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Master of Transportation Sciences

Master's thesis

Effect of inter-urban road geometric features and environmental condition on crashes involving commercial vehicles, Tigray Region

Danait Gebremichael Gebremeskel

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :

Prof. dr. Tom BRIJS

CO-SUPERVISOR :

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LOCAL- SUPERVISOR: Assistant Prof. Ashenafi Aregawi

PREFACE

This report presents the first and second part of the proceeding work "master's thesis" as part of the study program in masters of transportation sciences "Traffic safety" at Hasselt University. The study aims for research-based evidence effect of interurban road geometric features and environmental conditions on crashes involving commercial vehicles in Tigray region and will recommend measures to improve traffic safety of interurban areas. Despite its importance, there is no study conducted regarding the interurban geometric effect on road crash using CPM for this specific area. Thus, the paper can be used as an input for roadway safety improvement for the Tigray region.

Acknowledgment

I want to thank God Almighty, who gave a strong point to do this thesis with full of health and to study abroad

I express my thankfulness to Prof. Dr. Tom Brijs , Prof. Ir. Pirdavani Ali and Assistant Prof. Ashenafi Aregawi who was supervising me and for the constructive guidance throughout my master’s thesis period.

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I want to be appreciative of my families who helped me to achieve my goals.

I am thankful to VLIR and Hasselt university who provide me this scholarship and master's opportunities in Belgium.

Abstract

Road engineers and designers practice the crash prediction model as a valuable instrument. But there are limited studies regarding the crash reduction model in Ethiopia, especially in the Tigray region. This study aims to assess the effects of interurban roadway geometric characteristics on crash involving commercial vehicles in the Tigray region. The model has developed for all types of crashes severities as well as for fatal and severe injuries over three (2017-2019) years of the study period. Data was collected from three traffic police office districts for 29 road sections and each section differs from 0.16km to 3.42km. Geometric design features(shoulder material, shoulder width, carriageway width, number of vertical and horizontal curves, number of gradients, section length, village settlement, ADT, and terrain types) were collected from Ethiopia road authority design reports.

Due to the dispersion of the count data, Negative binomial regression distribution was used to develop the model. Two types of models namely simple and full model were developed for both (total crash severity and severe and fatal injuries) response variables. The number of horizontal curves, terrain type, ADT, and length of road section was found to be statistically significant explanatory variable with $p < 0.05$ for the total crash involvement. while the Number of vertical curves, the number of the horizontal curve, and ADT were significant explanatory for the fatal and severe crash involvement. For every one-unit increase in the number of horizontal curves per section length, there was an increase of 0.116 on the log count of total traffic counts. Similarly, for every unit increase on length of the road section and ADT, there was an increase of 0.575 and 1.354 on the log count of total traffic crash respectively. For a 1 unit rise of the length of the road section, the incident rate in terms of total road traffic crash increases by 77.7%. Similarly, for every one-unit increase in the number of horizontal curves per section length, there was an increase of 0.077 on the log count of severe and fatal traffic counts. Therefore, during highway planning and design, engineers should not only bother on curve radius and grade but also need to limit the density of grade, horizontal and vertical curve density because the developed model on this research showed us the increase in density of these geometric parameters increases traffic crashes.

Keywords*: *Crash prediction model, Geometric features, Road traffic crash Commercial vehicles, Two-way two- lane rural roads, Tigray region

TABLE OF CONTENT

Contents

TABLE OF FIGURE

LIST OF TABLES

LIST OF ABBREVIATIONS

AIC Akaike’s Information Criterion

AADT Annual Average Daily Traffic

ADT Average Daily Traffic Volume

’BIC Bayesian information criterion

CPM Crash Prediction Model

CR Cumulative residual

CCR Curvature Change Rate

DS design standards

E.C Ethiopian calendar

ERA Ethiopian road authority

G Gradients

GLM Generalized Linear Model

GVIF Generalized Variance inflation factor

HSM Highway Safety Manual

IR Incident Ratio

LRT Likelihood Ratio Test

MASL Meters Above Sea Level

NB Negative binomial

NHC Number of horizontal curves

NTC Number of total road crash counts

NVC Number of vertical curves

PHV peak hour traffic volume

RTC Road traffic crash

SPSS Statically package for Social Sciences

SW Shoulder width

TRA Tigray road authority

TT: Terrain type

UTM Universal Traverse Mercator

VIF Variance inflation factor

VS Village settlement within the road segment

WHO World health organization

GPS Global Positioning System

1 BACKGROUND

1.1 Introduction

Road traffic crash (RTC) remains intolerable throughout the world where 1.35 million death occurs each year and it becomes the 8th foremost cause of death for all ages (WHO, 2018). Further, road traffic is the first reason for mortality for adults and children particularly for 5-29 years of age and around 3-5% of the Gross Domestic Products (GDP) of the government is lost due to road crashes (WHO, 2018). According to World health organization (WHO) report, there is a relation between the income level of countries and risk of road traffic deaths, low- income countries have an average rate of 27.5 death per 100,000 population compared to high-income countries with an average rate of 8.3 death per 100,000 population (3 times lower risk) (WHO, 2018). The amount of road traffic death in Africa and South-East Asia has shown a higher rate of death per 100 population (26.6% and 20.7%) respectively, followed by Eastern Mediterranean and Western Pacific with 18% and 16.9% death per 100,000 population consecutively. The lowest rate of traffic death per 100,000 population was scored by America and Europe. However, the rate of death decrease was scored by the countries that have scored lower road death (America, Europe, and Western Pacific regions). Hence, this indicates that road traffic crash is upturning in a developing country and it requires serious remedies.

RTC involves different types of road users due to diverse contributing factors like road, vehicle, and geometric characteristics (GERBA, 2019). Additionally, looking at the distribution of death by road user type in Africa from WHO, (2018) report, it indicated each vulnerable road user and passenger (driver) of four-wheeled vehicles are susceptible to mortalities with 40% deaths as shown in figure 1. Total RTC by road user types in Ethiopia were also classified for the study of Abegaz et.al (2019), then the vulnerable road users belong to 36% and passenger vehicle occupants to 35% of RTC followed by drivers. Where the vulnerable road users were further divided into cyclists as 2.9%, pedestrians with 12.1%, and motorcyclists of 21. % of the total vulnerable road users' crashes. Thus, vulnerable road users and passengers are the most affected road user types in developing countries, especially in Africa.

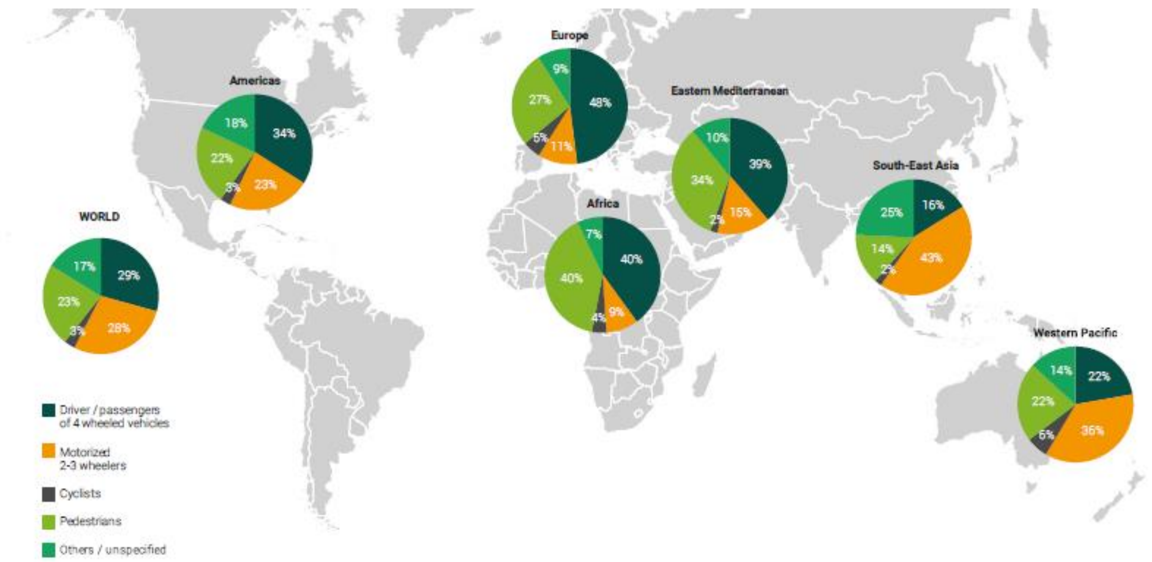


FIGURE 1 Distribution of death by road user type for the whole world (WHO, 2018).

The main health, economic, and social problem in a developing country are due to RTC (GERBA, 2019). Ethiopia is one of the developing and largest countries in African, facing in delivering wellorganized, consistent, comfortable, and safe transportation facilities. Immense road safety disaster is happening to Ethiopia as stated by the Ethiopian Federal police commission report in Abegaz & Gebremedhin,(2019) study and it specified that thousands of economically energetic road user communities pass away annually due to RTC. Similarly, (WHO, 2018) report predicted that in Ethiopia 26.7 road crash fatalities per 100,000 population to occur in the 2016 time period and the increase of RTC per 100,000 population in Ethiopia is shown in figure 2 using nine (2008-2016) years of data. Besides, Abegaz & Gebremedhin, (2019) used two city administrations and nine regions between 75, 271 members of the community to held review about the occurrence of injury and crashes in Ethiopia concerning 12 months. Then, the result presented with 123 road crashes and out of these total crashes, 28 (37% road crashes per 100,000population) belong to fatalities at 95% of the confidence interval. Hereafter, Ethiopia is facing a challenge regarding road safety issues.

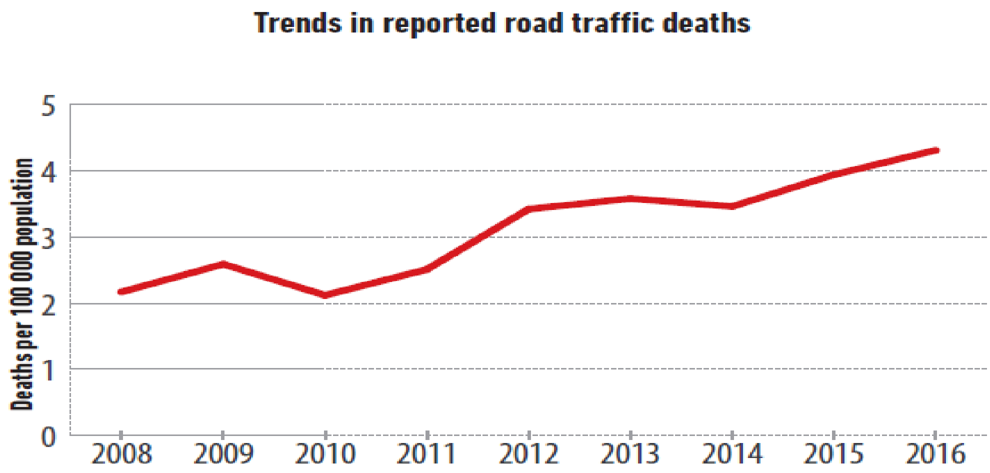


FIGURE 2 Tendencies of a road traffic crash for 2008-2016 time period in Ethiopia (WHO, 2018).

The primary road crashes in Ethiopia are shared by Addis Ababa city, which is the capital city of Ethiopia. However, there are other cities or regions in the country facing road traffic crashes as well and the Tigray region is among these cities. Tigray region is located in the northern part of Ethiopia and the terrain features of the region especially, the eastern part of Tigray is composed of mountainous and escarpment terrain types (Wedajo et al., 2017). This geographic location and the terrain types might be the factors for road crashes. The region is composed of different multifaceted landforms with; lowland (altitude range of fewer than 500.1500 meters above sea level(MASL)), highlands (with 2300.3200 MASL altitude) and mountain peaks up to 3935 MASL high(Aynalem Adugna, 2018). As well, the climate is mainly considered as the dry season for around 10 months (from September until June) and rainy season for two months (July and August). The region has five administrative zones with 47 districts (Weredas) and 673 sub-districts (Tabias) (Tigrai State, 2016).

A study carried out to assess the RTC of different regions in Ethiopia shows that Oromia and Amhara regions have larges road traffic deaths followed by Addis Ababa and Tigray regions according to the Ethiopian Federal police commission report in 2013 (Tulu, 2015). Then looking at the population size Oromia region belongs to 35,467,001, Amhara (21,143,988), Tigray regions (5,247,005), and Addis Ababa (3,434,000) regarding the survey conducted on 2017 (EthioVisit, 2017). Even though the number of fatalities in Tigray region is comparatively lower than Amhara and Oromia regions, calculating the rate of road traffic death per population size will be higher because Amhara and Oromia regions have much higher population compared to Tigray regions, for example, Oromia region has 37.64% population size, Amhara with 22.4% but Tigray region has 5.57% of population size compared with the whole regions in Ethiopia. Therefore, it can be concluded that the Tigray region has a higher RTC rate per population next to Addis Ababa compared with the other regions. Thus, this study will be carried out in the Tigray region of rural two-lane roads ways.

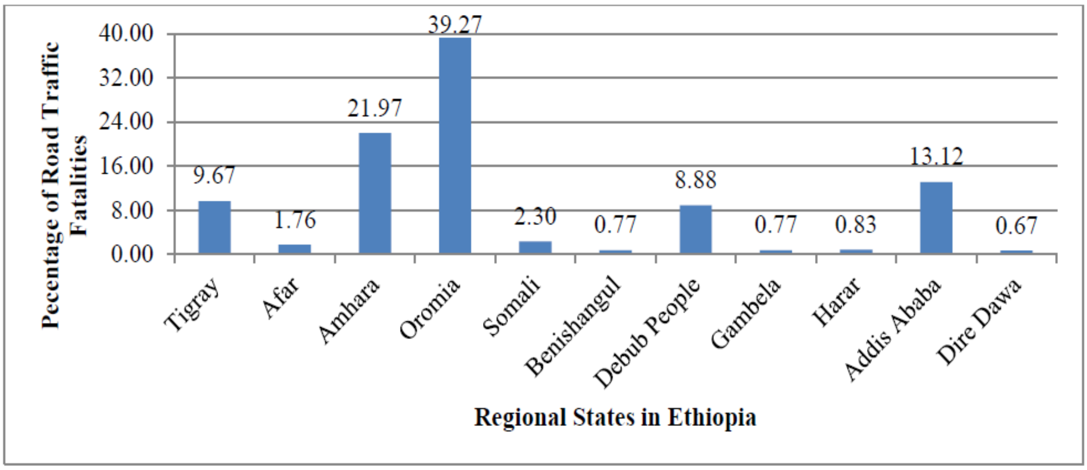


FIGURE 3 Road traffic fatalities distribution in percentage for different regions of Ethiopia (Tulu, 2015).

Deprived condition of vehicles, poor road network, the standard of road situations, irresponsible behaviour of drivers, failure to execution is core factors that contributed to the growth incident of a traffic crash in Ethiopia (Persson, 2008). Factors related to driver and roadway design have a significant role in road traffic occurrence (Abdel-Aty & Radwan, 2000). Fatal and severe injuries have a strong connection with infrastructure in road collisions and studies have shown that general road safety will be improved if road infrastructure is given better attention and upgraded (WHO, 2018). Nonetheless, new roads and infrastructure constructed in Ethiopia do not apply star rating or road Audits (WHO, 2018). Thus, many studies(Ackaah & Salifu, 2011; GERBA, 2019; Tulu, 2015) have been carried out taking in to account different contributing factors like road environment, geometric characteristics, design parameters, exposure data, site features to understand the safety performance of infrastructure for different types of crash and to improve the unsafe roadway networks. Nonetheless, there are fewer studies regarding rural two-lane roadways in developing countries and there is no study found specifically for the study location of this study.

RTC is taking human life due to many reasons as mentioned above and its amount is increasing through time in Tigray, Ethiopia as well as, roadway characteristic is one of the contributing factors for the occurrence of road crashes. Thus, the study will assess the contributing factors of geometric and contextual factors in road users crash at rural two-way two-lane roads, and at the end countermeasure and recommendation for rural roadway safety will be forwarded.

1.2 Problem Statement

Road crashes are increasing continuously in African countries and the safety issue of roadway in these regions seems to be a serious problem. Strategies, policies, and enforcement regarding the protection of vulnerable road users and safety matters of highway networks are insufficient. Most of the African regions have unsatisfactory road safety audits, traffic law implementation, emergency service after the crash occurred, and traffic rules (WHO, 2018). Thus, enormous effort and commitment are needed from every individual to improve the safety of these roads.

Several human lives, social and economic disasters happened due to RTC in Ethiopia. Based on the annual crash report, passengers represent roughly half (52%) of death and severe injury from RTC in the region (ATCR, 2018). Following the capital city of the Tigray region (Mekelle), most crashes occur in the interurban area due to public transport services (e.g. in the eastern region of Tigray) (ATCR, 2018). Pedestrians are the next largest (37%) of victims of severe injury and fatality due to RTC at interurban areas in the region (TTR, 2018). Five years (2010-14) crash data indicates that commercial vehicles followed by Government-owned vehicles have high crash involvement (TTR, 2018). Mostly used public transport in the interurban areas are vehicles like van and buses. Van is a minibus type that has to carry capacity of up to 12 passengers. According to Hirpa,(2016), vans and automobiles have been recorded as the highest classified vehicles in crash involvement in Addis Ababa as shown in table 1. This is similarly the case happening in Tigray interurban areas.

TABLE 1 Percentage of the vehicle involved in the crash in a year (Hirpa, 2016)

No	**Vehicle type**	**Year**			**Average**	**Percent of a fatal crash**
		2005	**2006**	**2007**		
1	Vans	23	69	77	56	14
2	Automobile	47	54	40	47	12
3	Pick-ups	43	34	39	39	10
4	Taxi	64	5	36	35	9
5	MGMV	21	37	35	31	8
6	Station wagon	21	27	37	28	7
7	HGMV	29	28	20	26	7
8	Mid buses	26	27	18	24	6
9	Buses	13	27	14	18	5
10	Others	33	55	60	49	13
11	Unknown	47	28	40	38	10
Total		**367**	**391**	**416**	**391**	**100**

Several fatalities and severe injuries occurred in the roadway segment and the probability of the rate of crash frequency in the road segment will increase when the vehicle cover longer distances (Ackaah & Salifu, 2011). Conferring to the Tigray crash traffic report, vehicles moving in straight followed by turning to the right and turning to left have caused a higher number of fatalities and severe injury crashes in terms of the vehicle type of movement crashes in the eastern region of Tigray. Moreover, a summary of roadway geometric conditions in the total crash type showed that straight roadways are the first most frequent type of roadway geometric variable that causes the number of fatalities and injuries followed by sharp horizontal curves and lanes with high grades (TTR, 2018). Quality and road infrastructure network in Ethiopia related to other developing countries is destitute but, since 1997, there is a great improvement in the road network (Tulu, 2015). A study conducted among interurban transport drivers in Ghana and Ethiopia showed that drivers complain about speeding, road curvature, pavement condition, and environmental factors as risk factors of RTC (Ojo et al., 2018; Wedajo et al., 2017). Also, a study conducted the crash prediction model (CPM) for road tunnel found out that annual average daily traffic per lane, percentage of trucks, number of lane and tunnel length were found to be the significant variables to be considered in the frequency of high crash risks (Caliendo et al., 2013). Sweden has also adopted a Vision Zero goal that aims to prevent severe injuries and fatal in RTC to save lives by having only slight injuries because having zero crash is ideal which cannot happen (WHO, 2018). Thus, the study of this study will focus on severe and fatal injuries in rural roadways due to commercial vehicles.

Furthermore, integrating safety features into road geometric design can improve and modify the problem of road crash frequency in road users GERBA,(2019) and incorporate these features, roadway network locations and severity level should be assessed by different techniques like using CPM. And several studies Ackaah & Salifu, (2011; Tulu, (2015) have indicated, road safety can be improved if these roadways' geometric characteristics are properly designed and constructed. Thus, the study will identify which geometric features are related to RTC in the study area. Generally, the roadway geometric typical of rural two-lane roadway in the Tigray region for the study area will be assessed to know their contribution to road crashes by developing a regression model. This developed regression model (CPM) will help to know the safety condition of the roadway network and the contributing factors of roadway features for the crashes as well as the locations that have a higher number of crashes. Thus, identifying the contributing factors of roadway features in RTC and the road segment with several crashes will be used as an indicator for applying countermeasures in that area.

1.3 Research Aim and Objectives

The primary aim of this research is to assess the effects of interurban roadway geometric characteristics and contextual conditions for the frequent RTC (fatalities and severe injuries) involvement by public transport commercial vehicles (code 3) and provide a recommendation to improve passenger safety. According to general vehicle license type in Ethiopia, commercial/ business vehicle is designated as code 3 vehicles (for example Vans, Taxi, and Buses). The second aim is to formulate an appropriate road user crash model for two-way two-lane rural roads in the northern part of Ethiopia, Tigray. These research aims are listed into three research objectives and these includes;

Specific objective

- To identify the contributing factor for fatal and severe injuries of passengers, pedestrians, and drivers due to commercial vehicles in the Tigray region.
- To explore the effect of each variable on crashes and identify explanatory variables that have a maximum reduction in the variability of response.
- To estimate the relative safety of rural roadway by developing the crash prediction model.

1.4 Research Questions

The main idea of this study is the cause of fatal and injury crashes by commercial public transport vehicles related to geometric characteristics in the interurban areas of Tigray region. The study will have the following research questions to address the issue.

The study will answer the following research questions:

- Which roadway geometric characteristics and environmental conditions causing the fatalities and severe injuries due to the involvement of commercial vehicles in the interurban area?
- What is the effect of the explanatory variables on severe and fatal injuries and which explanatory variables have a significant effect in reducing road traffic crash?
- How is the relative safety of the rural two-way two-lane roadway?

1.5 Significance of the study

Country development can be seriously affected by rate of traffic crash thus, identify the effect of roadway geometry design on traffic crash in this study can help Road Authorities to assess their design manuals difficulties.

Road authorities can be initiated to evaluate their design manuals and consistency of the country due to this study. Moreover, road maintenance cannot be handled for the whole road routes thus, identifying locations that have high crash locations due to shortage of roadway geometric design can be used for road maintenance.

This study will identifying the road geometry effect with road traffic crash using the existing road traffic crash data and after developing the model traffic crash can be predicted for the future in those locations as well as the model can also be used to predict traffic crash rate in locations that have the similar roadway geometric designs as the study locations.

2 AN EXPLANATORY STUDY OF LITERATURE

2.1 Road Corridor Selection for The Crash Prediction Model

The literature review that will be discussed below is regarding the crash frequency modeling for roadway networks especially for rural roads because the study focuses is on that type of facility. There are many reasons why many crash prediction models have not complete a set of road design parameters (van Petegem et.al 2014). This is due to, shortage of data availability (several roadways lack data regarding road characteristic which will be difficult to look at their relationship with crash frequencies). Beside to lack of data availability, to study all the roadways in the county or region will be quite difficult and impractical due to time and cost limitation, so to handle any studies it is a must to specify roadway corridors to deal with.

For the study of Tulu (2015), the road corridor was selected from Ethiopia roadways based on the crash data history from the Federal police commission i.e. roadway networks that have more crash data history(58%) were highway connecting among Oromia region and Addis Ababa city. Therefore, the road corridor for the study was selected to be rural two-lane roads that connect these two regions. Moreover, the study carried out in Ghana used two-lane single carriageway rural road segments for selecting the road section (Ackaah & Salifu, 2011). During that study three different highway categories that are roads which link (regional capital to the national capitals, regional capital to one another, and district capital to the regional capitals) were applied using stratified random sampling technique in the road section procedure. During road corridor selection, they have used crash data of road segments that have not to be improved for the study period.

To develop the model, Ackaah et al,(2011) used 14 corridors and these corridors were divided into a different link where the links are junction to junction, town to town, town to junction, junction to any major landmark and town to any major landmark), were landmark is either river or bridge. Were those all links belong to the three highway categories and covering 186.3km total length. While in this study regional road highway from Tigray regions will only be used since there is a limitation of the study period and cost.

Similarly, Tulu (2015) considered Addis Ababa to be a benchmark and the roads that are inside a 100km radius staring from the benchmark were taken as a study road corridor. Tulu (2015) have also specified, asphalt roads are used by considerable motorized and non-motorized vehicle than gravel or earth roads and due to that only asphalt roads are considered for the study of pedestrian crash modeling for a rural two-lane road. Thus, this study will only consider only asphalt rural roads and the road corridor will be on roads that connect from the capital city of Tigray (Mekelle) to other roads of cities within the region.

2.2 Road Segmentation Techniques

Segmentation is described as a road segment that has an ending and starting in a point where the road characteristic taken for segmentation starts to have different types in the road network then, the new segment will be considered (homogenous segmentation). For example, if Annual average daily traffic (AADT), shoulder width, and other parameters are taking as criterial for segmentation, then new segment road will start when one of these variables have changed (Green, 2018). The selection of segments is important to facilitate diverse traffic volume, speed, road characteristics geometry to know the effect of different variables on crashes (Ackaah & Salifu, 2011).

Method of segmentation which means the organization of data into different homogenous entities is the main comprehension in the development of CPM (AASHTO, 2010). Portions of roadway containing similar vehicular, geometrical, and operational features are considered as homogenous roadway segments. Besides, the road segment should be investigated differently if, considerable alteration on the features is perceived from one location to another (AASHTO, 2010) but, considering several criteria might leads to short segmentation. Another study also justifies that there will be very short homogenous segments when multiple variables are including during segmentation (Resende & Benekohal, 1997). However, if the criteria are not numerous the segmentation will not be quite short(Garach et al., 2016).

On contrary, taking into account less attribute variation for segmentation can let to have a longer length of the segment but, as stated above having more attribute into consideration will also cause short segmentation and both are not preferable for prediction models (Green, 2018). For instance, if the developed models are used for network screening purpose and looking at the cost, taking longer segment length will be unfeasible as well as, out of the longer section maybe some portion of the segment might require improvement but, due to the longer segmentation all the portion of the segment will be amended which is unfair in terms of cost and time. Furthermore, additional crash data variation will occur due to short segmentation and the developed SPF model can have uncertainly (Green, 2018).

There are differences attributed, and techniques used for segmentation of roadway network, for example, speed limit, shoulder with, horizontal curve, shoulder width, and roadway attributes were used for the study of rural highway in Hungary by Borsos, Ivan, & Orosz,(2016) to segment the road network. While, Roadside hazard rating, curvature change rate(CCR), average pavement width, and AADT were used for segmentation for the study of rural roadway in Italy(Cafiso, et.al, 2010). Roadway segmentation can similarly be carried out using crash data that is a segment that has similar crash data will be clustered into the group by their crash locations (Koorey, 2009). Moreover, diverse variables are included to divide the roadway network into homogenous segments and Garach et al. (2016) have considered CCR, average paved width, and AADT, to deal with a homogenous road segment. Seven attributes (lane width, lane number, shoulder width, AADT, functional classification, curvature, and regions) have also been taken into consideration to divide rural roadway of the united states into homogenous segments. Thus, ten homogenous sections were formed due to this different attribute considering some roadway network part in that study while, there were short segments that occurred during this process but, discussion in the literature review above declared that short segment length is not suitable for modeling SPF**.** There is no proved preferable method to use for the division of road section and due to that, different studies used different techniques to apply the breakdown of roadways (Borsos et al., 2016). Koorey, (2009) also stated, data accessibility is the factor to classify roadway into segment lengths.

Estimation of the linear regression model for short road length was found out to be disagreeable instead, long road sections were desirable for the model. (Miaou & Lum, 1993). However, it was inadequate to get long road sections for roadway geometry having curved and graded geometric characteristics because these types are relatively short lengths and they are undesirable for the model. Therefore, according to Miaou & Lum,(1993), having homogeneous road sections does not apply to those cases instead, it is better to maintain fixed long road sections. Moreover, Shankar et al., (1995) Stated that homogeneousness can cause having roadway length of 1km and less value especially for geometric highway taking curved and grade features and this causes the approach to be less preferable than fixed length. Even though the fixed-length method has its drawbacks but, it is preferable compared to homogeneity. Thus, including maximum grade, number of curves in the road length(in terms of curve density), maximum radius, and so on parameter while analysis can compensate the non-homogeneity during the fixed-length approach (Shankar et al., 1995).

Two methods have been considered by Miaou & Lum, (1993) to define the road sections which were, the homogenous sectioning and fixed length. The study carried out in four-lane divided urban roadway applied fixed segmentation length and each roadway was divided into 1km length (Vayalamkuzhi & Amirthalingam,2016). Similarly, another study revealed that a homogenous section (having consistent geometric features) and fixed-length approaches are mostly used to categorize the section length of roadway segments(Shankar et al., 1995). A study handled by Cafiso et.al (2013) used the Italian motorway data to investigate the influence of segmentation in estimating SPF using different approaches together with HSM procedures and stated that, there no apparent preferred approach for segmentation in road sections. Four segment approaches (using curvature and AADT based on HSM, one curve and one tangent, fixed-length method, and the last considering constant variables in each segmentation) were evaluated to investigate the influence of segmentation in SPF of roadway sections. The study used one model which was calibrated containing several explanatory variables for each segmentation approach listed above and two other models were also calibrated considering only AADT as an explanatory variable in the model and the other one having curvature and AADT as independent variables for every four approaches. The study showed that the best result obtained for the segmentation approach was using fixed length and taking two curves and two tangents (Cafiso et al., 2013). Besides, fixed segmentation is preferable for some locations that have a shortage of data accessibility that is to minimize the problem regarding the incorrect location of crashes(Cafiso et al., 2013). As mentioned above, to proceed with the segmenting of the road network it is required the convenience of data and this study will decide later segmentation approach looking at the data and location of the study area.

