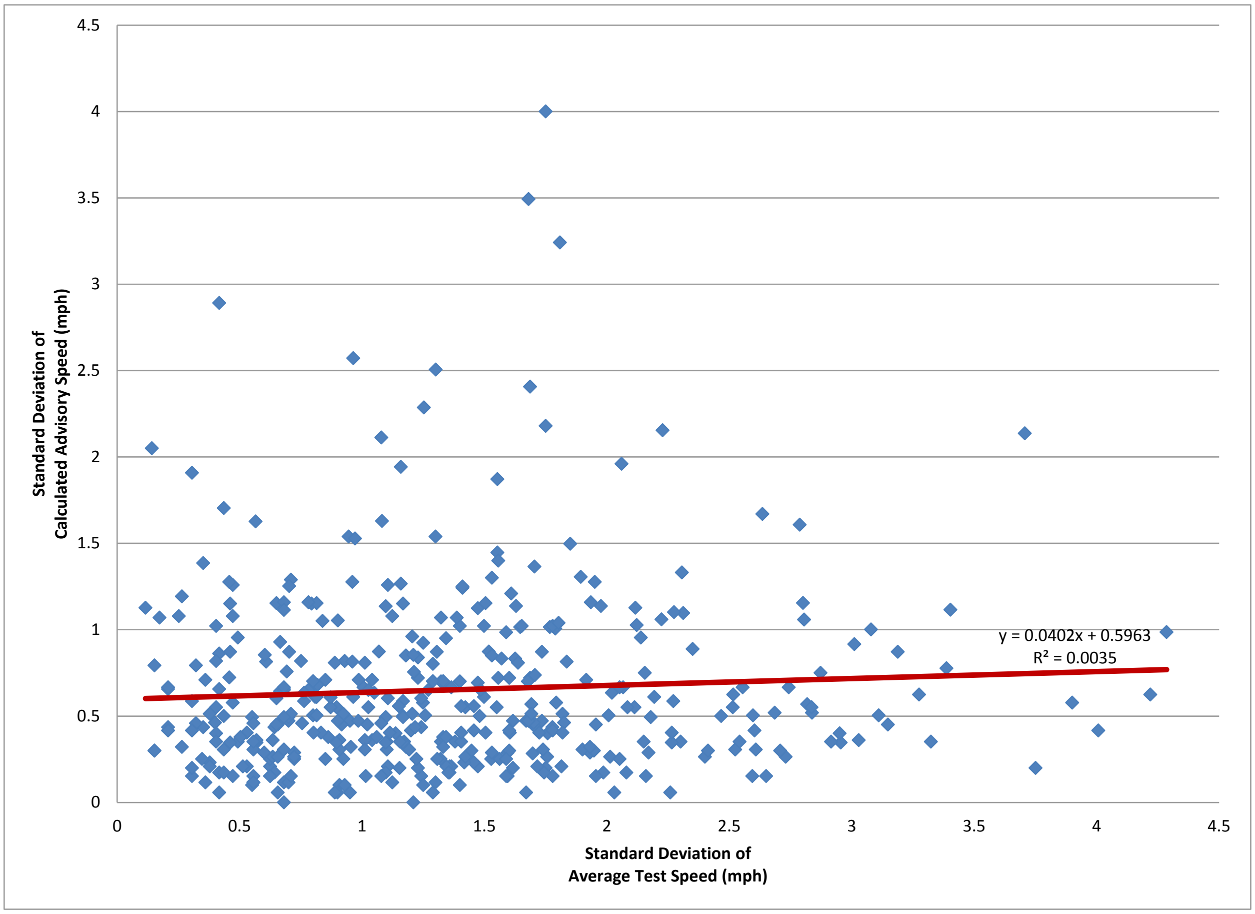
Theoretically, as long as the investigator travels through the curve smoothly (e.g. without jerking the wheel causing a spike in lateral acceleration), data can be gathered at any speed since it is used in combination with curve radius and lateral acceleration to calculate superelevation.

To test this, data were gathered on 3 Rivers Highway at different test speeds (see Data Gathering section and the Appendix). From these data, the following can be observed:

- The average difference between the maximum and minimum calculated advisory speed at each curve was 1.6 mph when all four runs were included.
- The average difference between the maximum and minimum calculated advisory speed at each curve was 0.9 mph when only the first three runs were included (similar test speeds).
- The average difference between the calculated advisory speed at each curve for the faster run when compared to the first three slower runs was 1.1 mph.
- The difference between the average and median calculated advisory speeds at each curve was no greater than 0.7 mph when only the first three runs were included (similar test speeds).

To further test if disparity between test speeds affects disparity between calculated advisory speeds when following the recommendations in the CARS Instruction Manual, the standard deviation of average test speeds were compared to the standard deviation of calculated advisory speeds from data gathered on 428 curve approaches on 3 Rivers Highway, Oregon Coast Highway, Mist-Clatskanie Highway, Siletz Highway, Yamhill-Newberg Highway, and Cascade Highway. These data were gathered following the recommendations given in the CARS Instruction Manual; the standard deviation of average test speeds did not exceed 4.5 mph. This comparison is shown in Figure 10, with a red line of best fit plotted through the data. Because the slope of the best fit line is very close to 0 mph/mph, there is no practical correlation between the disparity of average test speeds and the disparity of calculated advisory speeds.

Figure 10 | Std. Dev. of Calc. Advisory Speed vs. Std. Dev. of Avg. Test Speed



Based on these results, speed does not need to be constant from run to run in order to reach similar calculated advisory speeds. Speed of individual runs should be kept relatively constant in order to drive smoothly and avoid unnecessary spikes in lateral acceleration. Less variance in test speed of individual runs results in less variance in the calculated advisory speeds. Speed can vary from curve to curve; speed while driving through the curve should be kept relatively constant.

Another curve advisory software platform that gathers data in a similar way to CARS calculates superelevation to estimate advisory speed (Texas Curve Advisory Software, TCAS). This system sets a maximum speed for data collection of 45 mph in order to accurately estimate superelevation (standard deviation of calculated superelevation with 0.9 percent or less) and radius. Hence, with the TCAS system, 45 mph is considered an upper limit on test speed when superelevation rate is being measured, with a slower speed desired because it will yield a more accurate estimate [18].

The data collected and the TCAS recommendation support the recommendations in the CARS Instruction Manual – driving should be done as smoothly as practical and slower is better.

Effect of Different Drivers

Because ODOT will be using different investigators statewide for curve evaluations, and may be using interns who have not had the benefit of years of curve evaluation experience, Region 2 did an ad hoc test of the effect of different drivers. Kellie Tasselli collected CARS data on the entire length of Three Rivers Highway No. 032 on Friday June 6, 2014; one pass in each direction. Weldon Ryan collected multiple runs on the same highway on June 5 and 6, 2014. The data are summarized in the Appendix.

Weldon Ryan, Region 2's traffic investigator, is one of the most experienced curve evaluation drivers at ODOT and is likely representative of most experienced investigators after working with CARS for about 1 week. Kellie Tasselli, Region 2's sign designer, had little experience evaluating curves and may be representative of an intern who has been trained by an experienced investigator but has not yet collected data. Weldon discussed proper driving methods to Kellie before the test runs. Weldon was a passenger with Kellie during her test runs but did not coach on driving during data collection.

After data were collected, 10 curves were chosen along the corridor to test whether an experienced investigator and an inexperienced investigator would gather data that would result in similar calculated advisory speeds and the same recommended advisory speeds. One test run in each direction for Weldon was compared with one test run in each direction for Kellie. The results are summarized in Table 6 in the Appendix.

From these 10 test curves (20 test runs), the average difference in calculated advisory speed was -0.1 mph, meaning the calculated advisory speed using data Kellie collected was, on average, 0.1 mph higher than the calculated advisory speed using data Weldon collected. This is a small sample size; however, results this close after little training shows promise.

The curves resulting in different recommended advisory speeds had calculated advisory speeds 1.5 to 3.7 mph apart and were straddling the 5 mph rounding increments. Considering the difference of investigator experience, these results show the potential for an inexperienced investigator, if properly trained and with some practice, to achieve similar results to an experienced investigator.

More importantly, these results show the importance of multiple runs in the same direction to further test curves that have calculated advisory speeds very close to the 5 mph rounding increments; when a calculated advisory speed comes to 29.9 mph, the next run could easily be 30.1 mph, which would result in a different recommended advisory speed on the curve report.

Minimum Number of Runs

While one of the selling points of CARS is being able to calculate advisory speed with one pass in each direction, the same environmental variables at play during traditional ball-banking may affect CARS data (e.g.: driving style, pavement quality, GPS data precision, roadkill in the wheel path, etc.). These introduce some error into the analysis. This error may cause a different recommended advisory speed on curves where the calculated advisory speed could be very close to the 5 mph rounding increments for signing. Multiple runs should help account for some of these variables; however, no guidance is given in the Rieker CARS Instruction manual on minimum number of passes.

Minimum number of runs can be estimated using a statistical sampling size calculation. The sample size required to estimate the true mean μ with a level of confidence $(1-\alpha)$*100%, with a specified margin of error E, is calculated using Equation 14:

$$n = \left[\frac{\left(z_{\frac{a}{2}}\right)\sigma}{E}\right]^2 \qquad \textbf{Equation 14}$$

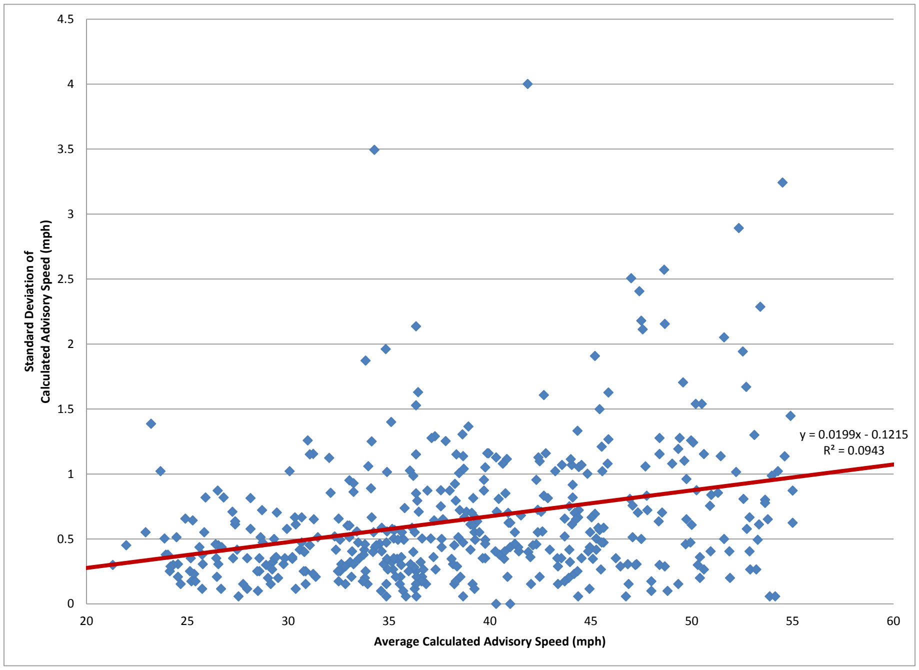
Where sample size, n is rounded up to the nearest whole number.

Ideally, estimating the standard deviation σ for this calculation should be based on a sample size of at least 30 passes per curve in order to minimize the margin of error of the standard deviation [19]. Since that level of data gathering was not practical for available investigators' workloads, the true standard deviation needed to be estimated using small sample sizes from a large number of curves. This does not minimize the margin of error for standard deviation but helps determine a conservative standard deviation to apply to the data.

In order to estimate standard deviation of the minimum calculated advisory speed, the standard deviation of three runs were calculated for the 428 curve approaches chosen on the Oregon Coast Highway, 3 Rivers Highway, Mist-Clatskanie Highway, Siletz Highway, Yamhill-Newberg Highway, and Cascade Highway given in the Appendix. Approaches with a calculated advisory speed greater than 55 mph at 12 degrees were not included because 55 mph is the maximum posted speed on these highways and would not be signed with an advisory speed.

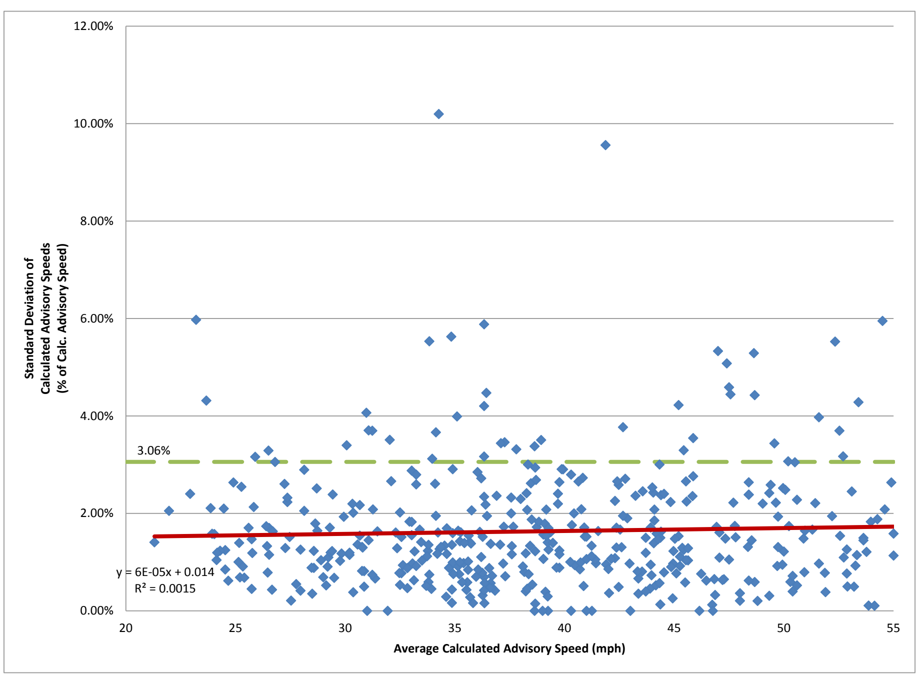
There appeared to be a slight correlation between the average calculated advisory speed and standard deviation of the calculated advisory speeds. Higher average advisory speeds may have a slightly greater standard deviation, shown in Figure 11 (the red line is a best-fit line through the data).

Figure 11 | Std. Dev. of Calc. Advisory Speeds vs. Average Calculated Advisory Speed



In order to account for this correlation, the standard deviation was taken as a percent of the average calculated advisory speed, shown in Figure 12. This relationship has practically no correlation, shown in 0 slope in the red best-fit line. The 90th percentile of the percent of calculated advisory speed was then assumed to be a conservative estimate of the true standard deviation (σ_{90}=3.06% of calculated advisory speed), shown as the green line.

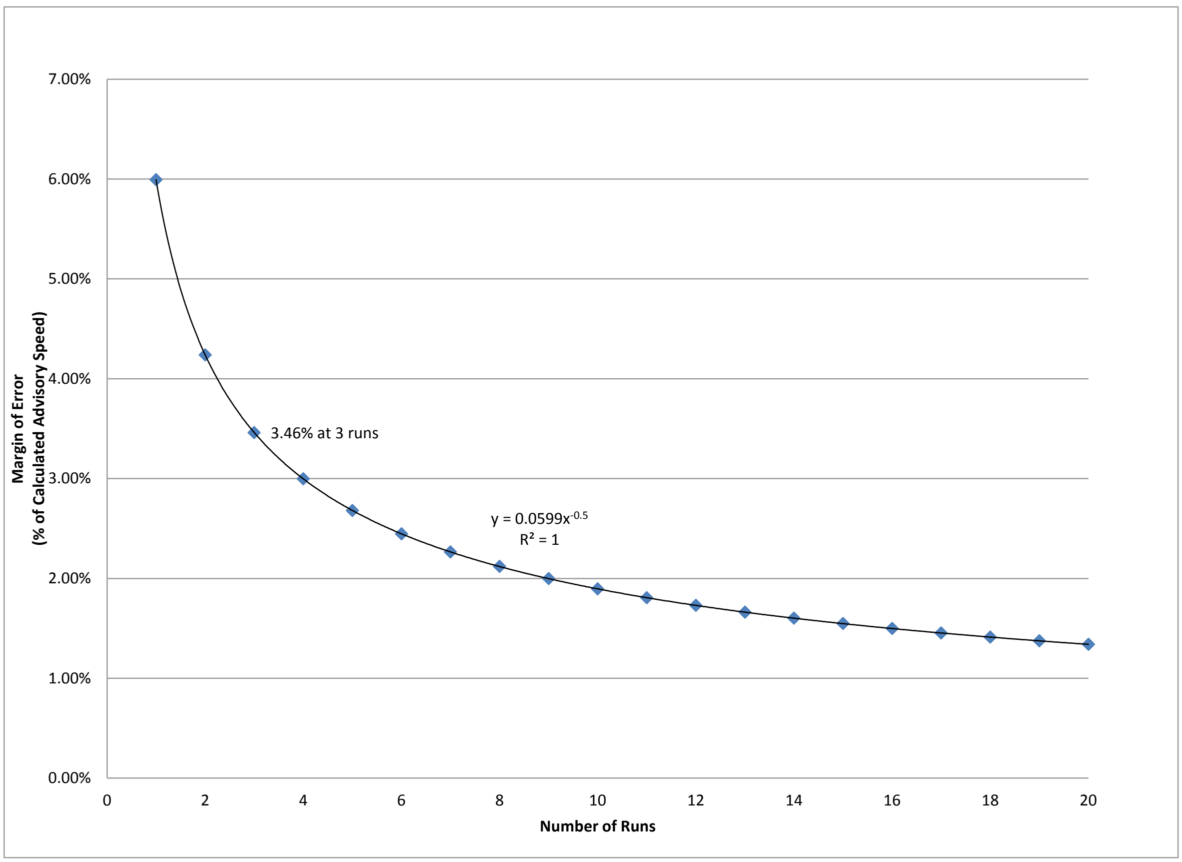
Figure 12 | Std. Dev. of Calc. Advisory Speed (%) vs. Avg. Calc. Advisory Speed



It is important to remember this standard deviation is based on data collected by one very experienced investigator (Weldon Ryan) along a select number of winding highways in the Oregon Coast Range and Willamette Valley. Smooth driving while collecting data kept the standard deviation of multiple runs low.

Assuming a normal distribution, $z\alpha/_2$=1.960 at the 95% confidence interval [19]. Plugging these values into Equation 14, Figure 13 shows a comparison between margin of error and number of runs at the 95% confidence interval. A high (95%) confidence interval should be used because curve advisory speeds will be relied upon by road users for navigation through curves.

Figure 13 | Margin of Error vs. Number of Runs – 95% Confidence Interval



More confidence in the results requires more runs. Since the rounding increments for signing are 5 mph, the margin of error should be less than ±2.0 mph to keep the error window smaller than the rounding increment. The margin of error for one run is ±6.0% at the 95% confidence interval. At very low speeds (<25 mph), this margin of error may be acceptable; however, as speed increases, margin of error increases. A margin of error less than ±2.0 mph can be achieved for speeds up to 57 mph in 3 runs (3.5% error) at the 95% confidence interval. This means there is a 95% probability that the true average is ±3.5% of the average of 3 runs. This percent error should be acceptable on most ODOT highways as advisory speeds should not be greater than 55 mph – less than the ±2.0 mph maximum desirable margin of error.

Recognizing the agency's limited resources for evaluating curves, ±3.5% of the average calculated advisory speed is a reasonable margin of error that can be achieved in a limited number of runs. Based on this analysis, the average calculated advisory speed of *at least* 3 runs should be used when determining the final advisory speed. More runs may be used for greater confidence. Using the average gives designers a confidence interval and margin of error to base and defend their judgments on.

Comparison to Existing Signing

In 2011, Dixon and Avelar [4] studied the effects of changing Oregon's ball-banking limits to the 2009 MUTCD limits. Dixon and Avelar examined 80 state-maintained corridors to see what signing changes would be required statewide if the 2009 MUTCD limits were adopted. They estimated:

- 29% of curves would not require signing changes,
- 28% of curves would require sign removal,
- 33% of curves would require a +5 mph adjustment,
- 6% of curves would require a -5 mph adjustment, and
- 3.5 % of curves would require a +10 mph adjustment.

CARS recommended advisory speeds and ODOT Ball-banking spreadsheet recommended advisory speeds were compared to existing advisory speeds. Data were collected on Oregon Coast Highway 009 (US 101) between OR 22 and Tillamook and Three Rivers Highway 032 (OR 22) (see Data Gathering section). Twenty-eight curves were chosen along these corridors that had signing unique to the curve (not part of a winding road series) for CARS data; 23 curves for ODOT Ball-banking data.

Of the 56 curve approaches compared to existing advisory speeds (28 curves, 2 approaches at each), CARS had a recommended advisory of:

- 0 mph difference at 11 approaches (20%)
- 5 mph higher at 29 approaches (52%)
- 10 mph higher at 12 approaches (21%)
- 15 mph higher at 2 approaches (4%)
- 20 mph higher at 2 approaches(4%)

Of the 46 curve approaches compared to existing advisory speeds (23 curves, 2 approaches at each), ODOT Ball-banking spreadsheet had a recommended advisory of:

- 0 mph difference at 16 approaches (35%)
- 5 mph higher at 24 approaches (52%)
- 10 mph higher at 5 approaches (11%)
- 15 mph higher at 1 approach (2%)

It is important to note existing signing is not a reliable measure of the magnitude of change when applying the new MUTCD limits. Region investigators, county engineers, other state DOTs, and researchers have all reported existing signing is so inconsistent that they are an unreliable measure of actual signing needs. Decades of sign replacements, inconsistent curve evaluation methods, and other related factors have led to the reason why ODOT is going through this exercise in the first place.

Method Differences

There are many different ways to determine curve advisory speeds. The 2009 MUTCD acknowledges three methods (including ball-banking and accelerometer that provides direct determination of side friction factors). The FHWA Safety Program discusses six methods in their publication *Procedures for setting Advisory Speeds on Curves* [10]. The different ball-banking methods ODOT has used in the past 5 years each have subtle differences and may result in different advisory speeds at some curves. The limitations of traditional ball-and-vial ball-banking are well known; differences between the ODOT ball-banking spreadsheet and CARS are not as well-known and are discussed here. For a comparison between analog and digital ball-banking devices, see Dixon and Rohani's report *Methodologies for Estimating Advisory Curve Speeds on Oregon Highways* [3].

Advisory Speed Recommendations

Recommended advisory speed differences were tested by comparing data collected using the ODOT spreadsheet and CARS on US 101, OR 22, OR 213, and OR 240 (see Data Gathering section and the Appendix). 38 curves were chosen along these corridors to compare ending advisory speed recommendations. Results are tabulated in Table 4 in the Appendix. CARS recommended advisory speeds are the average value of three runs rounded down to the nearest 5 mph.

Of the 76 curve approaches compared (38 curves, 2 approaches at each), CARS had a recommended advisory speed of

- 5 mph less than the ODOT spreadsheet at 1 approach (2%)
- 0 mph difference at 38 approaches (50%)
- 5 mph higher than the ODOT spreadsheet at 30 approaches (39%)
- 10 mph higher than the ODOT spreadsheet at 7 approaches (9%)

At the vast majority (91%) of approaches, CARS and the ODOT spreadsheet recommended advisory speeds within 5 mph of each other; however, when there were differences, CARS tended to recommend advisory speeds greater than the ODOT spreadsheet. The following discussion explores reasons why this may be the case.

Driving During Data Collection

Driving style during data collection is different between the two systems. Driving using the ODOT spreadsheet is the same as traditional ball-and-vial driving. The investigator needs to travel through the curve multiple times at various speeds to determine the advisory speed. In some locations, the investigator needs to rapidly accelerate or decelerate to get to the run speed, depending on curve spacing, traffic, or safe turn-around location, among other variables. The investigator also needs to set cruise control at the run speed prior to entering the curve – a task not always precise, accurate, nor easily accomplished.

Driving using CARS is more fluid than traditional ball-and-vial driving. The investigator does not need to travel through the curve multiple times to determine an advisory speed (though multiple passes are needed for confidence). The investigator can gather data at any speed without the need to set cruise control, so driving can be more fluid and controlled. This reduces the probability of artificial spikes in inclination due to the driver. CARS also eliminates the risk of the investigation vehicle not traveling at exactly the correct run speed by simultaneously collecting speed, location, and inclination data.

The small effect of body roll during data collection may also explain differences in recommended advisory speeds. Traditional ball-and-vial driving requires data gathering at the advisory speed, whereas CARS allows for data collection at any speed, but recommended slower than the advisory speed. Faster test speeds introduce more error due to body roll, albeit a small error. As discussed in the Kinematics section, Carlson and Mason [13] estimated if a vehicle with a roll rate of 7 degrees/g (1992 Taurus) were used for a traditional ball-banking investigating and the roll rate was neglected, the estimated safe speed would be 5 to 7 percent less than intended. At high speeds (>40 mph) this error could be at least 2.3 to 3.1 mph; greater error at higher speeds.

Because CARS allows data collection at slower speeds, inclination is affected less by body roll. This may result in slightly lower inclination measurements, which increases the calculated advisory speed. The magnitude of this affect is likely less than 5 to 7 percent and at the most extreme should affect the posted advisory speed by no more than +5 mph, assuming the vehicle is traveling fast enough to roll to the outside of the curve during data collection.

Based on driving style alone, CARS will likely calculate slightly higher advisory speeds than the ODOT spreadsheet because the driving style during data collection is more fluid and test speeds are slower. Fluid driving is closer to how the public travels through curves than ball-and-vial driving and the error due to body roll is likely less than ball-and-vial driving.

Post Processing

The ODOT ball-banking spreadsheet and CARS post process gathered data; however, differences in post-processing may result in different advisory speeds. The digital instruments used in both systems take multiple readings per second and are very sensitive to changes in the road surface; additionally, the CARS GPS is not survey-grade. The ODOT spreadsheet post-processes raw inclination data by developing a weighted moving average, shown in Equation 15 (for more information, see the ODOT spreadsheet instructions page). The spreadsheet cannot develop a best-fit model for curves because it does not know where a curve begins or ends.

$$S_t = \frac{1(BB_{t-0.50}) + 2(BB_{t-0.25}) + 3(BB_t) + 2(BB_{t+0.25}) + 1(BB_{t+0.50})}{\sum Weights} \qquad \textbf{Equation 15}$$

Where:

S_t = Smoothed ball-bank value at time = t seconds (degrees)
BB_t = Raw ball-bank reading for time = t seconds (degrees)
t = time (seconds)
$\Sigma Weights$ = Sum of the weights as assigned to each BB_t value (typically 1+2+3+2+1=9)

As discussed in the Variables section, CARS post-processes raw data using best-fit parabolic models for inclination, curve shape, and speed.

Used in this context, best-fit parabolic models will have a greater dampening affect than weighted moving average, meaning CARS can report a lower inclination value than the ODOT spreadsheet on the same curve at the same speed. This can translate to slightly higher calculated advisory speeds than the ODOT spreadsheet method.

Other Issues

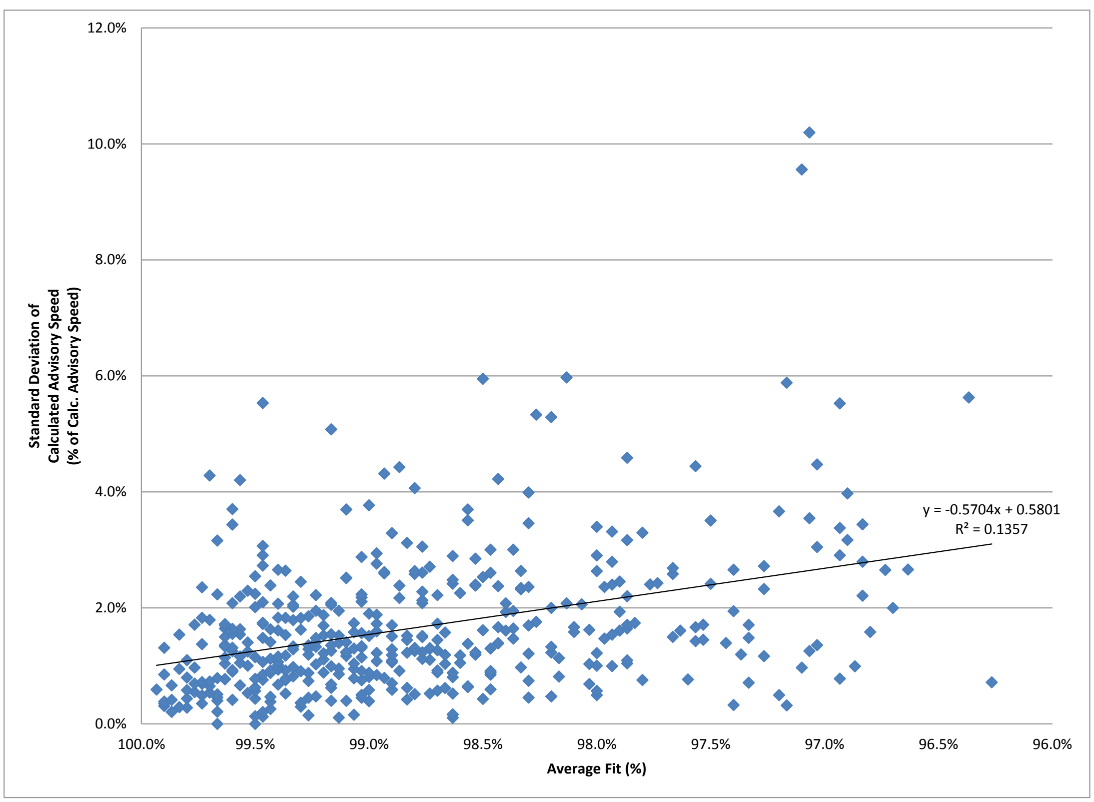
Other questions explored during this investigation included:

- Calculated advisory speed sensitivity to model fit,
- Cross-axis sensitivity,
- Loss of GPS signal, and

Advisory Sensitivity to Model Fit

The variance between calculated advisory speeds of runs appears to loosely correlate with the percent fit of the selected data. Figure 14 shows a comparison between calculated advisory speed standard deviations and average fit of the curve model for the 428 curve approaches on the selected highways listed in the Data Gathering section. The CARS Instruction Manual says a fit of 96% or better should be used. Based on these results, a fit of 96% is acceptable; a better fit appears to result in more precise estimates of advisory speed, with 99% or better being best.

