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# Evaluating the Impact of various Geometric Characteristics of Rural Two-Lane Road on Traffic Safety in Ethiopia

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***Abstract***

*Due to the fast economic change and growth in developing countries, the demand for transportation of goods and passengers is increasing day today. This needs a lot of transportation system arrangements on both highways and urban roads. However, the existing transportation systems are characterized by high accident levels and unsafe public transport. Studies indicated that the causes for these problems are due to poor infrastructure, lack of proper road design, and less priority for safety on the roads. The present study is to investigate the effect of road geometric and other roadway characteristics of rural two-lane roads on safety. Accident data is collected from the respective traffic police stations for 5 years from 2013 to 2017. The data is then sorted out based on the various causes of accidents that are recorded in the traffic police records. The geometric characteristics such as Sight Distance, Radius of Curvature, Road Width, Vertical Curves, Superelevation grade, and Curve Length are considered as major sources of occurrence of accidents on highways. The sorted accident data is studied to develop accident models using Poisson regression, Negative Binomial regression, multiple linear regression methods. Keeping because of the logical fitness and validation, the Multiple linear regression method is selected and various crash models are developed in relation to each geometric character. The analysis of the developed models is expected to understand the influence of each geometric character on road safety and will bring possible recommendations to mitigate the accidents and their severity thus reducing the human loss and property damages.*

**Keywords***: Geometric Characteristics, Crash Prediction, Crash frequency, Black Spot Road Section, Fatal accidents, Serious Injury, Light Injury, Traffic Volume, Multiple Linear Regression*

## I. INTRODUCTION

A road traffic accident is an unexpected event, which occurs suddenly. It is one of the major causes of human and economic losses in both developed and developing countries. Furthermore, globally1.3 million fatalities and up to 50 million non-fatal injuries reported **[1]**. It is the second most common cause of death among the most economically active population group 15–44year-old [2]. Therefore, it is considered that the rate of accidents is the main criterion for road safety since a safer transportation system is the engine of the economic activities in all urban and rural communities all over the world and consequently sustains the livelihood of the people living in areas.

In developing countries, road traffic accidents are among the leading cause of death and injury. Moreover, the country Ethiopia was one of the members that experience the highest rate of such accidents in Sub Saharan Africa. Car ownership has grown rapidly at about 7.0% per annum on average [3]. Also, the construction of roads is one of the major focus areas of the government to fast-track economic growth. Although the vehicle population growth rate per annum is increasing. The total population in Ethiopia as per data is 114,170,198 of which 78.7% of the population are living in the rural areas. The numbers of registered vehicles of all categories are 1,071,345 when compared to other developing countries the number of total vehicles in Ethiopia remains low. However, the traffic accident was highest in Ethiopia country.

Wolaita Zone is one of the principal towns in the Southern part of Ethiopia and is located at a distance of 325Kms from the capital state of Addis Ababa and 170Kms from Hawass. The total population in the zone is 2,400000 and one of a densely populated area in the region.

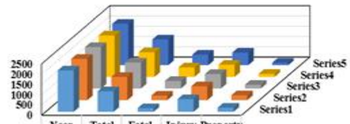
This research was to evaluate and modal crashes predication depending on the severity of accidents caused by geometric characteristics in the area. In the model, the accident rate is taken as the dependent variable and the following variables such as curve length, lane width, shoulder width, the radius of curvature, horizontal curvature, sight distances, number of horizontal curvatures per kilometer, number of vertical curvatures per kilometer, horizontal curve superelevation grade and exposure variable traffic volume, etc. are considered as independent variables. The model was developed by using a statistical modeling approach of multiple linear regressions. Moreover, the choice of the best model from those modeling approaches is by using logical fitness and also depends on whether actual and predicted values are nearer to each other or not respectively.

## II. STATEMENT OF PROBLEM

Rural road safety accounts for a considerable share of the total road safety problem. To improve road safety, the actual dangers and problems need to be identified, and measures should be targeted to tackle road safety problems. However, when compared to urban roads, rural roads are overall less safe. Historical data confirm that rural roadways carry less than half of America's traffic but account for over half of the nation's vehicular deaths [4].In 2008, nearly sixty-two percent of passenger vehicles occurred fatalities in rural areas. The same is the true majority of the Ethiopia road system consists of rural two-lane heterogeneous traffic conditions, which consists of different compositions of vehicles, pedestrian, animal, etc. are moving on the road thus causing traffic safety situation is more critical at such roads compared to other road classes.

According to [5] research, accident in Wolaita zone was very huge because, the zone has a great concentration of vehicles and traffic, takes the lion's share in car accidents. In addition, most of the topography of zones covered steeply or hilly topography on average subjected to crashes most of the time due to the poor geometric element of road that affects the safety of the road.

The following figure was developed based on the five years (2013-2017) police recorded road traffic crash of the South nation nationality and people region state(SNNPR) and Wolaita zone respectively. From the figure, it is seen that the road traffic crash is increasing from year to year except for a little reduction for the year 2016 in the region. So studying the possible influencing factors for traffic crashes in the region, the wolaita zone, and suggesting a mitigation measure is not an option but is an issue for road traffic professionals.




| | Year | Total Accident | Fatal Accident | Injury Accident | Property Damage Accident |
|---|---|---|---|---|---|
| Series1 | 2013 | 1000 | 180 | 620 | 200 |
| Series2 | 2014 | 1135 | 222 | 679 | 234 |
| Series3 | 2015 | 1261 | 371 | 708 | 182 |
| Series4 | 2016 | 1198 | 463 | 590 | 145 |
| Series5 | 2017 | 1250 | 513 | 615 | 122 |

Series1 Series2 Series3 Series4 Series5

**Figure 1: road traffic crash trends in SNNPR**


| | Total Accident | Fatal Accident | Injury Accident | Property Damage Accident |
|---|---|---|---|---|
| 2013 | 441 | 73 | 296 | 72 |
| 2014 | 361 | 69 | 186 | 106 |
| 2015 | 381 | 67 | 243 | 71 |
| 2016 | 222 | 80 | 92 | 50 |
| 2017 | 357 | 76 | 233 | 48 |

2013 2014 2015 2016 2017

**Figure 2: road traffic crash trends in Wolaita zone**

From the report, as shown above, in wolaita zone, traffic accidents were fluctuating from year to year, but a significant contribution to the death of the people. When a contest to the SNNPR, the wolaita zone has contributed approximately half of the accidents in the region. Therefore, this research was focused on the wolaita zone to know the main contributor factors for the occurrence of various types of traffic accidents.

**Figure 3: road traffic accident murder people**

## III. OBJECTIVES OF THE STUDY

### *A. General Objective*

The general objective of the study was to evaluate the impact of major geometric characteristics of rural roads that cause traffic safety problems.