During the formulation of the predictive model, there is no arranged and set minimum segment length(Cafiso et al., 2013). According to usRAP, (2016), the minimum length for the rural road to be 2 miles, for semi-urban areas of 1 mile and for urban areas to be 0.5miles were recommended during the safer road investment plans**.** However, the study in Japan has used 200m as minimum segment length, and road segment less than 200m were excluded during the crash frequency modeling (Rengarasu et al., 2009). Besides, Cafiso et al., (2013), suggested the minimum segment length to be 160m. Thus, diverse studies have recommended different minimum segment length and for this study, the lowest segment length will be identified later during the data analysis.

Two studies in Czech republic Ambros & Sedoník,(2016); Ambros et al.,(2016), have considered paved shoulder, road category, speed limit reduction, AADT, and several lanes to distribute the two region roadway in two homogenous sections. This segmentation method was also practiced by (Ambros et al., 2015) as shown in figure 4**.** Besides, during the segmentation approach road networks were divided into two-part when the segmentation exceeds more than 500 m sizes to avoid a long segment in the analysis. In this section, different segmentation approaches are discussed such as using crash data clustering group, fixed segmentation, and homogenous segmentation approach including their drawbacks. While for this study, the method of segmentation will be decided later looking at the data and location of the study areas to have a better decision because, as mentioned above the data accessibility are the factor to classify road segments.

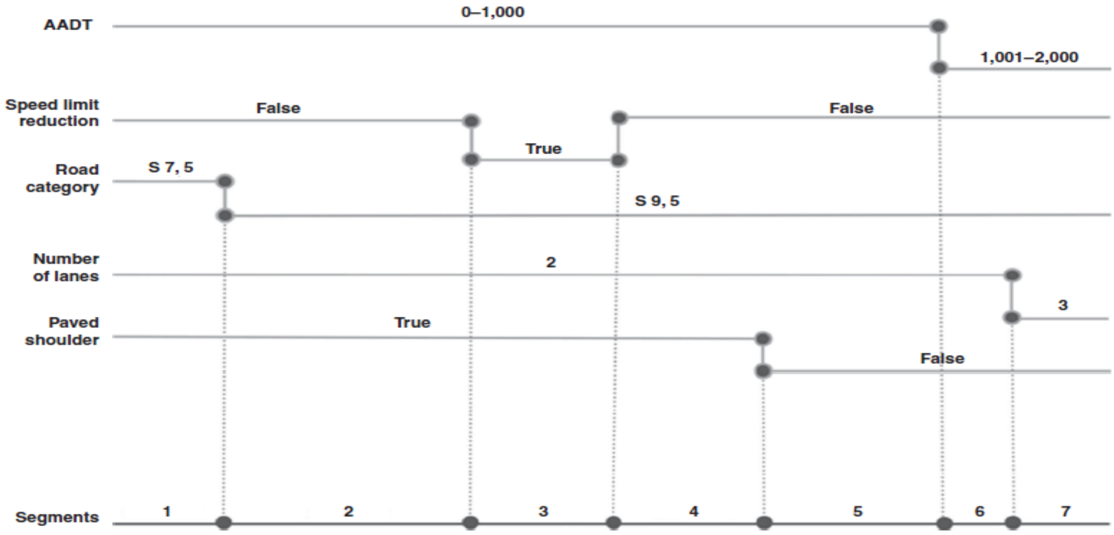


FIGURE 4 Homogenous Segmentation principle considering different variables (Ambros et al., 2016).

2.3 Roadway Geometric Characteristics and Road Traffic Crash

RTC is caused due to vehicle conditions and performance, drivers, and roadway characteristics (Vayalamkuzhi et.al, 2016). According to Peden et al.,(2004), causes of road traffic crash have been recognized as:

- Disproportionate speeding
- Light condition (traveling in dark state)
- Vehicle factors like maintenance, braking, age, and others
- Shortcomings of road design geometry, maintenance, and outline
- Lack of visibility for instance, difficult environment to the recognized vehicle or road user
- Road user visibility (deprived eyesight)
- Driving under influence (alcohol, drug or medicinal) and so on.

These factors are related to road traffic crashes and it is significant in developing counties thus, required fundamental studies and solutions (GERBA, 2019). These contributing factors are clustered in three groups as vehicle, roadway, and driver features and this study is concerned about roadway geometry effect on-road crashes. From these causative factors, the roadway will be safer if, the geometric design of the road is designed well and the cause of crash due to lack of roadway geometry is identified. Hence, Highway planners and designers are the main contributors to control roadway factors unlike, driver behaviors and vehicle factors (Vayalamkuzhi et.al, 2016).

A study in the location of Mekelle to Mokoni road section by Wedajo et al. (2017) was carried out to know a general character, main cause and contributing factors for RTC, their countermeasures as well as, the relation between an RTC and road designs. Furthermore, road safety audit was conducted to compare if the existing road design characteristics of geometric elements of their study area have compliance with the standard of Ethiopian road authority (ERA) road geometric standards. The result of Wedajo et al. (2017) revealed improper drainage, missing road marking, asphalt defects, limited sight distance, narrow carriageway, shoulder missing, absence of posted speed control and limits, nonexistence of guard rails, narrow and improper bus stop location were the shortcomings found out from the field study. The research similarly realizes, the cause of RTC using interviews from traffic officers specifically to that area. The result declared, road defects, shortage of awareness regarding road traffic safety, insufficient sight distance, and shoulder-width were the major cause for the occurrences of the crash and 33.9% was due to the road defect problem specific to that study area (Wedajo et al 2017).

Besides, road traffic light, insufficient walkway, and inferior quality of roadway design were also stated as a cause of the road crash for that study area. During the study, Wedajo et al. (2017) used ‘’Purposive sampling’’ for collecting the data of road design elements. During sampling, vehicle and pedestrian movement were used as traffic crash characteristics to know the vulnerable area to measure a sample of pedestrian movement, terrain characteristics, road design problem in the field. Nevertheless, using those characteristics to know the hazardous areas might not show the real vulnerable location of the crash because locations with more traffic flow do not mean that the zones are always dangerous. Thus, it is required to have some studies or methods (for example using CPM) to identify vulnerable areas or black spot locations to improve the road networks.

There have been different studies of Ackaah et.al (2011); Rengarasu et.al(2009); Tulu, (2015); Vayalamkuzhi et.al, 2016) regarding geometric effect in road traffic safety for several facility types. A study of pedestrian crash modeling in Ethiopia stated that pedestrian injuries and fatalities are significantly affected by the difference in light conditions(Tulu, 2015). Similarly, that finding recognized that land use(for example; residential, commercial, industrial areas) and access to roadway have a relation with road traffic crashes. While other studies of Borsos, et.al. (2015); van Petegem et.al (2014) acknowledged, Lane width, horizontal curve, maximum vertical grade, and shoulder-width were contributing factors for crash occurrence with a diverse level in crash severity. Along with that, poor alignment is discovered to be the cause of RTC (Rengarasu et al., 2009). when bridge and tunnel are available in the roadway network then, these elements cause the road segment around to have poor alignment and this degrades the level of safety.

Crash frequency modeling developed for the roadway in India also discovered, number of crashes is significantly affected by the operating speed and the study mentions, keeping the horizontal curvature at least to the minimum value will preserve the operating speed to be safer along with the roadway network (Vayalamkuzhi & Amirthalingam, 2016). Moreover, terrain type and access density were also found to have a relationship in a road traffic crash during the study carried in Ghana (Ackaah & Salifu, 2011).

As mentioned above, observed road design threats were identified that lack compliance with the standard of road design from ERA by Wedajo et al. (2017). Nonetheless, the study was not able to identify if these road design hazards are a contributing factor for the road crash and fatalities. Because the location of the data and back spot for the study area was not identified instead, the study used crash severity, the period of crash data, type of vehicle involved and contributing factor for the crash from the police reports to know the general characteristics and contributing factors of the road traffic crash. However, this study will use crash data concerning crash severity, the period for the crashes, type of vehicle involved, type of road user involved, and location of the crash to identify the contribution factor of geometric characteristics for the involvement of crash by recognizing the location of crashes. Hence, there are different geometric characteristic for the involvement of crash in highways as cited above and some features will be recognized for the crash occurred in rural two-lane roadways of Tigray regions during this study Furthermore, the model developed can correspondingly be used further for identifying the hot spot location of the study area as well as to estimate crash frequency for other locations by calibrating the model.

2.3.1 Rural Areas and Road Traffic Crash

A highway that crosses extents that have fewer inhabitants (less than 5000 inhabitants) which is not urbanize zones are defined as rural highway areas (Ackaah & Salifu, 2011). Garach et al. (2016) assumed that safety problems and traffic volumes are not representative of regular two-lane rural roads when traffic volumes are lower. Therefore, AADT greater than 500veh/day was only considered for the study on the rural highway. Statistics show that, out of all the total road traffic fatalities in Ghana, 70% of the report is related to the non-urban environment (rural highways)(Ackaah & Salifu, 2011). Crashes occurring in rural areas have a significant role in road safety problematic and crash data report of diverse European counties indicated that, more than half percent (28%-78%) of total road fatalities belongs to death occurred in rural road areas (Cafiso et al., 2010). Similarly, the study carried out in eastern Tigray region regarding the analysis of RTC identified the effect of geometric design parameter and it revealed that road traffic crash that occurred in urban areas (43.6%) are less compared to rural area (56.4%) as shown in figure 5 (Wedajo et al.,2017). The contributing factor for RTC was, lack of lane width., eroded shoulder, over speeding, overloading, and mountainous terrain were identified as some of the reasons for the road traffic occurrence according to the police commission reports. Due to these reasons, the study focuses on road traffic issues in rural areas of the Tigray region.

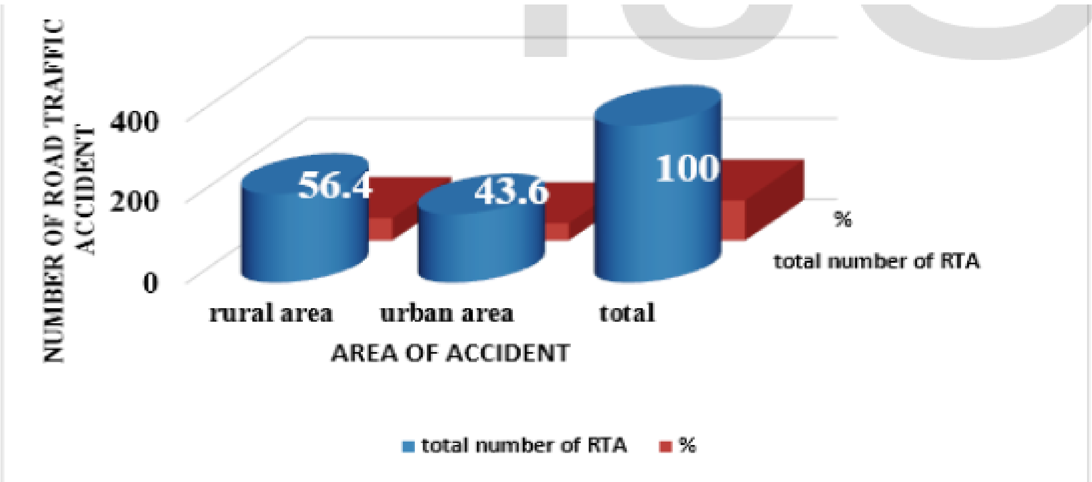


FIGURE 5 The number of road traffic crashes in the southern part of Tigray regarding urban and rural areas (Wedajo et al., n.d.).

2.4 Correlation of Explanatory Variables

The association among two parameters is recognized using correlation analysis and the association can have higher or lower strength with different magnitude (positive or negative)(Niveditha et al., 2015). The value of one variable will increase when the other variable increase and vice versa, if the correlation coefficient for these two elements is positive. whereas, when the correlation amount among two variables is the negative value at that time, as one variable increases then the other parameter will decrease. For instance, research carried out to developed CPM in India quantified, Non- fatal crash was higher when the quality of pavement condition diminishes i.e. pavement condition and non-fatal crash were negatively correlated (Niveditha et al., 2015). Besides, Harshit Gupta,(2017) declared that the Statically package for Social Sciences (SPSS) will analyze the “Bivariate correlation” among the dependent and independent variables. There is no unit measurement for correlation and the value varies between -1 to 1. The relation among two variables is strong when the correlation value is close to these two extreme values while a zero-correlation coefficient specifies a weak correlation (no relation) amid two parameters. Thus, this correlation analysis will help to identify the linear relationship between the dependent and independent variables because an assumption is considered to have a linear relation among the variable for regression analysis.

On the other side, when two predictors are correlated, then the model developed will have inappropriate results because, there is also an assumption made for the regression analyses not to have multicollinearity(Harshit Gupta, 2017). Multicollinearity in statics is defined as when a prediction model has included two extremely correlated variables. Harshit Gupta, (2017)stated that looking at the correlation matrix can be one of the methods to recognize if, there exists a higher or lower correlation among the independent variables and it is done before fitting the model. Then values greater than 0.8 or 0.9 are measured to be a higher correlation among parameters. Variance Inflation Factor (VIF) is likewise another method and it is generated during analysis using SPSS software and it is used to diagnosis the collinearity among independent variables and it will be discussed more below. CPM developed for urban cities has used correlation matrix as shown in table 2 to find the multicollinearity of predictors where correlation Significant level is 0.01 for (**) sign and 0.05 for (*) sign. Predictors were considered to have collinearity when the value is greater than 0.5 for the study held in India and the value for all independent variables taken for the study was less than 0.5. Hence, all the five predictors (shoulder and carriageway width, number of pedestrian volume, number of the access road, and traffic volume) were included in the prediction model (Harshit Gupta, 2017).

TABLE 2 Correlation matrix among predictors (Harshit Gupta, 2017)

Predictors	**Segment length**	**Carriageway width**	**Pedestrian volume**	**Traffic volume**	**No. of Access road**
Segment length	1	.052	.111	.089	.483**
Carriageway width	.052	1	.481**	-.416**	-.178
Pedestrian volume	.111	.481**	1	-.338**	-.043
Traffic volume	.089	-.416**	-.338**	1	.203
No. of Access road	.483**	-.178	-0.43	.203	1

predictors are added and removed into the model to look at their significance in the dependent variables and during this multicollinearity will be recognized when the estimated regression coefficient of the independent variables shows higher change Buteikis,(2018) and Variance inflation factors is a famous technique to check multicollinearity. The VIF is calculated using equation 1 where R^2 is the coefficient of determination of the regression. However, SPSS will automatically generate the value of VIF and there is no need to calculate it manually. multicollinearity is taken as high when the value is greater than 10. The predictor is taken to have noncollinearity with remaining parameters if, the value is less than five.

$$VIF = 1/(1-R^2) \qquad (1)$$

When predictors are continuous variable then, using the Generalized Variance inflation factor (GVIF) and VIF is the same technique to check the multicollinearity(Fox & Monette, 1992). However, when the variable is categorical (for example, shoulder width can be taken as paved and non-paved so, these will have two different regression coefficients) then, GVIF will be applied to know the multicollinearity. The same rule is used for GVIF to identify the collinearity or non-collinearity of predictors like VIF by squaring the value $GVIF^2$(1/(2*DF)) where, DF is designated as the degree of freedom(Fox & Monette, 1992). VIF and GVIF are used to know the collinearity before the process of model fitting are complete and the value is generated automatically from SPSS.

As stated above, the relation between the dependent variable and the predictor will be unclear and complex when the independent variables are correlated during prediction model development(van Petegem & Wegman, 2014). Whenever two variables are extremely correlated, then one of the correlated variables is adequate to clarify its effect in crash frequency instead of taking two-variable all together. The value of correlation among the predictors lies among -1 and 1, where both ends show high correlation and 0 is when there is no association among the parameters (van Petegem & Wegman, 2014).

Correlation among the variables was identified among the parameters considered in ((Ambros et al., 2016))and it was established to have a 0.67 correlation between road category and paved shoulder in the road network. And this was because the road category (category of 7.5m lane width and category of the lane with 9.5 and 11.5m) was having minimal road width difference which is shoulder will be paved for a roadway with wider width. Thus, the inter-correlation of both parameters was recognized and from that, road categories decided to be removed from the analysis because it is derived variable (variable expressed in terms of another variable).

According to Ackaah et.al (2011), speed was not a significant explanatory variable in the model because it was highly correlated with terrain type and presence of village settlement. Likewise, there was a correlation between traffic flow and shoulder type thus, shoulder type was not a significant explanatory variable on the study but, in other studies when vehicle steers out track, shoulder type takes along stability and take is as a predictor of crash frequency. There was similarly, a high correlation between lane width and traffic flow, as a result, road width was not a significant parameter in the study. Thus, finding collinearity of predictors is an essential step to avoid vague prediction model and one of the predictors that are highly correlated in the model should be removed from the model to have clear CPM.

2.5 Variables Used and Significance

Identification of variables related to crash on the rural highway was achieved predominantly using engineering judgment and literature reviews as well as depending on the availability of data (Ackaah & Salifu, 2011). Two criteria have been used to decide the variables that will be engaged in the model. The first one was to look the significance at 95 % level of a confidence interval that is p values less than 5% of the t- ratio and the second one was testing if there was a significant decline at 95% confidence interval in the scaled deviance when adding of variables into the model (Ackaah & Salifu, 2011). Besides, Ackaah et.al (2011) used Chi-Square statistics and Deviance statistics to evaluate the validity of the model. Variable as a minimum with a static significance of 95% will be used in formulating model using a backward elimination manner(Ambros et al., 2016). Besides, the model that best clarify the data is found by eliminating variable from the regression model that is the backward elimination process and overfitting will be diminished because of this process.

Furthermore, the Large number of variables have been collected for the study in Ghana and from these considered parameters length, traffic volume, presence of village settlement, junction density and terrain type were found to be significance estimated parameters with p values of less than 5% and included in the full model (Ackaah & Salifu, 2011). In the core model, Ackaah et al. (2011), found out that length and traffic volume has a significant effect in crash keeping other variables constant. Which means, as the vehicles covered longer distance there will be a probability of vehicles to be involved in the crash as well as crash frequency will rise when the traffic volume upturns. The regression coefficient for the study in Ghana was 0.37 for both predictors (length and AADT) while, it was 1.21 for (van Petegem & Wegman, 2014). As well as, variable’s (maximum daily rainfall, maximum and minimum horizontal curve radius, maximum grade and minimum grade in the road section, number of the vertical and horizontal curve in the roadway section and number of snowy roadway days) considered in the study of Shankar e.a., (1995) for developing CPM model and all these independent variables were found to have a positive influence in crash frequency and the increase of variables in the model showed that probability rise of the crash frequency. Comparing the number of horizontal curves in the road section with a design speed of below 96.5Kph caused less effect than a design speed greater than 96.5kph. This might be because of, the effect of both curve and higher speed at the same location. Having less speed in the curve might lower the crash severity compared to higher design speed in horizontal curves. Additionally, the Road section having grade higher than 2% and more cause greater crash frequency than road section with less than 2%, thus the study showed that crash frequency and grade have positive outcomes(Shankar et al., 1995). Hence, the radius of curvatures especially for horizontal curves has to be designed carefully to have coordination with speed limit to reduce RTC.

While explanatory parameters considered during the study of Ambros & Sedoník, (2016) were, AADT, segment length, average CCR (sum of angular changes in the segment length divided by the length), the density of road facility and density of intersections (where the density is expressed as the frequency within the segment divided by the length), number of the lane, type of shoulder material and speed reductions i.e. exposure and roadway characteristics were assigned for each segment. Considering all the parameters, CCR, AADT, and segment length were significant taking four years of the study period, and finally, the model was expressed AADT as exponential and segment length with both functions as exponential and power functions.

The finding of Ivan et al (2000) discovered, both multiple and the single-vehicle crash rate was significantly related with different driveways (private residence, apartment buildings, gas station, retail, industrial, office and others like church /recreations areas). While the study has used only 17 sample size(sites) and it suggested that this model will be better if not applied to other sites. Each variable considered in the study of Borsos et al. (2016), were checked their significance by entering individual parameter alone into the model to identify the predictor that will be included in the final CPM. In the case of the individual model (where only one variable is taken in the model for every predictor) formulation, shoulder width and post speed limit were insignificant but, AADT was significant. Regression coefficient for AADT was less than one similar to another study (Ackaah & Salifu, 2011). Furthermore, the full model included all the parameters (AADT, shoulder width, horizontal curvature, post speed limit, and roadway width) and they were significant predictors.

Moreover, other studies taken in Ethiopia used high way cross-sections, land use, and other factors for pedestrian crash modelling in rural and roundabout in urban areas of asphalt roads (Tulu, 2015). Thus, lane width, terrain type, shoulder type, pedestrian volume, and AADT were the predictor of the CPM due to their higher significance level. Alike, a study carried out in Ethiopia for urban areas and predictors that were significant in the analysis were the number of horizontal and vertical curves, number of lanes, sidewalk width, number of access, number of access control, and painted medians(GERBA, 2019).

CCR was one of the significant parameters considered and it was taken as a continuous variable in the study of the Czech Republic and similar, to other studies it was a significant variable (Ambros et al., 2015). Similarly, Curvature was one of the independent variables in the Netherlands run-off crash model for rural roads and it was taken as a categorical variable. Latterly, the radius of the curve was a significant variable and the run-off crash was estimated to be three-fold for a major horizontal curve compared to flat curves or straight roads (van Petegem & Wegman, 2014). Shoulder type was taken as a binary variable (0 for paved shoulder and 1 for unpaved shoulder) and Pavement quality as a continuous variable that is total segment length per the pavement quality level and both were important predictors of CPM (Ambros et al., 2015). Thus, road traffic safety might be improved if there is a careful design in horizontal curvature because these three studies indicated that CCR is a predictor of crash frequency.

Several studies (Ackaah & Salifu, 2011; GERBA, 2019; Tulu, 2015; van Petegem & Wegman, 2014) discovered that exposure is significantly correlated with crash rates and exposure increase there can be higher crash rates. However, the result of (van Petegem & Wegman, 2014) indicated that the relationship between AADT and the dependent variable will be declined when the value of traffic volume is higher. Percentage of a heavy good vehicle, AADT, and segment length was taken as exposure variable during modeling of the road network in the Czech Republic and these were also an important predictor of the crash frequencies (Ambros et al., 2015). When the exposure is zero, there will not be the crash frequency in the roadway segment or other facilities because the non- existence of AADT is related to the non-occurrence of RTC.

Additionally, obstacle also was taken as a predictor for the Netherlands rural roadway runoff crash prediction model and it was taken as a dummy variable (if an obstacle within 0-2m of the road in one or both sides of the road exists or not. Hence, the finding concluded that run off crash occurred by 50% due to the presence of obstacles within 2m of the road (van Petegem & Wegman, 2014). Besides, the study carried out by van Petegem & Wegman, (2014) revealed that a half percent run-off-road crash is expected to decrease due to the roadside barrier. The safety zone was considered as a parameter while developing the model but, its significance in estimating crash frequency was low and it was not considered in the final model. Multiple studies (Ackaah & Salifu, 2011; Tulu, 2015) carried out regarding CPM for the roadway network and these studies have used significant variables as predictors for the final model as discussed above. However, one significant variable in one study does not have to be an important predictor in other studies because, there are different road behavior, environment, and other condition among roadways. Besides, the sample size of data can affect the significance of variables (for example if the categorical variable of village settlement is taken and if the study area does not have village settlement then the variable might be insignificant due to the shortage data). Thus, for this study, the significance of the parameter will be checked by adding and removing variables during the analysis, and variables with high significance will be taken as variables.

2.6 Geometric Relation of Cross-section Element and Road Alignments on Road Crash

Land use, light, and roadside conditions, geometric features such as gradient, horizontal curve, segment length, shoulder, and carriageway width) and the speed limit is mostly useful variables for modelling crashes(Qin et al., 2004). This section has tried to review past studies concerning roadway alignment, cross-section elements of roads, and other relationships with a road crash in different facilities.

- Terrain type

Comparing hilly or rolling terrain type in the rural roadway of Ghana showed to have less crash rate compared to flat terrain from the model developed and road segment that has flat terrain showed,57.6% rise of injury crash comparative to other considered terrains during the study (Ackaah & Salifu, 2011). As a result, the study suggests, the driver will tend to drive slowly in hilly and rolling terrain types because of the geographical areas while flat terrains will let the driver speed up. Terrain type was taken as categorical variable as mountainous and rolling terrain type during the study of Dong et al., (2019) while, it was not the predictor for crash rate.

- Horizontal and vertical curvature

If the availability of curve in the roadwork is not clearly marked and the radius of the curve is small then, the risk for crash occurrence will be difficult (van Petegem & Wegman, 2014). For the study of Ghana, the curvature was not extracted for each horizontal and vertical profile due to the unavailability of the construction plans for these parameters. As a result, the effect of specific horizontal curvature was not included in the analysis instead as general the number of horizontal and vertical curvature (density of curve) per segment length was used (Ackaah & Salifu, 2011). Similarly, van Petegem & Wegman,(2014) did not measure the radius of the curves to incorporate curvature effect in run-off-road crashes model of rural roads instead, the degree of the curves (strong curvature, mild curvature and straight by rough estimation) was taken into account and these curved were measured subjectively by driving along with the study areas. Horizontal curvature was taken as a parameter in the study of (Borsos et.al, (2015) and it was clustered as categorical (tangent, <750m, 750m<x<1500m, 1500m<x<3000m, >3000m) and the result revealed that roadway with less radius of the curve has a higher crash rate and horizontal curves that have a larger radius to have less crash rate. Likewise, Savolainen et al., (2015) revealed that expanding the length of curvature, degree of curvature or both length and degree of curvature along a rural highway segment will lower crash occurrence.

- Shoulder type and width

During emergency events, the shoulder will assist the vehicle to stop along the roadway without interrupting the traffic movement and safe operation of traffic can be affected by the shoulder width shortage (Stapleton et al., 2018). Findings regarding lane width with the frequency of crash are varied which means that lane width can have an increase or decrease in crash frequency depending on the crash type, facility type, and traffic volume, while the discoveries for shoulder width were consistent that, crash frequency will reduce due to widening of the shoulder width and vice versa(Stapleton et al., 2018). Ackaah & Salifu, (2011) revealed, traffic flow was correlated with shoulder type hence, shoulder type was not taken as a valuable explanatory parameter for the model developed for the rural two-lane roadway in Ghana. In addition to that, the limited sample size of the unpaved shoulder (half percent less sample size than the paved shoulder) was also considered as the reason for the insignificance of shoulder type in the analysis. shoulder width variation considered was almost similar in width (2m.2.2m and 2.5 m) and this showed also less significance of shoulder width in the crash rate. Similarly, Borsos et al., (2016), have taken shoulder width as a categorical variable but it was significant in estimating crash rates. Shoulder type was taken as a binary variable (0 for paved shoulder and 1 for unpaved shoulder) and RTC was related to the type of shoulder material (Ambros et al., 2015). When the sample size of the variable is less compared to another variable, then this might cause for the insignificance of the explanatory variable but, studies have showed that shoulder width have high relation to RTC.

- Lane width

Reduction of lane width will limit traffic flow because, the vehicle will have a condensed amount of space and required to travel close together alongside the way and due to that road traffic safety will be improved as the lane width is enlarged (Sharma et al., 2014). Thus, lane width was considered as one of the descriptive variables for different studies (GERBA, 2019; van Petegem & Wegman, 2014). Carriageway width was an insignificant parameter in the crash model of (Tulu's, 2015) study because it was correlated with traffic flow. While, roadway width as a categorical variable was taken it to account for crash development in the rural way of Hungary and the result of (Borsos et al., 2016) indicated that, crash rate has a significant relation with the road with. The crash rate will increase when the width of the lane is narrow, and it will reduce for wider lane width. Likewise, lane width was also a predictor parameter in (GERBA, 2019). Carriageway width was also one of the predictors for crash frequency in the study held in urban cities (Harshit Gupta, 2017). Lane width is the main predictor considered in these studies for road crash frequency.

- Road marking

A sample size of road marking in the rural two-way road of Ghana was much higher compared to unmarked roads, and this sample difference is considered as a reason for the insignificance of the parameter in the crash model formulation (Ackaah & Salifu, 2011).

- Presence of Village settlement

Even though built-up areas and non-built-up areas have generally difference in speed limit but, there is no clear description for built-up areas (Kosztolanyi-Ivan et.al 2016).According to (United nations publications,(1968), areas that have a sign posted on the existence and entries was described to be the built-up areas as well as, shape or name of the built-up area or combined sign have to be installed at the beginning of these zones to indicated that it belongs to built-up areas.

A study conducted in Hungary has applied questionnaires and image-based classification was used to identify built-up and non-build up areas(Kosztolanyi-Ivan et al., 2016). Nevertheless, the result discovered that unclear sites (for example there were zones which are built-up area with a speed limit of the city but, with lack of road design or posted speed limits) were difficult to be classified as both built up and non-built up areas. Therefore, the study recommended that repetitive pavement marking, or speed limit signs should be posted on built-up areas or during the design phase to lets the drivers choose the right speed in the right place. Besides, (Kosztolanyi-Ivan et al., 2016)stated that these unclear locations can increase the occurrence of crashes. The statistic in Hungary indicated, 60% % of Fatalities and injuries happened in non-built up areas and the remaining in built-up areas ((Kosztolanyi-Ivan et al., 2016). Then, due to these principles listed above, the location of built-up and non-built ups areas of the study location will be identified to look at their effect in crash occurrence. Road crash had a relation with the presence of village settlement during the CPM for rural two-lane roads (Ackaah & Salifu, 2011).