Figure 14 | Std. Deviation of Calc. Advisory Speed vs. Average Fit



Cross Axis Sensitivity

While gathering CARS data on Timberline Highway No. 173, Ryan Virgin (Region 1 Traffic) voiced a concern that steep grades may affect inclination measurement because the RDS7-GPS-PRO is a 2-axis inclinometer (measuring inclination on a plane perpendicular to the vehicle).

Rieker's Joe Caruso responded in an email (dated August 15, 2014) that steep grades will have no measurable impact on the results of an investigated curve:

> *"The sensor the RDS7-GPS-PRO uses yields less than 0.5% error at pitch angles up to 30 degrees. That means on a corner at the limit of 12 degree inclination angle, the error would be 0.06 degrees on a 75% grade up or down. Since the sensor has an overall accuracy of 0.5 degrees over its operational range, a variance of ±0.06 degrees is not significant. And, driving slower to produce less than the 12 degrees, reduces that small error."*

Loss of GPS Signal

CARS relies on GPS information to determine the speed and location of the investigation vehicle as it travels around a curve. If GPS signal is lost, there will not be enough information to calculate an advisory speed.

If GPS signal is lost, Rieker has recommended returning to the section of highway at a different time of day and/or different time of week. This allows the satellites to rotate to a different orientation, which may improve GPS signal.

As of the date of this white paper, loss of GPS signal has not been a reported issue. The CARS Revisionary Mode was not examined as part of this shakedown. If GPS signal is not attainable after several attempts over several days, reverting to the ODOT Spreadsheet method may be an alternate option to determine advisory speeds.

Conclusions and Recommendations

Based on the above analysis and findings, the following can be concluded and recommended:

- The CARS methodology uses best-fit models and common design equations from the *Green Book* and is an acceptable method to determine curve advisory speed.
- CARS and the ODOT spreadsheet recommended advisory speeds are generally within 5 mph of each other. When different, CARS tends to recommend advisory speeds greater than the ODOT spreadsheet, within 5 mph.
- For statewide consistency, all Oregon highways should be evaluated using the CARS methodology.
- An inexperienced investigator can achieve similar results to an experienced investigator if properly trained and with some practice.
- Speed from run to run on the same curve does not need to be constant.
- When driving through a curve, speed should be kept relatively constant to avoid unnecessary spikes in lateral acceleration.
- Greater model fits generally result in more precise estimates of advisory speed. When building curves, strive for a fit of 99% or better; 96% or better is adequate.
- The average calculated advisory speed of 3 runs should be used when determining the final advisory speed. If data are collected properly, this average should be within ±3.5% of the true average at the 95% confidence level.
- A training class for traffic investigators and sign designers should be developed covering data collection and interpretation for statewide consistency.

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Appendix

Table 4 | Comparison Between CARS and ODOT Spreadsheet Recommended Advisory Speeds

Curve No.	Hwy No.	MP (mid curve)	Direction	Existing Advisory (mph)	Spreadsheet Recommended Advisory (mph)	CARS Recommended Advisory (mph)	CARS-Spreadsheet Difference (mph)
01	032	0.75	WB	35*	35	35	0
			EB	35*	35	35	0
02	032	4.35	WB	30*	40	40	0
			EB	30*	40	40	0
03	032	8.62	WB	55**	55	55	0
			EB	55**	55	55	0
04	032	10.60	WB	25	25	25	0
			EB	25	25	30	5
05	032	10.95	WB	25*	35	35	0
			EB	25*	35	35	0
06	032	11.51	WB	30	30	30	0
			EB	30	30	30	0
07	032	12.17	WB	30*	30	25	-5
			EB	30*	25	30	5
08	032	12.82	WB	30*	30	35	5
			EB	30*	30	35	5
09	032	14.10	WB	35*	30	30	0
			EB	35*	30	30	0
10	032	15.40	WB	40	45	45	0
			EB	40	45	45	0
11	032	18.05	WB	35	40	40	0
			EB	35	45	45	0
19	009	76.48	NB	35	45	55	10
			SB	35	50	55	5
20	009	76.90	NB	35	35	40	5
			SB	35	35	40	5
21	009	77.22	NB	30	35	35	0
			SB	30	35	40	5
22	009	77.53	NB	30	35	40	5
			SB	30	35	40	5
23	009	77.63	NB	40	40	45	5
			SB	40	45	45	0
24	009	78.10	NB	35	40	40	0
			SB	35	40	40	0
25	009	78.28	NB	35	45	45	0
			SB	35	40	45	5

Curve No.	Hwy No.	MP (mid curve)	Direction	Existing Advisory (mph)	Spreadsheet Recommended Advisory (mph)	CARS Recommended Advisory (mph)	CARS-Spreadsheet Difference (mph)
26	009	78.97	NB	35	40	45	5
			SB	35	40	45	5
27	009	79.21	NB	40	45	50	5
			SB	40	45	50	5
28	009	79.85	NB	35	35	40	5
			SB	35	35	35	0
29	009	80.30	NB	20	25	25	0
			SB	20	25	25	0
30	009	81.08	NB	35	35	40	5
			SB	35	35	40	5
31	009	81.27	NB	40	40	45	5
			SB	40	45	45	0
32	009	81.64	NB	45	50	50	0
			SB	45	50	50	0
33	009	81.77	NB	35	40	40	0
			SB	35	35	40	5
34	009	83.22	NB	35	35	40	5
			SB	35	40	40	0
35	009	83.50	NB	40	50	60	10
			SB	40	50	60	10
36	009	83.77	NB	35	40	40	0
			SB	35	35	35	0
37	009	84.40	NB	40	45	50	5
			SB	40	40	45	5
38	160	22.63	NB	35	45	55	10
			SB	35	45	55	10
39	160	26.03	NB	30	40	45	5
			SB	30	40	45	5
40	151	1.67	EB	40	45	55	10
			WB	55**	40	50	10
41	151	2.39	EB	35*	35	35	0
			WB	35*	30	35	5
42	151	2.86	EB	30	30	30	0
			WB	30	35	35	0
43	151	5.20	EB	35	45	45	0
			WB	40	45	50	5
44	151	5.45	EB	35	35	35	0
			WB	35	35	35	0
45	151	6.05	EB	30*	35	40	5
			WB	30*	35	40	5

*Part of winding road series/reversing curve

**No Advisory Sign

Table 5 | Comparison Between CARS Recommended Advisory and Existing Signing

Curve No.	Hwy. No.	MP (mid curve)	Direction	Existing Advisory (mph)	CARS Average Calculated Advisory (mph)	CARS Recommended Advisory (mph)	Difference (mph)
04	032	10.60	WB	25	27.5	25	0
			EB	25	29.0	25	0
06	032	11.51	WB	30	31.2	30	0
			EB	30	30.7	30	0
10	032	15.40	WB	40	48.4	45	5
			EB	40	48.7	45	5
11	032	18.05	WB	35	44.1	40	5
			EB	35	45.0	45	10
12	032	19.93	WB	35	41.2	40	5
			EB	40	44.4	40	0
13	032	20.45	WB	30	38.5	35	5
			EB	30	38.2	35	5
14	032	22.90	WB	30	38.2	35	5
			EB	30	40.9	40	10
15	032	23.83	WB	25	29.2	25	0
			EB	25	28.0	25	0
18	032	24.57	WB	35	37.7	35	0
			EB	35	38.7	35	0
19	009	76.48	NB	35	55.0	55	20
			SB	35	57.3	55	20
20	009	76.90	NB	35	40.5	40	5
			SB	35	40.3	40	5
21	009	77.22	NB	30	39.0	35	5
			SB	30	41.4	40	10
22	009	77.53	NB	30	42.5	40	10
			SB	30	42.5	40	10
23	009	77.63	NB	40	45.6	45	5
			SB	40	47.5	45	5
24	009	78.10	NB	35	42.9	40	5
			SB	35	41.9	40	5
25	009	78.28	NB	35	48.0	45	10
			SB	35	47.8	45	10
26	009	78.97	NB	35	46.7	45	10
			SB	35	45.2	45	10
27	009	79.21	NB	40	53.6	50	10
			SB	40	50.9	50	10
28	009	79.85	NB	35	40.9	40	5
			SB	35	38.8	35	0
29	009	80.30	NB	20	25.3	25	5
			SB	20	26.5	25	5

Curve No.	Hwy. No.	MP (mid curve)	Direction	Existing Advisory (mph)	CARS Average Calculated Advisory (mph)	CARS Recommended Advisory (mph)	Difference (mph)
30	009	81.08	NB	35	44.2	40	5
			SB	35	43.5	40	5
31	009	81.27	NB	40	45.5	45	5
			SB	40	46.8	45	5
32	009	81.64	NB	45	51.6	50	5
			SB	45	53.3	50	5
33	009	81.77	NB	35	42.7	40	5
			SB	35	41.0	40	5
34	009	83.22	NB	35	43.9	40	5
			SB	35	44.5	40	5
35	009	83.50	NB	40	60.0	55	15
			SB	40	60.5	55	15
36	009	83.77	NB	35	42.0	40	5
			SB	35	39.8	35	0
37	009	84.40	NB	40	51.9	50	10
			SB	40	49.3	45	5

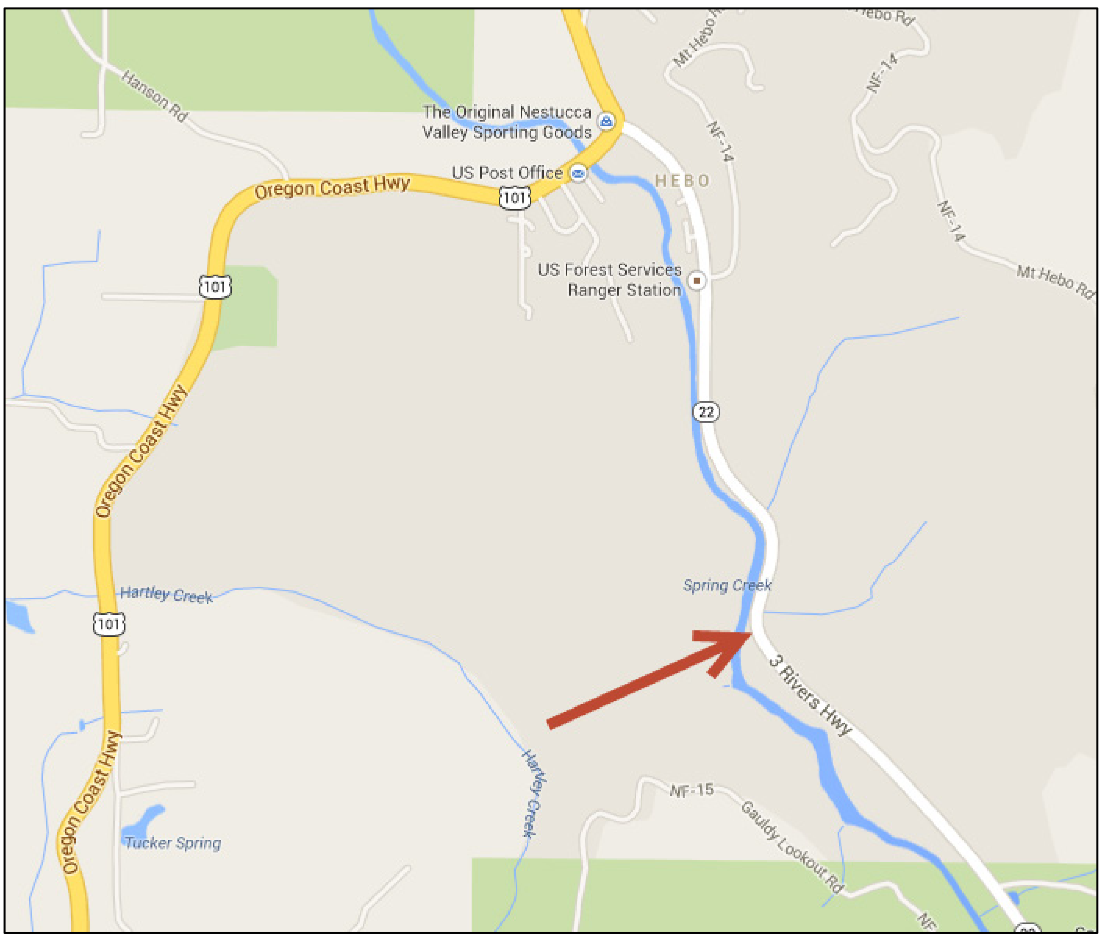
Table 6 | Comparison of Advisory Speed Calculations with Different Drivers
3 Rivers Highway (OR 22)

MP	Direction	Weldon Ryan		Kellie Tasselli		Δ Calculated Advisory (mph)	Same Rec. Advisory?
		Calculated Advisory (mph)	Recommended Advisory (mph)	Calculated Advisory (mph)	Recommended Advisory (mph)		
22.90	WB	38.1	35	39.0	35	-0.9	Yes
	EB	40.3	40	40.5	40	-0.2	Yes
20.96	WB	42.9	40	41.9	40	1.0	Yes
	EB	42.3	40	42.3	40	0.0	Yes
20.45	WB	39.7	35	38.3	35	1.4	Yes
	EB	38.7	35	37.8	35	0.9	Yes
19.92	WB	39.4	35	41.1	40	-1.7	No
	EB	45.2	45	43.7	40	1.5	No
19.02	WB	55.6	55	59.3	55	-3.7	Yes
	EB	63.7	60	62.9	60	0.8	Yes
17.40	WB	36.8	35	38.8	35	-2.0	Yes
	EB	39.2	35	39.4	35	-0.2	Yes
15.40	WB	47.1	45	47.6	45	-0.5	Yes
	EB	49.0	45	48.6	45	0.4	Yes
11.50	WB	30.8	30	31.2	30	-0.4	Yes
	EB	32.2	30	29.9	25	2.3	No
10.95	WB	35.8	35	36.3	35	-0.5	Yes
	EB	37.7	35	37.4	35	0.3	Yes
8.18	WB	68.2	65	70.2	70	-2.0	No
	EB	66.5	65	65.3	65	1.2	Yes

Curve Summary	
Curve No.	01
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	0.75
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	April 30, 2014
Radius (Horizontal Curve Report)	286 ft

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 35 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	35 mph	WB=	35 mph

Vicinity Map



Comparison of Test Speeds

Curve No.	01
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	0.75

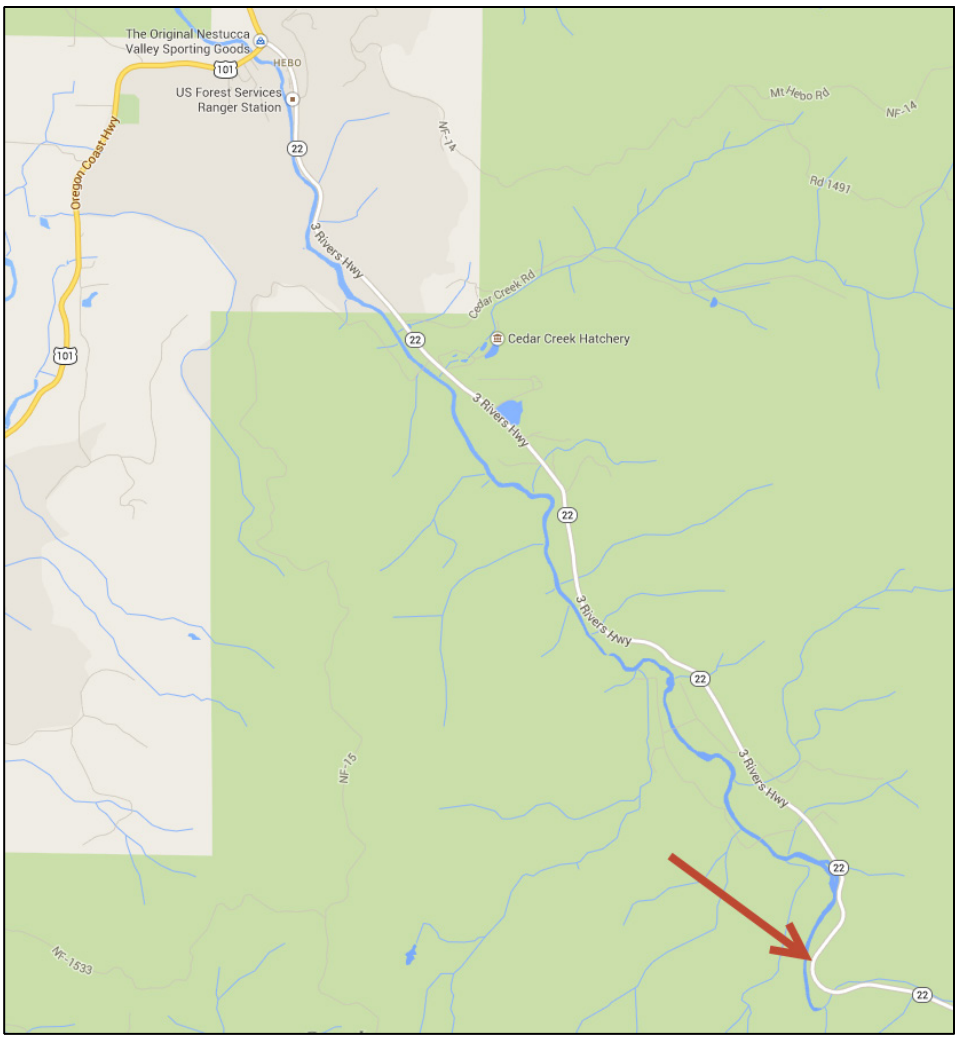
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	South	27.2	0.7	35.0
4	Left	South	30.4	1.1	35.0
6	Left	South	27.4	1.1	36.0
8	Left	South	40.0	1.7	34.6
		Min	27.2	0.7	34.6
		Max	40.0	1.7	36.0
		Difference	12.8		1.4

1	Right	Northeast	30.7	0.7	35.0
3	Right	Northeast	34.1	0.6	35.6
5	Right	Northeast	29.0	0.6	36.0
7	Right	Northeast	44.5	1.0	36.1
		Min	29.0	0.6	35.0
		Max	44.5	1.0	36.1
		Difference	15.5		1.1

Curve Summary	
Curve No.	02
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	4.35
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	April 30, 2014
Radius (Horizontal Curve Report)	Compound Curve

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 30 mph			
CARS Recommended Advisory	EB=	40 mph	WB=	40 mph
ODOT Spreadsheet Recommended Advisory	EB=	40 mph	WB=	40 mph

Vicinity Map



Comparison of Test Speeds	
Curve No.	02
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	4.35

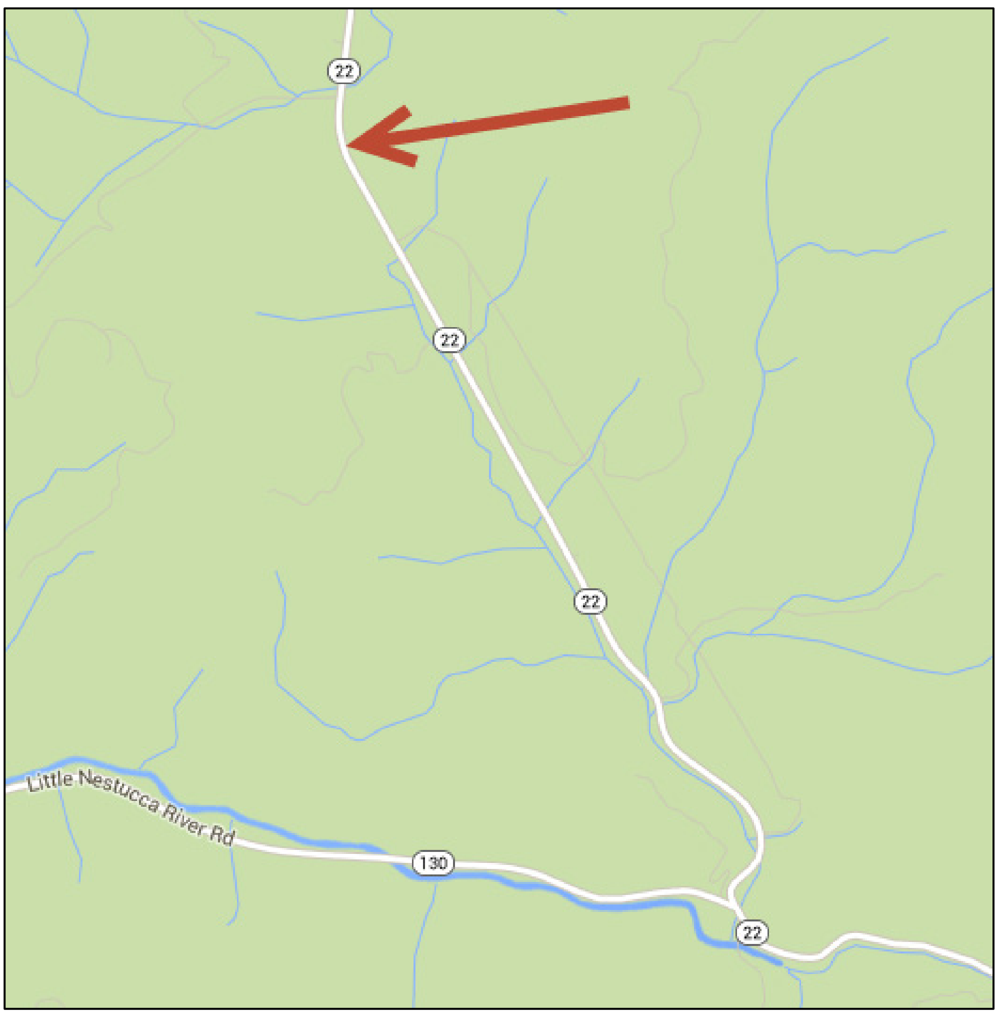
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	South	31.1	0.5	41.2
4	Left	South	35.3	0.5	42.4
6	Left	South	30.8	0.3	42.1
8	Left	South	47.3	1.0	38.0
		Min	30.8	0.3	38.0
		Max	47.3	1.0	42.4
		Difference	16.5		4.4

1	Right	Northeast	36.7	0.8	43.5
3	Right	Northeast	36.3	0.4	43.4
5	Right	Northeast	33.0	1.4	43.5
7	Right	Northeast	51.5	1.7	43.5
		Min	33.0	0.4	43.4
		Max	51.5	1.7	43.5
		Difference	18.5		0.1

Curve Summary	
Curve No.	03
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	8.62
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 7, 2014
Radius (Horizontal Curve Report)	1146 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	None			
CARS Recommended Advisory	EB=	55 mph	WB=	55 mph
ODOT Spreadsheet Recommended Advisory	EB=	55 mph	WB=	55 mph

Vicinity Map



Comparison of Test Speeds

Curve No.	03
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	8.62

Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	South	40.6	0.5	64.6
4	Left	South	44.0	0.6	63.4
6	Left	South	45.0	0.5	64.8
8	Left	South	56.6	1.2	63.2
		Min	40.6	0.5	63.2
		Max	56.6	1.2	64.8
		Difference	16.0		1.6

1	Right	Northeast	42.5	0.4	72.6
3	Right	Northeast	40.3	0.9	74.9
5	Right	Northeast	37.9	0.9	72.8
7	Right	Northeast	54.4	1.8	70.4
		Min	37.9	0.4	70.4
		Max	54.4	1.8	74.9
		Difference	16.5		4.5

Curve Summary	
Curve No.	04
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	10.60
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 12, 2014
Radius (Horizontal Curve Report)	159 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road/Turn 25 mph			
CARS Recommended Advisory	EB=	30 mph	WB=	25 mph
ODOT Spreadsheet Recommended Advisory	EB=	25 mph	WB=	25 mph

Vicinity Map

Comparison of Test Speeds

Curve No.	04
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	10.60

Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	South	23.7	0.4	28.8
4	Left	South	25.5	0.3	29.2
6	Left	South	22.0	0.5	29.0
8	Left	South	37.1	0.6	30.3
		Min	22.0	0.3	28.8
		Max	37.1	0.6	30.3
		Difference	15.1		1.5

1	Right	North east	22.9	0.7	27.5
3	Right	North east	24.7	0.9	27.5
5	Right	North east	25.4	1.0	27.6
7	Right	North east	35.0	1.4	29.4
		Min	22.9	0.7	27.5
		Max	35.0	1.4	29.4
		Difference	12.1		1.9

Curve Summary	
Curve No.	05
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	10.95
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 12, 2014
Radius (Horizontal Curve Report)	318 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 25 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	35 mph	WB=	35 mph

Vicinity Map

Comparison of Test Speeds	
Curve No.	05
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	10.95

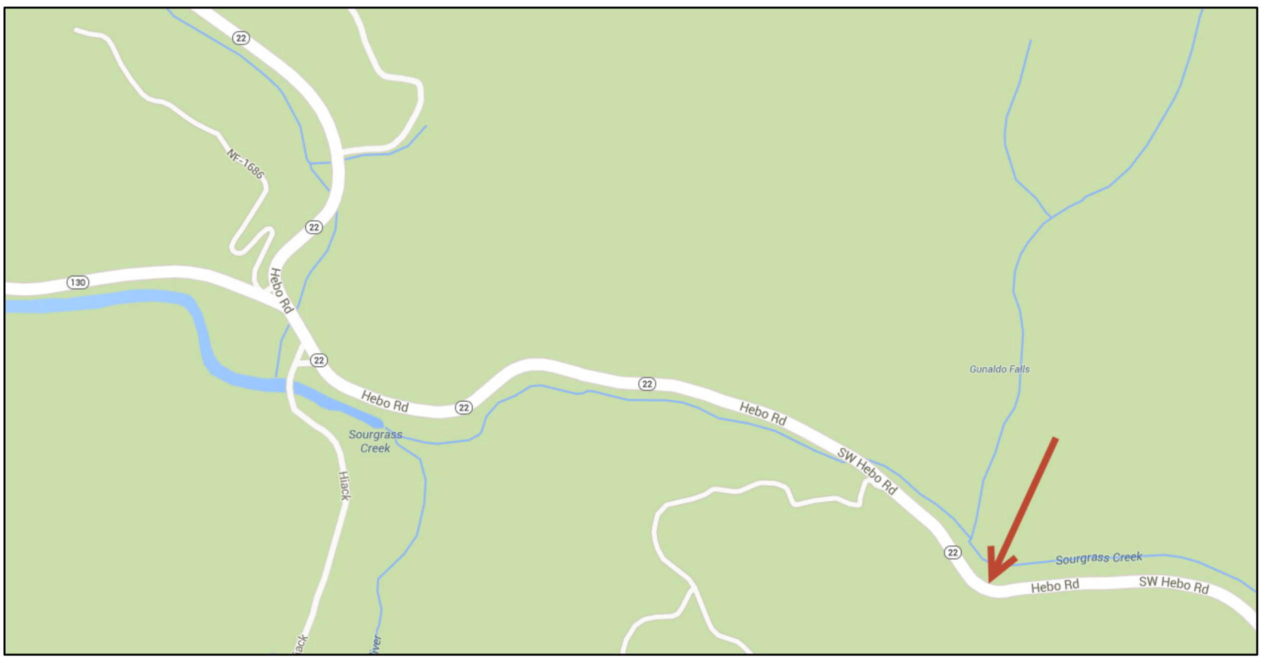
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Right	East	27.0	0.7	36.9
4	Right	East	30.5	0.2	36.8
6	Right	East	29.0	0.6	36.4
8	Right	East	44.5	1.4	37.6
		Min	27.0	0.2	36.4
		Max	44.5	1.4	37.6
		Difference	17.5		1.2

1	Left	West	27.8	0.4	37.0
3	Left	West	31.5	0.8	36.7
5	Left	West	32.8	1.6	36.8
7	Left	West	42.7	1.2	35.8
		Min	27.8	0.4	35.8
		Max	42.7	1.6	37.0
		Difference	14.9		1.2

Curve Summary	
Curve No.	06
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	11.51
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 12, 2014
Radius (Horizontal Curve Report)	220 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Turn 30 mph			
CARS Recommended Advisory	EB=	30 mph	WB=	30 mph
ODOT Spreadsheet Recommended Advisory	EB=	30 mph	WB=	30 mph