### *B. Specific Objectives*

The specific objectives of the study are:

- To identify high accident rate (Blackspot) road segments in the Wolaita zone
- To examine the relationships between the occurrence of crashes and the related causal factors due to geometric characteristics.

- Develop crash prediction models for each geometric characteristic to predict and reduce the rate of accidents.
- To identify the possible solutions and recommendations to curtail more number of accidents in the selected zone.

## IV. LITERATURE REVIEW

In Germany, [6] noted that nearly half of the crashes on non-built-up roads (i.e. Rural roads) occurred on curved roadway sections. In the UK,[7] found that, of all crashes on rural two-lane roads, 18.5% occurred on curves. Similar rates were found in Denmark, with 20% of all personal injury crashes and 13% of all fatalities occurring on horizontal curves in rural areas [8].

Almost, all previous studies' conclusions indicate that the rate of accident is high on horizontal curves, at intersections and bridges [9].

A study of crashes on vertical curves with limited stopping sight distances was conducted by [10].

A study conducted by [11] found that wide lanes had accident rates 10 to 39% lower than those on narrow lanes.

[12] Reviews from studies in Sweden and concluded that increasing sight distance results in decreasing the accident rate.

. Despite its event success in many applications, however, the regression approach can face serious difficulties when the independent variables are correlated with each other [13]. Previous safety studies such as [14] used multiple linear regression techniques to study the relationships between a vehicle accident and geometric features. Japanese researchers [15] tried to use multiple linear regressions to analyze accident rates related to geometric design elements.

## V. MATERIAL AND METHODS

### *A. Description of Study Area*

The present research has been carried out in the Wolaita zone. The zone is located in south nation nationality and people of the regional state in Ethiopia. It borders with Gamow Goff zone in the South, Dawro Zone in the West, Sidama Zone in the East, Kamabata &Tamabro, and Hadiya Zones in the North and with Oromia regional state in the Northern East. It is located at a distance of 325 km from the capital state of Addis Ababa and 170 km from Hawass. Astronomically, the zone is located 6046'-6053'North latitude and 37042'-37056' East longitude. The altitude of the zone ranges from 1784-2346 meters above sea level.

**Figure 4: administrative map of the Wolaita zone**

### *B. Method of Data Collection*

The research approach for this study is based on quantitative data that is collected from the respective traffic police departments and offices. Hence; first, collect the secondary data from the police department and different office working in road sectors after that identify black spot road segment. The primary data such as observations and direct field measurements were applied based on secondary data such as traffic accidents on a segment of the road section. Therefore, to fulfill the data, the researcher used primary and secondary data to resolve the accident problem. Then detail analysis of statistical method using SPSS software by fitting both dependent and independent variable based on correlation test result for evaluating regression models.

## VI. ANALYSES AND DISCUSSION

To analyze the relationship between road traffic crash and different contributing factors of the geometric elements and other factors at the places where frequent crashes are happening, the analysis is carried out by collecting the crash data from the police records for the last five years

### *A. Road Traffic Crash by High Speed*

Speed is one of the major parameters in geometric design and safety is synonymous with accident studies. One of the causes of the accident and for this research instantaneous speed of the vehicle during the period of the accident is required. However, to measure and obtain this speed data from the field is unanticipated and difficult due to the discreet nature of the behavior of the accident. The following figure shows the accident rate due to high speed.

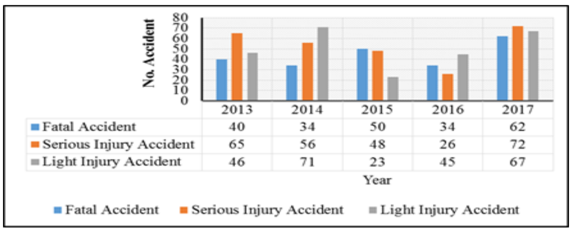



**Figure 5: road traffic crash due to higher speed data**

### *B. Road Traffic Crash by Drivers Behaviour*

Driver's behavioral characteristics, such as inattention, fatigue, experience, and risk-taking behavior (speeding, drunk-driving, and failure to wear a seatbelt), have all been identified as factors that significantly contribute to increased crash and injury risk on rural roads. Moreover, the entire above situations are critical factors for the occurrences of the accident. Therefore, drivers' problem with the five-year data from the traffic police can be segregated as the driver problem data as shown in the following figure.

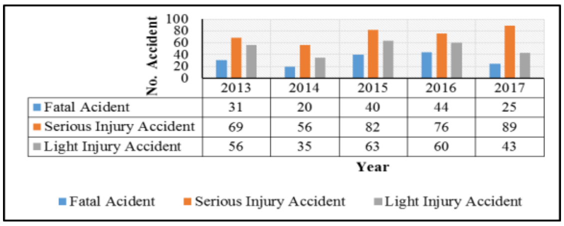



**Figure 6: road traffic crash due to drivers' behavior**

### *C. Road Traffic Crash by Pedestrian Problem*

National Highway Traffic Safety Administration defines a pedestrian as any person on foot, walking, running, jogging, hiking, sitting, or lying down who is involved in a motor vehicle traffic crash. This is one of the common causes of the accident; especially in the heterogeneous traffic system due to the road is congested by the animal, pedestrian, vehicle…Etc. and makes a lane less movement. Therefore, the vehicle hit the pedestrian or animal, etc. Due to this, the accident took place on the road. As shown below in figure 4.3 the pedestrian accident on the road during the five years in the case study area.

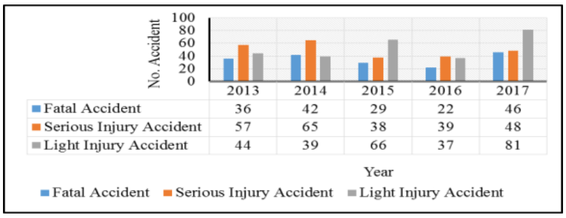



**Figure 7: road traffic crash due to pedestrian problem**

### *D. Traffic Accident in Related to Sight Distance*

Horizontal curve sight distance is one of the basic variables that control the aspect of the horizontal curve. Moreover, once a radius that seems to connect the two previously disjointed sections of the roadway safely and comfortably, it is required to make sure that sufficient sight distance is provided throughout the length of the horizontal curve. Therefore, from the police records of the traffic crash of five-year data, it is strained to identify the area where the accident occurs most of the time. Then the actual sight distances in the field are measured to realize the relationship between accident type and sight distances by clustering the data to the homogenous section of sight distances. The following tables represent the consolidated crash data from all types of accidents such as Fatal, Serious Injury and are prepared from the original crash data collected from the respective traffic police stations.