- Driveway/access control density

Improvement of suburban and commercial highway can be influenced due to the availability of the access point Sharma et al. (2014) and in that investigation, access density as one of the parameters for the CPM that ranges from 0-11 per Km for the highway. A study confirmed that crash frequency is influenced due to the availability of access point density (Gluck et al., 1999)Junction density was corresponding, the substantial parameter found in the model development of the rural area and it was concluded that crash rate can rise as the value of junction per segment length increases (Ackaah & Salifu, 2011). Similarly, the study held in Michigan declared that access type and density were found to be predictors of crash rate for rural two-lane road segments (Stapleton et al., 2018). The occurrence of head-on and the lateral collision was affected due to the existence of access density (Borsos et al., 2016). Borsos et al., (2016) stated, even though access density is the main predictor of crash rated mentioning to different studies, the study areas considered has limited access density. Due to that, it was not considered as independent variables in the analysis. One of the predictors for crash frequency was access density for the study carried out in Addis Ababa (GERBA, 2019). Even though the explanatory variable is significant in several studies, it might be insignificant due to the lack of data in other studies and access density have a relation with road traffic fatalities and injuries.

There are also other variables taken in to account during CPM development, such as Pavement quality, roadside barrier, and obstacles(vegetation like trees, poles, roadside elements, objects, and slopes) for rural roadways (Ambros et al., 2015; van Petegem & Wegman, 2014). The study carried out in the Netherlands has not included shoulder width, vertical alignments, road marking, and carriageway width during modeling due to the restriction of the availability of a database for the selected study areas (van Petegem & Wegman, 2014). Different cross-section elements and road alignment have a relation with RTC as illuminated above but, this does not mean that all must be included for CPM due to lack of data, time cost, and other constraints. The geometric features to be included during the modeling will be selected during the data collection process.

2.7 Crash Prediction Model

According to the highway safety manual report, CPM is used for a different purpose and it enables to know the relation between the crash and geometry, environmental and other factors among highway, intersection, junction, and different roadway facility by estimating the expected crash frequency of the roadway networks (AASHTO, 2010). Besides CPM is required to handle an extensive approach regarding investment and improvement for roadway networks considering the difficulty of the environment. Thus, the relation between roadway features and their safety performance is analyzed by a direct method of CPM (AASHTO, 2010). Variable describing exposure to crash risk and risk factors that influence the expected crash are the two major explanatory variables that apply to CPM (Garach et al., 2016). CPM uses the first independent risk factor (segment length and traffic volume which are the main predictor) and second independent risk factors (several risk factors that influence crash) to predict the crash frequency (dependent variable) on a road section for a certain period (van Petegem & Wegman, 2014). The relationship between traffic flow with crash frequency is assumed to be non-linear to have a fitted crash frequency model whereas in most studies length is considered to be linearly related to the crash (van Petegem et.al. 2014).

Average crash frequency of intersection or roadway segments are forecasted using a CPM regression model that is described as a function of exposure, geometric, traffic characteristics and others parameters as independent variables and expected crash frequencies as dependent variables (Lu et al., 2014)

The general form for CPM regression model is written as equation 2;

$$CPM = exp\,(\alpha + \beta \times ln(AADT) + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_n X_n) \qquad 2$$

Where CPM is expected crash frequency, X_1 X_n are geometric parameters, α, $\beta_1 \beta_2$ $..\beta_n$are regression coefficient and AADT is the annual daily traffic. Different studies(Ackaah & Salifu, 2011; GERBA, 2019; Tulu, 2015; van Petegem & Wegman, 2014) have displayed that negative binomial distribution is used for estimating crash frequency(the function form designated above). Correlation between geometric parameters and AADT occurs in model development which is the over-all problematic issues and to solve this safety analyst considers model only that include traffic volume or traffic volume and segment length that is called core model although other studies call it simple SPF (Lu et al., 2014). The function form described above is contrary to the simple SPF model since it illustrates all the interaction of geometric parameters including traffic volume.

According to the highway safety manual, a simple SPF model should be calibrated to use it for other sites because, the site was developed for specific base conditions (12ft lane width, 6ft shoulder width) having its geometric condition and other characteristics. Thus, a set of crash modification factors has to be applied for the different variables to be undertaken for predicting crash frequency for a particular site. Thus, for each geometric characteristics of the planned site can have a CMF that accounts for enlargement or reduction from the base condition on crash occurrence. According to (AASHTO, 2010), Predicted crash frequency is expressed as an equation 3 written below :

$$N_{predicted} = CPM\ X\ CMF_1\ X\ CMF_2 \ldots\ldots\ldots\ldots\ldots CMF_n \qquad (3)$$

Where $N_{predicted}$ is the predicted crash frequency for a site and CMF_1 , CMF_2 are the crash modification factor for the variables considered (e.g. for lane width will have its crash modification as well as for shoulder width and other n variables undertaken). For safety analyst application, we can either calibrate the default CPM for the planned site or develop CPM model for the specific site condition as the purpose of safety analyst application and Lu et al. (2014) tried to evaluate the possible advantage of local calibrating factor by comparing the value of crash frequency using the developed CPM and default CPM by local calibration factors for freeway segment and interchange influenced area using NB distribution.

The result of Lu et al. (2014) displayed that, the calibrated Safety Analyst of default CPM was found to be less fitted compared to Florida (base condition developed model) specific CPM model to the site. Besides, the residual cumulative in the cure plot was within the boundary of the standard deviation (close to zero), which implies that the base condition model was fitted(Ambros et al., 2015). while specifically, the study in Florida for the 4 lanes rural lane of the freeway(segment), the cumulative residual does not continuously fluctuate around the zero even though the cumulative residual of the basic segment was within the standard deviation of the limited value(±2σ) compared to the urban freeway and this was considered because of the sample size for urban segment's was more than the rural area comparatively. Then the study recommends developing local specific CPM for a specific location that can improve when agencies implement safety analysts instead of calibrating a model (Lu et al., 2014).

Besides, Ambros & Sedoník, (2016) have tested if the 5-year model is transferable which means, can the developed CPM in a different time and geographic areas of one region be transferred to the dissimilar region and time-space. Then the Cumulative residual graph and mean square prediction error was computed to test the transferability of the 5-year model in two regions of the southeast of the Czech Republic and the result of Ambros & Sedoník,(2016), presented that transferring model across the different region is not advantageous. Instead, it is better to develop a combined model of two regions then transfer it to one region and this is even competitive with the original model developed for specific regions. Thus, from those studies, we can conclude that developing models of one region can yield more truthful results instead of transferring models from different regions and time-space or using default CPM. Thus, this study will develop a CPM specifically to the rural two-lane roadway in the Tigray region instead of using the developed model in other regions by calibrating the model.

There are many reasons why many CPM have not a complete set of road design parameters (van Petegem & Wegman, 2014). The first reason is the shortage of data availability (several roadways lacks data regarding road characteristic which will be difficult to look at their relationship with crash frequencies. The second one is the variability of the data on the roads because, if the roads have similar road characteristics throughout the length then, the significance of the variable cannot be reflected on the crash occurrence and it will not be included in the analysis and the last one is the correlation of variables. When the variable is highly correlated, then the model will not be correct if both correlated variables are included in the model formulation. Van Petegem et.al (2014) concluded, during the formulation of these model's specific roadway networks, crash type, and road elements are considered due to these reasons. Thus, CPM to be used for this study will have NB regression distribution and this developed model will help to know the cause of geometric features on the crash occurrence of rural selected areas.

2.8 Transferability of the Crash Prediction Model

During developing the model, it is better to check the transferability to avoid the overfitting of the model because the overfitted model cannot estimate crash frequency correctly for different study periods and locations. Therefore, the main focus of Ambros & Sedoník, (2016); Ambros et al., (2016) were to have a transferable and updatable model so that, to use it for safety issues during network screening without requiring a huge updatable change of the base condition model.

The general objective of these two studies Ambros & Sedoník, (2016); Ambros et al., (2016) were, for network screening(to provide effective safety treatments by detecting dangerous road spots and giving significance list of the roadway for treatment) by developing CPM. The transportation road network is classified from least to most according to crash frequency to implement countermeasures and formulate policy measures using a well-known technique called network screening technique that is quite similar to hot crash spot identification (AASHTO, 2010). The study of this study is used to identify the geometric effect of rural two-way two-lane road network while this formulated model can further be applied to identify unsafe locations.

Furthermore, Ambros & Sedoník,(2016) examined to know the functional form, period and type of model to be used in developing CPM whereas, Ambros et al., (2016) are to develop CPM that is updatable for network screening and to identify the period that will yield the appropriate model and by filtering the predictors from the parameters considered. During the study carried out for in the Czech Republic, exposure, road and traffic features (such as road facilities and intersection density), segment length, quality of road pavement, environment and context variables (availability of forest in the road segment length and CCR) were the parameters used to develop the CPM in the rural two-lane roadway. The pavement quality was leveled in number where, 1 is for excellent and 5 is for wrecking pavement quality and both these were extreme values (Ambros et al., 2016). Roadside facilities and intersection density were defined in terms of frequencies in the road segment divide by the length. some variables like Speed limit reduction and several lanes were excluded from analysis in the roadway network of the Czech Republic because, 95% of segment number was a two-lane roadway and 99% of segments were without speed limit reduction (Ambros & Sedoník, 2016). The significance of Parameters that are included in the model or insignificance of variables that are discarded from the model does not have a relation with model fitting. It is a misunderstanding to conclude that, consideration of all significant factors will result in a fitted model (Elvik, 2011). Instead, the goodness of fit is used to check if the model fits or not and these techniques used will be discussed in section 2.10 below.

There is no fixed procedure to choose the functional form for explanatory variables to develop the model. A CPM is used for different safety studies such as for assessing and providing countermeasures using the Empirical Bayes approach i.e. combining the estimated crash employing the CPM and observed crash data for the study period and combining those will reduce the regression to mean bias (AASHTO, 2010). Thus, Ambros & Sedoník, (2016) have studied, if this CPM developed are transferable, which means, if the developed model in one region can be applied to another model with fewer errors and fewer updates of the model. The result revealed, CPM developed using combined data was a better estimator of crash frequency instead of using separate data for every region.

Besides, different studies have been conducted regarding the CPM for diverse facilities. Then during these studies, altered functional form (for example explanatory variables like segment length is set as an exponential form in studies of Ambros et al. (2016) nevertheless, Ambros & Sedoník, (2016) have used segment length as both exponential and power functions). Different types of models (core and full model) and period of study have been used. Even though there are diverse studies regarding CPM of a pedestrian crash, different countries have various socio-economic factors, road user behavior, roadway geometric characters, and environment so, due to this the prediction model developed in developed counties will not be used for developing countries (Tulu, 2015). The following sections will look at the study time period, functional form and model forms for developing CPM.

2.8.1 Study Period

The developed prediction model is estimated in terms of total crash or type of crash frequency per year in a road segment or other facility types. Thus, to develop the models, specifying the period is one of the obligatory steps. Most studies have been using 3 years of the period during network screening techniques (Elvik, 2008). While there are several studies also who used three years of the study period to develop CPM models (Ackaah & Salifu, 2011; Tulu, 2015)**.** Besides, the Current traffic situation will not be revealed when the length of the period for modeling is lengthy which can cause instability of the situation(Hauer & Persaud, 1984). Thus, a longer period taken for crash data has also affected in CPM development.

Identifying the period used for developing CPM model was part of the objective of Ambros & Sedoník, (2016) and to understand that, total eight years of crash data were divided to four sets of groups (3, 4, 5 and 6 years of the group) years by overlapping(as shown in figure 6) to develop the model and compare the appropriate time for CPM developing. But, due to'' non-invertible hessian matrix'', 3 years of the period was not included in the analysis and they included 4, 5 and 6 years which means, they have developed 12 models (6 models were excluded from 3 years group) with variables that have 95% significance level to evaluate the suitable time.

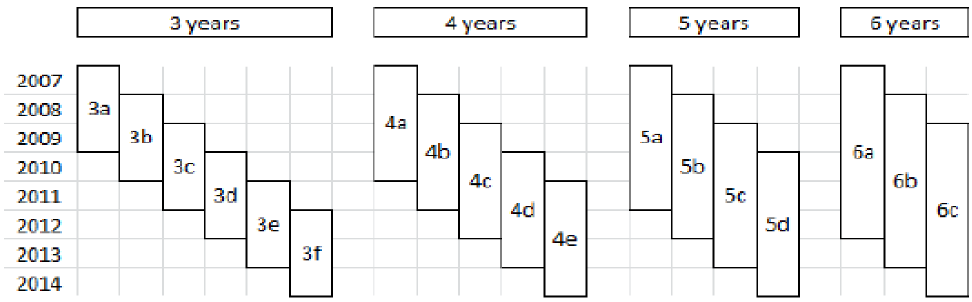


FIGURE 6 Different period for investigation of models and time frame(Ambros & Sedoník, 2016).

Thus ''Proportion of explained systematic variation(%SV)'' was used to compare the correctness study period for the developed model and three-time (4, 5, and 6 years) periods were considered in the evaluation of analysis(Ambros & Sedoník, 2016). Segment length having both power and exponential function form and AADT only with power form were considered in the model during calculating %SV for all the periods considered. At that time, %SV were calculated for every group year and the result of every group year was average to get the representative values for 4, 5, and 6 years. The outcome indicated that % SV for 4 time periods have 70% and 60% for segment length modeled as exponential function and power function respectively, whereas for 5 years period with 75% and 70%- and 6-years period with (74% and 69%). Finally, 5 years' time period was selected as a suitable period for modeling because there was no significant increase of % SV in the 6-year study period model. Numerous studies (Borsos & Koren, 2015; van Petegem & Wegman, 2014) have also used five years of crash data to formulate CPM.

While, 3 years study period was excluded in their study, down to that there is no conclusion provided for that specific period concerning %SV. Nonetheless, many studies have also been using 3 years period for developing CPM models(Ackaah & Salifu, 2011; Tulu et al., 2015). Besides, Elvik,(2010) stated that it is acceptable to select the study period for developing SPF taking into account the cooperation among both the availability of time for discovering the study and sufficiency of the data for the analysis because there is no provided standard for deciding on the study period. Besides, Cheng & Washington, (2008) stated, to characterize crash time, type, location, and reasons, 3 years of the study period is sufficient time frame. Tulu et al. (2015) finding also suggested if the crash data is collected greater than three years then, the marginal benefit will be less than the marginal cost. Therefore, the three years is considered an adequate time frame to predict the exposure of pedestrian crashes and developed a model for the pedestrian crash in Ethiopia. Thus, this study will use a three-year study period considering the shortage of data availability in developing countries as well as the time and cost for data collection.

2.8.2 Function Form

For different highway types (rural areas, intersections, suburban arterial, rural multilane, and so on) have several model forms and these can be adjusted depending on the type of facilities as well as, the regression coefficient in the model will also vary (Green, 2018). For instance, the model form below in equation 4 is recommended for rural multilane according to the HSM where a and b are regression coefficients then L and AADT are segment length (miles) and traffic volume respectively.

$$SPF = L \; X \; e^{a} \; X \; AADT^{b} \qquad (4)$$

There is no clear guideline to select the functional form for AADT and segment length in the model arrangement (Ambros & Sedoník, 2016). Segment length is used as power function in the research held by Ackaah & Salifu, (2011); Garach et al. (2016) but, some studies used segment length as exponential function form and segment length with non-regression coefficient or as an offset (AASHTO, 2010; Hauer et al., 2004). Moreover, AADT can also be used as both exponential and power function arrangements Hauer et al., (2004) even though, it is mostly used as a power functional form. Ackaah et.al (2011) considered Segment length and AADT both as power functions in the model of crash rate. But then again, the function form of SPF for rural highway in Hungary, the length was taken as an offset in all models (base model and full model) while, exposures (AADT) as exponential functional form (Borsos et al., 2016). AADT function form used for rural two-way two-lane in the Czech Republic was together as exponential and power function form ($AADT^{\beta}$ exp (β_2. AADT) and other exposure parameters and segment length as an exponential function (Ambros et al., 2016). Thus, different functional forms are taken in to account for different studies.

As pronounced previous there is no clear information which function form to use while developing SPF model and Ambros & Sedoník,(2016) tried to comprehend by developing CPM for these four different functional forms model shown in table 1, where I is for AADT, L is for segment length, χ_i is for the explanatory variable (intersection density, number of lane..) and βí are regression measurements.

TABLE 3: Model outline alternatives, AADT, and segment length with different power and exponential functional form (Ambros & Sedoník, 2016)

	Segment length in a power form	Segment length in an exponential form
AADT in a power form	$P = \beta_0 \cdot I^{\beta_1} \cdot L^{\beta_2} \cdot \exp(\beta_3 x_3 + \beta_4 x_4 + \cdots)$	$P = \beta_0 \cdot I^{\beta_1} \cdot \exp(\beta_2 L + \beta_3 x_3 + \cdots)$
AADT in both power and exponential form	$P = \beta_0 \cdot I^{\beta_1} \cdot L^{\beta_2} \cdot \exp(\beta_3 I + \beta_4 x_4 + \cdots)$	$P = \beta_0 \cdot I^{\beta_1} \cdot \exp(\beta_2 I + \beta_3 L + \cdots)$

All through the study of Ambros & Sedoník,(2016), 8 years of crash data have been used and divided those years into four years in groups as discussed in section 2.8.1 by overlapping arrangement and then developed a model for two regions considering segment length as exponential function and as power function as well as for AADT as power function and combination of power and exponential functional forms as shown in table 1in order to decide which function form to be used.

The crash data were taken for CPM development in the study of Ambros & Sedoník, (2016), and considered for AADT to have exponential and power function together and the model that used this form does not show a decrease in the predicted crash frequency after it reaches some threshold values of AADT. While, Hauer et al. (2004)stated that, data set having higher traffic volume (AADT greater than 68500) shows that reduction after they reach that threshold values of AADT. Besides, AADT in the exponential functional formula was not found to be significant in all the alternatives of 18 models taken. Accordingly, AADT in both function form was not considered for further analysis (AADT only in power function is considered). On the other hand, segment length with power and exponential function form was compared by developing altered alternative models and segment length with power function revealed better compared to a model having the exponential function of segment length. Thus, individually AADT and segment length having power function form were found to be suitable for forming the CPM in the study of (Ambros & Sedoník, 2016).

Moreover, two techniques (screening the geometric characteristic to be used to formulate the model and the second one, adding additional variables to the model) were applied to evaluate the SPF development of rural two-lane roadway and the attribute considered for the development of the model was (shoulder width, AADT ranges, speed limit, and land width)(Green, 2018). Green, (2018), suggested that the prediction model can be improved using the goodness of fit measures as well as, changing the function form. Thus, three model forms were compared to look at the prediction model: taking the first function form of the model to be ($Y= AADT^{b} * L * e^{a}$) used by (Hauer, Harwood, Council, & Griffith, 2002). Here, length as offset variable and AADT with power function was taken and mostly the relationship between AADT and the crash rate is conserved as nonlinear Green,(2018) similarly, Tulu, (2015) suggests, studies have confirmed that crash frequency and AADT have a nonlinear relationship; the second function form was a model($Y= AADT * L * 365 * 10^{-6} * e^{a}$) used for rural two-lane in HSM (taking both AADT and length as an offset variable) and the third function form ($Y= AADT^{b} * L^{c} * e^{a}$) is considering both AADT and length as power functions. A model was developed for a rural two-lane roadway having shoulder width of 2 miles, lane width of 9 miles, no vertical and horizontal curve, and intersections characteristics.

The standard techniques (AIC, $R^{2,}$ mean absolute deviation, maximum absolute CURE deviation, percentage CURE deviation, and overdispersion parameter) for evaluating the goodness fit of the crash prediction model was used to compare the models. The third model taking AADT and length as a power function performs better compared with the other model considering the standard technique measurements (Green, 2018). Model prediction state (using the regression coefficient of AADT and length to predict the crash frequency) were applied during the study of Green, (2018) to compare the functional form of the models in addition to this, metrics used to evaluate the function form. Then two prediction states were taken: prediction state one with AADT 1000 mile and 0.5 miles and AADT of 2000 and 1.8 miles for the second state. As shown in table 4, the third model has less crash frequency per mile considering less AADT and shorten segment length whereas, the other two models have the same crash prediction (van Petegem & Wegman, 2014). Thus Green, (2018) concluded that the models cannot be compared using the model prediction because the values are differing broadly while, in terms of goodness fit measures, the third model yields better than the others. Referring to the past studies finding, this study will apply the function form of AADT and segment length to be in power function because these functional forms were found to be the best function form models form as mentioned above and the other explanatory variables as exponential functions.

TABLE 4 Prediction state for different function form of ADT and segment length of CPM (Green, 2018)

Parameter	Model A	Model B	Model C
	$AADT^b * L * e^a$	$AADT * L * 365 * 10^{-6} * e^a$	$AADT^b * L^c * e^a$
a	-4.08	2.19	-4.46
b	0.76	n/a	0.74
c	n/a	n/a	0.68
Prediction 1	1.6	1.6	1.2
Prediction 2	9.8	11.7	4.8

2.8.3 The Simple and Multivariate Model

To decide the model type to be simple or multivariate is depending on the number of explanatory parameters taken (Ambros et al., 2016). The simple model of (Ambros et al., 2016; Ambros & Sedoník, 2016) includes AADT and segment length as power function and CCR as an exponential function. However, other studies showed that a simple model only using exposure (AADT and segment length) (Ackaah & Salifu, 2011).

Ackaah & Salifu,(2011) included two models in the prediction model of crash frequency that were the core model and the full model. The core model has included only exposure i.e. the traffic flow and length parameters while the full model has included the explanatory variables and in addition to the parameters involved in the core model. Garach et al. (2016) likewise, used the base model and fully specified models to develop SPF using a generalized linear model and explanatory variables related to roadside feature, design consistency, exposure, and geometric design were the variable in the full model. The base model includes only AADT in the study conducted in Hungary of rural two-lane roads ways and suggested that analysis about road safety ranking can be done using this model only (Borsos et al. 2016). The study in the United Kingdom determined that the distinction of the crash data was clarified better using a few explanatory variables in the model (Saha et al., 2015). As well the study in Czech republic also identified, simple model(including AADT, segment length, and CCR) was found to be sufficient intended for network screening than using multivariate models (Ambros & Sedoník, 2016). Thus, some studies suggest that developing only base model is sufficient for network screening and other safety measures while others developed both base and full model to assess the safety condition of roadway network and this study will have multivariate model since the main purpose is to look at the relation of the predictors with the dependent values not only to consider exposures.

2.8.3.1 Parsimonious

CPM with less parameter and fitted model is more recommended over the complex model and in statistics, this is called the parsimony principle (van Petegem & Wegman, 2014). According to van Petegem & Wegman, (2014), parsimonious characteristics are required because the model can be overfitted when there is an addition of predictors to the model and the overfitted model is not vital. In addition to that, when there is an additional explanatory variable to the model then the chance of correlation among variables will be much higher which makes the relation between the crash frequency and predictor uncertain. lastly, when a model has more parameter or for every other explanatory variable, it is required additional data gathering which is much expensive compared to including fewer parameters.

According to Brimley (2011), models are nominated and compared using the’’ Bayesian information criterion ‘’ (BIC**)** and a model will be selected when it’s BIC is smaller value. BIC value is dependent on several explanatory variables and residuals and these are directly related to BIC. The model will have poor estimation capability and it can overfit if, the explanatory variables are higher which means, the value of BIC will be higher if the independent value included increased. Thus Brimley (2011) concluded the criticality of parsimony by having fewer variables in CPM Principe with less variable to avoid complexity, poor prediction model, and overfitting. Similarly, Sawalha & Sayed, (2006) stated that ‘’ principle of parsimony’’ must be applied during the formulation of the model i.e. the smallest number of explanatory variables are required to describe the changeability of the data in the model. There will be a procedure to take in to account the parameters that will be used for the model development: initially different studies must be reviewed to identify the variable that has significance on the crash rate on different scenarios and the way how the variable must be applied in the functional model. Then lastly out of these variables that were collected for the data analysis, parameters that have significance in the crash rate will be taken as final parameters to be including the crash rate model ((Ackaah & Salifu, 2011). Thus, including fewer explanatory variables will be let to have less correlation, good quality of CPM, and to be economical and this principle will be considered during developing the CPM.

2.9 Crash Prediction Modeling Practices

Conferring to Ackaah & Salifu, (2011), RTC is distinct, and they are accidental occasions. Thus, there is a probabilistic nature for a vehicle to be involved in a road crash for a given period. Researches have studied that, during the data generation process, the’’ Generalized Linear Model’’(GLM) will undertake the probabilistic arrangement, and then sound estimated regression coefficients will be established due to consideration of the assumption(Ackaah & Salifu, 2011). Relationship of both vehicle crash and roadway geometric characteristics cannot be modeled using linear regression model because, vehicle crash on roads have non- negative, random, distinct, and irregular properties which are the limitation of linear regression models (Ackaah & Salifu, 2011). Different studies have confirmed that the limitation of the linear regression model for the relationship of crash data, roadway, and other properties (GERBA, 2019; Tulu et al., 2015; van Petegem & Wegman, 2014). Due to this, to formulate a model for crash rate, GLM is used. Link function that linearized the model and to have the rational result of crash rate are required criterial in the mathematical formula of safety CPM (Sawalha & Sayed, 2006). The crash rate has the probabilistic nature that is for a given period the crash occurred in the road segment is random and this randomness nature is assumed during GLM. Subsequently, the estimated coefficient in the model will have tests and confidence reports due to the randomness nature assumption taken (Ackaah & Salifu, 2011).

The binomial distribution is approximated by Poisson distribution for crash motor vehicles that happened randomly and with less probability. Nevertheless, the Poisson distribution is used when the mean and variance of crash data are equal. Due to that, crash data do not obey this assumption due to the overdispersion in the variance. As a result, the efficiency of the parameter estimate will be lost due to the violation of the assuming as well as due to the error-based assumption, t-statistic will be corrupted (Ivan et al., 2000). Thus, poison model estimation can lead to wrong conclusions for overdispersed data. Therefore, to account for random occurrences (for different mean and variance values) negative binomial distribution is used(Ackaah & Salifu, 2011; GERBA, 2019; Tulu et al., 2015; van Petegem & Wegman, 2014). Since crashes are non-negatives, relatively small numbers, and integers, hence Negative binomial and Poisson distribution is found to be a suitable choice(Garach et al., 2016). The study Used NB distribution because it is appropriated when the mean and variance are not equal.

The negative binomial regression model is used for different explanatory variables and AADT as a function to determine expected crash frequency per year of a roadway segment or intersection of an area. NB regression has the following general functional formula as equation 5:

$$\ln \lambda_i = \beta \chi_i + \varepsilon_i \qquad (5)$$

Where:

λ_i = is the number of expected crash frequency on a segment or intersection

β = vector of the estimable regression parameter

χ_i = is a vector parameter of traffic volume, geometric design and another explanatory variable to be considered in the roadway segment or intersection

ε_i= is the gamma-distributed error term

And for NB regression model the mean and variance link is as shown below in equation 6:

$$VarY_i = E(Y_i)\,[1 + \alpha E(Y_i)] \qquad (6)$$

Where

VarY_i = is the variance of the crash collected for those years on the roadway segment or intersection

E (Y_i) = is represented the expected crash frequency of the roadway segment for site

α = is the overdispersion parameter

Thus, when there is a higher dispersion parameter which is when the mean and the variance are equal then the poison model can be used instead of the NB regression model while if the dispersion parameter is large NB regression will be applied. Parameter coefficient's estimation was done by a GLM using STATA software and supposing the NB error distribution because the crash data standard deviation was greater than the mean (Ackaah & Salifu, 2011). Thus, this study will account for NB regression analysis to develop CPM for the study area.

2.10 Goodness of Fit

The CPM developed for a specific area will estimate the crash frequency, in this case when the observed and estimated crash frequency is much closer, then the model is taken as good quality. Consequently, Goodness of fit for a model is checked using different criteria and Pearson distribution value is one of the methods being used. Based on the degree of freedom and significant level, there will Critical value of Pearson distribution and the Pearson value to the model developed must be less than the critical value, and equation 7 below shows the formula used to calculate the value (Borsos, Ivan, & Orosz, 2016).

$$Pearson\ x^2 = \sum_{i=1}^{n} \frac{[y_i - \hat{E}(y_i)]^2}{Var(y_i)} \qquad (7)$$

For the sake of conciseness Ambros & Sedoník,(2016); Ambros et al., 2016) have used only one approach for checking the accuracy of a model that is the proportion of systematic variation. However Oh, et.al (2003) used all the five methods (mean prediction error, mean squared prediction, mean squared error, Pearson correlation coefficient for predicted crash frequency and observed and means absolute deviation) to check the validity or goodness of fit for the model. The coefficient of determination R- the square is used to regulate the overall goodness of fit in linear regression models while, in the Poisson and NB regression models, R square is not applied because the maximum likelihood estimation methods are usually used to maximize the R- square but, for the linear regression model the ordinary least square is used (Ackaah & Salifu, 2011). During the study of the pedestrian crash model, Tulu, (2015) have used the Likelihood of ration test(LRT) and AIC which are the goodness of fit methods for comparing the models. LRT methods are one of the popular methods used to measure the overall fit of models. Besides information regarding the formulated model is estimated using AIC and the model will be fitted when the values are higher (Washington et al., 2010).

