Safety Effectiveness Analysis of Horizontal Curves on Non Urban Roads

Anupama T[1]
M. Tech Scholar,
National Institute of Technology
Calicut,

Anjaneyulu M. V. L. R[3]
Professor,
National Institute of Technology
Calicut,

Neena M Joseph[2]
Research Scholar,
National Institute of Technology
Calicut,

Harikrishna M[4]
Assistant Professor,
National Institute of Technology
Calicut,

***Abstract*– Road safety is a multi-sectoral and multi dimensional subject. It includes orderly development and management of roads, provision of safer vehicles and a comprehensive response to road traffic crashes. To achieve the goal of safer transportation systems, it is necessary to ensure safety on roads. This can be attained through safer design, and implementing safety guidelines. It is therefore necessary to develop a tool for the safety engineers to measure the safety on roads. Some of the methods to measure safety are consistency measures, crash frequencies, crash rates, crash severity rates etc. This study aims at developing a tool that can be used by traffic and safety engineers, as well as, planners to predict the crash rates at horizontal curves on two-lane two-way non-urban roads. Models are also developed to predict the operating speed of all classes of vehicles at and near the curved section for all kinds of vehicles separately. The study also deals with finding the effect of AADT on traffic safety.**

Keywords: TIRTL, AADT, EPDO, Non linear regression

I INTRODUCTION

The goal of transportation is the safe and efficient movement of people and goods. But the road traffic crashes are a leading cause of death and injury worldwide. Thus road traffic safety has become one of the major concerns in the branch of traffic engineering. India holds the dubious distinction of registering the highest number of road traffic crashes in the world. The rise in number of road traffic crashes, injuries and deaths per lakh of population reflects the rise in motor vehicle population, increase in duration and number of travel trips along with rise in income. Several research studies in the field of road safety focus on establishing relationships between crashes and geometric, traffic and operational factors for road segments. This is accomplished mainly by developing crash prediction models that predict the expected crash frequency on a facility component with specific attributes. Linear and generalised model forms are commonly employed for crash prediction and recently, hierarchical modelling approach has gained popularity in crash modelling, owing to the hierarchical structure inherent in crash data. Most of this research has concentrated on non urban two-lane highways (Vogt and Bared, 1998; Harwood et al;, 2000). In this study, prediction models are developed using the above mentioned methods viz. multiple regression techniques, non linear regression methods, Poisson model, negative binomial model and the comparison of these techniques is made. A comparison with the developed models from previous research works is also made.

II LITERATURE REVIEW

Previous researchers have used a number of models for crash prediction. Detailed literature surveys through previous works gave some idea about latest and suitable models for crash analysis and also identify the advantages and disadvantages of all existing models.

Regression Models

Regression methods are among the oldest methods that were used for modelling highway crashes. Such models are developed by obtaining a database of crashes and roadway characteristics data from highway agency records or collected directly from field, selecting an appropriate functional form of the model, and using regression analysis to estimate the values of the coefficients or parameters in the model. Different methods used for development of crash prediction models are given below.

Linear Regression Model

Conventionally, crash modelling has been conducted using regression methods.

$$Y_i = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + \cdots + a_nX_n$$

$Y_i =$ Number of crashes at Road section *i*

$X_1, X_2, X_3 \cdots X_n$ are input parameters like, roadway width, shoulder width, free flow speed, section length and pavement condition etc. (Model variables).

$a_0, a_1, a_2 \cdots a_n$ are regression coefficients

The most common practice adopted for crash analysis is to use linear functional forms for regression. In this, dependent variable, crash frequency is explained as a linear function of independent variables.

Poisson Regression Model

Crash frequencies on highway sections are discrete and non negative. So Poisson regression technique is the first choice of crash modelling. Poisson models assume that vehicle crashes are independent and follow Poisson distribution. It considers the number of crashes occurring per year at various road sections. By Poisson regression model, the probability of a road section *i* having y_i crashes per year (where y_i is a non-negative integer) can be computed as

$$P(y_i) = \frac{e^{-\mu} \mu_i^{y_i}}{y_i!}$$

where,

$P(y_i)$ = The probability of occurrence of y_i crashes for a given time period on roadway segment *i*;

y_i = The number of crashes for a given time for a roadway segment *i*;

μ_i = The mean value of crash occurred for a given time period, i.e. Poisson parameter for section *i*,

Poisson regression models are estimated by specifying the Poisson parameter μ_i as a function of explanatory variables. The most common relationship between explanatory variables and the Poisson parameter is the log-linear model,

$$\mu_i = \text{Exposure} \times exp(\beta_j X_{ij}),$$

Exposure = Traffic exposure for road segment *i*

X_{ij}= Vector of independent variables for roadway segment *i*;

β_j = Vector of coefficient for the independent variables.