**Table 1: consolidated traffic fatal and serious injury accident related to sight distances**

| No. | Accident Type | Geometric Characteristics | | |
|---|---|---|---|---|
| | Fatal | Volume per day | Road Width | Horizontal Curve Sight Distances |
| 1 | 36 | 1325 | 8.6 | 10.6 |
| 2 | 19 | 1300 | 11.7 | 12.8 |
| 3 | 29 | 1325 | 10.6 | 14.96 |
| 4 | 12 | 1300 | 11.1 | 18 |
| 5 | 24 | 1375 | 10.5 | 18.49 |
| 6 | 22 | 1100 | 10.6 | 21.3 |
| 7 | 40 | 1200 | 7.2 | 25 |
| 8 | 6 | 506 | 11 | 28.84 |
| 9 | 20 | 1255 | 10.6 | 30 |
| 10 | 10 | 506 | 11.4 | 33 |
| 11 | 5 | 506 | 11.7 | 38 |
| 12 | 4 | 506 | 12 | 47.89 |
| 13 | 10 | 1255 | 10.8 | 50.6 |
| 14 | 2 | 506 | 12.6 | 81 |

| No. | Accident Type | Geometric Characteristics | | |
|---|---|---|---|---|
| | Serious Injury | Volume per day | Road Width | Horizontal Curve Sight Distances |
| 1 | 42 | 1325 | 8.6 | 10.6 |
| 3 | 20 | 1300 | 11.7 | 12.8 |
| 3 | 26 | 1325 | 10.6 | 14.96 |
| 4 | 15 | 1300 | 11.1 | 18 |
| 5 | 25 | 1375 | 10.5 | 18.49 |
| 6 | 18 | 1100 | 10.6 | 21.3 |
| 7 | 48 | 1200 | 7.2 | 25 |
| 8 | 15 | 506 | 11 | 28.84 |
| 9 | 22 | 1255 | 10.6 | 30 |
| 10 | 10 | 506 | 11.4 | 33 |
| 11 | 3 | 506 | 11.7 | 38 |
| 12 | 2 | 506 | 12 | 47.89 |
| 13 | 8 | 1255 | 10.8 | 50.6 |
| 14 | 1 | 506 | 12.6 | 81 |

### *E. Traffic Accident concerning Radius of Curvature*

The radius of curvature measurement is achieved by assigning a local measurement to each of the verified accident areas. It is one of the basic variables in which this study takes into consideration as an influencing factor in traffic crashes and affects the safety of the road. In this research, accident frequency data are correlated with a radius of curvature by collecting traffic accident data from police and identifying accident-prone zone. Then by going to the field, the causal factors from geometric elements are measured and also some observations are made by vision. The following tables represent the consolidated crash data from all types of accidents such as Fatal, Serious Injury are prepared from the original crash data collected from the respective traffic police stations.

Table 2: consolidated traffic fatal and serious injury accident related to the radius of curvature

| No. | Accident Types | Geometric Characteristics | | |
|---|---|---|---|---|
| | Fatal | Volume per day | Roadway width | Radius of curve |
| 1 | 30 | 1375 | 10.4 | 80.9 |
| 2 | 24 | 1100 | 10.6 | 90 |
| 3 | 19 | 1000 | 11.7 | 108 |
| 4 | 15 | 900 | 11.3 | 158.6 |
| 5 | 10 | 700 | 12.1 | 175.9 |
| 6 | 35 | 1400 | 10.2 | 80 |
| 7 | 19 | 1200 | 10.8 | 130 |
| 8 | 23 | 1220 | 10.5 | 97 |
| 9 | 11 | 1000 | 12 | 165 |
| 10 | 42 | 1375 | 8.2 | 80 |
| 11 | 13 | 1100 | 11.6 | 250 |
| 12 | 7 | 506 | 12.6 | 600 |
| 13 | 11 | 1200 | 11.7 | 537 |
| 14 | 17 | 1325 | 11 | 130 |

| No. | Accident Types | Geometric Characteristics | | |
|---|---|---|---|---|
| | Serious Injury | Volume per day | Roadway width | Radius of curve |
| 1 | 27 | 1375 | 10.4 | 80.9 |
| 2 | 24 | 1100 | 10.6 | 90 |
| 3 | 9 | 1000 | 11.7 | 108 |
| 4 | 8 | 900 | 11.3 | 158.6 |
| 5 | 4 | 700 | 12.1 | 175.9 |
| 6 | 29 | 1400 | 10.2 | 80 |
| 7 | 20 | 1200 | 10.8 | 130 |
| 8 | 25 | 1220 | 10.5 | 97 |
| 9 | 3 | 1000 | 12 | 165 |
| 10 | 54 | 1375 | 8.2 | 80 |
| 11 | 2 | 1100 | 11.6 | 250 |
| 12 | 9 | 506 | 12.6 | 600 |
| 13 | 1 | 1200 | 11.7 | 537 |
| 14 | 5 | 1325 | 11 | 130 |

### *F. Traffic Accidents in related to Roadway Width*

Roadway width should be sufficient to carry the traffic efficiently and safely. However, safety increases as roadway width increases and is based on the evidence that the roadway width reduces the consequences of driver deviations from their intended path. Vehicles traveling in opposite directions on undivided, two-way roads are separated by larger distances if the roadway is wider. Vehicles traveling in the same direction on multilane roads are also separated by larger distances if the roadway width is wider. Wider roadway width provides more scope for recovery in near-crash situations. This is one of the most important parameters for the safety as well as the reduction of accident rate on the rural two-lane road. Moreover, the driver psychologically feels comfortable in driving the vehicle on wider roads than narrow roads. Wider roadway width on a rural road is higher accident severity, and a lower accident rate and cost. The following tables represent the consolidated crash data from all types of accidents such as Fatal, Serious Injury are prepared from the original crash data collected from the respective traffic police stations.

