# COLLISION PREDICTION ON COMBINED HORIZONTAL AND VERTICAL ALIGNMENTS OF TWO-LANE RURAL HIGHWAYS

By

Qing Chong You

Master of Engineering, Fuzhou University,

Fuzhou, China, 1993

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# COLLISION PREDICTION ON COMBINED HORIZONTAL AND VERTICAL ALIGNMENTS OF TWO-LANE RURAL HIGHWAYS

**By**

**Qing Chong You**

**Master of Applied Science in Civil Engineering**

**Department of Civil Engineering**

**Ryerson University, Toronto**

**2008**

## Abstract

This study investigates the safety effects of combined horizontal and vertical alignments using accident occurrences on two-lane rural highways in Washington. Eight statistical models were developed to establish the relationships between vehicle accidents and their associated factors for eight combinations of alignments by the Poisson, negative binomial, zero-inflated Poisson, and zero-inflated negative binomial. Three selected models were validated. The findings show that degree of curvature is the most successful predictor for horizontal curves combined with vertical alignments. A minimum ratio of 25 of vertical curve radius to horizontal curve radius is recommended for a curve with radius of smaller than 6000 ft (or 1830 m). Vertical curves have relatively little influence on accident occurrences at horizontal tangents. The grade value and length of a grade increase accident occurrences when a horizontal curve or tangent is on a grade. A smaller curve should be avoided introducing at a steep grade.

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# Chapter 1. INTRODUCTION

## 1.1 BACKGROUND

Road safety has been becoming the top priority of highway agencies and the main focus of researchers, transportation engineers and administrators in Canada and overseas considering the impacts that it has on the society and the economy. In Canada only, 2,725 road users were killed and over 212,000 were injured on Canadian roads during 2004, which brought the annual economic cost of between $11 and $27 billion to society resulting from injury-producing and property damage traffic collisions (CCMTA 2005). Researchers, transportation engineers, and administrators and officials of various authorities have been searching for any possible solutions to the safety related issues on the roadways.

Roadway users (drivers), vehicles and roadways are three contributing factors in safety. Introducing safer vehicles and road technologies such as side air bags, electronic stability control, and other crash-avoidance technologies provides one way of solutions to safety. Enhancements on education of drivers to improve the drivers' behaviors, enhancements on enforcement measures and raising public safety awareness, etc. are also effective strategies to reduce accidents on the roads (CCMTA 2005; TRB 2006). Designing and building safer roads to meet drivers' expectancy from the beginning is a third promising technique. Drivers are more likely to become confused and, possibly, commit errors at features that violate their expectancy than at features that do not (Krammes 1997).

Most researchers have developed measures or techniques to identify inconsistent locations that may pose road safety problems (Wooldridge et al. 2003), or investigated the individual design elements to improve the design of the roadways. However, as TAC (1999) stresses, the most valuable tool for evaluating these measures, design elements, or treatments is actual collision experience that they have. In this aspect, different models that relate accident occurrences to highway design features have been built to explore the safety effects of those different design elements and predict accident occurrences on the roadways.

Much research work has improved our understanding of the safety effects of highway geometric design elements. However, most of it was limited to the single design elements. The combination of individual elements such as horizontal and vertical alignments, which may be designed separately in design practice, may detract from the favorable features and aggravate the deficiencies of each (Lamm et al. 1999).

Highway alignments are of three-dimensional nature. A large body of investigations of the effects of combined horizontal and vertical alignment on driver perception, operating speed, visual demand, sight distance, vehicle stability, aesthetics, and safety has given us a better understanding of the characteristics of combined horizontal and vertical alignment that may contribute to its safety. However, fewer efforts were made to evaluate the safety effects of the coordination and interaction of combined horizontal and vertical alignment in a quantitative manner.

Some research efforts on the safety analysis of the coordination and interaction of horizontal and vertical alignment were focused on the combination of curvature and grade only, for example, the study of Dunlap et al. in 1978 (as cited in Hauer 2001) and the study of Zador et al. (1987). Also, the findings are limited to some unfavorable combinations of extreme horizontal curvature and grade.

Due to the complexity of the superimposition of horizontal and vertical alignments, the available techniques and methods at the time of research, and the availability of complete and reliable data for sound safety analysis, not much statistically sound safety analysis on the safety effects of superimposed horizontal and vertical alignments has been conducted (Lamm et al. 1999). A major work on the superimposition of horizontal curve and grade done by Zador et al. (1987) was through comparisons of crash sites and comparison sites.

The statistics methodology applied to safety analysis of highway have advanced from the initial multiple regression technologies to the Poisson regression, to the negative binomial regression (NB), and to the zero-inflated regression including the zero-inflated Poisson (ZIP) and the zero-inflated negative binomial (ZINB), which provide a better solution to safety modeling.

In partial fulfillment of the requirement of M.A.Sc degree, the objective of this study was to:

- Investigate the safety effects of coordination and interaction of combined horizontal and vertical alignments using the available accident data;
- Develop statistical models for establishing the relationship between vehicle accidents and their associated factors such as geometric design features, traffic volume, etc with the aid of the Poisson, NB, and zero-inflated regression (ZIP and ZINB) technologies.

## 1.2 THESIS ORGANIZATION

The thesis is organized in the following major chapters:

Chapter 2 **LITERATURE REVIEW**: The chapter reviews the safety effects of individual geometric design elements, and the effects of combined horizontal and vertical alignment on driver perception, operating speed, visual demand, sight distance, vehicle stability, aesthetics, and safety to give us a better understanding of the characteristics of combined horizontal and vertical alignment that may contribute to its safety. The safety aspect includes the literature review of current researches on the safety analysis of combined horizontal and vertical alignment. The chapter also presents a review of statistical methodology applied to the development of safety models, and a discussion of sensitive issues such as divisions of road sections and treatment of exposure. The challenge of this study is given at the end.

Chapter 3 **STUDY METHODOLOGY:** The study methodology is presented in this chapter from three major aspects: statistical methodology, data collection, and detailed study design. The statistical methodology includes the Poisson, NB, ZIP, and ZINB regression. Data collection describes the features of the data collected from Highway Safety Information System (HSIS) and the availability of the variables defined for accident occurrences, roadways, traffic volume, and geometric alignment. Study design discusses division of roadways, extraction of road sections from data files, and ten types of combinations of alignments to be considered in the study. A summary of general descriptive statistics for the routes of two-lane rural roadways is also given in this chapter.

Chapter 4 **ANALYSIS:** This chapter discusses potential influencing factors that were considered during the process of developing the models for a specific type of combination. Some new variables were introduced. Also, a summary statistics for divided road sections of each type of combination is presented comprehensively.

Chapter 5 **MODEL DEVELOPMENT:** All the four types of models: the Poisson model, the NB model, the ZIP model, and the ZINB model were developed separately for ten preliminary alignment combinations. The significant influencing variables in explaining the variation of accident occurrences on different combinations of alignments were detected. This chapter is the core of this study.

Chapter 6 **MODEL SELECTION:** Comparisons were made between the Poisson, NB, ZIP, and ZINB models to choose one type of model that provides the best fit to the analyzed data for a specific combination of horizontal and vertical alignment in this study. Thereafter a summary of the selected models is given.

Chapter 7 **MODEL VALIDATION:** This chapter intends to present validation of the 3 selected models from eight final models to test the model's ability and accuracy to predict the accident behavior on the alignments combined with horizontal and vertical alignment. The validation process was conducted by redeveloping the 3 models on the 3 years of accident data from 2002 to 2004 for the combined alignments whose models were selected for validation, and then validating the redeveloped models based on the accident data for the year of 2005.

Chapter 8 **CONCLUSIONS AND RECOMMENDATIONS:** The chapter summarizes the major findings in the study, and recommends some suggestions for future design and research.

# Chapter 2. LITERATURE REVIEW

This chapter begins with a review of the safety effects of individual geometric design elements, and then the effects of combined horizontal and vertical alignment on driver perception, operating speed, visual demand, sight distance, vehicle stability, aesthetics, and safety are reviewed to give us a better understanding of the characteristics of combined horizontal and vertical alignment that may contribute to its safety. More importantly, the chapter discusses the progress and major findings of previous researches on the safety analysis of combined horizontal and vertical alignment. The chapter also presents a review of statistical methodology applied to the development of safety model, and a discussion of sensitive issues such as divisions of road sections and treatment of exposure regarding the modeling development. The challenge of this study is given at the end.

## 2.1 SAFETY EFFECTS OF ALIGNMENTS

### 2.1.1 Horizontal Curves

The safety of a horizontal curve is strongly related to the degree of curvature (denoted as D) or the radius. Degree of curvature is defined that the number of degrees are subtended by 100 feet of curve length. It has the following relationship with radius:

$$D = \frac{5729.6}{R} \tag{1}$$

where R = radius of curve, in feet,

D = degree of curvature.

Most studies found that accident rates increase with degree of curvature on flat terrain. Matthews and Barnes (1988) studied 4666 curves in New Zealand with five years of accident data and found that

$$\text{accidents / million vehicle kilometers} = 0.071 \times D^{0.64} \tag{2}$$

Lamm et al. (1988) built the following multivariate linear model from 261 road sections in New York State:

$$\text{accidents / million vehicle miles} = -0.88 + 1.41D \tag{3}$$

Vogt (1995) investigated the two-lane rural roads in Texas and obtained that

$$\text{accidents / million vehicle miles} = 0.102 \times e^{0.064D} - 0.1 \tag{4}$$

Zegeer et al. (1992) adopted a different form of model from the above models that was based on the number of accidents instead of the accident rates after analyzed 10,900 horizontal curves in Washington State:

$$A = (1.552L + 0.014D - 0.012S) \times V \times 0.978^{W-30} \quad (5)$$

where

A = number of accidents per year,

L = curve length, in miles,

D = degree of curve,

S = 1 if spirals exist and 0 otherwise,

V = volume of vehicles in both directions, in millions,

W= roadway width, equal to the total width of lanes and shoulders, in feet.

Therefore, various findings showed that degree of curvature is the strongest predictor for accident occurrences on horizontal curves.

### 2.1.2 Tangents

Driver behaviors on a tangent are affected by a wide array of road characteristics that include the length of tangent section, the curves before and after the section, cross-section elements, vertical alignment, terrain type, and available sight distance.

Tangents are classified as independent and nonindependent tangents in the handbook authored by Lamm et al. (1999). Nonindependent tangents are defined as tangents that are too short to exceed the possible 85th percentile speed differences for good design levels ($\Delta V85 \le 10 km/h$) or even for fair design levels ($\Delta V85 \le 20 km/h$) during the acceleration and/or deceleration maneuvers. In this case, the element sequence curve-to-curve, not the interim tangent control the safety evaluation design process. If tangents are long enough to permit a driver to exceed the 85th percentile speed difference for fair design levels ($\Delta V85 > 20 km/h$), the tangents are called independent tangents. In this case, the element sequence tangent-to-curve should control the safety evaluation of design process.

Fink et al. (1995) studied the effects of the tangent length, degree of horizontal curvature, and sight distance on safety and operation at horizontal curves. They found that the effects of approach tangent length and approach sight distance were not clear in the relationship with accident rates at horizontal curves, but suggested that the adverse safety effects of long approach tangent length and short approach sight distance become more pronounced on sharp curves.

Brenac (1996) reviewed some of research results in Europeans countries on safety at horizontal curves and described tangent length as an external factor to the safety at horizontal curves. The results show that the accident rate on curves increases when the radius decreases and the length of straight alignment or alignment with a radius of curvature larger than 1000 m (defined as easy length) preceding the curve increases.

In an attempt to identify and prioritize potential treatment sites on rural curves, Persaud et al. (2000) calibrated a model for tangent sections using Generalized Linear Modeling method on Ontario data. The model was of the following form:

$$\text{crashes / year} = (L)(AADT)^{b} e^{a} \tag{6}$$

where L is the section length in kilometers, and a and b are coefficients. The standard errors indicated that all of the parameter estimates were significant at the 5 percent level.

To sum up, researches on tangents were more focused on its influences on horizontal curves after tangents.

### 2.1.3 Vertical Curves

Vertical curves are designed to provide a smooth transition between adjacent grades. According to their orientation, vertical curves can be categorized into two types: crest vertical curves and sag vertical curves. Current design policies (TAC 1999; AASHTO 2001) require that crest vertical curves have to be flat enough to provide the required sight distance. The most common sight distances that have to be considered are stopping sight distance, passing sight distance, decision sight distance, and non-striping sight distance. For sag vertical curves, the headlight sight distance is the primary criterion to decide the length of the sag curves.

Lefeve (1953) examined the speed characteristics on vertical curves, and found that drivers reduce their operating speeds as they approach vertical curves with short sight distances. When drivers approached the point of the minimum sight distance of 45 m, the average speed reduction was 10 km/h. When drivers approached the point of the minimum sight distance of 120 m, the average speed reduction was only 3 km/h. Lefeve hypothesized that drivers seldom encounter critical situations on vertical curves and are not aware of the hazard involved. Thus, their perception of risk is low and they believe their reduction in speed is greater than it actually is.

Sight distance is one of the most important criteria in designing vertical curves. Its association with safety on vertical curves was explored by Olson et al. (1984). They concluded from examining the crest rates on crest vertical curves in Michigan that limited sight distance created safety problems. However, Fambro et al. (1989) in a Texas Transportation Institute research report found that limited sight distance did not create safety problems using multiple regression analysis to analyze relationship between crash rates and available sight distance at crest vertical curves in Texas. The inconsistency between results is the degree of deficiency that produces safety concerns. If the available sight distance was less than some threshold value, it did affect crash rates. They also concluded that stopping sight distance of 100 to 130 m did not affect crash rates unless an intersection was within the limited sight distance section.

Using another approach that examined cases of crashes in details, Fitzpatrick et al. (2000a) reviewed 439 narratives from crashes that occurred on 33 multilane and two-lane roadways with limited sight distance crest vertical curves and found that the crash rates on rural two-lane highways with limited stopping sight distance are similar to the crash rates on all two-lane rural highways. The percentage of accidents involving large trucks and older drivers was also investigated and has similarity on limited sight distance highways and all two-lane rural highways. It was concluded that for the range of conditions studied, limited stopping sight distance does not appear to be a safety problem.

Little attempt seems to have been made to explore accident occurrences on sag vertical curves in the reviewed literature.

### 2.1.4 Grades

Grade is generally believed to affect the speed of a vehicle and thus affect the accident occurrence and accident severity on a grade. Vehicles tend to slow down when they run on an upgrade, and speed up when they drive on a downgrade. The influences of the speed by the grade are more serious for trucks since trucks have a different deceleration and acceleration capabilities from passenger cars. A thorough literature review of the safety effect of the grade was conducted by Hauer (2001). Based on his review, all studies of divided roads on grades concluded that accident frequency increases with gradient on downgrades. For upgrades, however, some studies concluded that accident frequency increases with gradient, while other studies found the contrary results. For the joint effect of upgrade and downgrade, Miaou's study (as cited in Hauer 2001) recommended an accident modification factor of 1.08 be used for 1% increase in grade for two lane roads. Hauer also suggested that the length of the grade be considered in order to adequately describe or predict the safety effect of a grade, and that the safety effect of grade be evaluated in the context of the road profile and the speed distribution profile. He concluded that our understanding of how grade affects safety was only rudimentary.

Choueiri et al. (1994) conducted an international review of safety aspects of individual design elements on two-lane rural highways, and found that grades under 6% have relatively little effect on the accident rate and the accident rate increases sharply on grades of more than 6%.

## 2.2 EFFECTS OF COMBINED HORIZONTAL AND VERTICAL ALIGNMENTS

### 2.2.1 Driver Perception

Different combination of horizontal and vertical alignments produces different perspective views in front of drivers. Earlier attempts to use computer technologies to produce the three-dimensional (3D) views of the combination on a two-dimension plane were made by Park and Rowan (1966), and Smith et al. (1971). Lamm and Smith (1994) proposed the use of perspective methods for the 3D evaluation of roadways to ensure that roadway design meets drivers' expectations. 3D visualization of alignments helps to examine the combined effect of vertical and horizontal alignments and represents the perception of the driver of the road.

The importance of the driver's visual perception of the road features ahead was emphasized by several researchers. Alexander and Lunenfeld (1986) pointed out that about 90% of the information required for the driving task is obtained visually. Olson (1996) has also confirmed that vision plays a critical role in a moment-to-moment vehicle control operations and in acquiring information necessary for future actions although he argued the percentage of information required for the driving task. Therefore, any confusing or misleading cue perceived may make drivers maneuver their vehicles incorrectly and then increase the risk of crash.

When vertical and horizontal alignments overlap optical illusions or erroneous perception may occur. Smith and Lamm (1994) hypothesized that an overlapping sag vertical curve would cause a horizontal curve to appear flatter while an overlapping crest curve would cause a horizontal curve to look sharper. Mori et al. (1995) found that the coordination of vertical and horizontal curves may cause the driver to have an erroneous perception of horizontal curvature after examining existing highways from the point of view of the driver. Regarding the problems of curves with distorted appearance by overlaying sag (stretched image) or crest (compressed image) vertical alignment, Appelt (2000) developed a method of calculation of "apparent radii" that relate to the actual radius to quantify the visual distorted effects. Nomograms and simple equations were used. Hassan et al. (2002; 2003) and Bidulka et al. (2002) examined the hypothesis of Smith and Lamm by using a computer animation experiment and field measurements, and quantified the extent of erroneous perception resulting from the combination and developed a final model to estimate the perceived radius of any horizontal curve. The type of overlapping vertical curve, actual horizontal radius, and turning direction (on crest and sag curves) and sight distance (on sag curves) were found to significantly affect the perceived radius.

### 2.2.2 Operating Speed

3D nature of the combined horizontal and vertical alignments also affects the drivers' behaviors and their operating speeds. Field measurements were carried out by Hassan et al. (2003) to verify the findings about the drivers' perception of the combinations of alignments. 1211 speed observations were collected on 6 sites of combinations of horizontal and sag curves and 1329 observations on 7 sites of combinations of horizontal and crest curves. The measurements confirmed that driver behavior on the approach to the horizontal curve varies with the type of overlapping vertical curve. Drivers consistently reduced their operating speeds on the approach to crest combinations while drivers accelerated just before the beginning of horizontal curves in sag combinations. These trends of change in operating speeds were evident regardless of the value of the vertical grade of the approach tangent and may well reflect a misperception of the horizontal curvature.

Fitzpatrick et al. (2000b) finished a comprehensive Federal Highway Administration (FHWA) research project to predict operating speed for different combination of horizontal and vertical alignments on two-lane rural highways. Ten separate operating speed models were built for the different combinations of alignments. All the combinations can be categorized into the following cases: horizontal curves on grades, vertical curves on horizontal tangents, and combinations of horizontal and vertical curves. Horizontal curves were modeled on four different vertical grade condition $0\% \le G < 4\%$ upgrade, $4\% \le G < 9\%$ upgrade, $-4\% \le G < 0\%$ downgrade, and $-9\% \le G < -4\%$ downgrade. Vertical curves were analyzed by three types: sag vertical curves, nonlimited sight distance (NLSD) crest curves and limited sight distance (LSD) crest curves. The prediction models for operating speeds are listed in Table 1. The results showed that the inverse of the radius 1/R was identified as the single independent variable in most combinations of horizontal curves with grades, combination of horizontal curves with limited sight distance crest curves, and combination of horizontal curves with sag curves. The inverse of the rate of vertical curvature 1/K was the most highly correlated to the 85th percentile speeds for vertical crest curve with limited sight distance on horizontal tangents. No statistically significant model was found for NLSD curves on horizontal tangents, and horizontal curve combined with NLSD crest vertical curves.

Gibreel et al. (2001) also developed several prediction models based on two types of 3D combinations: a horizontal curve combined with a sag vertical curve and a horizontal curve combined with a crest vertical curve to account for 3D nature of highways. Different from other models based on midpoints of curves, the models were built separately on the five points of a curve. The results showed that the radius of horizontal curve, deflection angle of horizontal curve, horizontal distance between the point of horizontal intersection and the point of vertical intersection, length of vertical curve (rate of curvature), gradients, algebraic difference in grades, and superelevation rate have significant effect on the 85th percentile operating speeds.

### 2.2.3. Visual Demand

Increasing complexity of geometric features brings more driver workload. Driver workload can be defined as "the time rate at which drivers must perform a given amount of work or driving tasks" (Messer 1980). Visual occlusion was first documented as a measure of workload by Senders et al. (1967). It is a technique to measure driver visual demand while driving on a roadway. Easa and He (2006) examined the driver's visual demand on 3D alignments. The results showed that visual demand on 3D curves significantly varied with the inverse of the horizontal curve radius and the inverse of the vertical curvature. They also found that the visual demand for a horizontal alignment overlapping with either a crest or sag vertical curve is higher than that for a two-dimension horizontal curve.

**Table 1.** Operating Speed Models for Combined Horizontal and Vertical Alignments on Two-Lane Rural Highways (Source: Fitzpatrick et al. 2000b)

| AC EQ No. | Alignment Condition | Equation |
|---|---|---|
| 1. | Horizontal Curve on Grade: $-9\% \leq G < -4\%$ | $V_{85} = 102.10 - \frac{3077.13}{R}$ |
| 2. | Horizontal Curve on Grade: $-4\% \leq G < 0\%$ | $V_{85} = 105.98 - \frac{3709.90}{R}$ |
| 3. | Horizontal Curve on Grade: $0 \leq G < 4\%$ | $V_{85} = 104.82 - \frac{3574.51}{R}$ |
| 4. | Horizontal Curve on Grade: $4\% \leq G < 9\%$ | $V_{85} = 96.61 - \frac{2752.19}{R}$ |
| 5. | Horizontal Curve Combined with Sag Vertical Curve | $V_{85} = 105.32 - \frac{3438.19}{R}$ |
| 6. | Horizontal Curve Combined with NLSD Crest Vertical Curve | (see note 3) |
| 7. | Horizontal Curve Combined with LSD Crest Vertical Curve (i.e., $K \leq 43m/\%$) | $V_{85} = 103.24 - \frac{3576.51}{R}$ (see note 4) |
| 8. | Sag Vertical Curve on Horizontal Tangent | $V_{85}$ = assumed desired speed |
| 9. | Vertical Crest Curve with NLSD (i.e., $K > 43m/\%$) on Horizontal Tangent | $V_{85}$ = assumed desired speed |
| 10. | Vertical Crest Curve with LSD (i.e., $K \leq 43m/\%$) on Horizontal Tangent | $V_{85} = 105.08 - \frac{149.69}{K}$ |

Note:

1. AC EQ No. = Alignment Condition Equation Number.
2. Where: $V_{85}$ = 85th percentile speed of passenger cars (km/h),
   K = rate of vertical curvature, R = radius of curvature (m), G = grade (%)
3. Use lowest speed of the speeds predicted from AC EQ No.1 or 2 (for the downgrade) and AC EQ No. 3 or 4 (for the upgrade).
4. In addition, check the speeds predicted from AC EQ No.1 or 2 (for the downgrade) and AC EQ No. 3 or 4 (for the upgrade) and use the lowest speed. This will ensure that the speed predicted along the combined curve will not be better than if just the horizontal curve was present (i.e., that the inclusion of a limited sight-distance crest vertical curve results in a higher speed).

### 2.2.4. Sight Distance

3D coordination of horizontal and vertical alignments influences sight distance on highways. Sanchez (1994) studied the effect of 3D combined alignment of interchange connectors on sight distance, which was determined graphically. Hassan et al. (1996) built an analytical model for determining the available sight distance on 3D combined horizontal and vertical alignments. Their findings showed that the existing two-dimension models may underestimate or overestimate the available sight distance. Hassan and Easa (1998) quantitatively analyzed the coordination of horizontal and vertical curves and found two types of red zones that a horizontal curve should not be positioned relative to a sag vertical curve. One type of red zones is stopping sight distance (SSD) red zones where SSD needs are not satisfied. Another type of red zones, based on preview stopping distance, is the location where a horizontal curve should not start because drivers will not be able to perceive it and safely react to it.

### 2.2.5 Vehicle Stability

When a vehicle travels on a circular curve, it experiences a centrifugal force that should be resisted by substantial amount of centripetal force; otherwise skid movement would happen to cause safety problems. The centripetal forces are provided by the side friction between the tires and the pavement surface, or by a component of the vehicle's weight if the pavement surface is superelevated, or by both of them. Traditionally, the current North American design guidelines (AASHTO 2001; TAC 1999) idealize the vehicle as a point-mass model that regards the vehicle as a rigid body and assumes the undergoing forces acting on the center of gravity. From the laws of physics mechanics, the basic driving dynamics formula that governs vehicle operation on a curve is simply expressed as:

$$f_R + e = \frac{V^2}{127R} \tag{7}$$

where: $f_R$ = side friction (demand) factor,

e = superelevation rate (m/m),

V = vehicle speed (km/h),

R = curve radius (m).

This simplified driving dynamic formula is derived from the case that a vehicle moves on a flat curve.

Vehicle stability is evaluated by the difference $\Delta f$ between the side friction assumed ($f_{RA}$) for different design speed Vd and the actual side friction demand ($f_{RD}$) required for the expected 85th percentile operating speeds

$$\Delta f = f_{RA} - f_{RD} \;. \tag{8}$$

For 3D alignments, where a horizontal curve is superimposed by a vertical alignment, the vertical alignment affects the available side friction. On crest curves, another centrifugal force (different from that resulting from vehicle movement on a flat curve) is acting upward in a direction opposite to the vehicle's weight. The decreased forces cause driver discomfort or vehicle instability. On sag curves, another centrifugal force (different from that resulting from vehicle movement on a flat curve) is acting downward in the same direction of the vehicle's weight. In spite of no risk of stability, drivers may feel discomfort because of the combination of the centrifugal force and the vehicle's weight (Hassan et al. 1998). The longitudinal grade (different from the slope that superelevated roadway produces) of an alignment diminishes the force distribution of the vehicle's weight, and influences the interaction between longitudinal friction and side friction. Therefore, vertical alignments that are combined with horizontal curves affect the available side friction, and so affect vehicle stability or driver comfort.

Kontaratos et al. (1994) used a bicycle model to simulate the vehicle-road interaction on horizontal curves combined with upgrades and downgrades. The minimum radius for horizontal curves on upgrades was found to be larger than that obtained the AASHTO formula. However, the AASHTO formula would produce conservative radii for the combination of horizontal curves with downgrades. Easa and Dabbour (2003), Dabbour et al. (2004), Easa and Dabbour (2005) , and Easa et al. (2006) used computer simulation program VDM RoAD (vehicle dynamic models roadway analysis and design) that was developed at the University of Michigan to study design radius requirements for simple horizontal curves, reverse horizontal curves, and compound horizontal curves on 3D alignments. The results showed that an increase in the minimum radius with different percentage be required for the current design radius requirements defined in the design guides.

### 2.2.6 Aesthetics

Smith and Lamm (1994) emphasized and outlined the coordination of horizontal and vertical alignment with regard to highway aesthetics. Horizontal and vertical alignment should not only be built to eliminate driver's unsafe feeling and discomfort, but also be fitted gracefully into their surroundings and become acceptable components of the landscape as viewed from outside the highway. The authors pointed out that there is a subtle interrelationship between highway aesthetics and highway safety although the safety benefits of aesthetically pleasing highways have not been well quantified, in the literature review of Practical Highway Aesthetics (ASCE 1977). The AASHTO Green Book stresses that the proper use of overlapping vertical and horizontal curves generally makes a facility more pleasing, and that "Excellence in the design of each and of their combination increases usefulness and safety, encourages uniform speed, and improves appearance, nearly always without additional cost"(AASHTO 2001). Poor coordination of vertical and horizontal alignments may result in certain undesirable arrangements. In this connection, the AASHTO Green Book and TAC guide also have outlined some general guidelines and a general procedure to obtain appropriate coordination of horizontal and vertical alignments.

### 2.2.7 Safety

A large number of individual research efforts have been focused on the 3D nature of highways which is resulted from the combination of horizontal and vertical alignment in the aforementioned aspects to improve highway design and road safety. However, fewer efforts were made to evaluate the safety of the coordination and interaction of combined horizontal and vertical alignment in a quantitative manner. Instead, some of the safety assumptions were evaluated in a qualitative manner, in such aspects as highway aesthetics on road safety (Smith and Lamm 1994).

From a literature review on the interaction between grade and horizontal curvature conducted by Hauer (2001), the reliable results showing the interaction were only from the 1978 study of influence of combined highway grade and horizontal alignment on skidding conducted by Dunlap et al., and the 1987 study of Zador et al. The Dunlap et al. study of the Ohio and Pennsylvania turnpikes found that: "The analysis of the turnpike accident data shows no evidence of effects that can be attributed to grades and curves in combination." But as we can see from Figure 1, the maximum grade for upgrade and downgrade was 3%. Zador et al. (1987) examined data at sites of fatal single-vehicle rollover crashes in New Mexico and Georgia in comparison with some representative comparison sites and found that sites with sharp left hand curves in combination with steep downgrades had unusually more crashes.

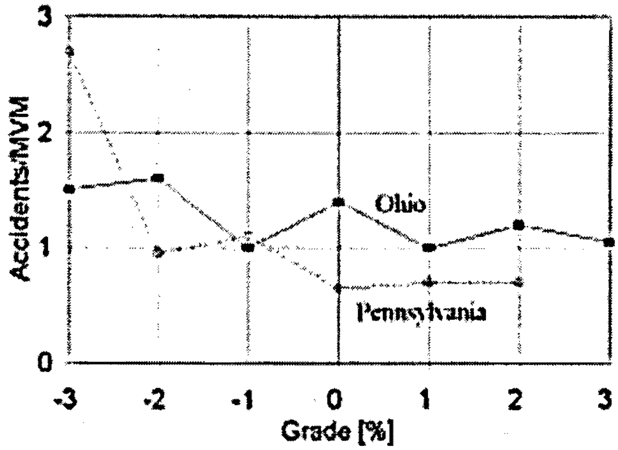



**Figure 1.** Accident Rate versus Grade (Source: Dunlap et al. Study as Cited in Hauer 2001)

Harwood et al. (2000) presented an accident prediction algorithm for the safety performance of two-lane rural highway segments and intersections. The algorithm consists of base models and accident modification factors (AMFs). The accident modification factors account for the effects of different highway characteristics on safety to adjust the base model predictions. The use of AMFs treats the safety effects of individual elements as independent and ignores the potential interactions between them.

3D nature of highway alignments is attributed to the coordination of horizontal and vertical alignments and the cross section. Due to its complexity and the available techniques and methods at the time of research, highway alignments were separated into individual elements, as we can see from the current design standards. As we may design individual elements separately, the influence of the superimposition of horizontal and vertical alignments on safety may be different (Lamm et al. 1999). Moreover, the available data may not be complete and reliable for sound safety analysis. Some accident data may not have associated traffic volume; or geometric data is missing; or the efficient link between accidents, traffic volume, and locations is lacking. Therefore, no much statistically sound safety analysis on the safety effects of superimposed horizontal and vertical alignments has been conducted.

## 2.3 MODELING METHODS

### 2.3.1 Statistical Approach

Regression equations that relate accident occurrences to traffic volumes, roadway geometric design, environment, and other associated characteristics have been proven to be a useful form of highway safety analysis. Several statistical methods have been employed in the literature to build such accident models.

Multiple linear regression is a conventional technique that was used in earlier safety analysis. One of its most important assumptions that must be met is that the dependent variable is normally distributed with constant variance. However, accident occurrences are usually sporadic events on the road, which are represented with no reported accidents for most of road sections. Excessive zeros make the distribution of accident occurrences positively or rightly skewed. Therefore, multiple linear regression with normal assumption and homoscedasticity has been recognized as inappropriate to model accident occurrences (Miaou and Lum 1993; Miaou et al. 1993).

Accident counts are non-negative, small, and integral count data and accident frequencies are generally believed to have a Poisson distribution. Poisson regression is another choice for building accident models. On the other hand, accident counts with a Poisson distribution should have distribution property of equivalent mean and variance. However, the variance of observed accident data usually exceeds the mean, namely overdispersion. This overdispersion phenomenon was believed to be from several possible sources. First, some omitted variables such as human factors and weather that may have influences on the occurrences of accidents are not included in the model. Second, sampling errors and nonsampling errors in the traffic data (e.g. daily, day of week, seasonal and spatial variations) and accident data (e.g. underreporting and the location of accidents) contribute to uncertainties on vehicle exposure data such as the annual average daily traffic (AADT) and accident counts. Third, roadway environment (including lighting and weather conditions) and traffic conditions may not be homogeneous on each road section during a sample period. Fourth, the occurrences of accidents on different analyzed road sections might be positively correlated. As a result of extra variations or overdispersions that exist in the data over a Poisson model, the variances of the estimated model coefficients tend to be underestimated (Miaou and Lum 1993; Miaou et al. 1993).

One simple way to adjust for the overdispersion problem is to allow the variance function of Poisson distribution to multiply a factor $\varphi$ (referred to as overdispersion factor). Therefore, the variance becomes $\varphi\mu$ , instead of $\mu$ as that originally assumed in the Poisson model (Wedderburn's suggestion, cited in Miaou 1994). The overdispersion factor $\varphi$ can be estimated by the scaled deviance and Pearson's chi-square statistics in the Maximum Likelihood Estimation (MLE). The covariance matrix of the parameter estimates is inflated by $\varphi$, and the log likelihoods are also divided by $\varphi$, which is an example of a quasi-likelihood function. However, this function is not a legitimate log-likelihood function. Both scaled deviance and Pearson's chi-square statistics are chi-square distributed only in certain regularity conditions, therefore may have lack of fit problems (McCullagh and Nelder 1989; "*SAS/STAT® 9.1 User's Guide*" 2004).

Alternative way of dealing with overdispersed data is to use more general probability distributions such as the negative binomial (NB) distribution or double Poisson distribution (Miaou and Lum 1993). NB models have been widely employed to investigate various safety effects in recent years (Miaou et al. 1993; Miaou 1994; Shankar et al. 1995; Poch and Mannering 1996; Wang and Nihan 2004; Zhang and Ivan 2005). Miaou et al. (1993) pointed out that "Although, the negative binomial model is more general than the Poisson model, it requires much more extensive numerical computation to estimate model parameters and to generate inferential statistics. In addition, the statistical properties of different estimators (e.g. MLE and moment estimators) of the negative binomial regression model for this particular problem have not yet been fully investigated"(Miaou et al. 1993, p. 99). However, with the advances of computation technology, computation and estimating of parameters and statistics do not become a problem at all.

Zero-inflated Poisson (ZIP) regression was introduced by Lambert (1992) to model a count data with excess zeros. It assumes that with probability $p_0$ the possible observation is zero, and with probability $1-p_0$, a Poisson distributed random variable is observed. Under this assumption, zero counts might come from two different sources or two distinct distributions. In the example of defects in manufacturing, when equipment is in a perfect state, defects may be nearly impossible; while equipment is in an imperfect state, defects may occur according to a Poisson distribution. Therefore, zero defects may come from equipment in a perfect state and that in an imperfect state. A logistic distribution is used to determine if a zero count comes from a perfect state or an imperfect state. The imperfect state can be modeled as Poisson or negative binomial distributed (Greene 1994).

Due to zero-inflated regression's applicability of modeling count data with excess zeros and its improved statistics fit in comparison with Poisson and NB models, zero-inflated regression models including the ZIP and the zero-inflated negative binomial (ZINB) have been widely employed to model accident counts, which also have typical excess zeros (Miaou 1994; Shankar et al. 1997; Lee and Mannering 2002; Lee et al. 2002; Qin et al. 2004). It seems that the first type of zero-inflated regression model was used in road safety analysis by Miaou (1994) in the earlier study of the relationship between truck accidents and geometric design of road sections to account for the potential underreporting of vehicle accidents. Shankar et al. (1997) cited it as a 'zero-truncated' Poisson model.

Shankar et al. explored the applicability of ZIP and ZINB to roadway accident frequencies. ZIP and ZINB distinguish sections of roadway that are truly safe (near zero-accident likelihood) from those that are unsafe but happen to have zero accidents observed during observation periods. In other words, accident occurrences may come from two states. One state is the zero-accident state when a road section is inherently safe. Another state is the accident state (which may be observed with zero accident count in an observation period) where accident frequencies follow the Poisson or NB distribution). The zero-accident state may be truly a zero-accident state on those inherently safe road sections or an accident state without being reported due to the fact that accidents may not have reached the prescribed accident reporting threshold, or an accident state just near misses on a potentially dangerous road section with zero accident reported.

Consider the issue of accident counts on short time scales, let say, a roadway section was observed with no accidents for a one-year period. This roadway section could be in the zero-accident state or may be in the accident state and just happened to have zero accident over the observed period. Shankar et al. cited the Lambert study and pointed out that slight changes in unobserved accident-inducing factors can cause the accident process to move back and forth between the zero-accident state and the accident state. The authors investigated the serial correlation issue resulting from using accident frequencies in consecutive years and found that no significant differences in the coefficient estimates.

In two newly published papers, Lord et al. (2005; 2007) provided some defensible guidance about how to appropriately model crash data, and presented two critical and relevant issues: the maximizing statistical fit fallacy and logic problems with the zero-inflated model in highway safety modeling.

To test the specification of zero-inflated regression models over the traditional Poisson and NB models, Greene (1994) testified the use of Vuong's statistic V that was proposed by Vuong (1989) for model selection of non-nested models. If |V| is less than 1.96 (the 95% confidence level for the t-test), it does not indicate any favored model. If V is greater than 1.96, the zero-inflated regression model is favored. If a V value is less than -1.96, the traditional Poisson or negative binomial model is favored. Also, Greene (1994) pointed out that Vuong's test can be used to test the restriction of the Poisson distribution on the negative binomial distribution.

In summary, there are several choices of statistical tools to model crash data in the road safety analysis. Multiple linear regressions have been proven inappropriate to model accident occurrences due to its distribution assumption and homoscedasticity. The Poisson model is believed to be suitable for discrete, nonnegative, and integral accident counts in highway safety analysis. The NB model can be used to account for the overdispersion phenomenon in the Poisson regression model. The zero-inflated regression models (ZIP and ZINB) are models for count data with excess zeros, and can improve statistical fit. Therefore, as Miaou (1994) recommended, the Poisson model can be used as an initial model for developing the relationship between accident occurrences and traffic characteristics, geometric design features, and environment, etc. If the overdispersion of accident data is found to be moderate or high, the NB regression and zero-inflated regression models (ZIP and ZINB) could be explored.

### 2.3.2 Division of Road Sections

In the reviewed literature, accident prediction models are usually built on the accident rates (e.g. Matthews and Barnes 1988; Lamm et al. 1988; Voigt 1995) or the accident counts (e.g. Zegeer et al. 1992). The accident rate is defined as the number of accidents per million vehicle kilometers or miles:

$$\text{Accident rate} = \frac{10^6 \times A}{AADT \times 365 \times L} \tag{9}$$

where

A = the number of accidents per year,

AADT = the average of annual daily traffic volume,

L = the length of road section, in kilometers or miles.

As we can see from the above formula, the accident rate and the length of road section are in a reciprocal relationship. In order to study the relationship of vehicle accident occurrences and highway geometric design, how do we divide our road sections, and what effects will the length of road sections have on the estimation of model coefficients based on the selected model forms and the model estimation methods? For example, if the observed accident happened to be located on a very short road section, the estimate can blow up.

Some studies chose to divide road sections into fixed-length sections (e.g. 1 mile in Urbanik et al. 1989; 1 kilometer in Zhang and Ivan 2005) to avoid the interference of section length. Miaou and Lum (1993) thoroughly investigated the issues of inclusion of short road sections, and designed a hypothetical example considering a set of $n$ homogenous road sections, one of which had one observed accident. They randomly divided that road section with one accident into $m$ smaller subsections with various lengths, which created $n+m-1$ homogeneous road sections. Their analyses of different models found that short road sections can have a detrimental impact on the estimation of model coefficients in the linear regression models while the Poisson regression models estimated by MLE is not sensitive to short road sections. Miaou (1994) also examined the effects of short road sections on the NB model and ZIP model, and concluded that these models using MLE are not sensitive to the inclusion of short road section and the NB model using the moment estimator is sensitive.

Besides the effects that the length of road sections may have on the estimation of model coefficients, changes in section lengths also affect the inclusion of variables in the models. Resende and Benekohal (1997) have shown that fewer variables will be present in the models as the section length increases. Therefore, the effects of individual geometric design elements may be ignored. Some studies selected long road sections (one consideration was the difficulty to find homogeneous road sections; another consideration was that the reported location of accidents are not always accurate) and used surrogate measures or composite measures (e.g. the extended NB model cited in Vogt and Bared 1998 and the NB generalized linear models in Zhang and Ivan 2005 that used a length weighted sum of values to represent horizontal curves, vertical curves and grades within each analyzed road section and ) to characterize those road sections that may contain multiple curves and multiple grades. Several problems may arise. One problem is that these measures are not unique, for example, different combinations of curves and grades can result in the same values. Another more important problem for studying relationship between accident occurrences and geometric features is that the individual effects are difficult to be considered; analyses of length of curve, length of grade, and continuous design conditions are difficult. Furthermore, these measures will also bring difficulty for design engineers in interpreting and incorporating these measures into their current design practice (Miaou and Lum 1993; Miaou et al. 1993, p.29).

To sum up, divisions of road sections may affect the estimation of model coefficients based on the selected models. However, the Poisson, NB, and ZIP models using the MLE are insensitive to the inclusion of short road sections. Besides, divisions of road sections are important to the study of relationship between accident occurrences and geometric features. They may influence the inclusion of variables for geometric features in the models, and also the evaluation of geometric characteristics within the analyzed sections.

### 2.3.3 Treatment of Vehicle Exposure

From the above section, we know that accident models can be formulated as two types based on the dependent variable. When the accident rate (number of accidents per million vehicle kilometers or miles) is modeled as the dependent variable, or the number of accidents as the dependent variable while the vehicle exposure AADT is an independent variable with coefficient equal to 1 (termed as "offset" in McCullagh and Nelder (1989)), the number of vehicle accidents occurring on a road section is actually believed to be proportional to vehicle exposure AADT. Another approach dealing with vehicle exposure (or road exposure) is to treat vehicle exposure AADT and section length as independent variables in the models and estimate the separate coefficients. Miaou and Lum (1993) recommended this way of treatment for part of the model diagnostic checking exercises.

Actually, the general belief that accident occurrences are linear with vehicle exposure AADT and road exposure (section length) is doubtful. Qin et al. (2004) examined the selection of exposure measures in crash prediction on two-lane highway segments in Michigan. The findings have shown that the relationship between crashes and vehicle exposure AADT is non-linear and varies by crash type. It is also shown that the relationship between crashes and section length is not linear, either. These results were consistent with some of the findings in the literature. For example, the estimated coefficients for the truck miles in two models of Miaou and Lum (1993) were 0.895 and 0.938, respectively.

## 2.4 CHALLENGES

A large number of individual research efforts have been focused on the 3D nature of highways which is resulted from the combination of horizontal and vertical alignment in the aforementioned aspects to improve highway design and road safety. However, fewer efforts were made to evaluate the safety effects of the coordination and interaction of combined horizontal and vertical alignment in a quantitative manner.

Most researches related to the safety effects of highway geometric alignments are limited to the individual elements. Some research efforts on the safety analysis of the coordination and interaction of combined horizontal and vertical alignment were focused on the combination of curvature and grade only, for example, the Dunlap et al. study in 1978 (as cited in Hauer 2001) and the study of Zador et al. (1987). Also, the findings are limited to some unfavorable combinations of extreme horizontal curvature and grade.

Due to the complexity of the superimposition of horizontal and vertical alignments, the available techniques and methods at the time of research, and the availability of complete and reliable data for sound safety analysis, not much statistically sound safety analysis on the safety effects of superimposed horizontal and vertical alignments has been conducted (Lamm et al. 1999). A major work on the superimposition of horizontal curve and grade done by Zador et al. (1987) was through comparisons of crash sites and comparison sites.

The statistics methodology applied to safety analysis of highway has advanced from the initial multiple regression technologies to the Poisson regression, to the NB regression, and to the zero-inflated regression (ZIP and ZINB). This study intends to explore the safety effects of superimposed horizontal and vertical alignment in a quantifiable manner with the aid of the Poisson, NB, and zero-inflated (ZIP and ZINB) methodology.

# Chapter 3. STUDY METHODOLOGY

In this chapter the study methodology is presented from three major aspects: statistical methodology, data collection, and detailed study design. The statistical methodology section presents the methodology of the Poisson, negative binomial (NB), zero-inflated Poisson (ZIP), and zero-inflated negative binomial (ZINB) models that were applied in the study. The second section describes the features of the data collected from Highway Safety Information System (HSIS) and the availability of the variables defined for accident occurrences, roadways, traffic volume, and geometric alignment. The study design section discusses in details the division of roadways, extraction of road sections from data files, and types of combinations of alignments to be considered in the study. In the end of the chapter, a summary of general descriptive statistics for the routes of two-lane rural roadways is given.

## 3.1 STATISTICAL METHODOLOGY

A number of statistical solutions to accident prediction models have been reviewed in the Chapter 2. Multiple linear regressions have been proven inappropriate to model accident occurrences due to its distribution assumption. To examine the safety effects of different combination of horizontal and vertical alignments, the Poisson model was first explored to find the relationship between accident occurrences and combination of horizontal and vertical alignments. After testing the overdispersion appearance, the NB and zero-inflated regression models (ZIP and ZINB) were examined too.

Vehicle exposure and road exposure were treated as an independent variable in the models and estimated separately. For one reason, vehicle accidents are not actually linear with vehicle exposure and road exposure, as shown from the previous chapter. For another reason, this treatment can check these relationships and diagnose if the models are appropriate. Furthermore, road exposure is the length of a road section, which is believed to be one of characteristics of a road section. The safety effect of a road section is represented by the probability of accident occurrences that vehicles travel along this road section with a specific length. Accident frequencies or the total number of vehicles involved in accidents after hundreds or thousands (or more) vehicles (same or different) run on this road section in a way represent the probability, although the accident occurrences are affected by vehicles' operating speed, the density of traffic, etc. and not linear with traffic volume. From the definition of the probability, the probability of a random event can be measured by the relative frequency of occurrences of an experiment's outcome when the experiment is repeated. Therefore, treating the length of a road section as an independent geometric variable is more plausible in understanding the influence of geometric design on safety effects of a road section (e.g. the length of a road section with a gradient affects the accident occurrences of trucks).

Based on the above consideration, the forms of four types of models (Poisson, NB, ZIP, and ZINB) were formulated as a function of traffic volume: annual average daily traffic (AADT), section length, and other geometric characteristic variables. The following illustrates briefly the four types of models explored in this study.

Let $Y_i$ be the dependent variable representing the number of accidents occurring on road section $i$ with the analyzed type of combination of horizontal and vertical alignments during the observed period of one year. Accident occurrences each year was considered as an observation. Let $y_i$ be the actual number of accidents observed on road section $i$ during the observation year, and $y_i$ is a nonnegative integer, where $y_i$= 0, 1, 2, 3, ..., and $i$ = 1, 2, 3, ..., n.

### 3.1.1 Poisson Model

The probability of $y_i$ accidents occurring on road section $i$ with a specific type of combination of horizontal and vertical alignments during the observation year, denoted as P($y_i$), is as follows if accident occurrences $Y_i$ follow a Poisson distribution:

$$P(Y_i = y_i) = \frac{e^{(-\lambda_i)}\lambda_i^{y_i}}{y_i!} \quad i = 1, 2, 3, \dots, n \tag{10}$$

where $\lambda_i$ is the expected value or mean of the Poisson distribution on road section $i$

$$\lambda_i = E(y_i). \tag{11}$$

In order to predict the safety effects on road section $i$, we need to build the expected value $\lambda_i$ as the function of a set of explanatory variables such as geometric design characteristics, traffic conditions, and other influencing factors, including a constant or intercept term on road section $i$ (denoted as $x_{i1}, x_{i2}, \dots, x_{ik}$). Assuming that $Y_i$, where $i$ = 1, 2, 3, ..., n, are independent Poisson distributed variables with mean of $\lambda_i$, a linear model would become in the following form:

$$\lambda_i = \mathbf{X}_i^{'}\boldsymbol{\psi}, \tag{12}$$

where $\boldsymbol{\psi}$ is the $k \times 1$ vector of unknown model coefficients, the transpose of which is denoted by $\boldsymbol{\psi} = (\psi_1, \psi_2, \ldots, \psi_k)$, and the transpose of the covariate vector is denoted by $\mathbf{X}_i^{'} = (x_{i1}, x_{i2}, \ldots, x_{ik})$. For a generality purpose, let $x_{i1}$ be a dummy variable equal to 1, and thus the corresponding coefficient $\psi_1$ represents the intercept.

However, this model can not guarantee that the mean $\lambda_i$ of the Poisson distribution on the left hand side of the equation is non-negative. A transformed mean, that is the logarithm of the mean here, is modeled instead. A generalized linear model for the Poisson distribution can be written as:

$$\log(\lambda_i) = \mathbf{X}_i^{'}\boldsymbol{\beta}. \tag{13}$$

If we write $\eta = \log(\lambda_i)$, log is the link function that link the response mean $\lambda_i$ to the linear predictor $\eta$ (McCullagh and Nelder 1989) .By changing log form in the above equation into an exponential form on both sides, a model is of the following form:

$$\lambda_i = \exp(\mathbf{X}_i^{'}\boldsymbol{\beta}) = \exp(\sum_{j=1}^{k} x_{ij}\beta_j), \tag{14}$$

which becomes the multiplicative Poisson regression model that was adopted in the literature (e.g. Miaou and Lum 1993; Miaou 1994; Vogt and Bared 1998).

The unknown model coefficients in the vector $\boldsymbol{\beta}$ can be estimated using Maximum Likelihood Estimation (MLE) (McCullagh and Nelder 1989). MLE maximizes the likelihood function that is the product of properties, or equivalently the log-likelihood function. Derived from Equation (13), the log-likelihood function for the Poisson distribution can be expressed as:

$$\log[L(\boldsymbol{\beta})] = \sum_i [y_i \times \log(\lambda_i) - \lambda_i - \log(y_i!)], \tag{15}$$

where $\lambda_i$ depends on the covariates in the vector $\mathbf{X}_i^{'} = (x_{i1}, x_{i2}, \ldots, x_{ik})$ and the unknown coefficients in the vector $\boldsymbol{\beta} = (\beta_1, \beta_2, \ldots, \beta_k)$ based on Equation (14).

### 3.1.2 Negative Binomial Model

The Poisson distribution has distribution property of equivalent mean and variance. However, due to several reasons as discussed in Chapter 2 (e.g. omitted variables in the model, sampling errors and nonsampling errors in the traffic and accident data, non-homogeneous roadway environment and traffic conditions, correlation of accident occurrences between analyzed road sections), the variance of the observed accident data usually exceeds the mean, namely overdispersion. An alternative way of dealing with overdispersion is to employ the NB distribution, which includes an independent gamma-distributed error term (Miaou et al. 1993; Miaou 1994; Shankar et al. 1995; Poch and Mannering 1996).

By adding a random error term $\varepsilon_i$ in the Poisson regression model to account for the overdispersion possible resources, Equation (14) can be rewritten as:

$$\lambda_i = \exp(\mathbf{X}_i^{'}\boldsymbol{\beta} + \varepsilon_i) \tag{16}$$

where $\exp(\varepsilon_i)$ is a Gamma-distributed error term with mean 1 and variance $\alpha$. A NB distribution can be derived as follows:

$$P(Y_i = y_i) = \frac{\Gamma(\theta + y_i)}{\Gamma(\theta)\Gamma(y_i + 1)} u_i^{\theta}(1 - u_i)^{y_i} \tag{17}$$

where $u_i = \theta/(\theta + \lambda_i)$, $\theta = 1/\alpha$, and $\alpha$, that is the variance of the gamma-distributed error term, is defined as the dispersion parameter.

The resulting variance for the NB distribution is given as

$$Var(Y_i) = E[Y_i](1 + \alpha E[Y_i]) = \lambda_i + \alpha\lambda_i^2 \tag{18}$$

As we can see from the above mean-variance relationship, the NB model allows the variance to be different from its mean, and thus relax the mean-variance equality constraint of the Poisson model. If $\alpha$ is significantly different from zero, the over-dispersion or under-dispersion phenomenon exists in the data. If $\alpha$ is not significantly different from zero, the NB distribution is equivalent to the Poisson distribution.

To test if the data are over-dispersed or under-dispersed, namely the dispersion parameter $\alpha$ is significantly different from zero, we constitute tests of the null hypothesis

$$H_0 : \alpha = 0 \tag{19}$$

against the alternative hypothesis

$$H_A : \alpha > 0. \tag{20}$$

Three statistical tests can be employed to test the null hypothesis against the alternative hypothesis: the Wald, the likelihood ratio (LR), and score or Lagrange multiplier (LM) tests (cited in Cameron and Trivedi 1986). The Wald test and LM test are available in most current statistical software packages (e.g. SAS®9). The Wald test can be performed based on the t-statistic for the estimated over-dispersion parameter $\alpha$ in the NB model. With SAS®9, the LM statistic can be obtained by using these options in the MODEL statement of the GENMOD procedure: DIST=NEGBIN SCALE=0 NOSCALE ("*SAS/STAT® 9.1 User's Guide*" 2004). The Wald and LM tests were employed in this study.

Again, the coefficients $\boldsymbol{\beta} = (\beta_1, \beta_2, \ldots, \beta_k)$ and the dispersion parameter $\alpha$ can be estimated by MLE maximizing the log-likelihood function for the NB distribution. The derived log-likelihood function is given as:

$$\begin{aligned}\log(L(\boldsymbol{\beta},\alpha)) = \sum_i \{&\log[\Gamma(1/\alpha + y_i)] - \log[\Gamma(1/\alpha)] - \log[\Gamma(y_i + 1)] \\ &+ y_i \log(\alpha\lambda_i) - (y_i + 1/\alpha)\log(1 + \alpha\lambda_i)\}\end{aligned} \tag{21}$$

where $\lambda_i = \exp(\mathbf{X}_i'\boldsymbol{\beta}) = \exp(\sum_{j=1}^{k} x_{ij}\beta_j)$.

### 3.1.3 Zero-Inflated Poisson Model

The ZIP model (e.g. Lee and Mannering 2002; Lee et al. 2002; Qin et al. 2004 ) assumes that accident occurrences on road section $i$ with the analyzed type of combination of horizontal and vertical alignments during the observed period of one year may come from two states. One state is the zero-accident state when a road section is inherently safe. Another state is the accident state or non-zero state where accident frequencies follow the Poisson distribution. Let $p_i$ be the probability that road section $i$ will exist in the zero-state over the observation year. Accordingly, the probability of road section $i$ existing in the accident state is $1-p_i$. Assuming that the accident occurrences $Y_i$ on road section i are independent, the probability distribution of the ZIP model is as follows:

$$P(Y_i = 0) = p_i + (1 - p_i)e^{-\lambda_i} \tag{22}$$

$$P(Y_i = y_i) = (1 - p_i)\frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}, \; y_i = 1, 2, 3, \ldots \tag{23}$$

The probability of being in the zero-accident state $p_i$ is formulated as a logistic distribution. A generalized linear model for the logistic distribution can be written as:

$$\log(\frac{p_i}{1 - p_i}) = \mathbf{Z}_i^{'}\boldsymbol{\gamma} \tag{24}$$

where $\boldsymbol{\gamma}$ is a vector of unknown model coefficients, and $\mathbf{Z}_i$ is the covariate vector, the transpose of which is denoted by $\mathbf{Z}_i^{'} = (z_{i1}, z_{i2}, \ldots, z_{ip})$. By exponentiating the above equation, a model for the probability of being in the zero-accident state $p_i$ is given as:

$$p_i = \frac{\exp(\mathbf{Z}_i^{'}\boldsymbol{\gamma})}{1 + \exp(\mathbf{Z}_i^{'}\boldsymbol{\gamma})} \tag{25}$$

The parameters $\boldsymbol{\gamma} = (\gamma_1, \gamma_2, \ldots, \gamma_p)$ can be estimated by MLE maximizing the log-likelihood function for the probability distribution of the zero-state part in the ZIP model:

$$\log(L(\boldsymbol{\gamma})) = \sum_i \log[p_i + (1 - p_i)e^{-\lambda_i}] \tag{26}$$

where $p_i$ depends on the covariates $\mathbf{Z}_i^{'}$ and a vector of $p$ parameters $\boldsymbol{\gamma}$ through Equation (25).