As mentioned above, when the actual data is represented soundly by the developed model then that model is said to be fitted model (van Petegem & Wegman, 2014). The study in the Netherlands for rural roadway has used AIC and LRT to check the goodness fit of the CPM (van Petegem & Wegman, 2014). While developing the model, parameters will be added and removed to check the significance level then LRT will relate the new model and the previous model before the addition of the new parameter. As a result, if the parameter gives statistical development and if the model fits better than before then, the parameter will be taken. If not, to avoid the overfitting and to follow the parsimonious model principle the parameter must be excluded. Besides, AIC also validates the best fit of the model and the lower value indicates the best model. Model are compared and selected using AIC and the formula to get the values is as shown in equation 8 where p stands for several explanatory variables considered and L is maximum log-likelihood (Borsos et al., 2016). A model will be ranked as the best model when the values of AIC is lowed as well as a model with less AIC means best-fit model.

$$ACI = 2 \log L + 2P \qquad (8)$$

However, the study carried out in Ghana used Pearson chi-square and deviance to check the goodness of fit for the full model (Ackaah & Salifu, 2011). Assumption of the NB distribution is taken to develop a CPM for the rural two lanes in Ghana, and this assumption will be acceptable if, the value of the of Pearson chi-square and Deviance per the degree of freedom (number of samples minus one) is within the range of 0.8 and 1.2. Therefore, the full model developed for the study areas of Ghana was found to be fitted model because the value was found to be 0.8 for Pearson chi-square and Deviance per the degree of freedom.

The model form is also evaluated using the cumulative residual plot and the values are calculated using the difference crash rate of estimated and observed values. For an individual homogenous section, a curve will be drawn that contains AADT versus cumulative residual plot and then the model form will be appropriate when the curve is close enough to the x-axis (Borsos et al., 2016). When the roadway network has varying geometric attributes throughout and when the difference in geometry is not included in the model development then, this heterogeneity lets to have overdispersion. Then the residual cumulative plot will contribute to noticing the neglect of the variable in the model (Green, 2018). According to (Srinivasan & Bauer, 2013), traffic volume (independent variable of the model) versus cumulative residual values (for a given site, the difference of crash estimated by CPM model and the observed crashes) will give a cure plot graph. When the residual plot is far from the x-axis (greater residual value), it means that the model is less fitted with poorer quality of prediction. Figure 7 below shows the cure plot graph example of CPM and a negative residual plot mean the actual crash data is higher than the prediction crash rate as well as the positive residual plot are when the predicted crash rate is greater than the observed crash value.

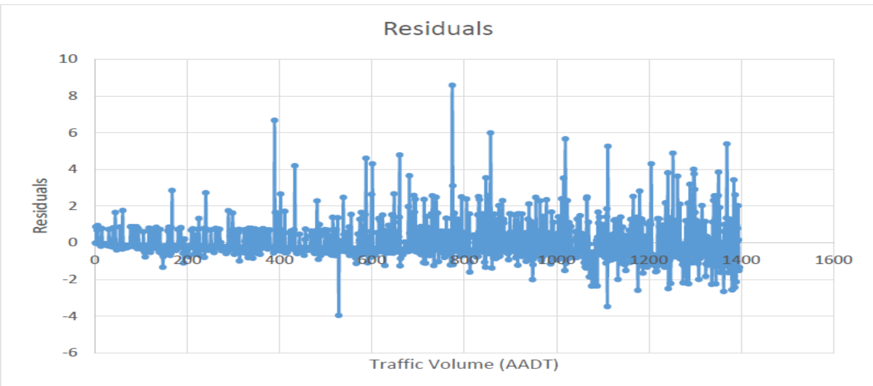


FIGURE 7 Residuals Vs traffic volume (cure plot graph)(Green, 2018).

Residuals loaded in similar traffic volumes will be better designated using Cumulative Residual (CR), and the value is determined by summing the residual value of a segment length to the CR of the preceding site. Figure 8 shows the CR value versus traffic volume and when the CR value associated around the x-axis in the closest way, then it shows the model fits it more (Hauer, 2015). As discussed above in the literature, the model of NB regression has a random error structure and this random error will let the CR oscillate around the x-axis (Hauer, 2015). The value will deviate from the x-axis when the distribution does not follow the random error, and this designated that the crash prediction model is not good or less fitted.

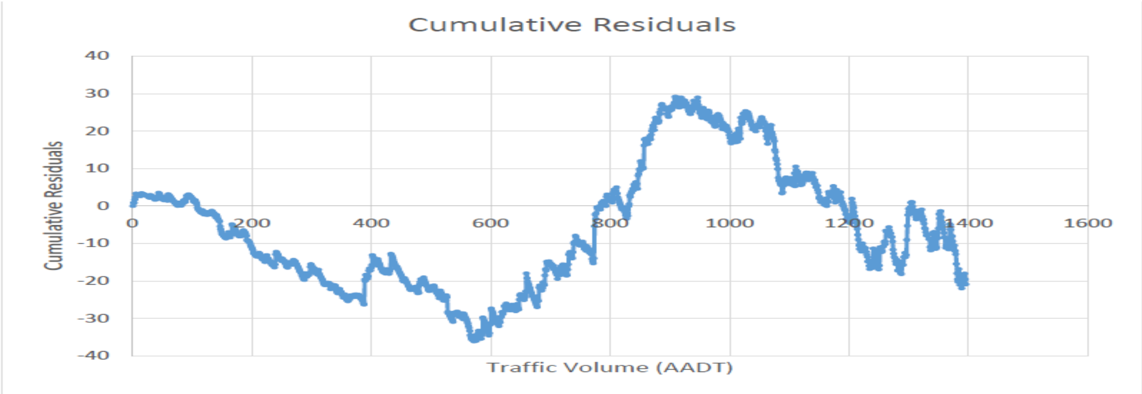


FIGURE 8 Cumulative residuals Vs traffic volume(Green, 2018).

According to (Green, 2018), CPM model can be compared and mark off by assessing the CURE plots and some situations make the model developed a good model by evaluating the CURE plots by the following conditions

- The oscillation around the x-axis should exist as well as the ending must be near zero.
- The variables in the model can be affected by the existence of outliers, so the model must be free of outliers
- The CR must be within the boundary provided
- The oscillation of the CR below and above the x-axis must be minimal

Erroneous data can also be identified due to the CURE plot in addition to improving the models (Green, 2018). And in the study showed that a Short segment of (0-0.7 miles) was analyzed in developing a model and the model revealed with less quality because indicative data error was dictated (a short segment of urban areas was incorrectly included in the analysis of rural roadway SPF model. Thus, the CURE plot of the model developed using incorrect data indicated the cumulative residual Vs AADT graph was not wavering in the x-axis as well as the data were quite far from the x-axis. Later looking at this graph, the model was review and improved by removing the improper data (urban short segments. Similarly, Srinivasan & Bauer, (2013) agreed that omitted variables are noticed using the cure plot by identifying if appropriate explanatory variables are included or not as well as identifies correctness of the functional form of the model.

2.10.1 Omitted Variable Bias

When a parameter that should have been included in the crash prediction model is excluded then omitted variable bias will occur (Green, 2018). When the model is developed on a road network that has heterogeneity (when the segment has a wider lane or carriageway and the others have the opposite) then this might lead to omitting of variable bias. This means a road network that has a heterogeneity attribute must be described in the crash model developed if not this will lead to the occurrence of omitted variable bias. This omitted variable bias can be minimalized by introducing more varying explanatory variable to the crash model however, overfitting of the model can occur due to the addition of variables(Srinivasan & Bauer, 2013) .which means, a model can be improved using the goodness of fit measuring standards by introducing variables in the model and during this overfitting of the model might happen. if the model is overfitted it will not predict correctly for the future periods. Besides having a homogenous road network can reduce the omitting of variable bias (Green, 2018).

Omitted variable bias can also be detected using the CURE plot, where the CURE plot is the graph of cumulative residual (summation of residuals i.e. the value of predict crash minus the observed crash) versus AADT (Green, 2018). Consequently, omitted variable bias will be displayed when there is a gradual upsurge of the residual values. Similarly, data error and outliers (excessive bounce in the graph) in the model are also identified using the CURE plot. SPF model will be improved when the outliers and errors are removed deepening on the size of the error. Hence, there are different methods to check the goodness of fit of models as discussed above as well as omitted variable and the correctness of function form can also be detected using the goodness of fit techniques. The methods to be used to check the goodness of the model will be selected later during the model development procedure.

3 METHODOLOGY

The previous chapter was concerning the explanatory literature review, assessing a previous study corresponding to this study area. However, this chapter dealt with the method of data collection applied, the type of research used, the practice of data collection, how data are processed, and the analysis decision made to know the effect of two-way two-lane rural roadway geometric effect on crash involving commercial vehicles in Tigray region. In addition to that, the administration, population size, and land use of the population living in the selected study areas are also clarified. The effect of geometric design features with crash data in rural two-lane rural roads are analyzed by using negative binomial regression analysis. Generally, the chapter encompassed the research method applied for developing a crash frequency model involving geometric feature predictors for rural roads.

3.1 Sampling method and selection of study route

There are different sampling techniques used to select samples from the population and these sampling techniques does not have restriction during section which makes the researcher to freely choose the methods. for this study, purposive sampling techniques were used for selection since there were criterial that guide the researcher to choose the study routes.

A study was conducted regarding the pedestrian crash model in a two- and one-way highway but the model was biased because it focused on areas of mid-block location with higher crash recordings (Diogenes & Lindau, 2010). Thus, roadway corridor selection must be randomly instead of using the only location with higher crashes to avoid partiality. Hence, a roadway that is in two different directions from Mekelle city was considered to exclude partiality during sampling

Possible study sites were selected for the study and selection criteria were also developed based on the availability of road geometric design data, year of road construction, and maintenance of the roads. Some roads have been constructed before 15 years and for these types of roads, it was difficult to find their road design report from Ethiopian road authority since their construction period was too long. Moreover, roads that have a longer period of construction tend to be maintained as well. Therefore, routes selected for this study area were roads that have design documents from ERA as well as roads that are not maintained within three years. Because three years of the study period is selected for this study and if the road is maintained within the selected study period, the crash data behavior will be different. Moreover, a field visit was also among the selection criteria for the study areas to know if the selected study areas are appropriate for this study, which is roads that have a good pavement condition state. Because crash statistics from Mekelle traffic police office of zone administration indicated pavement conditions that are in a good state are the ones that experience road traffic crashes.

Tulu, (2015), have used six major roads that diverge from the capital city Addis Ababa as a road corridor with 186km roadway network coverage. For the study of CPM for the pedestrian crash, road segments that are close to the benchmark (Addis Ababa) were used from the total road corridor of the study area. For this study, purposive sampling will be applied to select samples from the study areas because, there are locations where the design report of road geometric characteristics is not accessible as well as, to save traveling time. The road corridor for the study area will be a roadway network that diverges from the capital city of Tigray region in two directions to have different roadway features.

TABLE 5 Route selection for the study area (by the researcher)

Selection characteristics	Criteria
Field visit	Good state pavement condition

Road geometric design	Availability of roadway geometric design in ERA
Maintenance of roads	Roads that have not been maintained within the study periods
Cross -section	Two-way two-lane rural roads

The above criteria (table 5) were used to select an existing route of two-way two-lane rural roads (by different road sector organizations as development stage of the country) for this study. The selected routes were from Wukro to Adi-Abbagihe and Mekellel -Hagereselam with total coverage of 52.1km road length. These routes are among the road that has experienced several road traffic crash data records within the study periods. The study aims to evaluate the road geometric effect of the existing road network from Mekelle – Hagereselam (35.0 km) and Wukro to Negash(17.1km) road network concerning crash involving commercial vehicles.

An inhabitant of the Tigray regions is mainly Tigrayan ethnic linguistic communities. The road network that connects Mekelle to Hagereselam, as well as Wukro to Abi-Abbagihe, passes through small villages and towns where mainly the communities are an agronomist and permanently settled in for livings. Road network from Mekellel to Hageresleam and Wukro-Adi-Abbagihe (Figures 9 and 10).

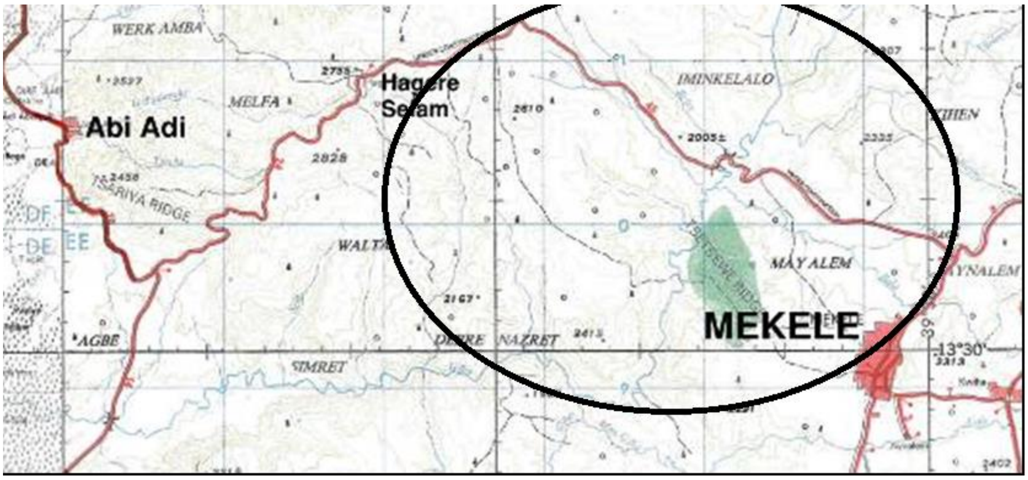


FIGURE 9 Location of Mekelle- Hagereselam and road network(Nordic Development Fund and ERA, 2010).

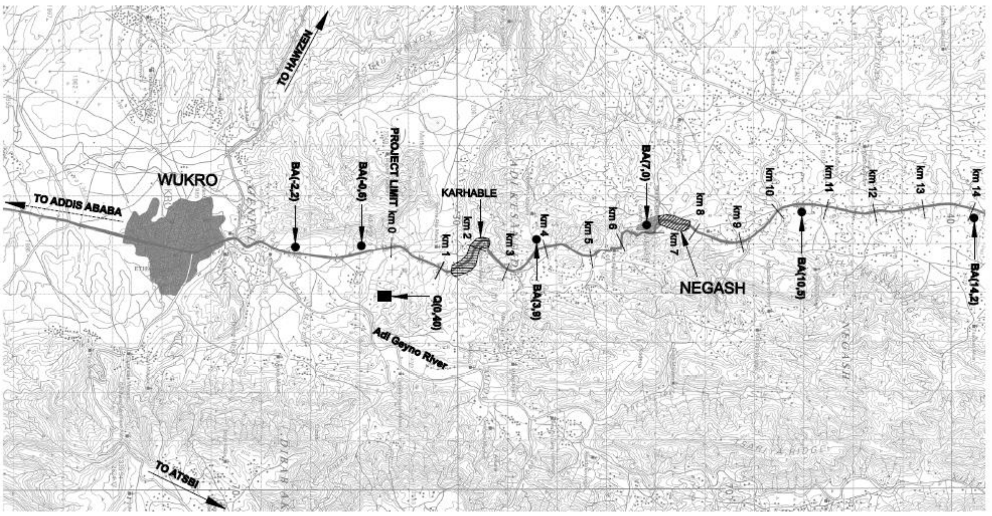


FIGURE 10 Location plan of Wukro -Abi-Abaggihe road network(Nordic Development Fund (NDF) and ERA, 2008).

3.1.1 Demographic characteristics and administration of the study area

A. Administration of the study area

Regionalization policy of the government is played by different roles and districts are among the administrations that have the central part. This means internal administration, budget distribution, human resources, and others are decided by the district administrations inside the districts. This implies it has the power to control matters related to their districts. Thus, district centres provide requested services to their population and these days are increasing due to the growth of population size and level of services. However, zone administration is an extension of the regional administration and they are not independent. In this case, Tigray is considered as a regional administration, Mekelle and other cities are taken as zone administrations and Kltewlaelo, Enderta and Deguea Tenben as district administrations. Consequently, for this study, the crash data are collected from three districts namely kltewlaelo, Enderta, and Deguea tenben.

B. Population living in the selected road route

According to the 2007 census, 4,314,456 were the population registers as living in the Tigray region. According to the resettlement plan of the Mekelle-Abi-Adi-Adwa road project report, population data that lives in rural areas individually for Enderta and Degua Temben districts was 114,277 and 106,258 consecutively in 2010(Nordic Development Fund and ERA, 2010). There is a higher ratio of females to the male population in these two districts compared to others. The population that lives along the road section Mekelle -Hagereselam has a homogeneous ethnic background and the language spoken by the population (99%) is Tigrigna. The homogenous ethnic population of the areas is fully reproduced by the language structure. Hence, the population living in the designated study route has homogenous ethnic with a proportional number of females to males.

C. Travel pattern to services and facilities in the study area

An environmental filed visit was handled during the project development of the Mekelle-Hageresleam road network and the road section has moderately and intensively cultivated areas as well as 33% protected areas like towns and villages. Moreover, 5% of the roadsides of the road section are covered by dense trees (Nordic Development Fund and ERA, 2010). The roadway that traverses towns and villages will experience road traffic crashes due to the movement of pedestrians in those locations.

The main economical sources of the population in the rural areas are agriculture and the farmlands of the communities are not close to their inhabited areas. The farmlands are located far away from the suburban locations that require to travel by foot for about 1 or 2 hours. Thus, they must travel by foot for farming including their animals in rural roadway sections which could cause the involvement of road traffic crashes for both pedestrians and animals. Future more, the communities must travel to visit markets which are located more than one-hour walking ways that let them walk in the rural section outside the villages.

Communities move out of their inhabited areas for the sake of farming, social connections, and marketing. In addition to that, the two-lane rural road of the study route traverse along with villages and towns, and this will cause the involvement of road traffic crash in rural roads. Thus, village presence is considered as one of the predictors for predicting the crash frequency of rural roads during the study.

This study aims to look at the relation of geometric features and road traffic crash data in the rural road of the Tigray region. For the study, the road network was selected based on the availability of road design reports, good state condition of pavements, and the maintenance period. Two road networks were selected that have 52.1km total length coverage. These selected two routes traverse villages and towns and communities in the study areas travel outside inhabited areas for marketing, social connection, and forming purposes. Hence, this all will cause the involvement of road traffic crash in selected two-lane rural roads of the Tigray region and needs assessment of traffic safety to provide harmless means of movement for the communities.

3.2 Traffic crash data

Traffic crash data are the main predictors used as the response variable for developing crash frequency predictor model. Traffic crash data report for an incident gives a summary of the state which provide information like the type of severity, several road users involved during traffic crash incidence, general (region, zone and unique names) location of the crash, date, time, the vehicle involved, vehicle and driver information, type of road user (passenger, pedestrian, and animal)involved in a crash with detailed personal information, weather condition and plate number of the vehicle. Moreover, the reports have a different description for the reason of crash involvement, road condition (dry, snow, raining or wet) during crash involvement, safety apparatus's used, use of drugs or alcohol during driving and other similar information that which helps the traffic police in recording the crash events. Risk factors thought by the traffic police officer for the crash occurrence are reported as well thus, to take benefit, traffic crash that are recorded due to geometric design fault are also extracted, which will support the data analysis and conclusion later.

The following each traffic crash information is required to know the relation among the traffic crash and geometric design elements:

- where traffic crash happened, roadway classification, the location like in tangent or horizontal curves, the specific address of the crash and road names
- when does traffic crash happen: the year, month, day of the week, and time of the day?
- who were involved during the traffic incidence: cyclist, motorcyclist, pedestrian, passenger, driver including their demographic details, animals, and roadside items?
- what are the results of the crash incidence: fatality, slight injury, severe injury, and property damage?
- What were the environmental condition during the traffic crash incidence: weather pavement and light condition?
- What was the contributing factor for the crash incidence: road defects, speeding, driver illegal behavior, vehicle difficulties, and others?

Thus, traffic crash data was collected from Enderta, Kltewlaelo and Alasa traffic police commission office district for three (2009-2011E.C) study periods and the detail traffic crash data required for the study are listed as follows;

- Location of the crash incidence like road address specifically, region, zone, unique name of the location, land use (residential, church, hospital, and others) near the location.
- Month, year and day of the weeks including their time of crash incidence
- Traffic incidence plan that shows a rough drawing of the road geometric design of the crash location
- Code (plate number) of the vehicle including their type of crash (head-on crash, overturning and rear-end collision

- Contributing factors for the crash occurrence but this roughly done by the traffic police office commission which needs other professionals to identify the risk factor for the road crash.
- Road user involved (pedestrian, cyclist, motorcyclist, and passengers)
- Road surface condition in crash incidence (wet, dry).

Traffic crash data was collected in hard and soft copies. Crash data was collected by using photographs from the hardcopy's files of every crash incidents and ADT was also counted for specified routes and recorded in hardcopies and then lastly recorded both data in softcopies at Excel sheet.

The statistical relationship between road traffic crash frequency and road geometric design is done using the existing road geometric design and crash data reports. Crash data are taken from the Tigray police office commission. Specifically, crash data for the route from Wukro to Adi-Abbagihe was taken from Klteawlaelo police commission office while for the route from Mekelle to Hagereselam was taken from Enderta and Alasa traffic police commission office districts. Where the route from Messebo to river Giba is administered by the Enderta district and the route from River Giba until Hageresealm is by Alasa district. The data was not recorded in the database, instead they have it in hard copy. Thus, the data collection for the crash data was handled by taking a photograph from the set of files (figure 11).

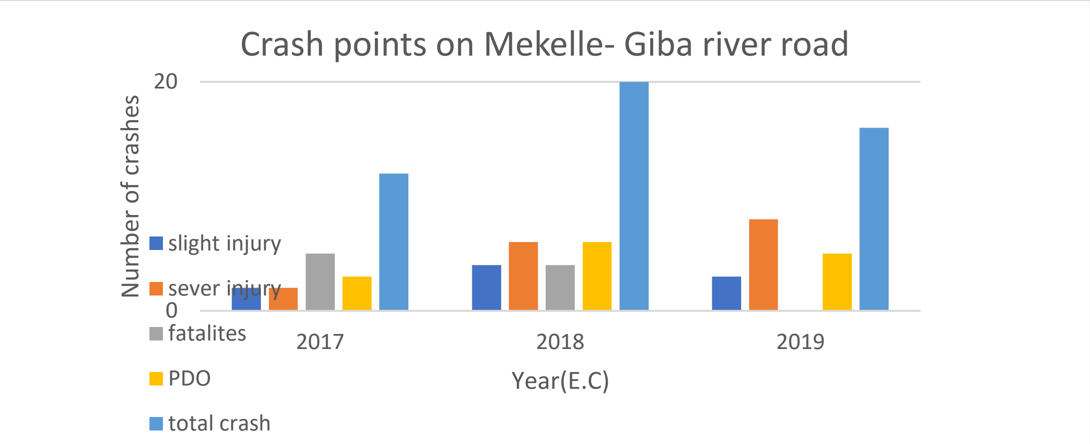
FIGURE 11 Collecting crash data by taking a photograph from the set of files for every crash event (taken by the researcher).

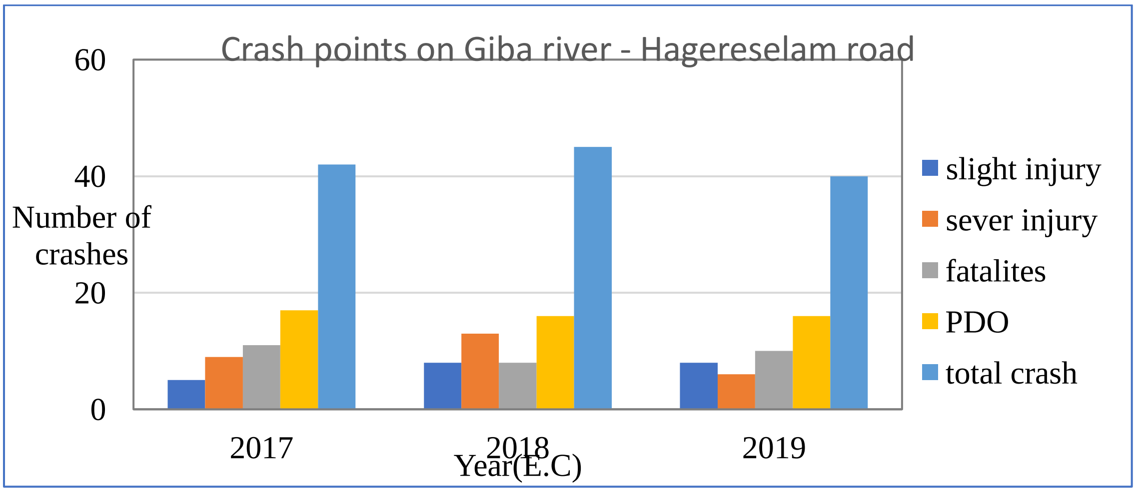
when traffic crash happens, there is two responsibility to be handle by Tigray traffic police office commission, plan taker (that draws the plan of roadway geometry in the location of crash incidence as well as interviews all the participant that happen to be there during the traffic crash to have evidence later) and vehicle performance regulator (that records the condition of the vehicle during the crash existence). Thus, the file of one traffic crash incidence encompasses different files inside it but the file that has been used by the researcher was plan drawing (to know the date and approximate location of the crash)and sue paper (to take information regarding the number of road users involved in crash and type of severity of the traffic crash). The samples of plan drawing and sue paper for one crash indecent is found in APPENDIX A1 and A2.

3.2.1 Characteristic of collected traffic crash data

Traffic crash data that occurred in rural two-way two-lane of the Tigray region have been collected for the study from three traffic police office districts for three years of the study period. These collected data were taken by a photograph and later recorded in Excel shit. Thus, descriptive statistics of the total collected traffic crash data have been analyzed and will be discussed in this section.

Crash data collected for three districts indicates that there was 305 total crash occurred for three study periods (2017-2019). Severe injury (29.5%) and PDO (32.13%) are the type of severities with a larger number followed by slight injury (20%) and fatality (18.4%). Looking at the number of crashes per district, Alasa and Kltewlaelo districts have 41.6% and 42.62% total road traffic crash respectively followed by Enderta district with 15.73% total road traffic crash in three years (figure 12). Moreover, there was a reduction of severity and fatality from 2017 to 2019 in the road route of Mekelle to river Giba while the number increased from years to years for both routes of Wukor-Adi-Abaggihe and river -Giba to Hagereselam.





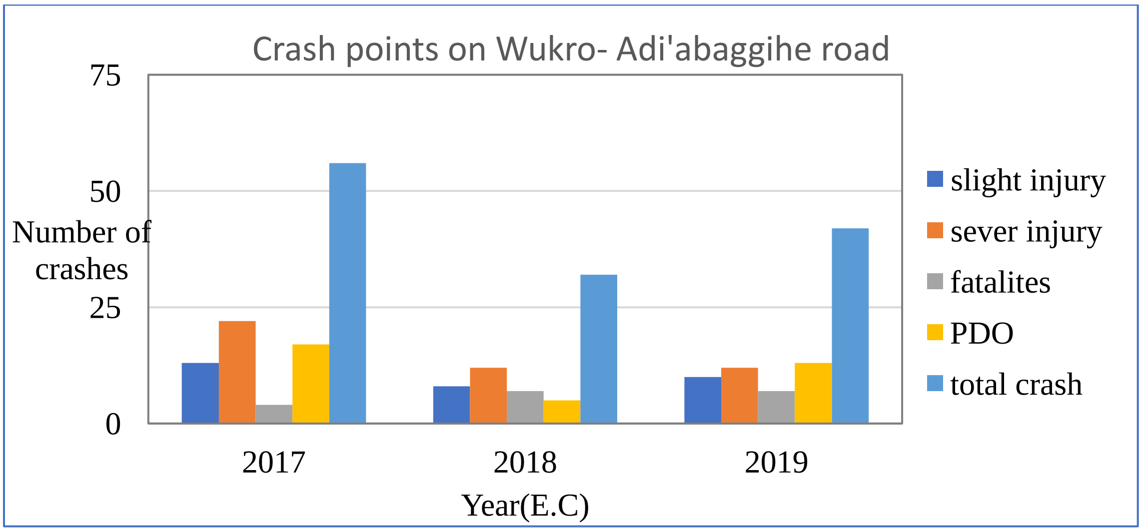


FIGURE 12 Traffic crash characteristic for three districts (analysed by researcher).