**Table 3: consolidated traffic fatal and serious injury accident related to roadway width**

| No. | Accident Types | Geometric characteristics' | |
|---|---|---|---|
| | Fatal | Volume per day | Roadway Width |
| 1 | 20 | 1200 | 10.1 |
| 2 | 5 | 1200 | 12.6 |
| 3 | 9 | 1200 | 11.7 |
| 4 | 19 | 1255 | 10.54 |
| 5 | 7 | 1255 | 12 |
| 6 | 28 | 1325 | 10.2 |
| 7 | 15 | 506 | 11.4 |
| 8 | 69 | 1325 | 8.6 |
| 9 | 22 | 1255 | 10.4 |
| 10 | 6 | 1305 | 12.1 |
| 11 | 42 | 1325 | 9.9 |
| 12 | 17 | 506 | 10.56 |
| 13 | 11 | 506 | 11.6 |
| 14 | 2 | 1325 | 15 |

| No. | Accident Types | Geometric characteristics' | |
|---|---|---|---|
| | Serious Injury | Volume per day | Roadway Width |
| 1 | 32 | 1200 | 10.1 |
| 2 | 6 | 1200 | 12.6 |
| 3 | 14 | 1200 | 11.7 |
| 4 | 25 | 1255 | 10.54 |
| 5 | 9 | 1255 | 12 |
| 6 | 22 | 1325 | 10.2 |
| 7 | 18 | 506 | 11.4 |
| 8 | 72 | 1325 | 8.6 |
| 9 | 21 | 1255 | 10.4 |
| 10 | 8 | 1305 | 12.1 |
| 11 | 31 | 1325 | 9.9 |
| 12 | 23 | 506 | 10.56 |
| 13 | 16 | 506 | 11.6 |
| 14 | 3 | 1325 | 15 |

### *G. Traffic Accident in Related to Vertical Curvature*

Vertical Curvature which is called sags and crest curve is one of the variables considered in this research. For the safety of the road, the number of vertical curves per 1.5 km was considered in the accident frequency. The table below indicates that as the number of vertical curves per km increases, the traffic accident rate will escalate and increases rapidly. Finally, it was possible to conclude that the presence of several vertical curves per 1.5 kilometers is a significant effect on safety and raises the accident rate. Therefore, the number of vertical curves is counted per 1.5-kilometer road section in the accident occurrence area and included in the modeling process depending on the correlation test result in SPSS software

The following tables represent the consolidated crash data from all types of accidents such as Fatal and Serious Injury are prepared from the original crash data collected from the respective traffic police stations.

**Table 4: consolidated traffic fatal and serious injury accident related to vertical curvature**

| No. | Accident Types | Geometric characteristics' | | |
|---|---|---|---|---|
| | Fatal | Volume per day | Roadway Width | Number of Vertical Curvature (per 1.5km) |
| 1 | 27 | 1325 | 9 | 1 |
| 2 | 34 | 1255 | 8 | 4 |
| 3 | 29 | 1325 | 10.6 | 3 |
| 4 | 21 | 1200 | 8.6 | 2 |
| 5 | 25 | 1255 | 7.96 | 2 |
| 6 | 21 | 1200 | 15 | 3 |
| 7 | 14 | 1000 | 10 | 2 |
| 8 | 32 | 1255 | 8.16 | 1 |
| 9 | 42 | 1325 | 10.2 | 4 |
| 10 | 13 | 1255 | 10.6 | 2 |
| 11 | 7 | 506 | 10.6 | 1 |
| 12 | 29 | 1305 | 10.8 | 3 |
| 13 | 14 | 1200 | 10.6 | 1 |
| 14 | 6 | 506 | 11.1 | 2 |
| 15 | 28 | 1325 | 8.2 | 3 |

| No. | Accident Types | Geometric characteristics' | | |
|---|---|---|---|---|
| | Serious Injury | Volume per day | Roadway Width | Number of Vertical Curvature (per 1.5km) |
| 1 | 32 | 1325 | 9 | 1 |
| 2 | 29 | 1255 | 8 | 4 |
| 3 | 34 | 1325 | 10.6 | 3 |
| 4 | 39 | 1200 | 8.6 | 2 |
| 5 | 43 | 1255 | 7.96 | 2 |
| 6 | 20 | 1200 | 15 | 3 |
| 7 | 18 | 1000 | 10 | 2 |
| 8 | 36 | 1255 | 8.16 | 1 |
| 9 | 58 | 1325 | 10.2 | 4 |
| 10 | 19 | 1255 | 10.6 | 2 |
| 11 | 9 | 506 | 10.6 | 1 |
| 12 | 39 | 1305 | 10.8 | 3 |
| 13 | 13 | 1200 | 10.6 | 1 |
| 14 | 5 | 506 | 11.1 | 2 |
| 15 | 42 | 1325 | 8.2 | 3 |

### *H. Traffic Accidents in related to Curve Length (Section length)*

Curve length for each road section refers to the distance between major changes in the geometric characteristics of the roadway in a curve. As the curve length increases, all other factors remaining the same, the number of crashes is expected to increase. However, such a relationship is not necessarily linear. Therefore, this can play a significant role in reducing road traffic crashes and maintaining the safety of roads in rural areas. Finally, it is concluded that traffic accidents will increase as the curve length increases, which roughly indicates that the curve length of the road is one of the significant factors in the crash events. The following tables represent the consolidated crash data from all types of accidents such as Fatal, Serious Injury are prepared from the original crash data collected from the respective traffic police stations.

**Table 5: consolidated traffic fatal and serious injury accident related to curve length**

| No. | Accident Types | Geometric characteristics' | | |
|---|---|---|---|---|
| | Fatal | Volume per day | Roadway Width | Curve Length |
| 1 | 18 | 1255 | 10.4 | 200 |
| 2 | 16 | 1200 | 10.6 | 160 |
| 3 | 14 | 1100 | 10.6 | 100 |
| 4 | 13 | 1325 | 11.7 | 80 |
| 5 | 15 | 1375 | 10.4 | 100 |
| 6 | 17 | 1255 | 10.6 | 150 |
| 7 | 10 | 1200 | 12.1 | 100 |
| 8 | 29 | 1325 | 10.2 | 150 |
| 9 | 23 | 1200 | 10.8 | 120 |
| 10 | 34 | 1325 | 10.5 | 300 |
| 11 | 21 | 1255 | 12 | 200 |
| 12 | 42 | 1375 | 8.2 | 300 |
| 13 | 20 | 506 | 11.6 | 210 |
| 14 | 10 | 506 | 12.6 | 100 |
| 15 | 11 | 1200 | 11.7 | 150 |
| 16 | 20 | 1325 | 11 | 300 |

| No. | Accident Types | Geometric characteristics' | | |
|---|---|---|---|---|
| | Serious Traffic | Volume per day | Roadway Width | Curve Length |
| 1 | 20 | 1255 | 10.4 | 200 |
| 2 | 18 | 1200 | 10.6 | 160 |
| 3 | 12 | 1100 | 10.6 | 100 |
| 4 | 11 | 1325 | 11.7 | 80 |
| 6 | 19 | 1375 | 10.4 | 100 |
| 8 | 22 | 1255 | 10.6 | 150 |
| 10 | 13 | 1200 | 12.1 | 100 |
| 11 | 35 | 1325 | 10.2 | 150 |
| 12 | 27 | 1200 | 10.8 | 120 |
| 13 | 33 | 1325 | 10.5 | 300 |
| 14 | 24 | 1255 | 12 | 200 |
| 15 | 61 | 1375 | 8.2 | 300 |
| 16 | 12 | 506 | 11.6 | 210 |
| 17 | 9 | 506 | 12.6 | 100 |
| 18 | 13 | 1200 | 11.7 | 150 |
| 19 | 18 | 1325 | 11 | 300 |