Similar to the Poisson distribution, the mean of the probability distribution of the accident-state part in the ZIP model can be modeled as:

$$\lambda_i = \exp(\mathbf{X}_i^{'}\boldsymbol{\beta}) \tag{27}$$

where $\mathbf{X}_i^{'}$ is the covariate vector, and $\boldsymbol{\beta}$ is the coefficient vector. The coefficients $\boldsymbol{\beta}$ are obtained by maximizing the log-likelihood function for the Poisson distribution of the accident-state part in the ZIP model:

$$\log[L(\boldsymbol{\beta})] = \sum_i [\log(1 - p_i) + y_i \times \log(\lambda_i) - \lambda_i - \log(\Gamma(y_i + 1)] \tag{28}$$

where $\lambda_i$ depends on the covariates $\mathbf{X}_i^{'}$ and a vector of $k$ coefficients $\boldsymbol{\beta}$ through Equation (27). The covariates that affect the mean $\lambda_i$ of the Poisson distribution may or may not be the same as the covariates that affect the probability of the zero-accident state $p_i$. When all the covariates are the same, the ZIP model is simplified to become a ZIP($\tau$) model (Lambert 1992).

### 3.1.4 Zero-Inflated Negative Binomial Model

The ZINB regression model (e.g. Shankar et al. 1997; Lee and Mannering 2002) can be formulated in a similar way to the ZIP model. Assuming that the accident occurrences $Y_i$ on road section i are independent, the probability distribution of the ZINB model is as follows:

$$P(Y_i = 0) = p_i + (1 - p_i) u_i^{\theta} \tag{29}$$

$$P(Y_i = y_i) = (1 - p_i)\left[\frac{\Gamma(\theta + y_i)}{\Gamma(\theta)\Gamma(y_i + 1)} u_i^{\theta}(1 - u_i)^{y_i}\right],\ y_i = 1, 2, 3, \ldots \tag{30}$$

where $u_i = \theta / (\theta + \lambda_i)$, and $\theta = 1/\alpha$, $\alpha$ is the dispersion parameter; $p_i$ is the probability for the zero-accident state on road section $i$ during the observation year.

$p_i$ is formulated as a logit model such that:

$$p_i = \frac{\exp(\mathbf{Z}_i' \boldsymbol{\gamma})}{1 + \exp(\mathbf{Z}_i' \boldsymbol{\gamma})} \tag{31}$$

and the mean $\lambda_i$ of the NB distribution of the accident-state part in the ZINB model can be modeled as a generalized linear model form:

$$\lambda_i = \exp(\mathbf{X}_i' \boldsymbol{\beta}) \tag{32}$$

where $\mathbf{Z}_i'$ and $\mathbf{X}_i'$ are covariate vectors; $\boldsymbol{\gamma}$ and $\boldsymbol{\beta}$ are coefficient vectors. The estimation of coefficients $\boldsymbol{\gamma}$ and $\boldsymbol{\beta}$ together with the dispersion parameter $\alpha$ can be obtained by MLE maximizing the following log-likelihood functions in the ZINB model:

$$\log(L(\boldsymbol{\gamma})) = \sum_i \log\left[p_i + (1 - p_i)\left(\frac{1}{1 + \alpha\lambda_i}\right)^{1/\alpha}\right] \tag{33}$$

$$\log(L(\boldsymbol{\beta}, \alpha)) = \sum_i \{\log(1 - p_i) + \log[\Gamma(1/\alpha + y_i)] - \log[\Gamma(1/\alpha)]$$

$$- \log[\Gamma(y_i + 1)] + y_i \log(\alpha\lambda_i) - (y_i + 1/\alpha)[\log(1 + \alpha\lambda_i)]\} \tag{34}$$

## 3.2 DATA COLLECTION

To investigate the safety effects of different combinations of horizontal and vertical alignments, seeking the complete and reliable data is paramount for sound safety analysis. The ideal database has accident data, associated traffic volume and locations, and geometric data. The efficient link between accidents, traffic volume and geometric data exists so that data can be assembled and the potential impacts of alignment combinations can be analyzed.

The HSIS in the Unite States is a system developed by the Federal Highway Administration (FHWA) to facilitate highway safety research. The HSIS provides quality data on a large number of accident, roadways, and traffic conditions collected by the States for the management of the highway system and for the study of highway safety. At present, the HSIS includes data from nine States: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, Utah, and Washington. Depending on the States, the files for crash data, roadway inventory, traffic volume, roadway geometrics, vehicle identification number, intersection, interchange/ramp, and guardrail/barrier may be available (http://www.hsisinfo.org).

By preliminarily examining the available variables in the guidebooks for each HSIS State and the exact files that were obtained (the files including those for Washington, Minnesota, California, and Ohio), the Washington State was selected to have the most complete and reliable information on highway geometric features: horizontal curves, vertical curves, and vertical grades. The requested data included the following nine separate files for each of the four years (2002-2005) in the Excel format:

1) Roadway inventory files,
2) Accident files,
3) Horizontal curve files,
4) Grade files (including vertical curves and grades),
5) Vehicle files,
6) Special-use lane files,
7) Left/right crossing files,
8) Railroad crossing files.

The data covered accident experiences on eleven different roadway classes:

'01' = 'URBAN FREEWAYS'
'02' = 'URBAN FREEWAYS < 4 LN'
'03' = 'URBAN 2 LANE ROADS'
'04' = 'URBAN MULTILANE DIVIDED NON FREEWAYS'
'05' = 'URBAN MULTILANE UNDIVIDED NON FREEWAYS'
'06' = 'RURAL FREEWAYS'
'07' = 'RURAL FREEWAYS < 4 LN'

'08' = 'RURAL 2 LANE ROADS'

'09' = 'RURAL MULTILANE DIVIDED NON FREEWAYS'

'10' = 'RURAL MULTILANE UNDIVIDED NON FREEWAYS'

'99' = 'OTHERS'

This study was to focus on the safety effects of combined horizontal and vertical alignments on rural two-lane highways with legal speed limits ranged from 55 to 65 mile per hour (88.5-104.6 kilometers per hour).

### 3.2.1 Accident Data

The accident data that were obtained via HSIS were collected statewide by all police departments in the Washington state on a standard accident report form. The prescribed accident reporting threshold was $750 or personal injury since January 1, 2000. The crash location was consistently coded by coding staff in the Transportation Data Office based on location-related information provided by the investigating officer on the form and on his/her reference map/sketch. The reference points of accident occurrences were coded based on standard accident locator log and physical reference markers that were installed on interstates and other state routes in both urban and rural locations. While some may be missing in urban areas, the rural state systems seem to be intact. Therefore, according to the HSIS Guidebook for the Washington State Data Files (Council et al. 2006), over 95% of the rural accidents were located to at least the nearest 1/10 of a mile. The accurate locations of accident occurrences were of great importance for this study to analyze the potential impacts of combined horizontal and vertical alignments on road safety, and made it possible to divide roadway sections into smaller subsections with more specific combination of alignments.

The obtained accident data files contained the basic accident information on a case-by-case basis. The following main relevant variables were available:

- Route number,
- Milepost,
- Roadway class,
- Case number,
- Accident type,
- Severity,
- Collision type,

- Collision type for first collision,
- Collision type for second collision,
- Weather condition,
- Lighting condition, etc.

They were "point" files describing accident information about specific points (mileposts) on the roadway. A separate vehicle file was also provided for each of the four years, which can be linked the basic accident file based on the case number. Although the total number of all types of accidents occurred on the road sections were counted and included in the roadlog files, those number were not useful in this study. For one reason, not all types of accidents were related to geometric design, for example, the accidents caused by animals, trains, pedestrians, pedal-cyclists, etc. For another reason, the road sections in the roadlog files were not road sections to be analyzed in this study.

One important limitation about the accident data is that the location of an accident occurrence was not specified by the driving direction as left or right side of the roadway. Due to this limitation, the accidents occurring on the grade road sections were not able to be identified as whether they were attributed to the appearance of downgrades or upgrades.

The types of accidents caused by animals, trains, pedestrians, pedal-cyclists, non-collision fire were eliminated based on the general accident type variable; those types of accidents resulted from turning, parked, passing and entering vehicles were removed from the accident data file by the variable of collision type for first collision. The removed accidents were the same as what some researchers considered (e.g. Fitzpatrick et al. 2000b, and Zegeer et al. study cited in Fitzpatrick et al. 2000b).

The analysis in this study only considered non-intersection-related accidents for the safety effects of combined horizontal and vertical alignments. The range of intersections where accidents that were believed to be intersection-related occurred was considered differently in the reviewed literature. Fitzpatrick et al. (2000b) eliminated portions of the roadway within 0.8 km (800 m) of an intersection with stop or signal control for traffic, and railroad grade-crossing during the safety analysis of highway geometric design consistency. Vogt and Bared (1998, p.38) considered accidents that occurred within 250 feet (about 76 m) of an intersection as intersection-related accidents. Ng and Sayed (2004) considered accidents that occurred within 50 m of signalized intersections or within 20 m of all other types of intersections as accidents that might be related to the presence of a nearby intersection. Harwood et al. (2000, p.7) categorized accidents that occurred within 76 m (250 ft) of the intersection and occurred because of the presence of the intersection as intersection- related accidents during modeling the expected safety performance of rural two-lane highways. After a general review of the current literature, accidents that occurred within 76 m (250 ft) of an intersection were removed during this study. The intersection types included the following determined through *trf_cntl*, a variable for intersection control type, in the roadway inventory files:

1) 'SS' = 'STOP SIGN',

2) 'SG' = 'STOP AND GO',

3) 'RF' = 'RED FLASHING',

4) 'RS' = 'RAILROAD SIGNAL',

5) 'YS' = 'YIELD SIGN';

and railroad grade crossing intersections in the railroad crossing files with the variable *rrx_type* = G (GRADE CROSSING). The milepost of an intersection was at the beginning of the section in the raw files. Thus, the beginning milepost and end milepost of an intersection range that was removed were determined. For close intersections with a distance of less than 3 times 75 m, accidents that occurred between 76 m (250 ft) before the milepost of first intersection and 76 m (250 ft) after the milepost of last intersection were eliminated, too.

### 3.2.2. Roadway and Traffic Volume

Roadway information and traffic volume were shown in the basic roadway inventory files (referred to as roadlog files in HSIS). The files contained information on a homogeneous section of roadway, which was a stretch of road with consistent roadway characteristics. When any of the characteristics changed, a new section was defined. Therefore, the roadlog files were "section" files. According to the requested data files in this study, each record in the roadlog files contained the main variables as follows:

- Route number,
- Beginning and end milepost of road section,
- Roadway class,
- Annual Average Daily Traffic (AADT),
- Legal speed limit,

- Function class,
- Surface width,
- Lane width and type,
- Shoulder width and type,
- Median information,
- Rural/urban codes,
- Traffic control.

There were some roadway sections with AADT equal to zero or missing in the original roadlog files. They were removed from this study.

### 3.2.3 Geometric Data

The data on the geometrics of horizontal alignments and vertical alignments were given in two separate files. The horizontal curve files included the following relevant variables:

- Route number,
- Beginning and end mileposts of horizontal curve: *begmp* and *endmp*,
- Radius,
- Degree of horizontal curve,
- Curve central angle,
- Horizontal curve length,
- Direction of horizontal curve.

The grade files included the following relevant variables:

- Route number,
- Beginning milepost of approach grade: *begmp* (in miles),
- Percentage of approach grade: *pct_grad*,
- Direction of approach grade,
- Grade type (indicating whether the end of the grade is connected to the succeeding grade with a vertical curve or an angle point),
- Vertical curve length: *vcurv_lgt* (in feet)
- End milepost of vertical curve (equal to the beginning milepost of departure grade): *endmp* (in miles)
- Section length: *seg_lng* (in feet).

Each record in the grade files showed the information about the road section from the beginning milepost of the approach grade to the end milepost of vertical curve, which was the beginning milepost of departure grade (refer to Figure 2).

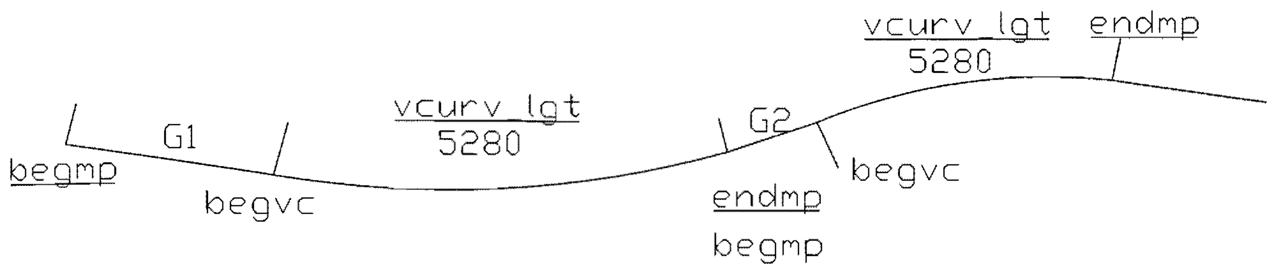



**Figure 2.** Draft Road Sections Shown in the Data Record of Grade Files

More variables about the characteristics of grade and vertical curves were calculated based on the available variables.

- Beginning milepost of vertical curve:

$$begvc = endmp - \frac{vcurv\_\lg t}{5280} \tag{35}$$

- Grade length:

$$grad\_\lg t = begvc - begmp \tag{36}$$

- Algebraic difference in grade: Based on the *pct_grad* variable and direction of grade of the first record and the *pct_grad* variable and direction of grade of the succeeding record, algebraic difference in grade was calculated.

$$A = | G_2 - G_1 | \tag{37}$$

- Rate of vertical curvature:

$$K = \frac{vcurv\_\lg t}{A} \tag{38}$$

- Vertical type: Vertical curves were classified as crest vertical curves (type I and II) and sag vertical curves (type III and IV) based on AASHTO (2001, p. 269).

## 3.3 STUDY DESIGN

Since the objective of this study was to analyze the safety effects of combined horizontal and vertical alignments, models for relating accident occurrences to highway horizontal and vertical alignments, traffic, and other relevant characteristics needed to be developed. In order to explore how the different combinations and their interactions of horizontal and vertical alignment affect the safety, several separate combinations were examined. To this end, roadways have to be divided into analyzed road sections; the roadway characteristics, alignment features, traffic conditions, and other relevant characteristics relating to the road sections, and accident counts occurring on the road sections need to be determined. This section is organized as follows. The first subsection, *Subdivision of Analyzed Road Sections*, discusses the selected method of subdividing roadways into road sections to be analyzed. The second subsection, *File Merging*, describes how to rely on the SAS program to obtain roadway data, geometric data, and accident data on a road section before subdivision of road sections with the defined combinations of horizontal and vertical alignments. The third subsection, *Types of Alignment Combinations*, discusses the types of combinations to be considered in the study. How to extract the road sections with the defined combinations from the data files is presented in the last subsection, *Extraction of Alignment Combinations*.

### 3.3.1 Subdivision of Analyzed Road Sections

As the above indicated, the accident data in the accident files were identified by the route number and milepost where accidents occurred. They were "point" files indicating the location of accidents on the roadway. The roadlog files, horizontal curve files, and grade files were "section" files describing a homogeneous road section on the roadway, which was identified by the beginning milepost and end milepost and route number. However, all the beginning and end mileposts for a homogeneous road section in these three separate files may be different. In other words, each road section in the roadlog files was homogeneous in terms of basic roadway characteristics and traffic conditions and not necessarily homogeneous in terms of its horizontal alignment and vertical alignment. Similarly, each homogeneous road section in the horizontal curve and grade files in terms of it horizontal alignment or vertical alignment had not necessarily the same roadway characteristic and traffic conditions. Therefore, each road section in the roadlog files may contain multiple horizontal curves, vertical curves, or vertical grades, or may contain only part of those features. The road sections in the data files were not able to be used for analysis. For one reason, all the roadway characteristics, traffic conditions, horizontal and vertical characteristics have to be obtained on a road section. For another reason, the combination of the alignments is difficult to be determined.

Two ways of dealing with characterizing the road sections were used in the literature. One way is to create surrogate measures or composite measures to characterize horizontal curve and vertical alignments along with the length of each road section in the roadlog file, as Joshua and Garber's study cited in the Miaou et al. (1993). The limitations have been discussed in the *Division of Road Section* subsection in the literature review. Another way is to disaggregate those road sections with multiple horizontal curves, vertical curves, or vertical grades into smaller subsections in such a way that each subsection contains a unique set of horizontal curves, vertical curves, or vertical grades, as was the case with Miaou et al. (1993) study of the relationship between truck accidents and geometric design. As Miaou et al. pointed out, this way is considerably easier to interpret in a design context. Considering the combinations of horizontal and vertical alignments, it was decided in this study to subdivide each route of roadway into road sections with individual horizontal curves and tangents, in which the vertical curves or vertical grades were decided and thus the combination types of horizontal alignments and vertical alignments. This method provides an accurate way of characterizing road characteristics on a road section, and a proper way of exploring the interaction of combined horizontal and vertical alignments. Also, it may have more variables for individual characteristics to be accounted for in the models. However, it may create short road sections. As discussed in the literature, it will not influence the coefficients estimation in the models such as the Poisson, NB, and ZIP estimated by MLE method.

In this study, the same route of roadway was separately divided into road sections with specific types of combination based on the geometric design features in that year when the data were collected. In the meantime, even the same road section without any change of geometric design in different observation year was considered as a separate road section. This approach may create a serial correlation problem over time that would affect of coefficient estimates. The potential impact of this serial correlation was investigated by several researchers in their studies, and was shown that there were no significant differences in coefficients (Poch and Mannering 1996; Shankar et al. 1997; Shankar et al. 1998). This approach has the benefits of allowing the year-to-year changes on highway geometric design and traffic conditions to be considered in the model (Miaou and Lum 1993; Miaou 1994).

### 3.3.2 File Merging

As mentioned, the roadlog files, horizontal curve files, and grade files were "section" files identifying a homogeneous road section on the roadway by the beginning milepost and end milepost and route number. One pair of the beginning milepost and end milepost on the same route in these three data files may not necessarily represent the same road section. The roadway characteristics, alignment features, traffic conditions, and other relevant characteristics relating to a road section (possibly different) were stored in the three data files. In order to get the values of the variables regarding these characteristics and traffic conditions, it was considered to convert and merge all the section-based roadlog file, horizontal curve file, and grade file for each year into a "point" file describing all the roadway attributes, traffic conditions, alignment features, and other relevant characteristics relating to the special "points".

These "points", namely mileposts, included the beginning milepost and end milepost of a road sections in the roadlog files, the beginning milepost (point of curvature) and end milepost (point of tangent) of a horizontal curve and a vertical curve, the beginning milepost and end milepost of a road section that was removed due to an intersection interference, and the beginning milepost and end milepost of a route of roadway.

The following describes major steps to obtain those feature mileposts, all the roadway and geometric data, and traffic volume AADT related to them. Step 3 to step 6 are involved in converting section-based files into "point" files describing the general variables of roadway characteristics and AADT, horizontal curve variables, vertical curve variables, and grade variables related to a feature milepost such as point of curvature, point of tangent, point of vertical curvature, etc.

**Step 1.** Select rural two-lane highways with legal speed limits equal to or greater than 55 mile per hour (88.5 kilometers per hour) from the roadlog file. Before the selection of road sections, remove those road sections with AADT of zero or missing in the roadlog file.

It was found that there were 457 road sections in 2002, 472 road sections in 2003, 777 road sections in 2004, and 492 road sections in 2005 with AADT of zero or missing in the roadlog files, which were eliminated from this study.

**Step 2.** Eliminate the road sections that are within the range of 76 m (250 ft) of an intersection or close intersections that are 3 times 76 m (3 x 250 ft) away from each other (shown in Figure 3), thus accidents within this range of road section are not counted and intersection-related accidents are removed from the study. The resulted roadlog file, denoted as *waxxroad_rural* here ('xx' represents the observation year), becomes the major reference file into which other files merge. All the roadways covered by the road sections in the resulted roadlog file were selected for analysis in this study. Refer to Figure 4 and 5 for detailed procedures.

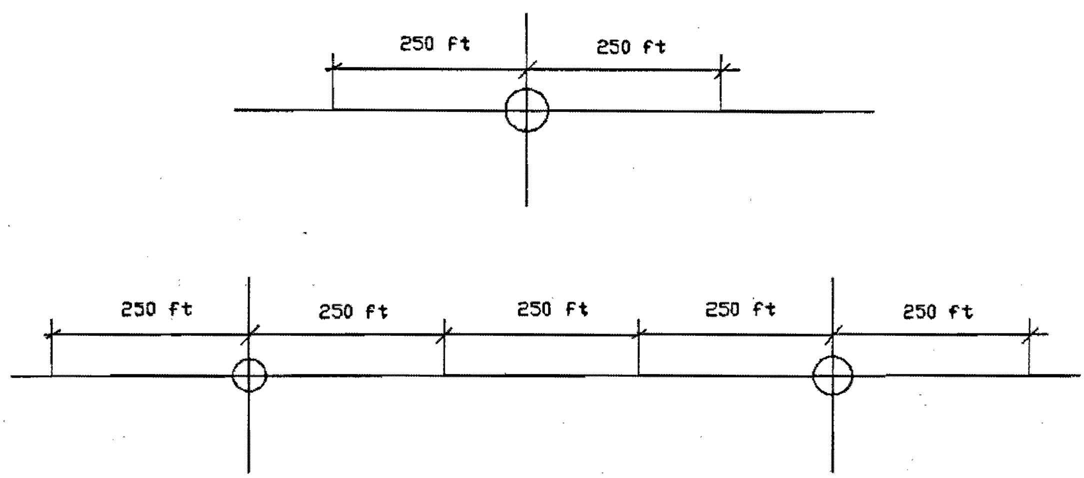



**Figure 3.** Intersection Range to be Eliminated

**Step 3.** Extract mileposts of the beginning and end of cut-off sections (including the sections cut off by intersections, railroad grade-crossing, and introduction of a new route of roadway) from the roadlog file: *waxxroad_rural*. The resulted table is a 'point' file with general variables of roadway characteristics and AADT.

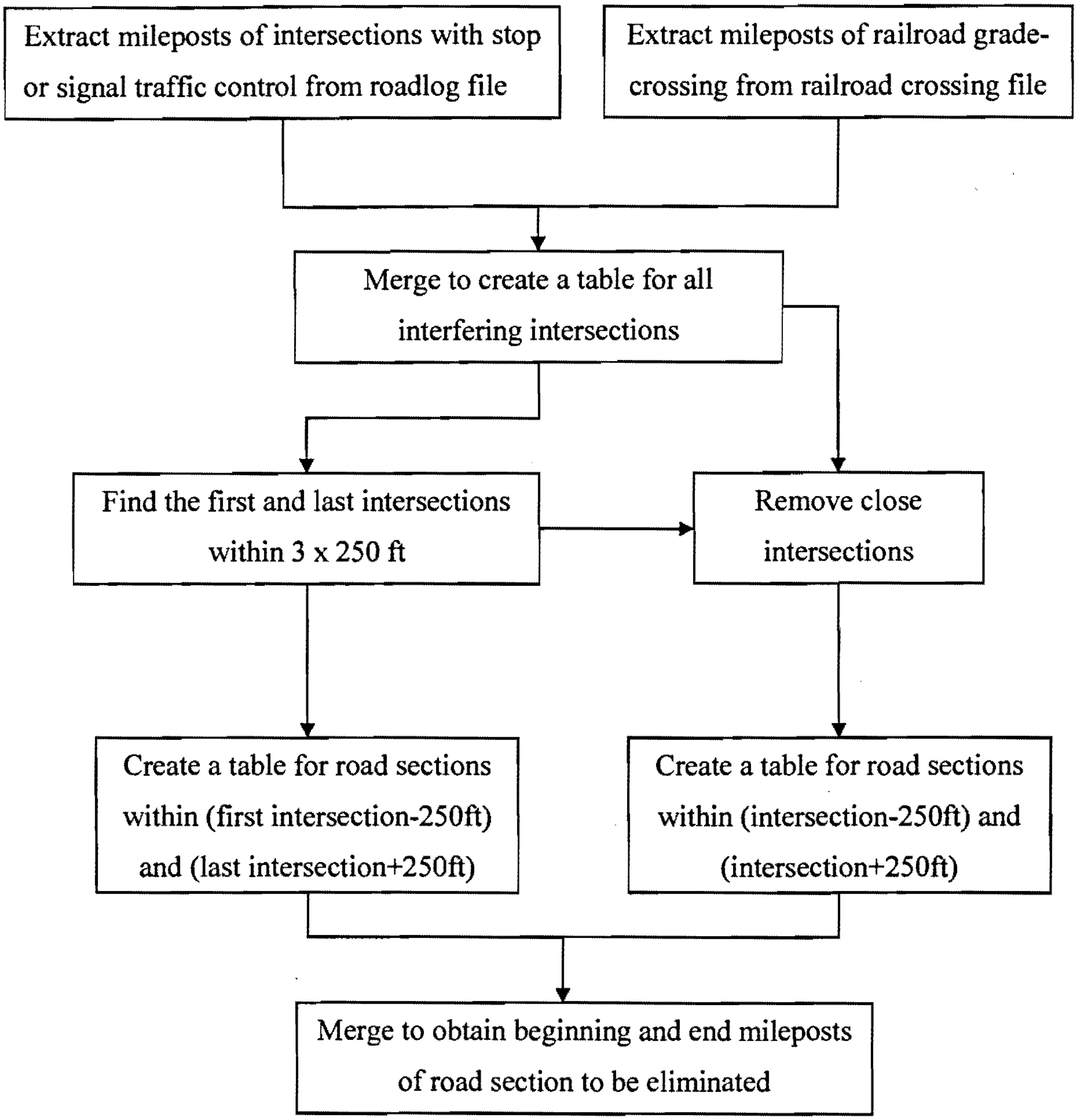



**Figure 4.** Extraction of Road Sections Influenced by Intersections

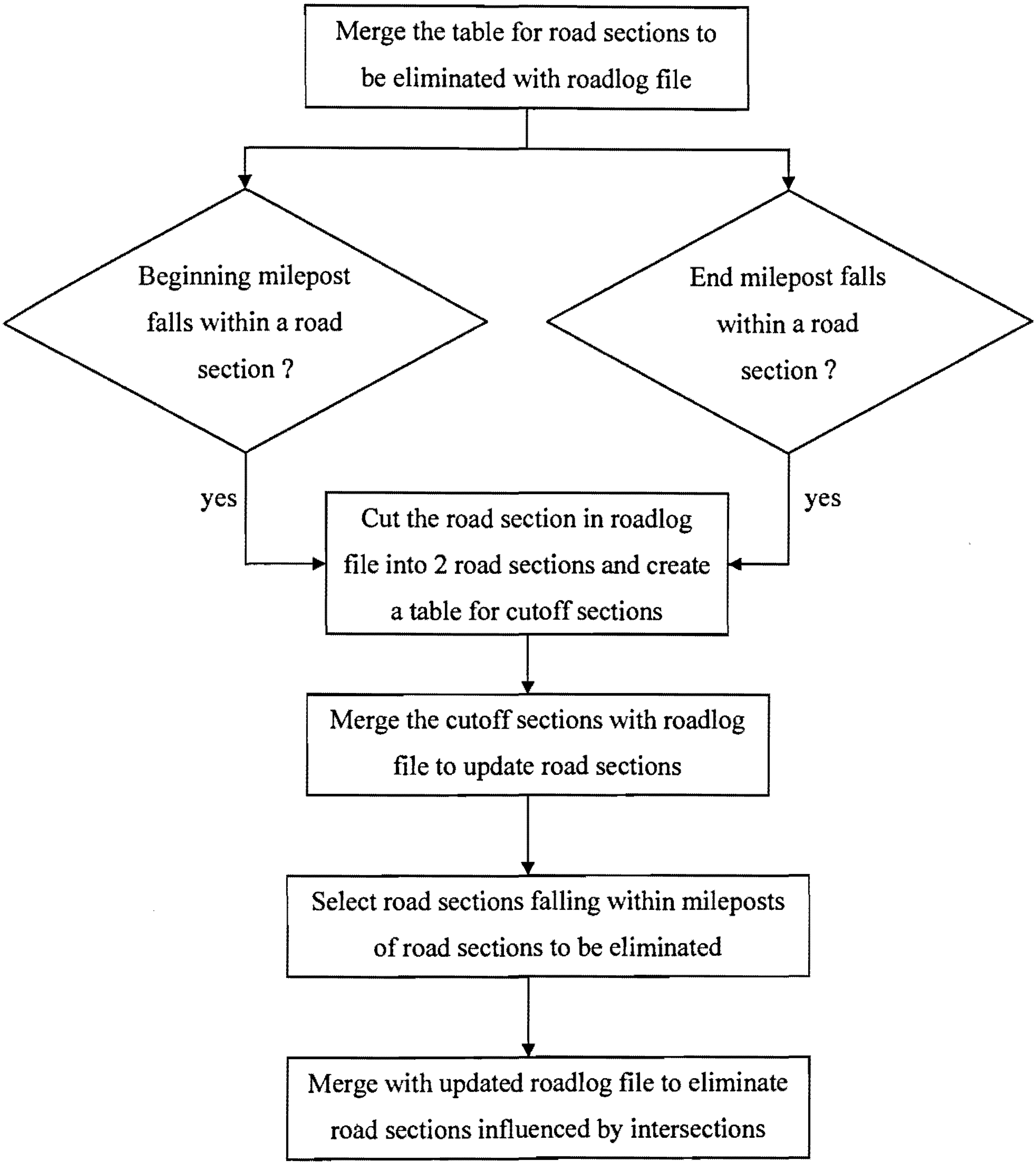



**Figure 5.** Elimination of Road Sections Influenced by Intersections

**Step 4.** Merge the horizontal curve file into the roadlog file by the beginning and end milepost of a horizontal curve, and route number and produce a roadlog file: *waxxroad_hcurv*. The flow chart of this process is shown in Figure 6. The beginning and end milepost of a horizontal curve are all listed as *begmp* variable in the resulted roadlog file, thus *waxxroad_hcurv* is a "point" file describing the beginning milepost and end milepost of a road sections in the original roadlog files, the beginning milepost (point of curvature) and end milepost (point of tangent) of a horizontal curve, the beginning milepost and end milepost of a road section that was removed due to an intersection interference, and the beginning milepost and end milepost of a route of roadway. In the mean time, *waxxroad_hcurv* can also be taken as a "section" file that road sections in the original roadlog file are not changed. It still can be used as a base file to retrieve the roadway characteristics and AADT. The merging of the grade file hereinafter will use the *waxxroad_hcurv* file.

**Step 5.** Similarly, merge the grade file into the roadlog file by the beginning milepost of a grade and the beginning milepost of a vertical curve, and produce a roadlog file: *waxxroad_hcurv_grad_vcurv*. Figure 7 represents the flow chart of this process. However, the horizontal curve, grade, and vertical curve variables are missing for those mileposts or road sections. Some mileposts may be the beginning of a horizontal curve and/or a grade and/or a vertical curve.

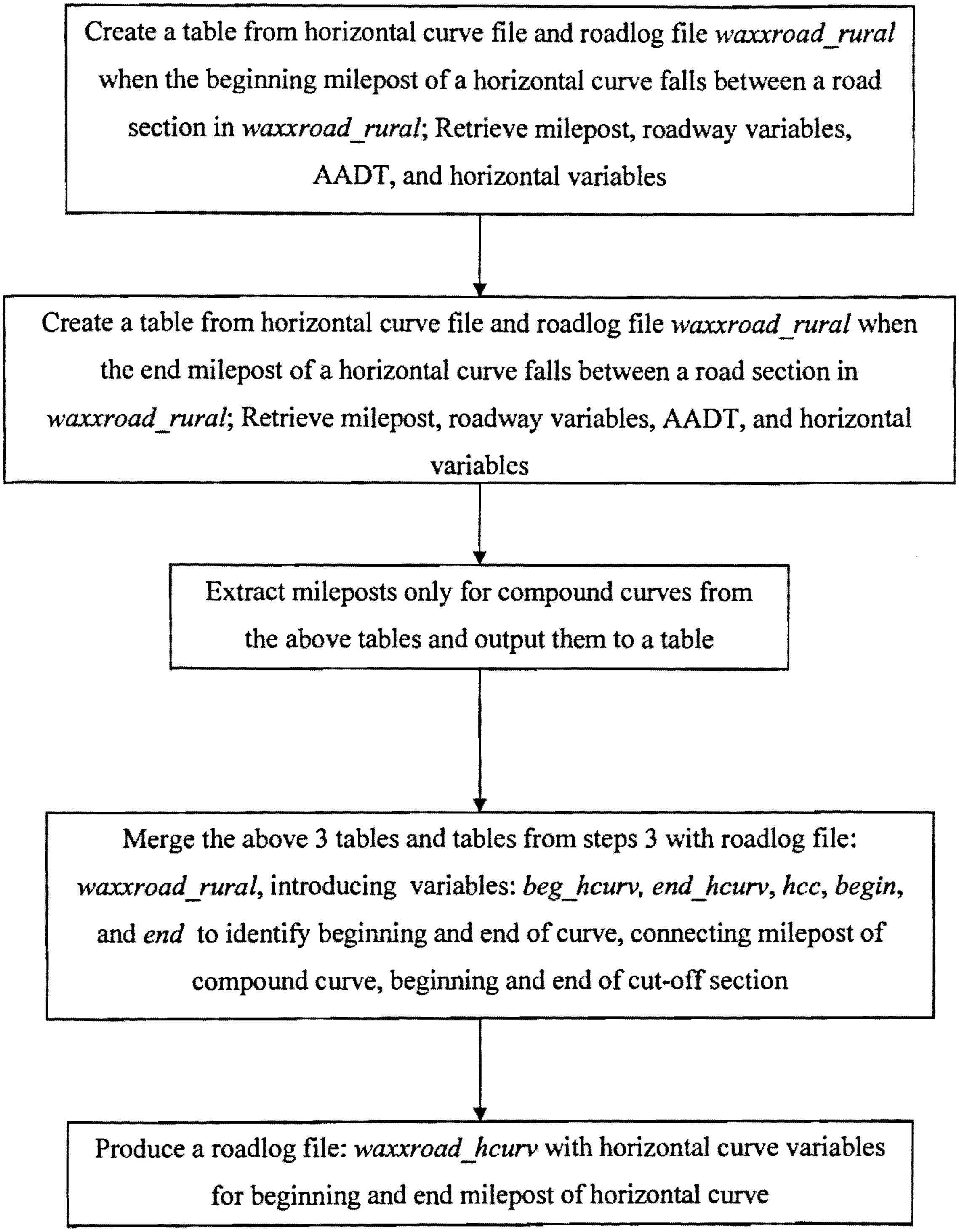



**Figure 6.** Merging of Horizontal Curve File with Roadlog File

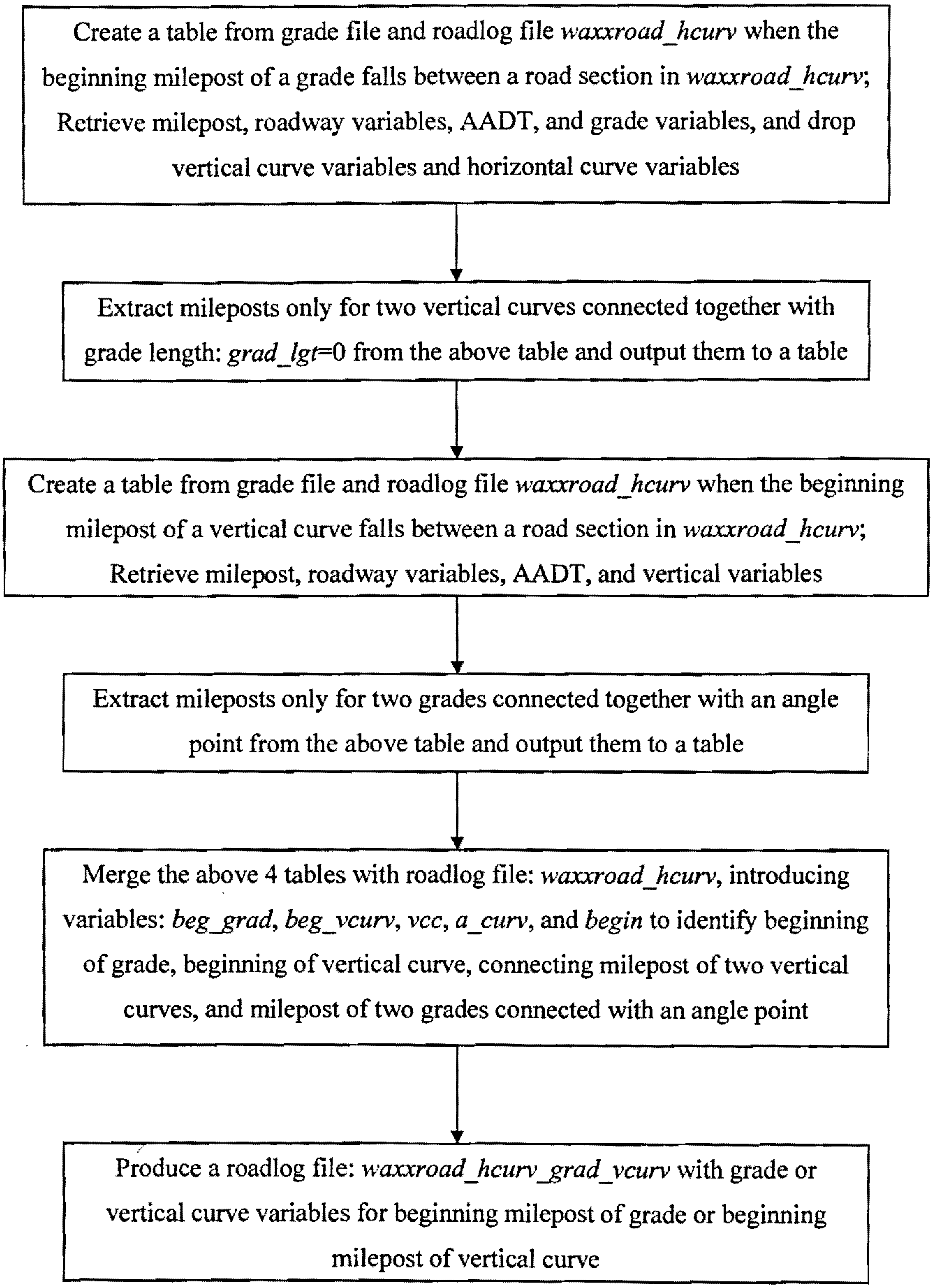



**Figure 7.** Merging of Grade File with Roadlog File

**Step 6.** If a road section that falls within a horizontal curve, or a grade, or a vertical curve, assign to it the same horizontal vertical variables, grade variables, or vertical curve variables as the horizontal curve, grade, or vertical curve that it falls within. In this way, it is easy to check the range of geometric design feature along the roadway in the records of the roadlog file *waxxroad_hcurv_grad_vcur*.

Therefore, after the merging of the horizontal file and grade file into the roadlog file for each of the observation years 2002-2005, the current roadlog file contains the general roadway variables, AADT, horizontal curve variables, grade variables, and vertical curve variables for those feature mileposts such as the beginning (point of curvature) and end (point of tangent) of a horizontal curve and a vertical curve, the beginning of a grade, the beginning and end of a road section that was removed due to an intersection interference, the beginning and end of a route of roadway as well as the beginning and end of a homogeneous road section defined in the original roadlog file. Except the beginning and end of a homogeneous road section defined in the original roadlog file, all other feature mileposts are merged and listed in the same column: *begmp* as the beginning milepost of those homogeneous road sections. As can be imagined, all the mileposts in the same column: *begmp* picture a "map" of the roadways to be analyzed. In other words, the merged roadlog file *waxxroad_hcurv_grad_vcur* is actually a "point" file that describes the important feature mileposts along the route of roadways.

During the file merging, it was found that there were some errors and some special values of variables that interfered with the merging operations or can be ignored during the analysis in the data files provided. The following treatments were applied:

- Horizontal curves with section length of zero in the horizontal curve files were removed: 7 curves in both 2002 and 2003, and 8 curves in both 2004 and 2005. Due to their very short curve length, their beginning and end milepost were equal, and section length was 0 after the number being rounded.
- Grades with section length of zero in the grade files were removed: 455 records in 2002, 462 records in 2003, 465 records in 2004, and 472 records in 2005. These records did not represent any alignments and would not influence the analysis.
- The mileposts at which two horizontal curves connected together were modified: for 5 records in the 4 years (representing 2 horizontal curves only), the beginning milepost of the second curve were made to equal to the end milepost of the first curve. In the year of

2002, the beginning milepost 21.61 at route 004 was modified to be 21.63. In the year of 2002, 2003, 2004, and 2005, the beginning milepost 40.45 was modified to be 40.47.

### 3.3.3 Classifications of Alignment Combinations

As we can see in the literature review, a large number of individual research efforts have been attracted to explore the three-dimensional (3D) nature of highways, which is resulted from the combination of horizontal and vertical alignment and its impact on drivers' perception, visual demand, sight distance, operating speed on the road, vehicles' stability, highway aesthetics, and road safety. A systematic quantitative evaluation of the safety effects of the combination and coordination of horizontal and vertical alignments does not seem to exist.

However, their approaches to the 3D nature of highway alignments shed light on this study. Some studies examined various effects such as drivers' perception, vehicles' stability, etc. from a 3D point of view. How the individual horizontal and vertical alignments affect those 3D attributes and interact with each other was not quite fully examined. Smith and Lamm (1994) conducted detailed analysis of the influence of the coordination of horizontal and vertical alignments on highway aesthetics. They cited six types of combinations of horizontal and vertical alignments in German design guidelines and discussed definitive guidelines for achieving safe and esthetically pleasing 3D alignments. The six types of 3D design elements include:

1) Curved crest vertical curve,
2) Curved sag vertical curve,
3) Curve with constant longitudinal slope,
4) Straight crest vertical curve,
5) Straight sag vertical curve,
6) Tangent with constant longitudinal slope.

Fitzpatrick et al. (2000b) explored the effects of superimposition of horizontal and vertical alignments on operating speed from ten different combinations (see Table 1) and their interaction in the effects. Therefore, it has been shown that separate different combinations of horizontal and vertical alignments help to investigate and understand their individual effects and interaction.

Based on the possible combinations, it was determined preliminarily in this study to investigate the safety effects of combinations of horizontal and vertical alignments and their interaction from the types defined in Table 2.

**Table 2.** Combinations of Preliminary Horizontal and Vertical Alignments

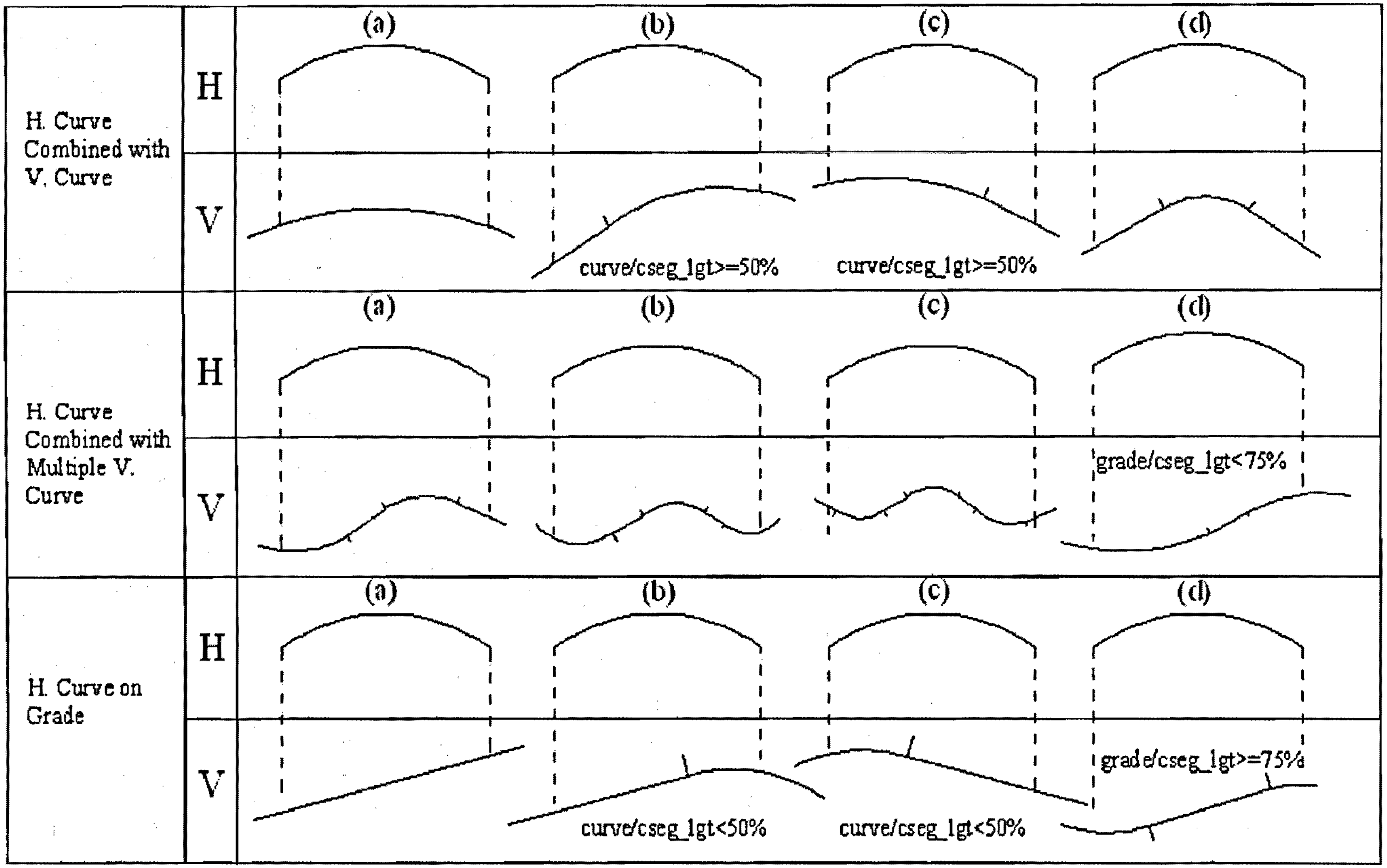
| Category | Combination No. | Type of Combination |
|---|---|---|
| Horizontal Curve Combined with Vertical Curve(s) | 1 | Horizontal Curve Combined with Crest Vertical Curve |
| | 2 | Horizontal Curve Combined with Sag Vertical Curve |
| | 3 | Horizontal Curve Combined with Multiple Vertical Curves |
| Horizontal Curve on Grade | 4 | Horizontal Curve on Grade: $\|G\| < 5$ |
| | 5 | Horizontal Curve on Grade: $\|G\| \geq 5$ |
| Vertical Curve (s) on Horizontal Tangent | 6 | Crest Vertical Curve on Horizontal Tangent |
| | 7 | Sag Vertical Curve on Horizontal Tangent |
| | 8 | Multiple Vertical Curves on Horizontal Tangent |
| Horizontal Tangent with Constant Grade | 9 | Horizontal Tangent with Constant Grade: $\|G\| < 5$ |
| | 10 | Horizontal Tangent with Constant Grade: $\|G\| \geq 5$ |

However, the determination of the combination types on the roadway is not straightforward because the superimposition of horizontal alignments and vertical alignments each other can be located anywhere. As to a specific combination of alignments, how to evaluate the geometric characteristics properly is another issue. As an example, when a vertical curve is combined with a horizontal curve, a vertical curve maybe superimposed with the horizontal curve fully or partly (see Figure 8). In other words, if we identify the range of a vertical curve by its point of curvature (VPC) and its point of tangent (VPT), the VPC or VPT maybe in or outside of the horizontal curve. In the case of (b) (in the second column of Figure 8) that only the VPC is located in the horizontal curve, the VPC maybe introduced near the beginning of the horizontal curve or the end of the horizontal curve. For both cases, if we characterize the superimposed vertical curve by the rate of vertical curvature $K$ or algebraic difference in gradient $A$, it is obviously unreasonable. For the case of the VPC introduced at the end of the horizontal curve, a vehicle mostly travels on a grade.

Motivated by the above considerations, this study classified a vertical curve superimposed with a horizontal curve on the VPC only based on the ratio of the length of the combined part of a vertical curve (denoted as *curve*) to the length of a horizontal curve (denoted as *cseg_lgt*). If the ratio *curve/cseg_lgt* is greater than 50%, the combination is classified as horizontal curve combined with vertical curve (further subdivided into crest vertical curve or sag vertical curve); Otherwise it is defined as horizontal curve on grade (further subdivided into grade: $|G|< 5$ or grade: $|G|\geq 5$). This applies to a vertical curve superimposed with a horizontal curve on the VPT only.

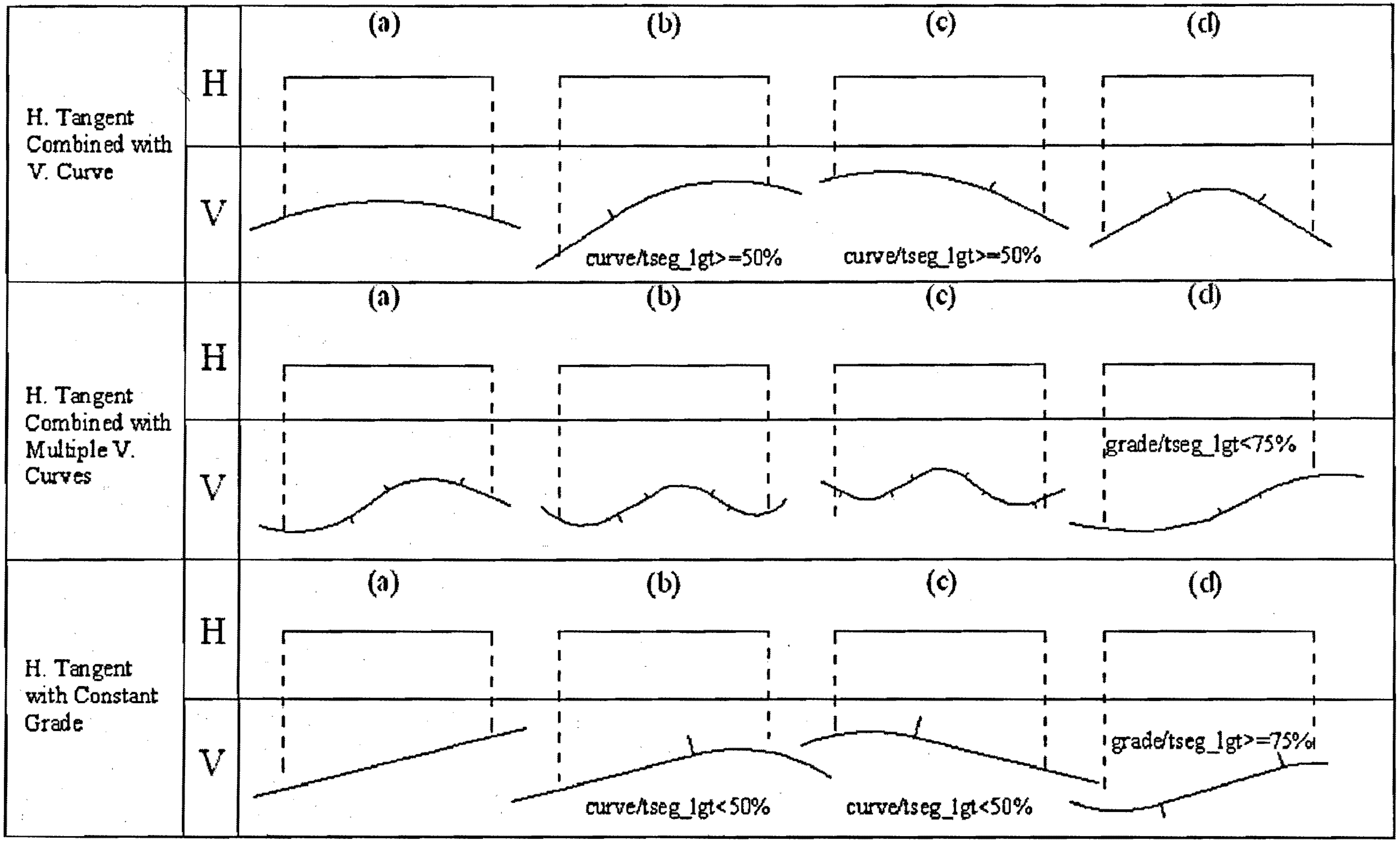
Similarly, when a vertical curve is superimposed with a horizontal curve on both VPC and VPT, the combinations may be the cases of (d) (see the column (d) in the Figure 8). If the VPC is followed by the VPT, then a vertical curve is superimposed fully with a horizontal curve. However, if it is the VPT that is followed the VPC, the combination will be two vertical curves superimposed with a horizontal curve and a grade between two vertical curves. In this case, this study classified it based on the ratio of the length of the grade (denoted as *grade*) to the length of a horizontal curve (denoted as *tseg_lgt*). If the ratio *grade/tseg_lgt* is greater than 75%, the combination is classified as horizontal curve on grade; otherwise it is defined as horizontal curve on multiple vertical curves.

The same classification rules apply to a horizontal tangent combined with vertical alignments (grade, crest and sag). See Figure 9 for detailed illustrations. Please note that only crest vertical curves are shown in the figures, and that they can be sag vertical curves, too. Multiple vertical curves can be the combination of multiple sag curves and/ or crest vertical curves.




Note: Vertical curve shown in the draft can be crest or sag vertical curve. Horizontal is denoted as H and vertical as V.

**Figure 8. Classifications of Horizontal Curve Combined with Vertical Alignment**




Note: Vertical curve shown in the draft can be crest or sag vertical curve. Horizontal is denoted as H and vertical as V.

**Figure 9. Classifications of Horizontal Tangent Combined with Vertical Alignment**

### 3.3.4 Extraction of Alignment Combinations

The above section illustrates the classification of the combinations of horizontal and vertical alignments. We can infer that it can be determined by the number of VPC and VPT, the relative sequence of VPC and VPT, and the percentage of the length of grade or vertical curve in the total length of horizontal curve or tangent. The VPC is identified by the beginning milepost of vertical curve: *beg_vcurv* variable and the VPT by the beginning of grade: *beg_grad* variable. The number of VPC is denoted as *no_beg_vcurv* and the number of VPT is denoted as *no_beg_grad.* Based on this analysis, specific alignment combinations can be extracted from the merged roadlog files relying on the SAS Data Step tool. The process is shown in the Figure 10 and 11.