Vicinity Map



Comparison of Test Speeds

Curve No.	06
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	11.51

Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	East	26.9	1.6	31.0
4	Left	East	28.5	1.6	29.9
6	Left	East	24.4	1.1	31.1
8	Left	East	39.1	1.9	32.0
		Min	24.4	1.1	29.9
		Max	39.1	1.9	32.0
		Difference	14.7		2.1

1	Right	Northwest	22.8	1.5	31.9
3	Right	Northwest	27.7	1.4	31.9
5	Right	Northwest	27.6	2.5	29.9
7	Right	Northwest	38.9	2.2	30.9
		Min	22.8	1.4	29.9
		Max	38.9	2.5	31.9
		Difference	16.1		2.0

Curve Summary	
Curve No.	07
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	12.17
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 12, 2014
Radius (Horizontal Curve Report)	191 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 30 mph			
CARS Recommended Advisory	EB=	30 mph	WB=	25 mph
ODOT Spreadsheet Recommended Advisory	EB=	25 mph	WB=	30 mph

Vicinity Map

Comparison of Test Speeds	
Curve No.	07
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	12.17

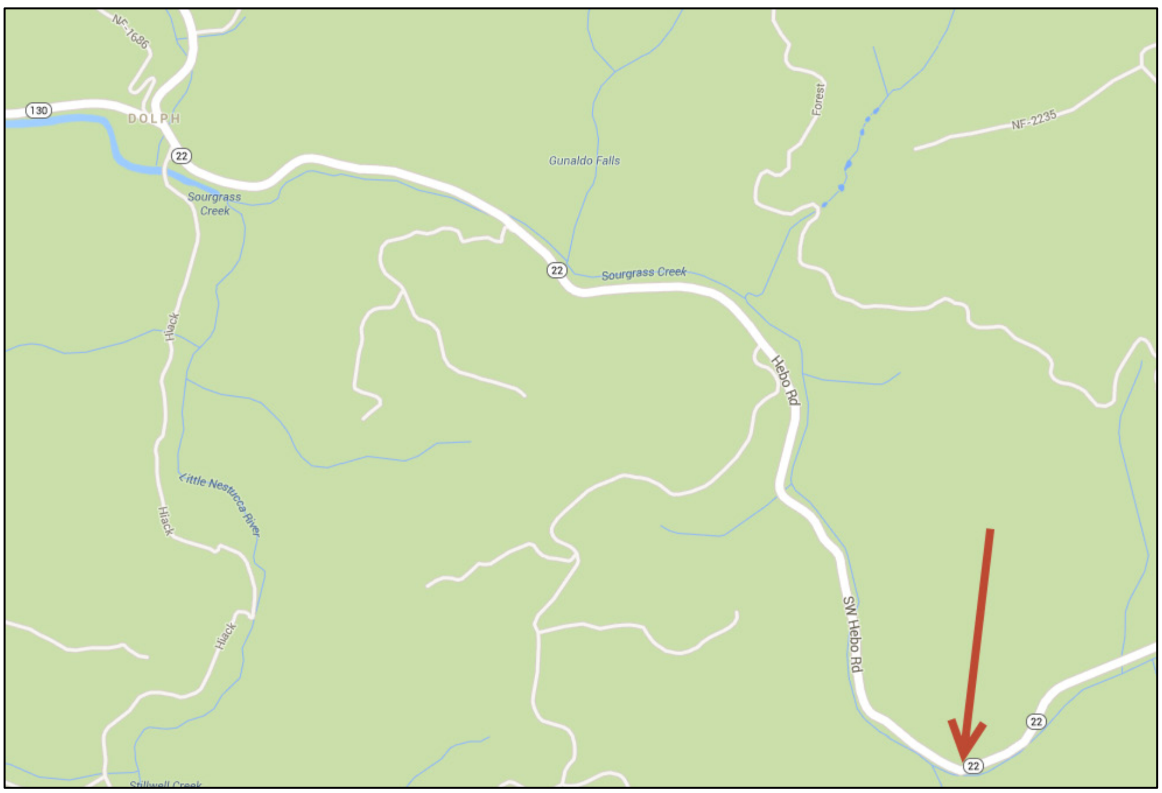
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	South	25.3	1.3	28.2
4	Left	South	28.5	1.4	28.5
6	Left	South	25.4	1.4	29.2
8	Left	South	37.8	1.5	28.5
		Min	25.3	1.3	28.2
		Max	37.8	1.5	29.2
		Difference	12.6		1.0

1	Right	North	25.5	1.0	27.5
3	Right	North	26.1	1.4	27.9
5	Right	North	24.5	1.7	26.7
7	Right	North	34.1	2.4	28.1
		Min	24.5	1.0	26.7
		Max	34.1	2.4	28.1
		Difference	9.6		1.4

Curve Summary	
Curve No.	08
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	12.82
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 13, 2014
Radius (Horizontal Curve Report)	286 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 30 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	30 mph	WB=	30 mph

Vicinity Map



Comparison of Test Speeds

Curve No.	08
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	12.82

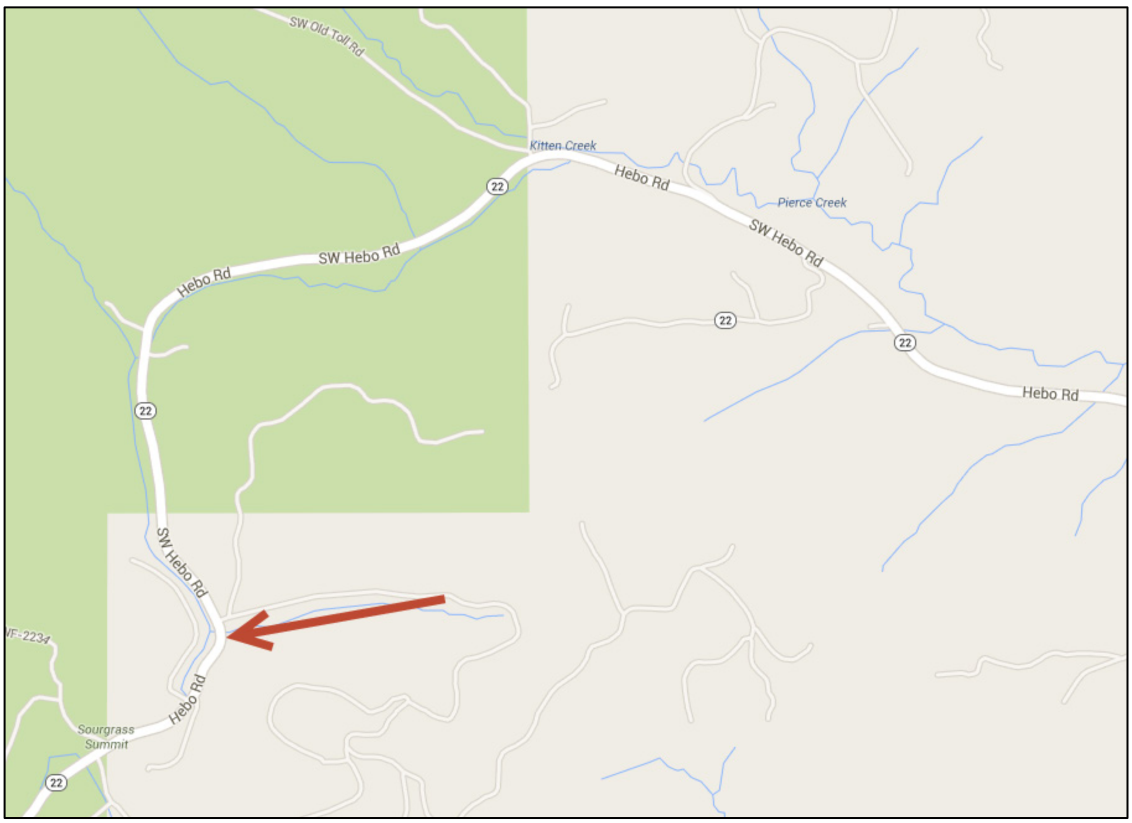
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	East	28.0	1.8	34.0
4	Left	East	30.8	1.4	34.7
6	Left	East	27.9	1.2	36.0
8	Left	East	38.0	2.0	33.2
		Min	27.9	1.2	33.2
		Max	38.0	2.0	36.0
		Difference	10.1		2.8

1	Right	Northwest	29.9	1.2	34.8
3	Right	Northwest	30.3	0.9	34.8
5	Right	Northwest	30.7	1.7	34.0
7	Right	Northwest	42.4	1.8	34.5
		Min	29.9	0.9	34.0
		Max	42.4	1.8	34.8
		Difference	12.5		0.8

Curve Summary	
Curve No.	09
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	14.10
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 13, 2014
Radius (Horizontal Curve Report)	191 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 35 mph			
CARS Recommended Advisory	EB=	30 mph	WB=	30 mph
ODOT Spreadsheet Recommended Advisory	EB=	30 mph	WB=	30 mph

Vicinity Map



Comparison of Test Speeds	
Curve No.	09
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	14.10

Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	Northeast	28.6	1.1	32.8
4	Left	Northeast	29.9	0.8	32.3
6	Left	Northeast	29.8	1.2	32.6
8	Left	Northeast	41.2	1.4	30.8
		Min	28.6	0.8	30.8
		Max	41.2	1.4	32.8
		Difference	12.6		2.0

1	Right	South	26.2	0.7	33.6
3	Right	South	26.3	0.5	32.9
5	Right	South	26.9	0.8	32.6
7	Right	South	41.0	0.5	33.4
		Min	26.2	0.5	32.6
		Max	41.0	0.8	33.6
		Difference	14.8		1.0

Curve Summary	
Curve No.	10
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	15.40
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 21, 2014
Radius (Horizontal Curve Report)	637 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Curve 40 mph			
CARS Recommended Advisory	EB=	45 mph	WB=	45 mph
ODOT Spreadsheet Recommended Advisory	EB=	45 mph	WB=	45 mph

Vicinity Map

Comparison of Test Speeds	
Curve No.	10
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	15.40

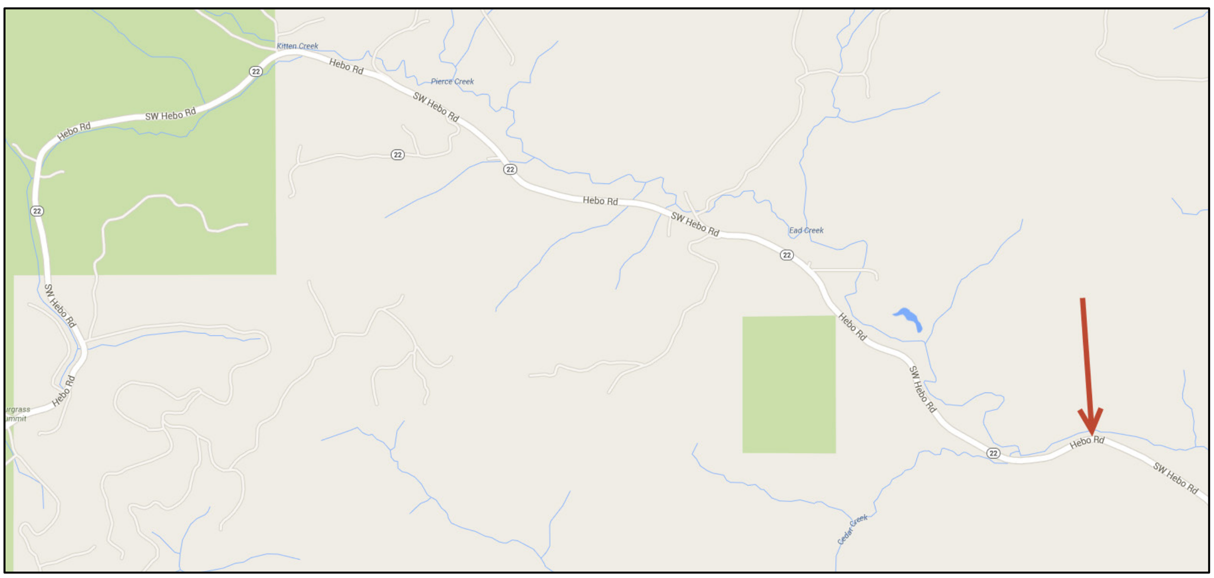
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	East	37.8	0.7	48.5
4	Left	East	40.3	0.6	48.5
6	Left	East	36.5	1.4	49.0
8	Left	East	52.2	1.5	49.3
		Min	36.5	0.6	48.5
		Max	52.2	1.5	49.3
		Difference	15.7		0.8

1	Right	West	30.8	0.5	48.0
3	Right	West	34.3	0.9	49.1
5	Right	West	34.3	0.7	48.0
7	Right	West	45.8	1.1	47.1
		Min	30.8	0.5	47.1
		Max	45.8	1.1	49.1
		Difference	15.0		2.0

Curve Summary	
Curve No.	11
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	18.05
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	May 21, 2014
Radius (Horizontal Curve Report)	239 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Curve 35 mph			
CARS Recommended Advisory	EB=	45 mph	WB=	40 mph
ODOT Spreadsheet Recommended Advisory	EB=	45 mph	WB=	40 mph

Vicinity Map



Comparison of Test Speeds

Curve No.	11
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	18.05

Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	East	34.3	1.2	45.5
4	Left	East	34.6	0.6	44.4
6	Left	East	36.9	1.0	45.0
8	Left	East	53.5	1.4	44.7
		Min	34.3	0.6	44.4
		Max	53.5	1.4	45.5
		Difference	19.2		1.1
1	Right	West	31.2	1.1	44.3
3	Right	West	32.5	2.6	43.2
5	Right	West	30.7	0.8	44.8
7	Right	West	46.7	1.2	44.1
		Min	30.7	0.8	43.2
		Max	46.7	2.6	44.8
		Difference	16.0		1.6

Curve Summary	
Curve No.	12
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	19.93
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	358 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Reversing Curve 35 mph WB, 40 mph EB			
CARS Recommended Advisory	EB=	40 mph	WB=	40 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map

Comparison of Test Speeds	
Curve No.	12
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	19.93

Pass #	**Curve**	**Travel**	**Average Test Speed (mph)**	**Test Speed Std. Dev. (mph)**	**Calculated Speed at 12° (mph)**
2	Right	East	35.2	0.2	44.3
4	Right	East	37.1	0.6	44.4
6	Right	East	32.6	0.1	44.4
8	Right	East	49.4	0.6	44.7
		Min	32.6	0.1	44.3
		Max	49.4	0.6	44.7
		Difference	16.8		0.4

1	Left	Northwest	32.3	0.5	40.7
3	Left	Northwest	36.1	0.8	41.2
5	Left	Northwest	32.6	0.8	41.8
7	Left	Northwest	47.3	1.0	38.8
		Min	32.3	0.5	38.8
		Max	47.3	1.0	41.8
		Difference	15.0		3.0

Curve Summary	
Curve No.	13
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	20.45
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	318 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Curve 30 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map

Comparison of Test Speeds

Curve No.	13
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	20.45

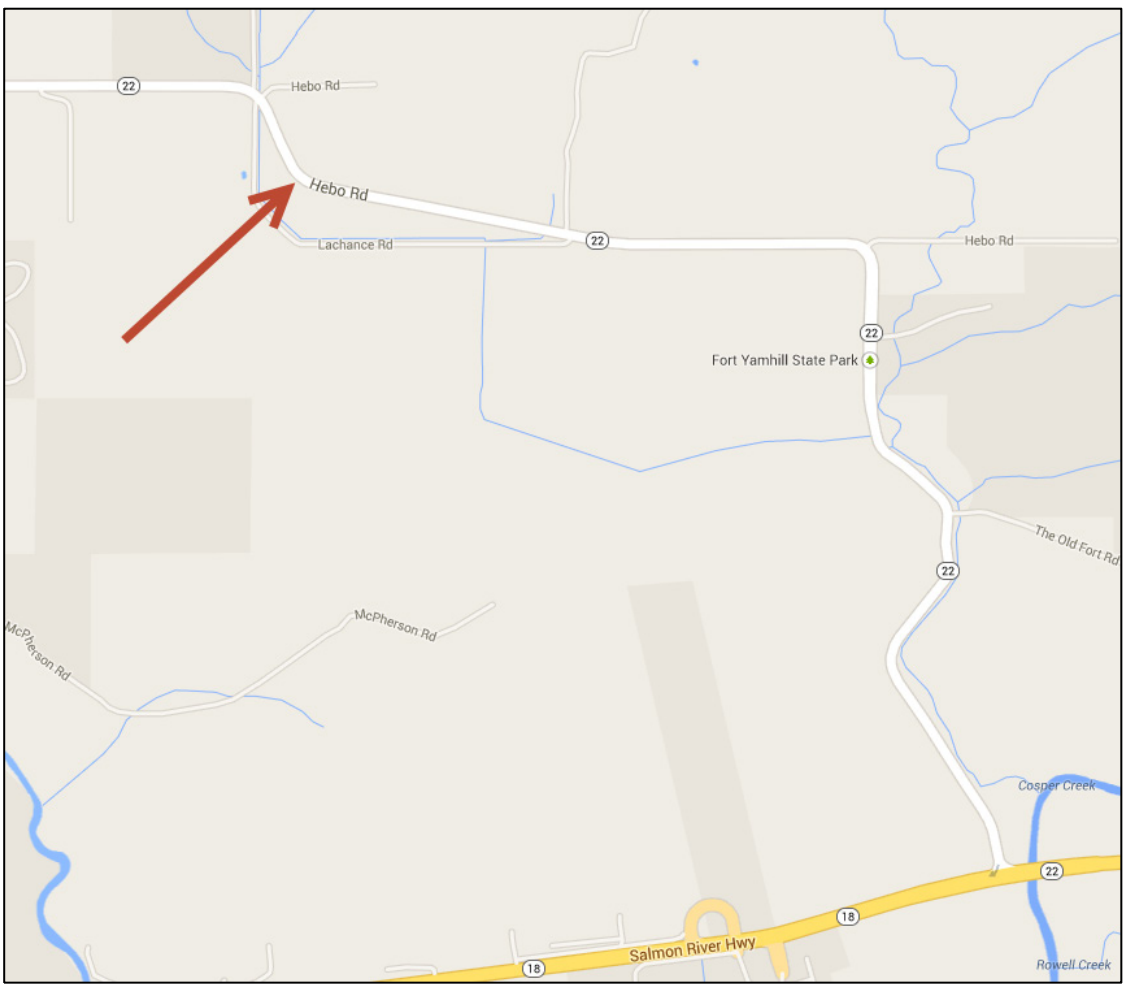
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	East	31.7	1.1	37.9
4	Left	East	35.2	1.1	38.1
6	Left	East	30.3	1.0	38.5
8	Left	East	47.1	0.5	39.2
		Min	30.3	0.5	37.9
		Max	47.1	1.1	39.2
		Difference	16.8		1.3

1	Right	Northwest	26.8	1.0	38.3
3	Right	Northwest	29.7	0.7	38.7
5	Right	Northwest	27.8	0.5	38.6
7	Right	Northwest	44.4	0.8	39.7
		Min	26.8	0.5	38.3
		Max	44.4	1.0	39.7
		Difference	17.6		1.4

Curve Summary	
Curve No.	14
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	22.90
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	358 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Turn 30 mph			
CARS Recommended Advisory	EB=	40 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map



Comparison of Test Speeds	
Curve No.	14
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	22.90

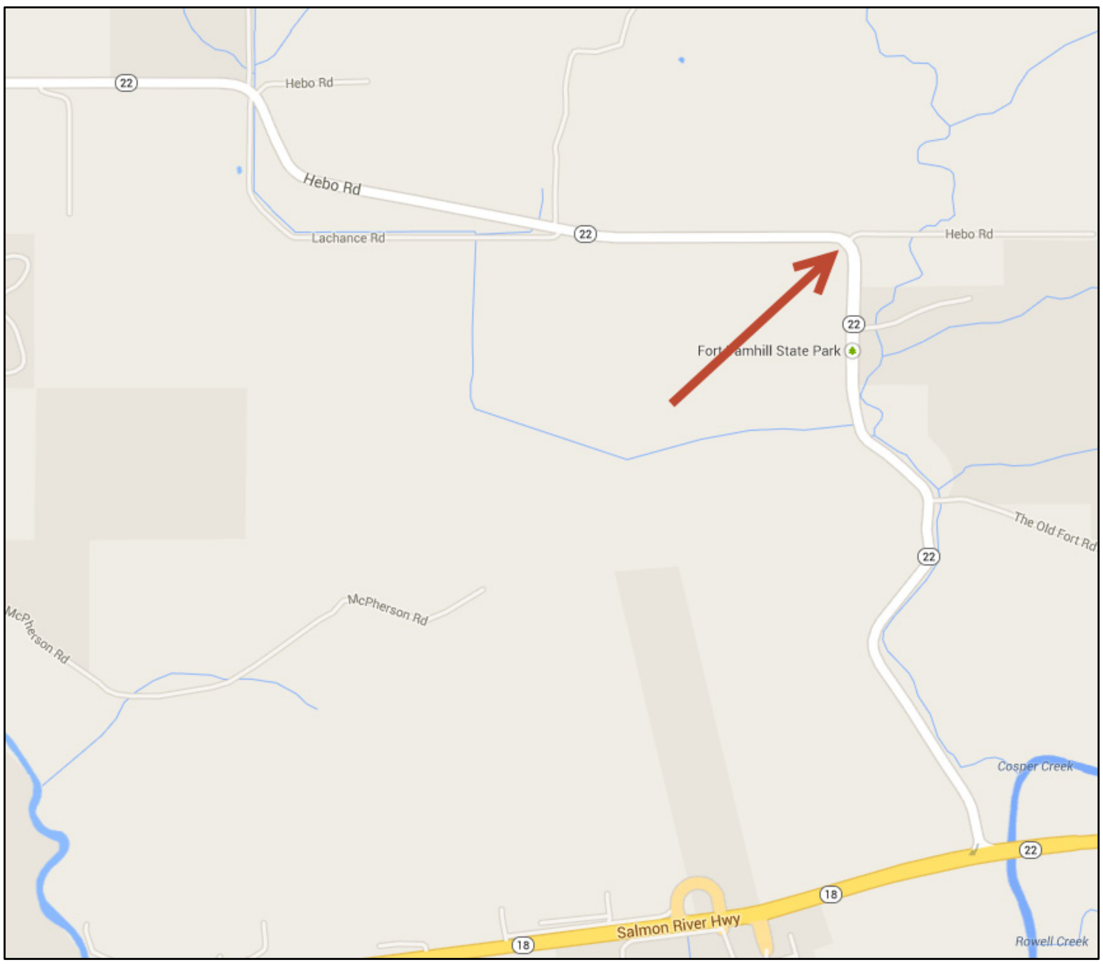
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	Southeast	33.3	0.7	41.1
4	Left	Southeast	31.2	1.1	40.7
6	Left	Southeast	29.9	1.0	40.8
8	Left	Southeast	40.0	0.8	40.5
		Min	29.9	0.7	40.5
		Max	40.0	1.1	41.1
		Difference	10.1		0.6

1	Right	North	31.2	1.0	38.2
3	Right	North	28.7	0.6	38.1
5	Right	North	26.9	0.6	38.4
7	Right	North	44.7	0.6	38.0
		Min	26.9	0.6	38.0
		Max	44.7	1.0	38.4
		Difference	17.8		0.4

Curve Summary	
Curve No.	15
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	23.83
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	151 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Turn 25 mph			
CARS Recommended Advisory	EB=	25 mph	WB=	30 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map



Comparison of Test Speeds

Curve No.	15
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	23.83

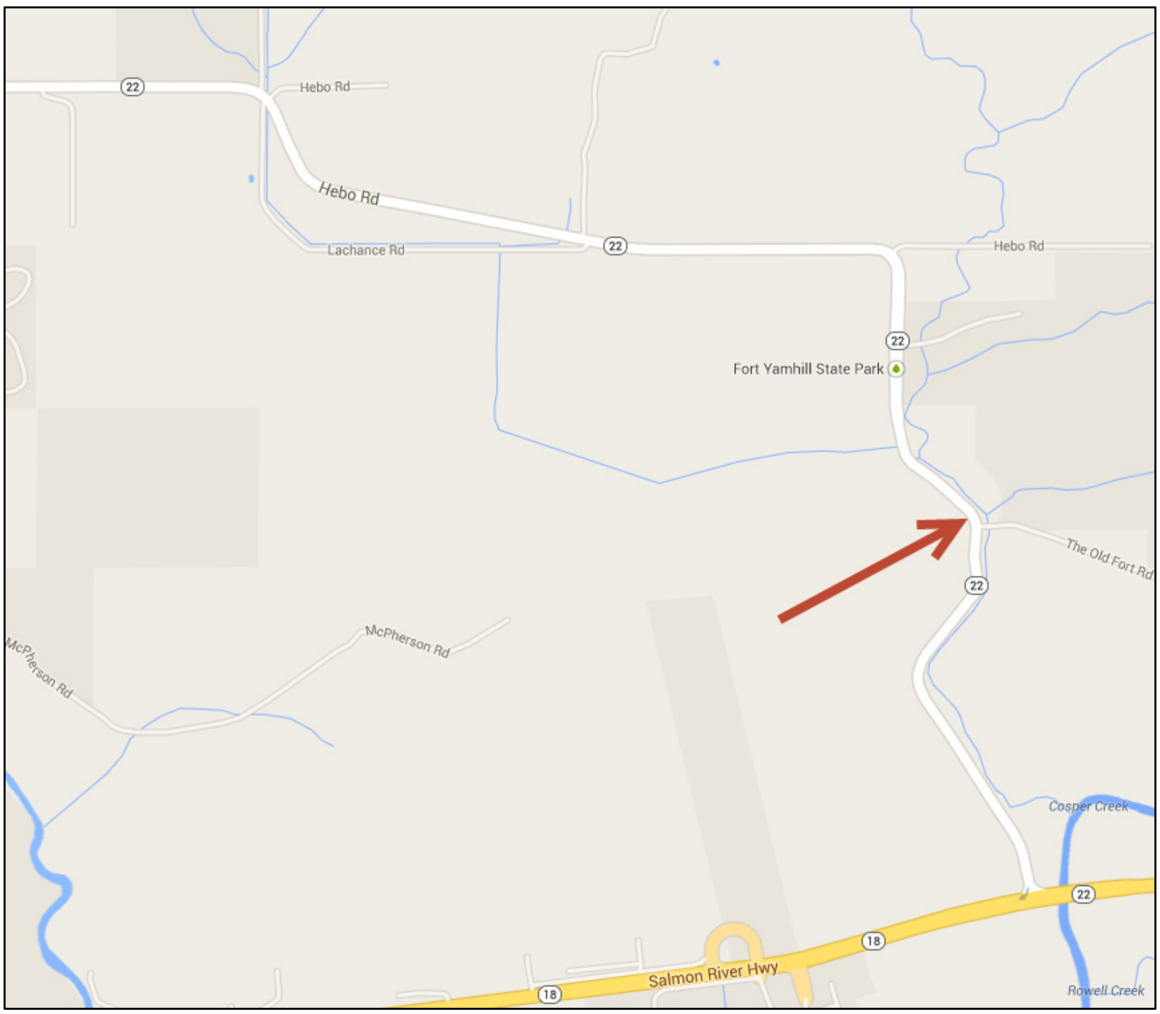
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Right	Southeast	24.2	0.6	27.9
4	Right	Southeast	25.3	0.9	28.1
6	Right	Southeast	24.6	0.8	27.9
8	Right	Southeast	37.8	1.2	29.1
		Min	24.2	0.6	27.9
		Max	37.8	1.2	29.1
		Difference	13.6		1.2

1	Left	North	23.1	1.0	29.0
3	Left	North	25.4	0.8	29.1
5	Left	North	23.8	0.7	29.6
7	Left	North	36.6	1.1	30.1
		Min	23.1	0.7	29.0
		Max	36.6	1.1	30.1
		Difference	13.5		1.1

Curve Summary	
Curve No.	16
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	24.29
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	143 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 25 mph			
CARS Recommended Advisory	EB=	30 mph	WB=	30 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map



Comparison of Test Speeds

Curve No. 16
Highway 3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS) 24.29