### *I. Traffic Accidents in related to the rate of Superelevation Grade*

The superelevation rate is a critical geometric element in a horizontal curve to maneuver the curve, especially in the case of big-size vehicles, in which the bigger vehicles may roll out of the curve having a smaller radius. The data of superelevation rate is actual as-built road section data taken from Ethiopia Road Authority (ERA) of Sodo district office in black spot area to know the effect of super elevation rate on the accident frequency. The table below indicates that at higher super elevation rates, the accident rate is low as much as when contest to the lower super elevation grade rates in the horizontal curve and it also depends on the radius of curvature. Finally, it is concluded that super elevation was one of the precautionary elements of the safety of the road and in accident reduction. The following tables represent the consolidated crash data from all types of accidents such as Fatal, Serious Injury are prepared from the original crash data collected from the respective traffic police stations.

**Table 6: consolidated traffic fatal and serious injury accident related to super elevation**

| No. | Accident Types | Geometric characteristics | | |
|---|---|---|---|---|
| | Fatal | Volume per day | Roadway Width | Super elevation Grade |
| 1 | 33 | 1255 | 10.4 | 0.02 |
| 2 | 11 | 1325 | 11.7 | 0.06 |
| 3 | 13 | 1375 | 10.4 | 0.04 |
| 4 | 10 | 1255 | 10.6 | 0.06 |
| 5 | 26 | 1305 | 11.3 | 0.03 |
| 6 | 6 | 1200 | 12.1 | 0.08 |
| 7 | 17 | 1325 | 10.2 | 0.04 |
| 8 | 14 | 1200 | 10.8 | 0.06 |
| 9 | 39 | 1375 | 8.2 | 0.02 |
| 10 | 9 | 506 | 11.6 | 0.04 |
| 11 | 4 | 506 | 12.6 | 0.08 |
| 12 | 10 | 1200 | 11.7 | 0.06 |
| 13 | 12 | 1325 | 11 | 0.04 |

| No. | Accident Types | Geometric characteristics' | | |
|---|---|---|---|---|
| | Serious Injury | Volume per day | Roadway Width | Super elevation Grade |
| 1 | 42 | 1255 | 10.4 | 0.02 |
| 2 | 16 | 1325 | 11.7 | 0.06 |
| 3 | 23 | 1375 | 10.4 | 0.04 |
| 4 | 17 | 1255 | 10.6 | 0.06 |
| 5 | 20 | 1305 | 11.3 | 0.03 |
| 6 | 11 | 1200 | 12.1 | 0.08 |
| 7 | 18 | 1325 | 10.2 | 0.04 |
| 8 | 14 | 1200 | 10.8 | 0.06 |
| 9 | 50 | 1375 | 8.2 | 0.02 |
| 10 | 10 | 506 | 11.6 | 0.04 |
| 11 | 6 | 506 | 12.6 | 0.08 |
| 12 | 13 | 1200 | 11.7 | 0.06 |
| 13 | 18 | 1325 | 11 | 0.04 |

## VII. ACCIDENT PREDICTION MODELLING

### A. *Multiple Linear Regressions*

Multiple Linear regression analysis is one of the most widely and the earliest used methodologies for expressing the dependence of a response variable on several independent (predictor) variables). The main idea of the multiple linear regression method is to build a correlation analysis between dependent and independent variables. The form of the multiple linear regressions is as follows:

Y=b0+b1x1+b2x2+b3x1+…+bmxm

Where, Y= Dependent variable, b0= regression constant, $b_1$, $b_2$, $b_3$... BM is regression coefficients of the respective m independent variables. $x_1$, $x_2$, $x_3$………… $x_m$ is the independent variable from geometric characteristics. Then the best model is selected from them depending on the statistical requirements such as F- test, t-test, and $R^2$ test and in addition to actual and predicted values are nearer to each other or not.

***Case 1: Development of Multiple Linear Regression model for predicting Traffic Fatal and serious Injury Accident is related to sight Distance***

**Table 7: fatal and serious injury crash model relation to sight distances**

| | Coefficient | Std. Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constant | 71.075 | 14.48 | 4.906 | 0.001 |
| Traffic Volume (TV) | 0.009 | 0.005 | 2.036 | 0.019 |
| Roadway Width (RW) | -5.585 | 1.144 | -4.882 | 0.001 |
| Horizontal Curve Sight Distances (SD) | -0.105 | 0.091 | -1.16 | 0.027 |

Number of Data = 14
**Coefficient of determination ($R^2$) = 0.886 (88.6%)**
**Significance Test of Regression Equation (F) = 25.83**
**Result…………………….. Accepted**

| | Coefficient | Std. Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constant | 99.97 | 14.060 | 7.111 | 0.000 |
| Traffic Volume (VT) | 0.005 | 0.004 | 2.115 | 0.029 |
| Road Width (RW) | -7.636 | 1.110 | -6.878 | 0.000 |
| Horizontal Curvature Sight Distances (HCSD) | -0.151 | 0.088 | -1.97 | 0.012 |

Number of Data = 14
**Coefficient of determination ($R^2$) = 0.920 (92%)**
**Significance Test of Regression Equation (F) = 38.336**
**Result………………………………. Accepted**

The table shows the goodness of the fit of the model with an $R^2$ value of 0.886, 0.92, and t- ratio > 1.96 and an F - ratio equal to 25.83, 38.336, and P-value < 0.05 respectively.

### A. *Validation of the developed Model*

A plot is drawn between the observed number of Fatal and serious Injury accidents and the predicted number of fatal and serious injuries as shown in the figure below. The graph indicates the closeness between the observed and predicted values. Hence the developed Multiple Linear Regression model is said to be validated and is more appropriate to use for the analysis.