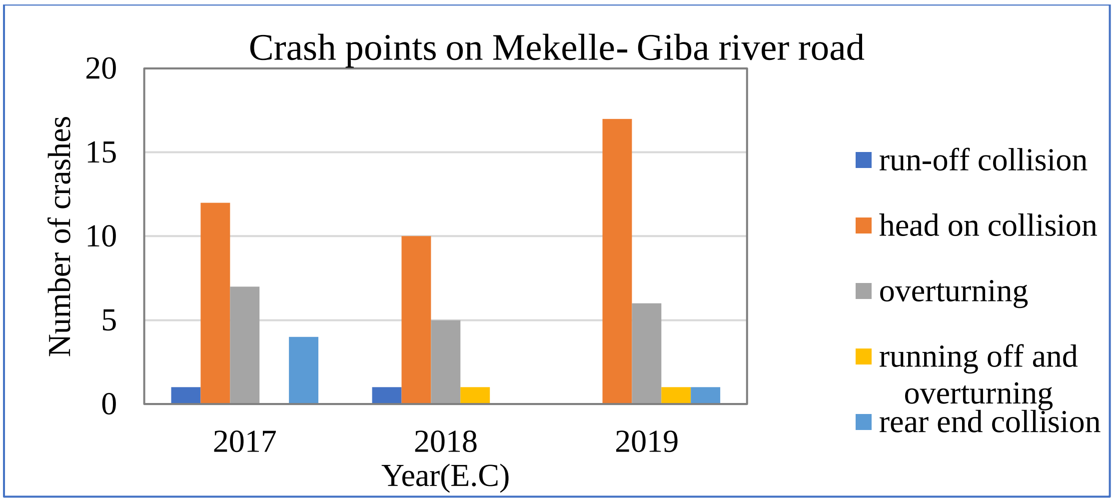
Road traffic that happened at the intersection was not included during data collection. All type of crashes was considered for this study and the collision types that are used for the study are listed below;

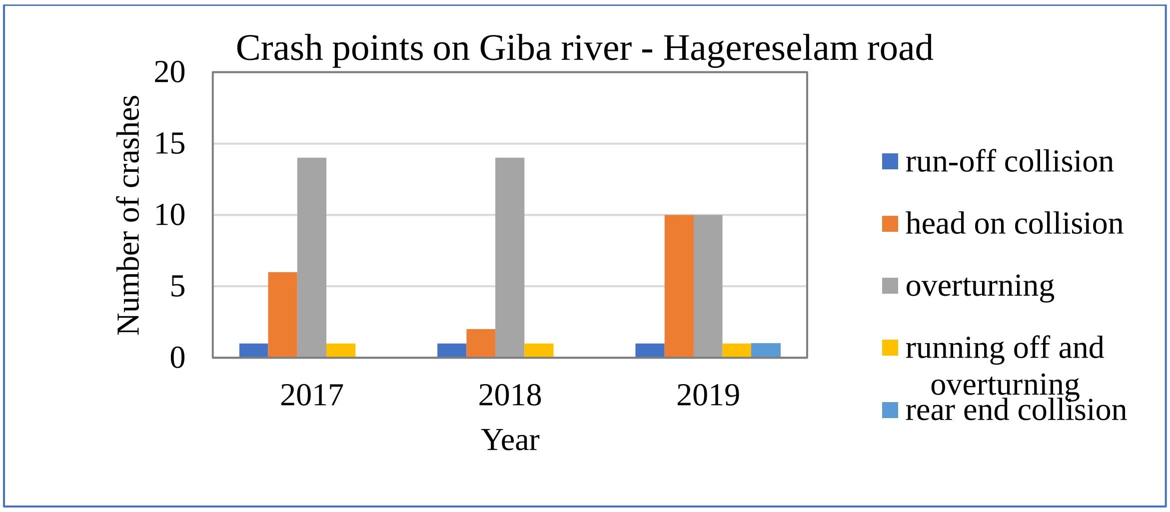
- Single overturn vehicle
- Multiple vehicle collision from the opposite direction
- Multiple vehicle collision traveling in the same direction
- Single vehicle running off the road
- Accident involving passing maneuvers and turning
- Crash involving parking

All traffic crash involving these types of Collison was included however, crashes relating animals were excluded from the data analysis.

The single-vehicle crash is a common type of crashes from the traffic crash data collected for both the routes. These vehicles can leave the main roadway and overturn, or they can collide with fixed objected like a house or other existing material on the roadside. These types of crashes can be due to different factors like the terrain type, speeding, weather condition, horizontal curvature, and other type of road features. Future more, the location of these fixed objects nearby the roadside can also have a role for the crash. when the fixed objects are far from the roadway, this can allow the car to have access to slide and control the car without colliding with the fixed object nearby. Where the existence of fixed objects in the roadside is quite near to the main roadway, then it is obvious that the level of injury and fatalities will be tough. Similarly, the number of multiple vehicle crashes like (head-on Collison, rear-end Collison, and side-on collision) is also considerable in number as indicated by the collected traffic crash data figure. Different factors such as vehicle characteristics, driver behavior, and road geometric features can be the reason. Therefore, the occurrence of severe and fatal injury for runoff crashes and multiple vehicle crashes can be a combination of different factors. However, for this study, all types of crash and Collison types are considered without specifying the collision types.

Descriptive analysis has also been made to collision types of crash data collected from three districts (figure 13). Five (run-off and overturning, run-off, head-on, overturning, and rear-end) types of the collision were revealed from the collected crash data. Road network from Mekellel -Hagereselam have higher overturning and head-on collision type whereas Wukro -Adi-Abbagihe have a considerable number of rear-ended collision type in addition to overturning and head-on collision types.





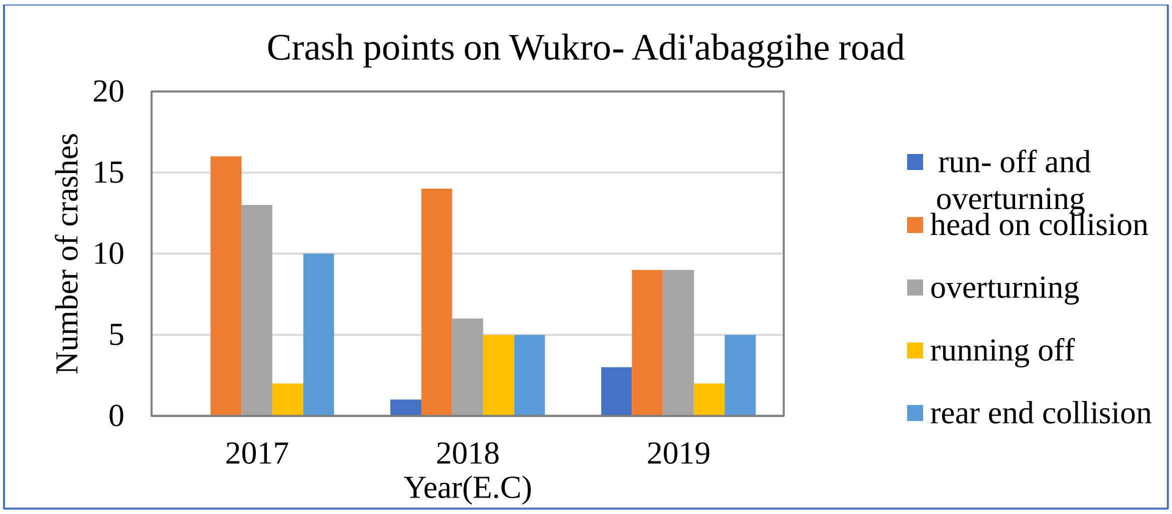


FIGURE 13 Collision type of crash data characteristic for three districts (analyzed by the researcher).

3.2.2 The material used and steps carried out to locate road traffic crash data

Material like Global Positioning System (GPS), papers, and cameras were used for collecting traffic crash data. The camera was used to take pictures of crash data records from three traffic police commission office districts. These taken pictures were later printed to practice it during the site visit. Besides, GPS was used to locate the coordinate of every road traffic crash point for the selected routes. ETREX/32x was the model of GPS used (figure14) and the coordinates were recorded in Universal Traverse Mercator (UTM) coordinate systems.

FIGURE 14 GPS(ETREX/32x) type used for locating crash points (GARMIN, 2019).

Crash data collected by taking photographs from the traffic police commission office gives information like the general location, type, and several crash severities but, the exact locations are not indicated in terms of coordinates. Thus, a site visit was a must to know the approximate location of every crash point. The site visit was handled with five traffic police (responsible for taking plan drawing during traffic crash involvement) to locate the location of crash points (Figures 16 and 17). The following steps were carried out to locate the crash point:

- All the crash data collected by taking photographs were printed to practice it during the site visit. It took three days to locate all crash point for both routes from Mekelle-Hagereselam and Wukro-Abi- Abbagihe.
- For the consecutively three days, the researcher rents a car during the site visit to save time and energy (figure 15).

FIGURE 15 Vehicle used for the site visit (taken by the researcher).

- The coordinates (easting northing and elevation) of every crash data were recorded using GPS and the detail are in Appendix B for all crash data collected from three districts.
- All the collected coordinate of crash points was recorded in excel file concerning their date, type of severity, number of involved road user during the crash occurrence.
- Finally, all crash coordinated recorded were signposted using Geographic Information System (GIS) software for all specific routes (Figures 18, 20, and 21).

FIGURE 16 Recording coordinate of crash points for Mekelle-Hagereselam route (taken by the researcher).

FIGURE 17 Recording coordinated of crash point for Wukro- Abi-Abbagihe route (photo by the researcher).

The location of collected crash points for both routes from Mekelle to Abi-Adi and Wukro to Adi-Abaggihe were positioned in the routes (Figures 18,20 and 21). The crash points from Mekelle to Abi-Adi was collected from three different district administration (Enderta kltewlaelo and Alasa). Thus, locating the point of a traffic crash for Mekelle to Hagerseam is done in two (Mekelle -Giba river and Giba river to Hagereseam.) different shits as signposted below.

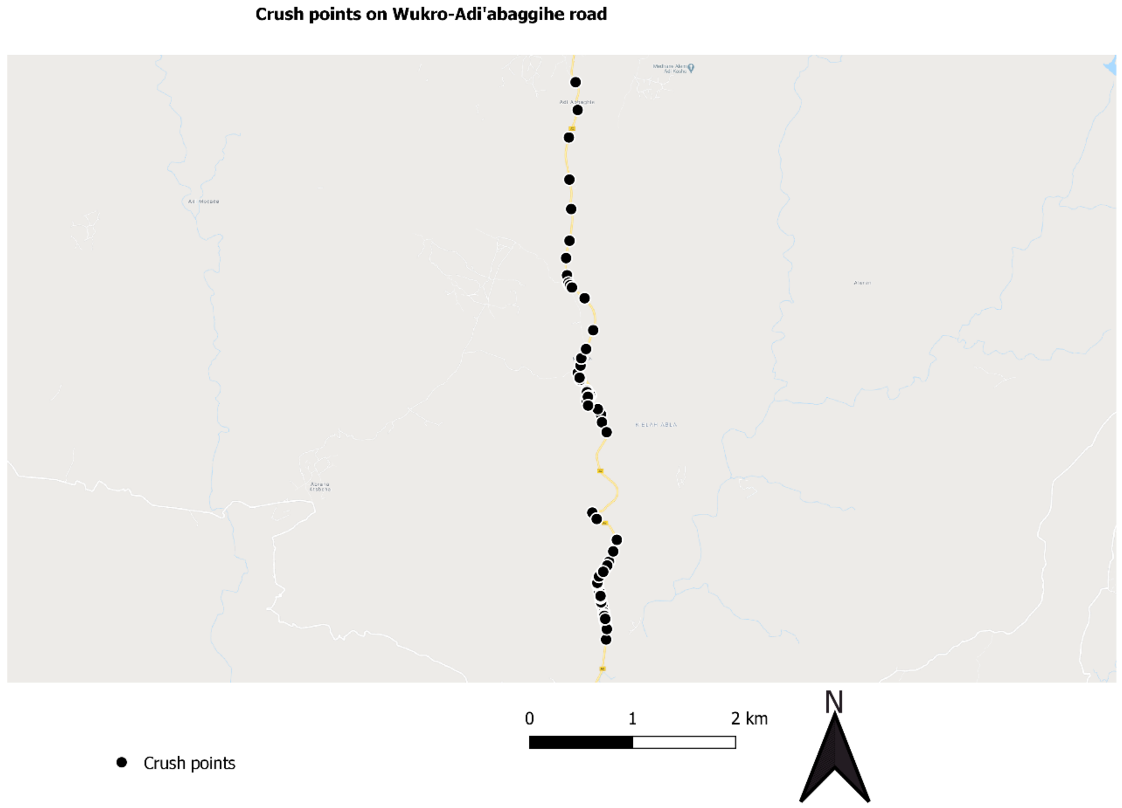


FIGURE 18 Crush points located in the roadway from Wukro to Adi-Abbagihe(by the researcher).

Figure 6 indicated among the horizontal curved that experienced several traffic crashes inside Wukro-Adi -Abaggie route. This specific road section has escarpment terrain type with 1 m shoulder width. This location is among the blackspot location identified by Kltewlael traffic police office district. Due to repeated crash incidence, the radius of this horizontal curve was redesigned again as revealed to the left side of figure 19.

FIGURE 19 Horizontal curve in route from Wukro -Adi-Abaggie that experienced higher traffic crash records (taken by the researcher during site visit).

Crush points on Giba river-Hagereselam road

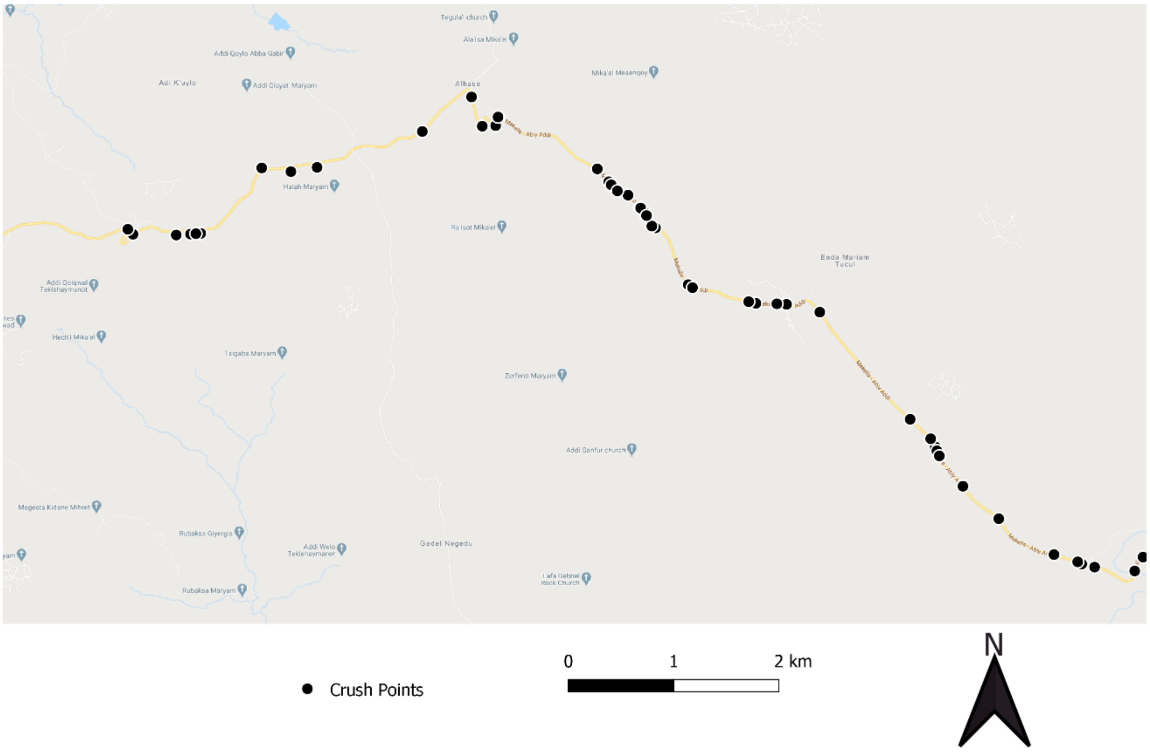


Figure 20 Crush points located in the roadway from Giba river to Hagereslam route (by the researcher).

Crush points on Mekelle-Giba river road

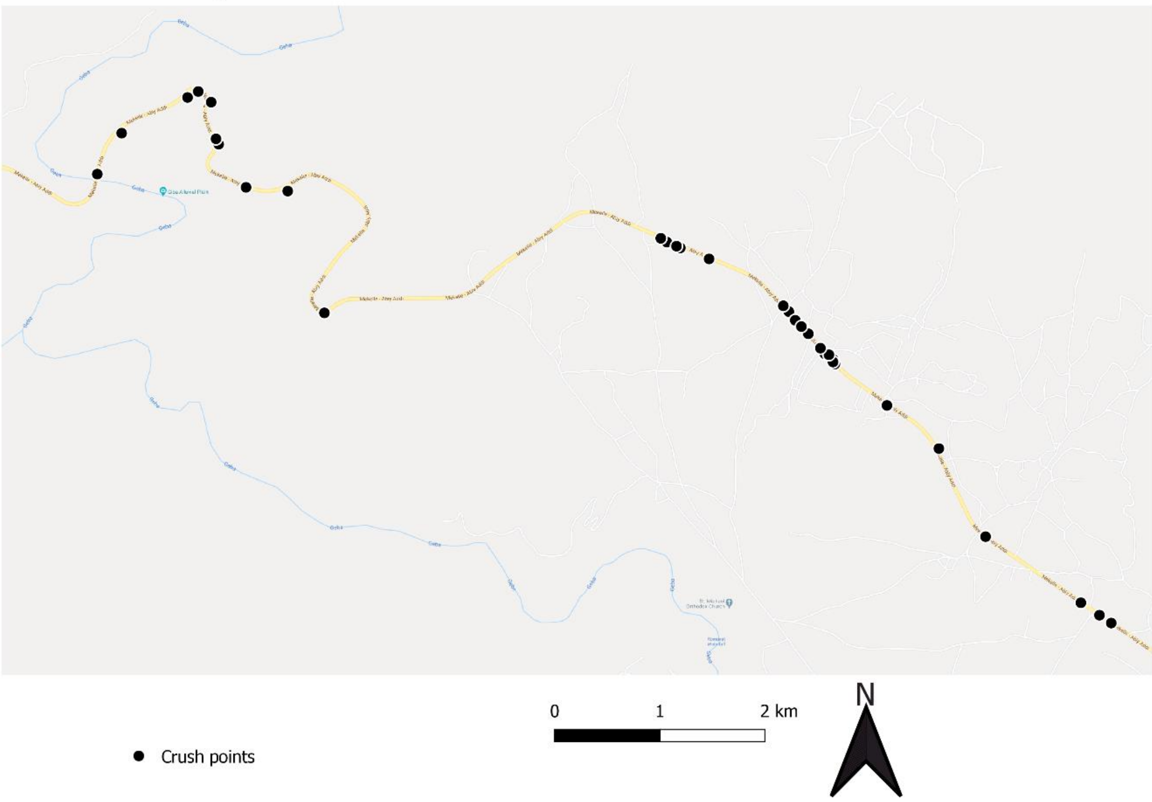


FIGURE 21 Crush points located in the roadway from Mekelle to Giba river route (by researcher.

Traffic crash data that occurred in two-way two-lane rural roads of the Tigray region have been collected for (2017-2019) study period from three (Enderta, Alasa, and Kltewlaelo) traffic police office commission districts. These data were recorded by a photograph and printed later to locate the crash points. All the traffic crash data collected including date, reason of crashes, general locations, weather conditions, crash severity, number of road users involved, type of collisions, and other related information. There was a 305 total road crash collected from Mekelle-Hagereselam and Wukro -Adi-Abbagihe routes for three years of the study period. Crash data collected from Enderta district have lowest (15.73%) traffic crash records and the remaining crashes are for Kltewlaelo and Alada districts. The locations of all crash data were located using GPS in the form of a UTM coordinate system during a field visit. Lastly, these crash locations were located at the nominated routes using GIS software.

3.3 Road geometric design data and traffic volume

Traffic crash involvement can be due to various risk factors like vehicle characteristics, human behavior, and road conditions. Effect of road conditions on traffic crash will only be the main concern here due to limited time and data availability to include other influences. Geometric features like shoulder type, shoulder presence, segment length, AADT, horizontal and vertical curve density within a segment, driveway density, and terrain type were collected to know their effect in traffic crash occurrence. Thus, a model was established to analyze the dynamic change and interruption within road geometric road elements and road traffic crash for the selected rural roadway of the Tigray region specifically from Mekelle to Alasa and Negash to Abi-Abbaghie routes.

To verify the correlation analysis effect of road geometric design on crash existence, different geometric elements have been collected for selected routes. Road geometric elements engaged during analysis are discussed in this section.

3.3.1 Terrain type

The terrain type where the road passes through is the determinant of other road geometric design elements (Ethiopian road authority, 2002). Appendix C indicates the type of cross-section for the flat, rolling, and mountainous terrain of the wukro-Adi-Abbagihe route as well as mountainous and escarpment terrain for Mekelle -Hagereseam route. Thus, the shoulder and carriageway width are reliant on terrain types and other factors. There are four classes of transverse terrain properties specifically flat, rolling, mountainous, and escarpment. There will be fewer obstacles during the construction of roads when the terrain types are flat and rolling with unrestricted vertical and horizontal alignments. However, when terrain types become difficult the construction effort and cost will be much higher.

For this report, the selected routes include all types of terrains. The route from Mekelle -Hagereselam road section has all the terrain types excepting flat terrain whereas route from Wukro to Abi-Abbagihe comprises all-terrain categories. Table 6 and 7 shows the terrain types for all selected routes. Moreover, terrain type was among the parameters applied for the method of homogenous sectioning for both selected routes and predictors to develop CPM.

TABLE 6 Design standard and Typical cross-section for Mekelle -Hagereselam road section (Nordic Development Fund and ERA, 2010)

Section (Km)			Design standards	Terrain type	Typical cross-section
From	To	Length (m)			

5.07	14.58	9.51	DS3	Rolling	N
14.58	17.75	3.17	DS3	Escarpment	M1
17.75	24.29	6.54	DS3	Mountainous	M1
24.29	28.24	3.95	DS3	Rolling	N
28.24	34.00	5.76	DS3	Mountainous	M1
34.00	35.80	1.80	DS3	Escarpment	M1
35.80	42.80	7.00	DS3	Mountainous	M1
42.80	45.15	2.35	DS3	Escarpment	M1

TABLE 7 Design standard and Typical cross-section for Wukro-Adi-Abbaghie road section (Nordic Development Fund (NDF) and ERA, 2008)

Station(M)		Length(m)	Design standards	Type of terrains	Typical cross-section
0	1159	1159	DS3	Flat	N1
1159	3547	2388	DS3	Rolling	N1
3547	4122	575	DS4	Mountainous	N1
4122	6522	2400	DS3	Rolling	N1
6522	6897	375	DS4	Mountainous	N1
6897	8572	1675	DS4	Escarpment	E1
8572	9822	1250	DS3	Rolling	T1
9822	11447	1625	DS3	Flat	N1
11447	11697	250	DS3	Rolling	N1
11697	16147	4450	DS3	Flat	N1
16147	17297	1150	DS3	Rolling	N1

3.3.2 Carriageway and shoulder of selected routes

Shoulder and carriageway width are among the geometric features of the roadway and these parameters were among the predictors used to develop CPM. Mekelle – Hagerelsam road route is serving for local areas within the region as well as it links two trunk roads. More importantly, the Tekeze hydro-power plant is mainly accessed using this roadway. The carriageway width of the road section for the Mekelle-Hagereselam road network is 7 meters with 1.5m wide shoulders, except for mountainous and escarpment sections with 0.5-1 m wide. Villages have wider (2.5m) shoulder width compared to other rural roads that do not traverse villages. Besides towns like Hagereselam and Abi- Adi has 3.5 wide paved shoulders (Table 8). However, town sections are not included in the data analysis because the objective of the study is to compute the relation of rural roadway geometric features. Thus, rural roadway sections including villages are only considered.

TABLE 8 Carriage way and shoulder width for different design standards (Ethiopian road authority, 2002)

Design Standard	AADT	Carriageway Width (m)	Shoulder Width (m)				
			Flat	Rolling	Mount.	Escarp.	Town **
DS3	1000 - 5000	7.0	1.5 - 3.0 *	1.5 - 3.0 *	0.5 - 1.5	0.5 - 1.5	2.5
DS4	200 - 1000	7.0 ***	1.5	1.5	0.5	0.5	2.5

There are four types of cross-section types for Mekelle - Hagereselam roadway network where type N refers to (normal section flat and rolling terrain), type M-1 (mountainous and escarpment terrains), type T (Town section) and type V (village sections). The selected routes have three (1.5m,2.5m, and 1.0m) different shoulder width for the normal, village, and mountainous sections respectively (table 9).

Correspondingly, Wukro-Adi-Abbagihe has three cross-sectional categories, with type N for flat, rolling and mountainous terrain, type M for escarpment terrain, and type T for town section. Escarpment terrains have 1m shoulder width with 6.7 m wide carriageway and normal sections with 1.5 m and 7.0m wide shoulder and carriageway consecutively (Table 10).

TABLE 9 Carriageway, shoulder width and cross-section type for Mekelle- Hagereselam route (Nordic Development Fund and ERA, 2010)

Road section		Cross Section Type	Carriageway width (m)	Shoulder width (m)	Total width (m)
Mekelle - Hagereselam (0-49.1 Km)	Normal (flat and rolling terrain)	TYPE N	7.0	1.5	10.0
	Village section	Type V	7.0	2.5	12.0
	Town section	Type T	7.0	3.5 paved	14.0
	Mountainous and Escarpment terrain	Type M-1	7.0	1.0	9.0

TABLE 10carriage way, shoulder width and cross-section type for Wukro- Adi-Abbagihe route (Nordic Development Fund (NDF) and ERA, 2008)

Road section		Cross Section Type	Carriageway width (m)	Shoulder width (m)	Total width (m)
Wukro -Adi-Abbagihe (17.057km)	Normal (flat, rolling and mountainous terrain)	Type N	7	1.5	10.0
	Town section	Type T	7	3.5 paved	14.0
	Escarpment terrain	Type E M1	6.7	1.0	8.7m

3.3.3 Villages transverse by Mekelle -Hagereselam road

The first route selected for this study was from Mekelle to Hagereselam two-way two-lane rural roadway. This selected road section passes through Enderta and Degua Temben districts. There are four villages in between these routes though Hagereselam is a town and it is excluded during road sectioning of the rural roads for the analysis. The villages and their kilometer coverage crossed by the selected road for this study are listed in Table 11. However, there is only one village that traverses the road network of Wukro -Adi-Abagihe. Villages have wider shoulder width compared to other typical sections, but they almost have similar carriageway width with all the terrain types. The village was also used as a variable to section the two-way two-lane rural roadway. Besides, the presence of a village in the road section was taken as a categorical variable to predict the crash frequency of selected road network.

TABLE 11 Villages along the Mekelle – Hagereselam road routes(Nordic Development Fund and ERA, 2010)

Location (Km)		Length	Village name
From	To	(Km)	
5.07	5.65	0.58	Hala'awlie village
10.19	11.41	1.22	Romanat Village
26.99	27.61	0.62	Tkull Village
35.68	35.96	0.28	Aleasa Village
47.88	49.23	1.35	Hagereselam

3.3.4 Horizontal and vertical alignments

The straight section, circular curve, transition curve, and superelevation section are the elements of horizontal alignment (Ethiopian road authority, 2002). The horizontal alignment of the road network is calculated using GPS tracking survey. There are horizontal curves that do not comply with the minimum radii requirements (Nordic Development Fund and ERA, 2010) and they are indicated in bold lines in the Appendix D. According to Nordic Developed Fund and ERA design reports, types of the radius that don't not full fill the design standards are mainly located in the roadway that has escarpment and mountainous terrain. Since these types of terrains are difficult for construction in terms of cost and effort.

Road geometric design affects the rate of a traffic crash and traffic safety. Sever crash and property damages happen in road surfaces where there is a horizontal curve because these lead to generating overturning, problem to control the vehicle as well as movement difficulties (Mulugeta, 2018). The number of horizontal curves(NHC) was used as one of the variables to predict the crash frequency.

Furthermore, vertical curvature which is governed by gradients and sight distance is the main feature of vertical alignments (Ethiopian road authority, 2002). There are maximum and minimum gradients provided for different design standards and terrain types. Moreover, gradient requirements of the road network that transverse villages are also restricted. Similarly, there are vertical alignments than have a gradient that exceeds the absolute maximum for a give design standard and some of the gradients are fixed to meet the design standards. Some gradient of the Mekelle-Hagereselam roadway network that exceeds the design standard are marked in bold and listed Appendix E. Number of vertical curves (NVC) along the rural roadways of both selected routes were also taken as predictors of crash frequency.

3.4 Traffic volume

Total yearly traffic volume divided by 365 days will be AADT and the total length of vehicle travel per day will give average daily vehicle kilometer of travel. While average daily traffic is the average number of vehicles traveled along the roadway for a specified period (often 7days or less). Thus, diving the number of vehicles count for days per the number of days yield ADT. ADT is the main basic unit used to forecasted and monitor traffic flow.

Several studies (Ackaah & Salifu, 2011; Cafiso, Di Graziano, Di Silvestro, La Cava, & Persaud, 2010; Garach, de Oña, López, & Baena, 2016; Tulu, 2015) have found that traffic volume has significant in up turning the crash rates. Ackaa et.al (2011) revealed that the crash rate can be higher by 11% when traffic volume increases by half percent while, if the traffic volume is folded, the crash rate is expected to be 19% higher.

Design standard (DS) of roadway sections is depending on the AADT flow taking the two-way traffic flow. There are four design standards from the ERA manual explicitly DS1, DS2, DS3, and DS4(Nordic Development Fund (NDF) and ERA, 2009). Route of Mekelle-Hagereslam has DS3 despite the fact route from Wukro to Adi- Abbagihe has involved both DS3 and DS4. These design standards are different due to the traffic volume variation along the routes and DS3 is used for designing a route when the AADT is within the range of 1000 and 5000.