In this formulation, the expected number of crashes per period is given by

$$E[y_i] = \text{Exposure} \times exp(\beta_j X_{ij})$$

In a Poisson distribution, the mean and variance are equal. When the variance is greater than the mean, the distribution is said to display over dispersion. In such a case, Poisson estimation is inappropriate and negative binomial regression model is used to estimate the number of crashes.

Negative Binomial Regression Model

The Negative Binomial model is used to estimate count model when the Poisson estimation is inappropriate due to over dispersion. To overcome this, an error term is added to the expected crash frequency. The equation is derived by rewriting equation (2.2) such that, for each observation *i*,

$$\mu_i = \text{Exposure} \times \exp(\beta_j X_{ij} + \varepsilon_i)$$

Where, $\exp(\varepsilon_i)$ is a gamma-distributed error term with mean 1 and variance α^2. The addition of this term allows the variance to differ from the mean as below:

$$Var(y_i) = E[y_i][1+\alpha E[y_i]] = E[E[y_i]+\alpha E[y_i]]^2$$

$$P(y_i) = \frac{\exp(-\mu_i \exp(\varepsilon_i))\mu_i^{y_i}}{y_i!}$$

The Poisson regression model is regarded as a limiting case of the negative binomial regression model as α approaches zero, which means that the selection between these two models is dependent on the value of α. The parameter α is often referred to as the over dispersion parameter.

Non Linear Regression Model

Zegeer et al., [1986] developed non-linear crash models using crash, traffic, roadway, and roadside data collected on 1,944 road sections covering 4,951 miles of rural two-lane roads in seven states. The purpose of that study was to quantify the benefits of lane widening, shoulder widening, side slope flattening etc. The model was developed for single vehicle crashes, head-on crashes, and sideswipe crashes (of same and opposite directions) and is given as follows:

$A=0.0019\times ADT^{0.8786}\times 0.9192W\times 0.9316PA\times 0.8824UP\times 1.2365H\times 0.8822T1\times 1.3221T2$

Where, ADT is the average daily traffic
W is the lane width in feet
PA is the average width of the paved shoulder in feet,
UP is the average width of the unpaved shoulder
H is the median or roadside hazard rating (1 to 7)
T1 is equal to 1 if the terrain is flat and 0 otherwise
T2 is equal to 1 if the terrain is mountainous and 0 otherwise.

The least-squares approach was used to estimate the regression coefficients. This was based on the assumption that the residuals would follow a normal or log-normal distribution. However, because crash distributions are typically skewed to the right, normality of the residuals may not be a tenable assumption for crash prediction models. Highway Safety Manual (2010) gives a generalised model form for crash frequency. Based on HSM it was found that non linear regression models can be used as a better tool for predicting crash frequency.

III METHODOLOGY

Data Collection

This work is confined to horizontal curves on two lane two way non urban roads. The study sites are selected in Kozhikode district. At the selected sites, data collection is carried out. Data collection consists of traffic data collection, geometric data collection and crash data collection. Traffic data is collected using Transportable Infra Red Traffic Logger (TIRTL) that can record the vehicle speed, lane, time sequence, headway, wheel base and many other characteristics of traffic flow. Geometric data is collected from a previous research work done by Jacob A. (2013). Crash data is collected from police records.

Preliminary Analysis

Preliminary analysis is done as an initial step in order to identify the trend and pattern of data collected. The analysis is carried out on traffic data, road geometric data and crash data. From the preliminary analysis results, the predominant factors that influence the operating speed on curves and speed reduction at curves are identified. The influencing factors of crashes on curves are also identified. These factors are further used in modelling procedures.

Operating Speed Models

Operating speed models are developed for different kinds of vehicles at mid curve and tangent sections. Linear regression technique was used for model development. The influencing variables on operating speed of vehicles are identified and the factors that cause speed reduction on curves are also obtained.