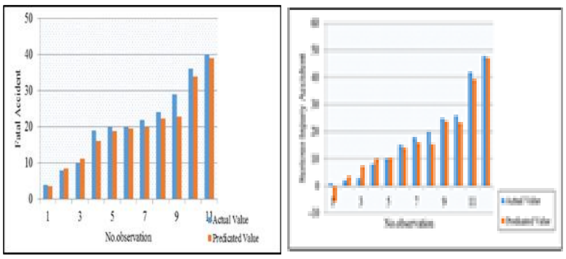



**Figure 8: Validation of the developed model for traffic fatal and serious injury accident**

### B. *Analysis of Traffic Fatal and serious Injury Accidents related to sight Distance*

From fig below in fatal accidents, for a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents is 37 for a sight distance of 20 m. When the sight distance is increased to 100m, for the same conditions, the rate of traffic fatal accidents is 25, which indicates that 32.43% of fatal accidents are reduced on two-lane rural roads by increasing the sight distance from 20 m to 100 m. And also for a serious injury accident, for a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents is 47 for a sight distance of 20 m. When the sight distance is increased to 100m, for the same conditions, the rate of traffic serious injury accidents is 34, which indicates that 27.65% of Serious Injury accidents are reduced on two-lane rural roads by increasing the sight distance from 20 m to 100 m.

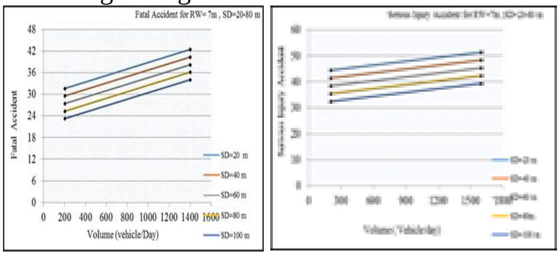


**Figure 9: analysis of traffic fatal and serious injury accident due to sight distances**

***Case 2: Development of Multiple Linear Regression model for predicting Traffic Fatal and Serious injury accident in related to Radius of Curvature***

The table below for both fatal and serious injury accidents shows the goodness of the fit of the model with an $R^2$ value of 0.894, 0.73 and t- ratio > 1.96 and an F - ratio equal to 28.18, 8.883, and P-value < 0.05 respectively.

**Table 8: fatal and serious injury crash model is related to the radius of curvature**

| | Coefficient | Std. Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 106.179 | 21.76 | 4.879 | 0.001 |
| Volume of Traffic (VT) | 0.02 | 0.006 | 2.278 | 0.008 |
| Roadway Width (RW) | -7.881 | 1.540 | -5.117 | 0.009 |
| Radius of Curve (RC) | -0.018 | 0.008 | -2.841 | 0.042 |

Number of Data =14
**Coefficient of determination ($R^2$) = 0.894 (89.4%)**
**Significance Test of Regression Equation (F) =28.181**
**Result.................................... Accepted**

| | Coefficient | Std. Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 158.163 | 52.205 | 3.030 | 0.013 |
| Volume of Traffic (VT) | 0.01 | 0.015 | 2.059 | 0.0015 |
| Roadway Width (RW) | -12.019 | 3.694 | -3.254 | 0.009 |
| Radius of Curve (RC) | -0.10 | 0.019 | -3.0182 | 0.0010 |

Number of Data =14
**Coefficient of determination ($R^2$) = 0.73 (73%)**
**Significance Test of Regression Equation (F) =8.883**
**Result...................................... Accepted**

***A. Validation of the developed Model***

The graph indicates the closeness between the observed and predicted values for both fatal and serious injury accidents.

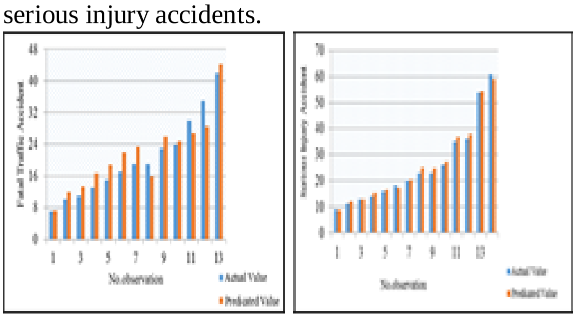


**Figure 10: Validation of the developed model for traffic fatal and serious injury accident**

***B. Analysis of Traffic Fatal and serious Injury Accidents in related to the Radius of Curvature***

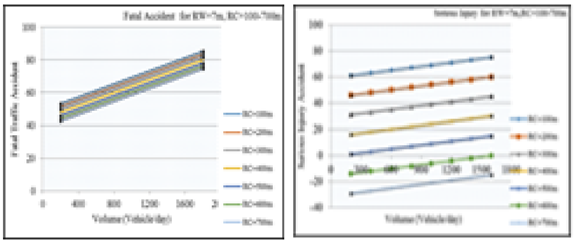


Figure 11: analysis of traffic fatal and serious injury accident due to the radius of curvature

For fatal accidents, a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents is 68 for a radius of curvature of 100 m. When the radius of curvature is increased to 500m, for the same conditions, the rate of traffic fatal accidents is 52, which indicates that 23.52% of fatal accidents are reduced on two-lane rural roads by increasing the radius of curvature from 100 m to 500 m. Also for serious injury accidents, a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents is 72 for a radius of curvature of 100 m. When the curve radius is increased to 400m, for the same conditions, the rate of traffic serious Injury accidents is 22, which indicates that 69.44% of Serious Injury accidents are reduced on two-lane rural roads by increasing the curve radius of 100 m to 400 m.

***Case 3: Development of Multiple Linear Regression model for predicting Traffic Fatal and Serious injury accident is related to Road Width***

**Table 9: fatal and serious injury crash model is related to road width**

| | Coefficient | Std.Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 116.38 | 22.66 | 5.136 | 0.000 |
| Volume of Traffic (VT) | 0.012 | 0.008 | 1.953 | 0.018 |
| Roadway Width (RW) | 9.787 | 1.820 | -5.378 | 0.000 |

Number of Data =14
**Coefficient of determination ($R^2$) = 0.739 (74%)**
**Significance Test of Regression Equation (F) =15.564**
**Result.................................... Accepted**

| | Coefficient | Std.Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 117.82 | 23.352 | 5.045 | 0.000 |
| Volume of Traffic (VT) | 0.0178 | 0.009 | 2.641 | 0.05 |
| Roadway Width (RW) | -9.165 | 1.875 | -4.887 | 0.000 |

Number of Data =14
**Coefficient of determination ($R^2$) = 0.789(79%)**
**Significance Test of Regression Equation (F) =12.179**
**Result.................................... Accepted**