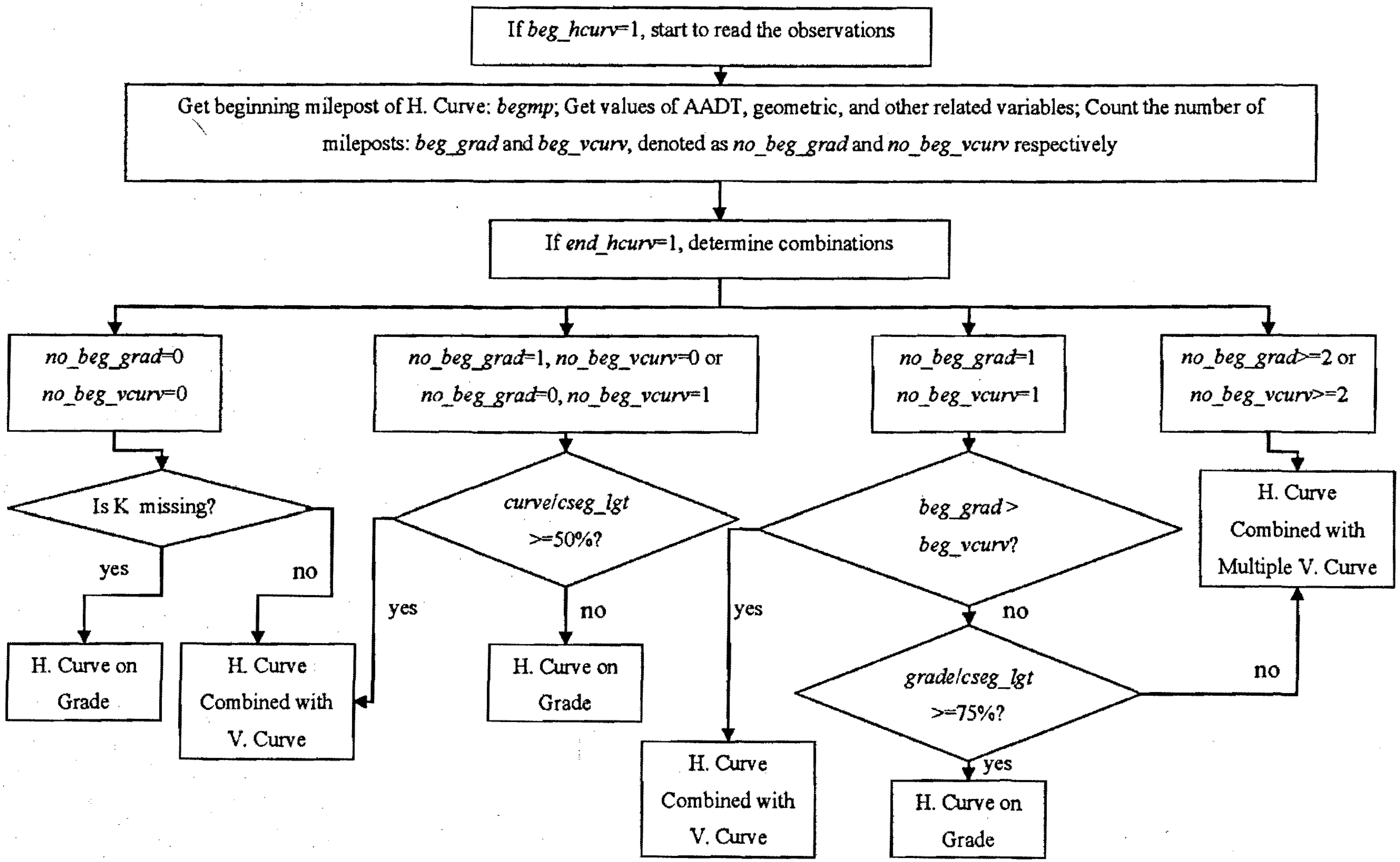



**Figure 10. Extraction of Horizontal Curve Combined with Vertical Alignment**

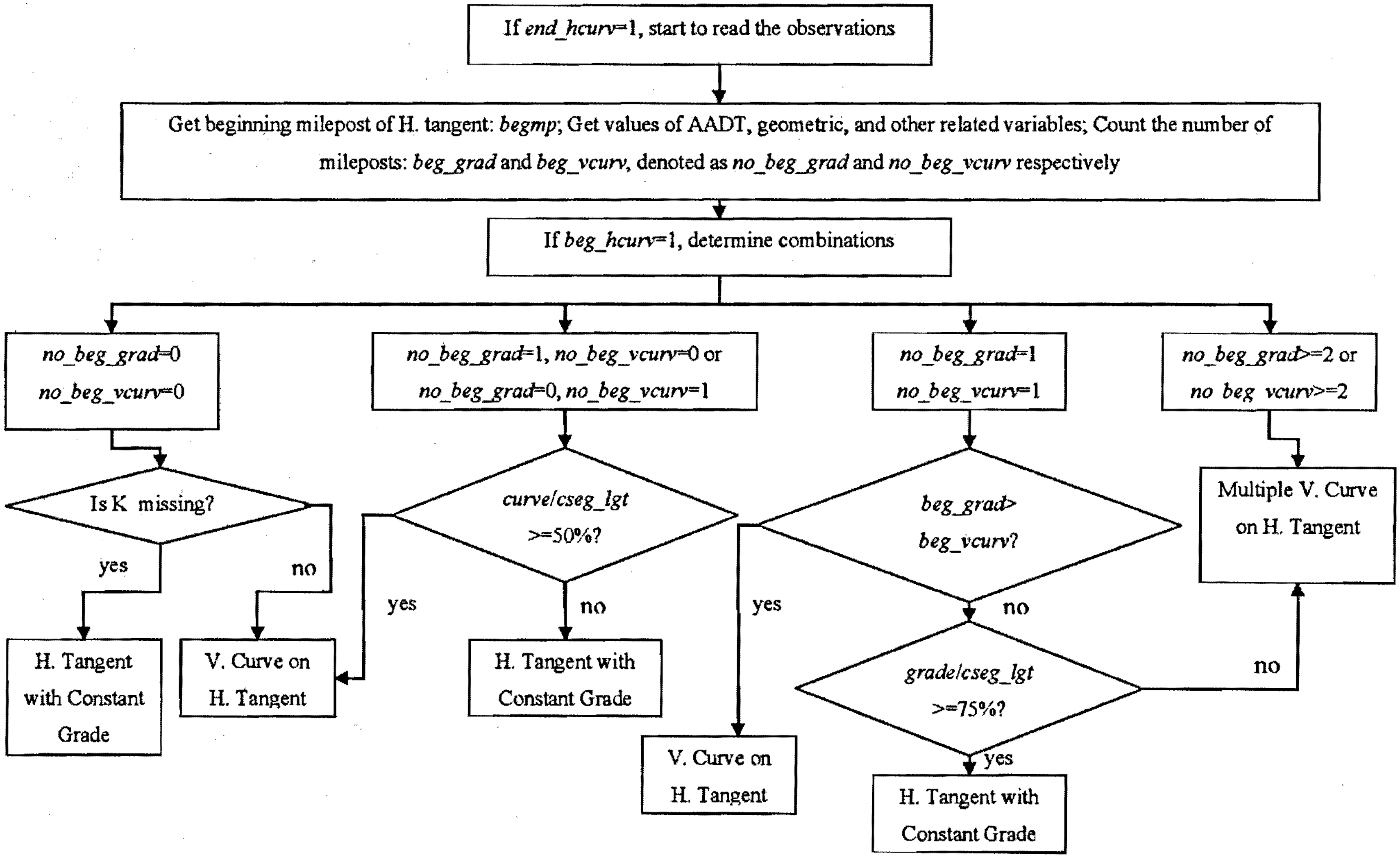



**Figure 11. Extraction of Horizontal Tangent Combined with Vertical Alignment**

### 3.4 SUMMARY STATISTICS

A summary of general descriptive statistics for the two-lane rural roadways is given in Table 3.

**Table 3.** Summary of Descriptive Statistics for Analyzed Roadways

| Characteristics | Observation Year | | | |
|---|---|---|---|---|
| | 2002 | 2003 | 2004 | 2005 |
| Legal Speed Limit (mile per hour)<br>(kilometer per hour) | 55-65<br>88.5-104.6 | | | |
| Function Class | '02' = 'RURAL-PRINCIPAL-ARTERIAL'<br>'06' = 'RURAL-MINOR-ARTERIAL'<br>'07' = 'RURAL-COLLECTOR' | | | |
| Total Sites | 95 | 94 | 91 | 91 |
| Total Mileage (mile) | 3642.16 | 3623.15 | 3519.33 | 3583.73 |
| Total Accidents | 3413 | 3291 | 2859 | 2966 |
| Average Annual Daily Traffic (AADT: vehicles/day) | 163-30158 | 157-30772 | 122-26359 | 120-25556 |
| Total Exposure (Million Vehicle Mileage) | 4276.88 | 4254.31 | 3861.25 | 3873.65 |
| Average Accident Rate (total accidents/total exposure) | 0.80 | 0.77 | 0.74 | 0.77 |
| Horizontal Curve Radius (feet) | 59-50000 | | | |
| Rate of Curvature for Vertical Curve | 6.85-50000 | 6.85-50000 | 6.85-50000 | 6.85-50000 |
| Gradient (%) | 0-9.56 | 0-9.56 | 0-9.36 | 0-9.87 |
| Shoulder Width | 0-36 | 0-36 | 0-36 | 0-36 |
| Total Surface Width | 17-55 | 17-55 | 17-59 | 17-59 |
| Surface Type:<br>'A' = 'ASPHALT'<br>'B' = 'BITUMINOUS'<br>'P' = 'PORTLAND CONCRETE'<br>'O' = 'OTHER' * | <br>51%<br>48%<br>1%<br>0% | <br>52%<br>47%<br>1%<br>0% | <br>52%<br>47%<br>1%<br>0% | <br>51%<br>48%<br>1%<br>0% |

* The values are written as zeros as a result of rounding in the percentages.

# Chapter 4. ANALYSIS

Road sections of a specific type of combination of horizontal and vertical alignments have been addressed in the previous chapter. As discussed, this study disaggregated the roadways into road sections by horizontal curves and horizontal tangents, and then the combination types were determined. This approach provides an accurate way of characterizing road characteristics on a road section, and a proper way of exploring the interaction of combined horizontal and vertical alignments. Also, it may have more variables for individual characteristics to be accounted for in the models.

The factors that may contribute to accidents on the roadways mainly come from three aspects: drivers, vehicles and roadways themselves. In order to examine the effect of the interaction of combined horizontal and vertical alignments, this study mainly focused on those geometric features that may affect accident occurrences. Other factors such as environmental factors (e.g. weather), human factors (e.g. driver population), and vehicle configurations were not accounted for in the analysis. This chapter touches on what potential influencing factors in geometric characteristics and traffic conditions were considered during the process of developing the models for a specific type of combination. Some variables were available directly from the data files; other new variables were developed from those available variables. Also, a summary statistics for road sections of each type of combination is presented comprehensively.

## 4.1 POTENTIAL INFLUENCING FACTORS

### 4.1.1 Exposure Variables

Traditionally, vehicle exposure of accident occurrences on the roadways can be measured by a composite term, namely millions of vehicle-miles of travel (MVMT), or millions of vehicle-kilometers of travel. Or it can be measured by two components: one is the traffic exposure, represented by the annual average daily traffic (AADT); another is the road exposure measured by section length.

The variable for section length can be calculated from the beginning milepost and end milepost of newly divided road section. The AADT is available from the original data files. However, a newly divided road section may contain two more sections with different AADT from the roadlog files. An average of AADT by the number of road sections was applied to the newly divided road section for each type of combination.

As discussed at the beginning of Chapter 3, the developed models were intended to be formulated as a function of traffic volume AADT, section length, and other geometric characteristic variables instead of a function of MVMT and other explanatory variables. A comparison was made about exposure treatment in the modeling. The accident rates based on MVMT were also provided. MVMT is calculated as:

$$MVMT = \frac{AADT \times 365 \times length}{10^6} \tag{39}$$

where *length* is the length of a road section.

### 4.1.2 Horizontal Curve Variables

The variables related to horizontal curves are as follows:

- Radius: *curv_rad*, in feet,
- Degree of horizontal curve: *deg_curv*, in degree,
- Curve central angle: *curv_ang*,
- Horizontal curve length, in mile, considered in the variable for section length: *cseg_lgt*.

All individual variables of horizontal curve characteristics were used to describe the analyzed road sections since a road section may contain only a horizontal curve.

### 4.1.3 Vertical Curve Variables

The attribute of a vertical curve is represented by the following variables:

- Rate of vertical curvature: $avc = \mathrm{K}$ for a single vertical curve,
- Algebraic difference in grade: $ava = A = | G_2 - G_1 |$ for a single vertical curve,
- Vertical curve type: *vc_typ*, vertical curves are classified as crest vertical curves (type I and II) and sag vertical curves (type III and IV) based on AASHTO (2001, p. 269). This variable with the following values was used to extract the types with crest vertical curve combination and sag vertical curve combination:

$$\text{vc\_typ} = \begin{cases} 1 & , \quad TypeI \\ 2 & , \quad TypeII \\ 3 & , \quad TypeIII \\ 4 & , \quad TypeIV \end{cases} \tag{40}$$

- Percentage of vertical curves in a road section: *pct_vcurv*,

$$pct\_vcurv = \frac{vertical\_curve\_length}{section\_length} \tag{41}$$

  where $vertical\_curve\_length$ is the length of a vertical curve in the appearance of a single vertical curve, calculated by the VPT and VPC of a vertical curve. $section\_length$ is represented by the variable *cseg_lgt* in the horizontal curve combination or the variable *tset_lgt* in the horizontal tangent combination.

The above variables were used to evaluate road sections with a unique vertical curve combination.

### 4.1.4 Variables for Multiple Vertical Curves

In the case of analyzed road sections combined with multiple vertical curves (Horizontal Curve Combined with Multiple Vertical Curves or Multiple Vertical Curves on Horizontal Tangent), an average approach was applied for the following variables:

- Rate of vertical curvature:

$$avc = \frac{\sum_{i}^{n} K}{n} \tag{42}$$

- Algebraic difference in grade:

$$ava = \frac{\sum_{i}^{n} A}{n} \tag{43}$$

- Percentage of vertical curves in a road section: *pct_vcurv*,

$$pct\_vcurv = \frac{vertical\_curve\_length}{section\_length} \tag{44}$$

  where $vertical\_curve\_length$ is the total length of a vertical curve, calculated by the VPT and VPC of a vertical curve. $section\_length$ is represented by the variable *cseg_lgt* in the horizontal curve combination or the variable *tset_lgt* in the horizontal tangent combination.

### 4.1.5 Variables for Combined Horizontal and Vertical Curves

In the combination of horizontal and vertical curves, a variable for the ratio of the vertical curve radius to the horizontal curve radius K_R was introduced.

Smith and Lamm (1994) suggested that the ratio of the horizontal curve radius to the vertical curve radius cannot be selected arbitrarily but must be related or tuned to each other; and that the ratio should be as small as possible and be in the range of 1/5 to 1/10. The rate of vertical curvature K can be translated to the vertical curve radius as:

$$R_V = 100K \tag{45}$$

This study used the ratio of the vertical curve radius to the horizontal curve radius K_R (the inverse of the ratio cited in Smith and Lamm (1994)) instead to convert small numbers in the data resulted from the fractions to numbers greater than 1. The ratio K_R is defined as:

$$K\_R = \frac{100K}{R} \tag{46}$$

where K is the rate of vertical curvature, and R is the radius of a horizontal curve. This study made an attempt to evaluate the safety effects of combined horizontal and vertical curves with this ratio.

### 4.1.6 Grade Variables

In most cases, the gradient of a single grade is used to describe the analyzed road sections. When vertical grades are connected with angle points instead of vertical curves, a length weighted average of gradient was used:

$$avg = \frac{\sum(l_i |G_i|)}{\sum l_i} \tag{47}$$

where $l_i$ and $G_i$ are the length and grade value of grade *i* in percentage.

A binary variable *spcl_ln* represents the presence of a climbing lane or truck climbing shoulder.

A combined variable *grad_hgt* was introduced in the study to explore the effect of a grade on the safety. It is defined as:

$$grad\_hgt = avg * length \tag{48}$$

where *length* is the length of a grade and *avg* is the grade value in percentage.

### 4.1.7 Horizontal Tangent Variables

Horizontal tangent can be taken as a dynamic design element (Lamm et al. 1999). Lamm et al. evaluated the effects of the placement of tangents between horizontal curves on speed and safety from the perspective of operating speed consistency. They classified tangents as independent and nonindependent tangents. Independent tangents may cause critical changes in the speed profiles, while nonindependent tangents do not. Nonindependent tangents are defined as tangents that are too short to exceed the possible 85th percentile speed differences for good design levels ($\Delta V85 \le 10 km/h$) or even for fair design levels ($\Delta V85 \le 20 km/h$) during the acceleration and/or deceleration maneuvers. In this case, the element sequence curve-to-curve, not the interim tangent control the safety evaluation design process. If tangents are long enough to permit a driver to exceed the 85th percentile speed difference for fair design levels ($\Delta V85 > 20 km/h$), the tangents are called independent tangents. In this case, the element sequence tangent-to-curve should the design process.

In the analysis of horizontal tangent combinations, this study considered several following potential influencing factors and classified road sections with horizontal tangent combinations as independent and nonindependent tangents. Only the independent tangents were selected to develop models of tangent combinations, including Combination No. 6, 7, 8, 9, and 10.

- Smaller radius of the horizontal curves before and after the tangent: *sml_r*,
- Ratio of larger radius to smaller radius of the horizontal curves before and after the tangent: *lar_smr*,
- Combination direction of the horizontal curves before and after the tangent: *hcurv_com*, $hcurv\_com = 1$ or 0. When the directions of both horizontal curves before and after the tangent are the same, then $hcurv\_com = 1$; when the directions of both horizontal curves before and after the tangent are the same, then $hcurv\_com = 0$.
- Variable indicating an independent or a nonindependent tangent: *depend_tan*,

$$depend\_\tan = \begin{cases} 1, & independent \\ 0 & nonindependent \end{cases}. \tag{49}$$

In order to determine if a tangent is an independent tangent or a nonindependent tangent, operating speed on the horizontal curves before and after the tangent must be evaluated. The actual 85th percentile speeds on the analyzed roadways were unavailable. However, there are some available models for predicting operating speed on two-lane rural highways, for example, a comprehensive set of models done by Fitzpatrick et al. (2000b) for a FHWA study (see Table 1), and the horizontal curve model developed by Ottesen and Krammes (2000) from a sample of horizontal curves and their approach tangents on two-lane rural highways in five states of the United States (New York, Pennsylvania, Texas, Oregon, and Washington).

The operating speed prediction models developed by Fitzpatrick et al. (2000b) consider combinations of horizontal and vertical alignment, and the Washington State was one of their selected states. Therefore, the operating speed prediction models developed by Fitzpatrick et al. (2000b) were adopted in this study to estimate the operating speed at the preceding and following horizontal curves of a horizontal tangent.

The maximum allowable length of a horizontal tangent regarded as a nonindependent tangent, denoted as $TL_S$, can be inferred from the following formula (Lamm et al. 1999):

$$TL_S = \frac{V85_1^2 - V85_2^2}{25.92a} \tag{50}$$

where

$TL_S$ = the maximum allowable length of a horizontal tangent, in meter,

$V85_1$, $V85_2$ = the 85th-percentile operating speeds at the two successive highway design elements, in km/h, and

a = the deceleration/ acceleration rate.

The values of $0.54 m/s^2$ and $1.00 m/s^2$ are recommended for deceleration and acceleration respectively in TAC (1999). In order to be conservative, the value of $0.54 m/s^2$ was adopted in the study to ensure that all selected segments of tangents were independent tangents. In order to meet fair (tolerable) design levels according to safety criterion II, the change in operating speeds $\Delta V85 \le 20 km/h$ should at least be met. In order to simplify the procedure of estimating $TL_S$, the lowest 85th–percentile speed of the curve is the controlling speed. Substituting $a = 0.54 m/s^2$, Equation (50) becomes as:

$$TL_s = \frac{(V85+20)^2 - V85^2}{14.00} \tag{51}$$

where $V85$ is the lowest 85th-percentile operating speed at the curve before or after the tangent. Simplifying Equation (51) and converting $TL_S$ into miles, a new equation is derived:

$$TL_s = \frac{400 + 40V85}{22525} \tag{52}$$

where $TL_S$ is the maximum allowable length of a horizontal tangent, in mile.

Since the maximum allowable length of a horizontal tangent regarded as a nonindependent tangent is determined, the existing tangent can be evaluated as an independent tangent or a nonindependent tangent with its tangent compared with $TL_S$ .The tangent is considered as a nonindependent tangent if its length is smaller than $TL_S$; otherwise, it is an independent tangent.

This study followed the process shown in Figure 12 to determine the types of tangents.

### 4.1.8 Other Variables

Several potential cross-section variables were explored in the study. An average shoulder width variable *shld_wid* is defined as the average of left shoulder width *lshld_wid* and right shoulder width *rshld_wid*. The variable *surf_wid* is defined as the total width of the travel width. The variable *roadway_wid* is calculated as the sum of the left shoulder width *lshld_wid*, the right shoulder width, and the total travel width *surf_wid*.

The access density variable access is defined as the number of driveways per mile on the analyzed segment.

## 4.2 SUMMARY STATISTICS FOR ANALYZED COMBINATION TYPES

A summary of descriptive statistics for the combination of horizontal curve combined with crest vertical curve is shown in Table 4. The statistics for other combinations are presented in Appendix A. An average accident rate on each type of combination is also given.

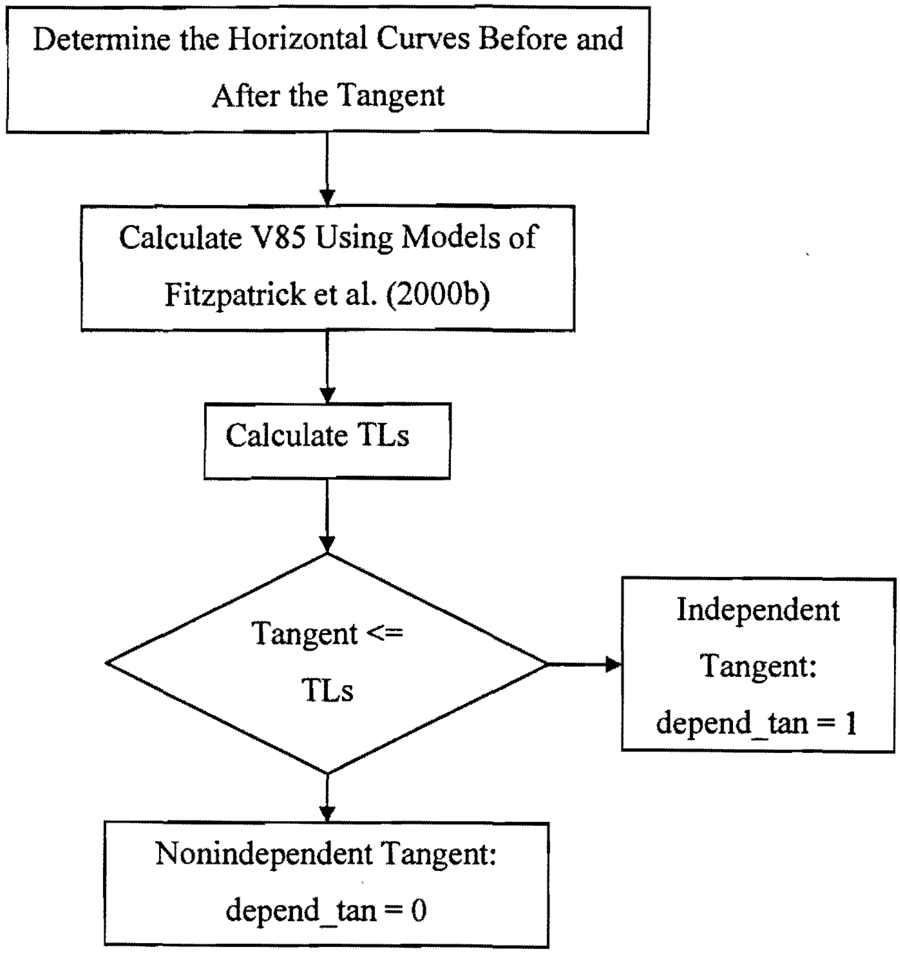



**Figure 12.** Determination of Independent Tangents and Nonindependent Tangents

**Table 4.** Summary Statistics of Road Sections for Horizontal Curve Combined with Crest Vertical Curve: 4193 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section Length (mile):cseg_lgt | 0.140 | 0.108 | 0.010 | 1.090 | 0.110 | |
| Number of Accidents on a Road Section: total_acc | 0.145 | 0.450 | 0 | 6 | 0 | 88.34 |
| Annual Average Daily Traffic (veh/day): caadt | 2895 | 3154 | 175 | 26359 | 1843 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.157 | 0.257 | 0.001 | 4.426 | 0.076 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.388 | 6.885 | 0 | 131.781 | 0 | |
| Horizontal Curve Radius: curv_rad (feet) | 2892 | 4099 | 191 | 50000 | 1910 | |
| Horizontal Degree of Curvature: deg_curv (degree/100ft) | 4.034 | 3.228 | 0.110 | 30.000 | 3.000 | |
| Rate of Vertical Curvature: avc (feet/%) | 450 | 796 | 9 | 12500 | 240 | |
| Algebraic Difference in Grade: ava (%) | 3.55 | 2.70 | 0.02 | 14.73 | 2.96 | |
| Ratio of Vertical Curve Radius to Horizontal Curve Radius: K_R | 24.70 | 52.51 | 0.79 | 1121.91 | 13.76 | |
| Percentage of Vertical Curve on Road Section: pct_vcurv | 0.74 | 0.26 | 0.06 | 1.00 | 0.75 | |
| Left Shoulder Width: lshldwid (feet) | 4.87 | 2.47 | 0.00 | 24.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.84 | 2.36 | 0.00 | 18.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.98 | 1.52 | 20.00 | 44.00 | 23.00 | |
| Total Number of Sections (Horizontal Curves) and Mileage | 4193 Sections with a total length of 588.810 miles | | | | | |
| Total Number of Accidents | 609 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 609 / 658.651 = 0.925 | | | | | |

# Chapter 5. MODEL DEVELOPMENT

The previous chapters have addressed statistical methodology used in this study; determined different combinations of horizontal and vertical alignment; divided the roadways into road sections and extracted from the data files based on the classifications of combinations; and analyzed the possible factors influencing vehicle accident involvement. This chapter illustrates how the models for these alignment combinations were developed separately. All the aforementioned four types of models: the Poisson model, the negative binomial (NB) model, the zero-inflated Poisson (ZIP) model, and the zero-inflated negative binomial (ZINB) model were investigated for different alignment combinations. The chapter begins with the introduction of modeling process, followed by the model development for each combination.

## 5.1 MODELING PROCESS

As discussed in Chapter 3, the mean number of accidents occurred on a road section of a specific type of alignment combination was modeled as a generalized linear function of traffic volume, namely annual average daily traffic (AADT), section length, and other geometric characteristic variables. The model development began with an examination of the model underlying distributional assumption by plotting accident frequency distributions from accident counts. Visual inspection of their shapes found that accident occurrences follow a Poisson distribution. Therefore, based on some researchers' experiences (e.g. Miaou 1994), the Poisson modeling technique was used as an initial step for developing the relationship between accident occurrences and traffic characteristics, geometric design features, and environment, etc. The importance of the variables to be included in the models can be detected. The SAS version 9.1 was used to establish all the models.

### 5.1.1 Indication of Overdispersion Phenomenon

To assess the goodness of fit of a given generalized linear model for a Poisson or NB distribution, two statistics are evaluated, which are the scaled deviance and Pearson's chi-square statistic (refer to "*SAS/STAT® 9.1 User's Guide*" 2004). These two statistics are computed by the GENMOD procedure in the SAS program. Under certain regularity conditions, both of the scaled statistics have a limiting chi-square distribution with degrees of freedom equal to the number of observations $n$ minus the number of parameters estimated $p$, namely $DF = n - p$. The deviance or Pearson's chi-square statistics divided its degrees of freedom is used as an estimate of the dispersion parameter. For the Deviance, the dispersion parameter, denoted as $\alpha$ here, is given as follows:

$$\alpha = \frac{D}{n-p} \tag{53}$$

For Pearson's chi-square statistics, the dispersion parameter $\alpha$ here, is estimated from the following:

$$\alpha = \frac{X^2}{n-p} \tag{54}$$

where D is the Deviance, and $X^2$ is the Pearson's chi-square statistics. If the estimated dispersion parameter deviates substantially from 1, the overdispersion phenomenon for the Poisson and NB models is indicated.

### 5.1.2 Testing of Overdispersion

If the scaled Deviance and Pearson's chi-square statistics indicate the overdispersion phenomenon in a Poisson model, we can build a NB model to test it further. As discussed, we know that the variance for the NB distribution is given as:

$$Var(Y_i) = E[Y_i](1 + \alpha E[Y_i]) = \lambda_i + \alpha \lambda_i^2. \tag{55}$$

With SAS®9, the Lagrange multiplier (LM) test can be obtained by using the following options in the MODEL statement of the GENMOD procedure: DIST=NEGBIN SCALE=0 NOSCALE. If the LM statistic is statistically significant at a significant level of 0.05, the $\alpha$ is significantly different from zero, and thus the over-dispersion phenomenon exists in the data.

Another strategy is to fit the data with the NB model and use the Wald test. The Wald test can be performed based on the t statistic for the estimated over-dispersion parameter $\alpha$ in the NB model using the NLMIXED procedure or the Wald 95% confidence limit available in the output of GENMOD procedure.

The Wald and LM tests were employed in this study for each case of alignment combination.

### 5.1.3 Selection of Explanatory Variables

An important aspect in the model development is to select the explanatory variables in the model. There are two often used strategies for the choice of variables, which are forward selection and backward elimination. A forward selection starts with building all possible models that include a single explanatory variable. A significant explanatory variable is retained based on the goodness-of-fit statistics. Another remaining variable is added to the model with the significant explanatory variables. The modeling stops when no other variables are available. A backward selection starts in the other direction by constructing a model that uses all the explanatory variables and then eliminates those variables that are not significant. The forward selection and backward selection are also referred to as stepwise regression in the statistical software programs (e.g. SAS).

Two convenient tools in the current SAS package are available to select important explanatory variables. Type 1 analysis provides a table summarizing twice the difference in log likelihoods between each successive pair of models. The results from this analysis depend on the order in which the explanatory variables are entered. That is, the chi-square value in the table represents twice the difference in log likelihoods between the model containing that variable and the model with all variables preceding it in the table. The Type 3 analysis does not depend on the order in which the variables for the model are specified. The chi-square value represents twice the difference between the log likelihood for the model with all the variables included and the log likelihood for the model with that variable excluded. The *p*-value corresponding to each chi-square statistic is also computed in both analyses. The p-value is the probability of erroneously rejecting the null hypothesis that the true value of the regression coefficient is zero. A p-value that is greater than the required significant level of 0.05 indicates that the corresponding variable is not significant and thus is removed from the model.

This study began with including all the variables that may affect vehicle accident occurrences. The possible influencing factors have been analyzed in Chapter 4. The results from Type 1 and Type 3 analysis were examined to determine if an explanatory variable was eliminated.

The number of accidents is believed to increase if the opportunities of the vehicles' traffic exposure and road exposure become greater. Since the mean number of accidents occurred on a road section of a specific type of alignment combination is modeled as a generalized linear function of traffic volume AADT, section length, and other geometric characteristic variables, the natural log of AADT and the natural log of section length are entered in the models.

## 5.2 MODELS FOR COMBINATIONS OF HORIZONTAL AND VERTICAL ALIGNMENTS

The following subsections describe that the Poisson model, the NB model, the ZIP model, and the ZINB model were investigated and constructed for each alignment combination discussed.

### 5.2.1 Horizontal Curve Combined with Crest Vertical Curve

The study obtained 4193 horizontal curves combined with crest vertical curve over the 4-year period from 2002 to 2005 (each year contributes an average of one-fourth of the total curves). For the 4193 curves (or sections), the length of each curve varied from 0.10 to 1.09 miles. A total length of 588.810 miles experienced a total of 609 accidents, with a mean of 1.388 accidents per million of vehicles-miles of travel per curve. The accident frequency distribution in Figure 13 shows that 88.34 percent of curves experience zero accidents.

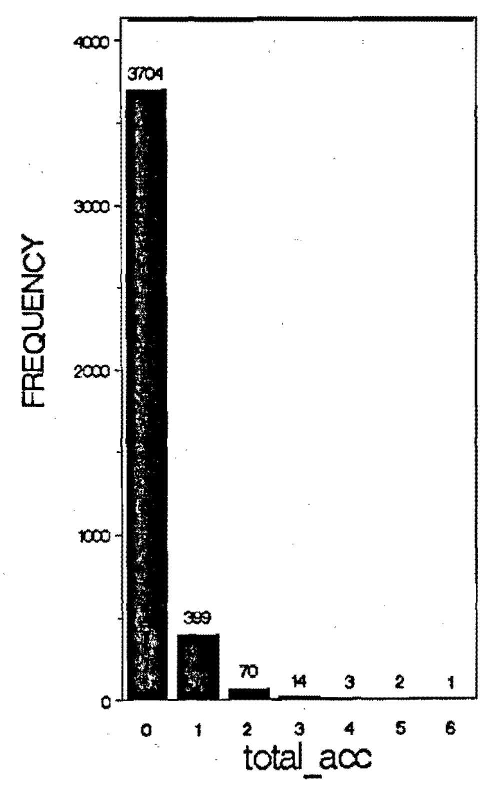



**Figure 13.** Accident Frequency Distribution for Horizontal Curve Combined with Crest Vertical Curve

All the analyses for the four types of models showed that the nature log of AADT and section length, degree of horizontal curvature *deg_curv*, the roadway width *roadway_wid*, and access density *access* are statistically significant. All the potential influencing variables related to the vertical curve, such as rate of vertical curvature *avc*, algebraic difference in grade *ava,* ratio of vertical curve radius to horizontal curve radius K_R, and percentage of vertical curve on road section *pct_vcurv* were found to be insignificant. Speed limit *spd_limt* was not found to be significant. Cross-section variables such as left shoulder width *lshld_wid*, right shoulder width *rshld_wid*, and the width of travel surface *surf_wid* were found to be insignificant. Instead, the average shoulder width *shld_wid* or the total roadway width: *roadway_wid* was found to be significant at the significant level of 0.05. The independent variable *roadway_wid* describing the cross-sections was included in the model. The negative sign of the coefficient for the variable *roadway_wid* shows that accident occurrences decrease when lane width or shoulder width increases. The greater access density increases accident occurrences on the roadway. The final models are shown in Table 5.

In spite of the fact that the variables related to vertical curves, and combination of horizontal and vertical alignments (e.g. K_R) were excluded from the models for the reason of statistical insignificance, it does not mean that those factors such as the ratio of vertical curve radius to horizontal curve radius K_R do not influence the safety effects of highway design. The correlations between the explanatory variables that explain geometric design exist in most cases.

The correlations between section length (here equal to curve length) *cseg_lgt*, degree of horizontal curvature *deg_curv*, horizontal curve radius *curv_rad*, central angle of horizontal curve *curv_rad*, rate of vertical curvature *avc*, algebraic difference in grade *ava*, and ratio of vertical curve radius to horizontal curve radius K_R were investigated through the study. The analysis of correlations is given in the Table 6. The p-value is the significance probability for testing the null hypothesis that the two corresponding variables are uncorrelated in the data files. The smaller the p-value, the stronger the evidence against the null hypothesis - that is, the stronger the evidence that the two variables are correlated in the data files.

**Table 5.** Models for Horizontal Curve Combined with Crest Vertical Curve: 4193 Sections

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -5.8176 (0.4365) | 177.66 | <.0001 | -5.4254 (0.4819) | -11.26 | <.0001 | -5.8405 (0.4763) | 150.38 | <.0001 | -5.8399 (0.4763) | -12.26 | <.0001 |
| AADT: log_aadt | 0.8110 (0.0517) | 245.75 | <.0001 | 0.7140 (0.05747) | 12.42 | <.0001 | 0.8076 (0.0583) | 191.99 | <.0001 | 0.8076 (0.05829) | 13.86 | <.0001 |
| Section Length: log_lgt | 1.0567 (0.0674) | 245.77 | <.0001 | 0.7115 (0.1158) | 6.14 | <.0001 | 1.0700 (0.0745) | 206.16 | <.0001 | 1.0700 (0.07451) | 14.36 | <.0001 |
| Degree of Curvature: deg_curv | 0.1192 (0.0127) | 87.52 | <.0001 | 0.1454 (0.01722) | 8.45 | <.0001 | 0.1279 (0.0154) | 69.24 | <.0001 | 0.1279 (0.01538) | 8.32 | <.0001 |
| Roadway width: roadway_wid | -0.0268 (0.0100 ) | 7.16 | 0.0074 | -0.02217 (0.01067) | -2.08 | 0.0378 | -0.0256 (0.0110) | 5.46 | 0.0194 | -0.02566 (0.01098) | -2.34 | 0.0194 |
| Access Density: access | 0.0223 (0.0092) | 5.87 | 0.0154 | 0.02153 (0.01067) | 2.02 | 0.0437 | 0.0224 (0.0102) | 4.85 | 0.0276 | 0.02244 (0.01018) | 2.20 | 0.0276 |
| | | | | | | | | | | | | |
| Disperson α | | | | | | | 0.5753 (0.1555) | Wald 95% [0.2704, 0.8802] | | 0.5752 (0.1556 ) | 3.70 | 0.0002 |
| LM Test of α=0 | | | | | | | | 13.5942 | 0.0002 | | | |
| -2 Log Likelihood | -2998.60 | | | 3167.70 | | | 3173.2 | | | 3173.20 | | |
| Vuong Test | | | | 2.17 * | | | 0.73*** | | | 0.32** | | |
| AIC (smaller is better) | | | | 3183.7 | | | 3187.2 | | | 3191.2 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

**Table 6.** Correlation Coefficients for Horizontal Curve Combined with Crest Vertical Curve

| | cseg_lgt | deg_curv | curv_rad | curv_ang | avc | ava | K_R |
|---|---|---|---|---|---|---|---|
| cseg_lgt | 1 | -0.29641 | 0.11322 | 0.42455 | 0.07512 | -0.07978 | -0.0372 |
| p-value | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.016 |
| deg_curv | -0.29641 | 1 | -0.44868 | 0.49229 | -0.1561 | 0.15323 | 0.19361 |
| p-value | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| curv_rad | 0.11322 | -0.44868 | 1 | -0.35257 | 0.25936 | -0.14014 | -0.12267 |
| p-value | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 |
| curv_ang | 0.42455 | 0.49229 | -0.35257 | 1 | -0.07438 | 0.08994 | 0.15803 |
| p-value | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 |
| avc | 0.07512 | -0.1561 | 0.25936 | -0.07438 | 1 | -0.33889 | 0.65718 |
| p-value | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 |
| ava | -0.07978 | 0.15323 | -0.14014 | 0.08994 | -0.33889 | 1 | -0.24905 |
| p-value | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 |
| K_R | -0.0372 | 0.19361 | -0.12267 | 0.15803 | 0.65718 | -0.24905 | 1 |
| p-value | 0.016 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | |

Note: In each cell of the table, the top value is the correlation coefficient between the row and column variable for that cell. The lower value is a p-value.

The correlation results show that there is a strong positive correlation between horizontal curve radius and curve length. As the horizontal curve radius becomes greater, the curve is usually longer. Conversely, as the horizontal curve radius becomes smaller, the curve is shorter. In other words, the curve of smaller radius is usually shorter. Therefore, the belief that the accident rate on a horizontal curve of smaller radius is higher than that on a horizontal curve of greater radius is biased, in spite of the fact that the number of accident occurrences is more on a horizontal curve of smaller radius than on a horizontal curve of greater radius. The evaluation of safety effects on horizontal curves using accident rates easily produces a biased result.

The correlation exists between the degree of curvature, the central angle of a horizontal curve, and the horizontal curve radius. The negative correlation between the degree of curvature and the horizontal curve radius is obvious since they are in an inverse relationship. The negative correlation between the degree of curvature and the central angle of a horizontal curve shows that a horizontal curve with a greater central angle is often designed with a smaller degree of curvature, namely with a large horizontal curve radius and vice versa.

The positive correlation of the horizontal curve radius and the rate of vertical curvature, or the negative correlation of the degree of curvature for a combined horizontal curve and the rate of vertical curvature shows that a combined horizontal curve of smaller radius often have a smaller rate of vertical curvature and vice versa.

The findings of correlations of the horizontal curve radius and the central angle, and the radius of the combined horizontal curve and the rate of vertical curvature reflects a normal design practice that low standards are often adopted in some critical situations and high-standard values are often applied to the favorable topography.

The best model that describes the property of a horizontal curve affecting its safety effects was explored. The degree of curvature variable produces a better result than the horizontal curve radius considering the goodness of fit statistics. The results of comparisons are given in Table 7.

**Table 7.** Comparisons of Horizontal Curve Variables

| | Poisson 1 | | | Poisson 2 | | |
|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | $\chi 2$ | p-value |
| Intercept | -5.8176 (0.4365) | 177.66 | <.0001 | -4.8786 (0.4173) | 136.70 | <.0001 |
| AADT: log_aadt | 0.8110 (0.0517) | 245.75 | <.0001 | 0.7637 (0.0516) | 219.30 | <.0001 |
| Section Length: log_lgt | 1.0567 (0.0674) | 245.77 | <.0001 | 0.9220 (0.0640) | 207.27 | <.0001 |
| Degree of Curvature: deg_curv | 0.1192 (0.0127) | 87.52 | <.0001 | | | |
| Curve Radius: curv_rad | | | | -0.0001 (0.0000) | 10.00 | 0.0016 |
| Roadway width: roadway_wid | -0.0268 (0.0100 ) | 7.16 | 0.0074 | -0.0332 (0.0100) | 11.05 | 0.0009 |
| Access Density: access | 0.0223 (0.0092) | 5.87 | 0.0154 | 0.0258 (0.0091) | 8.00 | 0.0047 |
| Deviance/DF | 0.5144 | | | 0.5269 | | |
| Pearson Chi-Square/DF | 1.1284 | | | 1.2152 | | |
| Log Likelihood | -1499.30 | | | -1525.50 | | |

The ratio of vertical curve radius to horizontal curve radius K_R that describes one important characteristics of combined horizontal and vertical alignments has a strong positive correlation with the degree of curvature *deg_curv* and a strong negative correlation with the horizontal curve radius *curv_rad*. Although it was excluded from the established models, whether the ratio of vertical curve radius to horizontal curve radius K_R affects the safety at a horizontal curve combined with a vertical curve was investigated further.

99 percent of the ratio of vertical curve radius to horizontal curve radius K_R is less than 190.4, and most of the ratio of vertical curve radius to horizontal curve radius K_R is smaller than 25 with a percentage of 75. The median value is around 13.76. The detailed quantile distribution is given in Table 8.

**Table 8.** Quantile Distribution of K_R for Horizontal Curve Combined with Crest Vertical Curve

| Quantile | Estimate |
|---|---|
| 100% Max | 1121.914734 |
| 99% | 190.415258 |
| 95% | 74.15757 |
| 90% | 46.538685 |
| 75% Q3 | 24.071734 |
| 50% Median | 13.761439 |
| 25% Q1 | 7.615421 |
| 10% | 4.41823 |
| 5% | 2.974905 |
| 1% | 1.401768 |
| 0% Min | 0.786885 |

From the scatter plot of accident occurrences against ratio of vertical curve radius to horizontal curve radius K_R in Figure 14 and the plot of accident rate versus ratio of vertical curve radius to horizontal curve radius K_R in Figure 15, it was found that the accident rate and the number of accidents decrease sharply when the ratio of vertical curve radius to horizontal curve radius K_R is greater than around 25.

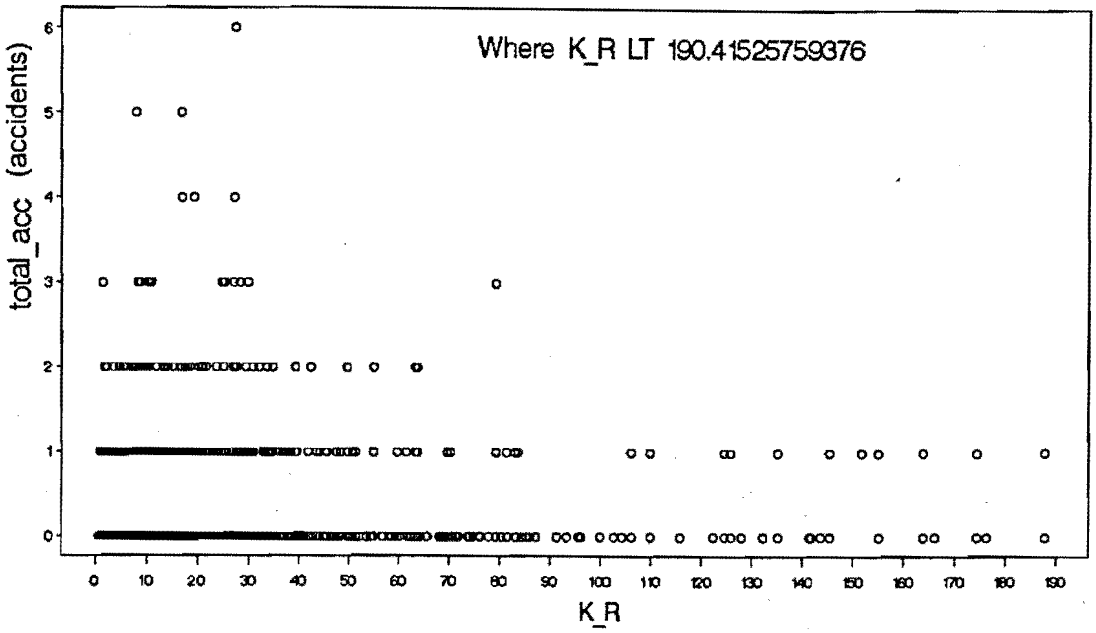



**Figure 14.** Scatter Plot of Number of Accidents against Ratio of Vertical Curve Radius to Horizontal Curve Radius (<190.4) for Horizontal Curves Combined with Crest Vertical Curve

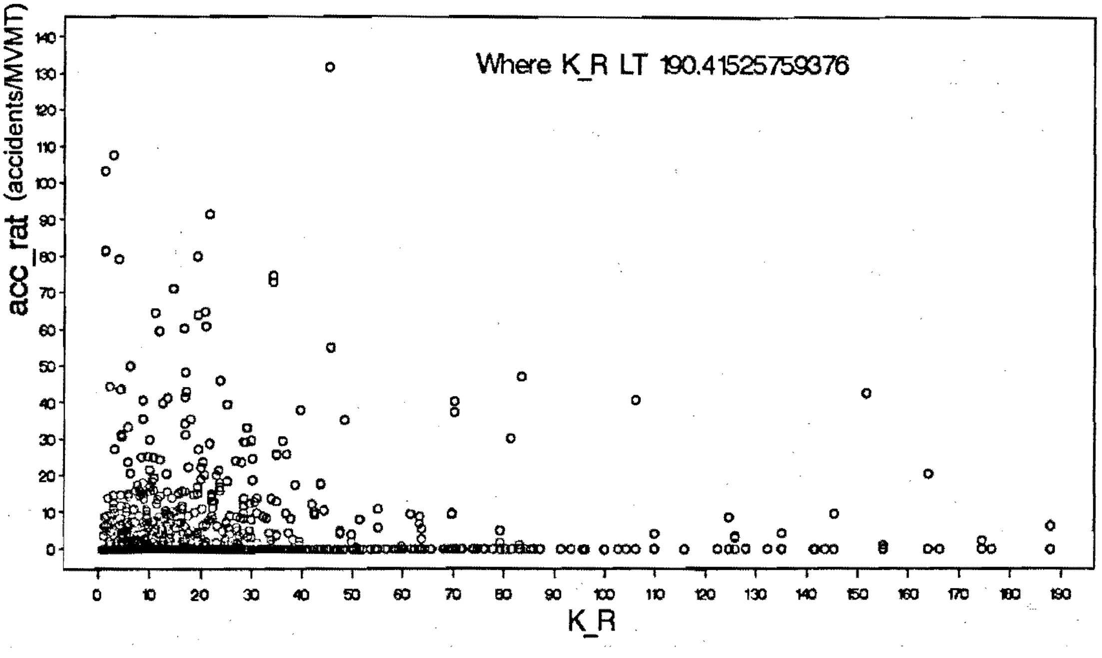



**Figure 15.** Relationship between Accident Rate and Ratio of Vertical Curve Radius to Horizontal Curve Radius (<190.4) for Horizontal Curves Combined with Crest Vertical Curve

However, we must be cautious to infer from the scatter plots because the negative correlation of K_R and the horizontal curve radius exists. Is it true that the accident rate decreases with the increase of the ratio of vertical curve radius to horizontal curve radius K_R? Below is the further investigation. By examining closely the two corresponding figures, Figure 16 and 17, which represent the combined horizontal curves with the ratio of vertical curve radius to horizontal curve radius K_R smaller than 25, the distribution of accident rate and accident occurrences looks even across the range of the ratio K_R. The safety effects of the ratio K_R are not obvious.

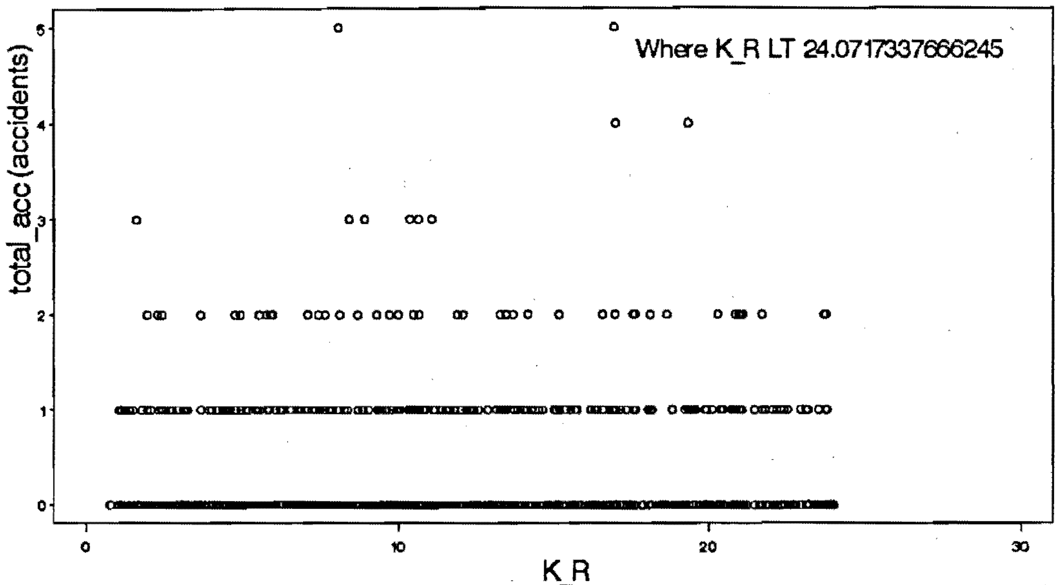



**Figure 16.** Scatter Plot of Number of Accidents against Ratio of Vertical Curve Radius to Horizontal Curve Radius (<24.1) for Horizontal Curves Combined with Crest Vertical Curve

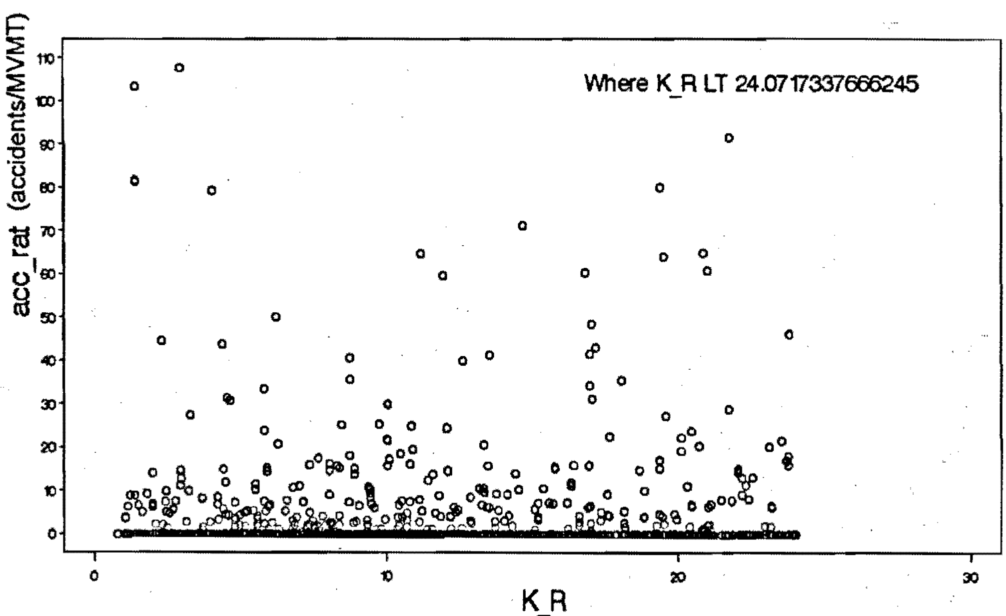



**Figure 17.** Relationship between Accident Rate and Ratio of Vertical Curve Radius to Horizontal Curve Radius (<24.1) for Horizontal Curves Combined with Crest Vertical Curve

But remember that the ratio K_R has a negative correlation with the horizontal curve radius *curv_rad* (see Table 6). In other words, the curves with a ratio K_R of smaller than 25 have greater radii than those curves with a ratio K_R of greater than 25. Taking a closer look at the following radius distribution in the range of ratio K_R in Table 9, the negative correlation between the ratio and the horizontal curve radius is showed further.

**Table 9.** Quantile Distribution of Curve Radius for Horizontal Curve Combined with Crest Vertical Curve

| Ratio K_R LT 24.07 | | Ratio K_R GT 24.07 | |
|---|---|---|---|
| Quantile | Estimate | Quantile | Estimate |
| 100% Max | 50000 | 100% Max | 22269 |
| 99% | 22000 | 99% | 7163 |
| 95% | 11370 | 95% | 4800 |
| 90% | 5730 | 90% | 2865 |
| 75% Q3 | 3820 | 75% Q3 | 1910 |
| 50% Median | 1910 | 50% Median | 1243 |
| 25% Q1 | 1273 | 25% Q1 | 819 |
| 10% | 819 | 10% | 573 |
| 5% | 637 | 5% | 478 |
| 1% | 382 | 1% | 287 |
| 0% Min | 200 | 0% Min | 191 |
| Mean | 3290.9182 | Mean | 1698.75737 |

Further investigation was conducted by grouping the horizontal curves with a close range of horizontal curve radii. A series of scatter plots for combined horizontal curves with a close range of radii such as Figure 18, Figure 19 and Appendix B clearly show that the accident rate decreases with greater ratio of vertical curve radius to horizontal curve radius K_R, namely higher rate of vertical curvature K. Therefore, especially when a horizontal curve of smaller radius is combined with a crest vertical curve, it is suggested that a greater ratio of vertical curve radius to horizontal curve radius K_R be applied.