For the study crash rates of two-lane highways in the USA, locations were existing which does not have automatic traffic recorder and to include these sites during developing the models, factors generated by ‘’Connecticut department of transportation’’ in the USA were used to convert the daily traffic count to AADT (Ivan et al., 2000). ADT was used during the modeling of the pedestrian crashes for the rural two-lane roadways in Ethiopia. For counting the pedestrian volume and the time frame used for recording the pedestrian flow was one day from weekdays and time was from 7 a.m. until 7 p.m.(Tulu, 2015). Besides in Ethiopia, pedestrian flow at weekends was almost constant because these days are mostly a day off for the community, and pedestrians are considered to travel for shopping and different social activities during these days. Due to that, two hours only are considered for counting the flow of pedestrians in one of the weekends(Tulu, 2015). Thus, PHV count can be used to calculated the ADT value of road networks.

Socio-economic activities of the country and the region are increasing from time to time and this will have a consequence of traffic volume growth. Moreover, due to the political issue in Ethiopia, there has been an increase in traffic flow in the Tigray region starting from 2018 until now. Thus, transportation of road users and goods is enhanced, and this is remarkable transportation growth in the study area. However, there has been a restricted movement in the regions consequently decrease in traffic volume due to the lockdown imposed in the region to reduce the spread of coronavirus. Then this might have affected traffic volume by a significant decrease from the previous experiences.

Conferring to an Ethiopian road authority, (2002), annual count report is handled to federal road networks found in Ethiopia and the count is done three times a year by season. In each of these seasons, traffic volume count will be held for consecutive seven days for 12 hours (6:00 AM-6:00 PM). Besides, it will be supplemented by 24-hour count for two days (one from the market day and one form holiday) from the week. Thus, ADT for the whole week will be calculated as the sum of daily volume vehicle count multiplies by its corresponding daily factors.

The only route used to travel from Mekelle the southern part of Tigray was only one route that is Mekelle -Adwa route, where the study route Wukro-Adi-Abbagihe route is contained within this. Nevertheless, starting 2012 roadway that connects Mekelle to Abi- Adi was constructed, some of the traffic volumes were then diverted from the other route. The route from Mekelle to Abi-Adi was constructed from 2012-2016, where the route of Mekelle to Hagereselam is located.

For this case, traffic volume was counted for 2 peak hours for Mekelle- Hagereselalm and Wukro- Adi-Abbagihe routes during the market day (expected to have a higher number) as indicated in table 12.

Thus, peak hour volume was changed to ADT using a factor K (PHV is calculated multiplying ADT by a factor K). The value of the K factor for the Tigray region is 0.16. However, ADT might be small due to restricted movement to reduce the spread of COVID-19. Therefore, ADT traffic count from ERA for 2019 is used for three (2017-2019) years of the study period.

TABLE 12 Traffic volume count for the selected routes (Source: peak hour count for one day by the researcher)

Vehicle type	Peak hour count for different road routes (Veh/hr)		
	Mekelle - Romanat	Romanat-Hagereselam	Wukro-Adi-Abbagihe
Cars (standard car, wagon, pickups, and minibus)	27	71	77
Large buses and single rear axle truck	0	4	5
Medium (dual rear axle Trucks)	0	2	10
Heavy (four axle trucks)	0	11	5
Articulated (large trucks)	0	0	2
Total	27	88	94

ADT used for the analysis is taken from ERA and the data are listed in section 1.5 together with other variables used to predict crash frequencies.

3.5 Method of road sectioning

Different methods of road sections are used like fixed-length, homogenous road segmentation approaches, and others. For the case of homogenous road segmentation methods, diverse type of variables has been practiced to divided roadway into road segments as stated in the literature review section. For this report, the homogenous method of road sectioning was applied to divide two-way two-lane rural roadway and the variables used for sectioning the road where, terrain type, design standard, AADT, and shoulder-width (figure 22). Accessibility of roadway geometric design reports and proximity were the means used to select two-way rural roads of the Tigray region for the study. Two routes (Mekelle- Hagereselam) and Wukro -Adi-Abbagihe) were selected for the analysis because these were the route that have roadway geometric design reports from ERA as well as close to Mekelle city where the researcher exists. The total length of the rural roadway taken for the analysis was 52.1km where the 17km route was taken from Wukro -Adi-Abbagihe route and the remaining road length from Mekelle-Hagereselam route.

According to, Ambros et al., (2015) roadways that are greater than 5km length must be divided into two road sections to avoid long road section segmentation which is not preferable for developing a model. Thus, road sections of the selected rural road that had more than 5km length were divided into two road segments for the analysis. Finally, applying the homogenous method of road sectioning produces 29 road sections for the selected routes from Mekelle to Hagereselalm and Wukor to Adi-Abbagihe (table 13). Those road sections have homogenous characteristics because every road section begins and ends when the geometric variables considered for segmentation changes.

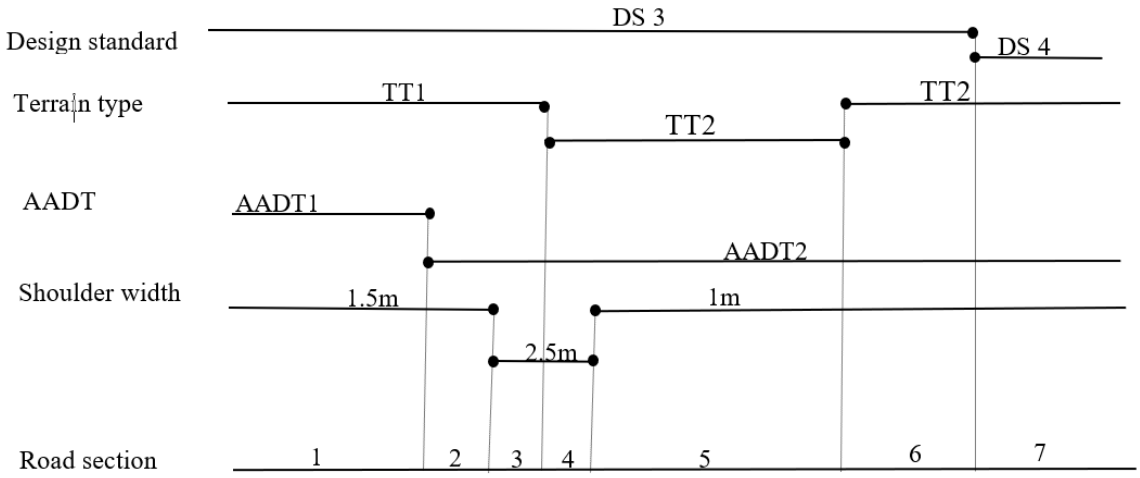


FIGURE 22 Homogenous road sectioning principle considered using four variables for the selected routes (source: researcher)

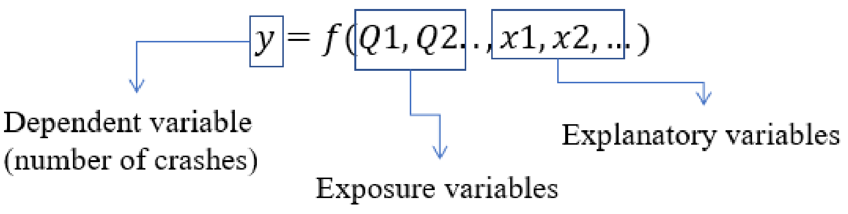
TABLE 13 Roadway geometric values and road sections (source: researcher)

No of sections	Observed crash count	ADT(Veh/day)	Section length (m)	Shoulder width(m)	Village presence	Terrain type	NHC	NVC	G
Section 1	5	4188	1250	1.5	N	Rolling	1	5	4
Section 2	3	4188	1220	2.5	Y	Rolling	2	3	3
Section 3	17	3828	3170	1.5	N	Rolling	4	7	7
Section 4	23	3828	3170	1.0	N	Escarpment	15	16	16
Section 5	13	3463	3270	1.0	N	Mountainous	8	16	15
Section 6	27	3463	3270	1.0	N	Mountainous	5	14	14
Section 7	8	3463	2700	1.5	N	Rolling	3	7	7
Section 8	2	3463	620	2.5	Y	Rolling	3	3	2
Section 9	2	2951	630	1.5	N	Rolling	2	4	4
Section 10	29	2951	2880	1.0	N	Mountainous	11	14	15
Section 11	7	2951	2880	1.0	N	Mountainous	12	12	11
Section 12	5	2951	1680	1.0	N	Escarpment	10	8	10
Section 13	0	2951	120	2.5	Y	Mountainous	1	0	0

Section 14	3	2951	160	2.5	Y	Mountainous	0	1	0
Section 15	6	2951	3420	1.0	N	Mountainous	7	18	19
Section 16	25	2951	3420	1.0	N	Mountainous	6	19	20
Section 17	0	2951	1150	1.0	N	Escarpment	3	4	3
Section 18	47	4248	1547	1.5	N	Flat	2	6	7
Section 19	20	4248	2000	1.5	N	Rolling	5	8	7
Section 20	3	4248	575	1.5	N	Mountainous	2	1	2
Section 21	1	4248	2400	1.5	N	Rolling	6	5	5
Section 22	4	4865	375	1.5	N	Mountainous	2	2	1
Section 23	20	4865	1675	1.0	N	Escarpment	25	8	9
Section 24	11	4865	1250	2.5	Y	Rolling	5	5	5
Section 25	6	3103	1625	1.5	N	Flat	2	4	5
Section 26	1	3103	250	1.5	N	Rolling	1	0	0
Section 27	6	3103	2225	1.5	N	Flat	6	6	7
Section 28	9	3103	2225	1.5	N	Flat	5	7	7
Section 29	2	3103	1150	1.5	N	Rolling	3	4	4

3.6 Model development

The main objective of the modeling is to look at the relation of exposure variables, explanatory variables with the response function. For this study, length of the road section and ADT are the exposure variables while, number gradient, NHC, NVC, terrain types, presence of village and shoulder-width as an explanatory variable, and traffic crash counts as response function. This developed model is useful to identify the road section of two-way two-lane rural roadways that have high crash frequencies. The prediction model including ADT and length of the road section is considered a simple model and model including both the predictor and exposure variable is called the full model.



$$E(Y)= a_o L^{a1} Q^{a2} \exp \sum_j b_j x_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

Where:

E(Y)=predicted crash frequency

a_o, a_1, a_2 are the regression coefficient of the independent variables

Q- is ADT (per day)

exp= is the exponential function and the value is equal to 2.7183

L= length of road section (m)

X_j = are explanatory variable

In line with the GLM outline, a log link function can be used to get a linear form. Thus, equation 1 will be transformed into a crash prediction model using a log-link function.

$$\log x = \ln x \text{ ……………………………………………2}$$

Then the full crash prediction model will be written as the form of equation 3;

$\ln E(Y) = \ln(a_o) + a_1 \ln(L) + a_2 \ln(Q) + \sum_j b_j x_j$ ……………………………………3

3.7 Type of analysis applied

Multiple regression analysis is carried out when it is required to predict one variable which is the dependent variable using two or more variables(covariate). Therefore, the connection between the response and the covariates are established and quantified using the multiple regression analysis.

Conferring to (Ackaah & Salifu, 2011), RTC is distinct and they are accidental occasions. Thus, there is a probabilistic nature in the crash occurring for the number of vehicles at a given period. Researches have studies that, during the data generation process that is crash, the GLM will undertake the probabilistic arrangement and sound estimated regression coefficients will be established due to consideration of the assumption. (Ackaah & Salifu, 2011).

The binomial distribution is approximated by Poisson distribution for crash motor vehicles that happened randomly and with less probability. Nevertheless, the Poisson distribution is used when the mean and variance of crash data are equal. Thus, poison model estimation can lead to wrong conclusions for overdispersed data. Therefore, to account for random occurrences (for different mean and variance values) negative binomial distribution was used (Ackaah & Salifu, 2011; Garach et al., 2016; van Petegem & Wegman, 2014). Since crashes are non-negatives, relatively small numbers, and integers, hence NB and Poisson distribution are found to be a suitable choice (Garach et al., 2016). Therefore, this study used NB distribution to estimate the parameter using SPPS (26) Software for the static analysis.

Moreover, the regression coefficient for each variable is analyzed including with their standard errors and significance. Variable needs to be removed from the analysis if their significance in the model is too small taking the confidence interval of 95%. The statistical package for social sciences (SPSS26) will be used to compute the regression coefficient, standard error, significance, and other important analyses to develop the prediction model of crash frequency. The variables that will be used for developing a prediction model are listed in table 15.

TABLE 14 Dependent and independent variables (source: researcher)

Variable name	Description of variables	Variable type	Abbreviation of variables

ln (average daily traffic volume)	Average daily traffic per road section length	Continuous	ADT
Terrain type	Terrain type per road section length	Categorical (1-flat, 2- rolling, 3-mountainous and 4-escarpment)	TT
Shoulder width	Shoulder width per road section length		SW
Number of horizontal curves	Number of horizontal curves per road section length	Continuous	NHC
Number of vertical curves	Number of vertical curves per road section length	Continuous	NVC
ln(length)	Length of road segment	Continuous	L
Village settlement	Village settlement within road section length	Categorical (1-village presence 0-village no presence)	VS
Gradient	Number gradients per road section length	Continuous	G

3.7.1 Data and stages used for the analysis

Road geometric paraments consider in the study were evaluated their effects using a statistical regression technique that is to know their significance level taking the alpha level to be 0.05. For every crash data collected, the following information has been recorded: location of the crash, data, number of road users involved, type of crash severity, and type of vehicles involved. Moreover, geometric measurement recordings during cash incidents were also extracted and recorded additionally to crash data.

SPSS 26 was the material used for statistical analysis to evaluate the relation amid traffic crash frequency and geometric design data. For this report, both primary and secondary data sources were used. Secondary data collection was done by reviewing existing documents like recording traffic crash data, extracting road geometric design elements from ERA for the specified route, and reviewing literature review. Whereas the primary data collected through counting ADT, site visiting for locating and recording traffic crash data collected form traffic police commission office districts as well as a site visit for checking the pavement condition of the routes.

For this research purpose, road traffic crash that occurred in rural two-way two-lane was collected over the consecutive three (2017-2019) study period and traffic crash that occurred in animals was excluded during data recording. These data have been provided from Tigray different districts of traffic police commission office as hardcopies in paper form for three years. During the data collections, accidents that occurred by the commercial vehicle were the target vehicle because road traffic crash that occurred in the rural two-way two-lane road is experienced mostly due to these types of automobiles.

While selecting sections the route for the study areas, they should not be depending on the crash frequency instead they should include all the location that have high crash occurrence as well as location with little crash rate, which will not be biased to know the effect of the road geometric design effect in the crash frequency.

Crash prediction models have been developed to look at the connection among different geometric elements of the road segment and accident frequency. The geometric elements are taken as the covariate which is independent variables and the response or dependent variable is the accident frequency. For the development accident frequency prediction model, carriageway width, shoulder width, shoulder material, presence of shoulder, number of the horizontal curve, number of the vertical curve, terrain type, land use that is the existence of village or not were considered as the dependent variable while ADT and length of the segment were taken as exposure and accident frequency as a dependent variable. From this, carriage width, road marking, and access density were excluded during analysis because they were similar across the selected two-way two-lane rural roads.

The study indicated that the increase of carriageway leads to the reduction of crash frequency because they will be more space for controlling and moving a vehicle. Nevertheless, the lane width of the selected road section is nearly constant with 7m (3.5 m for each lane) along the road except for 1.25km in Wukro -Adi Abbaghie with 6.7(3.35 m each lane). Thus, the lane with the roadway is similar across the roads and it will not be Signiant to be part of the analysis. The roadway for the study has also similar roadmaking along the road and due to that, it was not considered during the analysis. Moreover, access density is taken as a factor for the involvement of traffic crashes because it is a driveway that joins the road segment which will affect the side of the collision. However, the number of the access density for this case was few along the roadway thus, including access density will be insignificance in the study.

Roadway geometric features like sight distance, vertical curve, horizontal curve, terrain types, superelevation are taken as factors for the involvement of traffic crash. Conferring to the collected road traffic crash data, horizontal curve and grades were among the mentioned factors for the involvement of crash in the traffic reports, and due to that these geometric elements are the variables taken to be considered for the prediction of crash frequency.

The following phases were carried out after identifying the study area, routes, road geometric features, ADT, traffic crash counts and study periods for this report;

- Traffic crash data was collected from Kltewlaelo, Alasa, and Enderta traffic police commission offices districts.
- Road geometric design was collected from ERA, specifically, the office found in Adigrat zone administration.
- ADT specifically for the routes was counted in a day that has higher traffic flow which was on Saturday and then PHV was converted to ADT using a factor. However, traffic volume was reduced due to the restriction of movement to reduce the spread of COVID-19. Thus, to handle this ADT count from ERA for the 2019 study period was used for all years considered for this study.
- The selected route was divided into different section and crash data and roadway geometric design data was allocated to each section, as well as location with high crash spot, were identified.
- Data analysis and interpretation were carried out.
- Finally, recommendations and conclusions were specified.

CPM was developed using geometric features as independent variables and crash frequency as the dependent variable. To develop the model, the roadway route was selected by purposive sampling. The selected routes used for the analysis were from Mekelle-Hagereselam and Wukro -Adi-Abbagihe routes that cover 52.1km total length. Crash data of these selected routes were collected from three traffic police office districts and the location of the crash was later located by GPS during a field visit. Moreover, road geometric features (shoulder width, NVC, NHC, G, village settlement, terrain type, road length, and ADT) were extracted from ERA design reports. Selected rural roads were sectioned into 29 road segments for the use of analysis. Lastly, SPSS software was decided to be used for the analysis by considering negative binomial regression distribution.

Thus, in the end, the model was developed after collecting the data required. To develop CPM, several steps were required as stated in the literature review. Generally, how the multivariate CPM was developed for the rural two-lane roadway is shown in the model development procedure (figure 23).

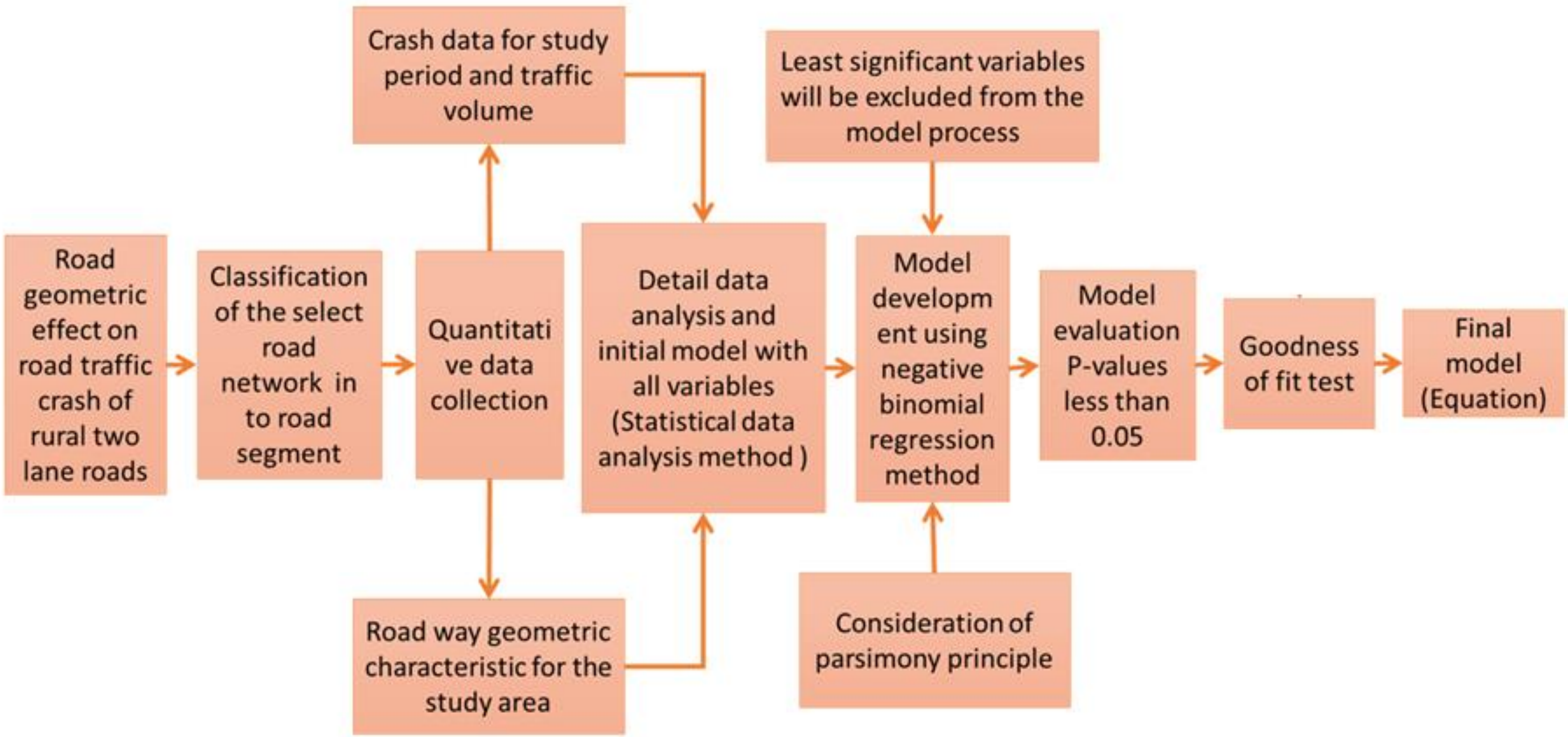


FIGURE 23 Model development procedure (source by the researcher.

4 Result

In the previous chapter, the sampling method, traffic crash data, road geometric design data, and traffic volume collection process, method of road sectioning, model development, and a section of analysis type for two-way two-lane rural roads of Tigray regions have been discussed. While in this chapter, the results found after analyses of the data have conversed.

All the collected data were analyzed to develop the crash frequency model. The main objective of this study was to look at the effect of road geometric features in a crash involving commercial vehicles. Therefore, crash data, roadway geometric features, and traffic volume were the main parameters used to developed crash frequency models and assess their relation.

Traffic crash data was collected from three different districts and 305 were the total road traffic crash collected for three years of study period particularity to selected routes. Besides, road geometric features specifically terrain type, Shoulder width, NHC, NVC, G, village settlement, and road length were extracted from ERA design reports and length. ADT count for 2019 was as well used from ERA reports for three routes.

SPSS 26 software was used for statistical analysis to evaluate the relation amid traffic crash frequency and geometric design data. Then this chapter will show the result of the data analysis in different sections.

4.1 The model developed for total crash involvement

4.1.1 Descriptive statistics of crash data

There are different types of models provided depending on the response means of measurement. Out of the diverse model available, Poisson regression and NB regression models are used for count type of data (data that is not measured in terms of decimals). Crash data are count data's and these models will be applied to assess the relationship among the count data and geometric features.

Descriptive statistics (variance and the mean of the count data) of the crash data is the determining factor to choose the type of model. The Poisson regression model is used when the mean and variance of the count data is equal (Tulu, 2015). However, if the count data is over-dispersed, NB regression will be the appropriate model to predict the response variable (Ambros & Sedoník, 2016; Tulu, 2015).

In this case, negative binomial regression has been adopted to deal with developing the CPM because the count data have higher variance (125.47) than the mean (10.52) as indicated in table 17.

TABLE 15 Descriptive statics of crash data

Descriptive Statistics						
	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Number of total road crash counts	29	0	47	10.52	11.201	125.473
Valid N (listwise)	29					

4.1.2 Correlation test for variable

The relation among each predictor and response variable will be undistinguishable to understand when there exists a high correlation among predictors (Ambros et al., 2016; van Petegem et al., 2014). Thus, multicollinearity should be examined amid the predictors.

Multicollinearity among the variables should be checked because the existence of predictors that have high collinearity among them reduces the reality of the model, therefore including one of the variables will be enough to explain or predict the result. There are different means to check multicollinearities like tolerance, VIF, and correlation matrix. The correlation matrix is used to check correlation among predictors and the value lies between the absolute value of 1(van Petegem & Wegman, 2014). VIF indicated to what extent the variable contributes to the multicollinearity issue within the data issue, the higher the value the bigger the problem caused by this variable.

The correlation among the dependent with exposure and explanatory variables was conducted using a correlation test. The correlation coefficient measures the degree of the linear relation between two variables. The response variable is expected to have a high relation with the independent variable (high correlation value). However, if the correlation value is zero, then it means that the independent variable has no relation with the dependent variable.

The correlation matrix was used to look at the multicollinearity of the predictors. Consequently, the regression coefficient was used from the correlation matrix to indicate the multicollinearity of the variables. The regression coefficient values lie between the absolute value +1 and -1(van Petegem & Wegman, 2014). When the correlation coefficient is closer to the absolute value of one, then the predictors are highly correlated and when the value is closer to zero then the predictors are less correlated. Finally, if multicollinearity among the predictors is detected, then one of the variables must be removed.

Donath et al., (2012) have used 0.5 cuts off value for the regression coefficient but, 0.8 is frequently representatively used as a cut off value (Berry et al., 1985). This correlation matrix (table 12) indicates the correlation coefficient among the predictors; namely terrain types, shoulder width, length of road section number of the horizontal, gradient, and vertical curves along the road section and presence of villages. Where the value of the correlation coefficient is close to the absolute value of 1 then, the variable is highly correlated. The number of gradients per road section is highly correlated (0.989) with the number of vertical curves of the road section taking a confidence interval of 95% where 0.8 is the cut off value used for the regression coefficient. when there is a change of gradient in the road section, there will be the development of vertical curves. Thus, the number of vertical curves and number gradient per road section were similar due to their relationship. Thus, a high correlation among both predictors was computed.

Moreover, shoulder-width was highly correlated (0.898) with the village presence. This was expected to have a high correlation because shoulder width in the rural road section increases when the road traverses through built-up areas. The correlation among the number gradient and a number of vertical curves per road section and length of the road section was as well closer to 0.8 with the value of 0.785. Other predictors might have also high correlation if 0.7 cuts off value were considered for the regression coefficient.

To conclude, the existence of a correlation between the variable, other methods like VIF, and tolerance should also be checked for the predictors in addition to the correlation coefficient from the correlation

TABLE 16   Correlation coefficient (from SPSS analysis)

		lnADT	lnL	SW	NHC	NVC	VS	G	TT
lnADT	Pearson Correlation	1	0.043	0.122	0.066	-0.207	-0.045	-0.206	-0.147
lnL	Pearson Correlation	0.043	1	-.638**	.589**	.785**	-.545**	.785**	-0.022
SW	Pearson Correlation	0.122	-.638**	1	-.514**	-.665**	.898**	-.681**	-.379*
NHC	Pearson Correlation	0.066	.589**	-.514**	1	.561**	-0.293	.576**	.411*
NVC	Pearson Correlation	-0.207	.785**	-.665**	.561**	1	-.407*	.989**	0.328
VS	Pearson Correlation	-0.045	-.545**	.898**	-0.293	-.407*	1	-.426*	-0.042
G	Pearson Correlation	-0.206	.785**	-.681**	.576**	.989**	-.426*	1	0.318
TT	Pearson Correlation	-0.147	-0.022	-.379*	.411*	0.328	-0.042	0.318	1

* Correlation is significant at the 0.05 level (2-tailed).

matrix. Thus, during the analysis, tolerance, and VIF of the predictors were calculated in addition to the correlation matrix (Table 19), to decide the independent variable to be discarded from the model development. One divided by tolerance is variance inflated factor (VIF). There is no agreed set of cut off values for the tolerance and VIF (Vatcheva et al., 2016). There is no common given cut off value for VIF nevertheless, VIF greater than 5 and 10 are suggested to know if there exists multicollinearity (Neter et al., 1996). However, if we are to take the widespread used value, the popular cut off value for tolerance needs to be greater than 0.1. Accordingly, less than 0.1 must be indicative of multicollinearity. Similarly, VIF greater than 10 will be problematic which is symbolic of multicollinearity among the variables. Another common tolerance cut off value is 0.2, which changes the value of VIF to 5. Thus, these are the two common guidelines for tolerance and VIF used to look at the multicollinearity among the predictors. In this case, the cut off value used for VIF is 10.

TABLE 17 Value of tolerance and variance inflation factor for predictor

Coefficients [a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	lnADT	0.605	1.654
	lnL	0.168	5.948
	SW	0.018	56.222
	NHC	0.412	2.424
	NVC	0.02	50.28
	VS	0.029	34.468
	G	0.02	50.581
	TT	0.171	5.833

a Dependent Variable: NTC

From the data analysis, VIF value for shoulder width, village presence, number of vertical curves, and number gradient per road section is greater than 10 or the tolerance is less than 0.1. Thus, one predictor with a higher value of VIF greater than 10 must be discarded from the analysis first. Later, the analysis continued to calculate tolerance and VIF value for the remaining predictors. For this case, shoulder-width was the variable that had a higher (56.22) VIF value than the other predictors. Thus, shoulder-width was removed and the VIF and tolerance value for the remaining variables was calculated (Table 14). From the second analysis, NVC was computed to have 50.2 VIF values which are necessary to be removed for the next analysis.