### *A. Validation of the developed Model*

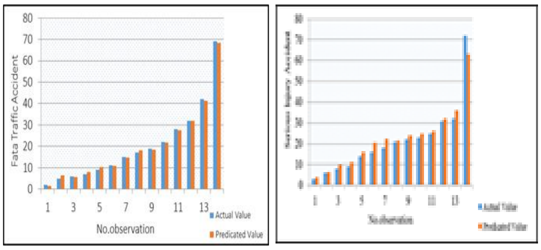



**Figure 12: Validation of the developed model for traffic fatal and serious injury accident**

### *B. Analysis of Traffic Fatal and serious Injury Accidents related to Road width*

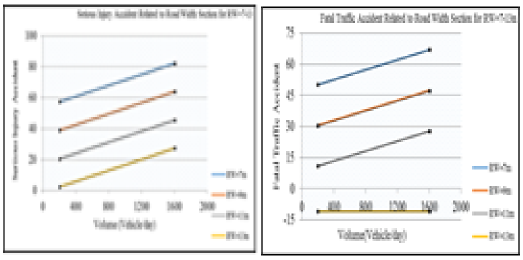


**Figure 13: analysis of traffic fatal and serious injury accident due to road width**

From analysis for the fatal accident, a traffic volume of 1000 veh/day, the occurrences of fatal accidents are 59, for a road width of 7 m. When the road width is increased to 11 m, for the same condition, the rates of fatal accidents are reduced to 17. Thus the rate of fatal accidents can be reduced to 71.18% for an increase in road width of 4 m from the existing road width. Also for serious injury accidents, a traffic volume of 1000 veh/day and a road width of 7 m, the rates of accidents are 72. For an increase in road width from 7 m to 11 m, the rate of Serious Injury accidents is reduced to 34. This indicates that by increasing a road width of 4 m, apart from the existing road width, Serious Injury accidents are reduced to 52.77%.

### *Case 4: Development of Multiple Linear Regression model for predicting Traffic Fatal and Serious injury accident in related to Vertical Curvature*

**Table 10: fatal and serious injury crash model is related to vertical curvature**

| | Coefficient | Std.Error | t-ratio | P-Value |
|---|---|---|---|---|
| Constants | 4.295 | 12.452 | 0.345 | 0.737 |
| Volume of Traffic (VT) | 0.021 | 0.006 | 3.223 | 0.008 |
| Roadway Width (RW) | -1.472 | 0.906 | -1.96 | 0.013 |
| Vertical Curvature (NVC) | 4.177 | 1.657 | 2.521 | 0.028 |

Number of Data = 15
**Coefficient of determination ($R^2$) = 0.750(75%)**
**Significance Test of Regression Equation (F) =10.98**
**Result.................................. Accepted**

| | Coefficient | Std.Error | t-ratio | P-Value |
|---|---|---|---|---|
| Constants | 14.745 | 19.728 | 0.747 | 0.47 |
| Volume of Traffic (VT) | 0.028 | 0.010 | 2.738 | 0.019 |
| Roadway Width (RW) | -2.845 | 1.435 | 1.982 | 0.007 |
| Vertical Curvature (NVC) | 4.749 | 2.635 | 2.809 | 0.009 |

Number of Data =15
**Coefficient of determination ($R^2$) = 0.789(79%)**
**Significance Test of Regression Equation (F) =8.139**
**Result.................................. Accepted**

### *A. Validation of the developed Model*

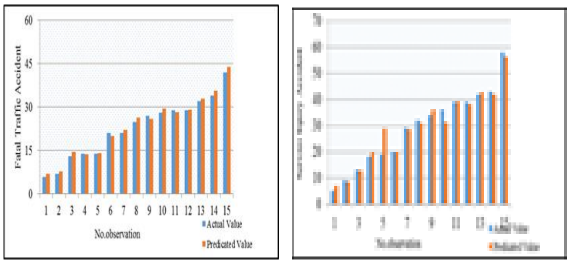



**Figure 14: Validation of the developed model for traffic fatal and serious injury accident**

### *B. Analysis of Traffic Fatal and serious Injury Accidents in related to Vertical Curvature*

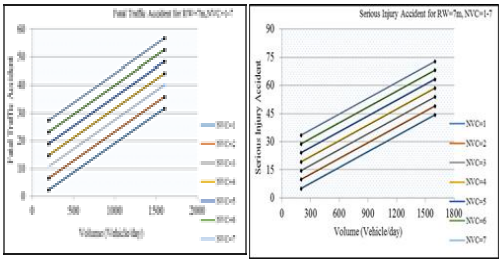



**Figure 15: analysis of traffic fatal and serious injury accident due to vertical curvature**

For the fatal accident, a traffic volume of 1000 veh/day and a road width of 7 m, the rate of fatal accidents are 42 when the number of vertical curves per km length of the road is 7 and is 17, for the presence of single vertical curve per km length of the road. This indicates that by providing a single vertical curve per km length of the road, the fatal accidents are reducing at the rate of 59.52%. Similary for a serious injury accident, a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents is 52 when the number of vertical curves per km length of the road is 7 and is 27 for the presence of single vertical curve per km length of the road. This indicates that the rate of Serious Injury accidents will be reduced by 48.07% by reducing the number of vertical curves per km length of the road from 7 to 11m.

***Case 5: Development of Multiple Linear Regression model for predicting Traffic Fatal and Serious injury accident is related to superelevation Grade***

**Table 11: fatal and serious injury crash model is related to superelevation grade**

| | Coefficient | Std.Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 63.019 | 28.144 | 2.239 | 0.05 |
| Volume of Traffic (VT) | 0.002 | 0.007 | 1.9325 | 0.001 |
| Roadway Width (RW) | -3.197 | 2.464 | -2.297 | 0.027 |
| Super elevation Grade (HG)) | -305.026 | 122.299 | -2.494 | 0.034 |

Number of Data = 13
**Coefficient of determination ($R^2$) = 0.78(78%)**
**Significance Test of Regression Equation (F) =10.402**
**Result...................................... Accepted**

| | Coefficient | Std.Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 97.412 | 33.105 | 2.943 | 0.016 |
| Volume of Traffic (VT) | 0.003 | 0.008 | 2.337 | 0.044 |
| Roadway Width (RW) | -6.383 | 2.899 | -2.202 | 0.05 |
| Super elevation Grade (HG) | -219.381 | 143.856 | 1.95 | 0.016 |

Number of Data =13
Coefficient of determination ($R^2$) = 0.781(78.1%)
Significance Test of Regression Equation (F) =10.678
**Result...................................... Accepted**