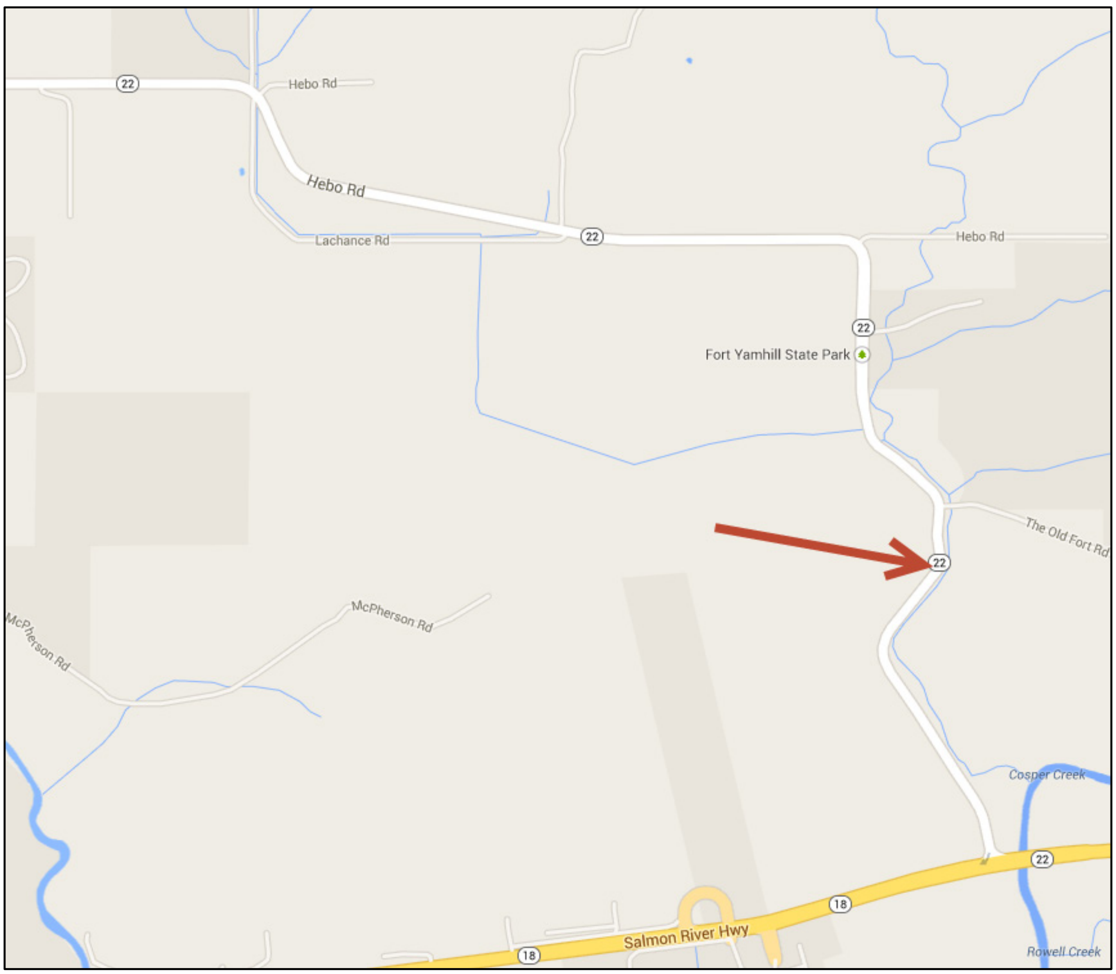
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	Northeast	26.0	0.6	33.0
4	Left	Northeast	27.2	0.9	32.8
6	Left	Northeast	26.8	0.4	32.3
8	Left	Northeast	38.1	1.6	31.7
		Min	26.0	0.4	31.7
		Max	38.1	1.6	33.0
		Difference	12.1		1.3

1	Right	South	25.5	0.6	33.5
3	Right	South	29.4	0.8	33.0
5	Right	South	27.3	0.6	32.7
7	Right	South	41.6	1.4	32.0
		Min	25.5	0.6	32.0
		Max	41.6	1.4	33.5
		Difference	16.1		1.5

Curve Summary	
Curve No.	17
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	24.41
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	151 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Winding Road 25 mph			
CARS Recommended Advisory	EB=	25 mph	WB=	25 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map



Comparison of Test Speeds

Curve No.	17
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	24.41

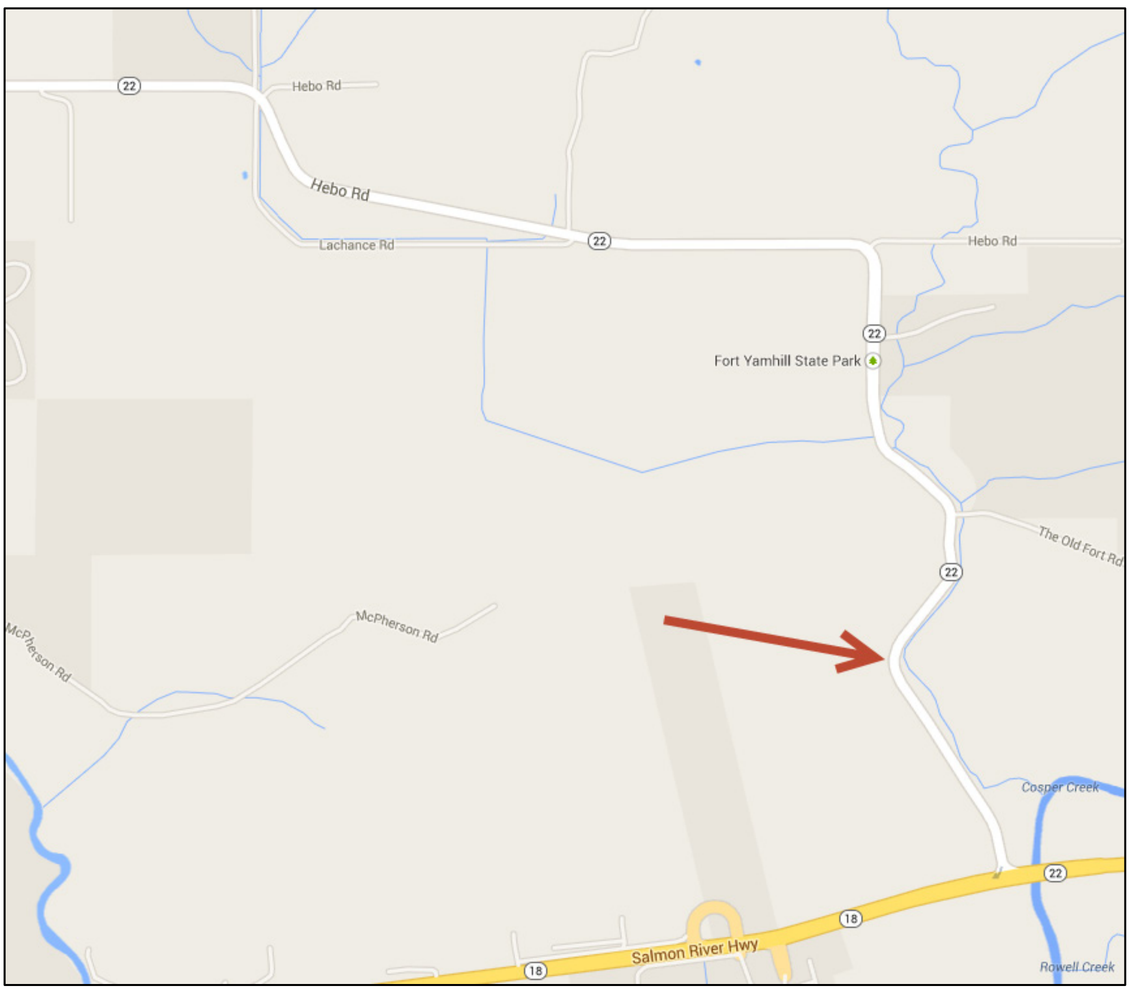
Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	Northeast	21.7	1.2	26.4
4	Left	Northeast	23.8	0.8	26.9
6	Left	Northeast	24.3	1.2	26.8
8	Left	Northeast	30.2	1.6	25.2
		Min	21.7	0.8	25.2
		Max	30.2	1.6	26.9
		Difference	8.4		1.7

1	Right	South	22.2	1.7	26.1
3	Right	South	26.0	1.3	27.6
5	Right	South	24.2	1.2	27.3
7	Right	South	38.6	1.4	30.7
		Min	22.2	1.2	26.1
		Max	38.6	1.7	30.7
		Difference	16.4		4.6

Curve Summary	
Curve No.	18
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	24.57
CARS Data Collection Date	June 5-6, 2014
ODOT Spreadsheet Date	No Data Collected
Radius (Horizontal Curve Report)	286 ft.

Advisory Speed Summary				
Existing Sign (Oct. 2013)	Curve 35 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	No Data	WB=	No Data

Vicinity Map



Comparison of Test Speeds

Curve No.	18
Highway	3 Rivers Highway No. 032 (OR 22)
MP at Mid-Curve (Trans GIS)	24.57

Pass #	Curve	Travel	Average Test Speed (mph)	Test Speed Std. Dev. (mph)	Calculated Speed at 12° (mph)
2	Left	South	28.3	0.7	37.8
4	Left	South	34.3	0.5	38.9
6	Left	South	29.5	0.5	39.3
8	Left	South	44.4	1.1	39.7
		Min	28.3	0.5	37.8
		Max	44.4	1.1	39.7
		Difference	16.2		1.9

1	Right	Northeast	27.0	1.3	37.1
3	Right	Northeast	29.6	1.6	38.0
5	Right	Northeast	30.3	1.0	37.9
7	Right	Northeast	41.2	1.2	37.6
		Min	27.0	1.0	37.1
		Max	41.2	1.6	38.0
		Difference	14.2		0.9

Curve Summary	
Curve No.	19
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	76.48
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 11, 2014
Radius (Horizontal Curve Report)	382 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	55 mph	SB=	55 mph
ODOT Spreadsheet Recommended Advisory	NB=	45 mph	SB=	50 mph

Vicinity Map

Curve Summary	
Curve No.	20
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	76.90
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 11, 2014
Radius (Horizontal Curve Report)	358 ft.

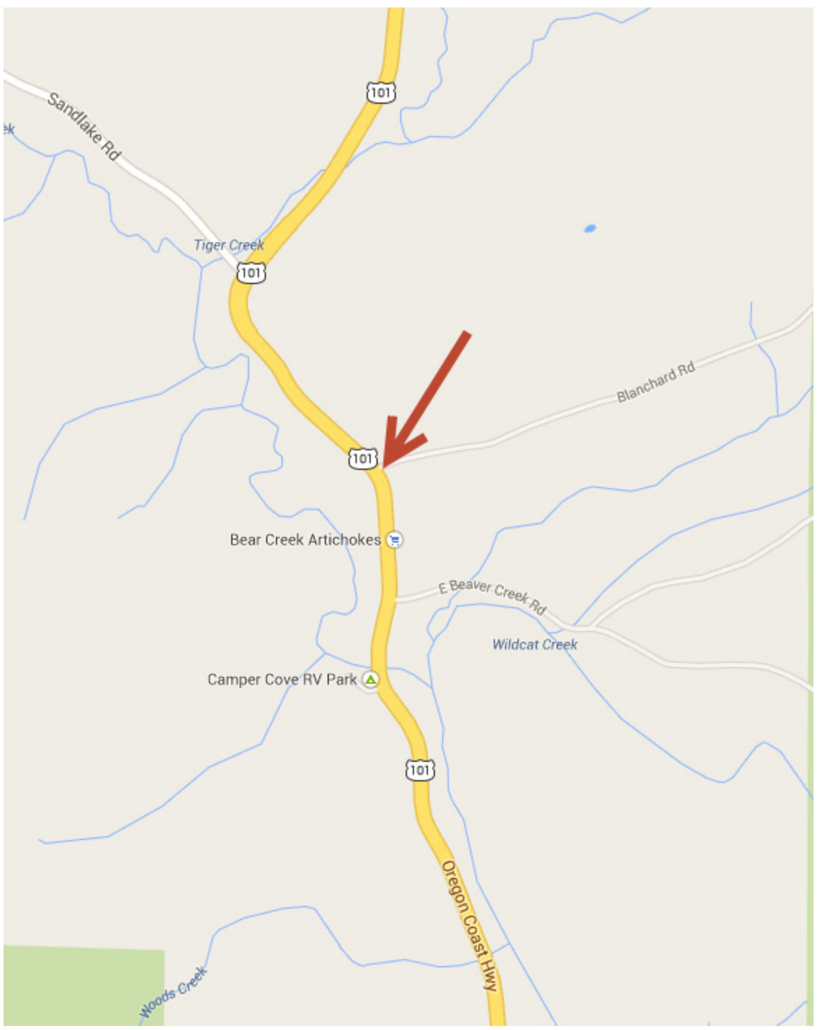
Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	35 mph	SB=	35 mph

Vicinity Map

Curve Summary	
Curve No.	21
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	77.22
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 11, 2014
Radius (Horizontal Curve Report)	286 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	30 mph			
CARS Recommended Advisory	NB=	35 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	35 mph	SB=	35 mph

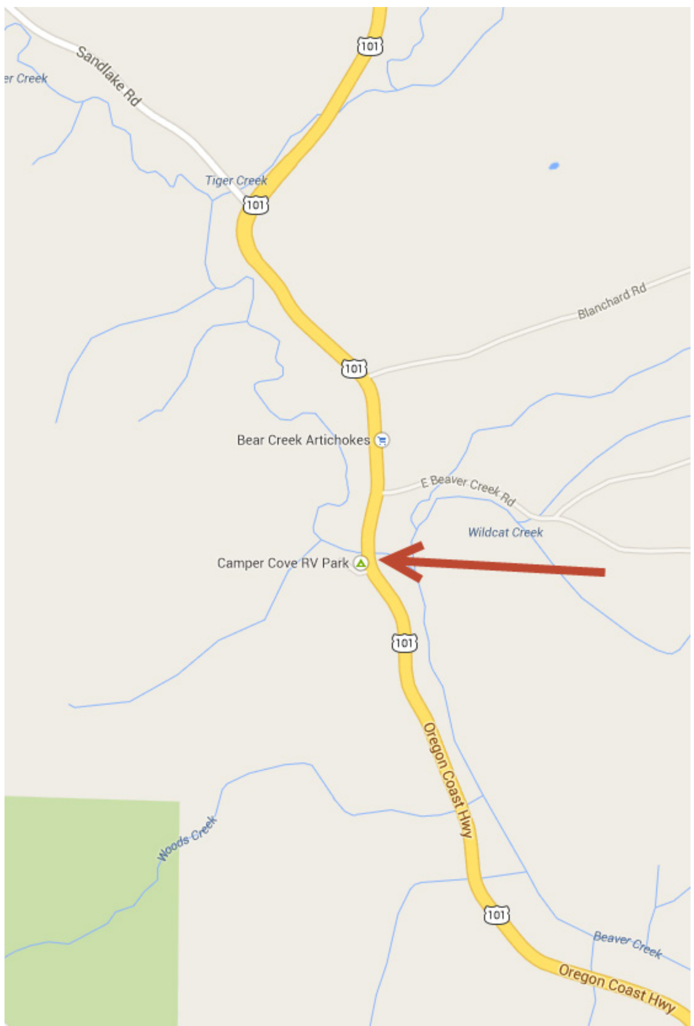
Vicinity Map



Curve Summary	
Curve No.	22
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	77.53
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	179 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	30 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	35 mph	SB=	35 mph

Vicinity Map



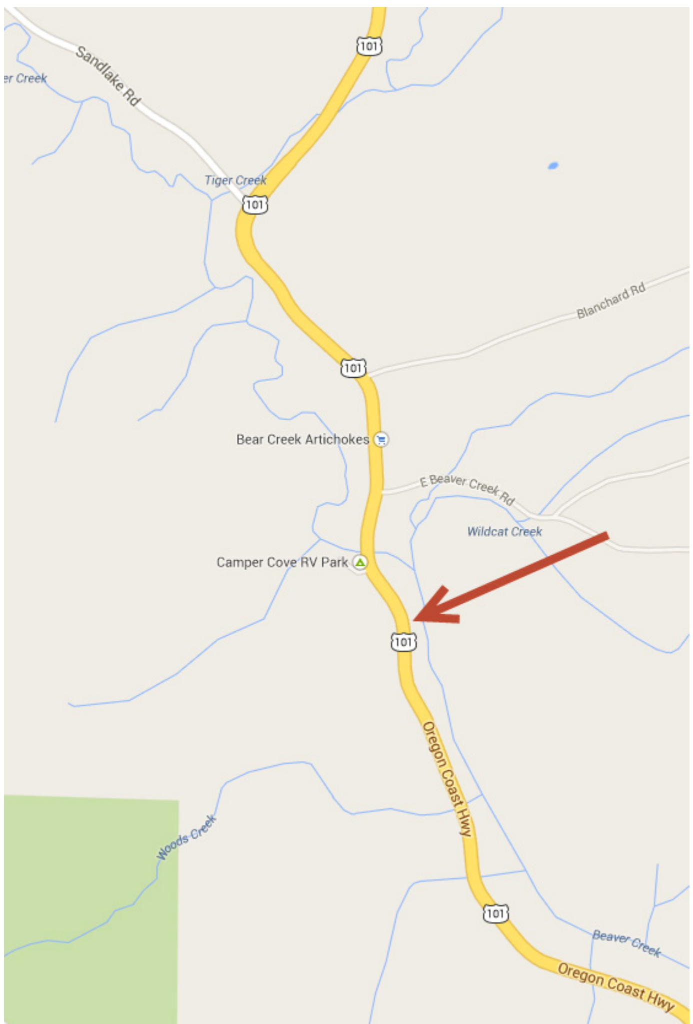
Curve Summary

Curve No.	23
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	77.63
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	477 ft.

Advisory Speed Summary

Existing Advisory Speed (Oct. 2013)	40 mph			
CARS Recommended Advisory	NB=	45 mph	SB=	45 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	45 mph

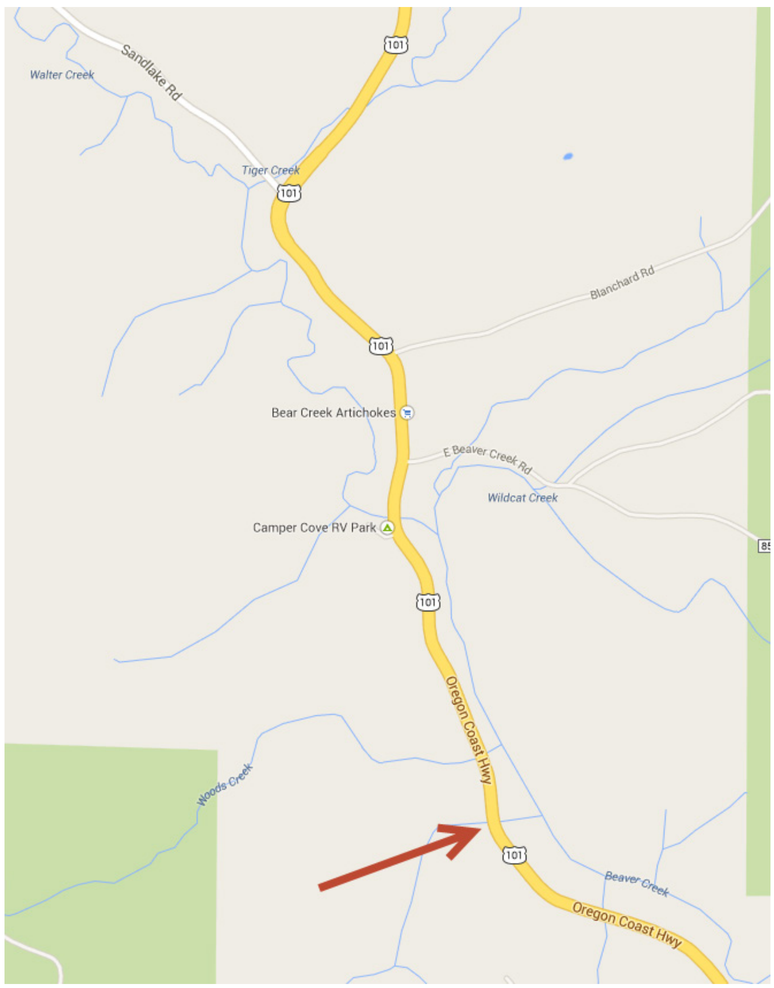
Vicinity Map



Curve Summary	
Curve No.	24
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	78.10
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	382 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	40 mph

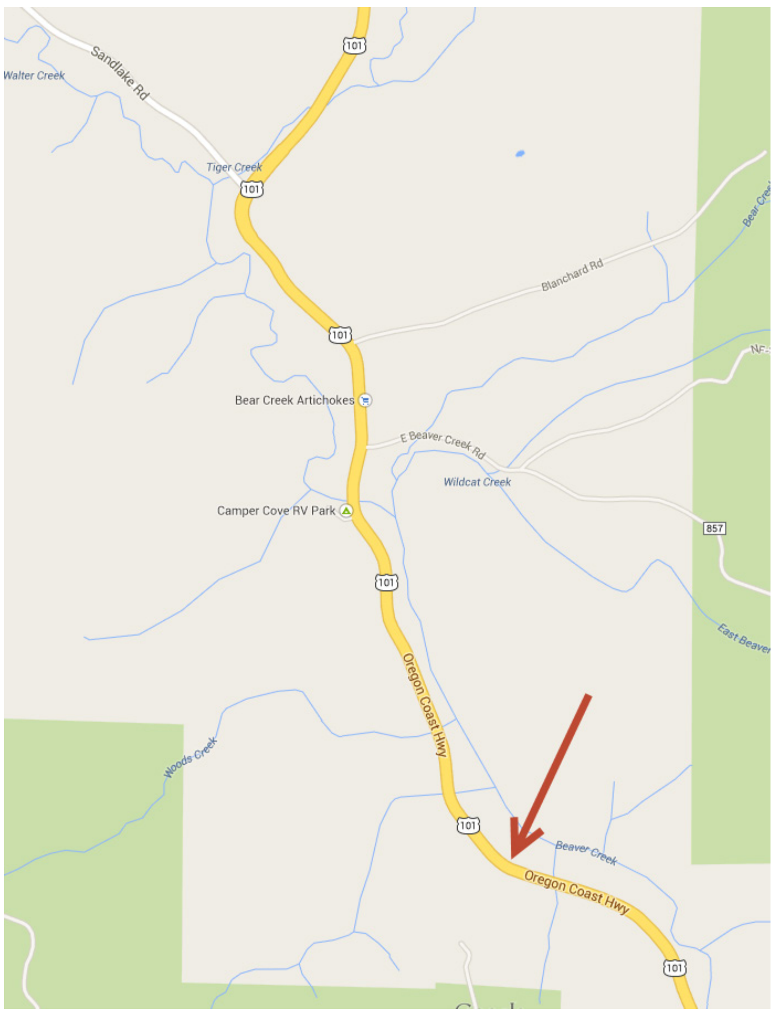
Vicinity Map



Curve Summary	
Curve No.	25
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	78.28
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	382 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	45 mph	SB=	45 mph
ODOT Spreadsheet Recommended Advisory	NB=	45 mph	SB=	40 mph

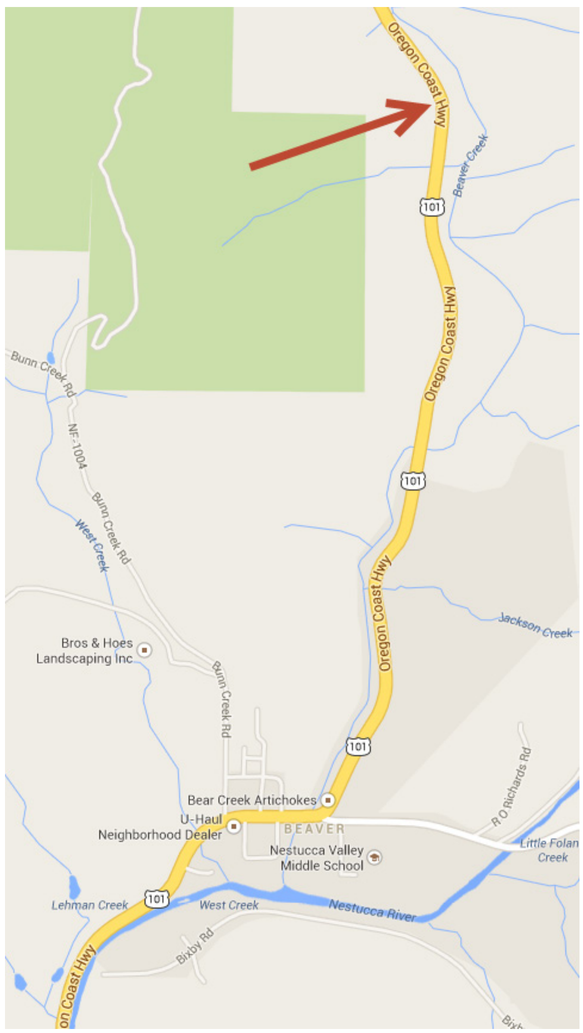
Vicinity Map



Curve Summary	
Curve No.	26
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	78.97
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	603 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	45 mph	SB=	45 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	40 mph

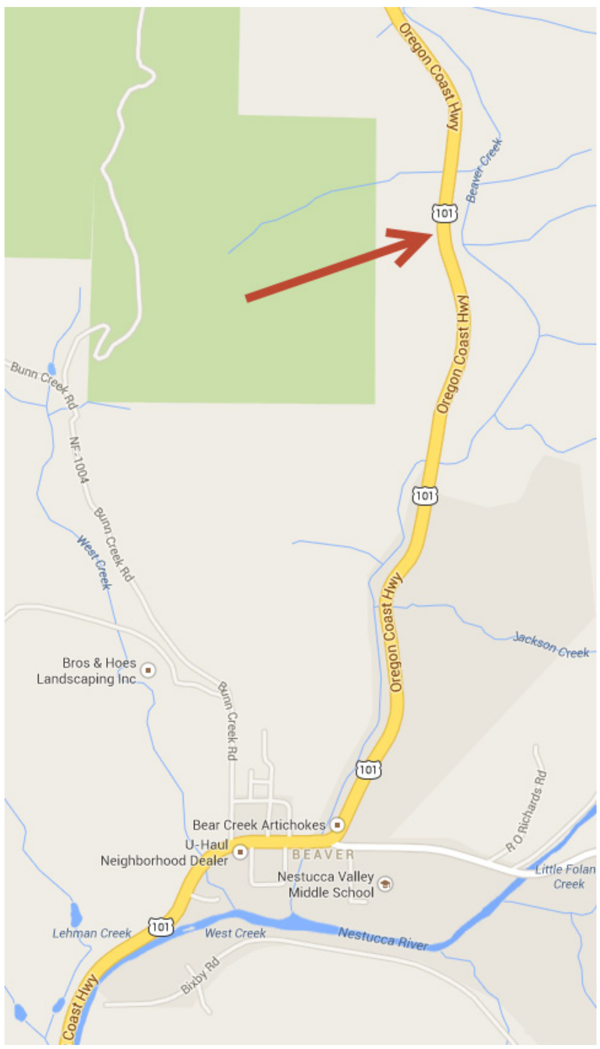
Vicinity Map



Curve Summary	
Curve No.	27
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	79.21
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	409 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	40 mph			
CARS Recommended Advisory	NB=	50 mph	SB=	50 mph
ODOT Spreadsheet Recommended Advisory	NB=	45 mph	SB=	45 mph

Vicinity Map



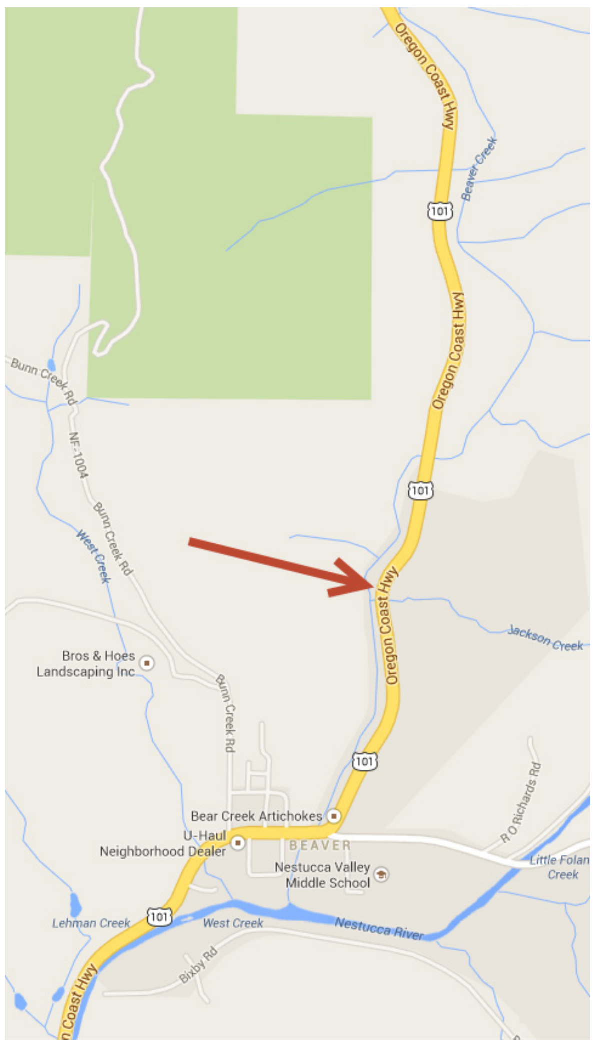
Curve Summary

Curve No.	28
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	79.85
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 12, 2014
Radius (Horizontal Curve Report)	382 ft.