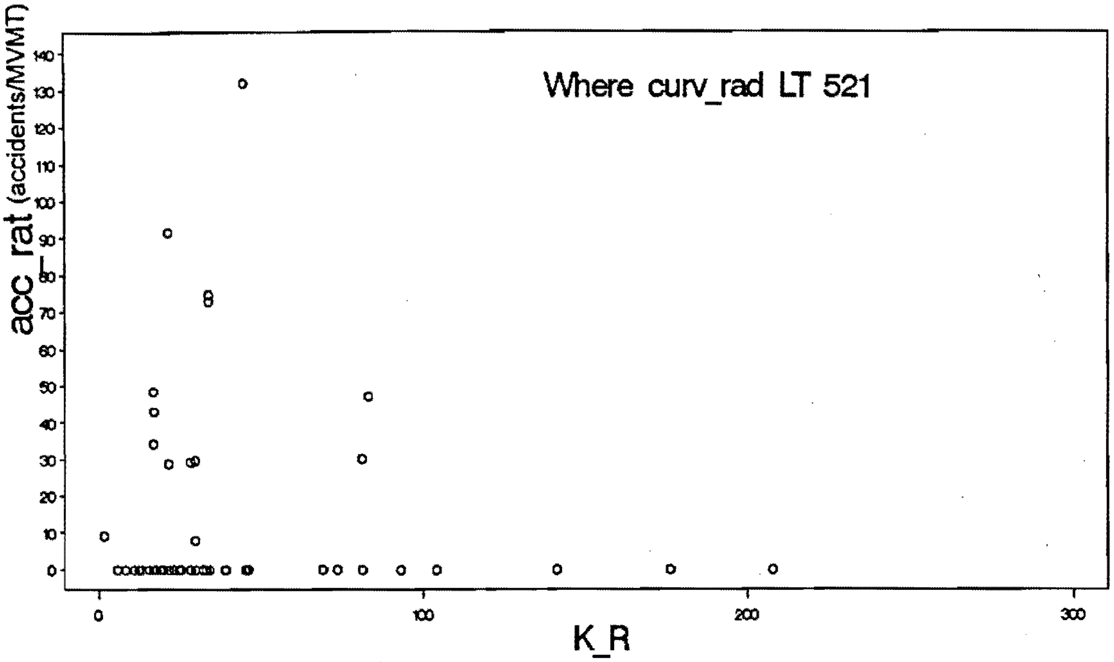



**Figure 18.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Less Than 521 ft

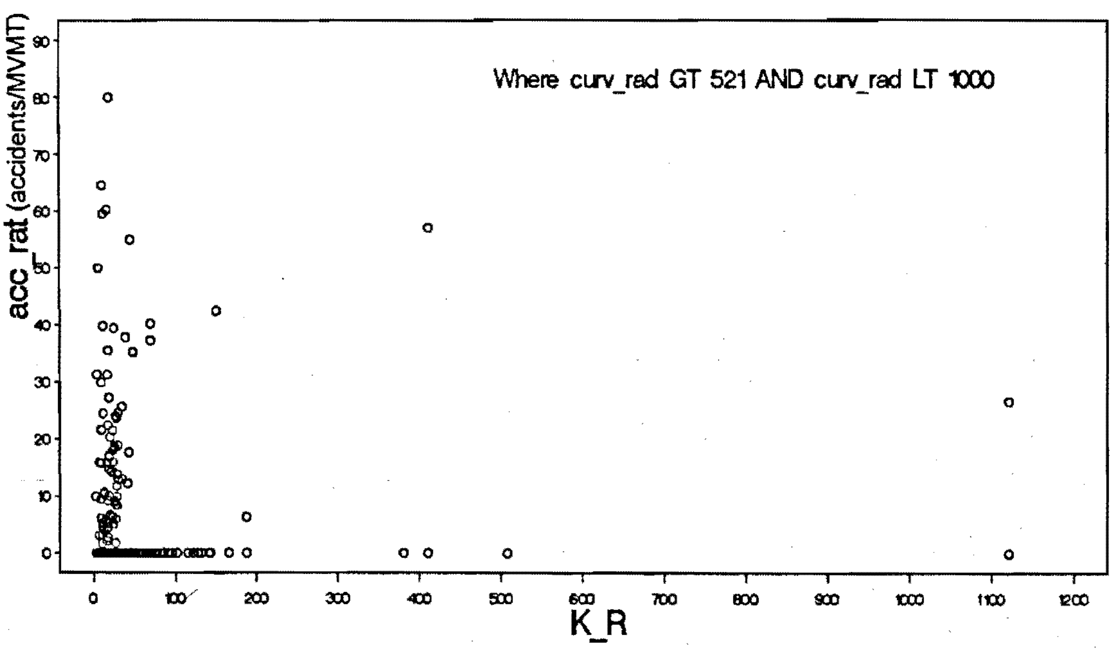



**Figure 19.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 521 and Less Than 1000 ft

Smith and Lamm (1994) suggested that the ratio should be in the range of 5 to 10 (They suggested the ratio of horizontal curve radius to vertical curve radius be in the range of 1/5 to 1/10, a ratio of the inverse of K_R). After a comparison was made from Figure 18, Figure 19 and other figures in Appendix B, it was found that the range of 5 to 10 is not sufficient enough, especially for a curve radius of smaller than 6000 feet. This study suggested that a ratio of vertical curve radius to horizontal curve radius K_R be more than 25 for a horizontal curve of smaller than 6000 ft when it is combined with a vertical curve, and that a ratio be more than 10 for a combined horizontal curve of larger than 6000 ft.

### 5.2.2 Horizontal Curve Combined with Sag Vertical Curve

The study analyzed 3242 road sections of horizontal curve combined with sag vertical curve that experienced a total of 535 accidents over the 4-year period from 2002 to 2005, with a mean of 1.479 accidents per million of vehicles-miles of travel per curve. The accident frequency distribution is given in Figure 20.

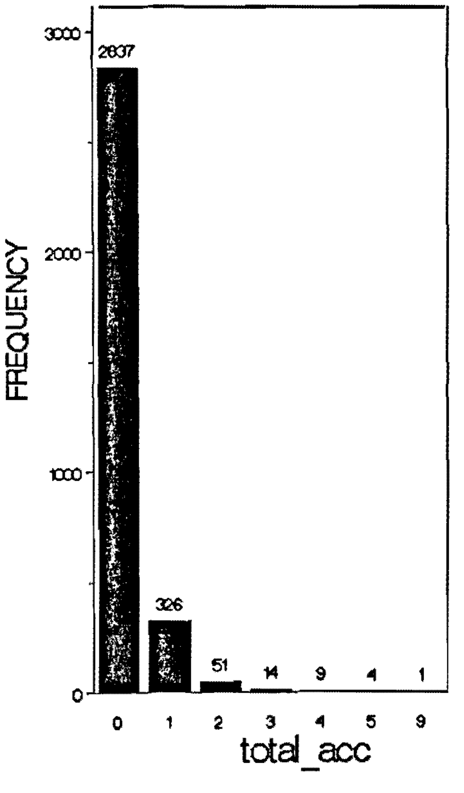



**Figure 20.** Accident Frequency Distribution for Horizontal Curve Combined with Sag Vertical Curve

Similar models to the combined horizontal curve with crest vertical curve were constructed for the combination of horizontal curve with sag vertical curve. It was found that the nature log of AADT and section length, degree of horizontal curvature *deg_curv*, roadway width *roadway_wid*, and access density *access* are statistically significant. The final models are shown in Table 10.

**Table 10. Models for Horizontal Curve Combined with Sag Vertical Curve: 3242 Sections**

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | t Statistic | p-value |
| | -6.5913 | | | -6.3660 | | | -6.7921 | | | -7.3499 | | |
| Intercept | 0.4683 | 198.08 | <.0001 | 0.5199 | -14.16 | <.0001 | 0.5545 | 150.05 | <.0001 | 0.5629 | -13.15 | <.0001 |
| | 0.9606 | | | 0.8702 | | | 1.0141 | | | 1.0059 | | |
| AADT: log_aadt | 0.0587 | 267.45 | <.0001 | 0.06638 | 13.11 | <.0001 | 0.0743 | 186.13 | <.0001 | 0.07233 | 13.91 | <.0001 |
| | 0.9065 | | | 0.6211 | | | 1.0059 | | | 0.9051 | | |
| Section Length: log_lgt | 0.0669 | 183.34 | <.0001 | 0.1032 | 6.02 | <.0001 | 0.0838 | 144.20 | <.0001 | 0.09890 | 9.15 | <.0001 |
| | 0.0751 | | | 0.1149 | | | 0.0971 | | | 0.1378 | | |
| Degree of Curvature: deg_curv | 0.0081 | 86.62 | <.0001 | 0.01214 | 9.47 | <.0001 | 0.0126 | 59.44 | <.0001 | 0.01640 | 8.40 | <.0001 |
| | -0.0414 | | | -0.03367 | | | -0.0456 | | | -0.03680 | | |
| Roadway width: roadway_wid | 0.0100 | 17.14 | <.0001 | 0.01079 | -3.12 | 0.0018 | 0.0122 | 14.02 | 0.0002 | 0.01184 | -3.11 | 0.0019 |
| | 0.0342 | | | 0.04177 | | | 0.0379 | | | 0.05347 | | |
| Access Density: access | 0.0047 | 53.53 | <.0001 | 0.006748 | 6.19 | <.0001 | 0.0067 | 32.09 | <.0001 | 0.008574 | 6.24 | <.0001 |
| | | | | | | | | | | | | |
| | | | | | | | 1.0227 | Wald 95% | | 0.7452 | | |
| Disperson α | | | | | | | 0.1850 | [0.6601,1.3854] | | 0.1614 | 4.62 | <.0001 |
| LM Test of α=0 | | | | | | | | 30.4626 | <.0001 | | | |
| -2 Log Likelihood | 2445.58 | | | 2610.10 | | | 2613.60 | | | 2564.70 | | |
| Vuong Test | | | | 3.35 * | | | | | | 3.77** | | |
| AIC (smaller is better) | | | | 2626.1 | | | 2627.6 | | | 2582.7 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB.

Similar strong correlations between section length (here equal to curve length) *cseg_lgt*, degree of horizontal curvature *deg_curv*, horizontal curve radius *curv_rad*, central angle of horizontal curve *curv_rad*, rate of vertical curvature *avc*, algebraic difference in grade *ava*, and ratio of vertical curve radius to horizontal curve radius K_R were also found in the analyzed road sections. The correlations are given in the Table 11.

**Table 11.** Correlation Coefficients for Horizontal Curve Combined with Sag Vertical Curve

| | cseg_lgt | deg_curv | curv_rad | curv_ang | avc | ava | K_R |
|---|---|---|---|---|---|---|---|
| cseg_lgt | 1 | -0.29083 | 0.21968 | 0.44567 | 0.10764 | -0.15364 | -0.06353 |
| p-value | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0003 |
| deg_curv | -0.29083 | 1 | -0.46376 | 0.45762 | -0.12202 | 0.12148 | 0.28062 |
| p-value | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| curv_rad | 0.21968 | -0.46376 | 1 | -0.39871 | 0.14524 | -0.09359 | -0.19539 |
| p-value | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 |
| curv_ang | 0.44567 | 0.45762 | -0.39871 | 1 | -0.03425 | 0.0044 | 0.18481 |
| p-value | <.0001 | <.0001 | <.0001 | | 0.0512 | 0.8022 | <.0001 |
| avc | 0.10764 | -0.12202 | 0.14524 | -0.03425 | 1 | -0.35956 | 0.72453 |
| p-value | <.0001 | <.0001 | <.0001 | 0.0512 | | <.0001 | <.0001 |
| ava | -0.15364 | 0.12148 | -0.09359 | 0.0044 | -0.35956 | 1 | -0.2904 |
| p-value | <.0001 | <.0001 | <.0001 | 0.8022 | <.0001 | | <.0001 |
| K_R | -0.06353 | 0.28062 | -0.19539 | 0.18481 | 0.72453 | -0.2904 | 1 |
| p-value | 0.0003 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | |

Note: In each cell of the table, the top value is the correlation coefficient between the row and column variable for that cell. The lower value is a p-value.

The ratio of vertical curve radius to horizontal curve radius K_R has a strong negative correlation with the horizontal curve radius *curv_rad* and a strong positive correlation with the degree of curvature *deg_curv*. Considering the inverse relationship between the horizontal curve radius *curv_rad* and the degree of curvature *deg_curv*, the relationship of the ratio K_R and the horizontal curve radius *curv_rad* was chosen to be investigated.

Similar relationships between the accident rate and K_R, and accident counts and K_R are shown in Figure 21 and 22 for this combination. By extracting the combined horizontal curves based on a close range of horizontal radii (see part of series of scatter plots in Figure 23 and 24), the study also found that the accident rate decreases as the ratio of vertical curve radius to horizontal curve radius K_R increases for a combined horizontal curve with a sag vertical curve.

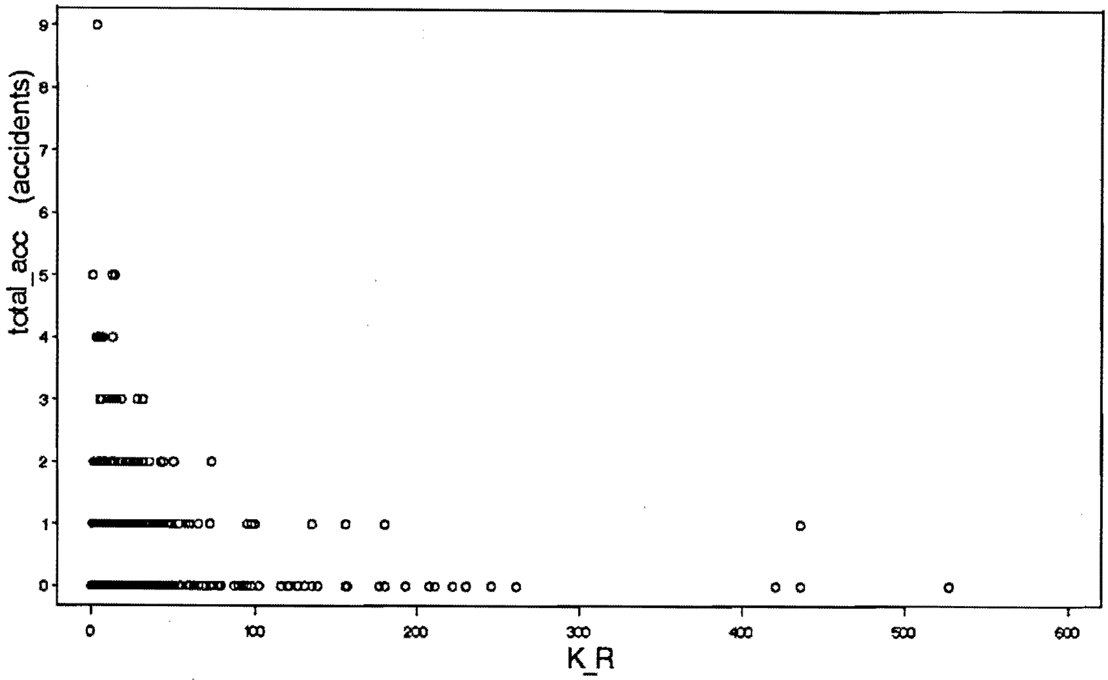



**Figure 21.** Scatter Plot of Number of Accidents against Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curves Combined with Sag Vertical Curve

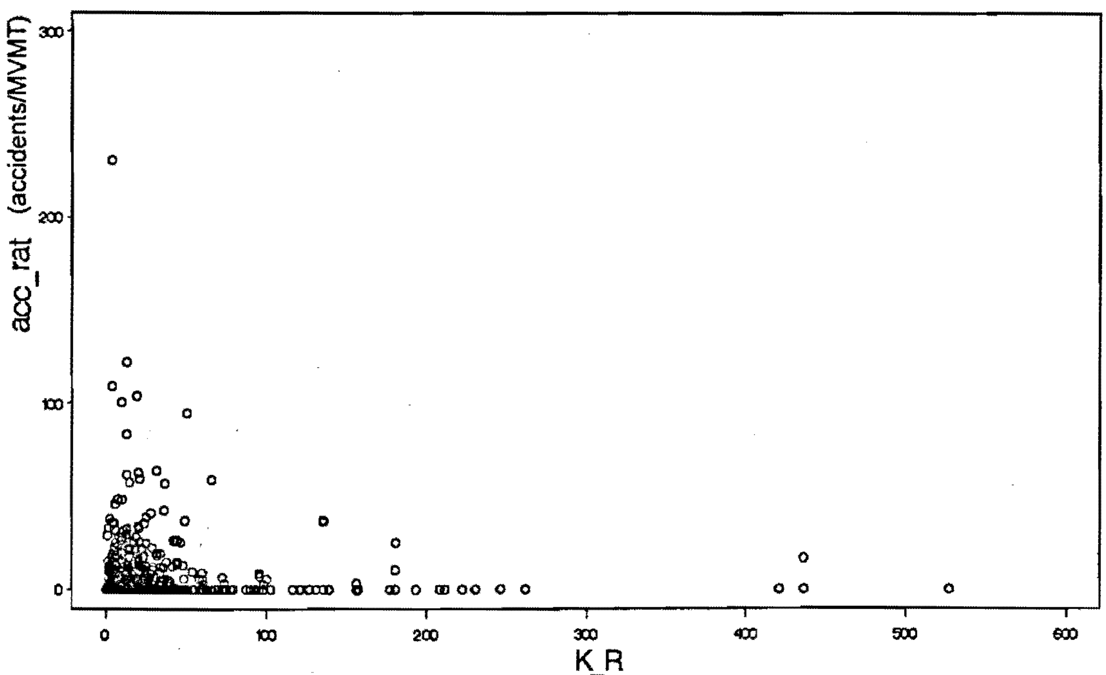



**Figure 22.** Relationship between Accident Rate and Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curves Combined with Sag Vertical Curve

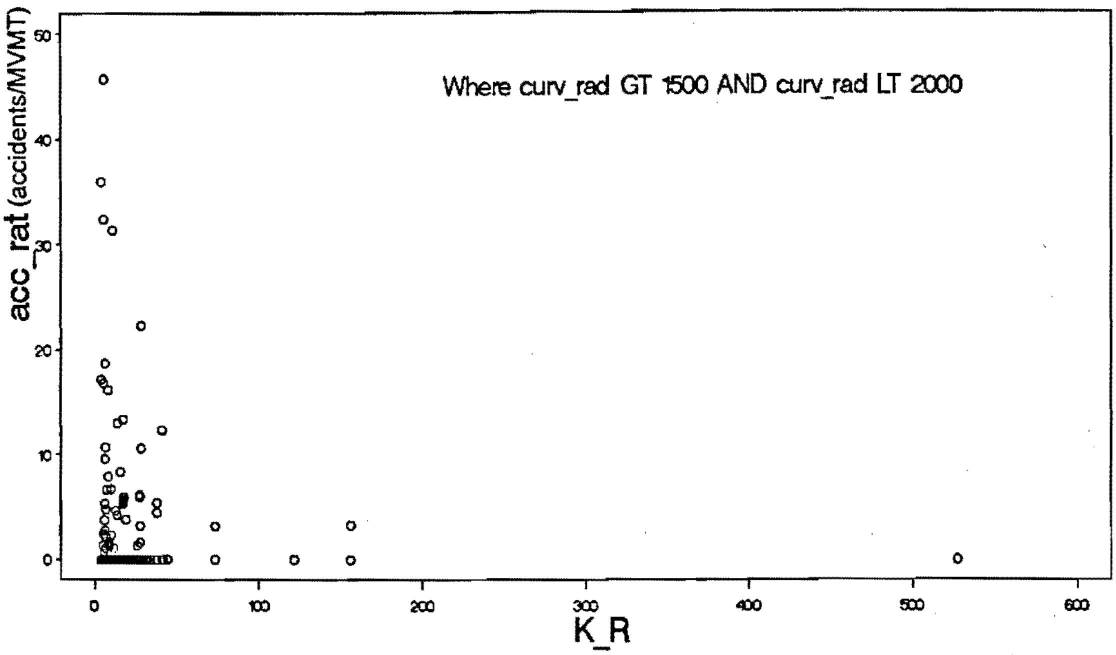



**Figure 23.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve of Radius Greater Than 1500 and Less Than 2000 ft Combined with Sag Vertical Curve

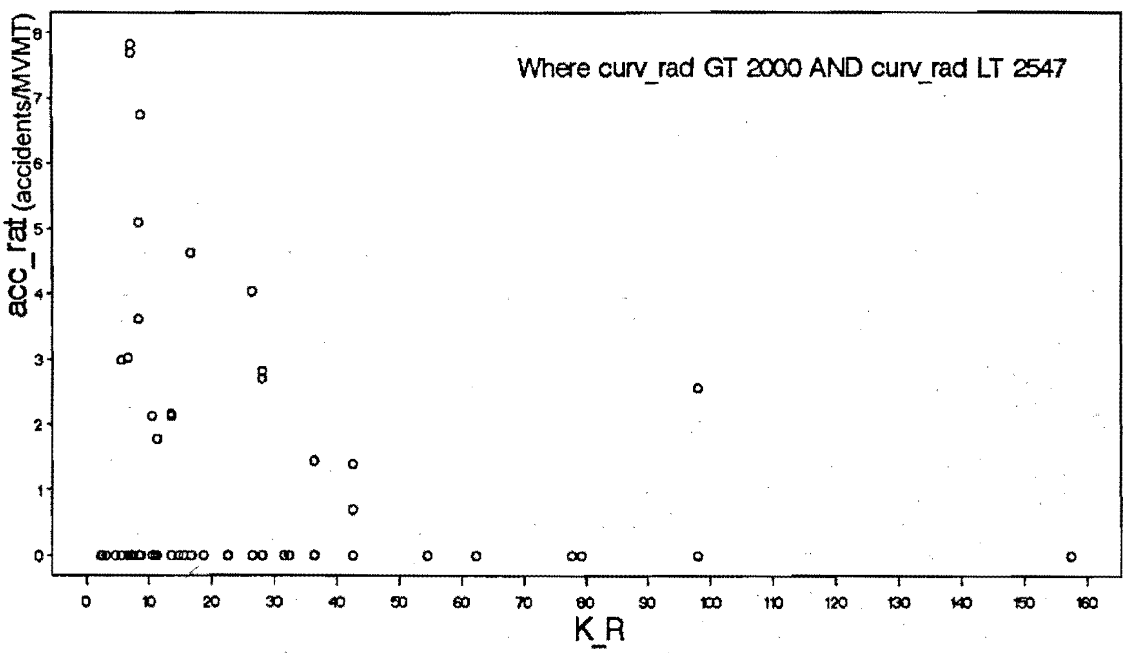



**Figure 24.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve of Radius Greater Than 2000 and Less Than 2547 ft Combined with Sag Vertical Curve

### 5.2.3 Horizontal Curve Combined with Multiple Vertical Curves

A total of 2892 horizontal curves combined with multiple vertical curve over the 4-year period from 2002 to 2005 (each year contributes an average of one-fourth of the total curves) were investigated for the safety effects. The length of each curve varied from 0.05 to 1.85 miles. A total length of 822.08 miles experienced a total of 760 accidents, with a mean of 1.097 accidents per million of vehicles-miles of travel per curve. The accident frequency distribution is plotted in Figure 25 showing that 80.98 percent of curves experience zero accidents.

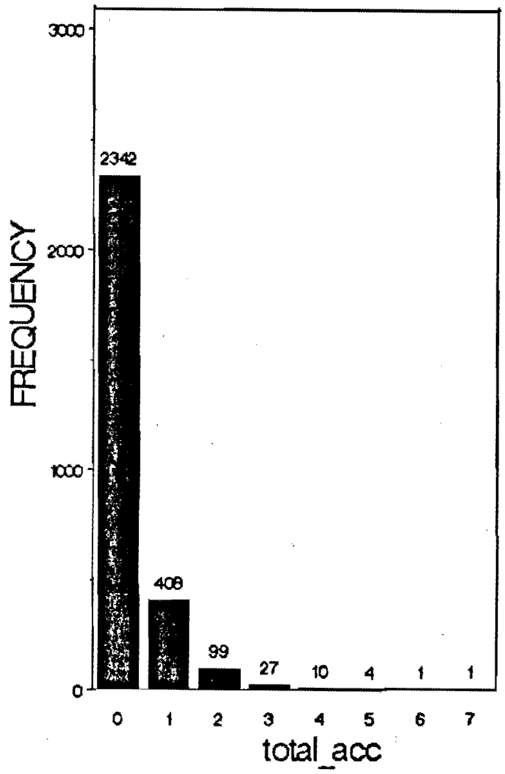



**Figure 25.** Accident Frequency Distribution for Horizontal Curve Combined with Multiple Vertical Curves

Through all the analyses for the four types of models, only the nature log of AADT and section length, and degree of horizontal curvature *deg_curv* were found to be statistically significant. The variables for cross-section widths, access density, and speed limit as well as all the potential influencing variables related to the vertical curve (including rate of vertical curvature *avc*, algebraic difference in grade *ava*, ratio of vertical curve radius to horizontal curve radius K_R, and percentage of vertical curve on road section *pct_vcurv*) were insignificant variables in explaining the variability of accidents occurring on a road section of this type of combination. Table 12 shows the final results of the Poisson, NB, ZIP, and ZINB models.

**Table 12. Models for Horizontal Curve Combined with Multiple Vertical Curves: 2892 Sections**

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -7.2997 (0.3665) | 396.71 | <.0001 | -6.6203 (0.3955) | -16.74 | <.0001 | -7.4004 (0.4108) | 324.59 | <.0001 | -6.9910 (0.4356) | -16.05 | <.0001 |
| AADT: log_aadt | 0.8456 (0.0424) | 398.13 | <.0001 | 0.7692 (0.04570) | 16.83 | <.0001 | 0.8563 (0.0481) | 316.66 | <.0001 | 0.7990 (0.05101) | 15.66 | <.0001 |
| Section Length: log_lgt | 0.8820 (0.0618) | 203.72 | <.0001 | 0.6739 (0.08984) | 7.50 | <.0001 | 0.9201 (0.0728) | 159.54 | <.0001 | 0.7976 (0.09694) | 8.23 | <.0001 |
| Degree of Curvature: deg_curv | 0.1308 (0.0140) | 87.58 | <.0001 | 0.1358 (0.01563) | 8.68 | <.0001 | 0.1514 (0.0192) | 61.97 | <.0001 | 0.1657 (0.02228) | 7.44 | <.0001 |
| | | | | | | | | | | | | |
| Disperson α | | | | | | | 0.4946 (0.1121) | Wald 95%: [0.2748, 0.7143] | | 0.3696 (0.1237) | 2.99 | 0.0028 |
| LM Test of α=0 | | | | | | | | 19.2577 | <.0001 | | | |
| Deviance/DF | 0.7025 | | | | | | 0.5895 | | | | | |
| Pearson Chi-Square/DF | 1.0962 | | | | | | 0.9667 | | | | | |
| -2 Log Likelihood | 2872.40 | | | 3211.10 | | | 3204.40 | | | 3197.30 | | |
| Vuong Test | | | | 2.21* | | | -0.65*** | | | 1.32** | | |
| AIC (smaller is better) | | | | 3223.1 | | | 3214.4 | | | 3211.3 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

The correlations between explanatory variables were investigated through the study, too. Similar strong correlations between section length (here equal to curve length) *cseg_lgt*, degree of horizontal curvature *deg_curv*, horizontal curve radius *curv_rad*, central angle of horizontal curve *curv_rad*, rate of vertical curvature *avc*, algebraic difference in grade *ava*, and ratio of vertical curve radius to horizontal curve radius K_R were also found in the analyzed road sections (See Appendix C for details).

### 5.2.4 Horizontal Curve on Grade: $|G|<5$ and $|G|\geq 5$

There were 14320 horizontal curves on grades over the 4-year period from 2002 to 2005 (each year contributes an average of one-fourth of the total curves). A total length of 1715.49 miles experienced a total of 1979 accidents, with a mean of 1.523 accidents per million of vehicles-miles of travel per curve. The average accident rate based on the total number of accidents and a total of 1770.07 million of vehicles-miles of travel of was 1.12 per million of vehicles-miles of travel. The scatter plot of accident rate against the gradient is shown in Figure 26.

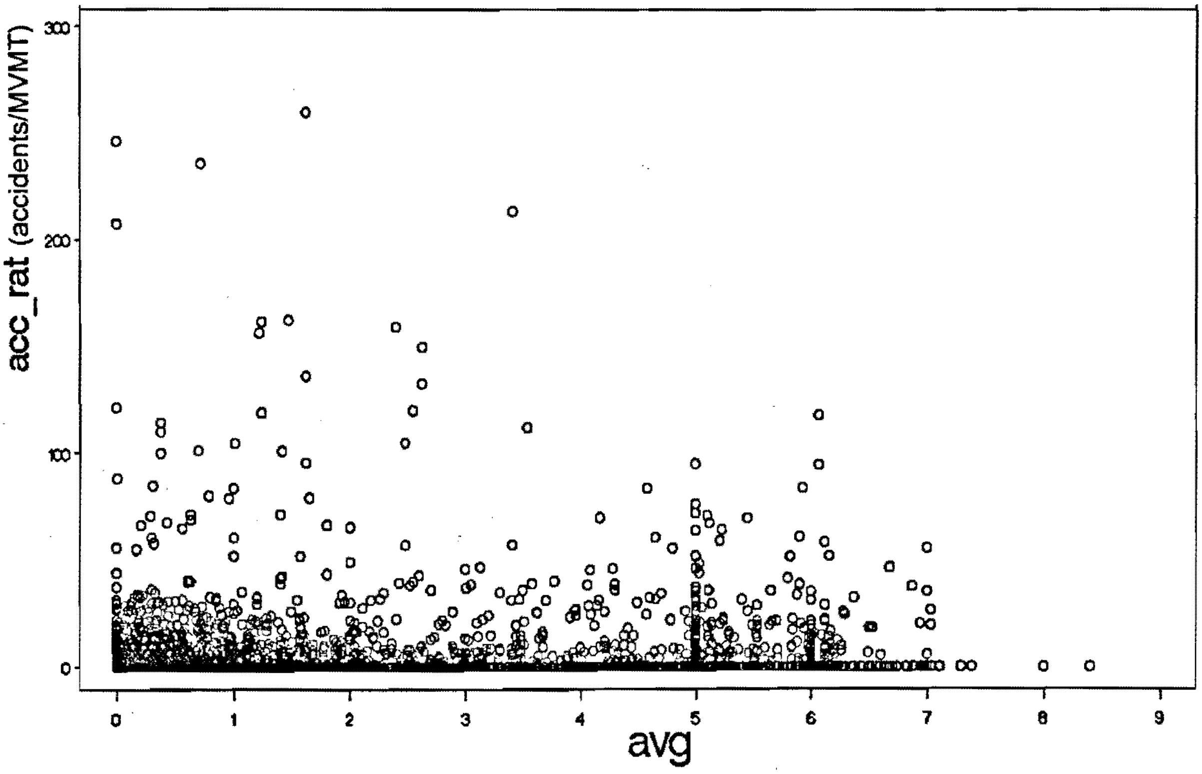



**Figure 26.** Scatter Plot of Accident Rate versus Gradient for Horizontal Curve on Grade

By visual inspection of the scatter plot for accident rate versus gradient, it seems that as the gradient increases, the accident rate decreases. However, the interaction of grade and horizontal curvature should be considered.

Given the findings in the literature about the gradient, the study divided the available road sections into two groups: $|G|<5$ and $|G|\geq 5$ to explore the safety effects of the gradient. 12108 horizontal curves on grade $|G|<5$ experienced a total of 1608 accidents, with a mean of 1.434 accidents per million of vehicles-miles of travel per curve, and 2212 horizontal curves on grade $|G|\geq 5$ experienced a total of 371 accidents, with a mean of 2.013 accidents per million of vehicles-miles of travel per curve over the 4-year period. Therefore, as we can see, the mean accident rate at a horizontal curve on grade $|G|\geq 5$ was greater than that at a horizontal curve on grade $|G|<5$. Even evaluating the average accident rate based on the total number of accidents and the total million of vehicles-miles of travel, the average accident rate at a horizontal curve on grade $|G|\geq 5$ was greater than that at a horizontal curve on grade $|G|<5$. The analysis results are shown in Table 13.

**Table 13.** Accident Rates for Horizontal Curve on Grade

| Statistic Variables | Grade (<5): 12108 Sections | Grade (≥5): 2212 Sections |
|---|---|---|
| Mean Accident Rate Per Curve(Accidents/mvmt): acc_rat | 1.434 | 2.013 |
| Total Exposure (Millions of Vehicle-Miles of Travel): mvmt | 1554.48 | 215.59 |
| Total Number of Accidents | 1608 | 371 |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 1.034 | 1.721 |
| Mean Horizontal Curve Radius:curv_rad | 2763 | 1553 |

Yet we can not conclude that the gradient has an influence on the safety at a horizontal curve on grade, because the greater accident rate may be attributed to the degree of horizontal curvature or the horizontal curve radius for that group. Here we discuss the horizontal curve radius for easy illustration. Take a look at the summary statistics of both groups; the group of grade $|G|<5$ has a mean horizontal radius of 2763 feet while the group of grade $|G|\geq 5$ has a mean horizontal radius of 1553 feet. It can be found that when a steep grade is combined with a smaller horizontal radius the accident rate increases accordingly.

Based on the above investigation, the combination of a horizontal curve on grade was modeled separately into the two $|G|<5$ and $|G|\geq 5$ groups. The accident frequency distributions are shown in Figure 27 and 28.

The initial model development found that gradient was not a significant variable in predicting accidents occurring on a road section of a horizontal curve on a grade of less than 5%, while gradient was a significant predictor for a road section of a horizontal curve on a grade of greater than 5%. The findings seem in agreement with what Choueiri et al. (1994) found after an international review of safety aspects of individual design elements on two-lane rural highways that grades under 6% have relatively little effect on the accident rate. The negative sign for grades larger than 5% indicates that accident occurrences decrease as the grades larger than 5% increase, which seems to confirm Hauer's (2001) analysis: the accident benefits on the upgrade may offset the excess accidents on the downgrade.

However, besides the gradient of a grade, its length may have an important effect on the safety of a grade, too. The study introduced a combined variable: *grad_hgt*, which is the product of grade value and grade length. The study found that the combined variable is a significant safety factor in explaining the variation of accident occurrences in the two groups: $|G|<5$ and $|G|\geq 5$. Two series of Poisson, NB, ZIP, and ZINB models were developed in this study. The results with the goodness-of-fit statistics are presented in Table 14 and 15. The results show that as the gradient or grade length increases, the accident occurrences increase, too.

Like the other horizontal curve combinations, the nature log of AADT and section length, degree of horizontal curvature *deg_curv*, and access density *access* were found to be statistically significant, too. The influence of the cross-section variables is a little different in the two groups. The average shoulder width *shld_wid* or the total roadway width *roadway_wid* was found to be significant for horizontal curves on grade $|G|<5$. However, neither the average shoulder width *shld_wid* nor the total roadway width *roadway_wid* is significant for horizontal curves on grade $|G|\geq 5$. Only the travel surface width *surf_wid* was found to be significant in this combination. And the speed limit variable and the binary variable for climbing lanes on the grade were not detected as statistically significant variables, either.

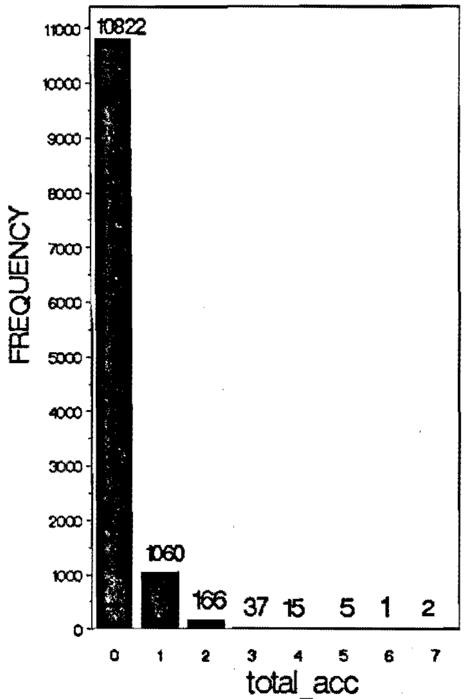



**Figure 27.** Accident Frequency Distribution for Horizontal Curve on Grade ($|G| < 5$)

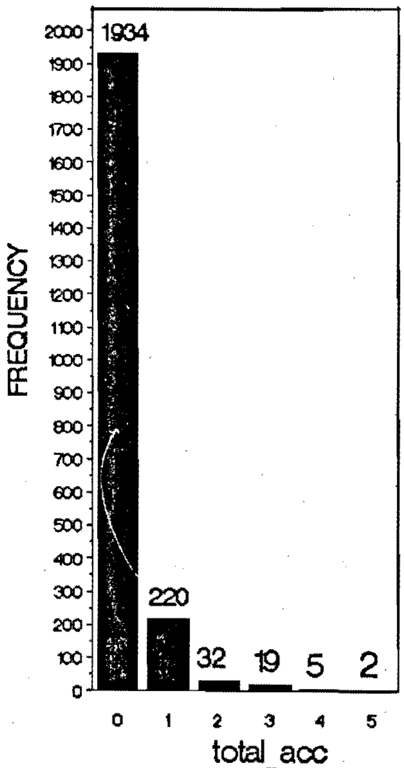



**Figure 28.** Accident Frequency Distribution for Horizontal Curve on Grade ($|G| \geq 5$)

**Table 14.** Models for Horizontal Curve on Grade $|G| < 5$ : 12108 Sections

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -8.6764<br>(0.2533) | 1173.4 | <.0001 | -8.0024<br>(0.2798) | -22.70 | <.0001 | -8.8830<br>(0.2954) | 904.37 | <.0001 | -8.8225<br>(0.3358) | -26.27 | <.0001 |
| AADT: log_aadt | 0.9352<br>(0.0327) | 820.17 | <.0001 | 0.9399<br>(0.03563) | 26.38 | <.0001 | 0.9555<br>(0.0388) | 606.23 | <.0001 | 0.9382<br>(0.04081) | 22.99 | <.0001 |
| grad_hgt: avg * cseg_lgt | 0.8451<br>(0.0693) | 148.87 | <.0001 | 0.3266<br>(0.1081) | 3.02 | 0.0025 | 0.9372<br>(0.0978) | 91.82 | <.0001 | 0.9405<br>(0.09757) | 9.64 | <.0001 |
| Degree of Curvature: deg_curv | 0.0247<br>(0.0043) | 33.26 | <.0001 | 0.02572<br>(0.005439) | 4.73 | <.0001 | 0.0264<br>(0.0053) | 24.86 | <.0001 | 0.0484<br>(0.01079) | 4.49 | <.0001 |
| Roadway width: roadway_wid | -0.0300<br>(0.0057) | 27.76 | <.0001 | -0.02952<br>(0.006075) | -4.86 | <.0001 | -0.0296<br>(0.0065) | 21.00 | <.0001 | -0.02795<br>(0.006478) | -4.31 | <.0001 |
| Access Density: access | 0.0217<br>(0.0026) | 67.67 | <.0001 | 0.02991<br>(0.004055) | 7.38 | <.0001 | 0.0251<br>(0.0043) | 34.29 | <.0001 | 0.02481<br>(0.004367) | 5.68 | <.0001 |
| | | | | | | | | | | | | |
| Disperson α | | | | | | | 1.2858<br>(0.1383) | Wald 95%<br>[1.0148,1.5568] | | 1.1591<br>(0.1626) | 7.13 | <.0001 |
| LM Test of α=0 | | | | | | | | 86.1032 | <.0001 | | | |
| -2 Log Likelihood | 8580.80 | | | 8960.00 | | | 8930.50 | | | 8923.60 | | |
| Vuong Test | | | | 5.46* | | | -1.64*** | | | 0.63** | | |
| AIC (smaller is better) | | | | 8976.0 | | | 8944.5 | | | 8941.6 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

**Table 15.** Models for Horizontal Curve on Grade $|G| \geq 5$ : 2212 Sections

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -6.7075 (1.2514) | 28.73 | <.0001 | -6.7185 (1.3635) | -4.93 | <.0001 | -6.8556 (1.4525) | 22.28 | <.0001 | -7.1426 (1.4256) | -5.01 | <.0001 |
| AADT: log_aadt | 0.9114 (0.0571) | 254.67 | <.0001 | 0.8961 (0.06538) | 13.71 | <.0001 | 0.9535 (0.0752) | 160.98 | <.0001 | 0.9702 (0.07404) | 13.10 | <.0001 |
| grad_hgt: avg * cseg_lgt | 0.7995 (0.0885) | 81.64 | <.0001 | 0.8566 (0.1039) | 8.25 | <.0001 | 0.8463 (0.1154) | 53.78 | <.0001 | 0.5279 (0.1840) | 2.87 | 0.0042 |
| Degree of Curvature: deg_curv | 0.0397 (0.0081) | 24.23 | <.0001 | 0.09439 (0.01456) | 6.48 | <.0001 | 0.0400 (0.0098) | 16.83 | <.0001 | 0.08508 (0.01705) | 4.99 | <.0001 |
| Travelled width: surf_wid | -0.1291 (0.0537) | 5.78 | 0.0162 | -0.1193 (0.05796) | -2.06 | 0.0398 | -0.1383 (0.0631) | 4.80 | 0.0285 | -0.1216 (0.06151) | -1.98 | 0.0481 |
| Access Density: access | 0.0538 (0.0119) | 20.55 | <.0001 | 0.05133 (0.01481) | 3.47 | 0.0005 | 0.0509 (0.0173) | 8.62 | 0.0033 | 0.05044 (0.01824) | 2.77 | 0.0057 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Disperson α | | | | | | | 1.0805 (0.2475) | Wald 95% [0.5954,1.5656] | | 0.6171 (0.2378) | 2.60 | 0.0095 |
| LM Test of α=0 | | | | | | | | 20.2810 | <.0001 | | | |
| -2 Log Likelihood | 1719.13 | | | 1838.10 | | | 1839.10 | | | 1801.00 | | |
| Vuong Test | | | | 3.37* | | | | | | 3.60** | | |
| AIC (smaller is better) | | | | 1854.1 | | | 1853.1 | | | 1821.0 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB.

From Table 14 and Table 15, the ZINB models provide the best fit to the data of two types of combinations with a lower AIC value. Right now, we can make comparisons from these two models to predict the number of accidents at a horizontal curve on grade $|G| \geq 5$ and a horizontal curve on grade $|G| < 5$ , and explore the results in Table 13 whether the greater accident rate on grade $|G| \geq 5$ was due to a smaller mean radius or not.

The number of accidents for two groups was predicted on the same curve length and same traffic volume AADT, and the two curves have travel lane width of 24 ft and no shoulder with one driveway access. The results are given in Table 16. It was found that the predicted number of accidents is greater for horizontal curve on grade $|G| \geq 5$. Therefore, the grade increases accident occurrences when a horizontal curve is on a grade. Another important finding can be inferred from Table 16, too. As the gradient increases, accident occurrences increase more sharply on a curve of smaller radius.

**Table 16.** Comparison of Number of Accidents on Grade $|G| \geq 5$ and Grade $|G| < 5$

| Curve Radius (ft) | Number of Accidents | |
|---|---|---|
| | Horizontal Curve on Grade=6% | Horizontal Curve on Grade=4% |
| 800 | 2.66 | 2.16 |
| 1500 | 2.00 | 1.83 |
| 2000 | 1.84 | 1.75 |
| 3000 | 1.70 | 1.67 |
| Notes: AADT=20000 Curve Length=0.1 miles | | |

### 5.2.5 Crest Vertical Curve on Horizontal Tangent

A total of 1171 road sections with crest vertical curve on independent horizontal tangent were extracted from the data over the 4-year period from 2002 to 2005.The accident frequency distribution is given in Figure 29. 78.99 percent of road sections experience zero accidents.

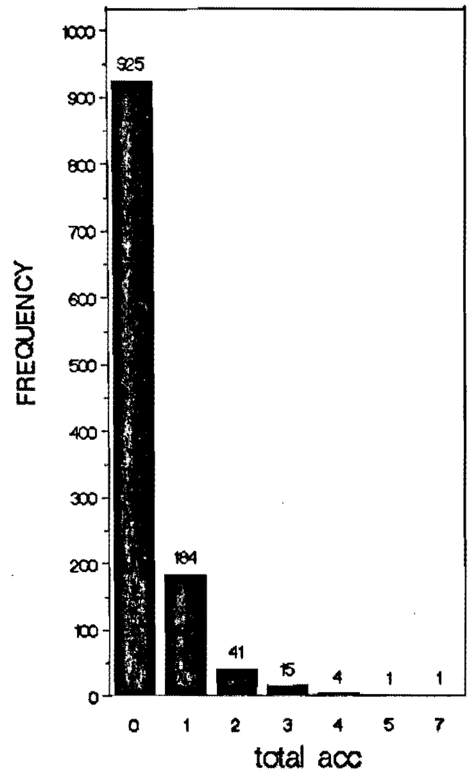



**Figure 29.** Accident Frequency Distribution for Crest Vertical Curve on Horizontal Tangent

The study found that only the nature log of AADT and section length as well as access density *access* was statistically significant (Table 17). All the characteristics of the combined crest vertical curve such as the rate of vertical curvature *avc* were not found to be significant. The smaller radius *sml_r*, ratio of larger radius to smaller radius *lar_smr*, and combination direction *hcurv_com* of the horizontal curves preceding and succeeding the tangent were insignificant variables in explaining the variability of accident occurrences on independent tangent with crest vertical curve. The cross-section variables and access density were not detected as significant variables. The reason may be due to the small number of observations.

A close to 1 value of Pearson's chi-square statistics in Table 17 shows that the overdispersion phenomenon does not exist in the data. The Lagrange multiplier (LM) test also shows that the LM statistic is not statistically significant at a significant level of 0.05. Therefore, the NB and ZINB models were not successfully constructed. In this case, the NB and ZINB models do not show any advantage over the Poisson model. And the Vuong statistic of 0.66 that is less than 1.96 does not show that the ZIP model has advantage over the Poisson model in the data, either.

**Table 17.** Models for Crest Vertical Curve on Horizontal Tangent: 1171 Sections

| | Poisson | | | ZIP | | | NB | | |
|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value |
| Intercept | -7.2931 (0.5274) | 191.19 | <.0001 | -6.9682 (0.5852) | -11.91 | <.0001 | -7.3833 (0.5664) | 169.95 | <.0001 |
| AADT: log_aadt | 0.8635 (0.0616) | 196.68 | <.0001 | 0.8328 (0.06580) | 12.66 | <.0001 | 0.8749 (0.0671) | 169.83 | <.0001 |
| Section Length: log_lgt | 0.9226 (0.0971) | 90.27 | <.0001 | 0.9115 (0.09963) | 9.15 | <.0001 | 0.9254 (0.1063) | 75.74 | <.0001 |
| Driveway density: access | 0.0804 (0.0240) | 11.21 | 0.0008 | 0.07959 (0.02455) | 3.24 | 0.0012 | 0.0818 (0.0259) | 9.94 | 0.0016 |
| | | | | | | | | | |
| Disperson α | | | | | | | 0.2433 (0.1315) | Wald 95% [-0.0145,0.5011] | |
| LM Test of α=0 | | | | | | | | 3.3626 | 0.0667 |
| Deviance/DF | 0.7023 | | | | | | 0.4419 | | |
| Pearson Chi-Square/DF | 1.0076 | | | | | | 1.0376 | | |
| -2 Log Likelihood | 1197.34 | | | 1358.70 | | | | | |
| Vuong Test | | | | 0.66* | | | | | |
| AIC (smaller is better) | | | | 1368.7 | | | | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

### 5.2.6 Sag Vertical Curve on Horizontal Tangent

The study developed the models on 1225 independent horizontal tangents with sag vertical curve. The accident frequency distribution is given in Figure 30. 78.12 percent of tangents experience zero accidents during the four years.

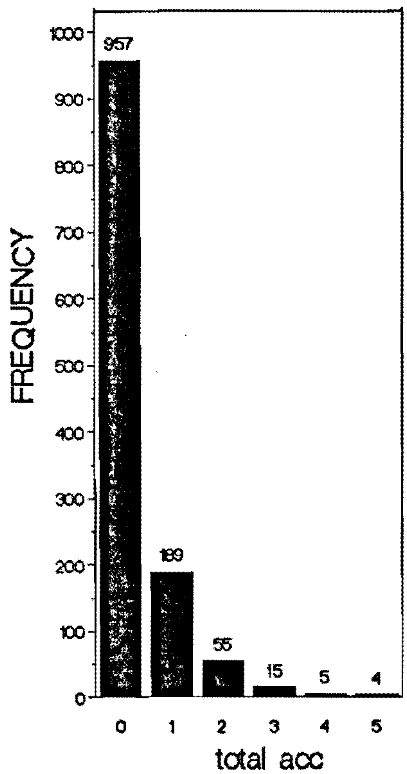



**Figure 30.** Accident Frequency Distribution for Sag Vertical Curve on Horizontal Tangent

The findings were that the rate of vertical curvature as well as the nature log of AADT and section length was statistically significant in explaining the variability of accident occurrences (see Table 18). However, by examining the chi-square value, the contribution for the rate of vertical curvature was very little. The smaller radius sml_r, ratio of larger radius to smaller radius lar_smr, and combination direction hcurv_com of the horizontal curves preceding and succeeding the tangent were insignificant variables in explaining the variability of accident occurrences on independent tangent with sag vertical curve. The small number of observations in the data may influence the cross-section variables and access density being detected as significant variables.

**Table 18.** Models for Sag Vertical Curve on Horizontal Tangent: 1225 Sections

| | Poisson | | | ZIP | | | NB | | |
|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value |
| Intercept | -7.5088 (0.5341) | 197.65 | <.0001 | -6.9683 (0.5724) | -12.17 | <.0001 | -7.4466 (0.5821) | 163.63 | <.0001 |
| AADT: log_aadt | 0.9162 (0.0613) | 223.57 | <.0001 | 0.8773 (0.06469) | 13.56 | <.0001 | 0.9102 (0.0676) | 181.12 | <.0001 |
| Section Length: log_lgt | 0.9158 (0.0987) | 86.07 | <.0001 | 0.9133 (0.1086) | 8.41 | <.0001 | 0.9398 (0.1125) | 69.78 | <.0001 |
| Rate of Vertical Curvature:avc | -0.0004 (0.0001) | 6.46 | 0.0110 | -0.00036 (0.000150) | -2.39 | 0.0170 | -0.0003 (0.0002) | 5.37 | 0.0205 |
| | | | | | | | | | |
| Disperson α | | | | | | | 0.3118 (0.1373) | Wald 95% [0.0427,0.5810] | |
| LM Test of α=0 | | | | | | | | 5.1837 | 0.0228 |
| -2 Log Likelihood | 1314.94 | | | 1505.00 | | | 1507.40 | | |
| Vuong Test | | | | 1.58* | | | 0.73*** | | |
| AIC (smaller is better) | | | | 1515.0 | | | 1517.4 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

### 5.2.7 Multiple Vertical Curves on Horizontal Tangent

A total of 5947 independent horizontal tangents with multiple vertical curves over the 4-year period from 2002 to 2005 were obtained and investigated for the safety effects. Figure 31 presents the accident frequency distribution of the analyzed road sections. 67.28 percent of tangents experience zero accidents.

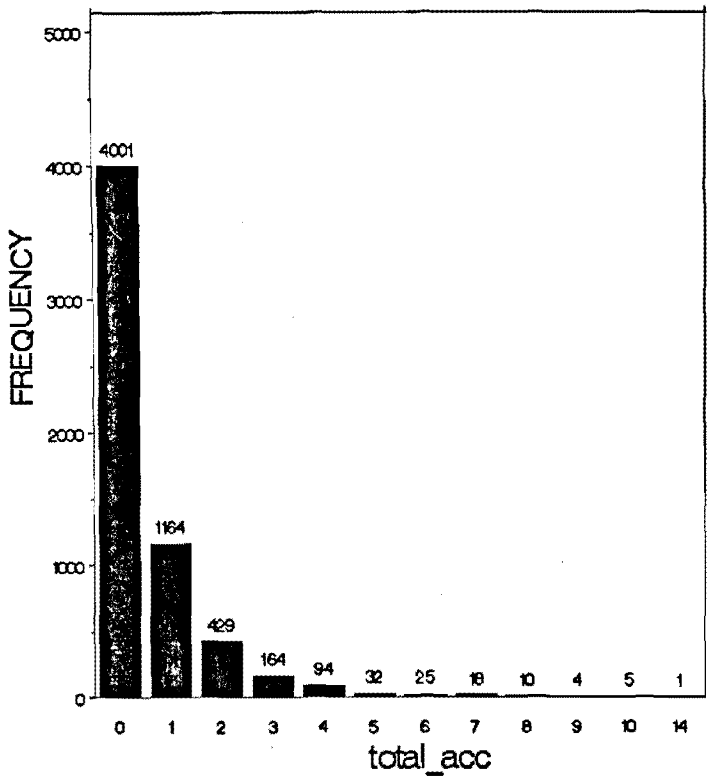



**Figure 31.** Accident Frequency Distribution for Multiple Vertical Curves on Horizontal Tangent

The findings in Table 19 show that the rate of vertical curvature, roadway width *roadway_wid*, access density *access*, and the nature log of AADT and section length are statistically significant variables. However, the contributions of the rate of vertical curvature, roadway width *roadway_wid*, access density *access* were relatively small by examining their chi-square values. Although the smaller radius variable *sml_r* before and after the tangent is excluded from the models due to its close to -0.0000 parameter coefficient, the study found that it has significant impact on the accident occurrences at the tangent. The negative sign of its estimated coefficient suggests that as the smaller radius before and after a tangent increases, accident occurrences at the tangent decrease.

**Table 19. Models for Multiple Vertical Curves on Horizontal Tangent: 5947 Sections**

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -7.3758 (0.1751) | 1774.6 | <.0001 | -5.9393 (0.2791) | -21.28 | <.0001 | -7.5724 (0.2012) | 1417.08 | <.0001 | -6.9458 (0.3029) | -22.93 | <.0001 |
| AADT: log_aadt | 0.9293 (0.0243) | 1459.6 | <.0001 | 0.7752 (0.03402) | 22.79 | <.0001 | 0.9545 (0.0285) | 1124.27 | <.0001 | 0.8845 (0.03774) | 23.44 | <.0001 |
| Section Length: log_lgt | 0.9219 (0.0207) | 1979.4 | <.0001 | 0.8518 (0.02815) | 30.26 | <.0001 | 0.9174 (0.0241) | 1454.83 | <.0001 | 0.9152 (0.02418) | 37.85 | <.0001 |
| Rate of Vertical Curvature:avc | -0.0001 (0.0000) | 8.26 | 0.0041 | -0.00011 (0.000036) | -3.13 | 0.0017 | -0.0001 (0.0000) | 6.16 | 0.0131 | -0.00011 (0.000038) | -2.76 | 0.0057 |
| Roadway width: roadway_wid | -0.0128 (0.0043) | 8.79 | 0.0030 | -0.01260 (0.004490) | -2.81 | 0.0050 | -0.0129 (0.0049) | 7.01 | 0.0081 | -0.01310 (0.004822) | -2.72 | 0.0066 |
| Access Density: access | 0.0737 (0.0099) | 54.93 | <.0001 | 0.07551 (0.01063) | 7.11 | <.0001 | 0.0687 (0.0111) | 38.00 | <.0001 | 0.07097 (0.01109) | 6.40 | <.0001 |
| Disperson α | | | | | | | 0.2291 (0.0316) | Wald 95% [0.1671,0.2912] | | 0.1923 (0.03444) | 5.58 | <.0001 |
| LM Test of α=0 | | | | | | | | 53.1136 | <.0001 | | | |
| -2 Log Likelihood | 6843.32 | | | 10020.00 | | | 9987.70 | | | 9978.50 | | |
| Vuong Test | | | | 3.55* | | | | | | 1.37** | | |
| AIC (smaller is better) | | | | 10038 | | | 10002 | | | 9996.5 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

### 5.2.8 Horizontal Tangent with Constant Grade

There were 2948 independent tangent sections with grade $|G|<5$ and 440 independent tangent sections with grade $|G|\geq 5$ over the 4-year period from 2002 to 2005. The length of tangents for grade $|G|<5$ varied from 0.11 miles to 3.39 miles with a mean of 0.38 miles, and the length of tangents for grade $|G|\geq 5$ varied from 0.13 miles to 0.71 miles with a mean of 0.28 miles. The accident frequency distributions are shown in Figure 32 and 33.