### *A. Validation of the developed Model*

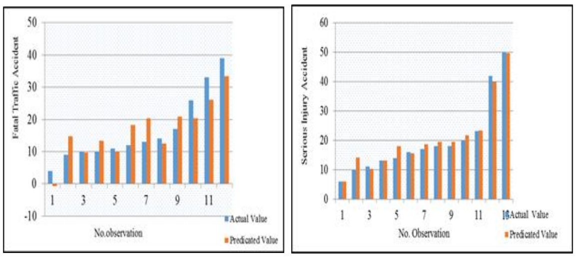


**Figure 16: Validation of the developed model for traffic fatal and serious injury accident**

### *B. Analysis of Traffic Fatal and serious Injury Accidents in related to Superelevation Grade*

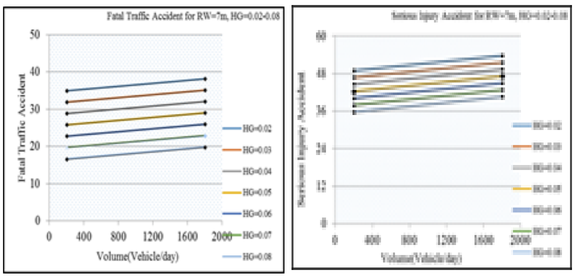


**Figure 17: analysis of traffic fatal and serious injury accident due to super elevation**

For fatal accidents, a traffic volume of 1000 veh/day and a road width of 7m, the rate of accidents are 37 for a Superelevation Grade of 0.02. When the Superelevation Grade is increased to 0.07, for the same conditions, the rate of traffic fatal accidents is 21, which indicates that 43.24% of fatal accidents are reducing on two-lane rural roads by increasing the Superelevation Grade from 0.02 to 0.07. Also, for serious injury accidents, a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents are 52 for a Superelevation Grade of 0.02 and are 39 for a Superelevation Grade of 0.07. This indicates that 25.0% of Serious Injury accidents are reducing on two-lane rural roads by increasing the Superelevation Grade from 0.02 to 0.07.

***Case 6: Development of Multiple Linear Regression model for predicting Traffic Fatal and Serious injury accident in related to Curve Length***

**Table 12:fatal and serious injury crash model is related to curve length**

| | Coefficient | Std.Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 64.412 | 22.824 | 2.822 | 0.015 |
| Volume of Traffic (VT) | 0.002 | 0.005 | -2.297 | 0.0017 |
| Roadway Width (RW) | -4.807 | 1.5993 | -3.016 | 0.011 |
| Curve Length (CL) | 0.057 | 0.019 | 2.990 | 0.011 |

Number of Data = 16
**Coefficient of determination ($R^2$) = 0.76(76%)**
**Significance Test of Regression Equation (F) =12.64**
**Result...................................... Accepted**

| | Coefficient | Std.Error | t- ratio | P-Value |
|---|---|---|---|---|
| Constants | 102.9 | 34.776 | 2.959 | 0.012 |
| Volume of Traffic (VT) | 0.003 | 0.008 | 1.96 | 0.0014 |
| Roadway Width (RW) | -8.438 | 2.428 | -3.475 | 0.005 |
| Curve Length (CL) | 0.046 | 0.029 | 1.984 | 0.039 |

Number of Data =16
Coefficient of determination ($R^2$) = 0.74(74%)
Significance Test of Regression Equation (F) =11.299
**Result...................................... Accepted**

### *A. Validation of the developed Model*

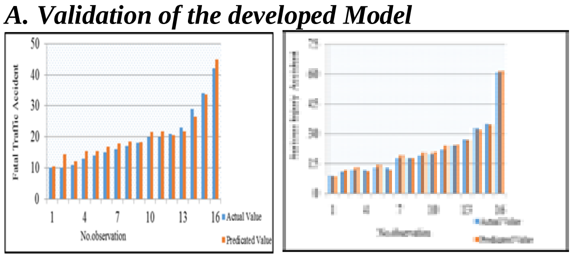


**Figure 18: Validation of the developed model for traffic fatal and serious injury accident**

### *B. Analysis of Traffic Fatal and serious Injury Accidents related to* Curve Length

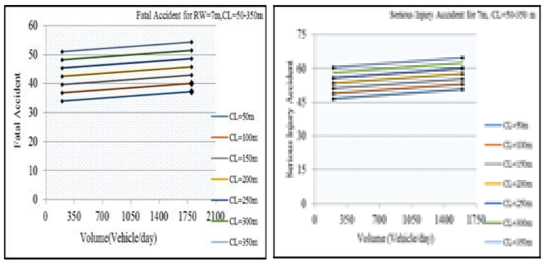


**Figure 19: analysis of traffic fatal and serious injury accident due to curve length**

For the fatal accident, a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents are 52 for a Curve Length of 350 m and are 36 for a decrease in Curve length of 50. This indicates that 30.76% of fatal accidents are reducing on two-lane rural roads by reducing the Curve length from 350 m to 50 m. Likewise, for serious injury accidents, for a traffic volume of 1000 veh/day and a road width of 7 m, the rate of accidents is 62 for a Curve length of 350 m. when the Curve length is decreased to 50 m, for the same conditions, the rate of traffic fatal accidents is 46, which indicates that 25.80% of Serious Injury accidents are reducing on two-lane rural roads by decreasing the Curve length from 350 m to 50 m.

## VIII. SUMMARY AND CONCLUSION

The rapid growth of population and vehicles in the developing countries is increasing the traffic problems day today. These traffic problems will multiply in a short time due to poor administration and planning of the transportation system that leads to various types of accidents on the roads. The geometry of the road surface is one of the primary causes for the occurrence of major accidents, especially on the highways.

The models are analyzed and the results indicated that for a traffic volume of 1000 veh/day on a rural two-lane two-way road having 7 m width, the fatal accidents are reducing at the rate of 32.43% by increasing the sight distance from 20 m to 100m. Similarly, the fatal accidents are reducing at the rate of 23.52% for an increase in the radius of curvature from 100 m to 500 m, keeping all other conditions constant. For the same traffic volume, when the road width is alone increased from 7 m to 11 m, the fatal accidents are reducing at the rate of 71.18%. The reduction in fatal accidents is 59.52% for a road width of 7 m and a traffic volume of 1000 veh/day when the vertical curves are reduced from 7 to 1. The numbers of fatal accidents are reduced at the rate of 43.24% for the increase in superelevation grade from 0.02 to 0.07, keeping the other conditions constant. Similarly, fatal accidents are reduced at the rate of 30.76% for a decrease in curve length from 350 m to 50 m for the same conditions. Similar results are obtained for an increase in road width from 7 m to 11 m and the cases of serious injury and light injury accidents.

## IX. RECOMMENDATIONS

The following recommendations are made from the study conducted at Wolaita Zone on a rural two-lane two-way road.

1. A minimum of 100 m Sight distance shall be maintained to limit the number of fatal and serious injury accidents
2. A minimum of 300 m radius of curvature is essential to minimize the rate of accidents
3. The road width can be increased from 7 m to at least 9 m at the points of curvatures to increase further sight distance and to reduce the conflicts on the two-lane two-way road
4. The number of Vertical curves on roads can be limited to 2 or 3 per km length of road
5. A minimum Superelevation of 0.07 is highly recommended on all highways to mitigate the number of accidents, especially in the sharp curve area.

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