Crash Prediction Models

Based on the literature, various analyses methods that can be used for predicting crashes are identified. Some of these techniques are used for predicting crashes. Linear regression technique, Poison regression technique, Negative Binomial regression technique and non linear regression methods are used for predicting crashes. A general comparison of these techniques is also done.

Summary and Conclusions

Models are developed for predicting the operating speed on horizontal curves and for predicting crashes on horizontal curves. Among the models developed the best models are identified. The most influencing variables on crashes are obtained. And the limitations and scope for future work are noted.

IV DATA COLLECTION

Data requirements

In order to evaluate the safety performance of proposed non urban highway traffic, geometric and crash data are necessary. Geometric data include pavement width, number of lanes, shoulder type and width, radius and degree of curve, deflection angle, length of curve, superelevation, approaching tangent length and sight distance. Traffic data mainly consist of traffic speed and traffic volume data. Traffic data collection was done at horizontal curves. At horizontal curves, crash history was collected from nearby police stations of the identified sites. Crash data mainly consisted of date and place of occurrence of crash, area, types of vehicles involved, severity, type of collision, day or night, number of persons involved, gender and age, and number of fatalities or injuries. Crash data sheet was prepared for the purpose.

Selection of site

The major National Highways in Kozhikode district include NH 17, NH 212 and NH 210. They sum up to a total of 77 km of road length. Total length of State Highways in Kozhikode is 376 km. This study is limited to some of the National and State Highways and other major roads in Kozhikode district. National Highway 212 (NH212), formerly NH 766, connects Kozhikode with Kollegal in Karnataka via Mysore, for the total distance of 272 km, 177 km is in Kerala and 155 km is in Karnataka. SH 34 starts from Koyilandy and ends in Edavanna, and the highway is 44 km long. The study is mainly concentrated to these highways.

The study stretches were identified based on the following criteria:

- The roads should pass through non urban areas
- Stretches should be of two lane two way roads
- Curves should be simple horizontal curves
- Curves should not have influence of intersections
- Curves should not have influence of other sections
- Horizontal curves should not have any gradient.
- No physical features or activities adjacent to, or in the course of, the roadway that may create an abnormal hazard such as narrow bridges, schools, factories, or recreational parks should be present.
- The study locations should not located close to towns or developed areas that may significantly affect the speed patterns on the curves.
- The study location should have significant shoulder width in order to install the equipment

A total of thirty two horizontal curves were identified. Among these, curves at Omassery, Chungam, Chudalamukku, Karassery, Nellikkaparamba, Mutheri. Mangapoyil, Neeleswaram, Koodathayi, Vezhupur, Thachampoyil and Cheenimukku are in SH 34, those at Pathimangalam, Muriyanal, Nellamkandy, Thamarassery, Perumbillil, Kathiyodu and Engapuzha are in NH 212 and those at Agasthyamuzhi, Mambatta and Manassery are in MDR.

Geometric data collection

The data has to be extracted by making use of available resources with maximum possible accuracy. Total Station Survey was carried out to obtain the geometric data. Data was imported to AutoCAD file in order to obtain the horizontal and vertical alignment details. In this study, the geometric data was obtained from the previous works done by Jacob A. (2013)

Traffic data

Traffic data mainly include speed and traffic volume data. Counts should be made on normal weekdays so that there is no much variation in flow characteristics. Count period should avoid special events and adverse weather condition. To acquire a clear idea regarding the type of equipment to be used and other field procedures, it is better to pre-plan with a review of the purpose, type of count performed, the count period, time intervals and geometric layout of the site. In this study, Transportable Infra Red Traffic Logger (TIRTL) was used to perform traffic survey.

Data Collection Using Transportable Infra Red Traffic Logger

The Infra Red Traffic Logger was used to collect the details of traffic stream at horizontal curves. At the sites identified, field visits were conducted and it was made sure that the sites have enough shoulder width so that the equipment can be properly placed facing the traffic stream. In this instrument once the battery is connected the data starts getting recorded. Laptop can be connected using the Ethernet cable and the data recording can be checked from time to time. Certain adjustments have to be made while setting up the instrument which includes checking of beam level, height and tilt. The instrument position was varied till all the checks come under required levels. Installation menu was used to enter the details and description of the site. Lane width was measured using tape and entered with respect to each site conditions. Traffic menu was used to check if all the vehicles were recorded properly. Vehicle log menu was used to retrieve the data from the instrument.