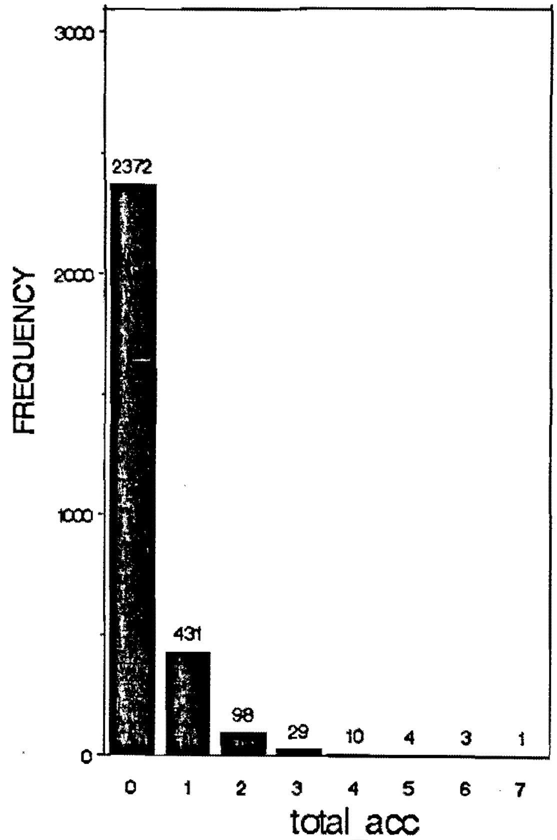



**Figure 32.** Accident Frequency Distribution for Horizontal Tangent with Grade ($|G|<5$)

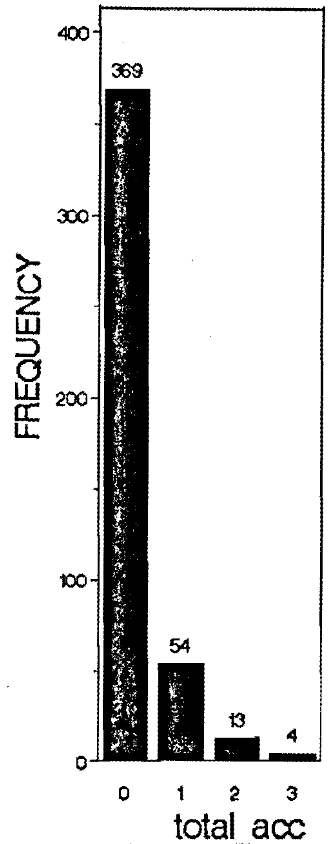



**Figure 33.** Accident Frequency Distribution for Horizontal Tangent with Grade ($|G| \geq 5$)

Similar to the study of horizontal curves on grades, the initial study began with examining the effect of the gradient. The same findings as horizontal curves on grades were obtained that gradient was not a significant variable in predicting accidents occurring on an independent horizontal tangent that is on a grade of less than 5%, while gradient was a significant predictor for an independent horizontal tangent on a grade of greater than 5%. The negative sign for grades larger than 5% indicates that accident occurrences decrease as the grades larger than 5% increase.

The study explored a combined variable *grad_hgt*, which is equal to the gradient times grade length. The study found that the combined variable was a significant safety factor in explaining the variation of accident occurrences on horizontal tangent on grade $|G| < 5$. Two series of Poisson, NB, ZIP, and ZINB models were developed successfully for this combination. The results with the goodness-of-fit statistics are presented in Table 20. Due to the small number of observations for grade $|G| \geq 5$, only the Poisson model was built (See Table 21). A close to 0.05 p-value of the chi-square statistic corresponding to the combined variable was obtained. The

Lagrange multiplier (LM) test also shows that the LM statistic is not statistically significant at a significant level of 0.05. The overdispersion phenomenon does not exist in the data for grade $|G| \geq 5$. The study suggested that a larger number of the observations for horizontal tangents on grade $|G| \geq 5$ be obtained to develop a better model.

The positive signs of the estimated coefficients for the results in two categories show that as the gradient or grade length increases, accident occurrences increase, too.

Besides the grade combined variable, the nature log of AADT, roadway width *roadway_wid*, and access density *access* were found to be statistically significant in the category of horizontal tangent with grade $|G| < 5$. The variables related to the horizontal curves before and after the horizontal tangent, such as the curve direction combination, ratio of large radius to small radius, and smaller horizontal curve radius, were not found to be significant variables in predicting accidents on horizontal tangent with grade. The speed limit variable *spd_limt* and the binary variable for the presence of a climbing lane were not found to be significant variables, either.

**Table 20. Models for Horizontal Tangent with Constant Grade $|G|<5$: 2948 Section**

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -8.2796 (0.3597) | 529.89 | <.0001 | -5.0263 (0.7507) | -6.70 | <.0001 | -8.5748 (0.4275) | 402.23 | <.0001 | -7.3125 (1.2157) | -6.01 | <.0001 |
| AADT: log_aadt | 0.9412 (0.0452) | 433.10 | <.0001 | 0.6158 (0.08729) | 7.05 | <.0001 | 0.9728 (0.0553) | 309.28 | <.0001 | 0.8387 (0.1321) | 6.35 | <.0001 |
| grad_hgt = avg * lgt | 0.3043 (0.0614) | 24.59 | <.0001 | 0.2623 (0.06329) | 4.14 | <.0001 | 0.2951 (0.0795) | 13.78 | 0.0002 | 0.8775 (0.04794) | 3.70 | 0.0002 |
| Roadway width: roadway_wid | -0.0186 (0.0076) | 6.03 | 0.0141 | -0.01976 (0.008296) | -2.38 | 0.0173 | -0.0170 (0.0087) | 3.80 | 0.0513 | -0.01789 (0.008720) | -2.05 | 0.0403 |
| Access Density: access | 0.0595 (0.0171) | 12.07 | 0.0005 | 0.06804 (0.02022) | 3.36 | 0.0008 | 0.0540 (0.0212) | 6.49 | 0.0109 | 0.05722 (0.02139) | 2.68 | 0.0075 |
| | | | | | | | | | | | | |
| Disperson α | | | | | | | 0.7706 (0.1283) | Wald 95% [0.5191,1.0221] | | 0.5862 (0.2114) | 2.77 | 0.0056 |
| LM Test of α=0 | | | | | | | | 36.7952 | <.0001 | | | |
| -2 Log Likelihood | 3124.44 | | | 3463.60 | | | 3446.80 | | | 3445.60 | | |
| Vuong Test | | | | 3.14* | | | -1.71*** | | | 0.45** | | |
| AIC (smaller is better) | | | | 3477.6 | | | 3458.8 | | | 3461.6 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

**Table 21.** Models for Horizontal Tangent with Constant Grade $|G| \geq 5$ : 440 Sections

| | Poisson | | | NB | | |
|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | $\chi 2$ | p-value | Estimated Coefficient | $\chi 2$ | p-value |
| Intercept | -8.2322<br>0.8636 | 90.87 | <.0001 | | | |
| AADT: log_aadt | 0.7828<br>0.0951 | 67.72 | <.0001 | | | |
| grad_hgt= avg * lgt | 0.3229<br>0.1650 | 3.83 | 0.0503 | | | |
| | | | | | | |
| Disperson α | | | | | | |
| LM Test of α=0 | | | | | 2.1196 | 0.1454 |
| Deviance/DF | 0.6457 | | | | | |
| Pearson Chi-Square/DF | 1.1320 | | | | | |
| -2 Log Likelihood | 403.76 | | | | | |

# Chapter 6. MODEL SELECTION

The previous chapter has addressed the development of ten preliminary categories of models for different combinations of horizontal and vertical alignments. Most categories contain four types of statistical models – the Poisson, negative binomial (NB), zero-inflated Poisson (ZIP), and zero-inflated negative binomial (ZINB) model. This chapter intends to make comparisons between them to choose one type of model that is favorable to the analyzed data of a specific combination of horizontal and vertical alignments in this study. Thereafter the selected models are given.

## 6.1 MODEL SELECTION CRITERION

As to the four candidate models, three possible selections exist, that is, selection between the NB model and the Poisson model if no appropriate zero-inflated models (ZIP or ZINB) can be built, selection between the zero-inflated model (ZIP or ZINB) and the NB or Poisson (ZIP versus Poisson or NB, and ZINB versus NB), and selection between ZIP and ZINB if both zero-inflated models are fit to the data.

As discussed before, the overdispersion phenomenon in the Poisson model can be tested by the Lagrange multiplier (LM) test or the Wald test in the NB model. If the overdispersion phenomenon exists, then the NB model provides a better fit to the data and is superior to the Poisson model.

In determining if the zero-inflated model (ZIP or ZINB) provides an improvement over the traditional Poisson or NB model, Vuong statistic test was carried out for the ZIP versus the Poisson, the ZINB versus the NB, and the ZIP versus NB if the ZINB does not fit the data well.

Vuong test (Vuong 1989) can be used to compare two non-nested competing models. Let $f_1(y_i \mid X_i)$ and $f_2(y_i \mid X_i)$ are the probability density function of two competing models Model 1 and Model 2 (e.g. ZIP and Poisson, ZINB and NB, or even ZIP and NB). The Vuong statistic is defined as:

$$V = \frac{\sqrt{N}m}{S_m}, \text{ where } m_i = \log(\left[\frac{f_1(y_i \mid X_i)}{f_2(y_i \mid X_i)}\right] \qquad (56)$$

where $\bar{m}$ is the mean, $\bar{m} = (1/n)\sum_n m_i$, $S_m$ is the standard deviation, $S_m = \sqrt{(1/n)\sum_n (m_i - \bar{m})^2}$,

and n is the sample size. V is the standard statistic for testing the hypothesis that $E[m_i]$ is zero. It has an asymptotically standard normal distribution. If |V| is less than 1.96 (corresponding to the 95% confidence level for the t-test), the test result does not favor either model. And if V is greater than 1.96, Model 1 is favored, while a V value of less than -1.96 favors Model 2 (Greene 1994).

In the case that both ZIP and ZINB fit the model well, the Akaike Information Criterion (AIC) (e.g. "*SAS/STAT® 9.1 User's Guide*" 2004; Miaou et al. 1993) was used to make a choice between them. The AIC is given by the following equation:

$$AIC = -2l(\hat{\beta}) + 2p \tag{57}$$

where $l(\hat{\beta})$ is the log-likelihood function of the parameter vector $\hat{\beta}$ estimated at the Maximum Likelihood Estimation (MLE), and p is the number of the parameters. The smaller the AIC, the better the model is believed to fit the data.

The AIC measure of goodness-of-fit penalizes for increasing model complexity with the number of parameters. However, the Vuong test, as mentioned in some of the literature (e.g. Lord et al. 2007), does not account for a penalty for additional parameters to be included in the model.

For the test of ZIP against NB, when the |V| value of less than 1.96 does not justify the selection of one of them, the AIC test is applied. The model with the smaller AIC value is favored.

## 6.2 SELECTION OF FINAL MODELS

### 6.2.1 Initial Results

Based on the model selection criterion, ten selected models for ten preliminary types of combinations are listed in Table 22.

**Table 22.** Summary of Selected Models for Ten Preliminary Combinations

| No. | Types of Combinations | Equation | Model | Obs.# |
|---|---|---|---|---|
| 1 | Horizontal Curve Combined with Crest Vertical Curve | $y = e^{-5.4254} AADT^{0.7140} \lg t^{0.7115} e^{0.1454 \deg\_curv} e^{-0.0222 roadway\_wid} e^{0.0215 access}$ | ZIP | 4193 |
| 2 | Horizontal Curve Combined with Sag Vertical Curve | $y = e^{-7.3499} AADT^{1.0059} \lg t^{0.9051} e^{0.1378 \deg\_curv} e^{-0.0368 roadway\_wid} e^{0.0535 access}$ | ZINB | 3242 |
| 3 | Horizontal Curve Combined with Multiple Vertical Curves | $y = e^{-6.9910} AADT^{0.7990} \lg t^{0.7976} e^{0.1657 \deg\_curv}$ | ZINB | 2892 |
| 4 | Horizontal Curve on Grade: $\|G\| < 5$ | $y = e^{-8.8225} AADT^{0.9382} e^{0.9405 avg * \lg t} e^{0.0484 \deg\_curv} e^{-0.0280 roadway\_wid} e^{0.0248 access}$ | ZINB | 12108 |
| 5 | Horizontal Curve on Grade: $\|G\| \geq 5$ | $y = e^{-7.1426} AADT^{0.9702} e^{0.5279 avg * \lg t} e^{0.0851 \deg\_curv} e^{-0.1216 surf\_wid} e^{0.0504 access}$ | ZINB | 2212 |
| 6 | Crest Vertical Curve on Horizontal Tangent | $y = e^{-6.9682} AADT^{0.8328} \lg t^{0.9115} e^{0.0796 access}$ | ZIP | 1171 |
| 7 | Sag Vertical Curve on Horizontal Tangent | $y = e^{-6.9683} AADT^{0.8773} \lg t^{0.9133} e^{-0.00036 avc}$ | ZIP | 1225 |
| 8 | Multiple Vertical Curves on Horizontal Tangent | $y = e^{-6.9458} AADT^{0.8845} \lg t^{0.9152} e^{-0.00011 avc} e^{-0.0131 roadway\_wid} e^{0.0710 access}$ | ZINB | 5947 |
| 9 | Horizontal Tangent with Constant Grade: $\|G\| < 5$ | $y = e^{-8.5748} AADT^{0.9728} e^{0.2951 avg * \lg t} e^{-0.0170 roadway\_wid} e^{0.0540 access}$ | NB | 2948 |
| 10 | Horizontal Tangent with Constant Grade: $\|G\| \geq 5$ | $y = e^{-8.2322} AADT^{0.7828} e^{0.3229 avg * \lg t}$ | Poisson | 440 |

By examining the three models for Category 6, 7 and 8, the estimated coefficients are pretty close. Even though there are different numbers of independent variables that are included in the three models, the contributions of the rate of vertical curvature *avc*, roadway width *roadway_wid*, and drive density *access* to the accident predictions are relatively small. Their exclusions in Category 6 and 7 may due to the smaller number of observations. Crest vertical curves and sag vertical curves have little different effects on accident occurrences when they are on horizontal tangents. The study combined all the data of Category 6, 7, and 8, and explored a model that presents vertical curve(s) on horizontal tangent.

### 6.2.2 Model Development for Vertical Curve(s) on Horizontal Tangent

A total of 8343 sections of vertical curve(s) on horizontal tangent were obtained after combination of all the data from preliminary Category 6, 7, and 8. 70.51 percent of horizontal tangents experience zero accidents. The accident frequency distribution is given in Figure 34.

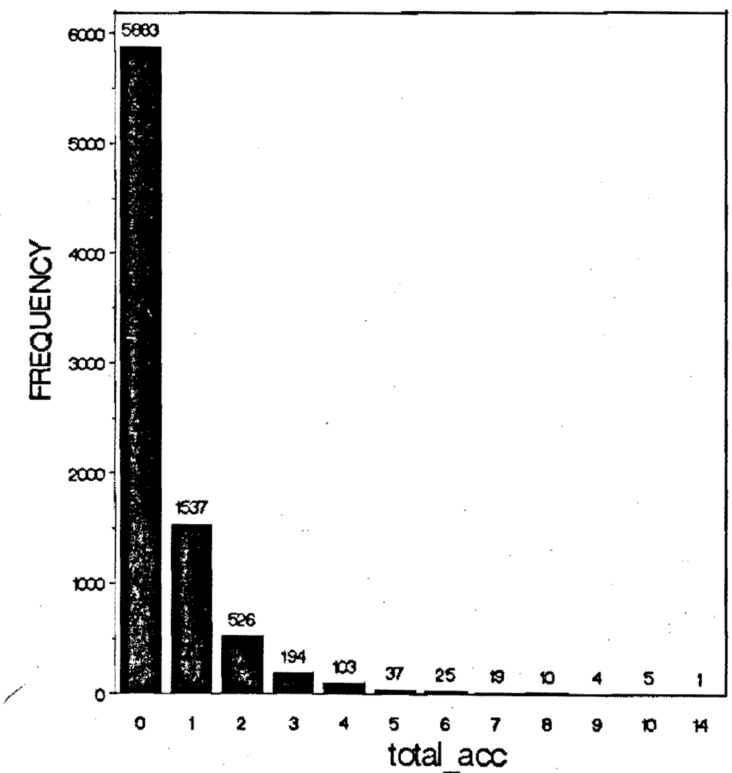



**Figure 34.** Accident Frequency Distribution for Vertical Curve(s) on Horizontal Tangent

All the four types of statistical models were successfully built. The findings in Table 23 show that the rate of vertical curvature *avc*, roadway width r*oadway_wid*, access density *access*, and the nature log of AADT and section length were found to be statistically significant variables. The ZINB model with its lowest AIC value was selected as the final model for the category of vertical curve(s) on horizontal tangent.

A similar evidence to the combination of multiple vertical curves on horizontal tangent was found that the smaller radius variable sml_r before and after the tangent has significant impact on accident occurrences at the tangent. It is excluded from the models due to its close to -0.0000 parameter coefficient. The negative sign suggests that a larger radius of the horizontal curves before and after the tangent improves safety at the tangent. The study also found that although the p value of the variable lar_smr is a little bit larger than the significant level 0.05, the positive sign also suggests that larger radius difference of the horizontal curves before and after the tangent has an adverse effect on the safety at the tangent.

### 6.2.3 Final Models for Combined Horizontal and Vertical Alignment

The study summarized eight models for eight final categories of combined horizontal and vertical alignment in Table 24.

**Table 23. Models for Vertical Curve(s) on Horizontal Tangent: 8343 Sections**

| | Poisson | | | ZIP | | | NB | | | ZINB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value | Estimated Coefficient | χ2 | p-value | Estimated Coefficient | t Statistic | p-value |
| Intercept | -7.3651 (0.1591) | 2143.8 | <.0001 | -5.8106 (0.2562) | -22.68 | <.0001 | -7.5326 (0.1805) | 1741.39 | <.0001 | -6.5593 (0.3124) | -21.00 | <.0001 |
| AADT: log_aadt | 0.9277 (0.0217) | 1826.4 | <.0001 | 0.7611 (0.03082) | 24.70 | <.0001 | 0.9462 (0.0250) | 1427.52 | <.0001 | 0.8398 (0.03703) | 22.68 | <.0001 |
| Section Length: log_lgt | 0.9163 (0.0181) | 2561.5 | <.0001 | 0.8398 (0.02510) | 33.45 | <.0001 | 0.9127 (0.0210) | 1882.22 | <.0001 | 0.8877 (0.02538) | 34.97 | <.0001 |
| Rate of Vertical Curvature:avc | -0.0001 (0.0000) | 11.75 | 0.0006 | -0.00012 (0.000033) | -3.67 | 0.0002 | -0.0001 (0.0000) | 9.24 | 0.0024 | -0.00012 (0.000035) | -3.36 | 0.0008 |
| Roadway width: roadway_wid | -0.0122 (0.0039) | 9.81 | 0.0017 | -0.01219 (0.004078) | -2.99 | 0.0028 | -0.0116 (0.0044) | 7.14 | 0.0076 | -0.01245 (0.004330) | -2.88 | 0.0040 |
| Access Density: access | 0.0678 (0.0087) | 61.39 | <.0001 | 0.06997 (0.009310) | 7.52 | <.0001 | 0.0656 (0.0096) | 46.15 | <.0001 | 0.06757 (0.009630) | 7.02 | <.0001 |
| Disperson α | | | | | | | 0.2372 (0.0303) | Wald 95% [0.1778,0.2965] | | 0.1841 (0.03415) | 5.39 | <.0001 |
| LM Test of α=0 | | | | | | | | 61.3599 | <.0001 | | | |
| -2 Log Likelihood | 9362.00 | | | 12881.00 | | | 12855.00 | | | 12836.00 | | |
| Vuong Test | | | | 4.15* | | | | | | 2.07** | | |
| AIC (smaller is better) | | | | 12899 | | | 12869 | | | 12856 | | |

Note: * Vuong Test for ZIP versus Poisson; ** Vuong Test for ZINB versus NB, *** Vuong Test for ZIP versus NB.

Table 24. Final Models for Eight Combinations of Horizontal and Vertical Alignment

| No. | Types of Combinations | Equation | Model | Obs.# |
|---|---|---|---|---|
| 1 | Horizontal Curve Combined with Crest Vertical Curve | $y = e^{-5.4254} AADT^{0.7140} \lg t^{0.7115} e^{0.1454 \deg\_curv} e^{-0.0222 roadway\_wid} e^{0.0215 access}$ | ZIP | 4193 |
| 2 | Horizontal Curve Combined with Sag Vertical Curve | $y = e^{-7.3499} AADT^{1.0059} \lg t^{0.9051} e^{0.1378 \deg\_curv} e^{-0.0368 roadway\_wid} e^{0.0535 access}$ | ZINB | 3242 |
| 3 | Horizontal Curve Combined with Multiple Vertical Curves | $y = e^{-6.9910} AADT^{0.7990} \lg t^{0.7976} e^{0.1657 \deg\_curv}$ | ZINB | 2892 |
| 4 | Horizontal Curve on Grade: $\lvert G \rvert < 5$ | $y = e^{-8.8225} AADT^{0.9382} e^{0.9405 avg*\lg t} e^{0.0484 \deg\_curv} e^{-0.0280 roadway\_wid} e^{0.0248 access}$ | ZINB | 12108 |
| 5 | Horizontal Curve on Grade: $\lvert G \rvert \geq 5$ | $y = e^{-7.1426} AADT^{0.9702} e^{0.5279 avg*\lg t} e^{0.0851 \deg\_curv} e^{-0.1216 surf\_wid} e^{0.0504 access}$ | ZINB | 2212 |
| 6 | Vertical Curve(s) on Horizontal Tangent | $y = e^{-6.5593} AADT^{0.8398} \lg t^{0.8877} e^{-0.00012 avc} e^{-0.0125 roadway\_wid} e^{0.0676 access}$ | ZINB | 8343 |
| 7 | Horizontal Tangent with Constant Grade: $\lvert G \rvert < 5$ | $y = e^{-8.5748} AADT^{0.9728} e^{0.2951 avg*\lg t} e^{-0.0170 roadway\_wid} e^{0.0540 access}$ | NB | 2948 |
| 8 | Horizontal Tangent with Constant Grade: $\lvert G \rvert \geq 5$ | $y = e^{-8.2322} AADT^{0.7828} e^{0.3229 avg*\lg t}$ | Poisson | 440 |

# Chapter 7. MODEL VALIDATION

This chapter is designated to present validation of the models that were developed in this study. The study selected three models: the zero-inflated Poisson (ZIP) model for horizontal curve combined with crest vertical curve, the zero-inflated negative binomial (ZINB) model for horizontal curve on grade $|G|< 5$ , and the ZINB model for vertical curve(s) on horizontal tangent, from eight final models for validation to test the model's ability and accuracy to predict the accident behavior on the alignments combined with horizontal and vertical alignments. As noted previously, those eight models were built on the four years of accident data from 2002 to 2005 in the Washington State two-lane rural highways in order to make full use of all the available data. The validation process was conducted by redeveloping those three models on the three years of accident data from 2002 to 2004 for the combined alignments whose models were selected for validation, and then validating the redeveloped models with the accident data for the year of 2005.

The first part of this chapter illustrates the validation techniques that were used. In the second part, the redevelopment of three selected models for validation, and their validation results are presented.

## 7.1 VALIDATION TECHNIQUES

Validation tests were performed for each of the three redeveloped models for the selected combined alignments as the following process (e.g. Miaou 1994):

- Calculate the observed relative frequency of road sections with k vehicle accidents involved during the observation year (namely 2005). The observed relative accident frequency $f_{obs}$ is evaluated by the number of road sections with k accident involvements divided by the total of road sections of a specific combination of alignments.
- Calculate the predicted relative frequency of road sections with k vehicle accidents involved during the prediction year. The predicted relative frequency is given by:

$$f_{pred} = \frac{\sum_{n} \hat{p}(Y_i = k)}{n} \quad (58)$$

where n is the total of road sections, and $\hat{p}(Y_i = k)$ is the predicted probability that k vehicle accidents would happen on a road section of a specific combination of alignment. The predicted probability is given by the characteristics of road section i (traffic, section length, geometric features, etc.) and the estimated parameters.

- A t statistic test was used to identify statistically significant difference between the observed relative frequency and the predicted relative frequency at the significant level of 0.05. If the p value is greater than the significant level, then the null hypothesis of no mean difference can not be rejected and there is no inconsistency detected between the accident behavior on the road section and model prediction. The t statistic is given by

$$t = \frac{\overline{d}}{S_d / \sqrt{K}} \tag{59}$$

where $\overline{d}$ is the mean difference $d = f_{obs} - f_{pred}$, $S_d$ is the standard deviation of the difference d, and K is the number of degrees of freedom.

## 7.2 REDEVELOPED MODELS AND VALIDATION RESULTS

### 7.2.1 Horizontal Curve Combined with Crest Vertical Curve

The selected final model in Table 24 for horizontal curve combined with crest vertical curve that was based on the four years of accident data was a ZIP model. The models were redeveloped on the 3120 horizontal curves combined with crest vertical curves from the years of 2002, 2003, and 2004. The best model was also a ZIP model given by the following equation:

$$y = e^{-5.6346} AADT^{0.7646} \lg t^{0.7059} e^{0.1557 \deg\_curv} e^{-0.0280 roadway\_wid} \tag{60}$$

The access density variable *access* was not found significant in this model. In fact, its contribution was very small in the selected final model in Table 24.

The accident data occurring on 1073 road sections of horizontal curve combined with crest vertical curve for the year of 2005 was used to validate this ZIP model. The observed versus predicted (relative) frequency of accident occurrences, t statistic and the p value of t are shown in Table 25. A graphical comparison of observed and predicted accident frequency is given in Figure 35. A p value of 0.9403 indicates that the null hypothesis of no mean difference can not be rejected, and that there is no inconsistency detected between the accident behavior on the road section and model prediction. Therefore, the redeveloped ZIP model provides the ability and accuracy to predict accident occurrences.

**Table 25.** Observed versus Predicted (Relative) Frequency of Accident Occurrences on 1073 Sections of Horizontal Curve Combined with Crest Vertical Curve in the Year of 2005

| Number of Accidents | Observed Relative Frequency | Observed Frequency | Predicted Relative Frequency | Predicted Frequency | Difference |
|---|---|---|---|---|---|
| 0 | 0.890960 | 956 | 0.881812 | 946 | 0.009148 |
| 1 | 0.091333 | 98 | 0.095000 | 102 | -0.003667 |
| 2 | 0.013979 | 15 | 0.018503 | 20 | -0.004523 |
| 3 | 0.003728 | 4 | 0.003668 | 4 | 0.000060 |
| Total | | 1073 | | 1072 | |
| Mean Difference = 0.00025 | | Standard Deviation = 0.00625 | | | |
| t Statistic = 0.081373 | | Pr > \|t\|: 0.9403 | | | |

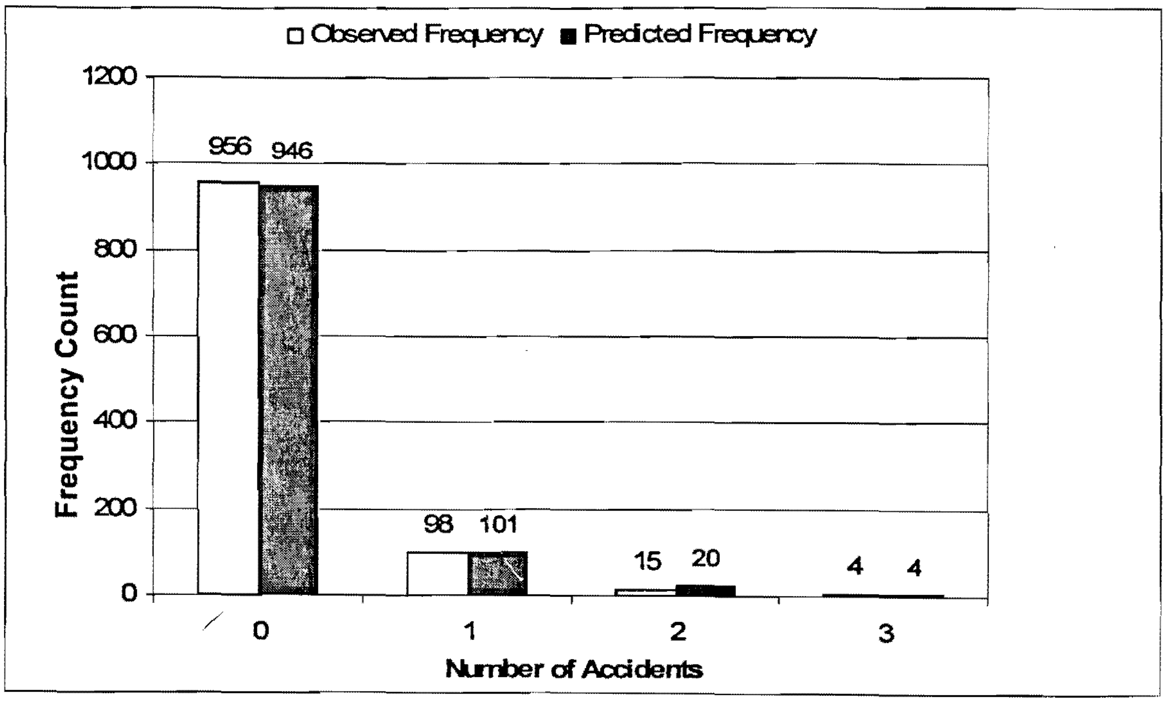



**Figure 35.** Comparison of Observed and Predicted Accident Frequency for 1073 Road Sections of Horizontal Curve Combined with Crest Vertical Curve in the Year of 2005

### 7.2.2 Horizontal Curve on Grade $|G| < 5$

The final model in Table 24 that was selected to best fit the accident data for horizontal curve on grade $|G| < 5$ was a ZINB model. Although the Vuong statistics do not favor the ZIP or ZINB model, the ZINB model was selected for the lower AIC value. In order to test how well the ZINB model estimates the accident frequency on the roadway, the ZINB model for horizontal curve on grade $|G| < 5$ was selected to be validated.

All the Poisson, NB, ZIP, and ZINB models for horizontal curve on grade $|G| < 5$ were developed again on the 9087 horizontal curves on grade $|G| < 5$ from the years of 2002, 2003, and 2004. Also, a ZINB model was selected to provide the best fit to the three years of accident data. The ZINB model is given as the following equation:

$$y = e^{-8.8562} AADT^{0.9513} e^{0.9926 avg*lgt} e^{0.04993 deg\_curv} e^{-0.03056 roadway\_wid} e^{0.02244 access} \tag{61}$$

The accident frequency on the 3021 road sections of horizontal curve on grade $|G| < 5$ in the year of 2005 were compared with the accident frequency predicted by this ZINB model. The t test was performed to identify if there is statistically significant difference between the observed relative frequency and the predicted relative frequency. The observed versus predicted (relative) frequency of accident occurrences, t statistic, and the p value of t are given in Table 26. Figure 36 shows a graphical comparison of observed and predicted accident frequency. A p value of 0.9695 indicates that the null hypothesis of no mean difference can not be rejected, and that there is no inconsistency detected between the accident behavior on the road section and model prediction. Therefore, the validity of the redeveloped ZINB model indicates that the model reflects accurately the accident behavior on the roadway.

**Table 26.** Observed versus Predicted (Relative) Frequency of Accident Occurrences on 3021 Sections of Horizontal Curve on grade $|G|<5$ in the Year of 2005

| Number of Accidents | Observed Relative Frequency | Observed Frequency | Predicted Relative Frequency | Predicted Frequency | Difference |
|---|---|---|---|---|---|
| 0 | 0.898709 | 2715 | 0.898305 | 2714 | 0.000404 |
| 1 | 0.085071 | 257 | 0.083893 | 253 | 0.001178 |
| 2 | 0.011586 | 35 | 0.013370 | 40 | -0.001784 |
| 3 | 0.001986 | 6 | 0.002965 | 9 | -0.000979 |
| 4 | 0.001324 | 4 | 0.000856 | 3 | 0.000468 |
| 5 | 0.000662 | 2 | 0.000308 | 1 | 0.000354 |
| 6 | 0.000331 | 1 | 0.000133 | 0 | 0.000198 |
| 7 | 0.000331 | 1 | 0.000066 | 0 | 0.000265 |
| Total | | 3021 | | 3021 | |
| Mean Difference = 0.000013 | Standard Deviation = 0.0009372 | | | | |
| t Statistic = 0.039626 | Pr > \|t\|: 0.9695 | | | | |

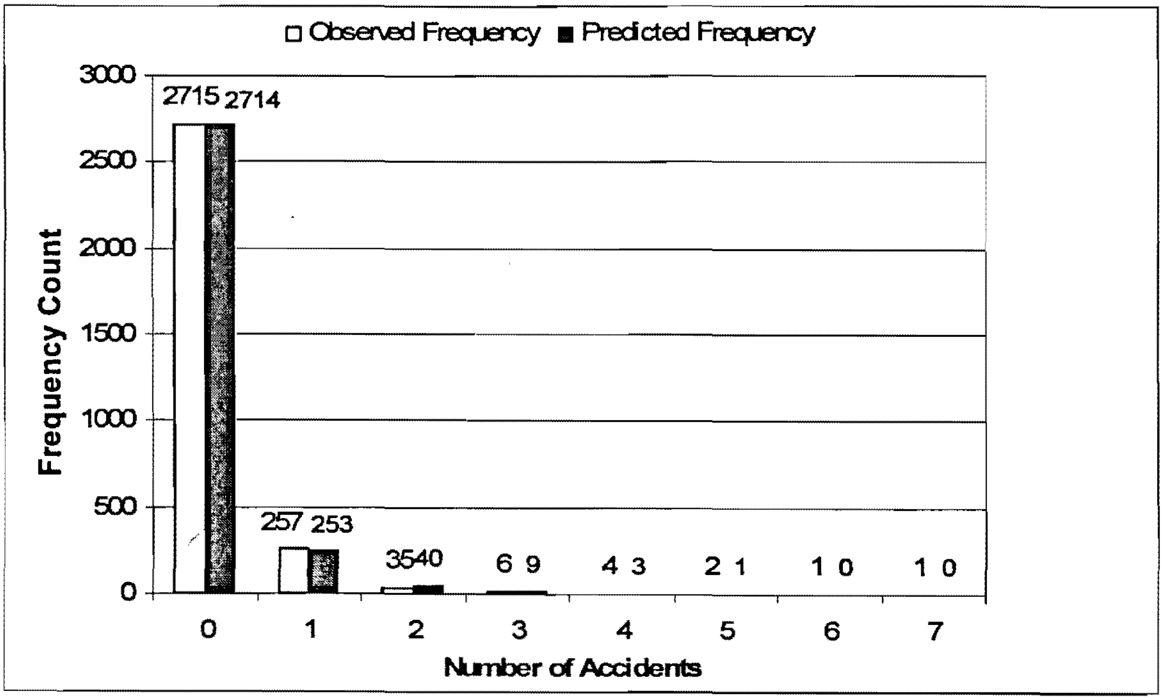



**Figure 36.** Comparison of Observed and Predicted Accident Frequency for 3021 Road Sections of Horizontal Curve on Grade $|G|<5$ in the Year of 2005

### 7.2.3 Vertical Curve(s) on Horizontal Tangent

All the Poisson, NB, ZIP, and ZINB models for vertical curve(s) on horizontal tangent were rebuilt on the accidents occurring on 6259 road sections of this alignment combination from the years of 2002, 2003, and 2004. The accident data on 2084 road sections of vertical curve(s) on horizontal tangent in the year of 2005 was reserved for validation use.

Similar results to the models in Table 24, the redeveloped ZINB model was selected with the lower AIC value and is given as the following equation:

$$y = e^{-6.7725} AADT^{0.8726} \lg t^{0.8724} e^{-0.00012avc} e^{-0.01423roadway\_wid} e^{0.06461access} \tag{62}$$

The accident frequency on 2084 road sections of vertical curve(s) on horizontal tangent in the year of 2005 were compared with the accident frequency predicted by this ZINB model. The observed versus predicted (relative) frequency of accident occurrences, t statistic, and the p value of t are given in Table 27. Figure 37 presents a graphical comparison of observed and predicted accident frequency. A p value of 0.9284 indicates that the null hypothesis of no mean difference can not be rejected. Therefore, there is no inconsistency detected between the accident occurrences on the road sections and the accident occurrences predicted by the model.

**Table 27.** Observed versus Predicted (Relative) Frequency of Accident Occurrences on 2084 Sections of Vertical Curve(s) on Horizontal Tangent in the Year of 2005

| Number of Accidents | Observed Relative Frequency | Observed Frequency | Predicted Relative Frequency | Predicted Frequency | Difference |
|---|---|---|---|---|---|
| 0 | 0.712092 | 1484 | 0.711213 | 1482 | 0.000879 |
| 1 | 0.182342 | 380 | 0.184008 | 383 | -0.001666 |
| 2 | 0.059981 | 125 | 0.060481 | 126 | -0.000500 |
| 3 | 0.023512 | 49 | 0.023089 | 48 | 0.000423 |
| 4 | 0.011516 | 24 | 0.010164 | 21 | 0.001353 |
| 5 | 0.001919 | 4 | 0.004971 | 10 | -0.003052 |
| 6 | 0.003359 | 7 | 0.002614 | 5 | 0.000745 |
| 7 | 0.003359 | 7 | 0.001444 | 3 | 0.001915 |
| 8 | 0.000960 | 2 | 0.000824 | 2 | 0.000135 |
| 9 | 0.000480 | 1 | 0.000481 | 1 | -0.000001 |
| 10 | 0.000480 | 1 | 0.000285 | 1 | 0.000195 |
| Total | | 2084 | | 2083 | |
| Mean Difference = 0.000039 Standard Deviation = 0.00139 | | | | | |
| t Statistic = 0.092173 Pr > \|t\|: 0.9284 | | | | | |

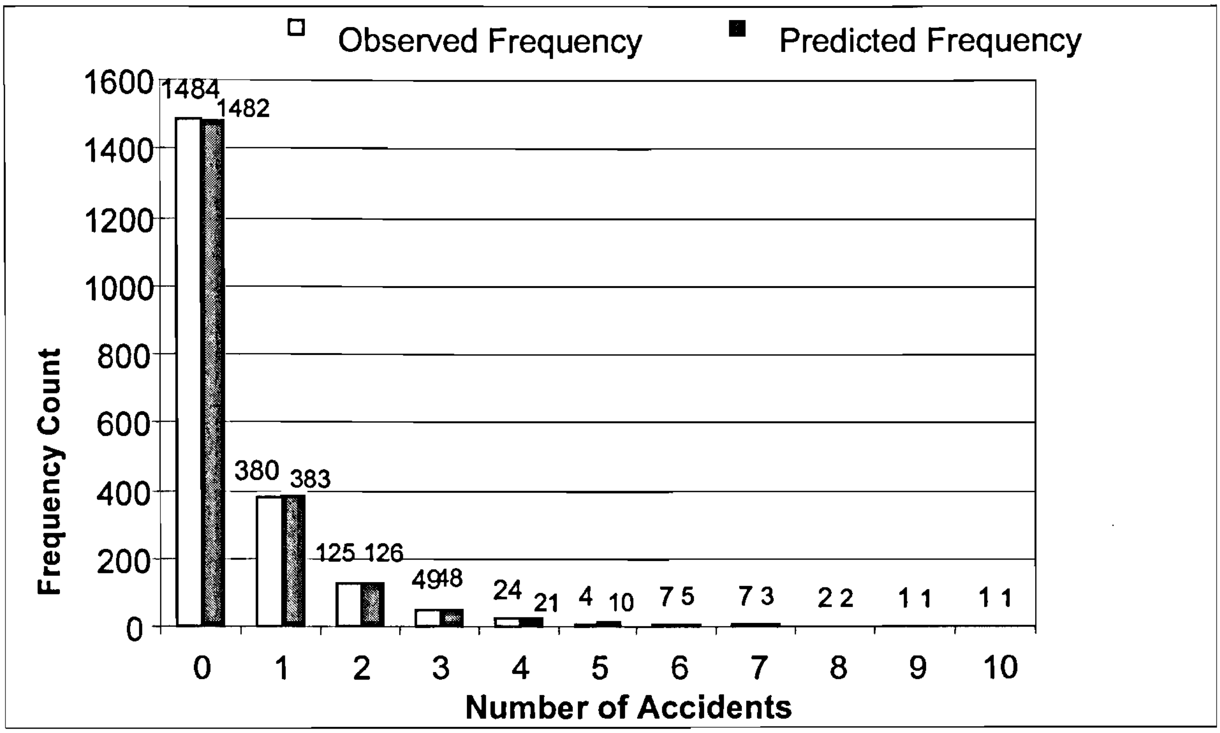



**Figure 37.** Comparison of Observed and Predicted Accident Frequency for 2084 Sections of Vertical Curve(s) on Horizontal Tangent in the Year of 2005

# Chapter 8. CONCLUSIONS AND RECOMMENDATIONS

## 8.1 CONCLUSIONS

The study has mainly investigated the effect of coordination and interaction of horizontal and vertical alignments on safety using collision data from the Washington State, and developed eight collision prediction models to establish the relationships between accident occurrences and geometric and traffic characteristics for individual types of combinations of horizontal and vertical alignments. The major findings are summarized in two groups: horizontal curve combined with vertical alignment and vertical alignment on horizontal tangent.

### 8.1.1 Horizontal Curve Combined with Vertical Alignment

The following findings pertaining to horizontal curve combined with vertical alignment are highlighted:

- When a horizontal curve is superimposed with a vertical curve or multiple vertical curves, or on a grade, the most successful variables in explaining the variation of accident occurrences are annual average daily traffic (AADT), curve length, and degree of horizontal curvature. The total roadway width and access density were found to be significant safety factors in most combinations.
- The study used accident data for the first time to investigate the coordination and interaction of superimposed horizontal and vertical curves, and found that accident rates decrease with greater ratio of vertical curve radius to horizontal curve radius. That is, the greater the rate of vertical curvature, the fewer accident occurrences at a horizontal curve of the same radius. Smith and Lamm (1994) suggestion of the ratio of 5 to 10 (They suggested the ratio of horizontal curve radius to vertical curve radius instead be in the range of 1/5 to 1/10, a ratio of the inverse of K_R) is not sufficient enough when a horizontal curve of smaller than 6000 feet (or 1830 m) is superimposed with a vertical curve.
- The study introduced a combined variable to explore the safety effect of a grade, and found that the gradient and the length of a grade increase accident occurrences when a horizontal curve is on a grade. As the gradient increases, accident occurrences increase more sharply on a curve of smaller radius.

- The investigation of correlations between variables found that a combined horizontal curve of smaller radius often have a smaller rate of vertical curvature and vice versa, and that a larger radius is usually applied at a horizontal curve with a larger central angle and vice versa. The phenomenon of correlations reflects a normal design practice that low standards are often adopted in some critical situations and high-standard values are often applied to the favorable topography.
- The curve length is usually shorter for a horizontal curve of smaller radius. The belief that the accident rate on a horizontal curve of smaller radius is higher than that on a horizontal curve of greater radius is biased, in spite of the fact that accident occurrences are more on a horizontal curve of smaller radius than on a horizontal curve of greater radius. The evaluation of safety effects on horizontal curves using the accident rates easily produces a biased result.
- The degree of curvature provides a better fit than the curve radius to the models predicting the accident occurrences on horizontal curves.

### 8.1.2 Vertical Alignment on Horizontal Tangent

The study found the following safety effects of vertical alignment on horizontal tangent:

- Vertical curves have relatively little influence on accident occurrences. Although the rate of vertical curvature was found to be a significant variable, its effect on the safety was small. Crest vertical curves were not found to have an influence on accident occurrences in this study possibly due to the small number of observations. The study did not distinguish crest vertical curves with limited sight distance.
- As is the case for horizontal curve on grade, the study found that the gradient and the length of a grade increase accident occurrences when a horizontal tangent is on a grade.
- The study mainly explored the safety effects of vertical alignment on independent horizontal tangent, and the models were established on independent horizontal tangents. Although the variables of the ratio of large radius to small radius and the smaller curve radius of the horizontal curves before and after a horizontal tangent are excluded from the models, the study found that larger radius difference of the horizontal curves before and after the tangent has an adverse effect on the safety at the tangent and that a larger horizontal radius before and after the tangent improves safety at the tangent.

- The total roadway width and access density were found to be significant safety factors in most combinations.

## 8.2 RECOMMENDATIONS

The study made the following recommendations:

- A greater ratio of vertical curve radius to horizontal curve radius is applied to the location where a horizontal curve is superimposed with a vertical curve. When a horizontal curve radius is smaller than 6000 feet (or 1830 m), it is suggested that the ratio of vertical curve radius to horizontal curve radius be more than 25. While a horizontal curve of larger than 6000 feet is superimposed with a vertical curve, the ratio should be more than 10.
- A smaller curve should be avoided introducing on a sharp grade.
- Further study may be needed to find accident data that distinguish accident occurrences by the driving direction to explore the safety effects of a grade. The study also recommended that more road sections of grade larger than 5% be obtained to enhance the model for horizontal tangent on grade larger than 5%.
- Further study was suggested to explore the speed differences at the adjacent curves entering a horizontal tangent and its relationship to the safety of the tangent.

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# APPENDIX A

## SUMMARY STATISTICS OF ROAD SECTIONS FOR EACH COMBINATION

**Table A1.** Summary Statistics of Road Sections for Horizontal Curve Combined with Sag Vertical Curve: 3242 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section Length (mile):cseg_lgt | 0.145 | 0.114 | 0.010 | 0.830 | 0.110 | |
| Number of Accidents on a Road Section: total_acc | 0.165 | 0.525 | 0 | 9 | 0 | 87.51 |
| Annual Average Daily Traffic (veh/day): caadt | 2756 | 2856 | 175 | 26270 | 1895 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.157 | 0.267 | 0.003 | 3.653 | 0.076 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.479 | 7.877 | 0 | 230.617 | 0 | |
| Horizontal Curve Radius: curv_rad (feet) | 2533 | 2788 | 114 | 30000 | 1796 | |
| Horizontal Degree of Curvature: deg_curv (degree/100ft) | 4.241 | 3.879 | 0.190 | 50.260 | 3.190 | |
| Rate of Vertical Curvature: avc (feet/%) | 332 | 520 | 16 | 10074 | 192 | |
| Algebraic Difference in Grade: ava (%) | 2.88 | 2.16 | 0.06 | 13.11 | 2.40 | |
| Ratio of Vertical Curve Radius to Horizontal Curve Radius: K_R | 20.45 | 33.27 | 0.30 | 527.40 | 11.44 | |
| Percentage of Vertical Curve on Road Section: pct_vcurv | 0.63 | 0.28 | 0.03 | 1.00 | 0.64 | |
| Left Shoulder Width: lshldwid (feet) | 4.75 | 2.32 | 0.00 | 16.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.81 | 2.32 | 0.00 | 12.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.97 | 1.54 | 20.00 | 42.00 | 23.00 | |
| Total Number of Sections (Horizontal Curves) and Mileage | 3242 Sections with a total length of 468.720 miles | | | | | |
| Total Number of Accidents | 535 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 535 / 508.925 = 1.05 | | | | | |

**Table A2.** Summary Statistics of Road Sections for Horizontal Curve Combined with Multiple Vertical Curves: 2892 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section Length (mile):cseg_lgt | 0.284 | 0.217 | 0.050 | 1.850 | 0.225 | |
| Number of Accidents on a Road Section: total_acc | 0.263 | 0.642 | 0 | 7 | 0 | 80.98 |
| Annual Average Daily Traffic (veh/day): caadt | 2916 | 2975 | 122 | 26359 | 1959 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.325 | 0.512 | 0.003 | 4.755 | 0.160 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.097 | 4.436 | 0 | 107.694 | 0 | |
| Horizontal Curve Radius: curv_rad (feet) | 3354 | 3470 | 239 | 34380 | 2149 | |
| Horizontal Degree of Curvature: deg_curv (degree/100ft) | 3.174 | 2.441 | 0.170 | 23.970 | 2.670 | |
| Rate of Vertical Curvature: avc (feet/%) | 412 | 967 | 35 | 21667 | 232 | |
| Algebraic Difference in Grade: ava (%) | 2.71 | 1.87 | 0.04 | 10.16 | 2.18 | |
| Ratio of Vertical Curve Radius to Horizontal Curve Radius: K_R | 20.23 | 73.02 | 0.83 | 1569.26 | 10.12 | |
| Percentage of Vertical Curve on Road Section: pct_vcurv | 0.55 | 0.21 | 0.08 | 1.00 | 0.54 | |
| Left Shoulder Width: lshldwid (feet) | 4.70 | 2.38 | 0.00 | 10.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.65 | 2.33 | 0.00 | 10.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 23.00 | 1.70 | 20.00 | 43.00 | 23.00 | |
| Total Number of Sections (Horizontal Curves) and Mileage | 2892 Sections with a total length of 822.08 miles | | | | | |
| Total Number of Accidents | 760 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 760 / 939.791 = 0.81 | | | | | |

**Table A3.** Summary Statistics of Road Sections for Horizontal Curve on Grade (< 5):12108 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section Length (mile):cseg_lgt | 0.122 | 0.096 | 0.010 | 1.590 | 0.100 | |
| Number of Accidents on a Road Section: total_acc | 0.132 | 0.440 | 0 | 7 | 0 | 89.38 |
| Annual Average Daily Traffic (veh/day): caadt | 2699 | 2820 | 144 | 29474 | 1777 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.128 | 0.200 | 0.001 | 3.194 | 0.063 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.434 | 8.655 | 0 | 259.690 | 0 | |
| Horizontal Curve Radius: curv_rad (feet) | 2763 | 3733 | 59 | 50000 | 1900 | |
| Horizontal Degree of Curvature: deg_curv (degree/100ft) | 4.406 | 5.081 | 0.110 | 97.110 | 3.020 | |
| Grade: avg (%) | 1.33 | 1.38 | 0 | 5.00 | 0.80 | |
| Left Shoulder Width: lshldwid (feet) | 4.44 | 2.48 | 0.00 | 36.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.48 | 2.38 | 0.00 | 27.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.85 | 1.50 | 19.00 | 40.00 | 22.00 | |
| Total Number of Sections (Horizontal Curves) and Mileage | 12108 Sections with a total length of 1475.880 miles | | | | | |
| Total Number of Accidents | 1608 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 1608 / 1554.48 = 1.03 | | | | | |

**Table A4.** Summary Statistics of Road Sections for Horizontal Curve on Grade (≥ 5): 2212 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section Length (mile):cseg_lgt | 0.108 | 0.078 | 0.010 | 0.630 | 0.090 | |
| Number of Accidents on a Road Section: total_acc | 0.168 | 0.515 | 0 | 5 | 0 | 87.43 |
| Annual Average Daily Traffic (veh/day): caadt | 2254 | 2853 | 175 | 22110 | 1457 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.097 | 0.171 | 0.002 | 2.087 | 0.045 | |
| Accident Rate (Accidents/mvmt): acc_rat | 2.013 | 8.308 | 0 | 117.686 | 0 | |
| Horizontal Curve Radius: curv_rad (feet) | 1553 | 1326 | 102 | 11460 | 1146 | |
| Horizontal Degree of Curvature: deg_curv (degree/100ft) | 6.563 | 6.427 | 0.500 | 56.170 | 5.000 | |
| Grade: avg (%) | 5.70 | 0.63 | 5.00 | 8.40 | 5.71 | |
| Left Shoulder Width: lshldwid (feet) | 4.15 | 2.15 | 0.00 | 18.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.18 | 2.24 | 0.00 | 22.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.89 | 1.03 | 20.00 | 25.00 | 22.00 | |
| Total Number of Sections (Horizontal Curves) and Mileage | 2212 Sections with a total length of 239.610 miles | | | | | |
| Total Number of Accidents | 371 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 371 / 215.59 = 1.72 | | | | | |

**Table A5. Summary Statistics of Road Sections for Crest Vertical Curve on Horizontal Tangent: 2721 Sections**

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section / Tangent Length (mile):tseg_lgt | 0.217 | 0.284 | 0.010 | 5.460 | 0.150 | |
| Number of Accidents on a Road Section: total_acc | 0.177 | 0.544 | 0 | 8 | 0 | 86.92 |
| Annual Average Daily Traffic (veh/day): caadt | 2660 | 2728 | 175 | 23352 | 1832 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.232 | 0.471 | 0.001 | 5.332 | 0.100 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.160 | 9.966 | 0 | 333.300 | 0 | |
| Rate of Vertical Curvature: avc (feet/%) | 486 | 742 | 22 | 8000 | 255 | |
| Algebraic Difference in Grade: ava (%) | 3.39 | 2.88 | 0.04 | 13.09 | 2.59 | |
| Ratio of Large Radius to Small Radius of Horizontal Curves : lar_smr | 1.95 | 1.53 | 1.00 | 20 | 1.40 | |
| Smaller radius of Horizontal Curves on Both Ends: sml_r | 1890 | 2976 | 220 | 50000 | 1432 | |
| Combination Type of Horizontal Curves: hcurv_com | hcurv_com=1, same direction; hcurv_com=0, reverse | | | | | |
| Type of Tangent: depend_tan | depend_tan=1, independent; depend_tan=0, nonindependent | | | | | |
| Left Shoulder Width: lshldwid (feet) | 4.72 | 2.35 | 0.00 | 16.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.79 | 2.36 | 0.00 | 13.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.94 | 1.24 | 20.00 | 32.00 | 23.00 | |
| Total Number of Sections and Mileage | 2721 Sections with a total length of 589.540 miles | | | | | |
| Total Number of Accidents | 481 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 481 / 648.18 = 0.74 | | | | | |