TABLE 18 Value of tolerance and variance inflation factor for remaining predictors

Coefficients [a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	lnADT	0.826	1.211
	lnL	0.175	5.699

	NHC	0.437	2.288
	NVC	0.02	50.205
	VS	0.668	1.497
	G	0.021	48.131
	TT	0.493	2.027
a Dependent Variable: Number of total road crash counts			

The value of VIF and tolerance was calculated for all predictors by discarding shoulder width and NVC parameters. Then the result (Table15) was indicated with VIF value of all predictor less than the cut off value (10). Since we take the cut-off value of VIF to be 10, the number of the horizontal curve, ADT, length of the road section, village settlement, number of gradients, and terrain type remained to be the predictor with less correlation among them.

TABLE 19 Value of tolerance and variance inflation factor for remaining predictors

Coefficients [a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	LnADT	0.827	1.209
	lnL	0.192	5.221
	NHC	0.458	2.183
	VS	0.692	1.444
	G	0.233	4.288
	TT	0.529	1.891
a Dependent Variable: NTC			

4.1.3 Significance of predictors

Predictors that should be included in the models have to be significant as well as multicollinearity among variables must be resolved. Multicollinearity among the predictors is checked above and in this section significance of the variable was checked. The significance of predictors is done by iteration which means by dropping out one variable and dropping in other variables. Therefore, variables that have significant values(P) less than 0.05 taking CI to be 95% are considered as significant variables. Thus, table 19 shows that terrain type (P=.0.015<.05), length of road section (P=.010<.05), number of horizontal curve per road section P=(.029<0.05) and ADT (P=.015<.05) were significance parameters. Thus, all the predictors are found to be substantial. While the terrain is significant as a general, but the detailed significance of all the categorical types of terrain will be indicated in the parameter estimate.

TABLE 20 Significance value of predictors

Tests of Model Effects			
Source	Type III		
	Wald Chi-Square	df	Sig.

(Intercept)	8.217	1	0.004
lnADT	5.965	1	0.015
lnL	6.661	1	0.010
NHC	4.769	1	0.029
TT	10.528	3	0.015
Dependent Variable: NHC . **Model: (Intercept), lnADT, lnL, NHC, TT**			

4.1.4 Full developed model

Multicollinearity and significance tests were handled to recognize the predictors that must be included in the final crash prediction model development. Thus, after carrying out both tests, four variables namely, number of horizontal curves, terrain type, ADT, and length of road section were identified as significant variables. Then a final model was developed using these variables as indicated in table 21.

The crash prediction model was developed by using the probability distribution called negative binomial with the log link function. The number of total road crash counts is the dependent variable, ADT, and length of road section as exposure variable and the remaining predictors as an explanatory variable.

Omnibus test tells us the overall statically significance of the model and the parameters estimated labels, the significance of each predictor with the dependent variable. For this case, the dependent variable in the count variable, the relationship among the dependent variable and predictors is characteristically non- linear. Thus, predictors and dependent variables are related using linear function by log link function. Thus, the Omnibus test indicated the significance value of p equal to 0.00 <0.005 which is Substantial.

4.1.5 The regression coefficient for the count model

The B value is the regression coefficient for the predictors and the values reflect predicted change in the log count of the traffic crash frequency per unit increase on the predicted variable. The positive value of the regression coefficient indicates an increasing score on the predictor associated with increasing count concerning crash frequency. The negative value of the regression coefficient indicates decreasing prediction of decrease count for every 1 unit on the predictor.

For every unit increase on the predictors, there are decreases (if the regression coefficient for the predictors is negative) or increase (if the regression coefficient for the predictors in positive) on the Log count of the crash frequency. Therefore, it is understood the regression coefficient in terms of Log count instead of the actual count, like for every regression coefficient means it is taken about the change on Log count.

Thus, the result indicated that for every one-unit increase in the number of horizontal curves per section length, there was an increase of 0.116 on the log count of total traffic counts. Road section that has higher horizontal curvature tends to experience higher total road traffic crash Similarly, for every unit increase on length of the road section and ADT, there was an increase of 0.575 and 1.354 on the log count of total traffic crash respectively. Thus, increasing road section length and traffic volume is expected to practice higher total traffic crash counts. This result is like other studies (Ackaah & Salifu, 2011; Tulu, 2015) conducted in African two-way two-lane rural roads.

Most of the findings (significance of terrain types, segment length, ADT, and a number of horizontal curves) for this study were consistent with earlier studies (Ackaah & Salifu, 2011; Dong et al., 2015; Singh et al., 2016; Tulu, 2015). However, the number of vertical curves and the number of gradients were found to be insignificant during the analysis which was like (Ackaah & Salifu, 2011) discovery. Ackaah et.al., (2011) States that, degree of curvature can apprehend the effect of curves. during the study number of curves per segment, length was used to express its effect with the response variable, and it concluded that this number of curves cannot show the real effect as the degree of curvature. similarly, this study used the number of vertical curves along the road section which will be difficult to capture the consequence gradient of each curve. Thus, this might be the reason for the insignificance of the vertical curves.

The variable that is expressed completely in terms of zero or ones are called dummy variables (John E. Floyd, 2010). When three is a categorical variable, the effect of individual elements under the categories will be investigated by dummy variables. The study has two dummy variable which is terrain type and village settlement. Terrain type has four (flat, rolling, mountainous, and escarpment along the road section) categories whereas village settlement has two (presence and non-presence of the village along the road section) categories and each type is examined during the analysis.

However, the regression coefficient of the terrain type is negative. Terrain type is categorized into four as flat, rolling, mountainous, and escarpment terrains. Thus, this predictor has three dummy variables. One basic reference was selected to compare the other type of terrains. Thus, flat terrain type is considered as reference. The first dummy variable tells the comparison between flat terrain and rolling terrain. The second dummy variable will be also the comparison among basic reference terrain and mountainous terrain. the same goes for the third dummy variable as well.

Therefore, the basic reference variable does not have a regression coefficient while the other variables have the coefficients. The result indicates that rolling terrain type would have lower log count in terms of total road traffic crash than flat terrains. The predicted log count for rolling terrain is 0.854-unit lessthen the predicted log count for flat terrains. The same goes for the comparisons of escarpment terrain with flat terrains

4.1.6 Simple developed model

Most studies (Ackaah & Salifu, 2011; 2016; Tulu, 2015) have include exposure variable only in the simple model. According to Borsos et al.,(2016), analysis of road safety ranking can be done using a simple model and during the study, the simple model developed for rural two-lane roads in Hungary included AADT only. Moreover, the study in Czech republic also identified, simple model (including AADT, segment length, and CCR) was found to be sufficient intended for network screening than using multivariate models (Ambros & Sedoník, 2016). Thus, some studies suggest that developing only base model is sufficient for network screening and other safety measures while others (Ackaah & Salifu, 2011; Tulu, 2015)developed both base and full model to assess the safety condition of roadway network and this study will have multivariate model since the main purpose is to look at the relation of the predictors with the dependent values not only to consider exposures.

TABLE 21 Parameter estimate of the full model

Parameter Estimates										
Parameter	B	Std. Error	95%Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-15.022	4.8562	-24.54	-5.504	9.569	1	0.002	2.99E-07	2.20E-11	0.004
lnADT	1.354	0.5544	0.267	2.441	5.965	1	0.015	3.873	1.307	11.479
lnL	0.575	0.2227	0.138	1.011	6.661	1	0.01	1.777	1.148	2.749
NHC	0.116	0.0531	0.012	0.22	4.769	1	0.029	1.123	1.012	1.246
[TT=1]	1.412	0.655	0.129	2.696	4.651	1	0.031	4.106	1.137	14.822
[TT=2]	0.558	0.5542	-0.528	1.645	1.015	1	0.314	1.748	0.59	5.179
[TT=3]	1.278	0.5383	0.223	2.333	5.64	1	0.018	3.591	1.25	10.312
[TT=4]	0a	.	.	.	.	.	.	1	.	.
Dependent Variable: Number of total road crash counts										
Model: (Intercept), ln ADT, lnL, NHC, TT										

The simple model is when the crash prediction model includes only exposure variables that are ADT and length of the road section. Hence, for every 1 unit increase of ADT, there was an increase of 1.407 on the log count of a total traffic crash. Correspondingly, for every 1 unit increase of the length of the road section, there will be an increase of 0.953 on the log count of a total traffic crash.

TABLE 22 Parameter estimate of a simple model

Parameter Estimates										
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Intercept	-16.414	5.0138	-26.241	-6.587	10.718	1	0.001	7.44E-08	4.02E-12	0.001
lnADT	1.407	0.5692	0.291	2.522	6.109	1	0.013	4.083	1.338	12.458
lnL	0.953	0.1863	0.588	1.319	26.175	1	0.00	2.594	1.801	3.738

Moreover, Incident ratio (IR) indicated the relationship among the count of crash frequency and the predictors, then the value of 1 indicated that there is no relation among the independent variables and the count. which is the count being neither increasing nor decreasing. Besides if the IR is equal to 1 then the regression coefficient will be zero and the relation among IR and regression coefficient is indicated in table 23. When the value of IR is >1 then it indicates increasing values on predictors will have an increase in the likelihood of greater count on the dependent variables. Similarly, when the value of IR is <1(value among 0 and 1) shows with a decrease in the likelihood of higher count. Furthermore, the incident rate can be described in terms of percentage, for every one-unit increase on predictors, the IR in terms of the number of counts for crash frequency will increase or decrease by the amount of (1- IR) *100 percent.

Moreover, for one unit increase of horizontal curvature per road segment, the incident rate in terms of a total road traffic crash is increasing by about12.3% percent. Likewise, for 1 unit rise of the length of the road section, the incident rate in terms of total road traffic crash increases by 77.7%.

4.1.7 Model Goodness of fit

The goodness of fit model is to check if the real data can be characterized by the developed model (van Petegem & Wegman, 2014). The goodness of fit model should be checked to make sure the model predicted properly. There are different means to check model goodness of fit. A model was developed to assess the geometric effect of a crash involving a truck in china and the model goodness of fit was examined using several significant predictors, AIC, and a graph of observed against expected crash occurrence (Dong et al., 2015).

Similarly, the study of Van Petegem, Goodness of fit of a model developed to evaluate road design elements on runoff crash was checked using AIC and LRT. A model is developed by adding and removing predictors and during this, the model fit will be examined using the value of AIC and LRT for the individual developed model. In every step, LRT of the previous and new model are compared. This means if there is statistical upgrading in the model fit of the new model (by addition of predictor) with the previous model (without the newly added model) (van Petegem & Wegman, 2014). Thus, van Petegem & Wegman, (2014) stated a model with a lower value of AIC is the best model.

For this case, Bayesian Information criterion, several significant variables, and Akaike's information criterion were used to check the goodness fit of the full model. Different models have been developed using different parameters. There have been diverse predictors included during the model development and comparing the AIC and BIC of the final developed full model fits better with a lower value. However, the AIC was lower for parameters including only AADT and NVC while the number of Significant variables was smaller compared to the model developed using ADT, terrain type, NHC, and length of the road section. Therefore, the model with a higher number of Significant variables and lower AIC were taken for the final model which fits better than the other model's table (18).

TABLE 23 Result of model goodness of fit

The goodness of Fit [a]			
	Value	df	Value/df
Deviance	11.793	22	0.536
Scaled Deviance	28.847	22	
Pearson Chi-Square	8.994	22	0.409
Scaled Pearson Chi-Square	22	22	
Log Likelihoodb,c	-87.974		
Adjusted Log-Likelihood	-215.184		
Akaike's Information Criterion (AIC)	189.947		
Finite Sample Corrected AIC (AICC)	195.28		
Bayesian Information Criterion (BIC)	199.518		
Consistent AIC (CAIC)	206.518		
Information criteria are in smaller-is-better form.			
b the full log-likelihood function is displayed and used in computing information criteria.			

4.2 The model developed for severing and fatal injuries

In this case, negative binomial regression has been adopted to deal with developing the CPM because the count data have higher variance (34.719) than the mean (5.17) as indicated in table 24.

TABLE 24 Descriptive statics of crash data

Descriptive Statistics						
	N	Minimum	Maximum	Mean	Std. Deviation	Variance

Number of total road crash counts	29	0	24	5.17	5.892	34.719
Valid N (listwise)	29					

4.2.1 Correlation test for variable

The number of gradients per road section is highly correlated (0.989) with the number of vertical curves of the road section taking a confidence interval of 95% where 0.8 is the cut off value used for the regression coefficient. Moreover, shoulder-width was highly correlated (0.898) with the village presence. The value of the correlation matrix was like table 16. The procedure for removing highly correlated variables is the same process as it is done in section 4.1.VIF value for shoulder width was found to be 66.6 and it was the parameters first removed from the analysis. The only difference done with section 4.1 was, number of vertical grades have the second next variable that had VIF greater than 10 while in section 4.1 number of grades was the one with higher value of VIF next to shoulder width. Thus, shoulder width and number of gradients per section length were removed from the analysis and the remaining variable were used to check the significance and develop the final model for sever and fatal crash frequency.

4.2.2 Significance of predictors

Predictors that should be included in the models have to be significant Multicollinearity among the predictors is checked above and in this section significance of the variable was checked. The significance of predictors is done by iteration which means by dropping out one variable and dropping in other variables like section 4.1. Therefore, variables that have significant values(P) less than 0.05 taking CI to be 95% are considered as significant variables. Thus, table 19 shows that ADT (P=0.02<.05), the number of horizontal curves per road section P= (.046<0.05), and the number of vertical curves (P=.00<.05) were significance parameters. Thus, all the predictors are found to be substantial

TABLE 25 Significance value of predictors

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	9.595	1	.002
LnAD	9.209	1	.002
NHC	3.995	1	.046
NVC	16.479	1	.000

Dependent Variable: NTC

Model: (Intercept), ln ADT, NHC,NVC

4.2.3 Full developed model

Multicollinearity and significance tests were handled to recognize the predictors that must be included in the final crash prediction model development. Thus, after carrying out both tests, three variables namely, number of horizontal curves, number of vertical curves and, ADT, were identified as significant variables. Then a final model was developed using these variables as indicated in table 21. Similar procedure was used for developing the model for severe and fatal injury of the crash frequency model as carried out in section 4.1 for crash frequency of total crash. Thus, number of horizontal curves(0.046<(p)0.05), number of vertical curve(0.00<(p)0.05), and ADT were the statistically significant result computes which is less than 0.005 of p value taking 95% CI (table 26).

TABLE 26 Parameter estimate of a simple model

Parameter Estimates										
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Intercept	-14.822	4.7849	-24.2	-5.443	9.595	1	0.002	3.66E-07	3.09E-11	0.004
lnADT	1.765	0.5817	0.625	2.905	9.209	1	0.002	5.843	1.869	18.272
NHC	0.077	0.0384	0.001	0.152	3.995	1	0.046	1.08	1.001	1.164
NVC	0.133	0.0327	0.069	0.197	16.479	1	0.00	1.142	1.071	1.217

a. Computed based on the Pearson chi-square.

4.2.4 The regression coefficient for the count model

The B value is the regression coefficient for the predictors and the values reflect predicted change in the log count of the traffic crash frequency per unit increase on the predicted variable. The positive value of the regression coefficient indicates an increasing score on the predictor associated with increasing count concerning crash frequency. The negative value of the regression coefficient indicates decreasing prediction of decrease count for every one unit on the predictor.

Thus, the result indicated that for every one-unit increase in the number of horizontal curves per section length, there was an increase of 0.077 on the log count of severe and fatal traffic counts. Road section that has higher horizontal curvature tends to experience higher severe and fatal road traffic crash. Similarly, for every unit increase on NVC and ADT, there was an increase of 0.133and 1.765 on the log count of severe and fatal traffic crash respectively. Thus, NVC and traffic volume is expected to practice higher total traffic crash counts. This result is like other studies (Tulu, 2015) conducted in African two-way two-lane rural roads.

4.2.5 Simple developed model

Conferring to Borsos et al.,(2016), analysis about road safety ranking can be done using a simple model and during the study, the simple model developed for rural two-lane roads in Hungary included AADT only. Thus, simple model was developed for sever and fatal traffic crash (table 27). Exposure variables that is ADT (0.003<(p)0.05),)and L(0.000<(p)0.05),) were statistically significant parameters similar to section 4.1 and (Ackaah & Salifu, 2011; Ambros et al., 2016; Tulu et al., 2015)findings.

TABLE 27 Parameter estimate of a simple model

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Intercept	-19.470	5.1300	-29.525	-9.416	14.405	1	0.000	3.501E-09	1.505E-13	8.144E-05
lnADT	1.671	0.5630	0.568	2.775	8.811	1	0.003	5.318	1.764	16.031
lnL	0.974	0.1995	0.583	1.364	23.816	1	0.000	2.647	1.791	3.914

a. Computed based on the Pearson chi-square.

b. Fixed at the displayed value.

The simple model is when the crash prediction model includes only exposure variables that are ADT and length of the road section. Hence, for every 1 unit increase of ADT, there was an increase of 1.671 on the log count of a total traffic crash. Correspondingly, for every 1 unit increase of the length of the road section, there will be an increase of 0.974 on the log count of a total traffic crash.

4.2.6 Model Goodness of fit

The goodness of fit model is to check if the real data can be characterized by the developed model (van Petegem & Wegman, 2014). The goodness of fit model should be checked to make sure the model predicted properly.

For this case, Bayesian Information criterion, several significant variables, and Akaike's information criterion were used to check the goodness fit of the full model similar to the developed model in section 4.17. Different models have been developed using different parameters. There have been diverse predictors included during the model development and comparing the AIC and BIC of the final developed full model fits better with a lower value. However, the AIC was lower for the final model including only ADT and L parameters while the number of Significant variables was smaller compared to the model developed using ADT, NHC, and NVC. Therefore, the model with a higher number of Significant variables and lower AIC were taken for the final model which fits better than the other model's (table28).

Table 28 Result of model goodness of fit

The goodness of Fit [a]

-	Value	df	Value/df
Deviance	19.251	26	0.740
Scaled Deviance	40.070	26	
Pearson Chi-Square	12.492	26	0.480
Scaled Pearson Chi-Square	26.000	26	
Log Likelihood [b, c]	-71.734		
Adjusted Log-Likelihoo[d]	-149.307		
Akaike's Information Criterion (AIC)	149.467		
Finite Sample Corrected AIC (AICC)	150.427		
Bayesian Information Criterion (BIC)	153.569		
Consistent AIC (CAIC)	156.569		

There were nine variables (terrain type, NHC, NVC, terrain type, village settlements shoulder width, length, ADT and crash counted) used for developing the crash frequency model. Traffic crash count of three studies (2017-2019 G.C) period was collected from each district of traffic police offices supplemented by a study visit to locate their point. Other explanatory and exposure variables were collected from ERA road geometric design reports. Crash count data were over dispersed and due to that negative binomial regression model was used to analyse the data. After analysis, NHC, ADT, length, and terrain type were found to be significant variables for the full model developed taking the response variable of total crash. The simple model includes only exposure variables (ADT and road section length) for total crash involvement. While, NVC, NHC, and ADT were significant variables found for response function of fatal and sever traffic crash. While the simple model has the same exposure variables with the model developed for total crash. There is difference on the regression coefficient of both developed models. This is expected because for the total crash developed model includes all type of severities namely, slight, severe, fatal and OPD. While the second model includes only sever and fatal injury as response function. Thus, geometric features have different impact on types of severity.

5 Conclusion

The objective of this research was to recognize the relation among road geometric features of two-way two-lane rural roads with road traffic crashes. Involving commercial vehicles. Different geometric elements are included namely number of horizontal and vertical curves, number of gradients, carriageway width, shoulder width, presence of village, terrain type, length of the road section, and ADT.

Road traffic crash count is considered as the response variable, ADT, and length as exposure variable and the remaining predictors as an explanatory variable. The crash count has been collected from three words for three years of the study period. However, road geometric characteristics were collected form ERA road design reports. The routes selected for this study were a route from Mekelle to Hagereselam and Wukro to Abi-Abaggie, with a total length of 52.1km. These roads have been sectioned into 29 road sections using a homogenous method of segmentation. the parameters used for homogenous segmentation approaches are ADT, terrain type, design standards, and shoulder-width

From the analysis, the number of vertical curves, the number of gradients, village settlements, carriageway width, and shoulder width were found to be insignificant. Thus, the predictors taken for model development were ADT, length of the road section, the number of the horizontal curve, and terrain type. Finally, the model was developed using these predictors which is both a full and simple model. The simple model only includes exposure variable (ADT and length of road section) and the full model with the variable of terrain type, a number of horizontal curves besides got the simple model.

Thus, the result for the first model developed indicated that for every one-unit increase in the number of horizontal curves per section length, there was an increase of 0.116 on the log count of total traffic counts. Road section that has higher horizontal curvature tends to experience higher total road traffic crash Similarly, for every unit increase on length of the road section and ADT, there was an increase of 0.575 and 1.354 on the log count of total traffic crash respectively. Thus, increasing road section length and traffic volume is expected to practice higher total traffic crash counts. This result is similar to other studies(Ackaah & Salifu, 2011; Tulu, 2015) conducted in African two-way two-lane rural roads.

Moreover, rolling terrain types would have lower log count in terms of total road traffic crash than flat terrains. The predicted log count for rolling terrain is 0.854unit less than the predicted log count for flat terrains. The same goes for the comparisons of escarpment terrain with flat terrains. For one unit increase of horizontal curvature per road segment, the incident rate in terms of a total road traffic crash is increasing by about12.3% percent. Likewise, for 1 unit rise of the length of the road section, the incident rate in terms of total road traffic crash increases by 77.7%.

The result for the second model indicated that, for every one-unit increase in the number of horizontal curves per section length, there was an increase of 0.077 on the log count of severe and fatal traffic counts. Road section that has higher horizontal curvature tends to experience higher severe and fatal road traffic crash. Similarly, for every unit increase on NVC and ADT, there was an increase of 0.133and 1.765 on the log count of severe and fatal traffic crash respectively. Thus, NVC and traffic volume is expected to practice higher total traffic crash counts.

Most of the findings (significance of terrain types, segment length, ADT and number of horizontal curves) for this study were consistent to earlier studies (Ackaah & Salifu, 2011; Dong et al., 2015; Singh et al., 2016; Tulu, 2015). However, number of vertical curves and number of gradients were found to be insignificant during the model development for total crash frequency. which was like (Ackaah & Salifu, 2011) discovery. Ackaah et.al., (2011) States that, degree of curvature can apprehend the effect of curves. during the study number of curves per segment length was used to express its effect with the response variable and it concluded that this number of curves cannot show the real effect as the degree of curvature. similarly, this study used the number of vertical curves along road section which will be difficult to capture the consequence gradient of each curves. Thus, this might be the reason for the insignificance of the vertical curves.

This study revealed that terrain type, length of road section, number of vertical curves, number of horizontal curves, and ADT were related with road traffic crashes From the analysis result, road traffic crash in two-way two-lane rural roads will be higher when the number of vertical and horizontal curves within road section increases. That is the average rate of traffic crash is lower than the average rate of crash for straight lines.Therefore, ERA in Tigray region must review road design features found in the design reports particularly the significant parameters found in this study.

6 Recommendation

Road engineers and planners use CPM to assess the effect of road geometric effect with crash frequencies. This developed model for both total road crash as well as severity and fatal crash shows the relation of geometric effect with the response variable. Especially, horizontal and vertical curvatures have effect on fatal and severe injuries.

In addition to this, there was a radius of curves roads that doesn't fill the ERA design standards indicted in bold sign in Appendix D and E. Thus, this paper will be useful document for Ethiopian road authority in Tigray region to review their design reports again particularity to design of horizontal curve and vertical curves. Moreover, terrain type was also significant related to the crash frequency and out of the terrain categories flat terrain involved in a higher crash than rolling's. Therefore, flat and rolling type of terrains need special attention in addition to horizontal and vertical curves.

Moreover ,during highway planning and design, engineers should not only bother on curve radius and grade but also need to limit the density of grade, horizontal and vertical curve density because the developed model on this research showed us the increase in density of these geometric parameters increases traffic crashes.

Road engineering and designers in Tigray region can use the developed model for both type of crashes in rural roads of Tigray region to know the back-spot locations. Then these locations required to be treated considering the best solution.

7 Limitations and Future implication

The study is limited only to rural two-way roads specifically in two routes from Mekelle to Alasa and Wukro to Negash routes since multi -lane rural roads are limited in the regions as well as traffic crash occurred in these roads are limited in number compared to the two-way rural roads. In addition to that traffic crash that occurred because of commercial vehicle are only included in the analysis.

This study does not specify the type of collision while developing the model for rural roadway in Tigray region. The model is developed without specifying the collision types. While, from the data analysis, there were head-on Collison, run-off and rear- end collisions. Thus, crash prediction model is required to be developed for specific collision types to understand deeply the effect of geometric effect on rural roadway on crash involving commercial vehicles. Moreover, black spots must be identified in addition to developing a model so that to reduce road traffic crashes of two-way two-lane rural roads.

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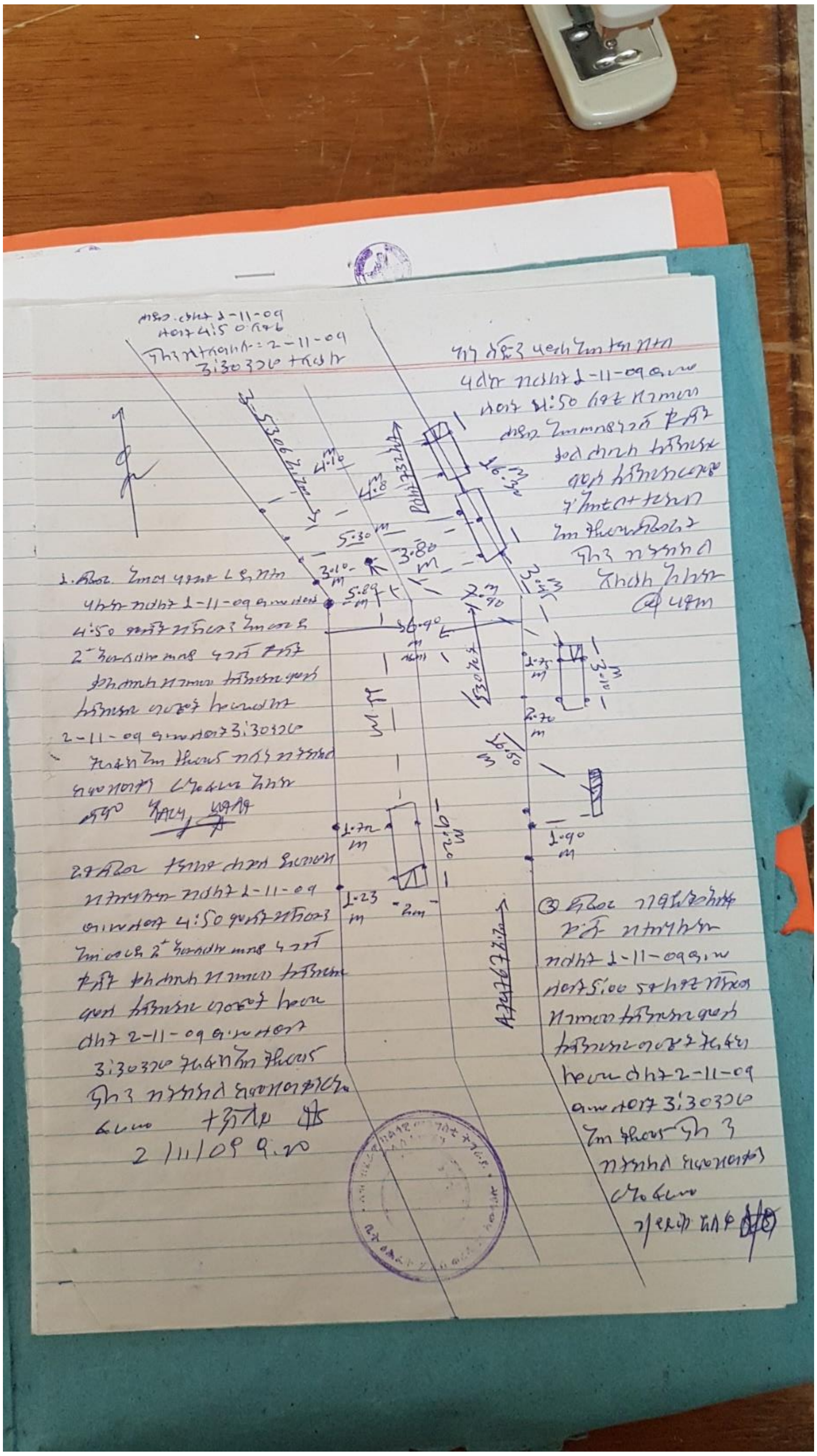
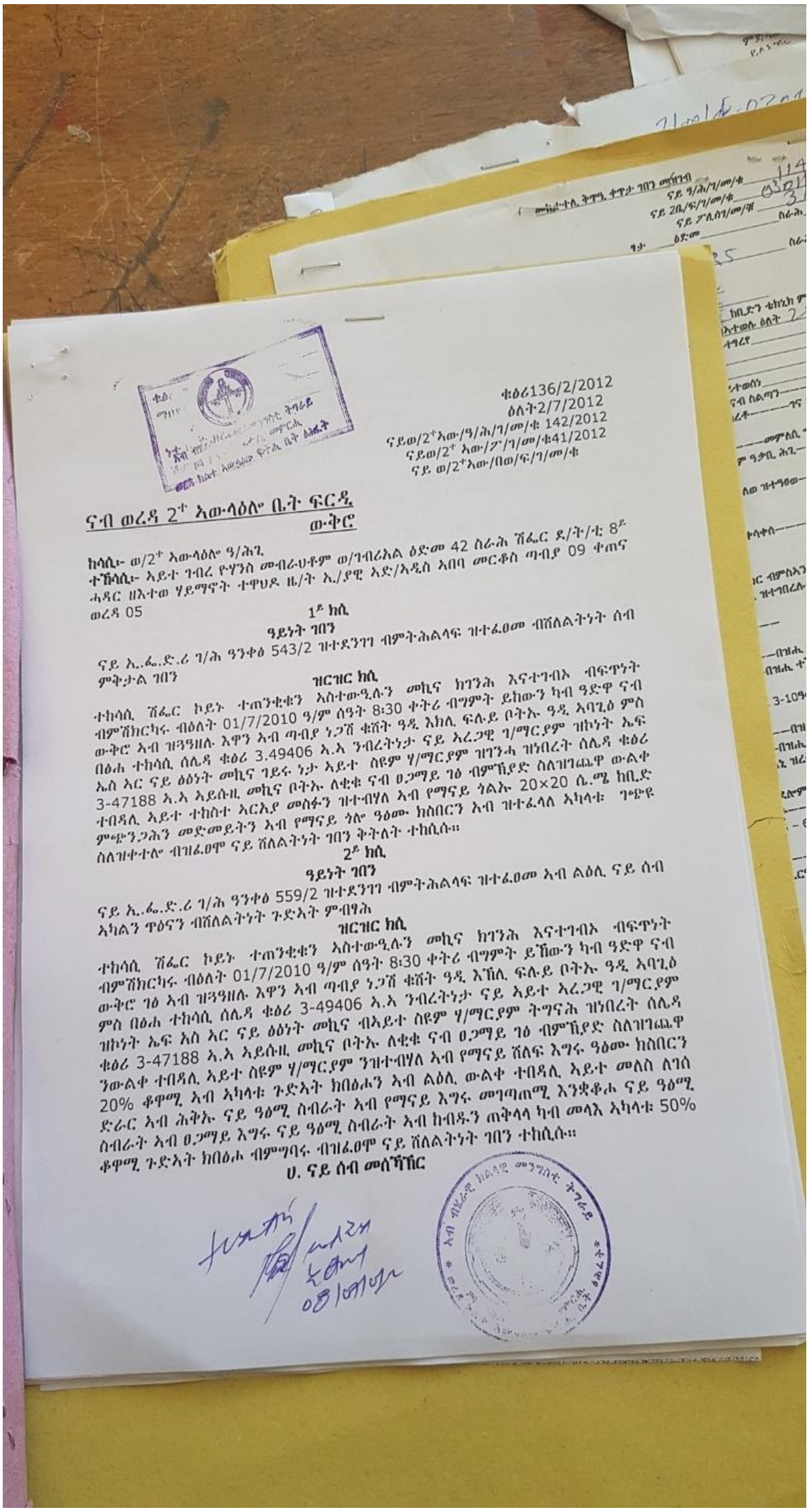
APPENDIX A: data used for collecting road traffic crash data from traffic police offices