Crash data

A "traffic crash" is the common word used to describe a failure in the performance of one or more of the driving components, resulting in death, bodily injuries and/or property damage. The police stations include those at Kunnamangalam, Thamarasserry, Mukkam, Koduvally and Balussery. Crash history of six years was collected from police records. Crashes at all thirty curve locations for a period of six years were collected. Classification of location wise crashes based on type and severity of crashes was also done. Crash frequency shows that Engapuzha location was found to have the maximum number of crashes. Crashes were found to be the minimum at Thachampoyil location. Crashes obtained were classified based on severity. Each type of crash was given a certain weightages based on previous research work by Jacob A. (2013). Fatal crashes were given a value of 9.5, grievous and non grievous crashes 3.5 and property damage only crash was given a value of 1 for the calculation of EPDO. For the purpose of further analysis and modelling crashes were scaled to Equivalent Property Damage Only (EPDO)

V DATA EXPLORATION

Data on traffic volume

Traffic volume data was collected using instrument TIRTL at selected horizontal curve locations. Data collection was carried out on normal working days. Days of religious importance, festivals, other processions etc. were avoided. Using TIRTL, 12 hour traffic data was collected starting from 6 AM to 6 PM. At some locations, manual data collection was also carried out in which volume count at morning peak hours and evening peak hours were taken. Peak hours include 9 AM to 12 PM in the morning and 3 PM to 6 PM in the evening. At each kind of road, a 24 hour data collection was also carried out in order to calculate the Average daily traffic (ADT) values. The vehicle counts were converted to corresponding passenger car unit (PCU) values as per PCU values suggested by IRC (IRC 108-1996). The data obtained shows that the vehicle volume mainly consists of cars and two wheelers. Around 70% of traffic volume was contributed by these two vehicle types, followed by MCV that include buses and small trucks. Count of bicycles was too less at most of the study location. It may be due to lesser number of bicycle ownership. In non urban roads of Kerala, para transit system also plays a major role in transportation. The data obtained was classified based on hourly traffic volume and type of vehicle. It was found that morning peak was around 9 to 10 AM and evening peak 5 to 6 PM. Out of total count, the maximum was shared by cars and two wheelers, followed by three wheelers.

Speed data

Speed data at curves has been collected from two points on the horizontal curve location. The maximum speed of vehicle was recorded at the tangent section before the vehicle negotiates the curve and the lowest speed is recorded as the vehicle approaches the mid curve portion. Mid curve portion consists of 10m length at the region of maximum curvature.

Speed data obtained is classified based on;

- Headway: Time headway of vehicles was considered. They were classified as those having a time headway of above 5 seconds, 10 seconds, 20 seconds, 30 seconds, 40 seconds, 50 seconds, 60 seconds and above 120 seconds.
- Direction: Those vehicles moving towards the curve and those moving away from the curve.
- Vehicle having a time gap of more than 5 seconds with the vehicle coming from opposite direction
- Vehicle type

Cumulative percentile speed - speed graph were plotted. The graph was plotted for each classification of headway. From the cumulative frequency plot, for different classes of vehicles, the 50th, 85th, 95th and 98th percentile speeds were found out. Thus the operating speed for each kind of vehicle belonging to each class of headway was found out separately. Same procedure was repeated for vehicle speeds at mid curve as well as at tangent section. Figure 4.3 shows the cumulative percentile speed – speed plot for two wheelers at Omassery site.

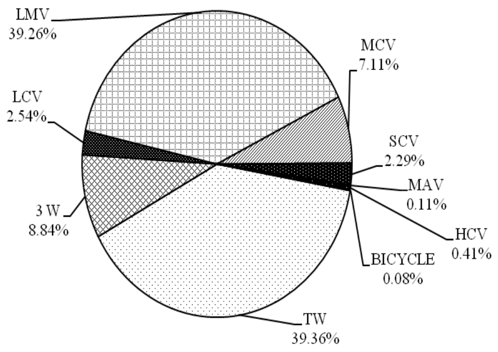

Figure **Error! No text of specified style in document.**.1 Cumulative Frequency plot for TW at Omasserry

From the figure 4.3

- 85th percentile speed is 40 kmphr
- 95th percentile speed is 44 kmphr
- 98th percentile speed is 48 kmphr

The values of 50th and 85th percentile speeds for each type of vehicle corresponding to particular headway classes are tabulated as shown in table 4.3. It was found that there is no particular trend of increase or decrease in operating speed with respect to time headway values. From the obtained values of percentile speeds, a comparison of 50th and 85th percentile speeds at mid curve and tangent sections is made. This was done for all classes of vehicle. The comparison is done by plotting graphs between headway and percentile speeds as shown below.