**Table A6.** Summary Statistics of Road Sections for Sag Vertical Curve on Horizontal Tangent: 2801 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section / Tangent Length (mile):tseg_lgt | 0.230 | 0.226 | 0.010 | 2.130 | 0.160 | |
| Number of Accidents on a Road Section: total_acc | 0.199 | 0.554 | 0 | 5 | 0 | 85.22 |
| Annual Average Daily Traffic (veh/day): caadt | 2741 | 2886 | 175 | 29474 | 1771 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.259 | 0.472 | 0.001 | 7.435 | 0.099 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.031 | 5.744 | 0.000 | 175.342 | 0.000 | |
| Rate of Vertical Curvature: avc (feet/%) | 356 | 457 | 32 | 6000 | 214 | |
| Algebraic Difference in Grade: ava (%) | 2.44 | 1.99 | 0.00 | 12.00 | 1.93 | |
| Ratio of Large Radius to Small Radius of Horizontal Curves : lar_smr | 2.12 | 1.73 | 1.00 | 23.88 | 1.59 | |
| Smaller radius of Horizontal Curves on Both Ends: sml_r | 1644 | 1687 | 214 | 25000 | 1432 | |
| Combination Type of Horizontal Curves: hcurv_com | hcurv_com=1, same direction; hcurv_com=0, reverse | | | | | |
| Type of Tangent: depend_tan | depend_tan=1, independent; depend_tan=0, nonindependent | | | | | |
| Left Shoulder Width: lshldwid (feet) | 4.63 | 2.42 | 0.00 | 18.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.64 | 2.27 | 0.00 | 13.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.99 | 1.56 | 20.00 | 47.00 | 23.00 | |
| Total Number of Sections and Mileage | 2801 Sections with a total length of 644.630 miles | | | | | |
| Total Number of Accidents | 557 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 557/ 726.48 = 0.77 | | | | | |

**Table A7.** Summary Statistics of Road Sections for Multiple Vertical Curves on Horizontal Tangent: 6924 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section / Tangent Length (mile):tseg_lgt | 0.854 | 1.148 | 0.030 | 16.370 | 0.530 | |
| Number of Accidents on a Road Section: total_acc | 0.564 | 1.210 | 0 | 19 | 0 | |
| Annual Average Daily Traffic (veh/day): caadt | 2982 | 2988 | 122 | 26359 | 2015 | 69.28 |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.892 | 1.501 | 0.004 | 23.005 | 0.406 | |
| Accident Rate (Accidents/mvmt): acc_rat | 0.783 | 2.865 | 0.000 | 117.711 | 0.000 | |
| Rate of Vertical Curvature: avc (feet/%) | 443 | 643 | 32 | 12661 | 269 | |
| Algebraic Difference in Grade: ava (%) | 2.55 | 1.68 | 0.08 | 13.06 | 2.22 | |
| Ratio of Large Radius to Small Radius of Horizontal Curves : lar_smr | 2.35 | 2.17 | 1.00 | 50.04 | 1.76 | |
| Smaller radius of Horizontal Curves on Both Ends: sml_r | 2342 | 2890 | 220 | 50000 | 1600 | |
| Combination Type of Horizontal Curves: hcurv_com | hcurv_com=1, same direction; hcurv_com=0, reverse | | | | | |
| Type of Tangent: depend_tan | depend_tan=1, independent; depend_tan=0, nonindependent | | | | | |
| Left Shoulder Width: lshldwid (feet) | 4.93 | 2.40 | 0.00 | 11.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.92 | 2.40 | 0.00 | 16.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.95 | 1.52 | 20.00 | 44.00 | 23.00 | |
| Total Number of Sections and Mileage | 6924 Sections with a total length of 5910.45 miles | | | | | |
| Total Number of Accidents | 3907 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 3907 / 6174.92 = 0.63 | | | | | |

**Table A8.** Summary Statistics of Road Sections for Horizontal Tangent with Constant Grade $|G|< 5$: 8669 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section / Tangent Length (mile):tseg_lgt | 0.194 | 0.225 | 0.010 | 3.390 | 0.130 | |
| Number of Accidents on a Road Section: total_acc | 0.150 | 0.481 | 0 | 7 | 0 | 88.42 |
| Annual Average Daily Traffic (veh/day): caadt | 2543 | 2643 | 175 | 26359 | 1684 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.199 | 0.436 | 0.001 | 9.850 | 0.082 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.125 | 8.515 | 0.000 | 293.647 | 0.000 | |
| Gradient: avg (%) | 1.42 | 1.44 | 0.00 | 4.99 | 0.88 | |
| Ratio of Large Radius to Small Radius of Horizontal Curves : lar_smr | 2.16 | 2.22 | 1.00 | 48.01 | 1.50 | |
| Smaller radius of Horizontal Curves on Both Ends: sml_r | 1733 | 2289 | 212 | 50000 | 1432 | |
| Combination Type of Horizontal Curves: hcurv_com | hcurv_com=1, same direction; hcurv_com=0, reverse | | | | | |
| Type of Tangent: depend_tan | depend_tan=1, independent; depend_tan=0, nonindependent | | | | | |
| Left Shoulder Width: lshldwid (feet) | 4.29 | 2.30 | 0.00 | 15.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.36 | 2.29 | 0.00 | 14.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.84 | 1.61 | 20.00 | 40.00 | 22.00 | |
| Total Number of Sections and Mileage | 8669 Sections with a total length of 1682.73 miles | | | | | |
| Total Number of Accidents | 1298 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 1298/ 1728.61= 0.75 | | | | | |

**Table A9.** Summary Statistics of Road Sections for Horizontal Tangent with Constant Grade $|G| \geq 5$: 1924 Sections

| Attributes and Variables | Mean | Std Dev. | Min | Max | Median | % Zeros |
|---|---|---|---|---|---|---|
| Section / Tangent Length (mile):tseg_lgt | 0.126 | 0.110 | 0.010 | 0.710 | 0.100 | |
| Number of Accidents on a Road Section: total_acc | 0.113 | 0.404 | 0 | 5 | 0 | 91.11 |
| Annual Average Daily Traffic (veh/day): caadt | 2334 | 2956 | 188 | 22546 | 1567 | |
| Exposure (Millions of Vehicle-Miles of Travel): mvmt | 0.131 | 0.298 | 0.001 | 3.041 | 0.048 | |
| Accident Rate (Accidents/mvmt): acc_rat | 1.123 | 6.786 | 0.000 | 188.039 | 0.000 | |
| Gradient: avg (%) | 5.73 | 0.64 | 5.00 | 8.40 | 5.83 | |
| Ratio of Large Radius to Small Radius of Horizontal Curves : lar_smr | 1.96 | 1.56 | 1.00 | 16.00 | 1.50 | |
| Smaller radius of Horizontal Curves on Both Ends: sml_r | 1167 | 867 | 212 | 6000 | 955 | |
| Combination Type of Horizontal Curves: hcurv_com | hcurv_com=1, same direction; hcurv_com=0, reverse | | | | | |
| Type of Tangent: depend_tan | depend_tan=1, independent; depend_tan=0, nonindependent | | | | | |
| Left Shoulder Width: lshldwid (feet) | 4.12 | 2.05 | 0.00 | 11.00 | 4.00 | |
| Right Shoulder Width: rshldwid (feet) | 4.15 | 2.04 | 0.00 | 12.00 | 4.00 | |
| Surface Width: surf_wid (feet) | 22.93 | 1.12 | 20.00 | 40.00 | 22.00 | |
| Total Number of Sections and Mileage | 1924 Sections with a total length of 242.71 miles | | | | | |
| Total Number of Accidents | 217 | | | | | |
| Average Accident Rate (Total Number of Accidents/Total mvmt) | 217 / 252.11 = 0.86 | | | | | |

# APPENDIX B

## SCATTER PLOTS OF ACCIDENT RATE VERSUS RATIO OF VERTICAL CURVE RADIUS TO HORIZONTAL CURVE RADIUS

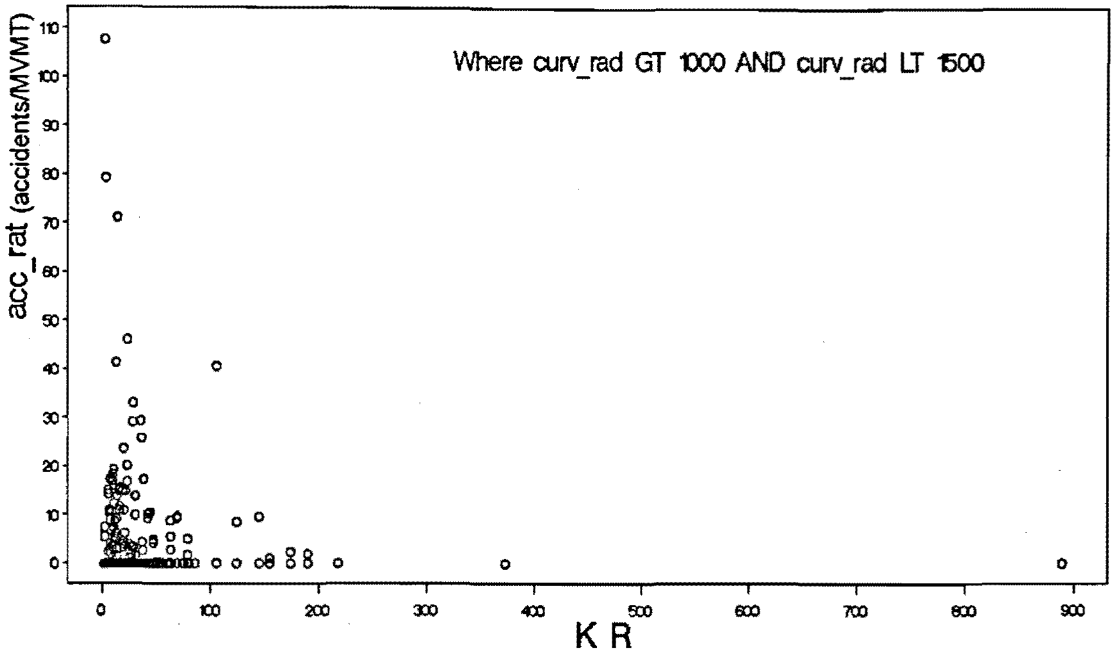


**Figure B1.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 1000 and Less Than 1500 ft

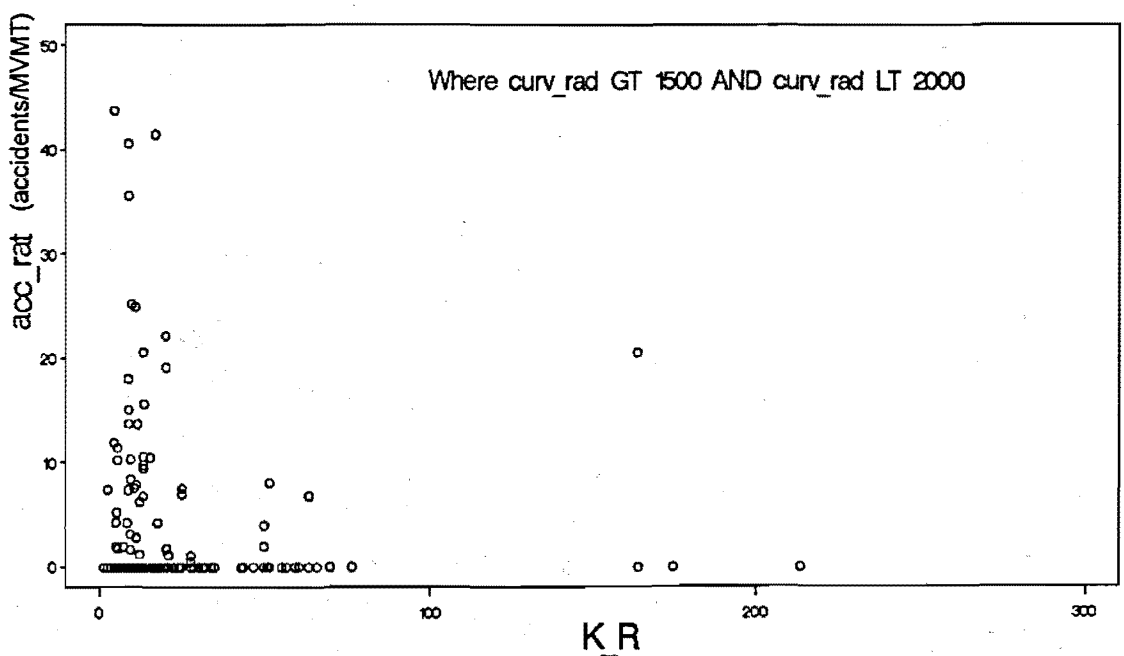


**Figure B2.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 1500 and Less Than 2000 ft

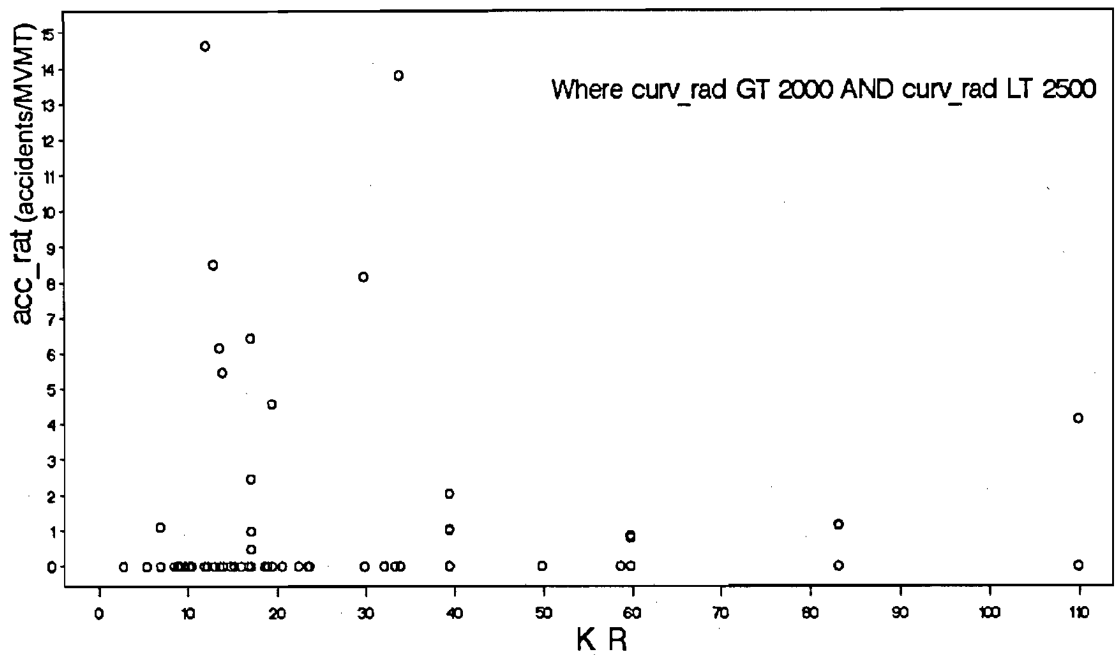


**Figure B3.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 2000 and Less Than 2500 ft

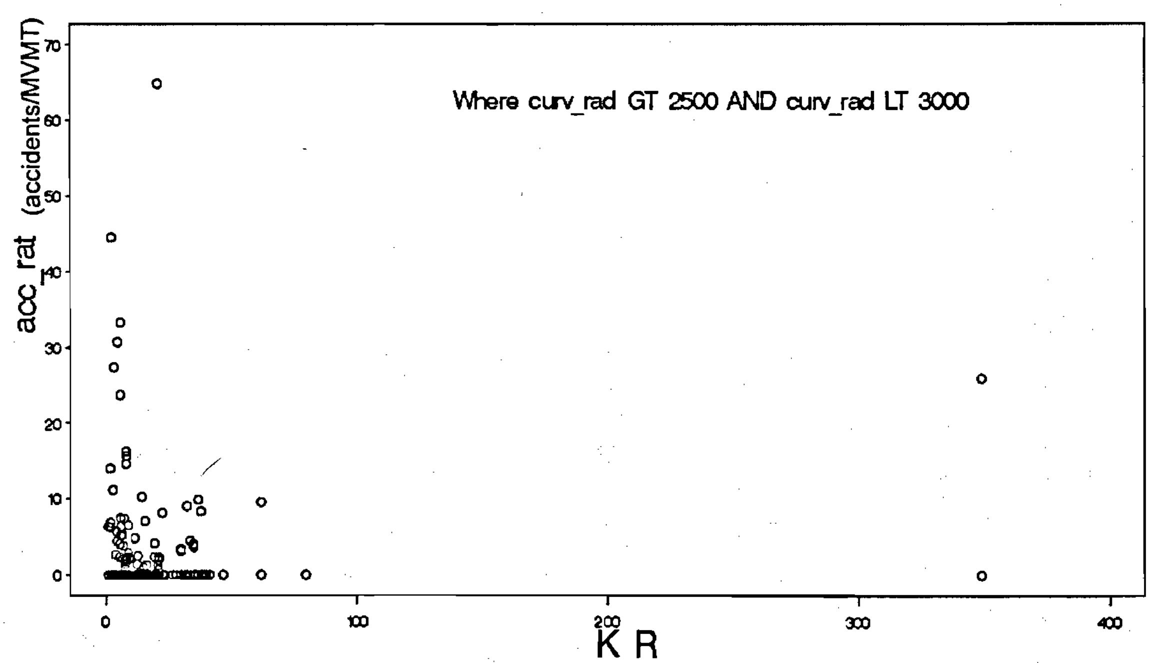


**Figure B4.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 2500 and Less Than 3000 ft

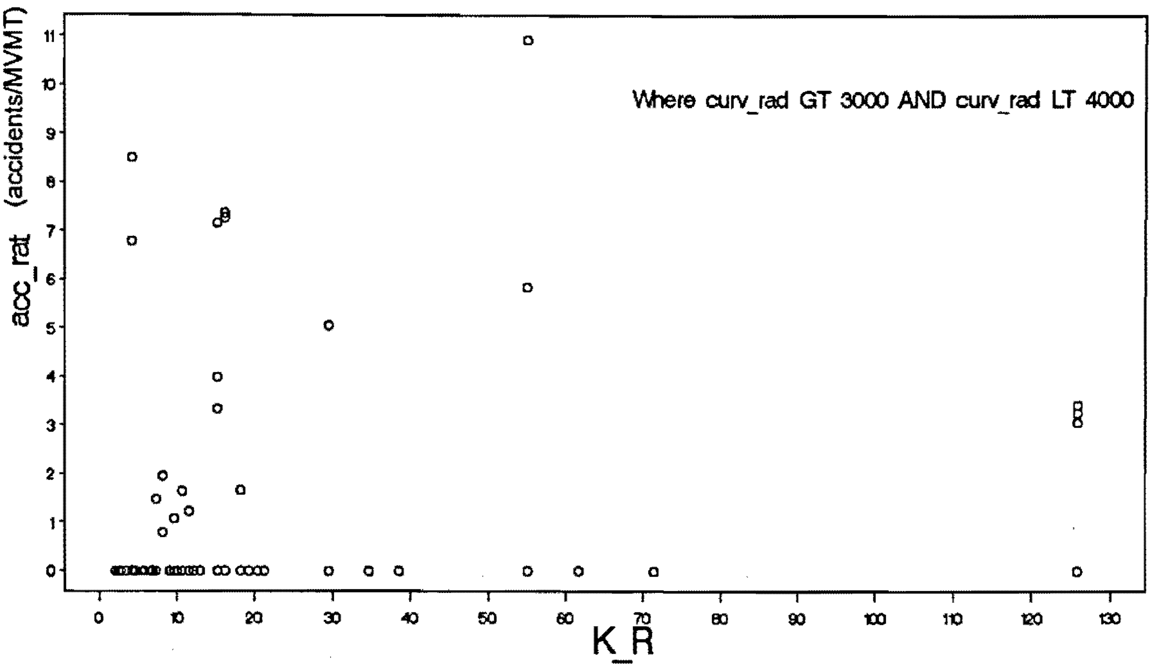


**Figure B5.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 3000 and Less Than 4000 ft

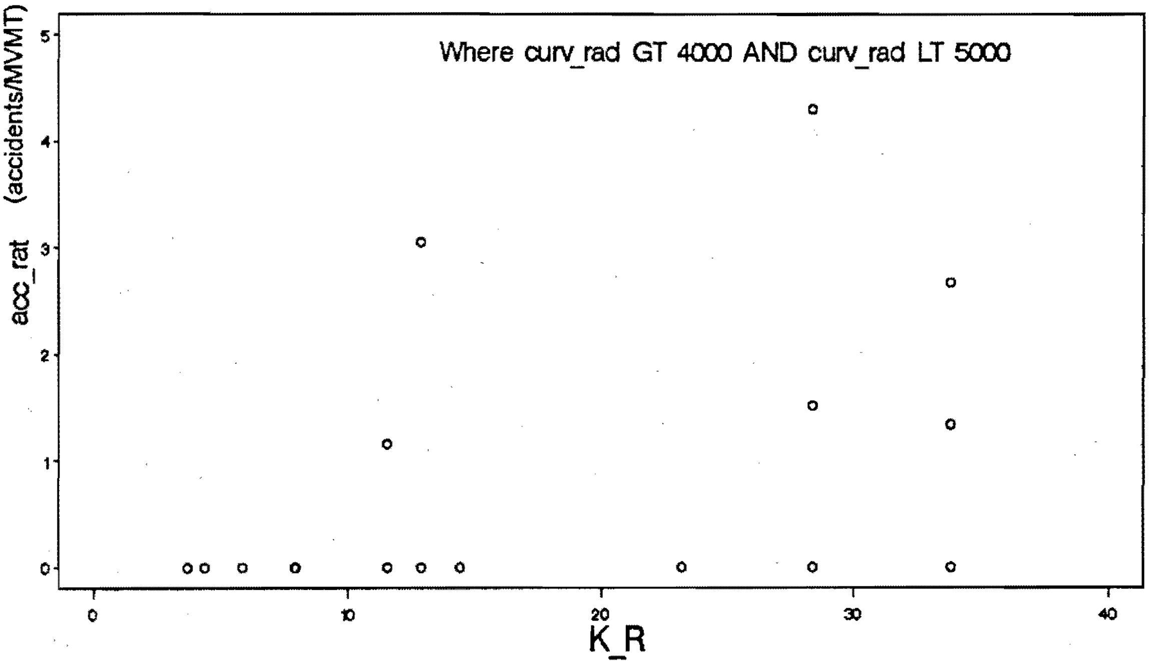


**Figure B6.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 4000 and Less Than 5000 ft

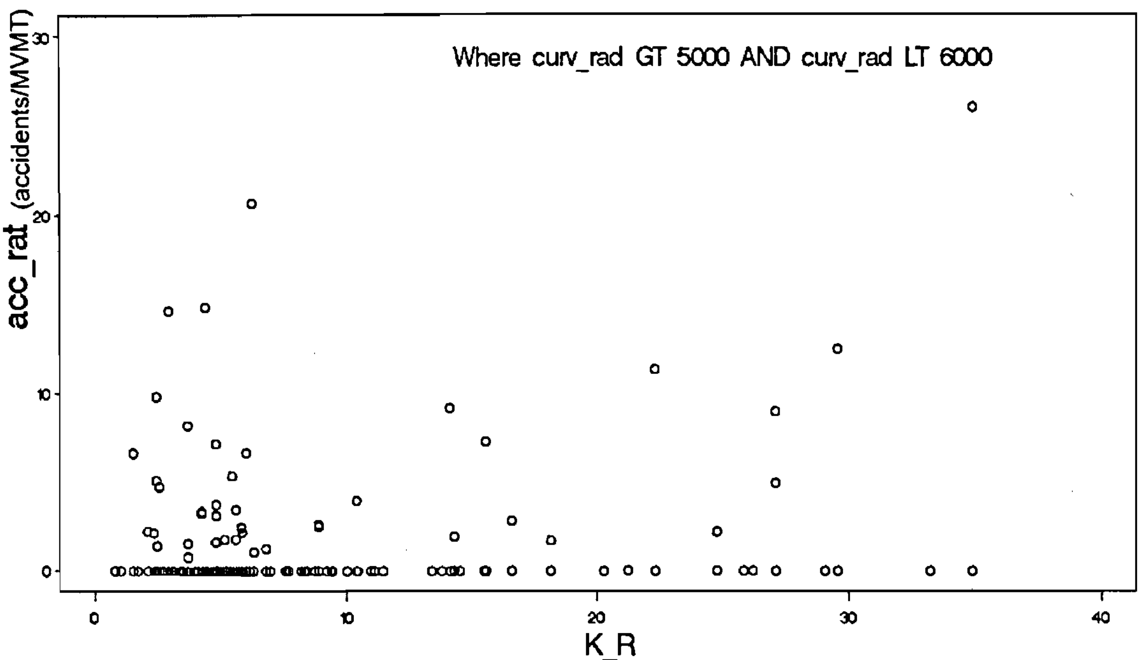


**Figure B7.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 5000 and Less Than 6000 ft

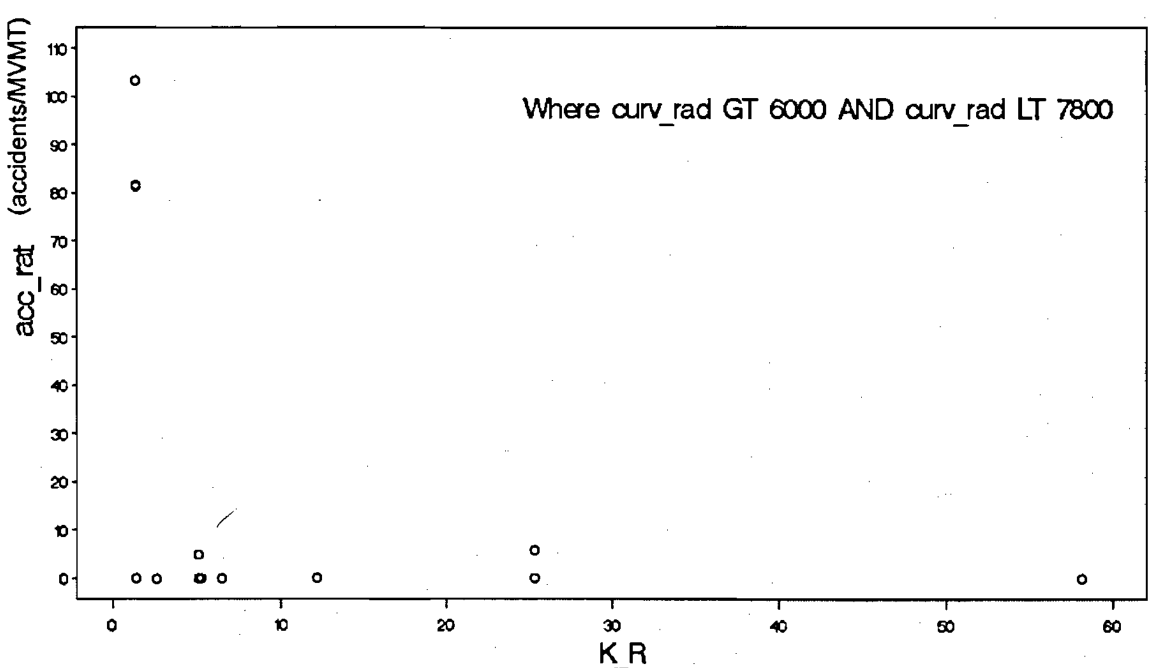


**Figure B8.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 6000 and Less Than 7800 ft

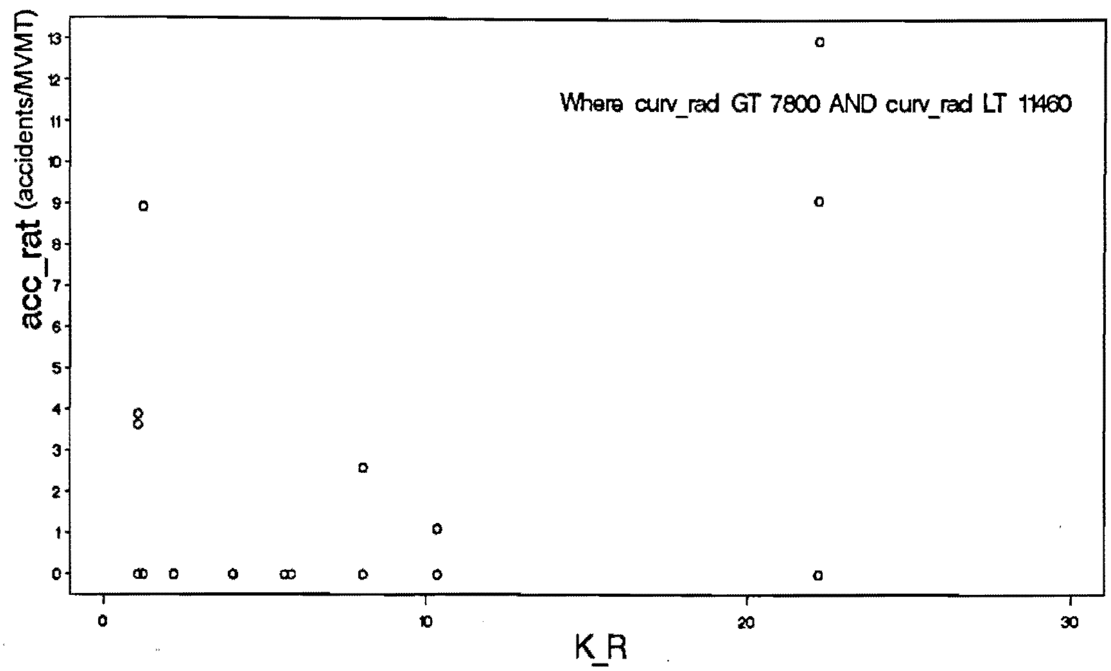


**Figure B9.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 7800 and Less Than 11460 ft

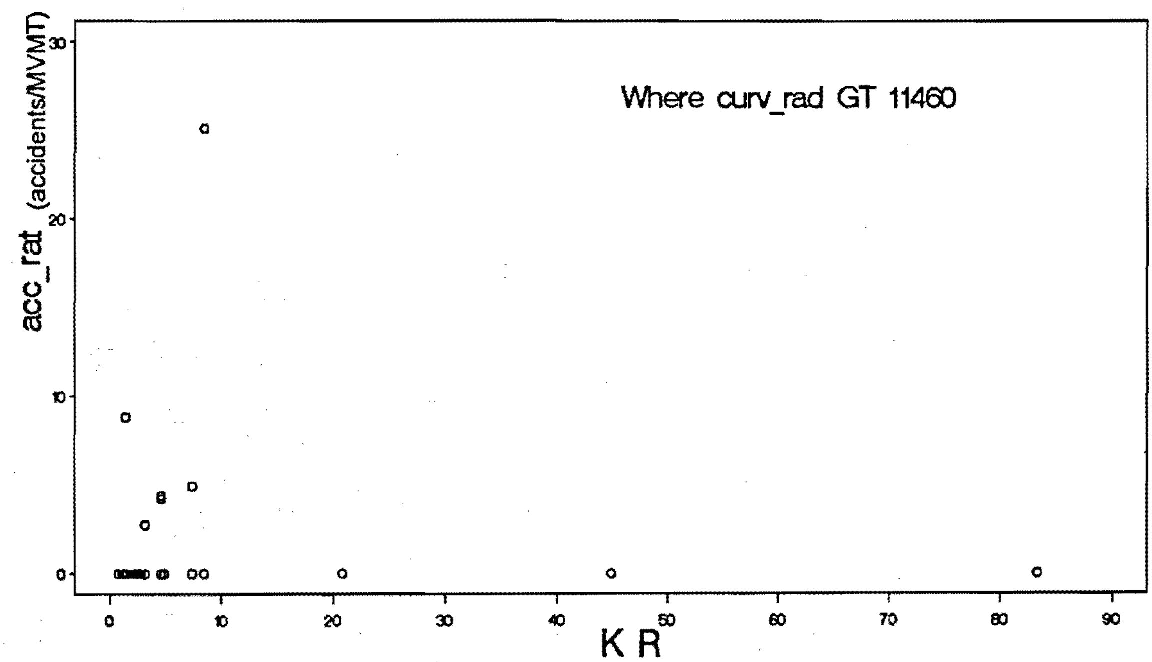


**Figure B10.** Scatter Plot of Accident Rate versus Ratio of Vertical Curve Radius to Horizontal Curve Radius for Horizontal Curve with Radius Greater Than 11460 ft

# APPENDIX C

## SUMMARY OF MODELING OUTPUT AND RESULTS

# 1. MODELS FOR HORIZONTAL CURVE COMBINED WITH CREST VERTICAL CURVE

## 1.1 Poisson Modeling:

### 1) Selection of Variables:

Horizontal Curve on Crest-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST_ACC |
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 4193 |
| Number of Observations Used | 4193 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 4180 | 2161.5025 | 0.5171 |
| Scaled Deviance | 4180 | 2161.5025 | 0.5171 |
| Pearson Chi-Square | 4180 | 4717.3529 | 1.1286 |
| Scaled Pearson X2 | 4180 | 4717.3529 | 1.1286 |
| Log Likelihood | | -1503.0885 | |

Analysis Of Parameter Estimates (Trial 1)

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.3791 | 0.6686 | -7.6894 | -5.0687 | 91.04 | <.0001 |
| log_aadt | 1 | 0.7791 | 0.0531 | 0.6749 | 0.8833 | 214.89 | <.0001 |
| log_lgt | 1 | 0.9067 | 0.1033 | 0.7043 | 1.1090 | 77.11 | <.0001 |
| deg_curv | 1 | 0.1087 | 0.0191 | 0.0713 | 0.1461 | 32.49 | <.0001 |
| curv_ang | 1 | 0.0000 | 0.0000 | -0.0000 | 0.0001 | 0.95 | 0.3301 |
| curv_rad | 1 | 0.0000 | 0.0000 | -0.0000 | 0.0000 | 0.00 | 0.9669 |
| avc | 1 | 0.0001 | 0.0001 | -0.0001 | 0.0002 | 0.79 | 0.3752 |
| ava | 1 | 0.0171 | 0.0189 | -0.0201 | 0.0542 | 0.81 | 0.3678 |
| K_R | 1 | -0.0003 | 0.0013 | -0.0027 | 0.0022 | 0.05 | 0.8172 |
| pct_vcurv | 1 | -0.2565 | 0.2036 | -0.6555 | 0.1425 | 1.59 | 0.2077 |
| lshldwid | 1 | -0.0030 | 0.0236 | -0.0492 | 0.0432 | 0.02 | 0.8986 |
| rshldwid | 1 | -0.0113 | 0.0287 | -0.0675 | 0.0450 | 0.15 | 0.6950 |
| surf_wid | 1 | -0.0099 | 0.0245 | -0.0579 | 0.0382 | 0.16 | 0.6876 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 4184 | 2149.7321 | 0.5138 |
| Scaled Deviance | 4184 | 2149.7321 | 0.5138 |
| Pearson Chi-Square | 4184 | 4687.8390 | 1.1204 |
| Scaled Pearson X2 | 4184 | 4687.8390 | 1.1204 |
| Log Likelihood | | -1497.2033 | |

Analysis Of Parameter Estimates (Trial 2)

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.4698 | 1.2192 | -8.8593 | -4.0802 | 28.16 | <.0001 |
| log_aadt | 1 | 0.8095 | 0.0558 | 0.7002 | 0.9189 | 210.56 | <.0001 |
| log_lgt | 1 | 1.0349 | 0.0684 | 0.9009 | 1.1689 | 229.03 | <.0001 |
| deg_curv | 1 | 0.1206 | 0.0129 | 0.0953 | 0.1458 | 87.34 | <.0001 |
| spd_limt | 1 | 0.0149 | 0.0147 | -0.0139 | 0.0438 | 1.03 | 0.3102 |
| surf_wid | 1 | -0.0389 | 0.0347 | -0.1070 | 0.0292 | 1.25 | 0.2633 |
| shld_wid | 1 | -0.0522 | 0.0227 | -0.0968 | -0.0076 | 5.27 | 0.0217 |
| spcl_ln | 1 | 0.1960 | 0.1177 | -0.0346 | 0.4267 | 2.77 | 0.0958 |
| access | 1 | 0.0233 | 0.0092 | 0.0052 | 0.0414 | 6.36 | 0.0116 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Horizontal Curve on Crest-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST_ACC |
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 4193 |
| Number of Observations Used | 4193 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 4187 | 2153.9229 | 0.5144 |
| Scaled Deviance | 4187 | 2153.9229 | 0.5144 |
| Pearson Chi-Square | 4187 | 4724.4570 | 1.1284 |
| Scaled Pearson X2 | 4187 | 4724.4570 | 1.1284 |
| Log Likelihood | | -1499.2987 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -5.8176 | 0.4365 | -6.6730 | -4.9621 | 177.66 | <.0001 |
| log_aadt | 1 | 0.8110 | 0.0517 | 0.7096 | 0.9124 | 245.75 | <.0001 |
| log_lgt | 1 | 1.0567 | 0.0674 | 0.9246 | 1.1888 | 245.77 | <.0001 |
| deg_curv | 1 | 0.1192 | 0.0127 | 0.0942 | 0.1442 | 87.52 | <.0001 |
| roadway_wid | 1 | -0.0268 | 0.0100 | -0.0465 | -0.0072 | 7.16 | 0.0074 |
| access | 1 | 0.0223 | 0.0092 | 0.0043 | 0.0404 | 5.87 | 0.0154 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 3) Examining Correlations:

Pearson Correlation Coefficients, N = 4193
Prob > |r| under H0: Rho=0

| | cseg_lgt | deg_curv | curv_rad | curv_ang | avc | ava | K_R |
|---|---|---|---|---|---|---|---|
| cseg_lgt | 1.00000 | -0.29641 | 0.11322 | 0.42455 | 0.07512 | -0.07978 | -0.03720 |
| | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0160 |
| deg_curv | -0.29641 | 1.00000 | -0.44868 | 0.49229 | -0.15610 | 0.15323 | 0.19361 |
| deg_curv | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| curv_rad | 0.11322 | -0.44868 | 1.00000 | -0.35257 | 0.25936 | -0.14014 | -0.12267 |
| curv_rad | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 |
| curv_ang | 0.42455 | 0.49229 | -0.35257 | 1.00000 | -0.07438 | 0.08994 | 0.15803 |
| curv_ang | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 |
| avc | 0.07512 | -0.15610 | 0.25936 | -0.07438 | 1.00000 | -0.33889 | 0.65718 |
| | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 |
| ava | -0.07978 | 0.15323 | -0.14014 | 0.08994 | -0.33889 | 1.00000 | -0.24905 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 |
| K_R | -0.03720 | 0.19361 | -0.12267 | 0.15803 | 0.65718 | -0.24905 | 1.00000 |
| | 0.0160 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | |

## 4) Deg_curv VS Curv_rad:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 4187 | 2206.3188 | 0.5269 |
| Scaled Deviance | 4187 | 2206.3188 | 0.5269 |
| Pearson Chi-Square | 4187 | 5087.9450 | 1.2152 |
| Scaled Pearson X2 | 4187 | 5087.9450 | 1.2152 |
| Log Likelihood | | -1525.4966 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -4.8786 | 0.4173 | -5.6964 | -4.0608 | 136.70 | <.0001 |
| log_aadt | 1 | 0.7637 | 0.0516 | 0.6626 | 0.8647 | 219.30 | <.0001 |
| log_lgt | 1 | 0.9220 | 0.0640 | 0.7965 | 1.0476 | 207.27 | <.0001 |
| curv_rad | 1 | -0.0001 | 0.0000 | -0.0001 | -0.0000 | 10.00 | 0.0016 |
| roadway_wid | 1 | -0.0332 | 0.0100 | -0.0528 | -0.0136 | 11.05 | 0.0009 |
| access | 1 | 0.0258 | 0.0091 | 0.0079 | 0.0438 | 8.00 | 0.0047 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 1.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 13.5942 | 0.0002 |

### 2) Final Model:

Horizontal Curve on Crest-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST_ACC |
| Distribution | Negative Binomial |

| | |
|---|---|
| Number of Observations Read | 4193 |
| Number of Observations Used | 4193 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 4187 | 1854.7174 | 0.4430 |
| Scaled Deviance | 4187 | 1854.7174 | 0.4430 |
| Pearson Chi-Square | 4187 | 4385.1505 | 1.0473 |
| Scaled Pearson X2 | 4187 | 4385.1505 | 1.0473 |
| Log Likelihood | | -1487.3049 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -5.8405 | 0.4763 | -6.7740 | -4.9070 | 150.38 | <.0001 |
| log_aadt | 1 | 0.8076 | 0.0583 | 0.6933 | 0.9218 | 191.99 | <.0001 |
| log_lgt | 1 | 1.0700 | 0.0745 | 0.9239 | 1.2160 | 206.16 | <.0001 |
| deg_curv | 1 | 0.1279 | 0.0154 | 0.0978 | 0.1581 | 69.24 | <.0001 |
| roadway_wid | 1 | -0.0256 | 0.0110 | -0.0472 | -0.0041 | 5.46 | 0.0194 |
| access | 1 | 0.0224 | 0.0102 | 0.0025 | 0.0424 | 4.85 | 0.0276 |
| Dispersion | 1 | 0.5753 | 0.1555 | 0.2704 | 0.8802 | | |

### 3) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3173.2 |
| AIC (smaller is better) | 3187.2 |
| AICC (smaller is better) | 3187.2 |
| BIC (smaller is better) | 3231.6 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -5.8404 | 0.4763 | 4193 | -12.26 | <.0001 | 0.05 | -6.7742 | -4.9067 | -0.00136 |
| b1 | 0.8076 | 0.05828 | 4193 | 13.86 | <.0001 | 0.05 | 0.6933 | 0.9218 | -0.01331 |
| b2 | 1.0700 | 0.07452 | 4193 | 14.36 | <.0001 | 0.05 | 0.9239 | 1.2161 | 0.003651 |
| b3 | 0.1279 | 0.01537 | 4193 | 8.32 | <.0001 | 0.05 | 0.09779 | 0.1581 | -0.00818 |
| b4 | -0.02565 | 0.01098 | 4193 | -2.34 | 0.0195 | 0.05 | -0.04717 | -0.00413 | -0.04161 |
| b5 | 0.02243 | 0.01018 | 4193 | 2.20 | 0.0276 | 0.05 | 0.002469 | 0.04240 | 0.00209 |
| alpha | 0.5753 | 0.1555 | 4193 | 3.70 | 0.0002 | 0.05 | 0.2704 | 0.8803 | 0.000916 |

## 1.3 ZIP Modeling:

### 1) ZIP Model:

Horizontal Curve on Crest-ZIP MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_<br>ON_CREST_ACC |

| | |
|---|---|
| Observations Used | 4193 |
| Observations Not Used | 0 |
| Total Observations | 4193 |
| Parameters | 8 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3167.7 |
| AIC (smaller is better) | 3183.7 |
| AICC (smaller is better) | 3183.8 |
| BIC (smaller is better) | 3234.5 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.2906 | 0.06104 | 4193 | -4.76 | <.0001 | 0.05 | -0.4103 | -0.1709 | 0.002018 |
| a2 | -0.9607 | 0.2177 | 4193 | -4.41 | <.0001 | 0.05 | -1.3874 | -0.5339 | -0.00057 |
| b0 | -5.4254 | 0.4819 | 4193 | -11.26 | <.0001 | 0.05 | -6.3702 | -4.4805 | -0.00017 |
| b1 | 0.7140 | 0.05747 | 4193 | 12.42 | <.0001 | 0.05 | 0.6013 | 0.8267 | -0.0007 |
| b2 | 0.7115 | 0.1158 | 4193 | 6.14 | <.0001 | 0.05 | 0.4844 | 0.9386 | 0.000677 |
| b3 | 0.1454 | 0.01722 | 4193 | 8.45 | <.0001 | 0.05 | 0.1117 | 0.1792 | -0.00158 |
| b4 | -0.02217 | 0.01067 | 4193 | -2.08 | 0.0378 | 0.05 | -0.04308 | -0.00125 | -0.00301 |
| b5 | 0.02153 | 0.01067 | 4193 | 2.02 | 0.0437 | 0.05 | 0.000605 | 0.04245 | -0.00015 |

## 2) Vuong Test:

## A. ZIP vs. Poisson:

Horizontal Curve on Crest-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.003511 | 0.10489 | 2.16774 |

## B. ZIP vs NB:

Horizontal Curve on Crest-ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000651 | 0.057661 | 0.731032 |

## 1.4 ZINB Modeling:

## A. ZINB Model:

Horizontal Curve on Crest-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 4193 |
| Observations Not Used | 0 |
| Total Observations | 4193 |
| Parameters | 7 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3173.2 |
| AIC (smaller is better) | 3191.2 |
| AICC (smaller is better) | 3191.2 |
| BIC (smaller is better) | 3248.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | -9.8456 | 48.4503 | 4193 | -0.20 | 0.8390 | 0.05 | -104.83 | 85.1426 | -0.00069 |
| a2 | -0.3511 | 8.6551 | 4193 | -0.04 | 0.9676 | 0.05 | -17.3196 | 16.6174 | 0.004886 |
| b0 | -5.8399 | 0.4763 | 4193 | -12.26 | <.0001 | 0.05 | -6.7737 | -4.9062 | 0.007325 |
| b1 | 0.8076 | 0.05829 | 4193 | 13.86 | <.0001 | 0.05 | 0.6933 | 0.9218 | 0.044442 |
| b2 | 1.0700 | 0.07451 | 4193 | 14.36 | <.0001 | 0.05 | 0.9239 | 1.2161 | -0.00579 |
| b3 | 0.1279 | 0.01538 | 4193 | 8.32 | <.0001 | 0.05 | 0.09780 | 0.1581 | 0.066254 |
| b4 | -0.02566 | 0.01098 | 4193 | -2.34 | 0.0194 | 0.05 | -0.04718 | -0.00414 | 0.112637 |
| b5 | 0.02244 | 0.01018 | 4193 | 2.20 | 0.0276 | 0.05 | 0.002482 | 0.04241 | 0.128954 |
| alpha | 0.5752 | 0.1556 | 4193 | 3.70 | 0.0002 | 0.05 | 0.2702 | 0.8803 | 0.004383 |

### B. ZINB vs NB:

Horizontal Curve on Crest-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 1.631E-7 | 0.000033 | 0.317953 |

## 2. MODELS FOR HORIZONTAL CURVE COMBINED WITH SAG VERTICAL CURVE

## 2.1 Poisson Modeling:

### 1) Selection of Variables:

Horizontal Curve on Sag-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_SAG_ACC |
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 3242 |
| Number of Observations Used | 3241 |
| Missing Values | 1 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 3228 | 1802.5517 | 0.5584 |
| Scaled Deviance | 3228 | 1802.5517 | 0.5584 |
| Pearson Chi-Square | 3228 | 3548.6146 | 1.0993 |
| Scaled Pearson X2 | 3228 | 3548.6146 | 1.0993 |
| Log Likelihood | | -1216.5628 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -3.4654 | 1.3097 | -6.0324 | -0.8984 | 7.00 | 0.0081 |
| log_aadt | 1 | 0.8968 | 0.0635 | 0.7723 | 1.0213 | 199.34 | <.0001 |
| log_lgt | 1 | 0.8928 | 0.0986 | 0.6996 | 1.0861 | 82.00 | <.0001 |
| deg_curv | 1 | 0.0724 | 0.0101 | 0.0526 | 0.0922 | 51.46 | <.0001 |
| avc | 1 | -0.0002 | 0.0002 | -0.0006 | 0.0002 | 0.83 | 0.3623 |
| ava | 1 | -0.0251 | 0.0274 | -0.0788 | 0.0285 | 0.84 | 0.3588 |
| pct_vcurv | 1 | -0.0667 | 0.2576 | -0.5716 | 0.4382 | 0.07 | 0.7956 |
| K_R | 1 | 0.0013 | 0.0032 | -0.0050 | 0.0076 | 0.17 | 0.6779 |
| spd_limt | 1 | -0.0347 | 0.0171 | -0.0683 | -0.0011 | 4.10 | 0.0428 |
| surf_wid | 1 | -0.0733 | 0.0360 | -0.1439 | -0.0028 | 4.15 | 0.0416 |
| shld_wid | 1 | -0.0414 | 0.0256 | -0.0916 | 0.0088 | 2.61 | 0.1063 |
| spcl_ln | 1 | 0.1545 | 0.1450 | -0.1296 | 0.4387 | 1.14 | 0.2865 |
| access | 1 | 0.0333 | 0.0047 | 0.0242 | 0.0425 | 51.06 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Examining Correlations:

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

| | cseg_lgt | deg_curv | curv_rad | curv_ang | avc | ava | K_R |
|---|---|---|---|---|---|---|---|
| cseg_lgt | 1.00000 | -0.29083 | 0.21968 | 0.44567 | 0.10764 | -0.15364 | -0.06353 |
| | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0003 |
| | 3242 | 3242 | 3242 | 3242 | 3241 | 3241 | 3241 |
| deg_curv | -0.29083 | 1.00000 | -0.46376 | 0.45762 | -0.12202 | 0.12148 | 0.28062 |
| deg_curv | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| | 3242 | 3242 | 3242 | 3242 | 3241 | 3241 | 3241 |
| curv_rad | 0.21968 | -0.46376 | 1.00000 | -0.39871 | 0.14524 | -0.09359 | -0.19539 |
| curv_rad | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 |
| | 3242 | 3242 | 3242 | 3242 | 3241 | 3241 | 3241 |
| curv_ang | 0.44567 | 0.45762 | -0.39871 | 1.00000 | -0.03425 | 0.00440 | 0.18481 |
| curv_ang | <.0001 | <.0001 | <.0001 | | 0.0512 | 0.8022 | <.0001 |
| | 3242 | 3242 | 3242 | 3242 | 3241 | 3241 | 3241 |
| avc | 0.10764 | -0.12202 | 0.14524 | -0.03425 | 1.00000 | -0.35956 | 0.72453 |
| | <.0001 | <.0001 | <.0001 | 0.0512 | | <.0001 | <.0001 |
| | 3241 | 3241 | 3241 | 3241 | 3241 | 3241 | 3241 |
| ava | -0.15364 | 0.12148 | -0.09359 | 0.00440 | -0.35956 | 1.00000 | -0.29040 |
| | <.0001 | <.0001 | <.0001 | 0.8022 | <.0001 | | <.0001 |
| | 3241 | 3241 | 3241 | 3241 | 3241 | 3241 | 3241 |
| K_R | -0.06353 | 0.28062 | -0.19539 | 0.18481 | 0.72453 | -0.29040 | 1.00000 |
| | 0.0003 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | |
| | 3241 | 3241 | 3241 | 3241 | 3241 | 3241 | 3241 |

## 3) Poisson Model:

Horizontal Curve on Sag-POISSON MODEL

Data Set THESIS.WA_HCURV_ON_SAG_ACC

| | |
|---|---|
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 3242 |
| Number of Observations Used | 3242 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 3236 | 1813.0072 | 0.5603 |
| Scaled Deviance | 3236 | 1813.0072 | 0.5603 |
| Pearson Chi-Square | 3236 | 3620.4934 | 1.1188 |
| Scaled Pearson X2 | 3236 | 3620.4934 | 1.1188 |
| Log Likelihood | | -1222.7905 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.5913 | 0.4683 | -7.5092 | -5.6734 | 198.08 | <.0001 |
| log_aadt | 1 | 0.9606 | 0.0587 | 0.8454 | 1.0757 | 267.45 | <.0001 |
| log_lgt | 1 | 0.9065 | 0.0669 | 0.7753 | 1.0377 | 183.34 | <.0001 |
| deg_curv | 1 | 0.0751 | 0.0081 | 0.0593 | 0.0910 | 86.62 | <.0001 |
| roadway_wid | 1 | -0.0414 | 0.0100 | -0.0611 | -0.0218 | 17.14 | <.0001 |
| access | 1 | 0.0342 | 0.0047 | 0.0251 | 0.0434 | 53.53 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 2365.2227 | | | |
| log_aadt | 2052.8191 | 1 | 312.40 | <.0001 |
| log_lgt | 1931.2555 | 1 | 121.56 | <.0001 |
| deg_curv | 1860.8549 | 1 | 70.40 | <.0001 |
| roadway_wid | 1847.6744 | 1 | 13.18 | 0.0003 |
| access | 1813.0072 | 1 | 34.67 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|

| | | | |
|---|---|---|---|
| log_aadt | 1 | 265.53 | <.0001 |
| log_lgt | 1 | 191.76 | <.0001 |
| deg_curv | 1 | 55.46 | <.0001 |
| roadway_wid | 1 | 17.31 | <.0001 |
| access | 1 | 34.67 | <.0001 |

## 2.2 NB Modeling:

## 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 30.4626 | <.0001 |

## 2) Final Model:

Horizontal Curve on Sag-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_SAG_ACC |
| Distribution | Negative Binomial |

| | |
|---|---|
| Number of Observations Read | 3242 |
| Number of Observations Used | 3242 |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.7921 | 0.5545 | -7.8788 | -5.7053 | 150.05 | <.0001 |
| log_aadt | 1 | 1.0141 | 0.0743 | 0.8684 | 1.1597 | 186.13 | <.0001 |
| log_lgt | 1 | 1.0059 | 0.0838 | 0.8417 | 1.1701 | 144.20 | <.0001 |
| deg_curv | 1 | 0.0971 | 0.0126 | 0.0724 | 0.1218 | 59.44 | <.0001 |
| roadway_wid | 1 | -0.0456 | 0.0122 | -0.0695 | -0.0217 | 14.02 | 0.0002 |
| access | 1 | 0.0379 | 0.0067 | 0.0248 | 0.0510 | 32.09 | <.0001 |
| Dispersion | 1 | 1.0227 | 0.1850 | 0.6601 | 1.3854 | | |

LR Statistics For Type 1 Analysis

| Source | 2*Log Likelihood | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | -2784.8996 | | | |
| log_aadt | -2570.7504 | 1 | 214.15 | <.0001 |
| log_lgt | -2479.5691 | 1 | 91.18 | <.0001 |
| deg_curv | -2411.0109 | 1 | 68.56 | <.0001 |
| roadway_wid | -2398.8859 | 1 | 12.12 | 0.0005 |
| access | -2371.6524 | 1 | 27.23 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 195.44 | <.0001 |
| log_lgt | 1 | 162.26 | <.0001 |
| deg_curv | 1 | 56.37 | <.0001 |
| roadway_wid | 1 | 14.25 | 0.0002 |
| access | 1 | 27.23 | <.0001 |

## 4) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 2613.6 |
| AIC (smaller is better) | 2627.6 |
| AICC (smaller is better) | 2627.7 |
| BIC (smaller is better) | 2670.2 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -6.7919 | 0.5545 | 3242 | -12.25 | <.0001 | 0.05 | -7.8791 | -5.7047 | 0.002441 |
| b1 | 1.0140 | 0.07433 | 3242 | 13.64 | <.0001 | 0.05 | 0.8683 | 1.1598 | 0.017855 |
| b2 | 1.0059 | 0.08377 | 3242 | 12.01 | <.0001 | 0.05 | 0.8417 | 1.1702 | -0.00643 |
| b3 | 0.09711 | 0.01260 | 3242 | 7.71 | <.0001 | 0.05 | 0.07241 | 0.1218 | -0.03869 |
| b4 | -0.04559 | 0.01218 | 3242 | -3.74 | 0.0002 | 0.05 | -0.06946 | -0.02172 | 0.074565 |
| b5 | 0.03791 | 0.006692 | 3242 | 5.67 | <.0001 | 0.05 | 0.02479 | 0.05103 | 0.067181 |
| alpha | 1.0228 | 0.1851 | 3242 | 5.53 | <.0001 | 0.05 | 0.6600 | 1.3857 | 0.003557 |