Advisory Speed Summary

Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	35 mph
ODOT Spreadsheet Recommended Advisory	NB=	35 mph	SB=	35 mph

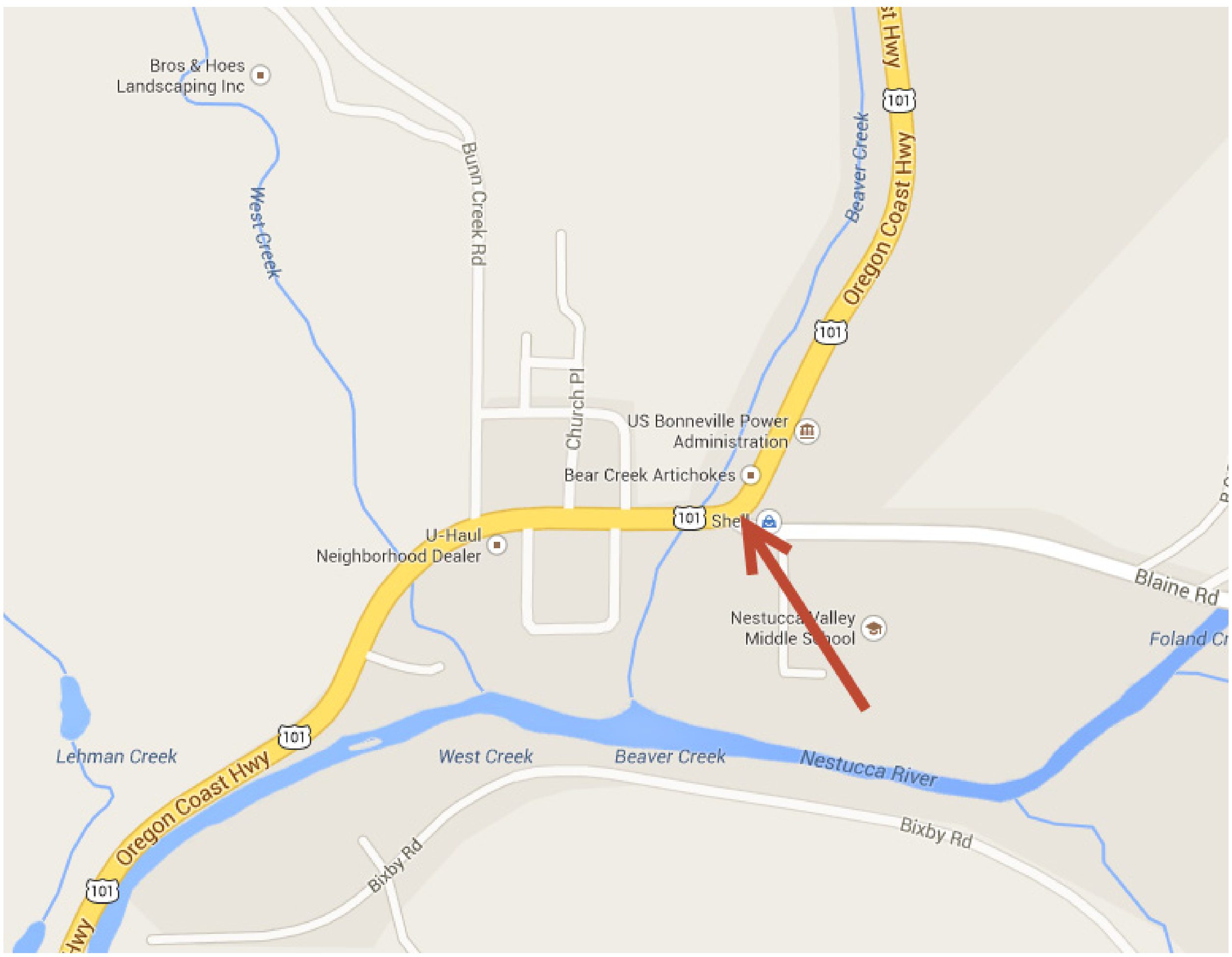
Vicinity Map



Curve Summary	
Curve No.	29
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	80.30
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	106 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	20 mph			
CARS Recommended Advisory	NB=	25 mph	SB=	25 mph
ODOT Spreadsheet Recommended Advisory	NB=	25 mph	SB=	25 mph

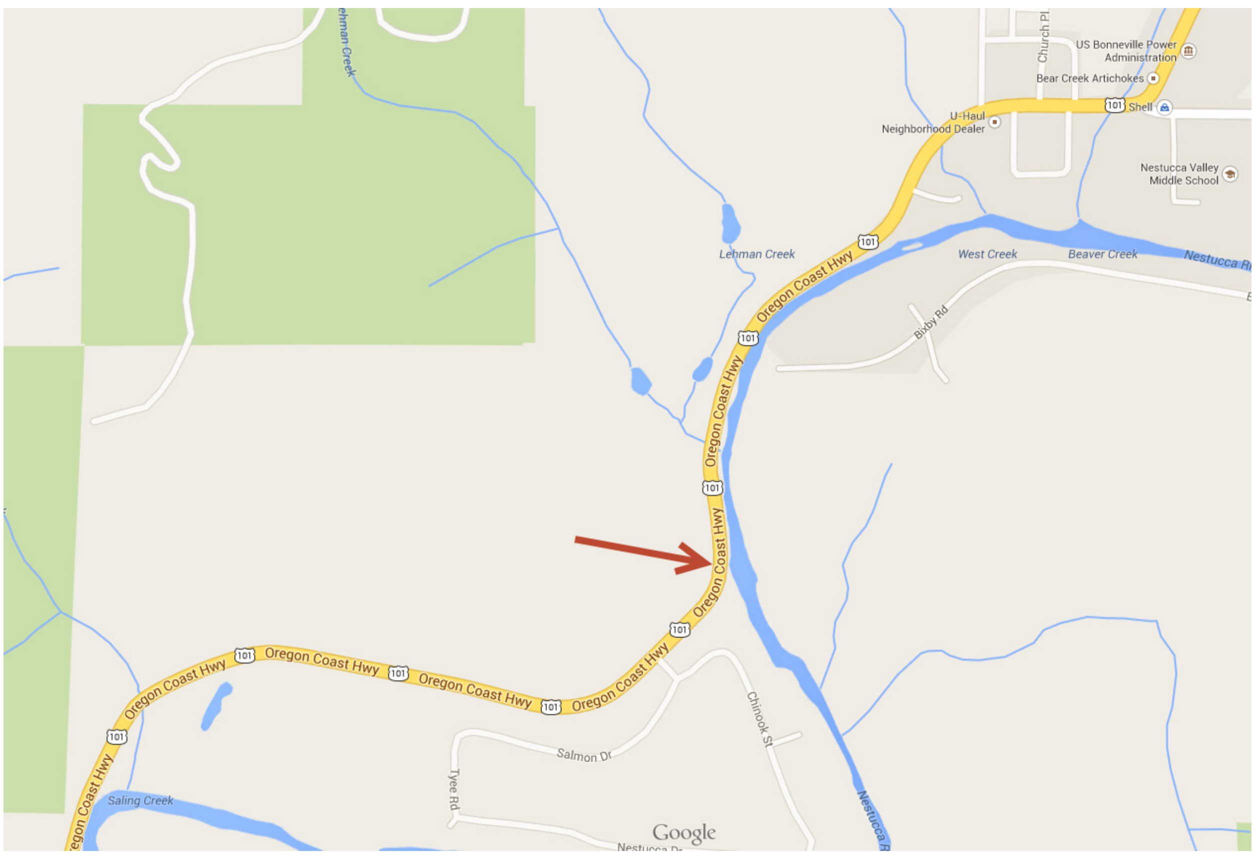
Vicinity Map



Curve Summary	
Curve No.	30
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	81.08
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	286 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	35 mph	SB=	35 mph

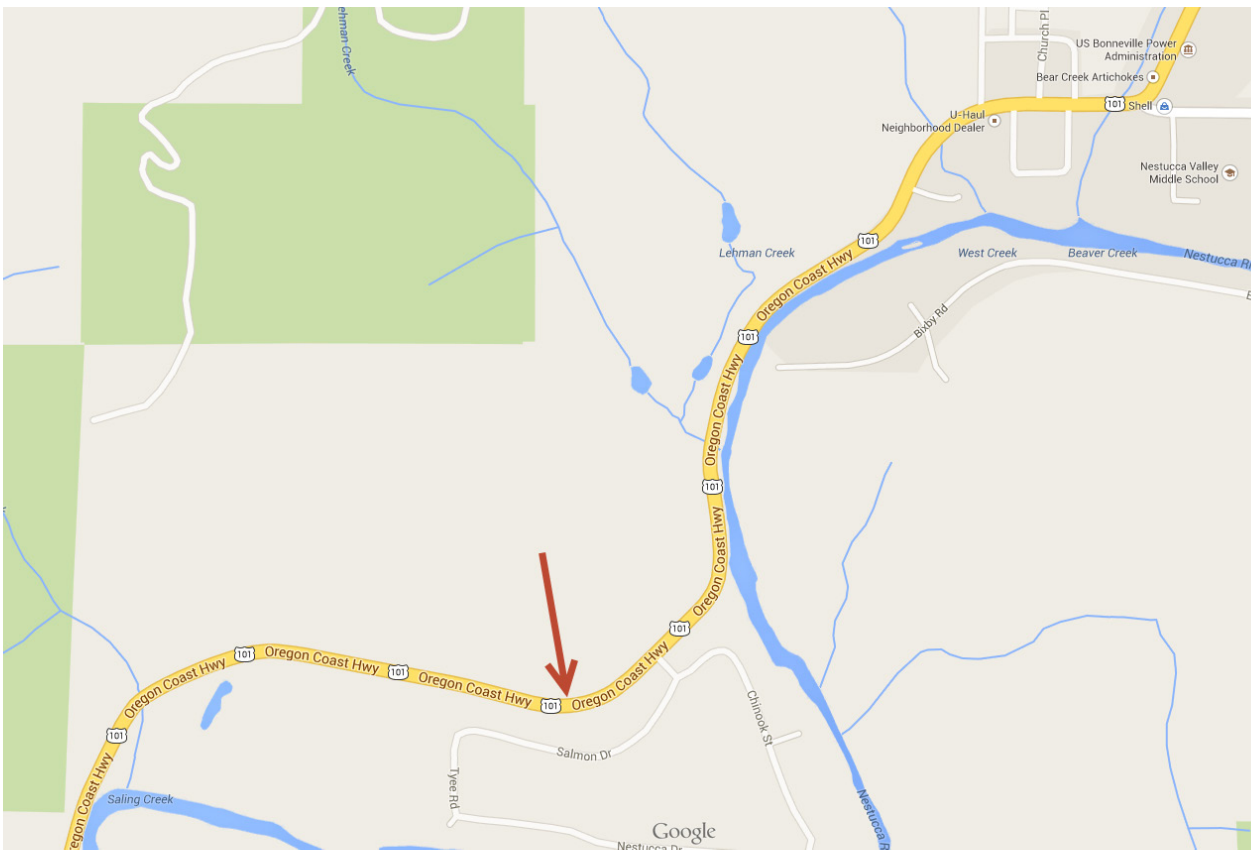
Vicinity Map



Curve Summary	
Curve No.	31
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	81.27
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	Compound Curve

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	40 mph			
CARS Recommended Advisory	NB=	45 mph	SB=	45 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	45 mph

Vicinity Map



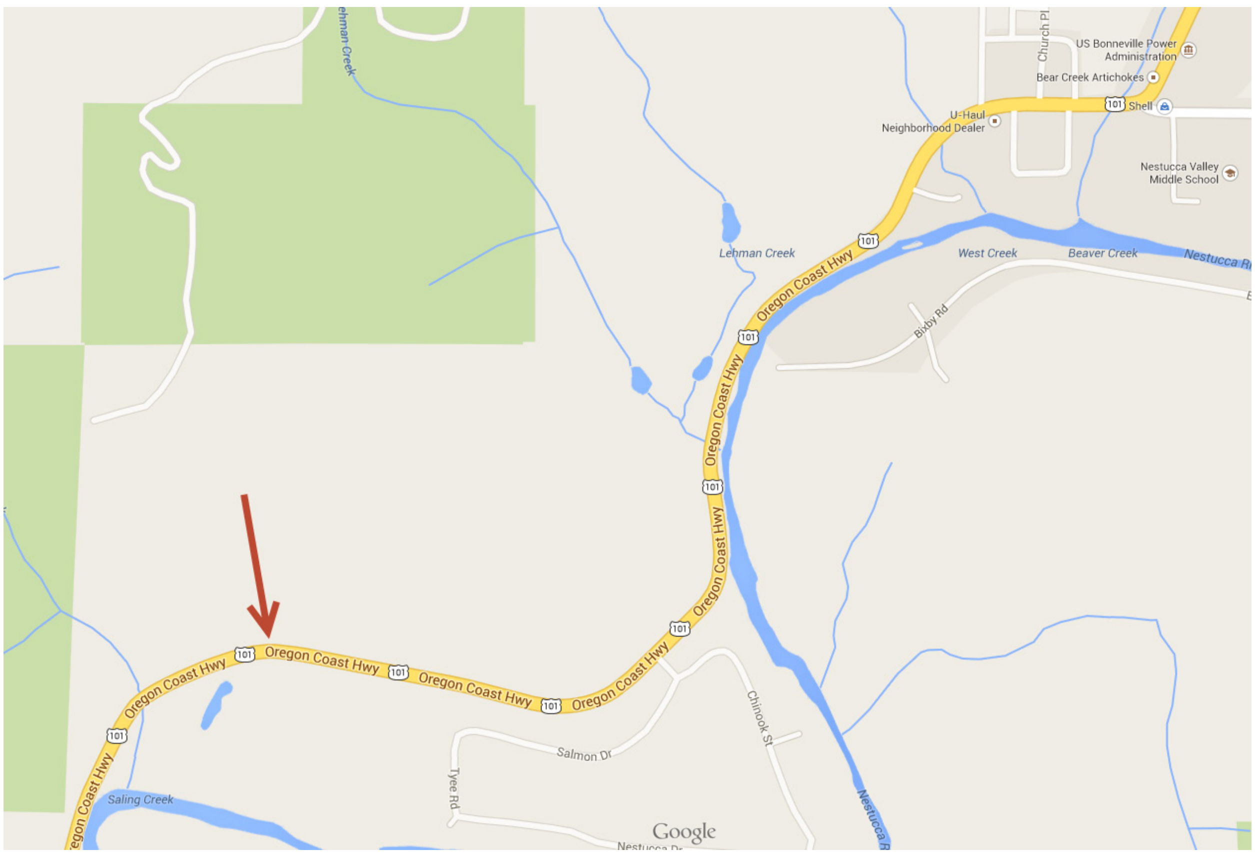
Curve Summary

Curve No.	32
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	81.64
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	477 ft.

Advisory Speed Summary

Existing Advisory Speed (Oct. 2013)	45 mph			
CARS Recommended Advisory	NB=	50 mph	SB=	50 mph
ODOT Spreadsheet Recommended Advisory	NB=	50 mph	SB=	50 mph

Vicinity Map



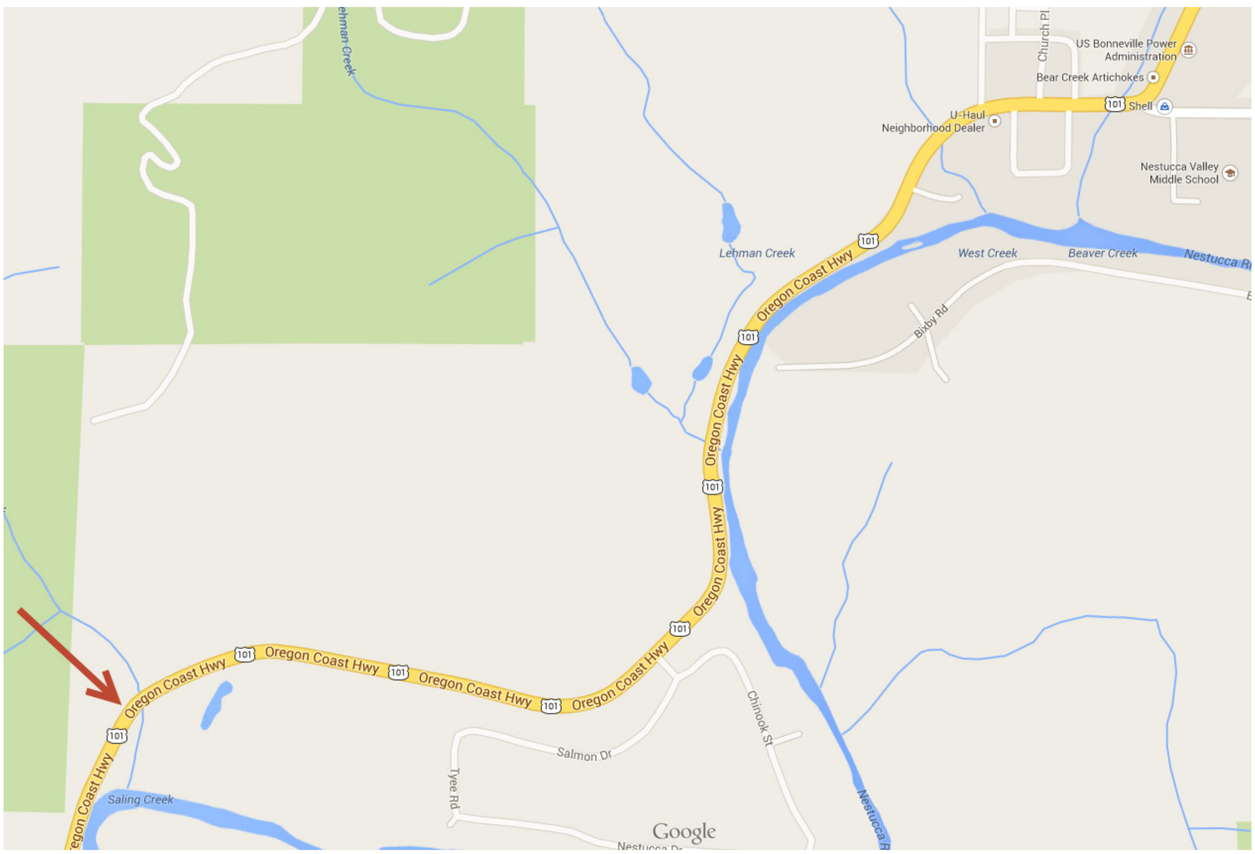
Curve Summary

Curve No.	33
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	81.77
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	191 ft.

Advisory Speed Summary

Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	35 mph

Vicinity Map



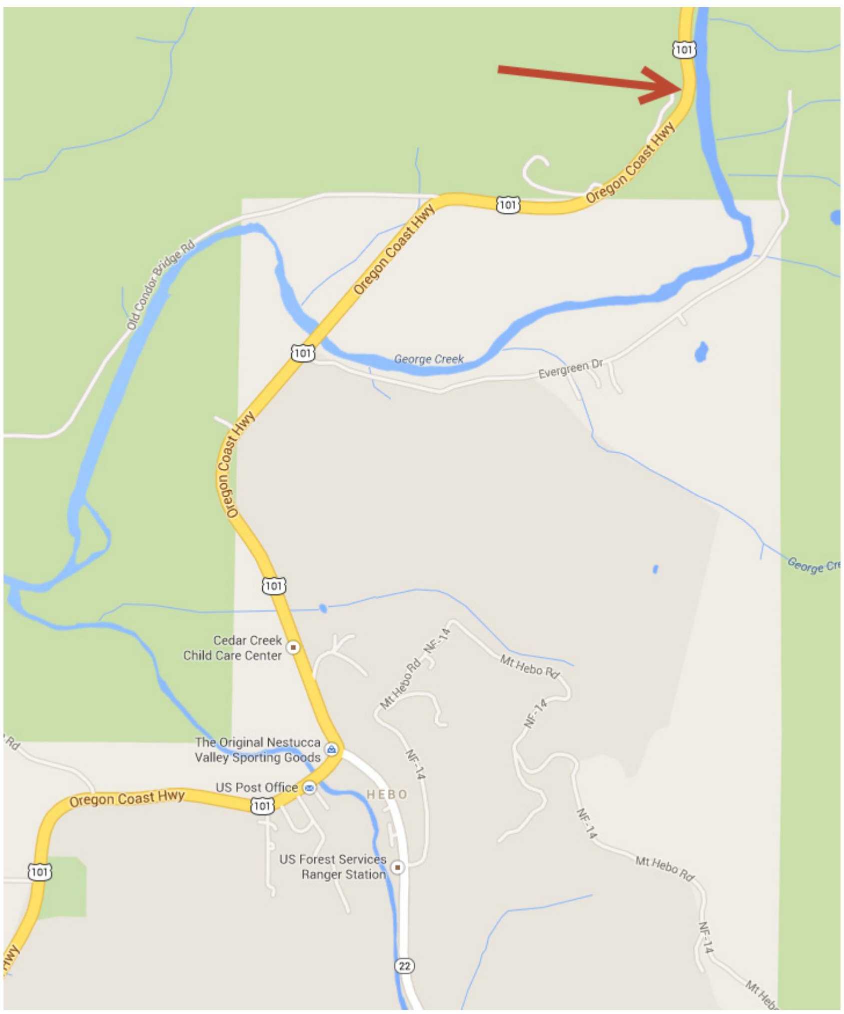
Curve Summary

Curve No.	34
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	83.22
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	286 ft.

Advisory Speed Summary

Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	40 mph
ODOT Spreadsheet Recommended Advisory	NB=	35 mph	SB=	40 mph

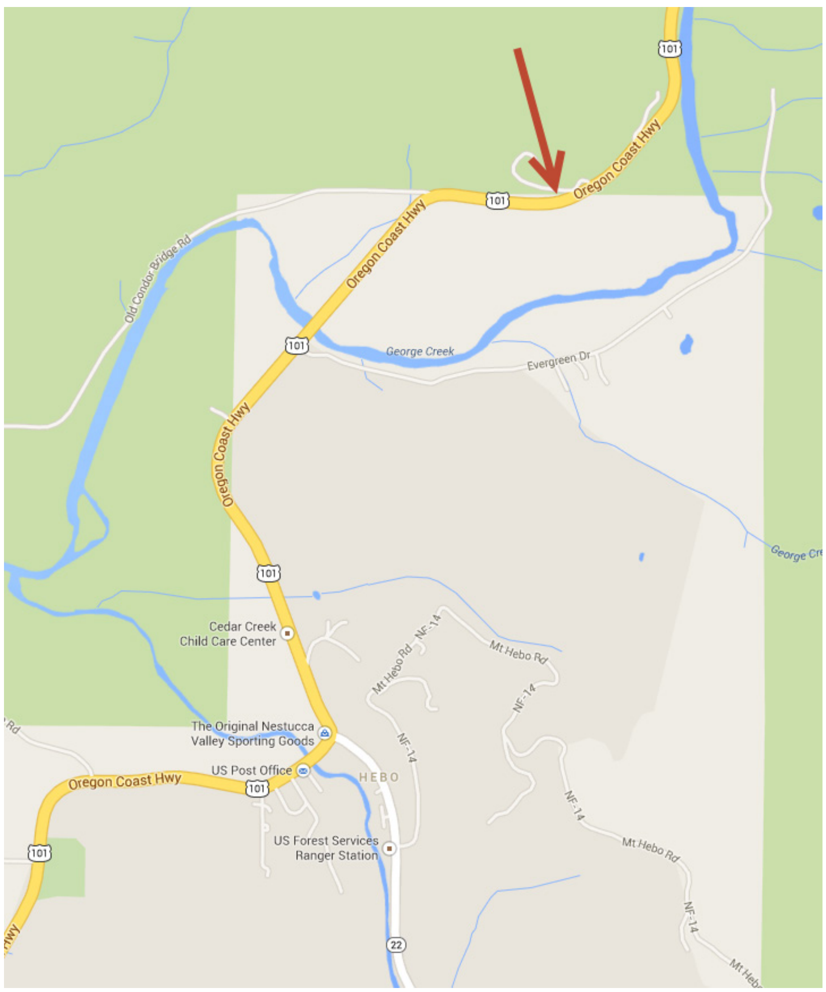
Vicinity Map



Curve Summary	
Curve No.	35
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	83.50
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	Compound Curve

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	40 mph			
CARS Recommended Advisory	NB=	55 mph	SB=	55 mph
ODOT Spreadsheet Recommended Advisory	NB=	50 mph	SB=	50 mph

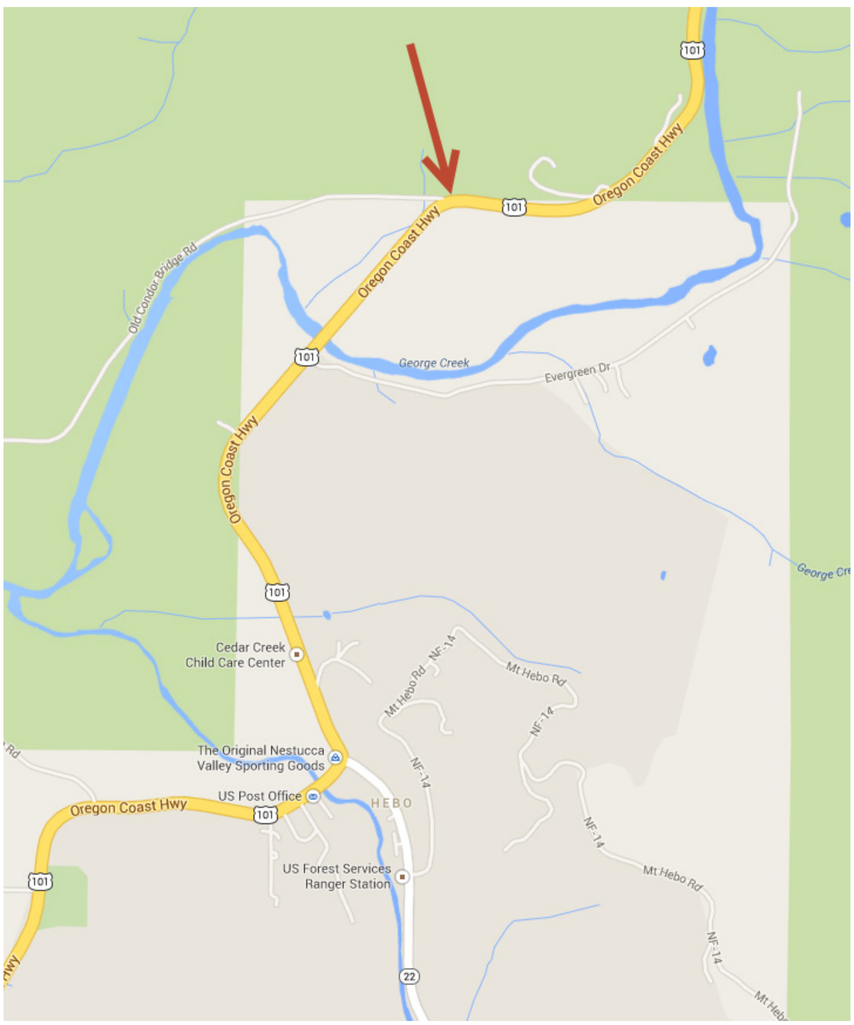
Vicinity Map



Curve Summary	
Curve No.	36
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	83.77
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	358 ft.

Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	35 mph			
CARS Recommended Advisory	NB=	40 mph	SB=	35 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	35 mph

Vicinity Map



Curve Summary	
Curve No.	37
Highway	Oregon Coast Highway No. 009 (US 101)
MP at Mid-Curve (Trans GIS)	84.40
CARS Data Collection Date	June 6, 2014
ODOT Spreadsheet Date	March 13, 2014
Radius (Horizontal Curve Report)	716 ft.