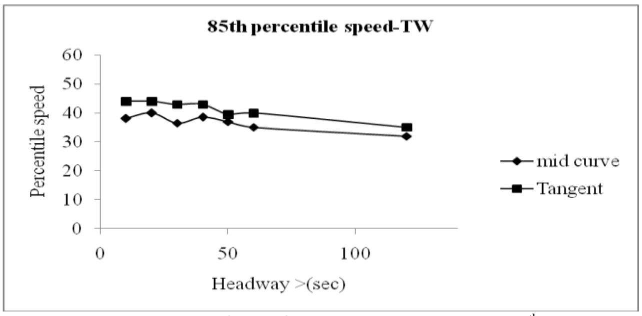

Figure **Error! No text of specified style in document.**.2 85th percentile speed of two wheelers at omasserry

Figure 4.4 shows the plot between 85th percentile speed and headway for two wheelers at Omassery site. It was observed that two wheelers shows a significant reduction in operating speed from tangent section to mid curve section. Figure 4.5 shows the plot between 50th percentile speed and headways for two wheelers at Omassery site. The reduction of 50th percentile speed of two wheelers is lesser than that of operating speed reduction.

The trend and pattern of speed data followed by each vehicle for different section were found out by plotting these graphs. Following inferences are made from the graphs,

- The curves indicate that two wheelers and LMV does not show a significant decrease in speed from tangent section to mid curve.
- Larger vehicles like HCV, MCV and LCV show a significant reduction in speed from tangent to mid curve.
- Test was done to check whether speed of vehicles approaching the curve is significantly different from those leaving the curve.
- Threshold value of headway was found to be 10 seconds.

The figures show that there is no significant change in the speed trend when a headway having value less than 10 seconds is chosen. Thus, based on the preliminary analysis results, 10 seconds was considered as the threshold value of headway and for further analysis of percentile speeds, vehicles having headway above 10 seconds are only considered and vehicles having headway less than 10 seconds are neglected. Using the same procedure, the speed percentiles at all the sites were also estimated.

Further, ANOVA test was conducted to identify the effect of headways on speed at different sections. It was observed that the value of observed F statistics was larger than the critical F statistic. This gives the evidence that the null hypothesis can be accepted that different headways were found to be significantly different from each other. The results of the ANOVA test are shown in table 4.4.

Table **Error! No text of specified style in document.**.1 ANOVA test results for check on difference of headways

SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Headway>120	54	1743.66	32.29	131.97		
Headway>10	146 4	61504.1	42.011	85.882		
ANOVA						
Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	4921.3	1	4921.3	56.248	1.08E-13	3.8476
Within Groups	132640	1516	87.493			
Total	137561	1517				

Direction wise classified data was used for the further analysis. The vehicles moving towards the curve and those moving away from the curve were separated. It is made sure that vehicles are considered in such a way that, once a vehicle is considered in the outer curve portion, there is no vehicle coming from the opposite direction within a time gap of five seconds. This was considered to obtain the free flow of vehicles. The percentile speeds of these vehicles were obtained from graphical methods. On these values of speed, ANOVA test is conducted to identify if those speeds were similar or not. Based on the ANOVA test it is found that speeds of vehicles moving in opposite directions are significantly different. It is also found that the speed of vehicles are not affected when there is a vehicle coming from the opposite direction when there is a time gap of 5seconds and more. The results indicate that different categories of headways are significantly different from each other.