## 2.3 ZIP Modeling:

## 1) ZIP Model:

Horizontal Curve on Sag-ZIP MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ ON_SAG_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 3242 |
| Observations Not Used | 0 |
| Total Observations | 3242 |
| Parameters | 8 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 2610.1 |
| AIC (smaller is better) | 2626.1 |
| AICC (smaller is better) | 2626.1 |
| BIC (smaller is better) | 2674.8 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.3481 | 0.09119 | 3242 | -3.82 | 0.0001 | 0.05 | -0.5269 | -0.1693 | 0.00091 |
| a2 | -1.1161 | 0.2666 | 3242 | -4.19 | <.0001 | 0.05 | -1.6388 | -0.5933 | -0.00019 |
| b0 | -6.3660 | 0.5199 | 3242 | -12.25 | <.0001 | 0.05 | -7.3854 | -5.3467 | -0.0002 |
| b1 | 0.8702 | 0.06638 | 3242 | 13.11 | <.0001 | 0.05 | 0.7401 | 1.0004 | -0.00172 |
| b2 | 0.6211 | 0.1032 | 3242 | 6.02 | <.0001 | 0.05 | 0.4188 | 0.8235 | 0.000201 |
| b3 | 0.1149 | 0.01214 | 3242 | 9.47 | <.0001 | 0.05 | 0.09114 | 0.1387 | -0.00055 |
| b4 | -0.03367 | 0.01079 | 3242 | -3.12 | 0.0018 | 0.05 | -0.05482 | -0.01252 | -0.00788 |
| b5 | 0.04177 | 0.006748 | 3242 | 6.19 | <.0001 | 0.05 | 0.02854 | 0.05500 | 0.003588 |

## 2) Vuong Test:

Horizontal Curve on Sag-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.011947 | 0.20329 | 3.34608 |

# 2.4 ZINB Modeling:

## 1) ZINB Model:

Horizontal Curve on Sag-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_SAG_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 3242 |
| Observations Not Used | 0 |
| Total Observations | 3242 |
| Parameters | 9 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 2564.7 |
| AIC (smaller is better) | 2582.7 |
| AICC (smaller is better) | 2582.7 |
| BIC (smaller is better) | 2637.4 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | -19.3673 | 8.0247 | 3242 | -2.41 | 0.0159 | 0.05 | -35.1012 | -3.6334 | -0.00051 |
| a2 | -6.1959 | 2.4710 | 3242 | -2.51 | 0.0122 | 0.05 | -11.0406 | -1.3511 | 0.001691 |
| b0 | -7.3499 | 0.5629 | 3242 | -13.06 | <.0001 | 0.05 | -8.4537 | -6.2462 | -0.00065 |
| b1 | 1.0059 | 0.07233 | 3242 | 13.91 | <.0001 | 0.05 | 0.8641 | 1.1477 | -0.00373 |
| b2 | 0.9051 | 0.09890 | 3242 | 9.15 | <.0001 | 0.05 | 0.7112 | 1.0990 | 0.00275 |
| b3 | 0.1378 | 0.01640 | 3242 | 8.40 | <.0001 | 0.05 | 0.1056 | 0.1699 | -0.02874 |
| b4 | -0.03680 | 0.01184 | 3242 | -3.11 | 0.0019 | 0.05 | -0.06002 | -0.01358 | -0.00801 |
| b5 | 0.05347 | 0.008574 | 3242 | 6.24 | <.0001 | 0.05 | 0.03666 | 0.07028 | 0.012491 |
| alpha | 0.7452 | 0.1614 | 3242 | 4.62 | <.0001 | 0.05 | 0.4286 | 1.0617 | 0.000513 |

### 2) Vuong Test:

Horizontal Curve on Sag-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.007547 | 0.113857 | 3.774396 |

## 3. MODELS FOR HORIZONTAL CURVE COMBINED WITH MULTIPLE VERTICAL CURVE

### 3.1 Poisson Modeling

### 1) Selection of Variables:

Horizontal Curve on Mutiple V_Curve-POISSON MODEL 1

Data Set THESIS.WA_HCURV_ON_MVCURV_ACC

Distribution Poisson

Number of Observations Read 2892

Number of Observations Used 2892

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2884 | 2022.3145 | 0.7012 |
| Scaled Deviance | 2884 | 2022.3145 | 0.7012 |
| Pearson Chi-Square | 2884 | 3157.4562 | 1.0948 |
| Scaled Pearson X2 | 2884 | 3157.4562 | 1.0948 |
| Log Likelihood | | -1432.9140 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.0784 | 0.3808 | -7.8247 | -6.3322 | 345.61 | <.0001 |
| log_aadt | 1 | 0.8441 | 0.0423 | 0.7613 | 0.9270 | 399.07 | <.0001 |
| log_lgt | 1 | 0.8971 | 0.0683 | 0.7633 | 1.0309 | 172.68 | <.0001 |
| deg_curv | 1 | 0.1196 | 0.0150 | 0.0902 | 0.1491 | 63.45 | <.0001 |
| avc | 1 | -0.0002 | 0.0001 | -0.0004 | -0.0000 | 5.15 | 0.0232 |
| ava | 1 | -0.0153 | 0.0242 | -0.0628 | 0.0322 | 0.40 | 0.5270 |
| K_R | 1 | 0.0027 | 0.0013 | 0.0001 | 0.0053 | 4.23 | 0.0397 |
| pct_vcurv | 1 | -0.1430 | 0.2141 | -0.5626 | 0.2767 | 0.45 | 0.5042 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 2707.7918 | | | |
| log_aadt | 2231.5197 | 1 | 476.27 | <.0001 |
| log_lgt | 2091.8642 | 1 | 139.66 | <.0001 |
| deg_curv | 2028.8904 | 1 | 62.97 | <.0001 |
| avc | 2027.0187 | 1 | 1.87 | 0.1713 |
| ava | 2026.3494 | 1 | 0.67 | 0.4133 |
| K_R | 2022.7612 | 1 | 3.59 | 0.0582 |
| pct_vcurv | 2022.3145 | 1 | 0.45 | 0.5039 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 428.36 | <.0001 |
| log_lgt | 1 | 170.10 | <.0001 |
| deg_curv | 1 | 48.09 | <.0001 |
| avc | 1 | 4.97 | 0.0258 |
| ava | 1 | 0.40 | 0.5252 |
| K_R | 1 | 3.28 | 0.0701 |
| pct_vcurv | 1 | 0.45 | 0.5039 |

## 2) Examining Correlations:

Pearson Correlation Coefficients, N = 2892
Prob > |r| under H0: Rho=0

cseg_lgt    deg_curv    curv_rad    curv_ang    avc    ava    K_R

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| cseg_lgt | 1.00000 | -0.40003 | 0.39329 | 0.24204 | 0.09579 | -0.10847 | -0.05244 |
| | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0048 |
| deg_curv | -0.40003 | 1.00000 | -0.58024 | 0.57855 | -0.06273 | 0.08574 | 0.13513 |
| deg_curv | <.0001 | | <.0001 | <.0001 | 0.0007 | <.0001 | <.0001 |
| curv_rad | 0.39329 | -0.58024 | 1.00000 | -0.44691 | 0.04658 | -0.11579 | -0.10526 |
| curv_rad | <.0001 | <.0001 | | <.0001 | 0.0122 | <.0001 | <.0001 |
| curv_ang | 0.24204 | 0.57855 | -0.44691 | 1.00000 | -0.00434 | 0.03922 | 0.08498 |
| curv_ang | <.0001 | <.0001 | <.0001 | | 0.8157 | 0.0349 | <.0001 |
| avc | 0.09579 | -0.06273 | 0.04658 | -0.00434 | 1.00000 | -0.25190 | 0.88960 |
| | <.0001 | 0.0007 | 0.0122 | 0.8157 | | <.0001 | <.0001 |
| ava | -0.10847 | 0.08574 | -0.11579 | 0.03922 | -0.25190 | 1.00000 | -0.16537 |
| | <.0001 | <.0001 | <.0001 | 0.0349 | <.0001 | | <.0001 |
| K_R | -0.05244 | 0.13513 | -0.10526 | 0.08498 | 0.88960 | -0.16537 | 1.00000 |
| | 0.0048 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | |

## 3) Poisson Model:

Horizontal Curve on Mutiple V_Curve-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_MVCURV_ACC |
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 2892 |
| Number of Observations Used | 2892 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2888 | 2028.8904 | 0.7025 |
| Scaled Deviance | 2888 | 2028.8904 | 0.7025 |
| Pearson Chi-Square | 2888 | 3165.6952 | 1.0962 |
| Scaled Pearson X2 | 2888 | 3165.6952 | 1.0962 |
| Log Likelihood | | -1436.2020 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.2997 | 0.3665 | -8.0180 | -6.5813 | 396.71 | <.0001 |
| log_aadt | 1 | 0.8456 | 0.0424 | 0.7625 | 0.9287 | 398.13 | <.0001 |
| log_lgt | 1 | 0.8820 | 0.0618 | 0.7609 | 1.0031 | 203.72 | <.0001 |
| deg_curv | 1 | 0.1308 | 0.0140 | 0.1034 | 0.1582 | 87.58 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 2707.7918 | | | |
| log_aadt | 2231.5197 | 1 | 476.27 | <.0001 |
| log_lgt | 2091.8642 | 1 | 139.66 | <.0001 |
| deg_curv | 2028.8904 | 1 | 62.97 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 428.50 | <.0001 |
| log_lgt | 1 | 201.13 | <.0001 |
| deg_curv | 1 | 62.97 | <.0001 |

## 3.2 NB Modeling

### 1) Selection of Variables:

Horizontal Curve on Mutiple V_Curve-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_MVCURV_ACC |
| Distribution | Negative Binomial |

| | |
|---|---|
| Number of Observations Read | 2892 |
| Number of Observations Used | 2892 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2879 | 2010.3383 | 0.6983 |
| Scaled Deviance | 2879 | 2010.3383 | 0.6983 |
| Pearson Chi-Square | 2879 | 3163.7899 | 1.0989 |
| Scaled Pearson X2 | 2879 | 3163.7899 | 1.0989 |
| Log Likelihood | | -1426.9259 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.6343 | 1.0945 | -10.7794 | -6.4892 | 62.24 | <.0001 |
| log_aadt | 1 | 0.8982 | 0.0540 | 0.7924 | 1.0040 | 276.75 | <.0001 |
| log_lgt | 1 | 0.9031 | 0.0724 | 0.7612 | 1.0450 | 155.62 | <.0001 |
| deg_curv | 1 | 0.1110 | 0.0161 | 0.0795 | 0.1424 | 47.68 | <.0001 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| avc | 1 | -0.0002 | 0.0001 | -0.0004 | -0.0000 | 3.96 | 0.0466 |
| ava | 1 | -0.0176 | 0.0249 | -0.0664 | 0.0312 | 0.50 | 0.4794 |
| pct_vcurv | 1 | -0.0541 | 0.2224 | -0.4901 | 0.3818 | 0.06 | 0.8077 |
| K_R | 1 | 0.0024 | 0.0015 | -0.0005 | 0.0053 | 2.72 | 0.0992 |
| spd_limt | 1 | 0.0283 | 0.0141 | 0.0006 | 0.0560 | 4.01 | 0.0452 |
| surf_wid | 1 | -0.0152 | 0.0300 | -0.0740 | 0.0436 | 0.26 | 0.6118 |
| shld_wid | 1 | -0.0398 | 0.0221 | -0.0830 | 0.0035 | 3.24 | 0.0717 |
| spcl_ln | 1 | 0.1679 | 0.1262 | -0.0795 | 0.4153 | 1.77 | 0.1834 |
| access | 1 | 0.0258 | 0.0125 | 0.0014 | 0.0502 | 4.29 | 0.0384 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2886 | 2022.4127 | 0.7008 |
| Scaled Deviance | 2886 | 2022.4127 | 0.7008 |
| Pearson Chi-Square | 2886 | 3160.6356 | 1.0952 |
| Scaled Pearson X2 | 2886 | 3160.6356 | 1.0952 |
| Log Likelihood | | -1432.9631 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.9700 | 0.3862 | -7.7270 | -6.2130 | 325.67 | <.0001 |
| log_aadt | 1 | 0.8906 | 0.0512 | 0.7903 | 0.9909 | 303.08 | <.0001 |
| log_lgt | 1 | 0.9109 | 0.0644 | 0.7847 | 1.0372 | 199.96 | <.0001 |
| deg_curv | 1 | 0.1212 | 0.0150 | 0.0919 | 0.1505 | 65.59 | <.0001 |
| roadway_wid | 1 | -0.0193 | 0.0093 | -0.0375 | -0.0011 | 4.33 | 0.0375 |
| access | 1 | 0.0213 | 0.0123 | -0.0028 | 0.0453 | 3.01 | 0.0828 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 2707.7918 | | | |
| log_aadt | 2231.5197 | 1 | 476.27 | <.0001 |
| log_lgt | 2091.8642 | 1 | 139.66 | <.0001 |
| deg_curv | 2028.8904 | 1 | 62.97 | <.0001 |
| roadway_wid | 2025.3007 | 1 | 3.59 | 0.0581 |
| access | 2022.4127 | 1 | 2.89 | 0.0892 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 316.77 | <.0001 |
| log_lgt | 1 | 202.85 | <.0001 |
| deg_curv | 1 | 52.83 | <.0001 |
| roadway_wid | 1 | 4.35 | 0.0370 |
| access | 1 | 2.89 | 0.0892 |

# 2) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 19.2577 | <.0001 |

# 3) NB Model:

Horizontal Curve on Mutiple V_Curve-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_MVCURV_ACC |
| Distribution | Negative Binomial |
| Link Function | Log |

| | |
|---|---|
| Number of Observations Read | 2892 |
| Number of Observations Used | 2892 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2888 | 1702.3423 | 0.5895 |
| Scaled Deviance | 2888 | 1702.3423 | 0.5895 |
| Pearson Chi-Square | 2888 | 2791.7389 | 0.9667 |
| Scaled Pearson X2 | 2888 | 2791.7389 | 0.9667 |
| Log Likelihood | | -1419.1886 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.4004 | 0.4108 | -8.2055 | -6.5953 | 324.59 | <.0001 |
| log_aadt | 1 | 0.8563 | 0.0481 | 0.7620 | 0.9506 | 316.66 | <.0001 |
| log_lgt | 1 | 0.9201 | 0.0728 | 0.7773 | 1.0629 | 159.54 | <.0001 |
| deg_curv | 1 | 0.1514 | 0.0192 | 0.1137 | 0.1891 | 61.97 | <.0001 |
| Dispersion | 1 | 0.4946 | 0.1121 | 0.2748 | 0.7143 | | |

LR Statistics For Type 1 Analysis

| Source | 2*Log Likelihood | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | -3341.0339 | | | |
| log_aadt | -3004.5839 | 1 | 336.45 | <.0001 |
| log_lgt | -2898.2486 | 1 | 106.34 | <.0001 |
| deg_curv | -2838.3771 | 1 | 59.87 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 333.66 | <.0001 |
| log_lgt | 1 | 164.15 | <.0001 |
| deg_curv | 1 | 59.87 | <.0001 |

## 4) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3204.4 |
| AIC (smaller is better) | 3214.4 |
| AICC (smaller is better) | 3214.5 |
| BIC (smaller is better) | 3244.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -7.4004 | 0.4108 | 2892 | -18.02 | <.0001 | 0.05 | -8.2058 | -6.5950 | 0.000346 |
| b1 | 0.8563 | 0.04812 | 2892 | 17.79 | <.0001 | 0.05 | 0.7620 | 0.9507 | 0.001287 |
| b2 | 0.9201 | 0.07285 | 2892 | 12.63 | <.0001 | 0.05 | 0.7773 | 1.0630 | -0.00221 |
| b3 | 0.1514 | 0.01923 | 2892 | 7.87 | <.0001 | 0.05 | 0.1137 | 0.1891 | -0.00323 |
| alpha | 0.4946 | 0.1121 | 2892 | 4.41 | <.0001 | 0.05 | 0.2747 | 0.7145 | 0.002744 |

## 3.3 ZIP Modeling

## 1) ZIP Model:

Horizontal Curve on Mutiple V_Curve-ZIP MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ ON_MVCURV_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 2892 |
| Observations Not Used | 0 |
| Total Observations | 2892 |
| Parameters | 6 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3211.1 |
| AIC (smaller is better) | 3223.1 |
| AICC (smaller is better) | 3223.2 |
| BIC (smaller is better) | 3258.9 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.2714 | 0.05628 | 2892 | -4.82 | <.0001 | 0.05 | -0.3817 | -0.1610 | -0.00797 |
| a2 | -0.9090 | 0.2567 | 2892 | -3.54 | 0.0004 | 0.05 | -1.4123 | -0.4058 | -0.00013 |
| b0 | -6.6203 | 0.3955 | 2892 | -16.74 | <.0001 | 0.05 | -7.3958 | -5.8448 | 0.001933 |
| b1 | 0.7692 | 0.04570 | 2892 | 16.83 | <.0001 | 0.05 | 0.6796 | 0.8588 | 0.017336 |
| b2 | 0.6739 | 0.08984 | 2892 | 7.50 | <.0001 | 0.05 | 0.4977 | 0.8500 | -0.00197 |
| b3 | 0.1358 | 0.01563 | 2892 | 8.68 | <.0001 | 0.05 | 0.1051 | 0.1664 | 0.002774 |

## 2) Vuong Test:

### A. ZIP vs. Poisson:

Horizontal Curve on Mutiple V_Curve-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.004729 | 0.11494 | 2.212411 |

### B. ZIP vs. NB:

Horizontal Curve on Mutiple V_Curve -ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| -0.00115 | 0.095341 | -0.65108 |

## 3.4 ZINB Modeling

### 1) ZINB Model:

Horizontal Curve on Mutiple V_Curve-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ |

ON_MVCURV_ACC

Dimensions

| | |
|---|---|
| Observations Used | 2892 |
| Observations Not Used | 0 |
| Total Observations | 2892 |
| Parameters | 7 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3197.3 |
| AIC (smaller is better) | 3211.3 |
| AICC (smaller is better) | 3211.3 |
| BIC (smaller is better) | 3253.1 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.5227 | 0.1868 | 2892 | -2.80 | 0.0052 | 0.05 | -0.8890 | -0.1564 | 0.003626 |
| a2 | -1.4979 | 0.5786 | 2892 | -2.59 | 0.0097 | 0.05 | -2.6325 | -0.3633 | -0.00105 |
| b0 | -6.9910 | 0.4356 | 2892 | -16.05 | <.0001 | 0.05 | -7.8451 | -6.1370 | -0.00264 |
| b1 | 0.7990 | 0.05101 | 2892 | 15.66 | <.0001 | 0.05 | 0.6990 | 0.8990 | -0.02244 |
| b2 | 0.7976 | 0.09694 | 2892 | 8.23 | <.0001 | 0.05 | 0.6075 | 0.9876 | 0.003436 |
| b3 | 0.1657 | 0.02228 | 2892 | 7.44 | <.0001 | 0.05 | 0.1220 | 0.2094 | -0.0097 |
| alpha | 0.3696 | 0.1237 | 2892 | 2.99 | 0.0028 | 0.05 | 0.1271 | 0.6121 | -0.00023 |

## 2) Vuong Test:

Horizontal Curve on Mutiple V_Curve-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.001236 | 0.050515 | 1.315377 |

# 4. MODELS FOR HORIZONTAL CURVE ON GRADE: $|G|<5$

## 4.1 Poisson Modeling:

### 1) Selection of Variables:

Horizontal Curve on Grade (<5)-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD_LT5_ACC |
| Distribution | Poisson |
| Link Function | Log |

| | |
|---|---|
| Number of Observations Read | 12108 |

| | |
|---|---|
| Number of Observations Used | 12108 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 12E3 | 5899.7195 | 0.4877 |
| Scaled Deviance | 12E3 | 5899.7195 | 0.4877 |
| Pearson Chi-Square | 12E3 | 13602.3087 | 1.1243 |
| Scaled Pearson X2 | 12E3 | 13602.3087 | 1.1243 |
| Log Likelihood | | -4044.3820 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.3565 | 0.7135 | -8.7549 | -5.9582 | 106.32 | <.0001 |
| log_aadt | 1 | 0.9481 | 0.0347 | 0.8800 | 1.0162 | 744.49 | <.0001 |
| log_lgt | 1 | 0.9260 | 0.0395 | 0.8487 | 1.0034 | 550.44 | <.0001 |
| deg_curv | 1 | 0.0524 | 0.0035 | 0.0457 | 0.0592 | 229.70 | <.0001 |
| avg | 1 | 0.0091 | 0.0193 | -0.0287 | 0.0469 | 0.22 | 0.6366 |
| surf_wid | 1 | -0.0143 | 0.0191 | -0.0518 | 0.0232 | 0.56 | 0.4550 |
| shld_wid | 1 | -0.0980 | 0.0131 | -0.1236 | -0.0723 | 55.89 | <.0001 |
| spd_limt | 1 | 0.0066 | 0.0096 | -0.0122 | 0.0254 | 0.47 | 0.4940 |
| access | 1 | 0.0320 | 0.0030 | 0.0261 | 0.0378 | 114.03 | <.0001 |
| spcl_ln | 1 | 0.1145 | 0.0986 | -0.0788 | 0.3078 | 1.35 | 0.2455 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Horizontal Curve on Grade (<5)-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD_LT5_ACC |
| Distribution | Poisson |
| Link Function | Log |

| | |
|---|---|
| Number of Observations Read | 12108 |
| Number of Observations Used | 12108 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 12E3 | 6391.7558 | 0.5282 |
| Scaled Deviance | 12E3 | 6391.7558 | 0.5282 |
| Pearson Chi-Square | 12E3 | 14621.9873 | 1.2082 |

| | | | | |
|---|---|---|---|---|
| Scaled Pearson X2 | 12E3 | 14621.9873 | 1.2082 |
| Log Likelihood | | -4290.4002 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.6764 | 0.2533 | -9.1729 | -8.1800 | 1173.40 | <.0001 |
| log_aadt | 1 | 0.9352 | 0.0327 | 0.8712 | 0.9992 | 820.17 | <.0001 |
| grad_hgt | 1 | 0.8451 | 0.0693 | 0.7094 | 0.9809 | 148.87 | <.0001 |
| deg_curv | 1 | 0.0247 | 0.0043 | 0.0163 | 0.0331 | 33.26 | <.0001 |
| roadway_wid | 1 | -0.0300 | 0.0057 | -0.0411 | -0.0188 | 27.76 | <.0001 |
| access | 1 | 0.0217 | 0.0026 | 0.0165 | 0.0269 | 67.67 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 7519.6582 | | | |
| log_aadt | 6582.6539 | 1 | 937.00 | <.0001 |
| grad_hgt | 6490.2000 | 1 | 92.45 | <.0001 |
| deg_curv | 6460.0459 | 1 | 30.15 | <.0001 |
| roadway_wid | 6437.1529 | 1 | 22.89 | <.0001 |
| access | 6391.7558 | 1 | 45.40 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 818.07 | <.0001 |
| grad_hgt | 1 | 111.00 | <.0001 |
| deg_curv | 1 | 23.79 | <.0001 |
| roadway_wid | 1 | 28.04 | <.0001 |
| access | 1 | 45.40 | <.0001 |

## 4.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 86.1032 | <.0001 |

## 2) NB Model:

Horizontal Curve on Grade (<5)-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD_LT5_ACC |
| Distribution | Negative Binomial |
| Link Function | Log |

| | |
|---|---|
| Number of Observations Read | 12108 |
| Number of Observations Used | 12108 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 12E3 | 4844.5521 | 0.4003 |
| Scaled Deviance | 12E3 | 4844.5521 | 0.4003 |
| Pearson Chi-Square | 12E3 | 12702.0445 | 1.0496 |
| Scaled Pearson X2 | 12E3 | 12702.0445 | 1.0496 |
| Log Likelihood | | -4188.6550 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.8830 | 0.2954 | -9.4619 | -8.3040 | 904.37 | <.0001 |
| log_aadt | 1 | 0.9555 | 0.0388 | 0.8794 | 1.0315 | 606.23 | <.0001 |
| grad_hgt | 1 | 0.9372 | 0.0978 | 0.7455 | 1.1289 | 91.82 | <.0001 |
| deg_curv | 1 | 0.0264 | 0.0053 | 0.0160 | 0.0368 | 24.86 | <.0001 |
| roadway_wid | 1 | -0.0296 | 0.0065 | -0.0422 | -0.0169 | 21.00 | <.0001 |
| access | 1 | 0.0251 | 0.0043 | 0.0167 | 0.0335 | 34.29 | <.0001 |
| Dispersion | 1 | 1.2858 | 0.1383 | 1.0148 | 1.5568 | | |

LR Statistics For Type 1 Analysis

| Source | 2*Log Likelihood | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | -9242.5181 | | | |
| log_aadt | -8527.4388 | 1 | 715.08 | <.0001 |
| grad_hgt | -8455.2499 | 1 | 72.19 | <.0001 |
| deg_curv | -8427.8113 | 1 | 27.44 | <.0001 |
| roadway_wid | -8409.6117 | 1 | 18.20 | <.0001 |
| access | -8377.3101 | 1 | 32.30 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 634.35 | <.0001 |
| grad_hgt | 1 | 88.82 | <.0001 |
| deg_curv | 1 | 20.65 | <.0001 |
| roadway_wid | 1 | 21.21 | <.0001 |
| access | 1 | 32.30 | <.0001 |

## 4) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 8930.5 |
| AIC (smaller is better) | 8944.5 |
| AICC (smaller is better) | 8944.5 |
| BIC (smaller is better) | 8996.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -8.8830 | 0.2954 | 12E3 | -30.07 | <.0001 | 0.05 | -9.4620 | -8.3040 | 0.006917 |
| b1 | 0.9554 | 0.03880 | 12E3 | 24.62 | <.0001 | 0.05 | 0.8794 | 1.0315 | 0.055225 |
| b2 | 0.9372 | 0.09781 | 12E3 | 9.58 | <.0001 | 0.05 | 0.7455 | 1.1289 | 0.003184 |
| b3 | 0.02644 | 0.005303 | 12E3 | 4.99 | <.0001 | 0.05 | 0.01604 | 0.03683 | 0.009118 |
| b4 | -0.02957 | 0.006452 | 12E3 | -4.58 | <.0001 | 0.05 | -0.04221 | -0.01692 | 0.283823 |
| b5 | 0.02508 | 0.004283 | 12E3 | 5.86 | <.0001 | 0.05 | 0.01668 | 0.03347 | 0.033463 |
| alpha | 1.2858 | 0.1383 | 12E3 | 9.30 | <.0001 | 0.05 | 1.0148 | 1.5569 | -0.00006 |

# 4.3 ZIP Modeling:

## 1) ZIP Model:

Horizontal Curve on Grade (<5)-ZIP MODEL

Data Set THESIS.WA_HCURV_ON_GRAD_LT5_ACC

Dimensions

| | |
|---|---|
| Observations Used | 12108 |
| Observations Not Used | 0 |
| Total Observations | 12108 |
| Parameters | 8 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 8960.0 |
| AIC (smaller is better) | 8976.0 |
| AICC (smaller is better) | 8976.1 |
| BIC (smaller is better) | 9035.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | 0.03071 | 0.01331 | 12E3 | 2.31 | 0.0211 | 0.05 | 0.004617 | 0.05679 | -0.01764 |
| a2 | -2.1208 | 0.5690 | 12E3 | -3.73 | 0.0002 | 0.05 | -3.2362 | -1.0055 | -0.00002 |
| b0 | -8.0024 | 0.2798 | 12E3 | -28.60 | <.0001 | 0.05 | -8.5508 | -7.4540 | 0.008819 |
| b1 | 0.9399 | 0.03563 | 12E3 | 26.38 | <.0001 | 0.05 | 0.8701 | 1.0097 | 0.072661 |
| b2 | 0.3266 | 0.1081 | 12E3 | 3.02 | 0.0025 | 0.05 | 0.1148 | 0.5385 | 0.001179 |
| b3 | 0.02572 | 0.005439 | 12E3 | 4.73 | <.0001 | 0.05 | 0.01506 | 0.03639 | 0.054533 |
| b4 | -0.02952 | 0.006075 | 12E3 | -4.86 | <.0001 | 0.05 | -0.04143 | -0.01761 | 0.263545 |
| b5 | 0.02991 | 0.004055 | 12E3 | 7.38 | <.0001 | 0.05 | 0.02196 | 0.03786 | 0.021583 |

### 2) Vuong Test:

### A. ZIP vs. Poisson:

Horizontal Curve on Grade (<5)-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.007183 | 0.144866 | 5.456306 |

### B. ZIP vs. NB:

Horizontal Curve on Grade (<5) -ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| -0.00122 | 0.08185 | -1.63982 |

## 4.4 ZINB Modeling:

### 1) ZINB Model:

Horizontal Curve on Grade (<5)-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ ON_GRAD_LT5_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 12108 |
| Observations Not Used | 0 |
| Total Observations | 12108 |
| Parameters | 9 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 8923.6 |
| AIC (smaller is better) | 8941.6 |
| AICC (smaller is better) | 8941.6 |
| BIC (smaller is better) | 9008.2 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.4011 | 0.1256 | 12E3 | -3.19 | 0.0014 | 0.05 | -0.6473 | -0.1549 | 0.009721 |
| a3 | 0.07720 | 0.02763 | 12E3 | 2.79 | 0.0052 | 0.05 | 0.02303 | 0.1314 | 0.024813 |
| b0 | -8.8225 | 0.3358 | 12E3 | -26.27 | <.0001 | 0.05 | -9.4808 | -8.1642 | 0.000168 |
| b1 | 0.9382 | 0.04081 | 12E3 | 22.99 | <.0001 | 0.05 | 0.8582 | 1.0182 | 0.015382 |
| b2 | 0.9405 | 0.09757 | 12E3 | 9.64 | <.0001 | 0.05 | 0.7492 | 1.1317 | -0.00887 |
| b3 | 0.04840 | 0.01079 | 12E3 | 4.49 | <.0001 | 0.05 | 0.02725 | 0.06956 | -0.02976 |
| b4 | -0.02795 | 0.006478 | 12E3 | -4.31 | <.0001 | 0.05 | -0.04065 | -0.01525 | 0.052824 |
| b5 | 0.02481 | 0.004367 | 12E3 | 5.68 | <.0001 | 0.05 | 0.01625 | 0.03337 | -0.04242 |
| alpha | 1.1591 | 0.1626 | 12E3 | 7.13 | <.0001 | 0.05 | 0.8404 | 1.4778 | 0.001855 |

### 2) Vuong Test:

Horizontal Curve on Grade (<5)-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000284 | 0.049334 | 0.633282 |

## 5. MODELS FOR HORIZONTAL CURVE ON GRADE: $|G| \geq 5$

## 5.1 Poisson Modeling:

### 1) Selection of Variables:

Horizontal Curve On Grade (>5)-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD5_ACC |
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 2212 |
| Number of Observations Used | 2212 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2202 | 1213.5046 | 0.5511 |

| | | | |
|---|---|---|---|
| Scaled Deviance | 2202 | 1213.5046 | 0.5511 |
| Pearson Chi-Square | 2202 | 2449.4417 | 1.1124 |
| Scaled Pearson X2 | 2202 | 2449.4417 | 1.1124 |
| Log Likelihood | | -826.9497 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -3.7790 | 1.9036 | -7.5101 | -0.0480 | 3.94 | 0.0471 |
| log_aadt | 1 | 0.8560 | 0.0769 | 0.7053 | 1.0067 | 123.97 | <.0001 |
| log_lgt | 1 | 0.8824 | 0.0874 | 0.7111 | 1.0538 | 101.87 | <.0001 |
| deg_curv | 1 | 0.0495 | 0.0082 | 0.0335 | 0.0654 | 36.80 | <.0001 |
| avg | 1 | -0.3412 | 0.1032 | -0.5434 | -0.1390 | 10.94 | 0.0009 |
| surf_wid | 1 | -0.1489 | 0.0561 | -0.2589 | -0.0389 | 7.04 | 0.0080 |
| shld_wid | 1 | 0.0278 | 0.0259 | -0.0230 | 0.0786 | 1.15 | 0.2839 |
| spd_limt | 1 | 0.0385 | 0.0217 | -0.0040 | 0.0810 | 3.15 | 0.0759 |
| access | 1 | 0.0483 | 0.0131 | 0.0227 | 0.0740 | 13.62 | 0.0002 |
| spcl_ln | 1 | 0.0900 | 0.1341 | -0.1728 | 0.3528 | 0.45 | 0.5023 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2206 | 1278.7345 | 0.5797 |
| Scaled Deviance | 2206 | 1278.7345 | 0.5797 |
| Pearson Chi-Square | 2206 | 2571.6902 | 1.1658 |
| Scaled Pearson X2 | 2206 | 2571.6902 | 1.1658 |
| Log Likelihood | | -859.5646 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.7075 | 1.2514 | -9.1602 | -4.2549 | 28.73 | <.0001 |
| log_aadt | 1 | 0.9114 | 0.0571 | 0.7995 | 1.0234 | 254.67 | <.0001 |
| grad_hgt | 1 | 0.7995 | 0.0885 | 0.6260 | 0.9729 | 81.64 | <.0001 |
| deg_curv | 1 | 0.0397 | 0.0081 | 0.0239 | 0.0554 | 24.23 | <.0001 |
| surf_wid | 1 | -0.1291 | 0.0537 | -0.2343 | -0.0238 | 5.78 | 0.0162 |
| access | 1 | 0.0538 | 0.0119 | 0.0306 | 0.0771 | 20.55 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 1626.4093 | | | |
| log_aadt | 1375.3756 | 1 | 251.03 | <.0001 |
| grad_hgt | 1320.1684 | 1 | 55.21 | <.0001 |
| deg_curv | 1299.4198 | 1 | 20.75 | <.0001 |
| surf_wid | 1293.5961 | 1 | 5.82 | 0.0158 |
| access | 1278.7345 | 1 | 14.86 | 0.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 234.94 | <.0001 |
| grad_hgt | 1 | 69.82 | <.0001 |
| deg_curv | 1 | 18.32 | <.0001 |
| surf_wid | 1 | 5.77 | 0.0163 |
| access | 1 | 14.86 | 0.0001 |

## 5.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 20.2810 | <.0001 |

### 2) NB Model:

Horizontal Curve On Grade (>5)-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD5_ACC |
| Distribution | Negative Binomial |

| | |
|---|---|
| Number of Observations Read | 2212 |
| Number of Observations Used | 2212 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2206 | 971.0278 | 0.4402 |
| Scaled Deviance | 2206 | 971.0278 | 0.4402 |

| | | | |
|---|---|---|---|
| Pearson Chi-Square | 2206 | 2209.6497 | 1.0017 |
| Scaled Pearson X2 | 2206 | 2209.6497 | 1.0017 |
| Log Likelihood | | -837.8645 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -6.8556 | 1.4525 | -9.7024 | -4.0089 | 22.28 | <.0001 |
| log_aadt | 1 | 0.9535 | 0.0752 | 0.8062 | 1.1008 | 160.98 | <.0001 |
| grad_hgt | 1 | 0.8463 | 0.1154 | 0.6201 | 1.0725 | 53.78 | <.0001 |
| deg_curv | 1 | 0.0400 | 0.0098 | 0.0209 | 0.0591 | 16.83 | <.0001 |
| surf_wid | 1 | -0.1383 | 0.0631 | -0.2620 | -0.0146 | 4.80 | 0.0285 |
| access | 1 | 0.0509 | 0.0173 | 0.0169 | 0.0848 | 8.62 | 0.0033 |
| Dispersion | 1 | 1.0805 | 0.2475 | 0.5954 | 1.5656 | | |

LR Statistics For Type 1 Analysis

| Source | 2*Log Likelihood | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | -1923.4654 | | | |
| log_aadt | -1743.4205 | 1 | 180.04 | <.0001 |
| grad_hgt | -1704.7962 | 1 | 38.62 | <.0001 |
| deg_curv | -1688.6007 | 1 | 16.20 | <.0001 |
| surf_wid | -1683.5217 | 1 | 5.08 | 0.0242 |
| access | -1675.7291 | 1 | 7.79 | 0.0052 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 165.71 | <.0001 |
| grad_hgt | 1 | 50.16 | <.0001 |
| deg_curv | 1 | 14.08 | 0.0002 |
| surf_wid | 1 | 4.82 | 0.0281 |
| access | 1 | 7.79 | 0.0052 |

## 3) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1839.1 |
| AIC (smaller is better) | 1853.1 |

| | |
|---|---|
| AICC (smaller is better) | 1853.2 |
| BIC (smaller is better) | 1893.0 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -6.8556 | 1.4525 | 2212 | -4.72 | <.0001 | 0.05 | -9.7040 | -4.0073 | 0.00142 |
| b1 | 0.9535 | 0.07515 | 2212 | 12.69 | <.0001 | 0.05 | 0.8061 | 1.1009 | 0.010961 |
| b2 | 0.8463 | 0.1154 | 2212 | 7.33 | <.0001 | 0.05 | 0.6200 | 1.0727 | 0.001352 |
| b3 | 0.04002 | 0.009756 | 2212 | 4.10 | <.0001 | 0.05 | 0.02089 | 0.05915 | 0.01015 |
| b4 | -0.1383 | 0.06312 | 2212 | -2.19 | 0.0286 | 0.05 | -0.2621 | -0.01450 | 0.03273 |
| b5 | 0.05087 | 0.01733 | 2212 | 2.94 | 0.0034 | 0.05 | 0.01689 | 0.08486 | -0.00097 |
| alpha | 1.0805 | 0.2475 | 2212 | 4.37 | <.0001 | 0.05 | 0.5951 | 1.5659 | 0.000112 |

## 5.3 ZIP Modeling:

### 1) ZIP Model:

Horizontal Curve On Grade (>5)-ZIP MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD5_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 2212 |
| Observations Not Used | 0 |
| Total Observations | 2212 |
| Parameters | 8 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1838.1 |
| AIC (smaller is better) | 1854.1 |
| AICC (smaller is better) | 1854.2 |
| BIC (smaller is better) | 1899.8 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.1305 | 0.04575 | 2212 | -2.85 | 0.0044 | 0.05 | -0.2202 | -0.04079 | -0.00002 |
| a3 | 0.07373 | 0.02085 | 2212 | 3.54 | 0.0004 | 0.05 | 0.03284 | 0.1146 | 0.000016 |
| b0 | -6.7185 | 1.3635 | 2212 | -4.93 | <.0001 | 0.05 | -9.3924 | -4.0447 | -1.15E-6 |
| b1 | 0.8961 | 0.06538 | 2212 | 13.71 | <.0001 | 0.05 | 0.7679 | 1.0243 | -0.00009 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b2 | 0.8566 | 0.1039 | 2212 | 8.25 | <.0001 | 0.05 | 0.6529 | 1.0602 | 0.000086 |
| b3 | 0.09439 | 0.01456 | 2212 | 6.48 | <.0001 | 0.05 | 0.06583 | 0.1229 | 0.000028 |
| b4 | -0.1193 | 0.05796 | 2212 | -2.06 | 0.0398 | 0.05 | -0.2329 | -0.00559 | -0.00012 |
| b5 | 0.05133 | 0.01481 | 2212 | 3.47 | 0.0005 | 0.05 | 0.02228 | 0.08037 | -0.00005 |

## 2) Vuong Test:

Horizontal Curve On Grade (>5)-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.010028 | 0.14013 | 3.365645 |

# 5.4 ZINB Modeling:

## 1) ZINB Model:

Horizontal Curve On Grade (>5)-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD5_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 2212 |
| Observations Not Used | 0 |
| Total Observations | 2212 |
| Parameters | 10 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1801.0 |
| AIC (smaller is better) | 1821.0 |
| AICC (smaller is better) | 1821.1 |
| BIC (smaller is better) | 1878.0 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | 0.2221 | 0.08461 | 2212 | 2.63 | 0.0087 | 0.05 | 0.05618 | 0.3880 | -0.00038 |
| a2 | -7.3863 | 2.5681 | 2212 | -2.88 | 0.0041 | 0.05 | -12.4224 | -2.3502 | -0.00002 |
| a3 | 0.05163 | 0.02509 | 2212 | 2.06 | 0.0397 | 0.05 | 0.002427 | 0.1008 | -0.00075 |
| b0 | -7.1426 | 1.4256 | 2212 | -5.01 | <.0001 | 0.05 | -9.9382 | -4.3470 | 0.000151 |
| b1 | 0.9702 | 0.07404 | 2212 | 13.10 | <.0001 | 0.05 | 0.8250 | 1.1154 | 0.001285 |
| b2 | 0.5279 | 0.1840 | 2212 | 2.87 | 0.0042 | 0.05 | 0.1670 | 0.8889 | -0.00014 |
| b3 | 0.08508 | 0.01705 | 2212 | 4.99 | <.0001 | 0.05 | 0.05165 | 0.1185 | -0.00048 |
| b4 | -0.1216 | 0.06151 | 2212 | -1.98 | 0.0481 | 0.05 | -0.2423 | -0.00099 | 0.003036 |
| b5 | 0.05044 | 0.01824 | 2212 | 2.77 | 0.0057 | 0.05 | 0.01468 | 0.08620 | 0.001063 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| alpha | 0.6171 | 0.2378 | 2212 | 2.60 | 0.0095 | 0.05 | 0.1509 | 1.0834 | -6.16E-6 |

### 2) Vuong Test:

Horizontal Curve On Grade (>5)-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.008613 | 0.112377 | 3.604652 |

## 6. MODELS FOR CREST VERTICAL CURVE ON HORIZONTAL TANGENT

## 6.1 Poisson Modeling:

### 1) Selection of Variables:

Tangent On Crest-POISSON MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_CREST11_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 1171 |
| Number of Observations Used | 1171 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 1160 | 805.9607 | 0.6948 |
| Scaled Deviance | 1160 | 805.9607 | 0.6948 |
| Pearson Chi-Square | 1160 | 1175.2632 | 1.0132 |
| Scaled Pearson X2 | 1160 | 1175.2632 | 1.0132 |
| Log Likelihood | | -591.8555 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -10.9512 | 1.8003 | -14.4798 | -7.4226 | 37.00 | <.0001 |
| log_aadt | 1 | 0.9815 | 0.0806 | 0.8236 | 1.1393 | 148.42 | <.0001 |
| log_lgt | 1 | 0.9589 | 0.1080 | 0.7471 | 1.1706 | 78.78 | <.0001 |
| avc | 1 | -0.0001 | 0.0001 | -0.0003 | 0.0001 | 1.06 | 0.3038 |
| sml_r | 1 | -0.0000 | 0.0000 | -0.0001 | 0.0000 | 1.77 | 0.1836 |
| lar_smr | 1 | 0.0429 | 0.0284 | -0.0127 | 0.0986 | 2.29 | 0.1305 |
| surf_wid | 1 | 0.0311 | 0.0506 | -0.0682 | 0.1303 | 0.38 | 0.5394 |
| shld_wid | 1 | -0.0692 | 0.0328 | -0.1334 | -0.0050 | 4.47 | 0.0346 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| spd_limt | 1 | 0.0422 | 0.0216 | -0.0002 | 0.0845 | 3.81 | 0.0508 |
| access | 1 | 0.0922 | 0.0256 | 0.0420 | 0.1424 | 12.94 | 0.0003 |
| spcl_ln | 1 | -0.0813 | 0.1587 | -0.3923 | 0.2298 | 0.26 | 0.6086 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 1167 | 819.5923 | 0.7023 |
| Scaled Deviance | 1167 | 819.5923 | 0.7023 |
| Pearson Chi-Square | 1167 | 1175.8753 | 1.0076 |
| Scaled Pearson X2 | 1167 | 1175.8753 | 1.0076 |
| Log Likelihood | | -598.6712 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.2931 | 0.5274 | -8.3268 | -6.2593 | 191.19 | <.0001 |
| log_aadt | 1 | 0.8635 | 0.0616 | 0.7428 | 0.9841 | 196.68 | <.0001 |
| log_lgt | 1 | 0.9226 | 0.0971 | 0.7323 | 1.1129 | 90.27 | <.0001 |
| access | 1 | 0.0804 | 0.0240 | 0.0334 | 0.1275 | 11.21 | 0.0008 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

# 6.2 NB Modeling:

## 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 3.3626 | 0.0667 |

## 2) NB Modeling:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 1167 | 743.1712 | 0.6368 |
| Scaled Deviance | 1167 | 743.1712 | 0.6368 |
| Pearson Chi-Square | 1167 | 1097.1942 | 0.9402 |
| Scaled Pearson X2 | 1167 | 1097.1942 | 0.9402 |
| Log Likelihood | | -596.1812 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.3833 | 0.5664 | -8.4934 | -6.2733 | 169.95 | <.0001 |
| log_aadt | 1 | 0.8749 | 0.0671 | 0.7433 | 1.0065 | 169.83 | <.0001 |
| log_lgt | 1 | 0.9254 | 0.1063 | 0.7170 | 1.1338 | 75.74 | <.0001 |
| access | 1 | 0.0818 | 0.0259 | 0.0309 | 0.1326 | 9.94 | 0.0016 |
| Dispersion | 1 | 0.2433 | 0.1315 | -0.0145 | 0.5011 | | |

## 3) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1355.0 |
| AIC (smaller is better) | 1365.0 |
| AICC (smaller is better) | 1365.1 |
| BIC (smaller is better) | 1390.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -7.3833 | 0.5664 | 1171 | -13.04 | <.0001 | 0.05 | -8.4945 | -6.2721 | 0.00086 |
| b1 | 0.8749 | 0.06714 | 1171 | 13.03 | <.0001 | 0.05 | 0.7432 | 1.0066 | 0.00578 |
| b2 | 0.9254 | 0.1063 | 1171 | 8.70 | <.0001 | 0.05 | 0.7168 | 1.1340 | -0.00232 |
| b3 | 0.08175 | 0.02593 | 1171 | 3.15 | 0.0017 | 0.05 | 0.03087 | 0.1326 | -0.00057 |
| alpha | 0.2433 | 0.1315 | 1171 | 1.85 | 0.0646 | 0.05 | -0.01475 | 0.5014 | -0.00017 |

# 6.3 ZIP Modeling:

## 1) ZIP Model:

Tangent On Crest-ZIP MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1358.7 |
| AIC (smaller is better) | 1368.7 |
| AICC (smaller is better) | 1368.8 |
| BIC (smaller is better) | 1394.1 |

Parameter Estimates (Selected Model)

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.2990 | 0.1259 | 1171 | -2.37 | 0.0177 | 0.05 | -0.5460 | -0.05191 | -0.00012 |
| b0 | -6.9682 | 0.5852 | 1171 | -11.91 | <.0001 | 0.05 | -8.1163 | -5.8202 | 0.000189 |
| b1 | 0.8328 | 0.06580 | 1171 | 12.66 | <.0001 | 0.05 | 0.7037 | 0.9619 | 0.001486 |
| b2 | 0.9115 | 0.09963 | 1171 | 9.15 | <.0001 | 0.05 | 0.7161 | 1.1070 | -0.00025 |
| b3 | 0.07959 | 0.02455 | 1171 | 3.24 | 0.0012 | 0.05 | 0.03141 | 0.1278 | 0.000275 |

## 2) Vuong Test:

Tangent On Crest-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000529 | 0.027241 | 0.664385 |

## 6.4 ZINB Modeling:

## 1) ZINB Model:

Tangent On Crest-ZINB MODEL

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1354.9 |
| AIC (smaller is better) | 1366.9 |
| AICC (smaller is better) | 1367.0 |
| BIC (smaller is better) | 1397.3 |

Parameter Estimates (Not Successful)

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.6166 | 0.7909 | 1171 | -0.78 | 0.4358 | 0.05 | -2.1684 | 0.9352 | 0.000016 |
| b0 | -7.3345 | 0.6184 | 1171 | -11.86 | <.0001 | 0.05 | -8.5478 | -6.1212 | 0.000037 |
| b1 | 0.8698 | 0.07174 | 1171 | 12.13 | <.0001 | 0.05 | 0.7291 | 1.0106 | 0.000426 |
| b2 | 0.9251 | 0.1064 | 1171 | 8.69 | <.0001 | 0.05 | 0.7163 | 1.1339 | 0.000043 |
| b3 | 0.08165 | 0.02594 | 1171 | 3.15 | 0.0017 | 0.05 | 0.03076 | 0.1325 | 0.000062 |
| alpha | 0.2368 | 0.1367 | 1171 | 1.73 | 0.0836 | 0.05 | -0.03145 | 0.5050 | 0.000017 |

# 7. MODELS FOR SAG VERTICAL CURVE ON HORIZONTAL TANGENT

## 7.1 Poisson Modeling:

## 1) Selection of Variables:

Tangent On Sag-POISSON MODEL

Data Set THESIS.WA_TANGENT_ON_SAG11_ACC

| | | |
|---|---|---|
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 1226 |
| Number of Observations Used | 1225 |
| Missing Values | 1 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 1214 | 915.0523 | 0.7537 |
| Scaled Deviance | 1214 | 915.0523 | 0.7537 |
| Pearson Chi-Square | 1214 | 1425.3001 | 1.1741 |
| Scaled Pearson X2 | 1214 | 1425.3001 | 1.1741 |
| Log Likelihood | | -655.9278 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -9.3127 | 1.7013 | -12.6471 | -5.9782 | 29.96 | <.0001 |
| log_aadt | 1 | 0.9376 | 0.0764 | 0.7879 | 1.0873 | 150.74 | <.0001 |
| log_lgt | 1 | 0.9152 | 0.1085 | 0.7026 | 1.1278 | 71.18 | <.0001 |
| avc | 1 | -0.0004 | 0.0002 | -0.0007 | -0.0001 | 5.65 | 0.0175 |
| sml_r | 1 | -0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.83 | 0.3629 |
| lar_smr | 1 | -0.0122 | 0.0452 | -0.1007 | 0.0763 | 0.07 | 0.7866 |
| surf_wid | 1 | 0.0021 | 0.0526 | -0.1010 | 0.1052 | 0.00 | 0.9686 |
| shld_wid | 1 | -0.0104 | 0.0285 | -0.0663 | 0.0455 | 0.13 | 0.7155 |
| spd_limt | 1 | 0.0294 | 0.0202 | -0.0101 | 0.0689 | 2.12 | 0.1452 |
| access | 1 | 0.0186 | 0.0283 | -0.0368 | 0.0740 | 0.43 | 0.5106 |
| spcl_ln | 1 | 0.0972 | 0.1850 | -0.2654 | 0.4599 | 0.28 | 0.5992 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Tangent On Sag-POISSON MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_SAG11_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 1225 |
| Number of Observations Used | 1225 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 1221 | 918.1404 | 0.7520 |
| Scaled Deviance | 1221 | 918.1404 | 0.7520 |
| Pearson Chi-Square | 1221 | 1427.4110 | 1.1691 |
| Scaled Pearson X2 | 1221 | 1427.4110 | 1.1691 |
| Log Likelihood | | -657.4718 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.5088 | 0.5341 | -8.5556 | -6.4620 | 197.65 | <.0001 |
| log_aadt | 1 | 0.9162 | 0.0613 | 0.7961 | 1.0363 | 223.57 | <.0001 |
| log_lgt | 1 | 0.9158 | 0.0987 | 0.7223 | 1.1092 | 86.07 | <.0001 |
| avc | 1 | -0.0004 | 0.0001 | -0.0007 | -0.0001 | 6.46 | 0.0110 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 7.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 5.1837 | 0.0228 |

### 2) NB Model:

Tangent On Sag-NB MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_SAG11_ACC | |
| Distribution | Negative Binomial | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 1225 |
| Number of Observations Used | 1225 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 1221 | 810.7587 | 0.6640 |

| | | | |
|---|---|---|---|
| Scaled Deviance | 1221 | 810.7587 | 0.6640 |
| Pearson Chi-Square | 1221 | 1305.7745 | 1.0694 |
| Scaled Pearson X2 | 1221 | 1305.7745 | 1.0694 |
| Log Likelihood | | -653.6426 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.4466 | 0.5821 | -8.5875 | -6.3056 | 163.63 | <.0001 |
| log_aadt | 1 | 0.9102 | 0.0676 | 0.7777 | 1.0428 | 181.12 | <.0001 |
| log_lgt | 1 | 0.9398 | 0.1125 | 0.7193 | 1.1603 | 69.78 | <.0001 |
| avc | 1 | -0.0003 | 0.0002 | -0.0006 | -0.0001 | 5.37 | 0.0205 |
| Dispersion | 1 | 0.3118 | 0.1373 | 0.0427 | 0.5810 | | |

## 3) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1507.4 |
| AIC (smaller is better) | 1517.4 |
| AICC (smaller is better) | 1517.4 |
| BIC (smaller is better) | 1542.9 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -7.4466 | 0.5821 | 1225 | -12.79 | <.0001 | 0.05 | -8.5887 | -6.3045 | -0.00291 |
| b1 | 0.9102 | 0.06764 | 1225 | 13.46 | <.0001 | 0.05 | 0.7776 | 1.0429 | -0.02425 |
| b2 | 0.9398 | 0.1125 | 1225 | 8.35 | <.0001 | 0.05 | 0.7190 | 1.1605 | 0.00005 |
| b3 | -0.00035 | 0.000151 | 1225 | -2.32 | 0.0207 | 0.05 | -0.00065 | -0.00005 | 0.228863 |
| alpha | 0.3118 | 0.1373 | 1225 | 2.27 | 0.0233 | 0.05 | 0.04241 | 0.5812 | -0.00059 |

## 7.3 ZIP Modeling:

## 1) ZIP Model:

Tangent On Sag-ZIP MODEL

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1505.0 |
| AIC (smaller is better) | 1515.0 |
| AICC (smaller is better) | 1515.1 |
| BIC (smaller is better) | 1540.6 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.1652 | 0.04262 | 1225 | -3.88 | 0.0001 | 0.05 | -0.2488 | -0.08158 | 0.000505 |
| b0 | -6.9683 | 0.5724 | 1225 | -12.17 | <.0001 | 0.05 | -8.0913 | -5.8454 | -0.00059 |
| b1 | 0.8773 | 0.06469 | 1225 | 13.56 | <.0001 | 0.05 | 0.7504 | 1.0043 | -0.00472 |
| b2 | 0.9133 | 0.1086 | 1225 | 8.41 | <.0001 | 0.05 | 0.7002 | 1.1265 | 0.000415 |
| b3 | -0.00036 | 0.000150 | 1225 | -2.39 | 0.0170 | 0.05 | -0.00065 | -0.00006 | -0.17356 |

## 2) Vuong Test:

Tangent On Sag-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.004076 | 0.090335 | 1.579084 |

# 7.4 ZINB Modeling:

## 1) ZINB Model:

Tangent On Sag-ZINB MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 1505.0 |
| AIC (smaller is better) | 1517.0 |
| AICC (smaller is better) | 1517.1 |
| BIC (smaller is better) | 1547.7 |

Parameter Estimates (not successful)

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.1652 | 0.06307 | 1225 | -2.62 | 0.0089 | 0.05 | -0.2890 | -0.04149 | -0.00159 |
| b0 | -6.9684 | 0.5744 | 1225 | -12.13 | <.0001 | 0.05 | -8.0953 | -5.8414 | 0.001037 |
| b1 | 0.8773 | 0.06470 | 1225 | 13.56 | <.0001 | 0.05 | 0.7504 | 1.0043 | 0.008523 |
| b2 | 0.9134 | 0.1113 | 1225 | 8.20 | <.0001 | 0.05 | 0.6950 | 1.1318 | -0.00168 |
| b3 | -0.00036 | 0.000150 | 1225 | -2.39 | 0.0171 | 0.05 | -0.00065 | -0.00006 | 0.1984 |
| alpha | 0.000113 | 0.1322 | 1225 | 0.00 | 0.9993 | 0.05 | -0.2593 | 0.2595 | -1.22792 |