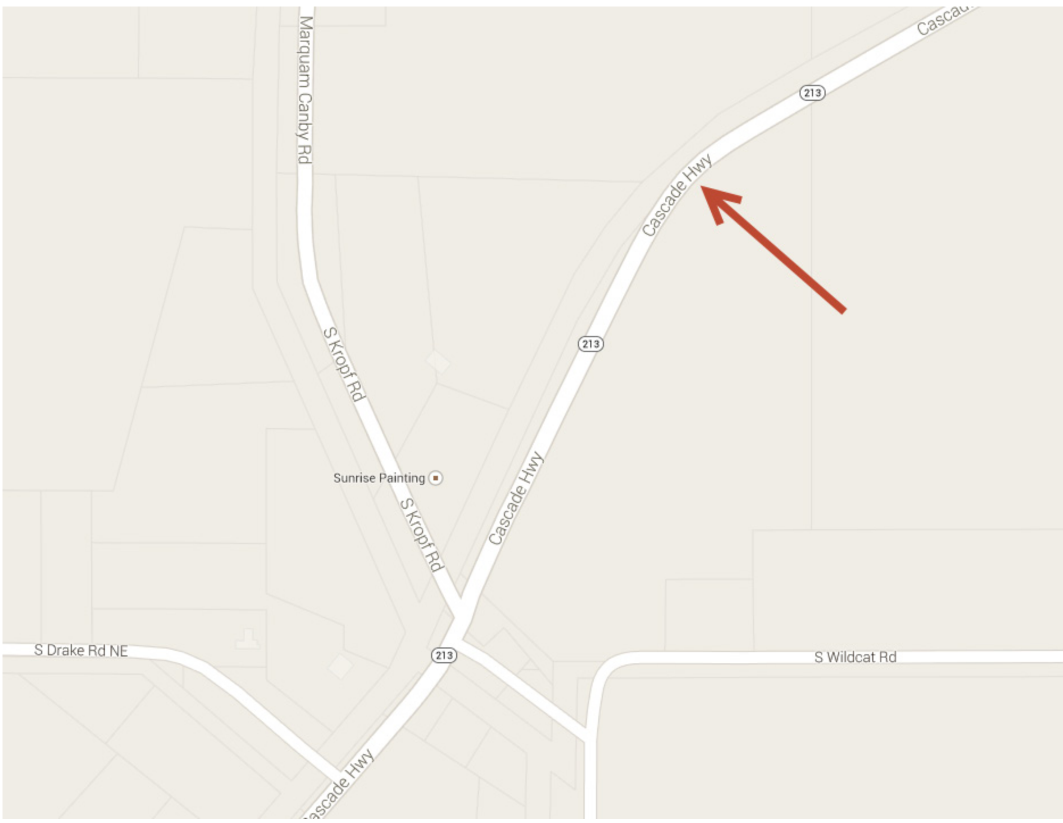
Advisory Speed Summary				
Existing Advisory Speed (Oct. 2013)	40 mph			
CARS Recommended Advisory	NB=	50 mph	SB=	45 mph
ODOT Spreadsheet Recommended Advisory	NB=	45 mph	SB=	40 mph

Vicinity Map

Curve Summary	
Curve No.	295
Highway	Cascade Highway No. 160 (OR213)
MP at Mid-Curve (Trans GIS)	22.63
CARS Data Collection Date	
ODOT Spreadsheet Date	April 7, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2013)	35 mph			
CARS Recommended Advisory	NB=	55 mph	SB=	55 mph
ODOT Spreadsheet Recommended Advisory	NB=	45 mph	SB=	45 mph

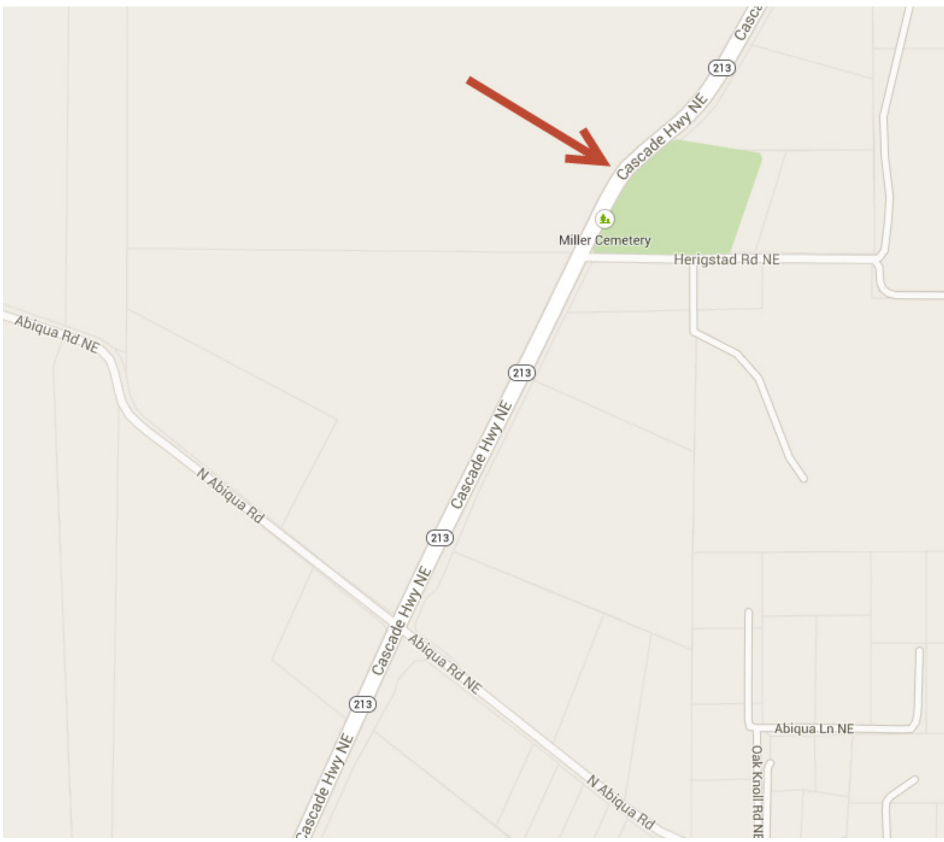
Vicinity Map



Curve Summary	
Curve No.	296
Highway	Cascade Highway No. 160 (OR213)
MP at Mid-Curve (Trans GIS)	26.03
CARS Data Collection Date	
ODOT Spreadsheet Date	April 7, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2013)	30 mph			
CARS Recommended Advisory	NB=	45 mph	SB=	45 mph
ODOT Spreadsheet Recommended Advisory	NB=	40 mph	SB=	40 mph

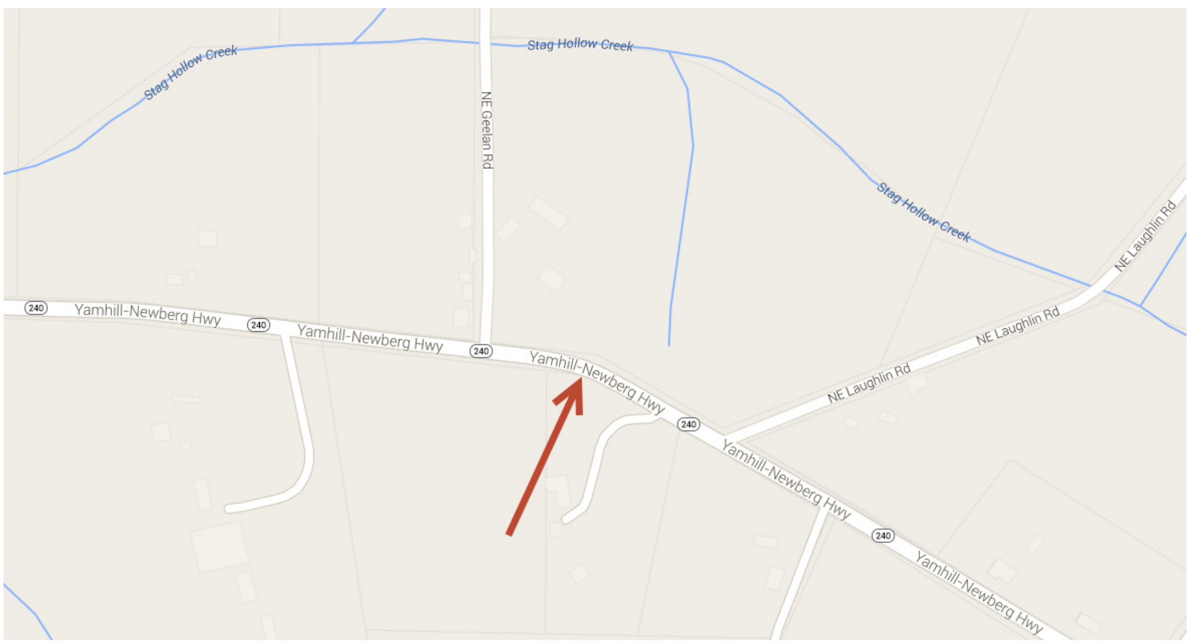
Vicinity Map



Curve Summary	
Curve No.	267
Highway	Yamhill-Newberg No. 151 (OR240)
MP at Mid-Curve (Trans GIS)	1.67
CARS Data Collection Date	
ODOT Spreadsheet Date	April 8-9, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2012)	40 mph			
CARS Recommended Advisory	EB=	55 mph	WB=	50 mph
ODOT Spreadsheet Recommended Advisory	EB=	45 mph	WB=	40 mph

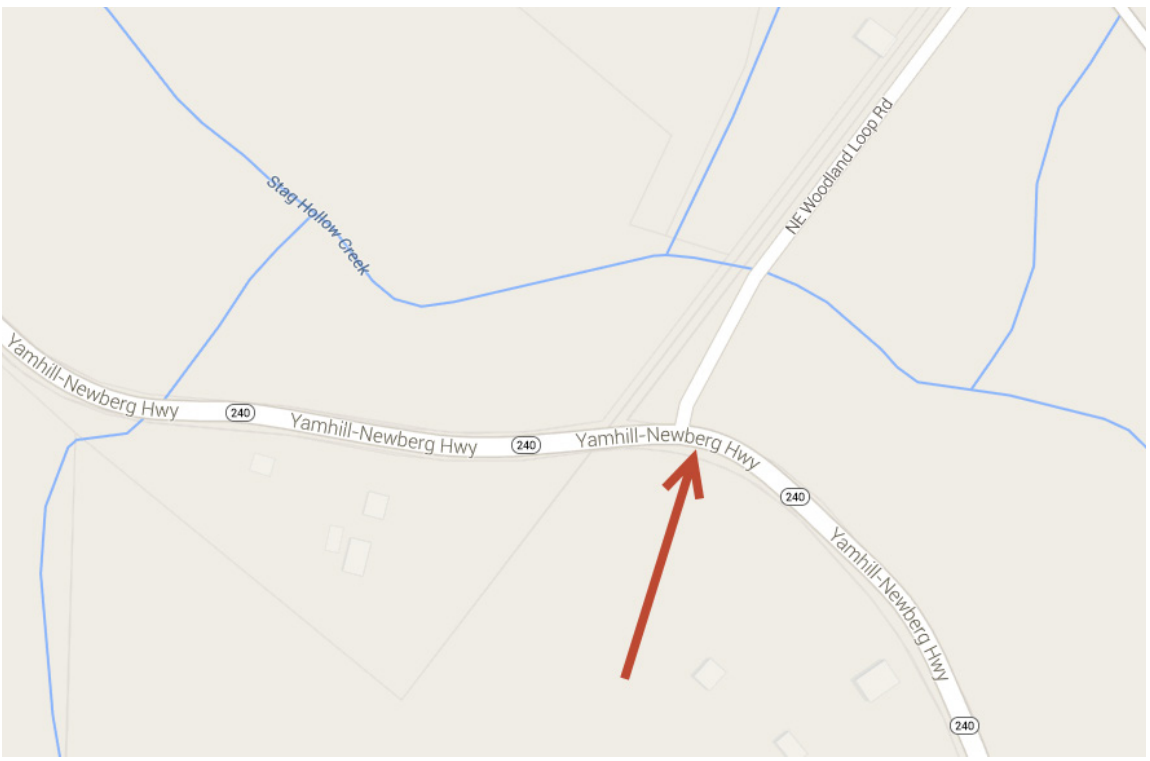
Vicinity Map



Curve Summary	
Curve No.	272
Highway	Yamhill-Newberg No. 151 (OR240)
MP at Mid-Curve (Trans GIS)	2.39
CARS Data Collection Date	
ODOT Spreadsheet Date	April 8-9, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2012)	35 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	35 mph	WB=	30 mph

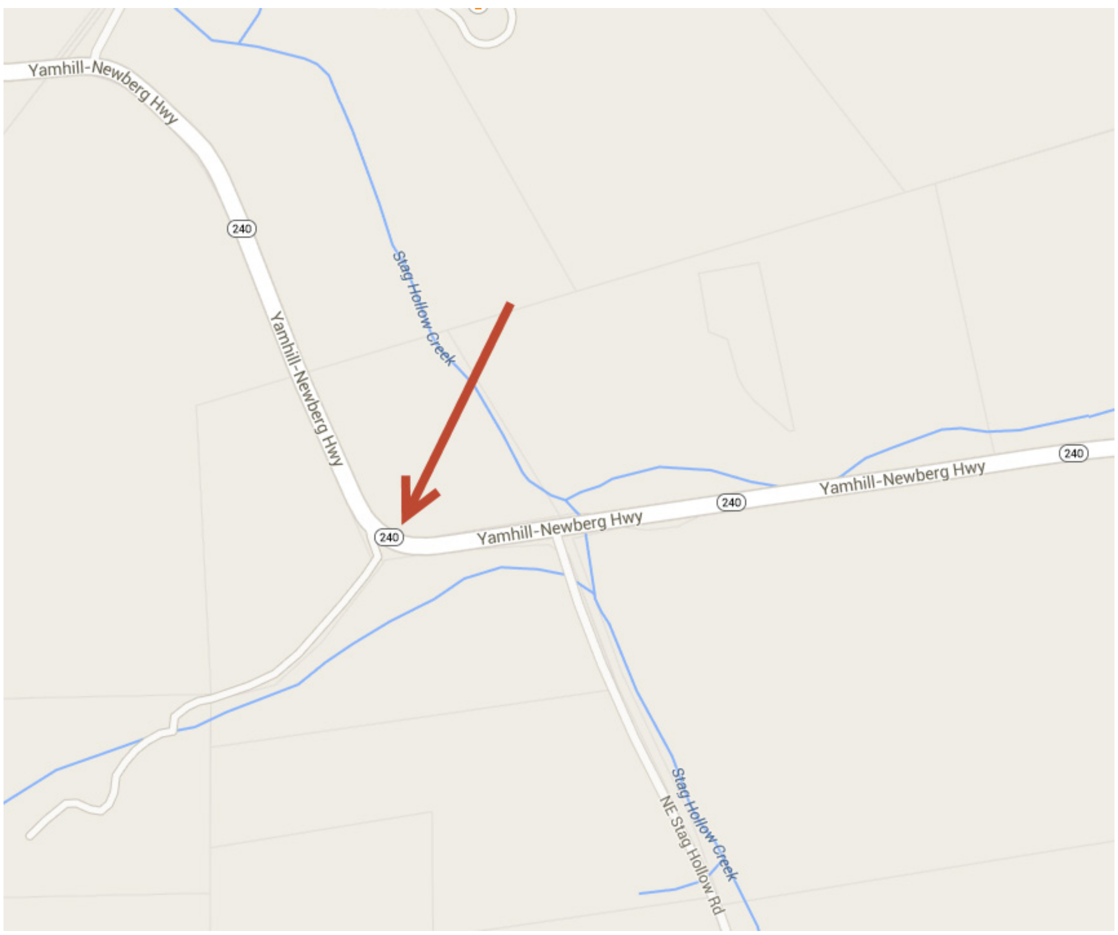
Vicinity Map



Curve Summary	
Curve No.	274
Highway	Yamhill-Newberg No. 151 (OR240)
MP at Mid-Curve (Trans GIS)	2.86
CARS Data Collection Date	
ODOT Spreadsheet Date	April 8-9, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2012)	30 mph			
CARS Recommended Advisory	EB=	30 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	30 mph	WB=	35 mph

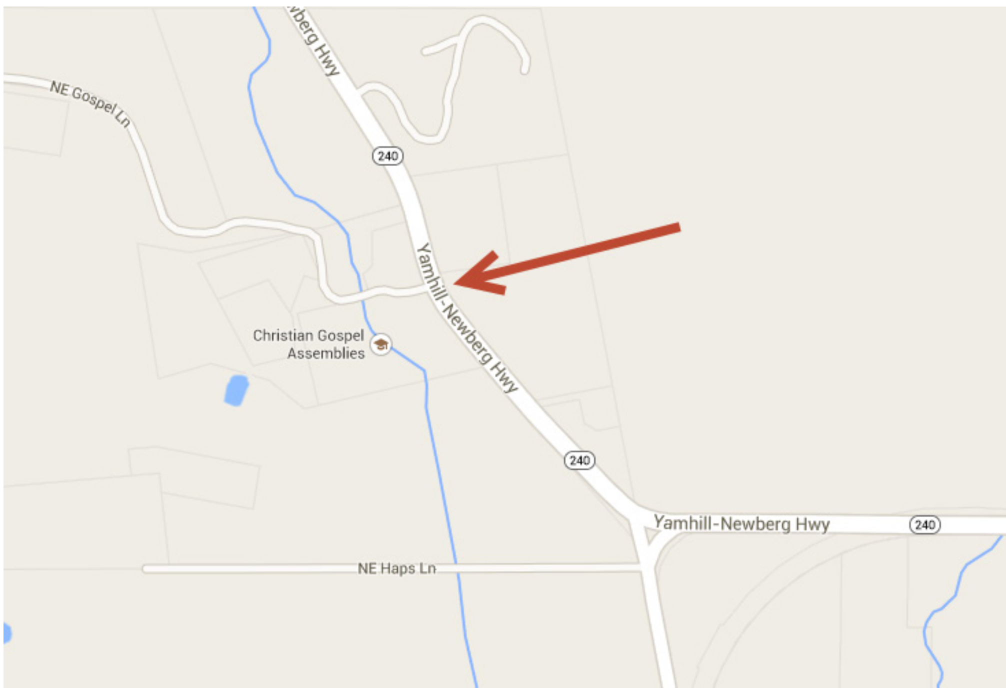
Vicinity Map



Curve Summary	
Curve No.	284
Highway	Yamhill-Newberg No. 151 (OR240)
MP at Mid-Curve (Trans GIS)	5.20
CARS Data Collection Date	
ODOT Spreadsheet Date	April 8-9, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2012)	35/40 mph			
CARS Recommended Advisory	EB=	45 mph	WB=	50 mph
ODOT Spreadsheet Recommended Advisory	EB=	45 mph	WB=	45 mph

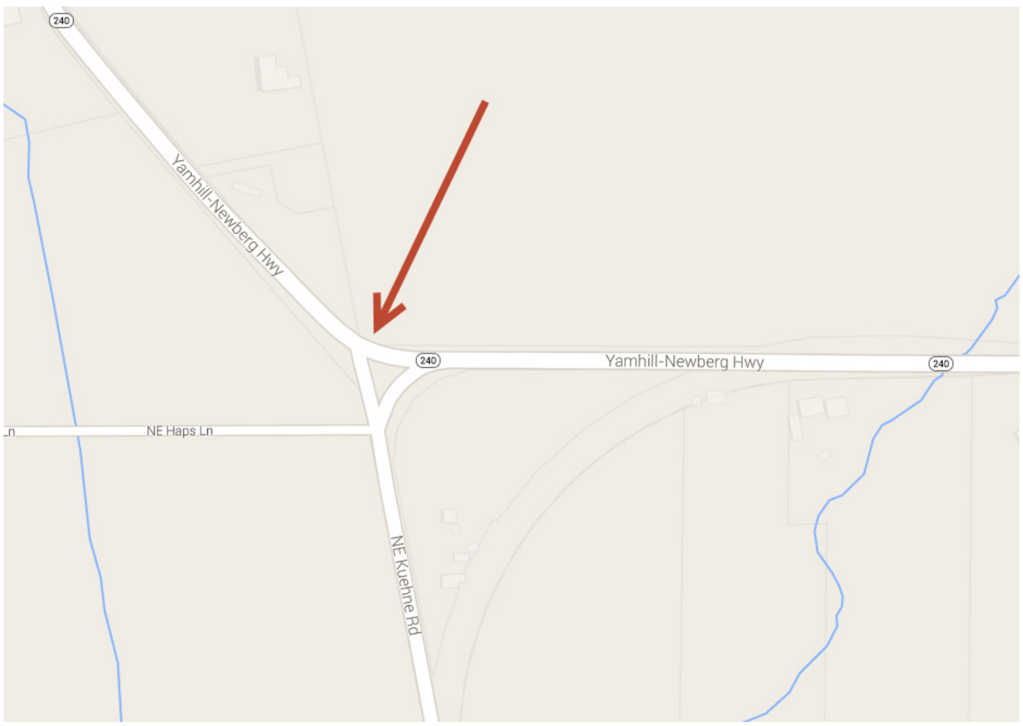
Vicinity Map



Curve Summary	
Curve No.	285
Highway	Yamhill-Newberg No. 151 (OR240)
MP at Mid-Curve (Trans GIS)	5.45
CARS Data Collection Date	
ODOT Spreadsheet Date	April 8-9, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2012)	35 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	35 mph
ODOT Spreadsheet Recommended Advisory	EB=	35 mph	WB=	35 mph

Vicinity Map



Curve Summary	
Curve No.	286-287
Highway	Yamhill-Newberg No. 151 (OR240)
MP at Mid-Curve (Trans GIS)	6.05
CARS Data Collection Date	
ODOT Spreadsheet Date	April 8-9, 2014

Advisory Speed Summary				
Existing Advisory Speed (Aug. 2012)	30 mph			
CARS Recommended Advisory	EB=	35 mph	WB=	40 mph
ODOT Spreadsheet Recommended Advisory	EB=	35 mph	WB=	40 mph

Vicinity Map

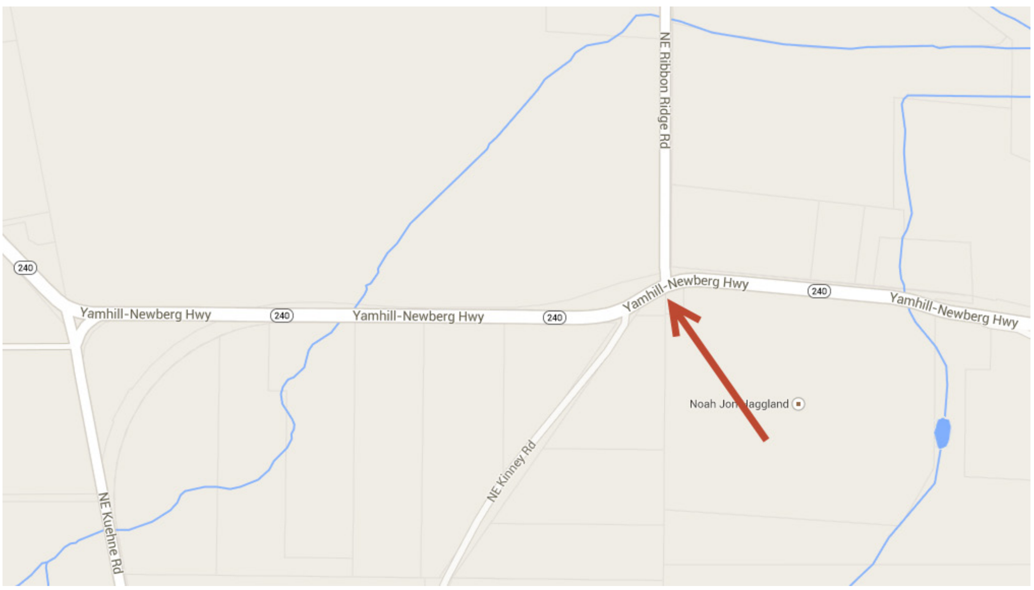


Table 7 | Additional Curves used for CARS Sensitivity Testing

Curve No.	Hwy	BMP	EMP	Date Collected
38	110	0.17	0.27	06/10/2014
39	110	0.33	0.45	06/10/2014
40	110	0.75	0.82	06/10/2014
41	110	0.82	0.89	06/10/2014
42	110	0.89	0.95	06/10/2014
43	110	0.95	1.05	06/10/2014
44	110	1.21	1.24	06/10/2014
45	110	1.45	1.51	06/10/2014
46	110	1.56	1.65	06/10/2014
47	110	2.09	2.15	06/10/2014
48	110	2.25	2.35	06/10/2014
49	110	2.53	2.67	06/10/2014
50	110	2.69	2.78	06/10/2014
51	110	3.09	3.14	06/10/2014
52	110	3.14	3.19	06/10/2014
53	110	3.28	3.35	06/10/2014
54	110	3.34	4.50	06/10/2014
55	110	4.50	4.70	06/10/2014
56	110	4.70	4.86	06/10/2014
57	110	4.87	4.97	06/10/2014
58	110	4.97	5.05	06/10/2014
59	110	5.06	5.20	06/10/2014
60	110	5.20	5.28	06/10/2014
61	110	5.33	5.44	06/10/2014
62	110	5.44	5.51	06/10/2014
63	110	5.62	5.69	06/10/2014
64	110	5.69	5.75	06/10/2014
65	110	5.75	5.82	06/10/2014
66	110	5.82	5.92	06/10/2014
67	110	5.96	6.03	06/10/2014
68	110	6.03	6.07	06/10/2014
69	110	6.07	6.13	06/10/2014
70	110	6.13	6.17	06/10/2014
71	110	6.17	6.23	06/10/2014
72	110	6.23	6.27	06/10/2014
73	110	6.27	6.32	06/10/2014
74	110	6.32	6.35	06/10/2014
75	110	6.35	6.41	06/10/2014
76	110	6.41	6.48	06/10/2014
77	110	6.48	6.54	06/10/2014
78	110	6.54	6.59	06/10/2014
79	110	6.69	6.74	06/10/2014
80	110	6.81	6.91	06/10/2014
81	110	7.08	7.19	06/10/2014
82	110	7.27	7.33	06/10/2014
83	110	7.33	7.38	06/10/2014
84	110	7.38	7.43	06/10/2014
85	110	7.48	7.54	06/10/2014
86	110	7.54	7.58	06/10/2014
87	110	7.58	7.64	06/10/2014
88	110	7.64	7.68	06/10/2014
89	110	7.76	7.85	06/10/2014
90	110	7.85	7.91	06/10/2014
91	110	7.95	8.02	06/10/2014
92	110	8.02	8.07	06/10/2014
93	110	8.13	8.20	06/10/2014
94	110	8.46	8.53	06/10/2014
95	110	8.53	8.61	06/10/2014
96	110	8.63	8.69	06/10/2014
97	110	8.69	8.77	06/10/2014
98	110	8.91	8.96	06/10/2014
99	110	8.96	9.02	06/10/2014
100	110	9.04	9.10	06/10/2014
101	110	9.10	9.14	06/10/2014
102	110	9.14	9.18	06/10/2014
103	110	9.18	9.22	06/10/2014
104	110	9.25	9.31	06/10/2014
105	110	9.33	9.38	06/10/2014
106	110	9.40	9.45	06/10/2014
107	110	9.47	9.51	06/10/2014
108	110	9.51	9.57	06/10/2014
109	110	9.63	9.68	06/10/2014
110	110	9.68	9.72	06/10/2014
111	110	9.75	9.79	06/10/2014
112	110	9.80	9.84	06/10/2014
113	110	9.84	9.87	06/10/2014

Curve No.	Hwy	BMP	EMP	Date Collected
114	110	9.91	9.98	06/10/2014
115	110	10.06	10.10	06/10/2014
116	110	10.23	10.29	06/10/2014
117	110	10.29	10.35	06/10/2014
118	110	10.37	10.43	06/10/2014
119	110	10.43	10.48	06/10/2014
120	110	10.48	10.53	06/10/2014
121	110	10.70	10.75	06/10/2014
122	110	10.76	10.86	06/10/2014
123	110	10.86	10.94	06/10/2014
124	110	11.02	11.08	06/10/2014
125	110	11.52	11.61	06/10/2014
126	181	0.01	0.08	07/01/2014
127	181	0.04	0.01	07/01/2014
128	181	0.17	0.1	07/01/2014
129	181	0.2	0.26	07/01/2014
130	181	0.99	1.06	07/01/2014
131	181	1.09	1.16	07/01/2014
132	181	1.09	1.16	07/01/2014
133	181	1.34	1.43	07/01/2014
134	181	1.43	1.54	07/01/2014
135	181	1.56	1.62	07/01/2014
136	181	1.63	1.72	07/01/2014
137	181	1.76	1.82	07/01/2014
138	181	1.87	1.92	07/01/2014
139	181	1.96	2.04	07/01/2014
140	181	2.10	2.30	07/01/2014
141	181	2.30	2.50	07/01/2014
142	181	2.73	2.90	07/01/2014
143	181	3.00	3.10	07/01/2014
144	181	3.20	3.44	07/01/2014
145	181	3.44	3.55	07/01/2014
146	181	3.55	3.65	07/01/2014
147	181	3.65	3.78	07/01/2014
148	181	3.79	3.92	07/01/2014
149	181	3.98	4.10	07/01/2014
150	181	4.15	4.30	07/01/2014
151	181	4.15	4.30	07/01/2014
152	181	4.81	4.90	07/01/2014
153	181	4.95	5.01	07/01/2014
154	181	5.04	5.10	07/01/2014
155	181	5.12	5.23	07/01/2014
156	181	5.33	5.4	07/01/2014
157	181	5.48	5.55	07/01/2014
158	181	5.65	5.69	07/01/2014
159	181	5.69	5.74	07/01/2014
160	181	5.75	6.10	07/01/2014
161	181	6.40	6.60	07/01/2014
162	181	6.60	6.90	07/01/2014
163	181	7.20	7.40	07/01/2014
164	181	7.40	7.56	07/01/2014
165	181	7.56	7.65	07/01/2014
166	181	7.75	7.95	07/01/2014
167	181	8.03	8.55	07/01/2014
168	181	8.70	8.80	07/01/2014
169	181	8.80	8.90	07/01/2014
170	181	8.91	9.04	07/01/2014
171	181	9.07	9.13	07/01/2014
172	181	9.16	9.20	07/01/2014
173	181	9.20	9.24	07/01/2014
174	181	9.24	9.28	07/01/2014
175	181	9.48	9.55	07/01/2014
176	181	9.56	9.63	07/01/2014
177	181	9.73	9.86	07/01/2014
178	181	10.06	10.1	07/01/2014
179	181	10.11	10.15	07/01/2014
180	181	10.15	10.21	07/01/2014
181	181	10.46	10.5	07/01/2014
182	181	10.50	10.56	07/01/2014
183	181	10.56	10.64	07/01/2014
184	181	10.71	10.8	07/01/2014
185	181	10.85	10.9	07/01/2014
186	181	10.93	10.98	07/01/2014
187	181	11.32	11.39	07/01/2014
188	181	11.55	11.60	07/01/2014
189	181	11.61	11.81	07/01/2014
190	181	11.83	11.89	07/01/2014
191	181	11.92	11.95	07/01/2014