Crash data

Six year crash history was collected. Crashes were classified based on severity, time of occurrence, type of vehicles involved, number of fatalities etc. As explained in previous chapter, based on severity crashes were classified. But in analysis, if crashes of different severity levels are summed up together, it results in loss of accuracy. In order to avoid this, different severity crashes were given separate weightages in order to obtain the Equivalent Property Damage Only (EPDO) value. EPDO is calculated using the equation given by Anitha et al., (2013).

$$\mathrm{EPDO} = \{9.5 \times (\mathrm{F} + \mathrm{G})\} + \{3.5 \times \mathrm{NG}\} + \mathrm{PD}$$

Where

F - Fatal Crashes
G - Grievous Crashes
NG - Non Grievous Crashes
PDO - Property Damage Only Crashes

The snapshot of the tabulated crash data sheet as recorded from police stations is as shown in figure 4.12. The crime number, exact location of the crash, date and time of crash, section of law, type of vehicle involved in the crash, type of collision and type of accident and the number of persons involved in the crash are recorded.

Crash Distribution

The crash data from all locations was analysed based on the type of vehicle involved, locations prone to crashes, time of occurrence etc. It is found that most of the crashes involve two wheelers followed by cars and heavy vehicles. This may be due to the rash driving of young two wheeler drivers. During the survey it was observed that most of the two wheeler users were not wearing helmet. It may also be the reason for increase in the severity of crashes. From 2013 to 2015, the crash rates are increasing. Increased number of vehicle ownership and the consequent exposure could be one of the main reasons for this increased crash rates. Figure 4.13 shows the year wise distribution of crashes.

When the daily variation in crashes is considered, it is found that, most of the crashes are reported during the peak hours. It includes the morning peak, as well as, evening peak hours. Crashes reported in these cases are of lesser severity. It is found that number of crashes during night is considerably less compared to those occurring at day time. But those crashes reported at night are having larger severity rates compared to that of day time crashes. Peak hour crashes mainly belongs to non grievous type and property damage only type crashes. Figure 4.15 shows the hour wise distribution of crashes.

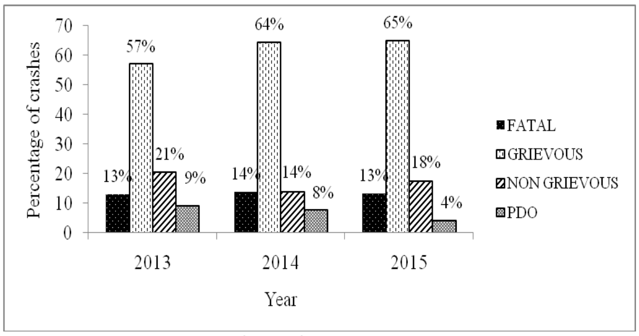

Figure **Error! No text of specified style in document.**.3 Year wise distribution of crashes

The details of crashes at each curve location are separated out. The location wise distribution of crashes at horizontal curve is plotted as shown in figure 4.17. From the plot it was found that the curves at Nellamkandy and Vavad are found to be the most severe. To get a clear idea about the severity of crashes instead of crash frequency, EPDO factor was used for the plot. The increased number of crashes at curves at Vavad and Nellamkandy may be due to the severity of the curves. At these locations the curve radius is too less that makes the drivers to use more effort in negotiating the curve.

Relationship between traffic volume and crashes

In many of the previous works, it was discussed that in non urban areas, the major contributing factors of road traffic crashes are vehicle speed and geometric features of the road stretches. In such cases, traffic volume is of lesser importance. Whereas, in urban areas, the contributing factor of road crashes is mainly traffic volume. In this case, vehicle speed is of lesser importance. Therefore the dependence of traffic volume with road crashes varies with respect to area under the study purpose. This work tries to explain the effect of traffic volume in road crashes on non urban roads. The crash history of the study sites was collected from the nearby police stations. The corresponding AADT values of the locations wer also estimated. A plot was made between EPDO values and AADT. Since EPDO could explain the trend in a better way than crash frequency, it was used for analysis.