## 2) Vuong Test:

### A. ZIP vs NB:

Tangent On Sag-ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.00095 | 0.045826 | 0.725353 |

# 8. MODELS FOR MULTIPLE VERTICAL CURVES ON TANGENT

## 8.1 Poisson Modeling:

### 1) Selection of Variables:

Tangent On Multiple V_Curves-POISSON MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_MVCURV11_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 5947 |
| Number of Observations Used | 5947 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 5936 | 5462.3751 | 0.9202 |
| Scaled Deviance | 5936 | 5462.3751 | 0.9202 |
| Pearson Chi-Square | 5936 | 6816.0172 | 1.1483 |
| Scaled Pearson X2 | 5936 | 6816.0172 | 1.1483 |
| Log Likelihood | | -3411.7132 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.9946 | 0.5410 | -9.0549 | -6.9343 | 218.38 | <.0001 |
| log_aadt | 1 | 0.9272 | 0.0261 | 0.8760 | 0.9784 | 1257.97 | <.0001 |
| log_lgt | 1 | 0.9230 | 0.0214 | 0.8810 | 0.9649 | 1859.61 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 6.63 | 0.0100 |
| sml_r | 1 | -0.0000 | 0.0000 | -0.0000 | -0.0000 | 8.53 | 0.0035 |
| lar_smr | 1 | 0.0114 | 0.0065 | -0.0014 | 0.0242 | 3.06 | 0.0802 |
| surf_wid | 1 | 0.0072 | 0.0173 | -0.0267 | 0.0412 | 0.17 | 0.6769 |
| shld_wid | 1 | -0.0269 | 0.0097 | -0.0459 | -0.0079 | 7.69 | 0.0056 |
| spd_limt | 1 | 0.0034 | 0.0063 | -0.0089 | 0.0157 | 0.29 | 0.5899 |
| access | 1 | 0.0724 | 0.0100 | 0.0527 | 0.0920 | 52.18 | <.0001 |
| spcl_ln | 1 | 0.0949 | 0.0550 | -0.0129 | 0.2027 | 2.98 | 0.0844 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

### 2) Poisson Model:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 5941 | 5482.2680 | 0.9228 |
| Scaled Deviance | 5941 | 5482.2680 | 0.9228 |
| Pearson Chi-Square | 5941 | 6865.9461 | 1.1557 |
| Scaled Pearson X2 | 5941 | 6865.9461 | 1.1557 |
| Log Likelihood | | -3421.6596 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.3758 | 0.1751 | -7.7190 | -7.0326 | 1774.58 | <.0001 |
| log_aadt | 1 | 0.9293 | 0.0243 | 0.8816 | 0.9769 | 1459.56 | <.0001 |
| log_lgt | 1 | 0.9219 | 0.0207 | 0.8813 | 0.9625 | 1979.37 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 8.26 | 0.0041 |
| roadway_wid | 1 | -0.0128 | 0.0043 | -0.0212 | -0.0043 | 8.79 | 0.0030 |
| access | 1 | 0.0737 | 0.0099 | 0.0542 | 0.0931 | 54.93 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 8.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 53.1136 | <.0001 |

### 2) NB Model:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 5941 | 4734.2914 | 0.7969 |
| Scaled Deviance | 5941 | 4734.2914 | 0.7969 |
| Pearson Chi-Square | 5941 | 6111.0347 | 1.0286 |
| Scaled Pearson X2 | 5941 | 6111.0347 | 1.0286 |
| Log Likelihood | | -3374.8046 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.5724 | 0.2012 | -7.9666 | -7.1781 | 1417.08 | <.0001 |
| log_aadt | 1 | 0.9545 | 0.0285 | 0.8987 | 1.0103 | 1124.27 | <.0001 |
| log_lgt | 1 | 0.9174 | 0.0241 | 0.8703 | 0.9646 | 1454.83 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 6.16 | 0.0131 |
| roadway_wid | 1 | -0.0129 | 0.0049 | -0.0224 | -0.0033 | 7.01 | 0.0081 |
| access | 1 | 0.0687 | 0.0111 | 0.0469 | 0.0906 | 38.00 | <.0001 |
| Dispersion | 1 | 0.2291 | 0.0316 | 0.1671 | 0.2912 | | |

## 3) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 9987.7 |
| AIC (smaller is better) | 10002 |
| AICC (smaller is better) | 10002 |
| BIC (smaller is better) | 10049 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -7.5724 | 0.2012 | 5947 | -37.64 | <.0001 | 0.05 | -7.9667 | -7.1780 | 0.001269 |
| b1 | 0.9545 | 0.02847 | 5947 | 33.53 | <.0001 | 0.05 | 0.8987 | 1.0103 | 0.015671 |
| b2 | 0.9174 | 0.02405 | 5947 | 38.14 | <.0001 | 0.05 | 0.8703 | 0.9646 | -0.00544 |
| b3 | -0.00009 | 0.000038 | 5947 | -2.48 | 0.0131 | 0.05 | -0.00017 | -0.00002 | 5.621611 |
| b4 | -0.01286 | 0.004856 | 5947 | -2.65 | 0.0081 | 0.05 | -0.02238 | -0.00334 | 0.004111 |
| b5 | 0.06871 | 0.01115 | 5947 | 6.16 | <.0001 | 0.05 | 0.04686 | 0.09057 | -0.03085 |
| alpha | 0.2291 | 0.03164 | 5947 | 7.24 | <.0001 | 0.05 | 0.1671 | 0.2912 | -0.00043 |

# 8.3 ZIP Modeling:

## 1) ZIP Model:

Tangent On Multiple V_Curves-ZIP MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 10020 |
| AIC (smaller is better) | 10038 |
| AICC (smaller is better) | 10038 |
| BIC (smaller is better) | 10098 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 6.0032 | 1.0000 | 5947 | 6.00 | <.0001 | 0.05 | 4.0429 | 7.9636 | 0.001562 |
| a1 | -0.9675 | 0.1322 | 5947 | -7.32 | <.0001 | 0.05 | -1.2266 | -0.7083 | 0.009317 |
| a2 | -0.3695 | 0.1096 | 5947 | -3.37 | 0.0008 | 0.05 | -0.5844 | -0.1547 | -0.00392 |
| b0 | -5.9393 | 0.2791 | 5947 | -21.28 | <.0001 | 0.05 | -6.4865 | -5.3921 | -0.00216 |
| b1 | 0.7752 | 0.03402 | 5947 | 22.79 | <.0001 | 0.05 | 0.7085 | 0.8419 | -0.00191 |
| b2 | 0.8518 | 0.02815 | 5947 | 30.26 | <.0001 | 0.05 | 0.7966 | 0.9070 | -0.01909 |
| b3 | -0.00011 | 0.000036 | 5947 | -3.13 | 0.0017 | 0.05 | -0.00018 | -0.00004 | -22.9365 |
| b4 | -0.01260 | 0.004490 | 5947 | -2.81 | 0.0050 | 0.05 | -0.02140 | -0.00379 | -0.09471 |
| b5 | 0.07551 | 0.01063 | 5947 | 7.11 | <.0001 | 0.05 | 0.05468 | 0.09634 | 0.008607 |

## 2) Vuong Test:

Tangent On Multiple V_Curves-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.005191 | 0.112779 | 3.549296 |

# 8.4 ZINB Modeling:

## 1) ZINB Model:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 9978.5 |
| AIC (smaller is better) | 9996.5 |
| AICC (smaller is better) | 9996.5 |
| BIC (smaller is better) | 10057 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 8.2349 | 2.0291 | 5947 | 4.06 | <.0001 | 0.05 | 4.2571 | 12.2126 | -0.00014 |
| a1 | -1.4723 | 0.3142 | 5947 | -4.69 | <.0001 | 0.05 | -2.0882 | -0.8564 | -0.00102 |
| b0 | -6.9458 | 0.3029 | 5947 | -22.93 | <.0001 | 0.05 | -7.5396 | -6.3520 | 0.002142 |
| b1 | 0.8845 | 0.03774 | 5947 | 23.44 | <.0001 | 0.05 | 0.8105 | 0.9585 | 0.017581 |
| b2 | 0.9152 | 0.02418 | 5947 | 37.85 | <.0001 | 0.05 | 0.8678 | 0.9626 | 0.000125 |
| b3 | -0.00011 | 0.000038 | 5947 | -2.76 | 0.0057 | 0.05 | -0.00018 | -0.00003 | 1.437548 |
| b4 | -0.01310 | 0.004822 | 5947 | -2.72 | 0.0066 | 0.05 | -0.02255 | -0.00365 | 0.077932 |
| b5 | 0.07097 | 0.01109 | 5947 | 6.40 | <.0001 | 0.05 | 0.04923 | 0.09271 | 0.003529 |
| alpha | 0.1923 | 0.03444 | 5947 | 5.58 | <.0001 | 0.05 | 0.1247 | 0.2598 | 0.000452 |

## 2) Vuong Test

## A. ZINB vs. NB:

Tangent On Multiple V_Curves-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000773 | 0.043404 | 1.372764 |

# 9. MODELS FOR VERTICAL CURVE(S) ON TANGENT

## 9.1 Poisson Modeling:

## 1) Selection of Varables:

Tangent On All V_Curves-POISSON MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_VCURV11_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 8343 |
| Number of Observations Used | 8343 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 8332 | 7200.6442 | 0.8642 |
| Scaled Deviance | 8332 | 7200.6442 | 0.8642 |
| Pearson Chi-Square | 8332 | 9387.4063 | 1.1267 |
| Scaled Pearson X2 | 8332 | 9387.4063 | 1.1267 |
| Log Likelihood | | -4668.1245 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.4058 | 0.4920 | -9.3701 | -7.4415 | 291.92 | <.0001 |
| log_aadt | 1 | 0.9342 | 0.0235 | 0.8881 | 0.9802 | 1580.26 | <.0001 |
| log_lgt | 1 | 0.9173 | 0.0187 | 0.8807 | 0.9540 | 2412.16 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 10.41 | 0.0013 |
| sml_r | 1 | -0.0000 | 0.0000 | -0.0000 | -0.0000 | 11.08 | 0.0009 |
| lar_smr | 1 | 0.0121 | 0.0063 | -0.0002 | 0.0244 | 3.75 | 0.0529 |
| surf_wid | 1 | 0.0100 | 0.0156 | -0.0205 | 0.0406 | 0.42 | 0.5194 |
| shld_wid | 1 | -0.0285 | 0.0088 | -0.0458 | -0.0113 | 10.54 | 0.0012 |
| spd_limt | 1 | 0.0089 | 0.0057 | -0.0023 | 0.0201 | 2.41 | 0.1203 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| access | 1 | 0.0688 | 0.0087 | 0.0517 | 0.0859 | 61.99 | <.0001 |
| spcl_ln | 1 | 0.0716 | 0.0494 | -0.0253 | 0.1684 | 2.10 | 0.1474 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 8337 | 7226.3909 | 0.8668 |
| Scaled Deviance | 8337 | 7226.3909 | 0.8668 |
| Pearson Chi-Square | 8337 | 9423.2779 | 1.1303 |
| Scaled Pearson X2 | 8337 | 9423.2779 | 1.1303 |
| Log Likelihood | | -4680.9978 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.3651 | 0.1591 | -7.6769 | -7.0533 | 2143.83 | <.0001 |
| log_aadt | 1 | 0.9277 | 0.0217 | 0.8852 | 0.9703 | 1826.44 | <.0001 |
| log_lgt | 1 | 0.9163 | 0.0181 | 0.8808 | 0.9518 | 2561.49 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 11.75 | 0.0006 |
| roadway_wid | 1 | -0.0122 | 0.0039 | -0.0198 | -0.0046 | 9.81 | 0.0017 |
| access | 1 | 0.0678 | 0.0087 | 0.0509 | 0.0848 | 61.39 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

# 9.2 NB Modeling:

## 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 61.3599 | <.0001 |

## 2) NB Model:

Tangent On All V_Curves-NB MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_VCURV11_ACC | |
| Distribution | Negative Binomial | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 8343 |
| Number of Observations Used | 8343 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 8337 | 6296.0325 | 0.7552 |
| Scaled Deviance | 8337 | 6296.0325 | 0.7552 |
| Pearson Chi-Square | 8337 | 8481.6196 | 1.0173 |
| Scaled Pearson X2 | 8337 | 8481.6196 | 1.0173 |
| Log Likelihood | | -4626.8560 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.5326 | 0.1805 | -7.8864 | -7.1788 | 1741.39 | <.0001 |
| log_aadt | 1 | 0.9462 | 0.0250 | 0.8971 | 0.9953 | 1427.52 | <.0001 |
| log_lgt | 1 | 0.9127 | 0.0210 | 0.8714 | 0.9539 | 1882.22 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 9.24 | 0.0024 |
| roadway_wid | 1 | -0.0116 | 0.0044 | -0.0202 | -0.0031 | 7.14 | 0.0076 |
| access | 1 | 0.0656 | 0.0096 | 0.0466 | 0.0845 | 46.15 | <.0001 |
| Dispersion | 1 | 0.2372 | 0.0303 | 0.1778 | 0.2965 | | |

# 3) AIC Value:

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 12855 |
| AIC (smaller is better) | 12869 |
| AICC (smaller is better) | 12869 |
| BIC (smaller is better) | 12918 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -7.5327 | 0.1805 | 8343 | -41.73 | <.0001 | 0.05 | -7.8865 | -7.1789 | 0.005996 |
| b1 | 0.9462 | 0.02504 | 8343 | 37.78 | <.0001 | 0.05 | 0.8971 | 0.9953 | 0.052428 |
| b2 | 0.9127 | 0.02104 | 8343 | 43.39 | <.0001 | 0.05 | 0.8714 | 0.9539 | 0.013185 |
| b3 | -0.00011 | 0.000035 | 8343 | -3.04 | 0.0024 | 0.05 | -0.00017 | -0.00004 | 3.115922 |
| b4 | -0.01164 | 0.004359 | 8343 | -2.67 | 0.0076 | 0.05 | -0.02019 | -0.00310 | 0.455998 |
| b5 | 0.06555 | 0.009649 | 8343 | 6.79 | <.0001 | 0.05 | 0.04663 | 0.08446 | -0.02504 |
| alpha | 0.2372 | 0.03028 | 8343 | 7.83 | <.0001 | 0.05 | 0.1778 | 0.2965 | 0.00212 |

## 9.3 ZIP Modeling:

### 1) ZIP Model:

Tangent On All V_Curves-ZIP MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 12881 |
| AIC (smaller is better) | 12899 |
| AICC (smaller is better) | 12899 |
| BIC (smaller is better) | 12962 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 6.0867 | 0.8889 | 8343 | 6.85 | <.0001 | 0.05 | 4.3442 | 7.8292 | 0.003223 |
| a1 | -0.9695 | 0.1176 | 8343 | -8.25 | <.0001 | 0.05 | -1.2000 | -0.7390 | 0.023017 |
| a2 | -0.3876 | 0.09369 | 8343 | -4.14 | <.0001 | 0.05 | -0.5713 | -0.2040 | -0.00257 |
| b0 | -5.8106 | 0.2562 | 8343 | -22.68 | <.0001 | 0.05 | -6.3129 | -5.3083 | -0.01364 |
| b1 | 0.7611 | 0.03082 | 8343 | 24.70 | <.0001 | 0.05 | 0.7007 | 0.8215 | -0.11058 |
| b2 | 0.8398 | 0.02510 | 8343 | 33.45 | <.0001 | 0.05 | 0.7906 | 0.8890 | 0.001043 |
| b3 | -0.00012 | 0.000033 | 8343 | -3.67 | 0.0002 | 0.05 | -0.00019 | -0.00006 | -7.05778 |
| b4 | -0.01219 | 0.004078 | 8343 | -2.99 | 0.0028 | 0.05 | -0.02018 | -0.00419 | -0.48393 |
| b5 | 0.06997 | 0.009310 | 8343 | 7.52 | <.0001 | 0.05 | 0.05172 | 0.08822 | -0.00532 |

### 2) Vuong Test:

Tangent On All V_Curves-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.004911 | 0.108063 | 4.151649 |

## 9.4 ZINB Modeling:

### 1) ZINB Model:

Tangent On All V_Curves-ZINB MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 12836 |
| AIC (smaller is better) | 12856 |
| AICC (smaller is better) | 12856 |
| BIC (smaller is better) | 12926 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 8.5031 | 1.6353 | 8343 | 5.20 | <.0001 | 0.05 | 5.2975 | 11.7086 | 0.000235 |
| a1 | -1.4336 | 0.2539 | 8343 | -5.65 | <.0001 | 0.05 | -1.9314 | -0.9358 | 0.001752 |
| a2 | -0.3187 | 0.1522 | 8343 | -2.09 | 0.0363 | 0.05 | -0.6171 | -0.02035 | -0.00016 |
| b0 | -6.5593 | 0.3124 | 8343 | -21.00 | <.0001 | 0.05 | -7.1717 | -5.9469 | -0.00202 |
| b1 | 0.8398 | 0.03703 | 8343 | 22.68 | <.0001 | 0.05 | 0.7672 | 0.9124 | -0.01396 |
| b2 | 0.8877 | 0.02538 | 8343 | 34.97 | <.0001 | 0.05 | 0.8380 | 0.9375 | 0.001204 |
| b3 | -0.00012 | 0.000035 | 8343 | -3.36 | 0.0008 | 0.05 | -0.00019 | -0.00005 | -1.85821 |
| b4 | -0.01245 | 0.004330 | 8343 | -2.88 | 0.0040 | 0.05 | -0.02094 | -0.00397 | -0.06343 |
| b5 | 0.06757 | 0.009630 | 8343 | 7.02 | <.0001 | 0.05 | 0.04869 | 0.08645 | -0.00178 |
| alpha | 0.1841 | 0.03415 | 8343 | 5.39 | <.0001 | 0.05 | 0.1171 | 0.2510 | -0.00202 |

## 2) Vuong Test:

Tangent On All V_Curves-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.001135 | 0.050106 | 2.069895 |

# 10. MODELS FOR HORIZONTAL TANGENT WITH CONSTANT GRADE: $|G|<5$

## 10.1 Poisson Modeling:

## 1) Selection of Varables:

Tangent On Grade (<5)-POISSON MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_GRAD411_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 2948 |
| Number of Observations Used | 2948 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2937 | 2021.1955 | 0.6882 |
| Scaled Deviance | 2937 | 2021.1955 | 0.6882 |
| Pearson Chi-Square | 2937 | 3212.1501 | 1.0937 |
| Scaled Pearson X2 | 2937 | 3212.1501 | 1.0937 |
| Log Likelihood | | -1444.6481 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.8566 | 0.9804 | -9.7782 | -5.9350 | 64.21 | <.0001 |
| log_aadt | 1 | 0.9012 | 0.0485 | 0.8062 | 0.9962 | 345.66 | <.0001 |
| log_lgt | 1 | 0.9350 | 0.0566 | 0.8241 | 1.0459 | 273.24 | <.0001 |
| avg | 1 | 0.0231 | 0.0325 | -0.0407 | 0.0868 | 0.50 | 0.4784 |
| sml_r | 1 | -0.0001 | 0.0000 | -0.0001 | -0.0000 | 5.64 | 0.0175 |
| lar_smr | 1 | 0.0047 | 0.0158 | -0.0263 | 0.0356 | 0.09 | 0.7680 |
| surf_wid | 1 | -0.0013 | 0.0250 | -0.0504 | 0.0478 | 0.00 | 0.9596 |
| shld_wid | 1 | -0.0535 | 0.0193 | -0.0914 | -0.0157 | 7.68 | 0.0056 |
| spd_limt | 1 | 0.0120 | 0.0135 | -0.0144 | 0.0385 | 0.80 | 0.3726 |
| access | 1 | 0.0578 | 0.0194 | 0.0199 | 0.0958 | 8.93 | 0.0028 |
| spcl_ln | 1 | -0.0381 | 0.1526 | -0.3371 | 0.2609 | 0.06 | 0.8028 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2) Poisson Model:

Tangent On Grade (<5)-POISSON MODEL

The GENMOD Procedure

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2943 | 2256.3355 | 0.7667 |
| Scaled Deviance | 2943 | 2256.3355 | 0.7667 |
| Pearson Chi-Square | 2943 | 3581.0672 | 1.2168 |
| Scaled Pearson X2 | 2943 | 3581.0672 | 1.2168 |
| Log Likelihood | | -1562.2181 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.2796 | 0.3597 | -8.9845 | -7.5746 | 529.89 | <.0001 |
| log_aadt | 1 | 0.9412 | 0.0452 | 0.8526 | 1.0298 | 433.10 | <.0001 |
| grad_hgt | 1 | 0.3043 | 0.0614 | 0.1840 | 0.4246 | 24.59 | <.0001 |
| roadway_wid | 1 | -0.0186 | 0.0076 | -0.0335 | -0.0038 | 6.03 | 0.0141 |
| access | 1 | 0.0595 | 0.0171 | 0.0259 | 0.0931 | 12.07 | 0.0005 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 10.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 36.7952 | <.0001 |

### 2) NB Model:

Tangent On Grade (<5)-NB MODEL

The GENMOD Procedure

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 2943 | 1745.6713 | 0.5932 |
| Scaled Deviance | 2943 | 1745.6713 | 0.5932 |
| Pearson Chi-Square | 2943 | 3001.6721 | 1.0199 |
| Scaled Pearson X2 | 2943 | 3001.6721 | 1.0199 |
| Log Likelihood | | -1524.3061 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.5748 | 0.4275 | -9.4128 | -7.7368 | 402.23 | <.0001 |
| log_aadt | 1 | 0.9728 | 0.0553 | 0.8644 | 1.0812 | 309.28 | <.0001 |
| grad_hgt | 1 | 0.2951 | 0.0795 | 0.1393 | 0.4509 | 13.78 | 0.0002 |
| roadway_wid | 1 | -0.0170 | 0.0087 | -0.0342 | 0.0001 | 3.80 | 0.0513 |
| access | 1 | 0.0540 | 0.0212 | 0.0124 | 0.0955 | 6.49 | 0.0109 |
| Dispersion | 1 | 0.7706 | 0.1283 | 0.5191 | 1.0221 | | |

### 3) AIC Value:

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3446.8 |
| AIC (smaller is better) | 3458.8 |
| AICC (smaller is better) | 3458.8 |
| BIC (smaller is better) | 3494.7 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -8.5748 | 0.4276 | 2948 | -20.06 | <.0001 | 0.05 | -9.4131 | -7.7364 | -0.00087 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b1 | 0.9728 | 0.05531 | 2948 | 17.59 | <.0001 | 0.05 | 0.8643 | 1.0812 | -0.00772 |
| b2 | 0.2951 | 0.07950 | 2948 | 3.71 | 0.0002 | 0.05 | 0.1393 | 0.4510 | 0.000316 |
| b4 | 0.05397 | 0.02119 | 2948 | 2.55 | 0.0109 | 0.05 | 0.01242 | 0.09552 | 0.000876 |
| b3 | -0.01703 | 0.008737 | 2948 | -1.95 | 0.0514 | 0.05 | -0.03416 | 0.000102 | -0.02816 |
| alpha | 0.7706 | 0.1283 | 2948 | 6.00 | <.0001 | 0.05 | 0.5190 | 1.0222 | -0.00008 |

## 10.3 ZIP Modeling:

### 1) ZIP Model:

Tangent On Grade (<5)-ZIP MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3463.6 |
| AIC (smaller is better) | 3477.6 |
| AICC (smaller is better) | 3477.6 |
| BIC (smaller is better) | 3519.5 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 5.8922 | 1.2875 | 2948 | 4.58 | <.0001 | 0.05 | 3.3676 | 8.4168 | -0.00114 |
| a1 | -0.7748 | 0.1575 | 2948 | -4.92 | <.0001 | 0.05 | -1.0837 | -0.4660 | -0.00751 |
| b0 | -5.0263 | 0.7507 | 2948 | -6.70 | <.0001 | 0.05 | -6.4983 | -3.5543 | 0.001497 |
| b1 | 0.6158 | 0.08729 | 2948 | 7.05 | <.0001 | 0.05 | 0.4446 | 0.7870 | 0.011269 |
| b2 | 0.2623 | 0.06329 | 2948 | 4.14 | <.0001 | 0.05 | 0.1382 | 0.3863 | 0.001319 |
| b3 | -0.01976 | 0.008296 | 2948 | -2.38 | 0.0173 | 0.05 | -0.03602 | -0.00349 | 0.051127 |
| b4 | 0.06804 | 0.02022 | 2948 | 3.36 | 0.0008 | 0.05 | 0.02839 | 0.1077 | |

### 2) Vuong Test:

Tangent On Grade (<5)-ZIP vs POISSON Vuong Test

```
  mbar          s         v
ƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒ
0.010014  0.173134   3.14051
```

## 10.4 ZINB Modeling:

### 1) ZINB Model:

Tangent On Grade (<5)-ZINB MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 3445.6 |
| AIC (smaller is better) | 3461.6 |
| AICC (smaller is better) | 3461.6 |

BIC (smaller is better) 3509.5

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 4.9360 | 2.3578 | 2948 | 2.09 | 0.0364 | 0.05 | 0.3128 | 9.5591 | 0.000306 |
| a1 | -0.8623 | 0.2893 | 2948 | -2.98 | 0.0029 | 0.05 | -1.4296 | -0.2951 | 0.002277 |
| b0 | -7.3125 | 1.2157 | 2948 | -6.01 | <.0001 | 0.05 | -9.6963 | -4.9287 | -0.00208 |
| b1 | 0.8387 | 0.1321 | 2948 | 6.35 | <.0001 | 0.05 | 0.5796 | 1.0978 | -0.01735 |
| b2 | 0.2890 | 0.07807 | 2948 | 3.70 | 0.0002 | 0.05 | 0.1359 | 0.4420 | -0.00054 |
| b3 | -0.01789 | 0.008720 | 2948 | -2.05 | 0.0403 | 0.05 | -0.03499 | -0.00079 | -0.07793 |
| b4 | 0.05722 | 0.02139 | 2948 | 2.68 | 0.0075 | 0.05 | 0.01529 | 0.09915 | -0.00333 |
| alpha | 0.5862 | 0.2114 | 2948 | 2.77 | 0.0056 | 0.05 | 0.1716 | 1.0007 | 0.000453 |

### 2) Vuong Test:

### A. ZINB vs. NB:

Tangent On Grade (<5)-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000205 | 0.024854 | 0.447478 |

### B.ZIP vs. NB:

Tangent On Grade (<5)-ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| -0.00285 | 0.090594 | -1.70566 |

## 11. MODELS FOR HORIZONTAL TANGENT WITH CONSTANT GRADE: $|G| \geq 5$

### 11.1 Poisson Modeling:

Tangent On Grade (>=5)-POISSON MODEL

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_GRAD511_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 440 |
| Number of Observations Used | 440 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 437 | 282.1660 | 0.6457 |
| Scaled Deviance | 437 | 282.1660 | 0.6457 |
| Pearson Chi-Square | 437 | 494.7035 | 1.1320 |
| Scaled Pearson X2 | 437 | 494.7035 | 1.1320 |
| Log Likelihood | | -201.8778 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.2322 | 0.8636 | -9.9249 | -6.5396 | 90.87 | <.0001 |
| log_aadt | 1 | 0.7828 | 0.0951 | 0.5963 | 0.9692 | 67.72 | <.0001 |
| grad_hgt | 1 | 0.3229 | 0.1650 | -0.0004 | 0.6462 | 3.83 | 0.0503 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 11.2 NB Modeling:

### 1) LM Test:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|
| Dispersion | 2.1196 | 0.1454 |

### 2) NB Model:

Tangent On Grade (>=5)-NB MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 432.9 |
| AIC (smaller is better) | 440.9 |
| AICC (smaller is better) | 441.0 |
| BIC (smaller is better) | 457.2 |

Parameter Estimates (Not Successful)

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -8.4495 | 0.9808 | 440 | -8.61 | <.0001 | 0.05 | -10.3772 | -6.5219 | 4.119E-6 |
| b1 | 0.8119 | 0.1115 | 440 | 7.28 | <.0001 | 0.05 | 0.5928 | 1.0311 | 0.000033 |
| b2 | 0.3160 | 0.1780 | 440 | 1.78 | 0.0766 | 0.05 | -0.03386 | 0.6658 | 7.214E-6 |
| alpha | 0.5481 | 0.3822 | 440 | 1.43 | 0.1523 | 0.05 | -0.2031 | 1.2992 | 1.708E-6 |

# APPENDIX D

## VALIDATION MODELS AND RESULTS

# 1. REDEVELOPED MODELS AND VALIDATION RESULTS FOR HORIZONTAL CURVE COMBINED WITH CREST VERTICAL CURVE

## 1.1 Poisson Model:

Horizontal Curve on Crest-POISSON MODEL 1

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST24_ACC |
| Distribution | Poisson |
| Link Function | Log |

| | |
|---|---|
| Number of Observations Read | 3120 |
| Number of Observations Used | 3120 |

Criteria For Assessing Goodness Of Fit **(TRIAL 1)**

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 3114 | 1616.3043 | 0.5190 |
| Scaled Deviance | 3114 | 1616.3043 | 0.5190 |
| Pearson Chi-Square | 3114 | 3567.0616 | 1.1455 |
| Scaled Pearson X2 | 3114 | 3567.0616 | 1.1455 |
| Log Likelihood | | -1124.4671 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -5.8805 | 0.4991 | -6.8588 | -4.9022 | 138.80 | <.0001 |
| log_aadt | 1 | 0.8594 | 0.0580 | 0.7457 | 0.9730 | 219.73 | <.0001 |
| log_lgt | 1 | 1.0880 | 0.0772 | 0.9367 | 1.2393 | 198.68 | <.0001 |
| deg_curv | 1 | 0.1175 | 0.0141 | 0.0898 | 0.1451 | 69.25 | <.0001 |
| roadway_wid | 1 | -0.0337 | 0.0114 | -0.0560 | -0.0114 | 8.79 | 0.0030 |
| access | 1 | 0.0188 | 0.0108 | -0.0025 | 0.0400 | 3.00 | 0.0834 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

Criteria For Assessing Goodness Of Fit **(FINAL POISSON MODEL)**

| Criterion | DF | Value | Value/DF |
|---|---|---|---|
| Deviance | 3115 | 1619.0256 | 0.5198 |
| Scaled Deviance | 3115 | 1619.0256 | 0.5198 |
| Pearson Chi-Square | 3115 | 3576.3490 | 1.1481 |
| Scaled Pearson X2 | 3115 | 3576.3490 | 1.1481 |
| Log Likelihood | | -1125.8277 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -5.9266 | 0.4968 | -6.9004 | -4.9529 | 142.31 | <.0001 |
| log_aadt | 1 | 0.8659 | 0.0576 | 0.7530 | 0.9789 | 225.79 | <.0001 |
| log_lgt | 1 | 1.0808 | 0.0768 | 0.9302 | 1.2313 | 198.02 | <.0001 |
| deg_curv | 1 | 0.1180 | 0.0140 | 0.0906 | 0.1454 | 71.22 | <.0001 |
| roadway_wid | 1 | -0.0335 | 0.0114 | -0.0558 | -0.0112 | 8.67 | 0.0032 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 2082.8665 | | | |
| log_aadt | 1851.5350 | 1 | 231.33 | <.0001 |
| log_lgt | 1688.0986 | 1 | 163.44 | <.0001 |
| deg_curv | 1627.6787 | 1 | 60.42 | <.0001 |
| roadway_wid | 1619.0256 | 1 | 8.65 | 0.0033 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 215.59 | <.0001 |
| log_lgt | 1 | 217.97 | <.0001 |
| deg_curv | 1 | 51.96 | <.0001 |
| roadway_wid | 1 | 8.65 | 0.0033 |

## 1.2 NB Model:

Horizontal Curve on Crest-NB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST24_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 3120 |
| Observations Not Used | 0 |
| Total Observations | 3120 |
| Parameters | 6 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 2396.1 |

| | |
|---|---|
| AIC (smaller is better) | 2408.1 |
| AICC (smaller is better) | 2408.2 |
| BIC (smaller is better) | 2444.4 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -5.9788 | 0.5456 | 3120 | -10.96 | <.0001 | 0.05 | -7.0486 | -4.9090 | -0.00084 |
| b1 | 0.8702 | 0.06594 | 3120 | 13.20 | <.0001 | 0.05 | 0.7409 | 0.9995 | -0.00812 |
| b2 | 1.0917 | 0.08509 | 3120 | 12.83 | <.0001 | 0.05 | 0.9249 | 1.2585 | 0.004186 |
| b3 | 0.1297 | 0.01763 | 3120 | 7.36 | <.0001 | 0.05 | 0.09513 | 0.1643 | -0.00812 |
| b4 | -0.03374 | 0.01254 | 3120 | -2.69 | 0.0072 | 0.05 | -0.05833 | -0.00915 | -0.01381 |
| alpha | 0.5577 | 0.1711 | 3120 | 3.26 | 0.0011 | 0.05 | 0.2222 | 0.8931 | -0.00051 |

## 1.3 ZIP Model:

Horizontal Curve on Crest-ZIP MODEL 3

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_CREST24_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 3120 |
| Observations Not Used | 0 |
| Total Observations | 3120 |
| Parameters | 7 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 2389.0 |
| AIC (smaller is better) | 2403.0 |
| AICC (smaller is better) | 2403.0 |
| BIC (smaller is better) | 2445.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.3306 | 0.06996 | 3120 | -4.73 | <.0001 | 0.05 | -0.4678 | -0.1935 | 0.00005 |
| a2 | -1.1042 | 0.2372 | 3120 | -4.66 | <.0001 | 0.05 | -1.5693 | -0.6391 | -0.00002 |
| b0 | -5.6346 | 0.5505 | 3120 | -10.24 | <.0001 | 0.05 | -6.7139 | -4.5553 | 8.75E-6 |
| b1 | 0.7646 | 0.06412 | 3120 | 11.92 | <.0001 | 0.05 | 0.6388 | 0.8903 | 0.000091 |
| b2 | 0.7059 | 0.1264 | 3120 | 5.58 | <.0001 | 0.05 | 0.4580 | 0.9537 | -7.96E-6 |
| b3 | 0.1557 | 0.02036 | 3120 | 7.64 | <.0001 | 0.05 | 0.1157 | 0.1956 | -0.00003 |
| b4 | -0.02796 | 0.01212 | 3120 | -2.31 | 0.0211 | 0.05 | -0.05174 | -0.00419 | 0.000401 |

| mbar | s | v |
|---|---|---|
| 0.00419 | 0.123161 | 2.202945 |

## 1.4 ZINB Model:

Horizontal Curve on Crest-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ ON_CREST24_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 3120 |
| Observations Not Used | 0 |
| Total Observations | 3120 |
| Parameters | 8 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 2385.0 |
| AIC (smaller is better) | 2401.0 |
| AICC (smaller is better) | 2401.0 |
| BIC (smaller is better) | 2449.3 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | -4.9092 | 1.5443 | 3120 | -3.18 | 0.0015 | 0.05 | -7.9371 | -1.8813 | -0.0003 |
| a2 | -1.7272 | 0.4670 | 3120 | -3.70 | 0.0002 | 0.05 | -2.6428 | -0.8117 | 0.000711 |
| b0 | -6.6041 | 0.5769 | 3120 | -11.45 | <.0001 | 0.05 | -7.7352 | -5.4730 | 0.001782 |
| b1 | 0.8739 | 0.06545 | 3120 | 13.35 | <.0001 | 0.05 | 0.7456 | 1.0023 | 0.014072 |
| b2 | 0.7643 | 0.1490 | 3120 | 5.13 | <.0001 | 0.05 | 0.4721 | 1.0565 | -0.00206 |
| b3 | 0.1503 | 0.01983 | 3120 | 7.58 | <.0001 | 0.05 | 0.1114 | 0.1892 | 0.004908 |
| b4 | -0.02897 | 0.01257 | 3120 | -2.30 | 0.0213 | 0.05 | -0.05363 | -0.00432 | 0.060969 |
| alpha | 0.2864 | 0.1791 | 3120 | 1.60 | 0.1099 | 0.05 | -0.06479 | 0.6376 | -0.00049 |

Horizontal Curve on Crest-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.001791 | 0.062846 | 1.845568 |

Horizontal Curve on Crest-ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|

ƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒ
0.001149 0.070813 1.050918

### 1.5 Validation Results (t Test):

The UNIVARIATE Procedure

Variable: difference (Observed Relative Accident Frequency - Predicted Relative Accident Frequency)

Moments

| | | | |
|---|---|---|---|
| N | 4 | Sum Weights | 4 |
| Mean | 0.00025445 | Sum Observations | 0.0010178 |
| Std Deviation | 0.00625387 | Variance | 0.00003911 |
| Skewness | 1.45558107 | Kurtosis | 1.78229752 |
| Uncorrected SS | 0.00011759 | Corrected SS | 0.00011733 |
| Coeff Variation | 2457.80688 | Std Error Mean | 0.00312694 |

Basic Statistical Measures

| Location | | Variability | |
|---|---|---|---|
| Mean | 0.00025 | Std Deviation | 0.00625 |
| Median | -0.00180 | Variance | 0.0000391 |
| Mode | . | Range | 0.01367 |
| | | Interquartile Range | 0.00870 |

Tests for Location: Mu0=0

| Test | -Statistic- | | -----p Value------ | |
|---|---|---|---|---|
| Student's t | t | 0.081373 | Pr > \|t\| | 0.9403 |
| Sign | M | 0 | Pr >= \|M\| | 1.0000 |
| Signed Rank | S | 0 | Pr >= \|S\| | 1.0000 |

## 2. REDEVELOPED MODELS AND VALIDATION RESULTS FOR HORIZONTAL CURVE ON GRADE: $|G|<5$

### 2.1 Poisson Model:

Horizontal Curve on Grade (<5)-POISSON MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD_LT524_ACC |
| Distribution | Poisson |

| | |
|---|---|
| Number of Observations Read | 9087 |
| Number of Observations Used | 9087 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Deviance | 9081 | 4786.1780 | 0.5271 |
| Scaled Deviance | 9081 | 4786.1780 | 0.5271 |
| Pearson Chi-Square | 9081 | 10855.5706 | 1.1954 |
| Scaled Pearson X2 | 9081 | 10855.5706 | 1.1954 |
| Log Likelihood | | -3234.5536 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -8.7061 | 0.2899 | -9.2742 | -8.1380 | 902.18 | <.0001 |
| log_aadt | 1 | 0.9420 | 0.0368 | 0.8698 | 1.0142 | 653.82 | <.0001 |
| grad_hgt | 1 | 0.9095 | 0.0772 | 0.7582 | 1.0607 | 138.87 | <.0001 |
| deg_curv | 1 | 0.0285 | 0.0045 | 0.0196 | 0.0373 | 39.40 | <.0001 |
| roadway_wid | 1 | -0.0317 | 0.0065 | -0.0444 | -0.0190 | 23.98 | <.0001 |
| access | 1 | 0.0209 | 0.0032 | 0.0147 | 0.0270 | 43.76 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

## 2.2 NB Model:

Horizontal Curve on Grade (<5)-NB MODEL

Data Set THESIS.WA_HCURV_ON_GRAD_LT524_ACC

Dimensions

| | |
|---|---|
| Observations Used | 9087 |
| Observations Not Used | 0 |
| Total Observations | 9087 |
| Parameters | 7 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 6745.7 |
| AIC (smaller is better) | 6759.7 |
| AICC (smaller is better) | 6759.7 |
| BIC (smaller is better) | 6809.5 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -8.9493 | 0.3376 | 9087 | -26.51 | <.0001 | 0.05 | -9.6111 | -8.2875 | -0.00028 |
| b1 | 0.9708 | 0.04392 | 9087 | 22.10 | <.0001 | 0.05 | 0.8847 | 1.0569 | -0.00033 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b2 | 0.9920 | 0.1092 | 9087 | 9.08 | <.0001 | 0.05 | 0.7780 | 1.2060 | 0.000167 |
| b3 | 0.03039 | 0.005751 | 9087 | 5.28 | <.0001 | 0.05 | 0.01912 | 0.04167 | 0.016417 |
| b4 | -0.03214 | 0.007299 | 9087 | -4.40 | <.0001 | 0.05 | -0.04645 | -0.01784 | 0.023966 |
| b5 | 0.02279 | 0.004798 | 9087 | 4.75 | <.0001 | 0.05 | 0.01339 | 0.03220 | 0.046223 |
| alpha | 1.1721 | 0.1518 | 9087 | 7.72 | <.0001 | 0.05 | 0.8745 | 1.4696 | -0.00043 |

## 2.3 ZIP Model:

Horizontal Curve on Grade (<5)-ZIP MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD_LT524_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 9087 |
| Observations Not Used | 0 |
| Total Observations | 9087 |
| Parameters | 8 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 6756.1 |
| AIC (smaller is better) | 6772.1 |
| AICC (smaller is better) | 6772.1 |
| BIC (smaller is better) | 6829.0 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | 0.02337 | 0.01533 | 9087 | 1.52 | 0.1275 | 0.05 | -0.00669 | 0.05342 | -0.0004 |
| a2 | -2.0805 | 0.6020 | 9087 | -3.46 | 0.0006 | 0.05 | -3.2607 | -0.9004 | 0.000089 |
| b0 | -8.1010 | 0.3203 | 9087 | -25.29 | <.0001 | 0.05 | -8.7288 | -7.4732 | 0.007177 |
| b1 | 0.9514 | 0.04051 | 9087 | 23.49 | <.0001 | 0.05 | 0.8720 | 1.0308 | 0.064284 |
| b2 | 0.4236 | 0.1133 | 9087 | 3.74 | 0.0002 | 0.05 | 0.2016 | 0.6456 | 0.001626 |
| b3 | 0.03012 | 0.005846 | 9087 | 5.15 | <.0001 | 0.05 | 0.01866 | 0.04158 | -0.01142 |
| b4 | -0.03125 | 0.006900 | 9087 | -4.53 | <.0001 | 0.05 | -0.04478 | -0.01773 | 0.258956 |
| b5 | 0.02807 | 0.004676 | 9087 | 6.00 | <.0001 | 0.05 | 0.01890 | 0.03723 | 0.022282 |

Horizontal Curve on Grade (<5)-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.006681 | 0.134063 | 5.483512 |

## 2.4 ZINB Model:

Horizontal Curve on Grade (<5)-ZINB MODEL

| | |
|---|---|
| Data Set | THESIS.WA_HCURV_ON_GRAD_LT524_ACC |

Dimensions

| | |
|---|---|
| Observations Used | 9087 |
| Observations Not Used | 0 |
| Total Observations | 9087 |
| Parameters | 9 |

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 6740.1 |
| AIC (smaller is better) | 6758.1 |
| AICC (smaller is better) | 6758.1 |
| BIC (smaller is better) | 6822.1 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a1 | -0.3818 | 0.1302 | 9087 | -2.93 | 0.0034 | 0.05 | -0.6369 | -0.1266 | -0.00491 |
| a3 | 0.06607 | 0.02798 | 9087 | 2.36 | 0.0182 | 0.05 | 0.01122 | 0.1209 | -0.03657 |
| b0 | -8.8562 | 0.3813 | 9087 | -23.22 | <.0001 | 0.05 | -9.6037 | -8.1087 | 0.006308 |
| b1 | 0.9513 | 0.04605 | 9087 | 20.66 | <.0001 | 0.05 | 0.8611 | 1.0416 | 0.047752 |
| b2 | 0.9926 | 0.1087 | 9087 | 9.13 | <.0001 | 0.05 | 0.7794 | 1.2058 | -0.00004 |
| b3 | 0.04993 | 0.01149 | 9087 | 4.34 | <.0001 | 0.05 | 0.02740 | 0.07246 | 0.037234 |
| b4 | -0.03056 | 0.007324 | 9087 | -4.17 | <.0001 | 0.05 | -0.04492 | -0.01621 | 0.168267 |
| b5 | 0.02244 | 0.004861 | 9087 | 4.62 | <.0001 | 0.05 | 0.01291 | 0.03197 | 0.043022 |
| alpha | 1.0366 | 0.1778 | 9087 | 5.83 | <.0001 | 0.05 | 0.6880 | 1.3851 | -0.00084 |

Horizontal Curve on Grade (<5)-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000306 | 0.048549 | 0.693612 |

Horizontal Curve on Grade (<5) -ZIP vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| -0.00057 | 0.065278 | -0.96588 |

## 2.5 Validation Results (t Test):

The UNIVARIATE Procedure

Variable: difference (Observed Relative Accident Frequency - Predicted Relative Accident Frequency)

Moments

| | | | |
|---|---|---|---|
| N | 8 | Sum Weights | 8 |
| Mean | 0.00001313 | Sum Observations | 0.00010504 |
| Std Deviation | 0.00093716 | Variance | 8.78265E-7 |
| Skewness | -1.1541406 | Kurtosis | 1.02933157 |
| Uncorrected SS | 6.14923E-6 | Corrected SS | 6.14786E-6 |
| Coeff Variation | 7137.79766 | Std Error Mean | 0.00033134 |

Basic Statistical Measures

| Location | | Variability | |
|---|---|---|---|
| Mean | 0.000013 | Std Deviation | 0.0009372 |
| Median | 0.000310 | Variance | 8.78265E-7 |
| Mode | . | Range | 0.00296 |
| | | Interquartile Range | 0.0008266 |

Tests for Location: Mu0=0

| Test | -Statistic- | | -----p Value------ | |
|---|---|---|---|---|
| Student's t | t | 0.039626 | Pr > \|t\| | 0.9695 |
| Sign | M | 2 | Pr >= \|M\| | 0.2891 |
| Signed Rank | S | 4 | Pr >= \|S\| | 0.6406 |

# 3. REDEVELOPED MODELS AND VALIDATION RESULTS FOR VERTICAL CURVE(S) ON HORIZONTAL TANGENT

## 3.1 Poisson Model:

Tangent On All V_Curves-POISSON MODEL
The GENMOD Procedure
Model Information

| | | |
|---|---|---|
| Data Set | THESIS.WA_TANGENT_ON_VCURV2341_ACC | |
| Distribution | Poisson | |
| Link Function | Log | |
| Dependent Variable | total_acc | total_acc |

| | |
|---|---|
| Number of Observations Read | 6259 |
| Number of Observations Used | 6259 |

Criteria For Assessing Goodness Of Fit

| Criterion | DF | Value | Value/DF |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Deviance | 6253 | 5434.6683 | 0.8691 |
| Scaled Deviance | 6253 | 5434.6683 | 0.8691 |
| Pearson Chi-Square | 6253 | 7017.2992 | 1.1222 |
| Scaled Pearson X2 | 6253 | 7017.2992 | 1.1222 |
| Log Likelihood | | -3512.8678 | |

Analysis Of Parameter Estimates

| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | -7.4494 | 0.1820 | -7.8062 | -7.0926 | 1674.83 | <.0001 |
| log_aadt | 1 | 0.9465 | 0.0246 | 0.8983 | 0.9947 | 1481.23 | <.0001 |
| log_lgt | 1 | 0.9026 | 0.0209 | 0.8616 | 0.9435 | 1866.19 | <.0001 |
| avc | 1 | -0.0001 | 0.0000 | -0.0002 | -0.0000 | 9.04 | 0.0026 |
| roadway_wid | 1 | -0.0142 | 0.0044 | -0.0229 | -0.0055 | 10.21 | 0.0014 |
| access | 1 | 0.0652 | 0.0099 | 0.0459 | 0.0846 | 43.64 | <.0001 |
| Scale | 0 | 1.0000 | 0.0000 | 1.0000 | 1.0000 | | |

LR Statistics For Type 1 Analysis

| Source | Deviance | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | 9115.8845 | | | |
| log_aadt | 7183.5904 | 1 | 1932.29 | <.0001 |
| log_lgt | 5503.1014 | 1 | 1680.49 | <.0001 |
| avc | 5483.1391 | 1 | 19.96 | <.0001 |
| roadway_wid | 5474.6011 | 1 | 8.54 | 0.0035 |
| access | 5434.6683 | 1 | 39.93 | <.0001 |

LR Statistics For Type 3 Analysis

| Source | DF | Chi-Square | Pr > ChiSq |
|---|---|---|---|
| log_aadt | 1 | 1510.38 | <.0001 |
| log_lgt | 1 | 1704.47 | <.0001 |
| avc | 1 | 9.91 | 0.0016 |
| roadway_wid | 1 | 10.16 | 0.0014 |
| access | 1 | 39.93 | <.0001 |

## 3.2 NB Model:

Lagrange Multiplier Statistics

| Parameter | Chi-Square | Pr > ChiSq |
|---|---|---|

| | | |
|---|---|---|
| Dispersion | 48.6737 | <.0001 |

Tangent On All V_Curves-NB MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 9690.2 |
| AIC (smaller is better) | 9704.2 |
| AICC (smaller is better) | 9704.2 |
| BIC (smaller is better) | 9751.4 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| b0 | -7.6274 | 0.2075 | 6259 | -36.76 | <.0001 | 0.05 | -8.0341 | -7.2207 | -0.02113 |
| b1 | 0.9657 | 0.02858 | 6259 | 33.79 | <.0001 | 0.05 | 0.9097 | 1.0217 | -0.16796 |
| b2 | 0.9035 | 0.02431 | 6259 | 37.16 | <.0001 | 0.05 | 0.8558 | 0.9512 | 0.009211 |
| b3 | -0.00011 | 0.000040 | 6259 | -2.67 | 0.0075 | 0.05 | -0.00019 | -0.00003 | -1.89817 |
| b4 | -0.01343 | 0.004990 | 6259 | -2.69 | 0.0071 | 0.05 | -0.02321 | -0.00365 | -0.72861 |
| b5 | 0.06253 | 0.01108 | 6259 | 5.65 | <.0001 | 0.05 | 0.04082 | 0.08425 | -0.07371 |
| alpha | 0.2408 | 0.03455 | 6259 | 6.97 | <.0001 | 0.05 | 0.1731 | 0.3086 | -0.00395 |

## 3.3 ZIP Model:

Tangent On All V_Curves-ZIP MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 9717.0 |
| AIC (smaller is better) | 9735.0 |
| AICC (smaller is better) | 9735.0 |
| BIC (smaller is better) | 9795.7 |

Parameter Estimates

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 5.4955 | 1.0278 | 6259 | 5.35 | <.0001 | 0.05 | 3.4806 | 7.5103 | 0.000024 |
| a1 | -0.8924 | 0.1328 | 6259 | -6.72 | <.0001 | 0.05 | -1.1526 | -0.6321 | 0.000043 |
| a2 | -0.4938 | 0.1103 | 6259 | -4.48 | <.0001 | 0.05 | -0.7100 | -0.2775 | -0.00244 |
| b0 | -5.9863 | 0.2962 | 6259 | -20.21 | <.0001 | 0.05 | -6.5669 | -5.4056 | -0.00653 |
| b1 | 0.7890 | 0.03521 | 6259 | 22.41 | <.0001 | 0.05 | 0.7200 | 0.8580 | -0.04694 |
| b2 | 0.8107 | 0.02945 | 6259 | 27.52 | <.0001 | 0.05 | 0.7530 | 0.8684 | 0.006552 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| b3 | -0.00012 | 0.000038 | 6259 | -3.12 | 0.0018 | 0.05 | -0.00019 | -0.00004 | -3.5652 |
| b4 | -0.01364 | 0.004674 | 6259 | -2.92 | 0.0035 | 0.05 | -0.02280 | -0.00447 | -0.22951 |
| b5 | 0.06864 | 0.01080 | 6259 | 6.35 | <.0001 | 0.05 | 0.04746 | 0.08982 | -0.02639 |

Tangent On All V_Curves-ZIP vs POISSON Vuong Test

| mbar | s | v |
|---|---|---|
| 0.004803 | 0.108073 | 3.516176 |

## 3.4 ZINB Model:

Tangent On All V_Curves-ZINB MODEL

The NLMIXED Procedure

Fit Statistics

| | |
|---|---|
| -2 Log Likelihood | 9679.1 |
| AIC (smaller is better) | 9699.1 |
| AICC (smaller is better) | 9699.1 |
| BIC (smaller is better) | 9766.5 |

Parameter Estimates (Selected Model)

| Parameter | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper | Gradient |
|---|---|---|---|---|---|---|---|---|---|
| a0 | 8.1731 | 2.1599 | 6259 | 3.78 | 0.0002 | 0.05 | 3.9390 | 12.4072 | 0.000012 |
| a1 | -1.4090 | 0.3390 | 6259 | -4.16 | <.0001 | 0.05 | -2.0736 | -0.7444 | 0.00013 |
| a2 | -0.4551 | 0.1985 | 6259 | -2.29 | 0.0219 | 0.05 | -0.8444 | -0.06592 | -0.0001 |
| b0 | -6.7725 | 0.3649 | 6259 | -18.56 | <.0001 | 0.05 | -7.4879 | -6.0570 | -0.0011 |
| b1 | 0.8726 | 0.04296 | 6259 | 20.31 | <.0001 | 0.05 | 0.7883 | 0.9568 | -0.00913 |
| b2 | 0.8724 | 0.03107 | 6259 | 28.08 | <.0001 | 0.05 | 0.8115 | 0.9333 | -0.00022 |
| b3 | -0.00012 | 0.000040 | 6259 | -2.87 | 0.0041 | 0.05 | -0.00019 | -0.00004 | -0.18769 |
| b4 | -0.01423 | 0.004962 | 6259 | -2.87 | 0.0041 | 0.05 | -0.02396 | -0.00450 | -0.04132 |
| b5 | 0.06461 | 0.01109 | 6259 | 5.82 | <.0001 | 0.05 | 0.04287 | 0.08636 | -0.00281 |
| alpha | 0.1965 | 0.04005 | 6259 | 4.91 | <.0001 | 0.05 | 0.1179 | 0.2750 | -0.00001 |

*******************************************

Tangent On All V_Curves-ZINB vs NB Vuong Test

| mbar | s | v |
|---|---|---|
| 0.000886 | 0.044235 | 1.585279 |

## 3.5 Validation Results (t Test):

The UNIVARIATE Procedure

Variable: difference (Observed Relative Accident Frequency - Predicted Relative Accident Frequency)

Moments

| | | | |
|---|---|---|---|
| N | 11 | Sum Weights | 11 |
| Mean | 0.00003869 | Sum Observations | 0.00042559 |
| Std Deviation | 0.00139218 | Variance | 1.93816E-6 |
| Skewness | -1.1211566 | Kurtosis | 1.48994129 |
| Uncorrected SS | 0.0000194 | Corrected SS | 0.00001938 |
| Coeff Variation | 3598.2791 | Std Error Mean | 0.00041976 |

Basic Statistical Measures

| Location | | Variability | |
|---|---|---|---|
| Mean | 0.000039 | Std Deviation | 0.00139 |
| Median | 0.000195 | Variance | 1.93816E-6 |
| Mode | . | Range | 0.00497 |
| | | Interquartile Range | 0.00138 |

Tests for Location: Mu0=0

| Test | -Statistic- | | -----p Value------ | |
|---|---|---|---|---|
| Student's t | t | 0.092173 | Pr > \|t\| | 0.9284 |
| Sign | M | 1.5 | Pr >= \|M\| | 0.5488 |
| Signed Rank | S | 7 | Pr >= \|S\| | 0.5771 |