Curve No.	Hwy	BMP	EMP	Date Collected
192	181	12.15	12.22	07/01/2014
193	181	12.24	12.31	07/01/2014
194	181	12.54	12.59	07/01/2014
195	181	12.59	12.63	07/01/2014
196	181	12.65	12.71	07/01/2014
197	181	12.71	12.77	07/01/2014
198	181	12.82	12.92	07/01/2014
199	181	12.97	13.02	07/01/2014
200	181	13.02	13.06	07/01/2014
201	181	13.06	13.11	07/01/2014
202	181	13.11	13.16	07/01/2014
203	181	13.49	13.53	07/01/2014
204	181	13.58	13.62	07/01/2014
205	181	13.75	13.79	07/01/2014
206	181	13.80	13.87	07/01/2014
207	181	13.92	13.97	07/01/2014
208	181	14.05	14.08	07/01/2014
209	181	18.08	14.14	07/01/2014
210	181	14.15	14.21	07/01/2014
211	181	14.23	14.29	07/01/2014
212	181	14.32	14.39	07/01/2014
213	181	14.41	14.50	07/01/2014
214	181	14.76	14.81	07/01/2014
215	181	14.91	14.97	07/01/2014
216	181	14.96	15.02	07/01/2014
217	181	15.20	15.27	07/01/2014
218	181	16.10	16.50	07/01/2014
219	181	16.50	16.70	07/01/2014
220	181	17.40	17.50	07/01/2014
221	181	17.55	17.65	07/01/2014
222	181	17.65	17.80	07/01/2014
223	181	17.90	18.10	07/01/2014
224	181	18.18	18.22	07/01/2014
225	181	18.22	18.27	07/01/2014
226	181	18.50	18.60	07/01/2014
227	181	18.60	18.70	07/01/2014
228	181	18.70	18.80	07/01/2014
229	181	18.88	18.94	07/01/2014
230	181	18.94	18.98	07/01/2014

Curve No.	Hwy	BMP	EMP	Date Collected
231	181	19.02	19.09	07/01/2014
232	181	19.16	19.21	07/01/2014
233	181	19.3	19.5	07/01/2014
234	181	19.94	19.99	07/01/2014
235	181	20.00	20.05	07/01/2014
236	181	20.07	20.13	07/01/2014
237	181	20.17	20.23	07/01/2014
238	181	20.25	20.32	07/01/2014
239	181	20.35	20.39	07/01/2014
240	181	20.51	20.56	07/01/2014
241	181	20.56	20.61	07/01/2014
242	181	20.91	20.97	07/01/2014
243	181	21.00	21.06	07/01/2014
244	181	21.15	21.2	07/01/2014
245	181	21.26	21.36	07/01/2014
246	181	21.39	21.47	07/01/2014
247	181	21.49	21.56	07/01/2014
248	181	21.60	21.68	07/01/2014
249	181	21.82	21.92	07/01/2014
250	181	22.21	22.29	07/01/2014
251	181	22.56	22.64	07/01/2014
252	181	22.75	22.95	07/01/2014
253	181	24.20	24.40	07/01/2014
254	181	24.40	24.60	07/01/2014
255	181	24.65	24.85	07/01/2014
256	181	25.85	26.00	07/01/2014
257	181	26.10	26.35	07/01/2014
258	181	26.50	26.7	07/01/2014
259	181	27.65	27.95	07/01/2014
260	181	28.20	28.40	07/01/2014
261	181	28.50	28.80	07/01/2014
262	181	28.95	29.25	07/01/2014
263	181	29.30	29.55	07/01/2014
264	181	29.60	29.80	07/01/2014
265	181	30.25	30.50	07/01/2014
266	181	30.75	31.05	07/01/2014
267	151	1.60	1.75	07/28/2014
268	151	2.00	2.09	07/28/2014
269	151	2.06	2.18	07/28/2014

Curve No.	Hwy	BMP	EMP	Date Collected
270	151	2.18	2.23	07/28/2014
271	151	2.23	2.34	07/28/2014
272	151	2.35	2.44	07/28/2014
273	151	2.48	2.53	07/28/2014
274	151	2.80	2.90	07/28/2014
275	151	3.40	3.60	07/28/2014
276	151	3.66	3.77	07/28/2014
277	151	4.05	4.11	07/28/2014
278	151	4.13	4.22	07/28/2014
279	151	4.55	4.63	07/28/2014
280	151	4.70	4.76	07/28/2014
281	151	4.77	4.85	07/28/2014
282	151	4.90	4.97	07/28/2014
283	151	5.09	5.14	07/28/2014
284	151	5.17	5.24	07/28/2014
285	151	5.40	5.48	07/28/2014
286	151	5.96	6.06	07/28/2014
287	151	6.06	6.12	07/28/2014
288	151	6.27	6.34	07/28/2014
289	151	6.93	6.99	07/28/2014
290	151	7.87	7.98	07/28/2014
291	151	8.98	9.08	07/28/2014
292	151	9.79	9.87	07/28/2014
293	151	10.45	10.65	07/28/2014
294	151	10.85	11.05	07/28/2014
295	160	22.55	22.70	07/17/2014
296	160	25.98	26.06	07/17/2014

Example Calculation Walk-Through

<u>Given</u>

The following latitude/longitude, speed, and inclination data from one pass of a CARS investigation at the subject curve. Calculated advisory speed report data is included for comparison.

Curve Summary

Highway	Mist-Clatskanie Highway No. 110 (OR47)
MP at PC-PT	7.58-7.64
CARS Data Collection Date	June 10, 2014

Vicinity Map

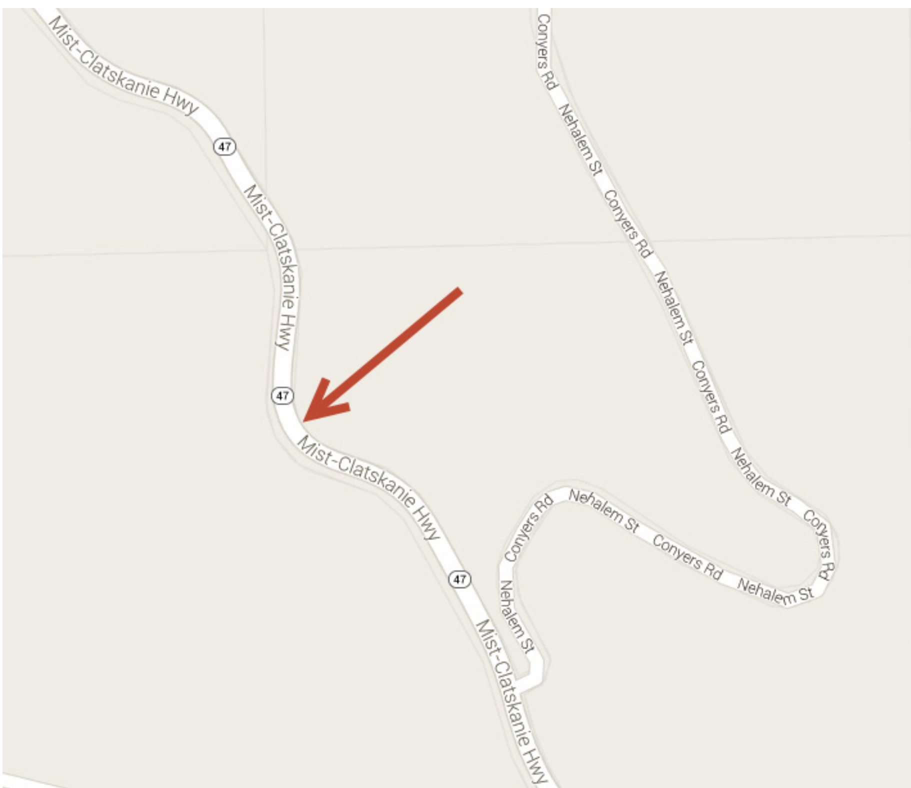


Table 8 | Raw Data – Pass 1

Number	Date Time	Latitude	Longitude	Speed
Number	Date Time	Inclination		
9777	41:30.2	46.04548	-123.252	27.4
9778	41:30.3	2.21		
9779	41:30.3	3.02		
9780	41:30.4	46.04549	-123.252	27.3
9781	41:30.4	3.14		
9782	41:30.5	4.25		
9783	41:30.6	5.14		
9784	41:30.6	46.0455	-123.252	27.3
9785	41:30.6	6.46		
9786	41:30.7	6.74		
9787	41:30.8	7.57		
9788	41:30.8	46.04551	-123.252	26.8
9789	41:30.8	7.45		
9790	41:30.9	7.93		
9791	41:31.0	8.06		
9792	41:31.0	46.04551	-123.252	26.5
9793	41:31.1	8.44		
9794	41:31.2	9.32		
9795	41:31.2	46.04552	-123.252	26.4
9796	41:31.2	10.57		
9797	41:31.3	7.76		
9798	41:31.4	6.52		
9799	41:31.4	46.04553	-123.252	25.9
9800	41:31.5	8.43		
9801	41:31.5	11.46		
9802	41:31.6	10.64		
9803	41:31.6	46.04554	-123.252	25.6
9804	41:31.7	9.41		
9805	41:31.8	9		
9806	41:31.8	46.04556	-123.252	25.4
9807	41:31.8	11.3		
9808	41:31.9	11.27		
9809	41:32.0	10.97		
9810	41:32.0	46.04557	-123.252	25.1
9811	41:32.1	9.98		
9812	41:32.1	8.66		
9813	41:32.2	11.15		
9814	41:32.2	46.04558	-123.252	25.1
9815	41:32.3	11.19		
9816	41:32.3	12.98		
9817	41:32.4	46.04559	-123.252	25.1
9818	41:32.4	6.02		
9819	41:32.5	7.18		
9820	41:32.6	14.1		
9821	41:32.6	46.0456	-123.252	25.3
9822	41:32.6	4.04		
9823	41:32.7	6.73		
9824	41:32.8	8.83		
9825	41:32.8	46.04562	-123.253	25.4
9826	41:32.9	10.82		
9827	41:32.9	10.45		
9828	41:33.0	46.04563	-123.253	25.2
9829	41:33.0	9.28		
9830	41:33.1	3.93		
9831	41:33.2	7.23		
9832	41:33.2	46.04565	-123.253	25.6
9833	41:33.2	7.08		
9834	41:33.3	12.17		
9835	41:33.4	10.19		
9836	41:33.4	46.04566	-123.253	25.6
9837	41:33.5	6.18		
9838	41:33.5	8.37		
9839	41:33.6	46.04568	-123.253	25.7
9840	41:33.6	7.66		
9841	41:33.7	10.02		
9842	41:33.7	9.89		
9843	41:33.8	46.0457	-123.253	26
9844	41:33.8	9.03		
9845	41:33.9	7.54		
9846	41:34.0	8.98		

Number	Date Time	Latitude	Longitude	Speed
Number	Date Time	Inclination		
9847	41:34.0	46.04572	-123.253	26.6
9848	41:34.1	9.08		
9849	41:34.1	11.59		
9850	41:34.2	10.64		
9851	41:34.2	46.04573	-123.253	26.7
9852	41:34.3	6.05		
9853	41:34.3	7.34		
9854	41:34.4	46.04575	-123.253	27
9855	41:34.4	14.97		
9856	41:34.5	4.6		
9857	41:34.6	5.44		
9858	41:34.6	46.04577	-123.253	27.1
9859	41:34.6	6.36		
9860	41:34.7	9.06		
9861	41:34.8	0.65		
9862	41:34.8	46.0458	-123.253	27.6
9863	41:34.9	11.69		
9864	41:34.9	8.65		
9865	41:35.0	4.88		
9866	41:35.0	46.04582	-123.253	27.9
9867	41:35.1	-0.67		
9868	41:35.2	12.33		
9869	41:35.2	46.04584	-123.253	27.7
9870	41:35.2	18.96		
9871	41:35.3	3.41		
9872	41:35.4	-5.01		
9873	41:35.4	46.04586	-123.253	28
9874	41:35.5	5.97		
9875	41:35.5	17.16		
9876	41:35.6	17.4		
9877	41:35.6	46.04588	-123.253	28.6
9878	41:35.7	5.49		
9879	41:35.8	2.86		
9880	41:35.8	46.04591	-123.253	28.6
9881	41:35.8	8.41		
9882	41:35.9	9.92		
9883	41:36.0	7.33		
9884	41:36.0	46.04593	-123.253	28.6
9885	41:36.1	6.27		
9886	41:36.1	6.3		
9887	41:36.2	46.04595	-123.253	28.7
9888	41:36.2	5.02		
9889	41:36.3	3.01		
9890	41:36.4	4		
9891	41:36.4	46.04598	-123.253	29.1
9892	41:36.4	6.91		
9893	41:36.5	3.89		
9894	41:36.6	-4.28		
9895	41:36.6	46.046	-123.253	29.1
9896	41:36.7	-0.76		
9897	41:36.7	4.86		
9898	41:36.8	1.61		
9899	41:36.8	46.04602	-123.253	29.3
9900	41:36.9	-4.04		
9901	41:36.9	-2.02		
9902	41:37.0	46.04605	-123.253	29.3
9903	41:37.0	0.44		
9904	41:37.1	-0.29		
9905	41:37.2	-0.36		
9906	41:37.2	46.04607	-123.253	29.6
9907	41:37.3	4.61		
9908	41:37.3	-0.59		
9909	41:37.4	-3.07		
9910	41:37.4	46.0461	-123.253	29.5
9911	41:37.5	-2.66		
9912	41:37.5	-0.18		
9913	41:37.6	46.04612	-123.253	29.6
9914	41:37.6	-0.42		
9915	41:37.7	-1.83		
9916	41:37.8	-0.52		

Table 9 | Reported (Processed) Data - Pass 1

Model X (feet)	Model Y (feet)	Radius (feet)	Measured Side Friction (degrees)	Test Speed (MPH)	Calc. Advisory Speed (MPH)
0.2	-0.2	282	5.04	26.8	37.1
-3.1	0.9	275	5.29	26.7	36.6
-7	2.2	266	5.59	26.6	36
-9.6	3.1	260	5.78	26.6	35.6
-12.8	4.3	253	6.02	26.5	35.2
-15.3	5.2	248	6.2	26.5	34.8
-18.4	6.4	242	6.42	26.4	34.4
-21.4	7.7	236	6.63	26.4	34
-23.8	8.7	231	6.8	26.4	33.7
-26.8	10	225	7	26.3	33.3
-29.2	11	221	7.16	26.3	33
-32.6	12.7	215	7.38	26.2	32.6
-35.5	14.1	210	7.56	26.2	32.3
-38.3	15.5	205	7.73	26.2	32
-40.5	16.6	201	7.87	26.1	31.8
-43.2	18.1	197	8.02	26.1	31.5
-45.9	19.6	193	8.18	26.1	31.3
-48	20.9	190	8.29	26	31.1
-50.6	22.4	186	8.43	26	30.9
-52.6	23.7	183	8.54	26	30.7
-55.7	25.7	179	8.69	26	30.5
-58.1	27.3	176	8.81	26	30.3
-60.1	28.7	173	8.9	25.9	30.2
-62.5	30.4	170	9.01	25.9	30
-64.8	32.1	167	9.11	25.9	29.9
-66.7	33.6	165	9.18	25.9	29.8
-69	35.4	163	9.27	25.9	29.7
-71.2	37.2	161	9.35	25.9	29.6
-73	38.7	159	9.4	25.9	29.5
-75.5	41	157	9.48	25.9	29.4
-77.2	42.5	156	9.53	25.9	29.3
-79.3	44.5	154	9.58	25.9	29.3
-81.3	46.5	153	9.63	25.9	29.2
-82.9	48.1	152	9.66	25.9	29.2
-84.9	50.1	151	9.69	25.9	29.2
-86.8	52.2	150	9.72	25.9	29.1
-88.3	53.9	149	9.73	25.9	29.1
-90.1	56	148	9.74	25.9	29.1
-91.9	58.2	148	9.75	26	29.1
-93.6	60.4	148	9.75	26	29.1
-95.3	62.6	147	9.74	26	29.2
-97	64.9	147	9.72	26	29.2
-98.3	66.7	147	9.7	26	29.2
-99.8	69.1	148	9.68	26.1	29.3
-101.1	70.9	148	9.65	26.1	29.3
-102.6	73.3	149	9.61	26.1	29.4
-104	75.7	149	9.56	26.2	29.5
-105.2	77.7	150	9.51	26.2	29.5
-106.8	80.6	151	9.44	26.2	29.6
-108.1	83.1	153	9.37	26.3	29.8
-109.2	85.1	154	9.31	26.3	29.8
-110.4	87.7	155	9.23	26.3	30
-111.6	90.3	157	9.14	26.4	30.1
-112.6	92.4	158	9.06	26.4	30.2
-113.7	95	160	8.96	26.5	30.4
-114.6	97.2	162	8.87	26.5	30.5
-115.6	99.9	164	8.76	26.6	30.7
-116.8	103.1	167	8.61	26.6	30.9
-117.6	105.4	170	8.5	26.7	31.1
-118.5	108.2	172	8.37	26.7	31.3
-119.4	111	176	8.23	26.8	31.5
-120.1	113.3	178	8.11	26.9	31.7
-120.9	116.2	181	7.95	26.9	31.9
-121.6	119.1	185	7.79	27	32.2
-122.2	121.4	188	7.65	27.1	32.4
-122.9	124.4	192	7.47	27.1	32.7
-123.7	128	197	7.25	27.2	33.1
-124.1	130.4	200	7.1	27.3	33.4
-124.7	133.5	205	6.9	27.4	33.7
-125.1	136	209	6.74	27.4	34
-125.6	139.1	214	6.53	27.5	34.4
-126	142.3	219	6.31	27.6	34.7
-126.3	144.8	223	6.14	27.7	35.1
-126.7	148	229	5.91	27.8	35.5
-127	151.3	235	5.67	27.8	35.9
-127.3	154.5	241	5.43	27.9	36.4
-127.5	157.8	247	5.17	28	36.9
-127.7	161.2	253	4.92	28.1	37.4
-127.8	163.9	259	4.7	28.2	37.8
-127.9	167.3	266	4.43	28.3	38.4
-128	170	272	4.21	28.4	38.8
-128	173.5	279	3.93	28.5	39.4
-128	176.9	287	3.64	28.6	40
-128	179.8	293	3.4	28.7	40.5
-127.9	183.3	301	3.1	28.8	41.1
-127.7	187.6	312	2.72	29	41.9
-127.5	191.2	320	2.4	29.1	42.6
-127.3	194.1	328	2.14	29.2	43.2
-127.1	197.8	337	1.81	29.3	44
-126.8	200.7	345	1.54	29.4	44.6
-126.5	204.4	355	1.2	29.5	45.4
-126.1	208.2	365	0.84	29.6	46.2
-125.8	211.2	373	0.56	29.7	46.9
-125.2	215.8	386	0.12	29.9	47.9
-124.7	219.7	397	-0.25	30	48.8
-124.3	222.8	406	-0.56	30.2	49.6
-123.7	226.7	418	-0.94	30.3	50.5
-123	230.6	430	-1.33	30.4	51.5
-122.5	233.8	440	-1.65	30.5	52.3

Required

Determine the calculated advisory speed at a ball-bank limit of 14 degrees for the northbound direction.

Solution

Step 1 – Convert Lat/Long to Northing/Easting relative to the PC

Latitude and longitude coordinates converted to northing and easting using this website: http://www.latlong.net/lat-long-utm.html. Reading number 9777 is the PC and is set to coordinates 0, 0. Northings and Eastings are given from the website in meters. Excel was used to convert to feet.

Table 10 | Lat/Long Conversion to X and Y

Number	Time	Latitude	Longitude	Easting	Northing	Coordinate Relative to PC			
						Meters		Feet	
						x	y	x	y
9777	41:30.19	46.04548	-123.25218	480489.13	5099131.56	0.0	0.0	0.0	0.0
9780	41:30.40	46.04549	-123.25221	480486.81	5099132.68	-2.3	1.1	-7.6	3.7
9784	41:30.60	46.04550	-123.25224	480484.49	5099133.80	-4.6	2.2	-15.2	7.3
9788	41:30.80	46.04551	-123.25227	480482.17	5099134.92	-7.0	3.4	-22.8	11.0
9792	41:31.01	46.04551	-123.25230	480479.85	5099134.93	-9.3	3.4	-30.4	11.1
9795	41:31.19	46.04552	-123.25233	480477.53	5099136.04	-11.6	4.5	-38.1	14.7
9799	41:31.41	46.04553	-123.25235	480475.99	5099137.16	-13.1	5.6	-43.1	18.4
9803	41:31.60	46.04554	-123.25238	480473.67	5099138.28	-15.5	6.7	-50.7	22.0
9806	41:31.80	46.04556	-123.25240	480472.13	5099140.51	-17.0	9.0	-55.8	29.4
9810	41:31.99	46.04557	-123.25243	480469.82	5099141.62	-19.3	10.1	-63.4	33.0
9814	41:32.19	46.04558	-123.25245	480468.27	5099142.74	-20.9	11.2	-68.4	36.7
9817	41:32.40	46.04559	-123.25247	480466.73	5099143.86	-22.4	12.3	-73.5	40.4
9821	41:32.60	46.04560	-123.25249	480465.18	5099144.97	-24.0	13.4	-78.6	44.0
9825	41:32.80	46.04562	-123.25252	480462.87	5099147.20	-26.3	15.6	-86.2	51.3
9828	41:32.99	46.04563	-123.25253	480462.10	5099148.31	-27.0	16.8	-88.7	55.0
9832	41:33.19	46.04565	-123.25256	480459.79	5099150.54	-29.3	19.0	-96.3	62.3
9836	41:33.40	46.04566	-123.25257	480459.02	5099151.66	-30.1	20.1	-98.8	65.9
9839	41:33.60	46.04568	-123.25259	480457.48	5099153.88	-31.7	22.3	-103.8	73.2
9843	41:33.79	46.04570	-123.25260	480456.71	5099156.11	-32.4	24.6	-106.4	80.5
9847	41:33.99	46.04572	-123.25262	480455.17	5099158.34	-34.0	26.8	-111.4	87.9
9851	41:34.19	46.04573	-123.25263	480454.40	5099159.45	-34.7	27.9	-113.9	91.5
9854	41:34.40	46.04575	-123.25264	480453.63	5099161.67	-35.5	30.1	-116.5	98.8
9858	41:34.60	46.04577	-123.25266	480452.09	5099163.90	-37.0	32.3	-121.5	106.1
9862	41:34.80	46.04580	-123.25266	480452.10	5099167.23	-37.0	35.7	-121.5	117.0
9866	41:35.01	46.04582	-123.25267	480451.34	5099169.46	-37.8	37.9	-124.0	124.3
9869	41:35.19	46.04584	-123.25268	480450.57	5099171.68	-38.6	40.1	-126.5	131.6
9873	41:35.40	46.04586	-123.25268	480450.58	5099173.91	-38.5	42.4	-126.5	138.9
9877	41:35.60	46.04588	-123.25268	480450.58	5099176.13	-38.5	44.6	-126.5	146.2
9880	41:35.80	46.04591	-123.25269	480449.82	5099179.46	-39.3	47.9	-129.0	157.2
9884	41:36.01	46.04593	-123.25269	480449.83	5099181.69	-39.3	50.1	-128.9	164.5
9887	41:36.19	46.04595	-123.25269	480449.83	5099183.91	-39.3	52.4	-128.9	171.8
9891	41:36.40	46.04598	-123.25269	480449.84	5099187.24	-39.3	55.7	-128.9	182.7
9895	41:36.60	46.04600	-123.25269	480449.85	5099189.46	-39.3	57.9	-128.9	190.0
9899	41:36.80	46.04602	-123.25268	480450.63	5099191.68	-38.5	60.1	-126.3	197.2
9902	41:37.01	46.04605	-123.25268	480450.64	5099195.02	-38.5	63.5	-126.3	208.2
9906	41:37.19	46.04607	-123.25268	480450.65	5099197.24	-38.5	65.7	-126.2	215.5
9910	41:37.40	46.04610	-123.25267	480451.43	5099200.57	-37.7	69.0	-123.7	226.4
9913	41:37.60	46.04612	-123.25267	480451.44	5099202.79	-37.7	71.2	-123.7	233.7

Step 2 – Develop Best-Fit Model for x and y

Plot the x coordinates over time and y coordinates over time and fit a parabolic best-fit line to the data. These parabolic x and y models can be combined to fit the vehicle travel path, shown in Figure 15 to confirm the vehicle path makes sense.

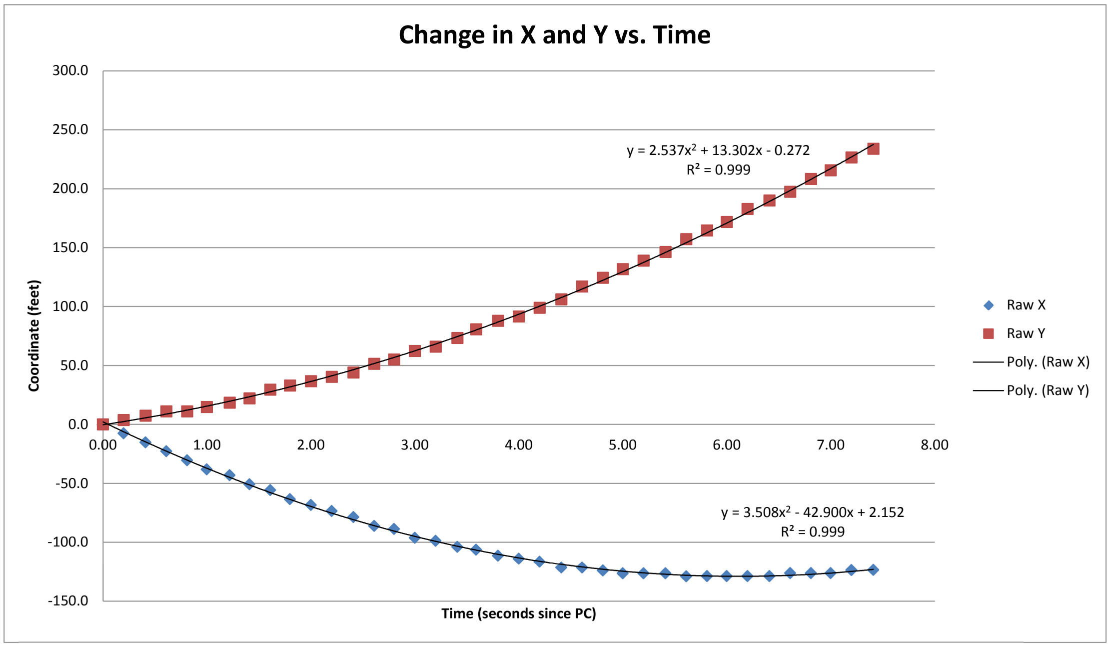
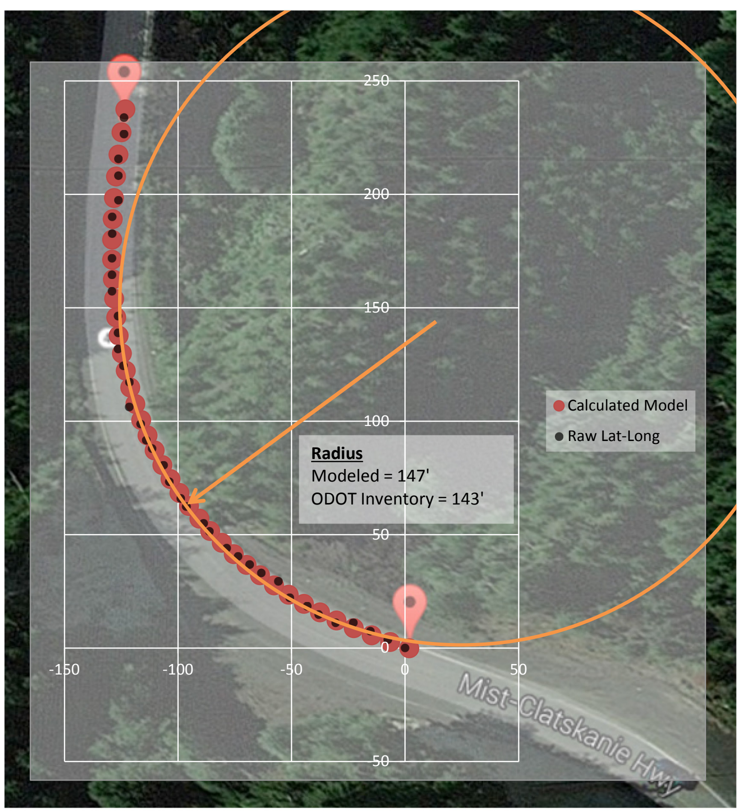


Figure 15 | Raw and Modeled Data over Map

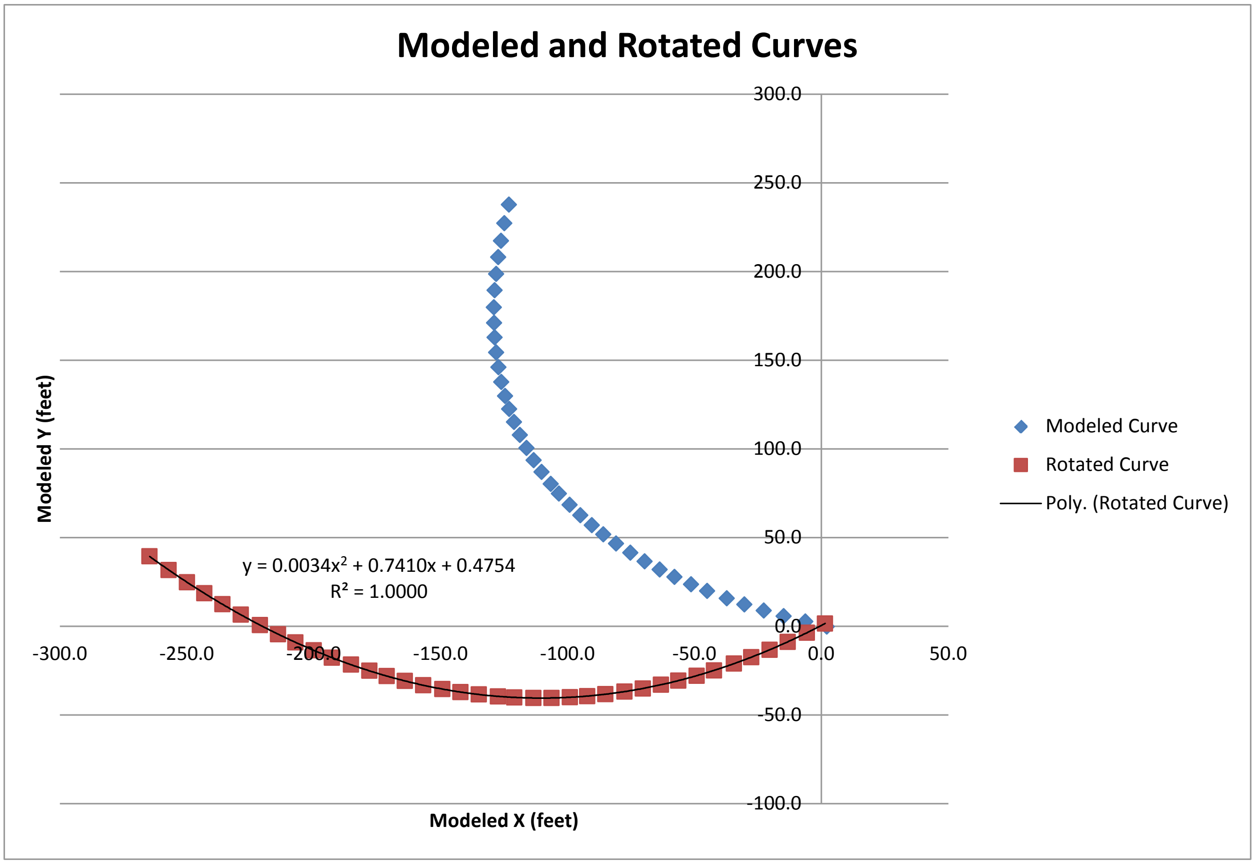


Step 3 – Develop Radius Equation

Based on 4 points on the modeled curve, rotate the modeled curve so it is symmetrical about the y-axis (calculates to 54.14 degrees for this model). This allows Excel to calculate the equation of the line. From this equation, the first and second derivatives can be found, which allows radius at each point along the model to be calculated.