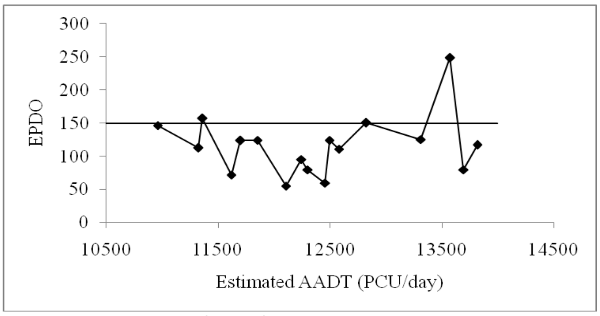

Figure **Error! No text of specified style in document.**.4 EPDO-AADT relationship at lower traffic volume

Figure 4.18 shows the dependence of EPDO value with traffic volume at lower values of traffic volume. The collected data set of estimated AADT values ranges from 10,965 PCU/day to 22,811 PCU/day. Figure shows that there is a significant shift in the EPDO range when the traffic volume is increased. To identify the trend different plots are made at lower and higher ranges of estimated AADT. It is found that at lower values of AADT, ie from 10,500 PCU/day to 14,500 PCU/day, the numbers of data points are more below an EPDO value of 150 as shown in figure 4.18. But at higher values of AADT, ie from 19,000 PCU/day to 23,000 PCU/day, the data points are more above an EPDO value of 150 as shown in figure 4.19. The figures 4.18 and 4.19 evidently show that the crash crashes are found to increase in number when the AADT range increases.

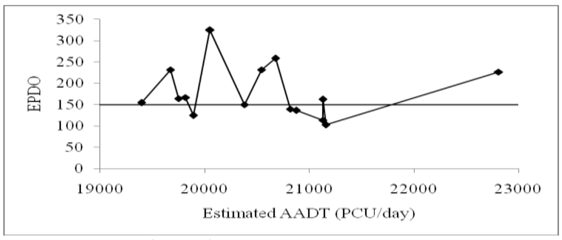

Figure **Error! No text of specified style in document.**.5 AADT-EPDO relationship at higher traffic volume

VI CONCLUSIONS

1. Operating speed of vehicle at mid curve is mainly influenced by curve geometric features.
2. As the preceding tangent length increases, operating speed of vehicle increases at the tangent section
3. Operating speed of vehicle at tangent section is not influenced by features of the curves.
4. At curves with smaller radius, there is a significant reduction in speed for larger vehicles and then gradually increases towards the end of the curve.
5. Smaller vehicles are not having a larger speed reduction while negotiating a sharp curve.
6. Along the horizontal curve, the operating speed of vehicle moving towards the curve is not affected by the vehicle from the opposite direction having a time gap more than 5 seconds.
7. Different categories of headways are significantly different from each other
8. The curves at Nellamkandy and Vavad are found to be the most severe horizontal curves
9. EPDO value shifts below 150 when the range of AADT is increased above 19000PCU
10. Traffic volume at non urban roads has increased alarmingly that shows that volume can also be an influencing variable in predicting crashes on non urban roads as in case of urban roads.
11. The crashes on non urban roads can be predicted using speed, curve geometrics as well as traffic volume. The best non linear crash prediction model is given by;

$$CF = 0.0466 \times Ex^{1.245} \times \exp(0.2317SW + 0.0007R - 0.0012TL)$$

Where,

CF – Crash Frequency
Ex – Exposure
SW – Shoulder width
R – Radius
TL – Tangent Length

12. Operating speed model developed for tangent section is

    i. Three Wheeler V_{85}=34.289+0.051PTLS (R^2=0.929)

    ii. LMV V85=24.93+11.68LnPTLS (R^2=0.61)

    iii. LCV $V_{85}=57.308-\frac{950.263}{\sqrt{PTLS}}$ (R^2=0.835)

    iv. Two Wheeler V_{85}=39.918+0.02PTLS+0.013R (R^2=0.925)

    Where,
    PTLS – Preceding Tangent Length
    R – Radius
    CL – Curve length

Def – Deflection Angle

13. Operating speed model developed for mid curve section is

    i. Three Wheeler V_{85}=16.467+0.242CL (R^2=0.831)

ii. LMV
V_{85}=25.22+0.233CL
(R^2=0.813)

iii. LCV
V_{85}=-30.788+32.674LnR
(R^2=0.851)

iv. MCV
V_{85}=21.589+0.256CL
(R^2=0.662)

v. Two Wheeler
V_{85}=2.019+17.252LnR
(R^2=0.417)

Where,
CL – Curve Length
R – Radius
PWtn – Pavement width at tangent section
Def - Deflection Angle

14. All models are logical based on signs of the coefficients and they are significant at 95 percentage significance level.
15. As per non linear model, Crash frequency increases with AADT and road geometrics variables.

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