Figure 16 | Rotated Curve Model Coordinates

	Best-Fit Modeled Coordinates		Rotated Coordinates	
Time from PC	x	y	x'	y'
00.00	2.1	-0.3	1.5	1.6
00.20	-6.4	2.5	-5.7	-3.6
00.41	-14.7	5.6	-13.2	-8.7
00.61	-22.7	8.8	-20.4	-13.3
00.81	-30.4	12.2	-27.6	-17.4
01.00	-37.2	15.6	-34.4	-21.1
01.22	-44.9	19.7	-42.3	-24.9
01.41	-51.3	23.5	-49.2	-27.8
01.61	-57.8	27.7	-56.3	-30.6
01.80	-63.6	31.8	-63.2	-32.9
02.00	-69.6	36.5	-70.3	-35.1
02.20	-75.3	41.3	-77.5	-36.8
02.41	-80.8	46.4	-85.1	-38.3
02.61	-85.9	51.7	-92.3	-39.3
02.80	-90.4	56.8	-99.1	-40.0
03.00	-95.0	62.5	-106.3	-40.4
03.20	-99.3	68.4	-113.4	-40.4
03.41	-103.3	74.5	-121.0	-40.1
03.59	-106.7	80.3	-127.5	-39.5
03.80	-110.2	86.8	-135.0	-38.4
04.00	-113.3	93.5	-142.2	-37.1
04.20	-116.2	100.5	-149.4	-35.4
04.41	-118.8	107.6	-156.9	-33.2
04.61	-121.1	114.9	-164.1	-30.8
04.81	-123.1	122.5	-171.3	-28.0
05.00	-124.6	129.6	-178.1	-25.1
05.20	-126.1	137.6	-185.3	-21.6
05.41	-127.2	145.8	-192.8	-17.7
05.61	-128.1	154.2	-200.0	-13.5
05.81	-128.7	162.7	-207.2	-9.0
06.00	-128.9	170.9	-214.0	-4.4
06.20	-129.0	179.9	-221.2	0.7
06.41	-128.7	189.1	-228.8	6.5
06.61	-128.1	198.5	-235.9	12.4
06.81	-127.3	208.1	-243.1	18.6
07.00	-126.2	217.1	-250.0	24.9
07.20	-124.8	227.2	-257.1	31.8
07.41	-123.1	237.4	-264.7	39.4



$$Radius\ of\ Curvature, R = \frac{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}{\left|\frac{d^2y}{dx^2}\right|}$$

Where:

$$\frac{dy}{dx} = 0.0068x' + 0.7410$$

$$\frac{d^2y}{dx^2} = 0.0068$$

$$x' = x\cos 54.14° - y\sin 51.14°$$

$$x = Modeled\ curve\ x\ coordinate$$

$$y = Modeled\ curve\ y\ coordinate$$

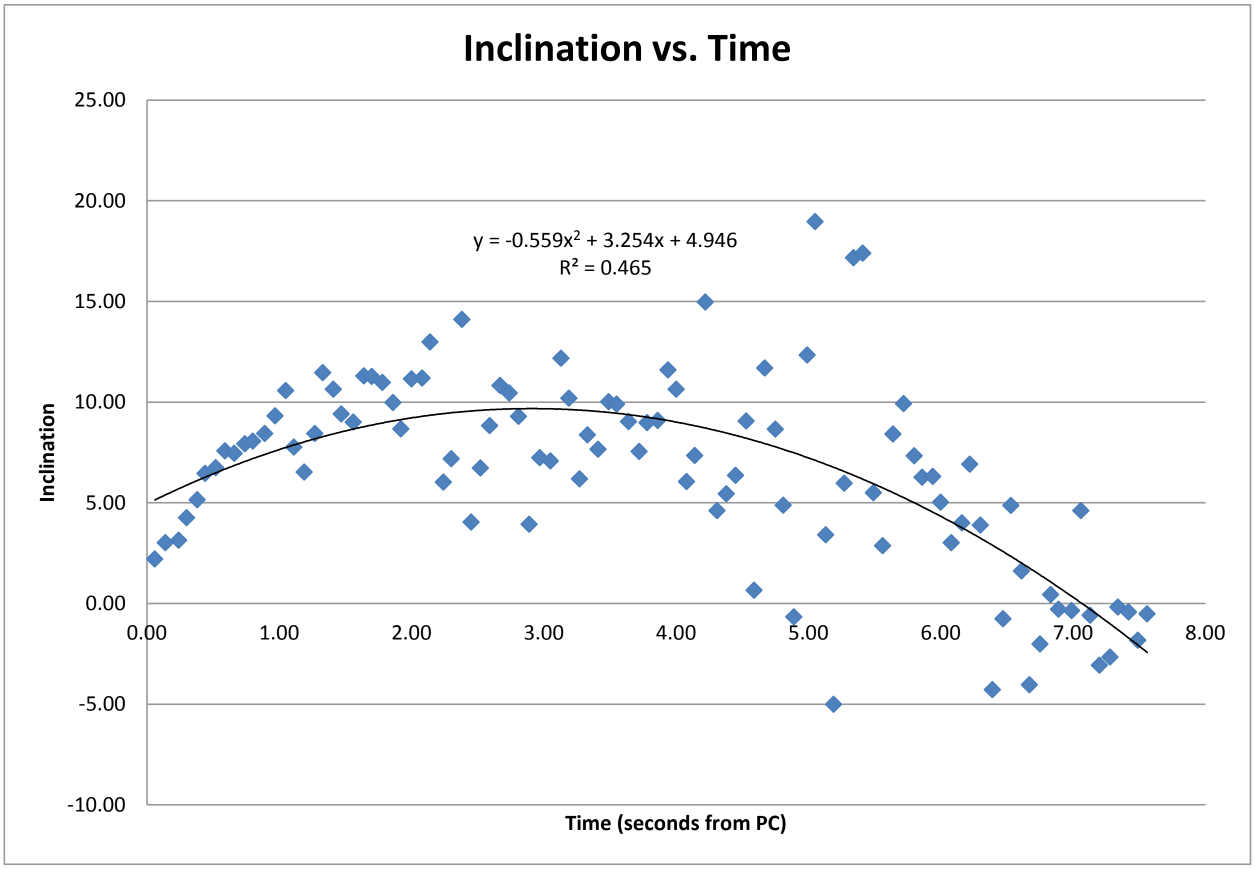
Step 4 – Develop Inclination Model

Plot inclination data over time and fit a parabolic best-fit line to the data.

Time from PC	Raw Inclination
00:00.06	2.21
00:00.14	3.02
00:00.24	3.14
00:00.30	4.25
00:00.38	5.14
00:00.44	6.46
00:00.52	6.74
00:00.59	7.57
00:00.66	7.45
00:00.74	7.93
00:00.80	8.06
00:00.89	8.44
00:00.97	9.32
00:01.05	10.57
00:01.11	7.76
00:01.19	6.52
00:01.27	8.43
00:01.33	11.46
00:01.41	10.64
00:01.47	9.41
00:01.56	9.00
00:01.64	11.30
00:01.70	11.27
00:01.78	10.97
00:01.86	9.98
00:01.92	8.66
00:02.00	11.15
00:02.08	11.19
00:02.14	12.98
00:02.24	6.02
00:02.30	7.18
00:02.38	14.10
00:02.45	4.04
00:02.52	6.73
00:02.59	8.83
00:02.67	10.82

Time from PC	Raw Inclination
00:02.74	10.45
00:02.81	9.28
00:02.89	3.93
00:02.97	7.23
00:03.05	7.08
00:03.13	12.17
00:03.19	10.19
00:03.27	6.18
00:03.33	8.37
00:03.41	7.66
00:03.49	10.02
00:03.55	9.89
00:03.64	9.03
00:03.72	7.54
00:03.78	8.98
00:03.86	9.08
00:03.94	11.59
00:04.00	10.64
00:04.08	6.05
00:04.14	7.34
00:04.22	14.97
00:04.31	4.60
00:04.38	5.44
00:04.45	6.36
00:04.53	9.06
00:04.59	0.65
00:04.67	11.69
00:04.75	8.65
00:04.81	4.88
00:04.89	-0.67
00:04.99	12.33
00:05.05	18.96
00:05.13	3.41
00:05.19	-5.01
00:05.27	5.97
00:05.34	17.16

Time from PC	Raw Inclination
00:05.41	17.40
00:05.49	5.49
00:05.56	2.86
00:05.64	8.41
00:05.72	9.92
00:05.80	7.33
00:05.86	6.27
00:05.94	6.30
00:06.00	5.02
00:06.08	3.01
00:06.16	4.00
00:06.22	6.91
00:06.30	3.89
00:06.39	-4.28
00:06.47	-0.76
00:06.53	4.86
00:06.61	1.61
00:06.67	-4.04
00:06.75	-2.02
00:06.83	0.44
00:06.89	-0.29
00:06.99	-0.36
00:07.06	4.61
00:07.13	-0.59
00:07.20	-3.07
00:07.28	-2.66
00:07.34	-0.18
00:07.42	-0.42
00:07.49	-1.83
00:07.56	-0.52

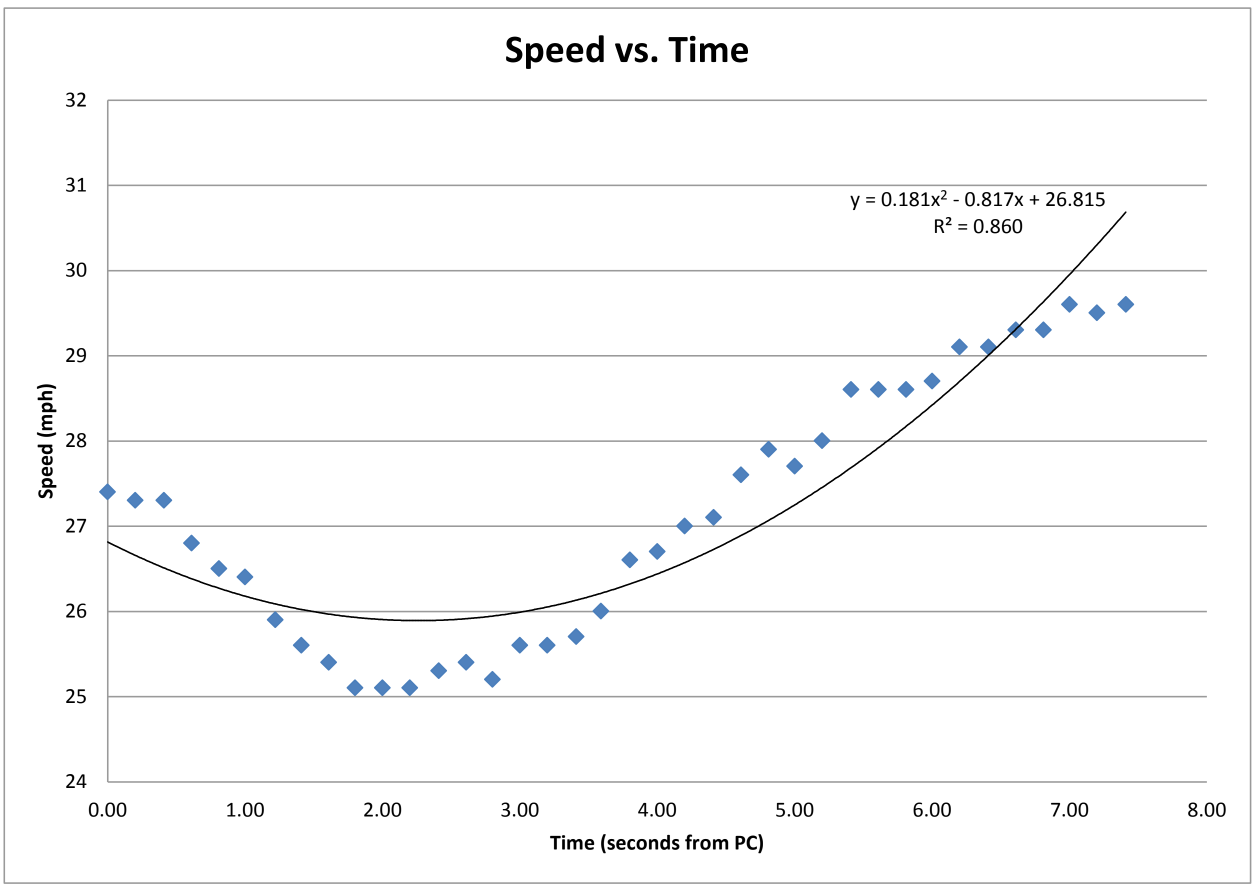

Inclination vs. Time
y = -0.559x² + 3.254x + 4.946
R² = 0.465
Inclination
Time (seconds from PC)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

Step 5 – Develop Speed Model

Plot speed data over time and fit a parabolic best-fit line to the data.

Time from PC	Raw Speed
00.00	27.4
00.20	27.3
00.41	27.3
00.61	26.8
00.81	26.5
01.00	26.4
01.22	25.9
01.41	25.6
01.61	25.4
01.80	25.1
02.00	25.1
02.20	25.1
02.41	25.3
02.61	25.4
02.80	25.2
03.00	25.6
03.20	25.6
03.41	25.7
03.59	26.0
03.80	26.6

Time from PC	Raw Speed
04.00	26.7
04.20	27.0
04.41	27.1
04.61	27.6
04.81	27.9
05.00	27.7
05.20	28.0
05.41	28.6
05.61	28.6
05.81	28.6
06.00	28.7
06.20	29.1
06.41	29.1
06.61	29.3
06.81	29.3
07.00	29.6
07.20	29.5
07.41	29.6



Step 6 – Calculate Speed at 14 Degrees

From the above best-fit models, the following equations describe the variables needed to calculate superelevation and speed at 14 degrees (0.24 ft/ft) of inclination, *t* seconds of travel from the PC. Results are tabulated in Table 11 with the minimum calculated speed highlighted yellow.

$$Model\ X\ (feet) = 3.508t^2 - 42.901t + 2.154$$

$$Model\ Y\ (feet) = 2.537t^2 + 13.302t - 0.272$$

$$Radius\ (feet) = \frac{[1 + [0.0068[X\cos(54.14°) - Y\sin(54.14°)] + 0.7410]^2]^{(3/2)}}{0.0068}$$

$$Inclination\ (degrees) = -0.559t^2 + 3.254t + 4.946$$

$$Speed\ (mph) = 0.181t^2 - 0.817t + 26.815$$

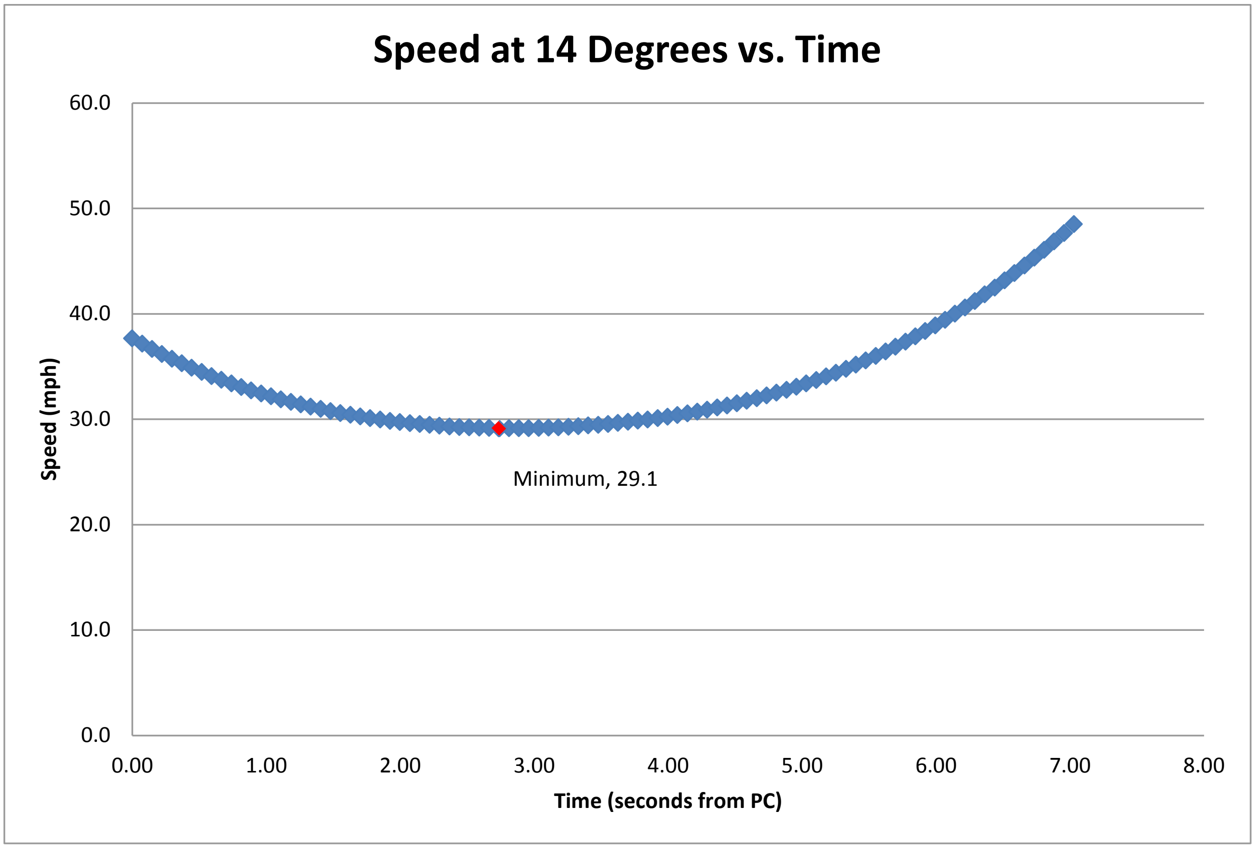
$$Superelevation, e = 100\left[\frac{(1.47V_c)^2}{gR} - f_D\right]$$

$$Advisory\ Speed, V_c = \frac{\sqrt{gR\left(f_D + \frac{e}{100}\right)}}{1.47}$$

Table 11 | Calculated Results

Time since PC	Model X (ft)	Model Y (ft)	Radius (ft)	Inclination (degrees)	Test Speed (mph)	Superelevation (ft/ft)	Speed @ 14 Degrees
0.00	2.2	-0.3	287.9	4.95	26.8	0.08	37.6
0.07	-1.0	0.7	280.5	5.18	26.8	0.08	37.1
0.15	-4.1	1.8	273.4	5.42	26.7	0.08	36.6
0.22	-7.2	2.8	266.5	5.64	26.6	0.08	36.2
0.30	-10.2	3.9	259.8	5.86	26.6	0.08	35.7
0.37	-13.2	5.0	253.4	6.07	26.5	0.08	35.3
0.44	-16.2	6.1	247.2	6.28	26.5	0.08	34.8
0.52	-19.1	7.3	241.2	6.48	26.4	0.08	34.4
0.59	-22.0	8.5	235.4	6.68	26.4	0.08	34.1
0.67	-24.9	9.7	229.9	6.87	26.4	0.08	33.7
0.74	-27.7	11.0	224.5	7.05	26.3	0.08	33.4
0.81	-30.4	12.2	219.4	7.22	26.3	0.08	33.0
0.89	-33.2	13.5	214.4	7.39	26.2	0.09	32.7
0.96	-35.9	14.9	209.7	7.56	26.2	0.09	32.4
1.04	-38.5	16.2	205.2	7.72	26.2	0.09	32.1
1.11	-41.1	17.6	200.8	7.87	26.1	0.09	31.9
1.18	-43.7	19.0	196.7	8.02	26.1	0.09	31.6
1.26	-46.3	20.5	192.7	8.15	26.1	0.09	31.4
1.33	-48.8	21.9	188.9	8.29	26.0	0.10	31.1
1.41	-51.2	23.4	185.3	8.42	26.0	0.10	30.9
1.48	-53.7	25.0	181.9	8.54	26.0	0.10	30.7
1.55	-56.0	26.5	178.6	8.65	26.0	0.10	30.6
1.63	-58.4	28.1	175.6	8.76	26.0	0.10	30.4
1.70	-60.7	29.7	172.6	8.86	25.9	0.11	30.2
1.78	-63.0	31.4	169.9	8.96	25.9	0.11	30.1
1.85	-65.2	33.0	167.3	9.05	25.9	0.11	29.9
1.92	-67.4	34.7	164.9	9.14	25.9	0.11	29.8
2.00	-69.6	36.4	162.7	9.22	25.9	0.11	29.7
2.07	-71.7	38.2	160.6	9.29	25.9	0.12	29.6
2.15	-73.8	40.0	158.6	9.35	25.9	0.12	29.5
2.22	-75.8	41.8	156.8	9.41	25.9	0.12	29.4
2.29	-77.8	43.6	155.2	9.47	25.9	0.12	29.3
2.37	-79.8	45.5	153.7	9.52	25.9	0.13	29.3
2.44	-81.7	47.3	152.4	9.56	25.9	0.13	29.2
2.52	-83.6	49.3	151.2	9.59	25.9	0.13	29.2
2.59	-85.4	51.2	150.2	9.62	25.9	0.13	29.2
2.66	-87.2	53.2	149.3	9.65	25.9	0.13	29.1
2.74	-89.0	55.2	148.6	9.66	25.9	0.13	29.1
2.81	**-90.7**	**57.2**	**148.0**	**9.68**	**25.9**	**0.13**	**29.1**
2.89	-92.4	59.2	147.5	9.68	26.0	0.14	29.1
2.96	-94.1	61.3	147.2	9.68	26.0	0.14	29.1
3.03	-95.7	63.4	147.1	9.67	26.0	0.14	29.1
3.11	-97.3	65.6	147.1	9.66	26.0	0.14	29.2
3.18	-98.8	67.7	147.2	9.64	26.0	0.14	29.2
3.26	-100.3	69.9	147.5	9.61	26.1	0.14	29.2
3.33	-101.8	72.2	147.9	9.58	26.1	0.14	29.3

Time since PC	Model X (ft)	Model Y (ft)	Radius (ft)	Inclination (degrees)	Test Speed (mph)	Superelevation (ft/ft)	Speed @ 14 Degrees
3.40	-103.2	74.4	148.5	9.55	26.1	0.14	29.4
3.48	-104.6	76.7	149.2	9.50	26.2	0.14	29.4
3.55	-106.0	79.0	150.0	9.45	26.2	0.14	29.5
3.63	-107.3	81.3	151.0	9.40	26.2	0.14	29.6
3.70	-108.6	83.7	152.2	9.33	26.3	0.14	29.7
3.77	-109.8	86.1	153.5	9.26	26.3	0.14	29.8
3.85	-111.0	88.5	154.9	9.19	26.4	0.14	29.9
3.92	-112.1	90.9	156.5	9.11	26.4	0.14	30.1
4.00	-113.3	93.4	158.3	9.02	26.4	0.14	30.2
4.07	-114.3	95.9	160.2	8.93	26.5	0.14	30.4
4.14	-115.4	98.4	162.3	8.83	26.5	0.14	30.5
4.22	-116.4	101.0	164.5	8.73	26.6	0.13	30.7
4.29	-117.4	103.6	166.9	8.61	26.6	0.13	30.9
4.37	-118.3	106.2	169.4	8.50	26.7	0.13	31.1
4.44	-119.2	108.8	172.2	8.37	26.8	0.13	31.3
4.51	-120.0	111.5	175.0	8.24	26.8	0.13	31.5
4.59	-120.8	114.2	178.1	8.11	26.9	0.13	31.7
4.66	-121.6	116.9	181.3	7.97	26.9	0.13	32.0
4.74	-122.3	119.6	184.7	7.82	27.0	0.13	32.2
4.81	-123.0	122.4	188.3	7.66	27.1	0.13	32.5
4.88	-123.7	125.2	192.0	7.50	27.1	0.13	32.8
4.96	-124.3	128.0	196.0	7.34	27.2	0.12	33.1
5.03	-124.9	130.9	200.1	7.17	27.3	0.12	33.4
5.11	-125.4	133.8	204.4	6.99	27.4	0.12	33.7
5.18	-125.9	136.7	208.9	6.80	27.4	0.12	34.0
5.25	-126.4	139.6	213.6	6.61	27.5	0.12	34.4
5.33	-126.8	142.6	218.5	6.41	27.6	0.12	34.8
5.40	-127.2	145.6	223.6	6.21	27.7	0.12	35.1
5.48	-127.6	148.6	228.9	6.00	27.8	0.12	35.5
5.55	-127.9	151.7	234.5	5.79	27.9	0.12	36.0
5.62	-128.2	154.8	240.2	5.57	27.9	0.12	36.4
5.70	-128.4	157.9	246.2	5.34	28.0	0.12	36.9
5.77	-128.6	161.0	252.3	5.10	28.1	0.12	37.3
5.85	-128.8	164.2	258.7	4.86	28.2	0.12	37.8
5.92	-128.9	167.4	265.3	4.62	28.3	0.12	38.3
5.99	-129.0	170.6	272.2	4.37	28.4	0.12	38.9
6.07	-129.0	173.9	279.3	4.11	28.5	0.12	39.4
6.14	-129.0	177.1	286.6	3.84	28.6	0.12	40.0
6.22	-129.0	180.4	294.2	3.57	28.7	0.13	40.6
6.29	-128.9	183.8	302.1	3.30	28.8	0.13	41.2
6.36	-128.8	187.1	310.1	3.01	28.9	0.13	41.8
6.44	-128.6	190.5	318.5	2.73	29.1	0.13	42.5
6.51	-128.5	193.9	327.1	2.43	29.2	0.13	43.1
6.59	-128.2	197.4	335.9	2.13	29.3	0.13	43.8
6.66	-128.0	200.8	345.1	1.82	29.4	0.14	44.5
6.73	-127.7	204.3	354.5	1.51	29.5	0.14	45.3
6.81	-127.3	207.9	364.2	1.19	29.6	0.14	46.0
6.88	-126.9	211.4	374.2	0.86	29.8	0.14	46.8
6.96	-126.5	215.0	384.4	0.53	29.9	0.15	47.6
7.03	-126.1	218.6	395.0	0.20	30.0	0.15	48.5



The minimum calculated advisory speed at 14 degrees is 29.1 mph, which matches the minimum calculated advisory speed reported by CARS.