APPENDIX A1: Traffic plan drawing



APPENDIX A2: Sue paper from traffic crash data history



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ዕለት2/7/2012
ናይወ/2ተ አው/ዓ/ሕ/ገ/መ/ቁ 142/2012
ናይወ/2ተ አው/ፖ/ገ/መ/ቁ41/2012
ናይ ወ/2ተአው/በወ/ፍ/ገ/መ/ቁ

ናብ ወረዳ 2ተ ኣውላዕሎ ቤት ፍርዲ
ውቅሮ

ከሳሲ፦ ወ/2ተ ኣውላዕሎ ዓ/ሕጊ
ተኸሳሲ፦ ኣይተ ገብረ ዮሃንስ መብራህቶም ወ/ገብረኣል ዕድመ 42 ስራሕ ሽፌር ደ/ት/ቲ 8ይ ሓዳር ዘእተወ ሃይማኖት ተዋህዶ ዜ/ት ኢ/ያዊ ኣድ/ኣዲስ ኣበባ መርቆስ ጣብያ 09 ቀጠና ወረዳ 05

1ይ ክሲ

ዓይነት ገበን

ናይ ኢ.ፌ.ድ.ሪ ገ/ሕ ዓንቀፅ 543/2 ዝተደንገገ ብምትሕልላፍ ዝተፈፀመ ብሸለልትነት ሰብ ምቅታል ገበን

ዝርዝር ክሲ

ተከሳሲ ሽፌር ኮይኑ ተጠንቂቑን ኣስተውዒሉን መኪና ክገንሕ እናተገብኦ ብፍጥነት ተከሳሲ ሽፌር ኮይኑ ... ብግምት ይኸውን ካብ ዓድዋ ናብ ... ብምሽክርካሩ ብዕለት 01/7/2010 ዓ/ም ሰዓት 8:30 ቀትሪ ብግምት ይከውን ካብ ዓድዋ ናብ ... ዓዲ እክሊ ፍሉይ ቦትኡ ዓዲ ኣባጊዕ ምስ ውቅሮ ኣብ ዝጓዓዘሉ እዋን ኣብ ጣብያ ነጋሽ ቁሸት ዓዲ እክሊ ፍሉይ ቦትኡ ዓዲ ኣባጊዕ ምስ በፅሐ ተከሳሲ ሰሌዳ ቁፅሪ 3.49406 ኢ.ኦ ንብረትነታ ናይ ኣረጋዊ ገ/ማርያም ዝኾነት ኤፍ ኤስ ኣር ናይ ዕፅነት መኪና ገይሩ ነታ ኣይተ ስዩም ሃ/ማርያም ዝገንሓ ዝነበረት ሰሌዳ ቁፅሪ 3-47188 ኢ.ኦ ኣይሱዚ መኪና ቦትኡ ለቒቑ ናብ ፀጋማይ ገፅ ብምኻያድ ስለዝገጨዋ ውልቀ ተበዳሊ ኣይተ ተከስተ ኣርኣያ መስፉን ዝተብሃለ ኣብ የማናይ ጎልኡ 20×20 ሴ.ሜ ከቢድ ምጭንጓሕን መድመይትን ኣብ የማናይ ጎሎ ዓፅሙ ክስበርን ኣብ ዝተፈላለ ኣካላቱ ገጭዩ ስለዝቀተሎ ብዝፈፀሞ ናይ ሸለልትነት ገበን ቅትለት ተከሲሱ።

2ይ ክሲ

ዓይነት ገበን

ናይ ኢ.ፌ.ድ.ሪ ገ/ሕ ዓንቀፅ 559/2 ዝተደንገገ ብምትሕልላፍ ዝተፈፀመ ኣብ ልዕሊ ናይ ሰብ ኣካልን ጥዕናን ብሸለልትነት ጉድኣት ምብፃሕ

ዝርዝር ክሲ

ተከሳሲ ሽፌር ኮይኑ ተጠንቂቑን ኣስተውዒሉን መኪና ክገንሕ እናተገብኦ ብፍጥነት ብምሽክርካሩ ብዕለት 01/7/2010 ዓ/ም ሰዓት 8:30 ቀትሪ ብግምት ይኸውን ካብ ዓድዋ ናብ ውቅሮ ገፅ ኣብ ዝጓዓዘሉ እዋን ኣብ ጣብያ ነጋሽ ቁሸት ዓዲ እኸሊ ፍሉይ ቦትኡ ዓዲ ኣባጊዕ ምስ በፅሐ ተከሳሲ ሰሌዳ ቁፅሪ 3-49406 ኢ.ኦ ንብረትነታ ናይ ኣይተ ኣረጋዊ ገ/ማርያም ዝኾነት ኤፍ ኣስ ኣር ናይ ዕፅነት መኪና ብኣይተ ስዩም ሃ/ማርያም ትግናሕ ዝነበረት ሰሌዳ ቁፅሪ 3-47188 ኢ.ኦ ኣይሱዚ መኪና ቦትኡ ለቒቑ ናብ ፀጋማይ ገፅ ብምኻያድ ስለዝገጨዋ ንዝተብሃለ ኣብ የማናይ ሽለፍ እግሩ ዓፅሙ ክስበርን ንውልቀ ተበዳሊ ኣይተ ስዩም ሃ/ማርያም ኣብ ልዕሊ ውልቀ ተበዳሊ ኣይተ መለስ ለገሰ 20% ቆዋሚ ኣብ ኣካላቱ ጉድኣት ክበፅሖን ኣብ ልዕሊ ውልቀ ተበዳሊ ኣይተ መለስ ለገሰ ድራር ኣብ ሕቅኡ ናይ ዓፅሚ ስብራት ኣብ የማናይ እግሩ መገጣጠሚ እንቋቆሖ ናይ ዓፅሚ ስብራት ኣብ ፀጋማይ እግሩ ናይ ዓፅሚ ስብራት ኣብ ከብዱን ጠቕላላ ካብ መላእ ኣካላቱ 50% ቆዋሚ ጉድኣት ክበፅሖ ብምግባሩ ብዝፈፀሞ ናይ ሸለልትነት ገበን ተከሲሱ።

ሀ. ናይ ሰብ መሰኻኽር

APPENDIX B: Total road traffic crash and coordinates for three districts

APPENDIX B1: Total road crash and coordinate for Enderta (Mekelle-River Giba road network) district

year	slight injury	severe injury	fatalities	PDO	x, coordinate	y, coordinate	Z, coordinate
2009	0	0	0	0	547569	1500594	1923m
2009	1	0	1	0	541352	1503657	1749m
2009	0	0	0	1	546548	1501653	1912m
2009	0	0	1	0	545887	1502190	1922m
2009	0	0	1	0	545594	1502523	1913m
2009	0	1	0	0	545876	1502219	1923m
2009	0	1	0	0	545822	1502256	1922m
2009	0	0	2	1	542641	1502515	1940m
2009	1	0	0	1	541969	1503587	1787m
2010	0	0	1	0	547451	1500673	1925m
2010	0	0	1	0	457451	1500673	1925m
2010	0	1	0	0	545875	1502203	1921m
2010	3	2	0	1	541301	1503397	1746m
2010	0	2	0	0	541839	1503922	1764m
2010	0	1	0	1	541952	1503621	1792m
2010	0	0	0	1	545559	1502560	1912m
2010	0	0	1	0	545849	1502249	1922m
2010	0	0	0	1	544818	1502965	1926m
2010	0	0	1	0	544904	1502928	1923m
2010	0	0	0	1	544880	1502939	1923m
2010	1	0	0	1	542408	1503289	1834m
2011	0	1	0	0	544780	1502989	1927m

2011	1	0	0	1	542143	1503313	1822m
2011	1	0	0	1	541921	1503854	1776m
2011	1	0	0	1	541771	1503884	1764m
2011	0	0	0	1	545635	1502468	1913m
2011	0	1	0	0	545795	1502291	1923m
2011	0	1	0	0	545718	1502382	1922m
2011	0	1	0	0	546845	1501093	1925m
2011	0	1	0	0	547451	1500673	1925m
2011	0	1	0	0	546218	1501927	1925m
2011	0	1	0	0	545674	1502428	1917m
2011	0	1	0	0	545087	1502858	1918m
2011	0	0	0	1	541771	1502856	1764m

N.B: The years of crash data are indicated in the Ethiopian calendar where the 2009 Ethiopian calendar(E.C) means the 2017 Gorgonian calendar(G.C), 2010 is similar to 2018 G.C and 2011 E.C is comparable to 2019 G.C.

APPENDIX B2: Total road crash and coordinate for Wukro (Wukro-Abi-Abbagihe road network) district

year of crash	slight injury	severe injury	fatality	PDO	x, coordinate	y, coordinate	z, coordinate
2009	2	1	0	0	565277.6	1528164	2088.7m
2009	0	1	0	0	565313.2	1527938	2026.8m
2009	0	0	0	1	565237.3	1528341	2091m
2009	0	1	0	0	565120.6	1528862	2049.49m
2009	0	1	0	0	565191.2	1528538	2045.65m
2009	2	0	0	0	565613	1500039	2092m
2009	1	0	0	1	565616.5	1530051	2093.21m
2009	0	0	0	1	565456.8	1529381	2057.9m

2009	0	1	0	1	565272.6	15292245	2052.9m
2009	0	2	3	0	565262.2	1529217	2107.09m
2009	1	0	0	1	565201.5	1533322	2253.43m
2009	0	0	0	1	564596.7	1534404	2378.9m
2009	3	0	0	1	564838.7	1533673	2293.25m
2009	1	3	0	0	565350.8	1532859	2269.24m
2009	0	1	0	0	564928.9	1533820	2327.8m
2009	0	1	0	1	565313.4	1527989	2084.97m
2009	0	0	0	1	564999.7	1535518	2388.97m
2009	0	1	0	0	564814.5	1535028	2389.55m
2009	1	0	0	0	565091.6	1530595	2189.57m
2009	0	1	0	0	564999.7	1535518	2388.97m
2009	0	1	0	0	564867.1	1533553	2281.9m
2009	0	1	0	0	565190.9	1528587	2098.3m
2009	1	0	0	1	564837.4	1533903	2316.35m
2009	0	0	0	1	564876.1	1533798	2313.26m
2009	0	0	1	1	564977.2	1530761	2119.25m
2009	0	0	0	1	564914.7	1533833	2329.81m
2009	1	0	0	1	565121.4	1533459	2234.7m
2009	0	0	0	1	564814.5	1535028	2389.5m
2009	0	0	0	1	564356.4	1536753	2404m
2009	0	0	0	1	564862.6	1533783	2296.23m
2009	0	1	0	0	564644.5	1534279	2386.9m
2009	0	1	0	0	564394.1	1536689	2403.5m
2009	0	1	0	0	564446.8	1536633	2404m

2009	0	1	0	0	564776.4	1536352	2388.9m
2009	0	2	0	0	565190.9	1528587	2098.3m
2010	1	0	0	0	564426.2	1538679	2411.9m
2010	0	4	1	0	564379.7	1539446	2430.5m
2010	1	0	0	1	564595.4	1541262	2427.3m
2010	0	2	1	0	564366.5	1540545	2426.2m
2010	0	0	1	0	564382.9	1537852	2402.7m
2010	0	0	1	0	564644.5	1534279	2386.9m
2010	0	0	1	0	565104.7	1528969	2050.92m
2010	0	1	1	0	565310.3	1527973	2025.69m
2010	0	1	0	0	565109.9	1528906	2049.85m
2010	0	1	0	1	565207.1	1528424	2038.6m
2010	1	0	0	1	565107.9	1528929	2050.28m
2010	0	1	0	0	565151.5	1529094	2052.16m
2010	0	1	0	0	565185.5	1528558	2045.94m
2010	0	1	0	0	565356	1527724	2022.1m
2010	0	0	0	1	565414.3	1529480	2055.96m
2010	2	0	0	1	565522.8	1529750	2084.74m
2010	0	0	1	0	564689.8	1534787	2388.7m
2010	3	0	0	0	564776.4	1536352	2388.87m
2010	0	0	0	0	564293.9	1537400	2398.2m
2011	4	3	2	0	565156.6	1528704	2048.9m
2011	0	1	0	1	565190.9	1528587	2029.1m
2011	0	1	1	0	565283.1	1528097	2027.4m
2011	0	1	0	0	565283.1	1528097	2027.38m

2011	0	2	1	0	565313.4	1527989	2084.97m
2011	1	0	0	1	565326.3	1529320	2053.56m
2011	0	0	1	0	565227.1	1529185	2052.63m
2011	1	2	0	1	565347.1	1527782	2035m
2011	1	0	0	1	565113.1	1529008	2051.4m
2011	0	0	0	1	565290.1	1528068	2027.03m
2011	0	0	0	1	564977.2	1530761	2119.25m
2011	0	0	0	1	565313.2	1527938	2026.85m
2011	0	0	0	1	564659.3	1534227	2370.78m
2011	0	0	0	1	565229.3	1533117	2273.75m
2011	0	0	1	0	564836.2	1533745	2321.26m
2011	1	0	0	1	564837.5	1533947	2317m
2011	0	1	0	0	564862.6	1533783	2296.23m
2011	0	0	0	1	564860.3	1533682	2319.67m
2011	0	1	0	0	564834.5	1533658	2318.9m
2011	2	0	0	1	565456.6	1534596	2380.32m
2011	0	0	1	0	564318.4	1536951	2392.7m
2011	0	0	0	1	564382.9	1537852	2402.77m

APPENDIX B3: Total road crash and coordinate for Alasa (River Giba -Hagereselam road network) district

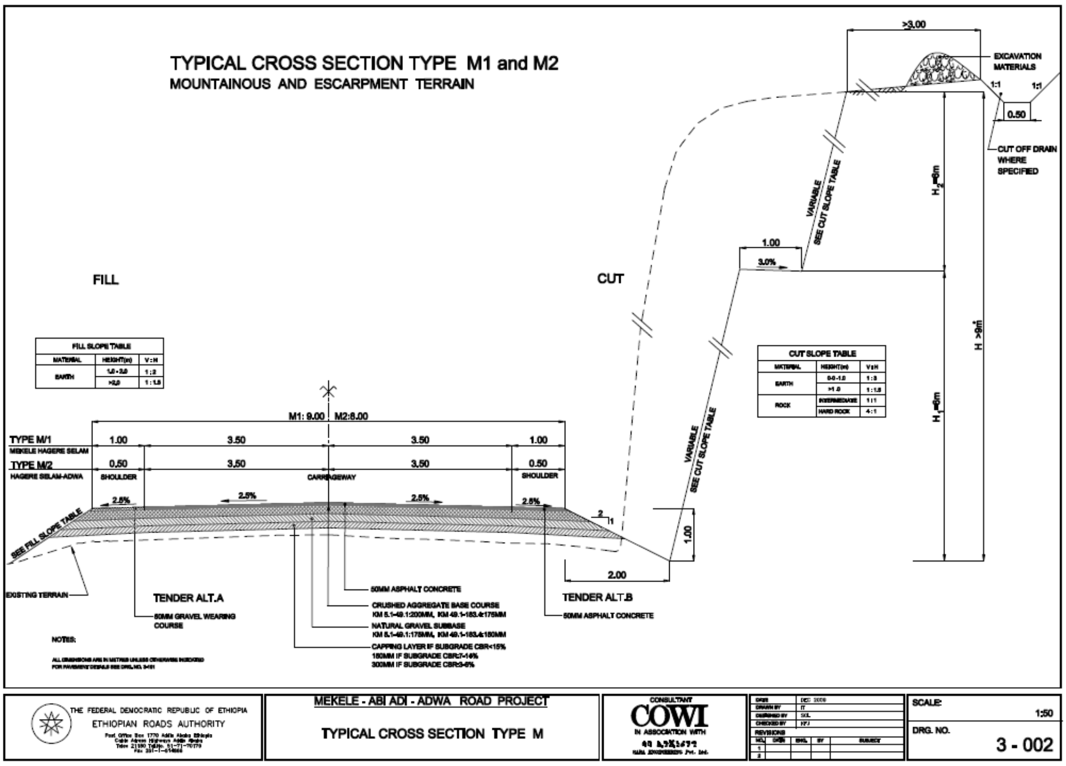
year of crash	slight injury	severe injury	fatalities	PDO	x, coordinate	y, coordinate	z, coordinate
2009	1	0	0	1	540390.2	1503683	1814.5m
2009	0	1	0	1	540073	1503573	1799m
2009	0	1	0	0	540099	1503564	1798m
2009	0	1	0	0	540148	1503547	1800m

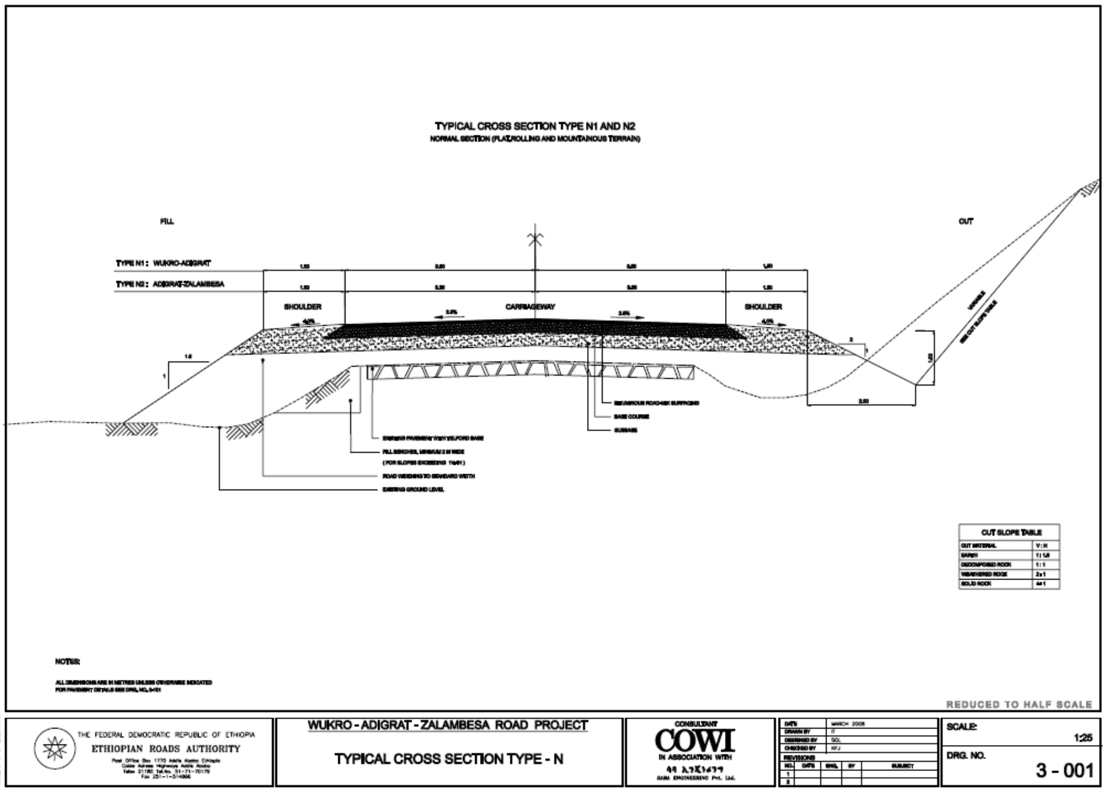
2009	0	1	0	1	528968	1511746	2394m
2009	0	1	0	1	537523	1505619	1887m
2009	0	0	1	1	522421	1509741	2483m
2009	0	0	2	0	522421	1509741	2483m
2009	0	0	1	0	522421	1509741	2483m
2009	0	0	1	0	522421	1509741	2483m
2009	0	0	2	1	522421	1509741	2483m
2009	1	0	0	1	523690	1509754	2433m
2009	0	0	0	1	523687	1509757	2435m
2009	1	0	0	1	531902	1510258	2127m
2009	0	1	0	0	532185	1509830	2085m
2009	0	1	0	1	531899	1510266	2129m
2009	0	0	1	1	527848	1511564	2459m
2009	0	0	1	0	537441	1505794	1884m
2009	1	0	0	1	534594	1508376	1959m
2009	0	0	1	0	527848	1511564	2459m
2009	1	0	0	1	523226	1511564	2448m
2009	0	0	0	1	531672	1510446	2149m
2009	0	1	0	1	528968	1511746	2394m
2009	0	0	1	1	529255	1511900	2332m
2009	0	1	0	1	529247	1511718	2344m
2010	0	0	0	1	538599	1504430	1865m
2010	0	0	2	0	537507	1505652	1887m
2010	4	4	3	1	537517	1505622	1887m
2010	1	0	0	1	535265	1508289	1946m

2010	1	0	0	1	532810	1508822	2019m
2010	0	1	0	1	532876	1508722	2014m
2010	1	0	0	1	532107	1509927	2093m
2010	0	1	0	1	531311	1510733	2180m
2010	0	1	1	1	525861	1510993	2423m
2010	0	0	0	1	525372	1510913	2440m
2010	0	4	2	1	523229	1509727	2432m
2010	1	0	0	1	523496	1509744	2432m
2010	0	0	0	1	523596	1509752	2435m
2010	0	1	0	1	532018	1510134	2111m
2010	0	1	0	1	531955	1516187	2126m
2010	0	0	0	1	528835	1512309	2420m
2010	0	0	0	1	531466	1510542	2164m
2011	0	0	1	1	540073	1503573	1799m
2011	0	1	0	1	539631	1503697	1820m
2011	0	1	0	1	540073	1503573	1799m
2011	0	0	1	1	522421	1509741	2483m
2011	1	0	0	1	537337	1505916	1883m
2011	0	0	1	0	536943	1506280	1900m
2011	0	0	1	0	537517	1505627	1887m
2011	1	0	0	1	537473	1505721	1885m
2011	0	0	2	0	534633	1508320	1942m
2011	0	0	1	0	534061	1508399	1956m
2011	1	0	0	1	534452	1508376	1962m
2011	0	0	1	1	537929	1505048	1875m

2011	0	0	1	1	537518	1505625	1887m
2011	0	0	1	0	533926.2	1508645	1977.86m
2011	1	0	0	1	532058	1510085	2109m
2011	0	0	0	1	531984	1510167	2121m
2011	0	1	0	1	531907	1510251	2128m
2011	0	1	0	1	532116	1509924	2094m
2011	1	0	0	1	531377	1510666	2173m
2011	0	0	0	1	532044	1510091	2108m
2011	3	0	0	1	531472	1510547	2163m
2011	0	1	0	0	529242	1511904	2335m
2011	0	1	0	0	522469	1509818	2453m

APPENDIX C: Typical cross-section for Mekelle -Haggereselalm and Wukro -Adi-Abbagihe





APPENDIX D: Horizontal Alignment for Mekelle -Hagereselam(35km) road segment

Numbering	Station	radius	Terrain type	Design standards	minimum radius required	Improved radius
12	7.82	**+200**	Flat	DS3	395	+395
13	9.66	**+300**	Flat	DS3	395	+395
14	10.33	-400	Flat	DS3	395	
15	10.98	+700	Flat	DS3	395	
16	11.82	**-250**	Rolling	DS3	270	-270
17	12.99	**-150**	Rolling	DS3	270	-270
18	13.71	-800	Rolling	DS3	270	
19	13.96	**+150**	Rolling	DS3	270	+270
20	14.73	**-180**	Rolling	DS3	270	-270
21	14.95	**+82**	Escarpment	DS3	125	+85
22	15.45	+800	Escarpment	DS3	125	
23	15.68	**-85**	Escarpment	DS3	125	-90
24	15.89	+600	Escarpment	DS3	125	
25	16.07	+200	Escarpment	DS3	125	
26	16.16	**-35**	Escarpment	DS3	125	-40
27	16.29	+400	Escarpment	DS3	125	
28	16.51	+250	Escarpment	DS3	125	
29	16.93	**+40**	Escarpment	DS3	125	+45
30	17.07	**-85**	Escarpment	DS3	125	-90
31	17.31	+175	Escarpment	DS3	125	
32	17.45	**-40**	Escarpment	DS3	125	-45
33	17.56	**-150**	Mountainous	DS3	175	-125
34	17.68	**+150**	Mountainous	DS3	175	+175
35	18.13	**-150**	Rolling	DS3	270	-270
36	18.55	+400	Rolling	DS3	270	
37	18.68	**+40**	Rolling	DS3	270	
38	19.24	-400	Rolling	DS3	270	
39	19.59	+500	Rolling	DS3	270	
40	19.95	-2000	Rolling	DS3	270	
41	20.53	+800	Rolling	DS3	270	
42	21.08	+320	Rolling	DS3	270	

43	21.60	**-175**	Rolling	DS3	270	-270
44	22.02	+600	Rolling	DS3	270	
45	23.02	+800	Rolling	DS3	270	
46	23.49	**-250**	Rolling	DS3	270	-270
47	24.51	+2000	Rolling	DS3	270	
48	26.21	+2000	Rolling	DS3	270	
49	26.74	-800	Rolling	DS3	270	
50	26.96	**-95**	Rolling	DS3	270	
51	27.05	**-150**	Rolling	DS3	270	
52	27.29	**+50**	Rolling	DS3	270	
53	27.44	**-200**	Rolling	DS3	270	-270
54	27.93	+600	Rolling	DS3	270	
55	28.54	+900	Rolling	DS3	270	
56	28.81	-400	Rolling	DS3	270	
57	29.28	+175	Mountainous	DS3	175	
58	29.45	-320	Mountainous	DS3	175	
59	29.62	+320	Mountainous	DS3	175	
60	29.80	-320	Mountainous	DS3	175	
61	29.96	+500	Mountainous	DS3	175	
62	30.26	-320	Mountainous	DS3	175	
63	30.53	-180	Mountainous	DS3	175	
64	30.79	**+135**	Mountainous	DS3	175	+175
65	30.97	-200	Mountainous	DS3	175	
66	31.24	+500	Mountainous	DS3	175	
67	31.38	-400	Mountainous	DS3	175	
68	31.53	-300	Mountainous	DS3	175	
69	31.69	+300	Mountainous	DS3	175	
70	31.80	+300	Mountainous	DS3	175	
71	31.91	-300	Mountainous	DS3	175	
72	32.06	**+150**	Mountainous	DS3	175	+175
73	32.15	**-80**	Mountainous	DS3	175	-85
74	32.23	-250	Mountainous	DS3	175	
75	32.31	+250	Mountainous	DS3	175	
76	32.71	+500	Mountainous	DS3	175	
77	33.29	-200	Mountainous	DS3	175	

78	33.87	+180	Mountainous	DS3	175	
79	34.12	-300	Mountainous	DS3	175	
80	34.56	**-24**	Escarpment	DS3	125	-25
81	34.78	**+49**	Escarpment	DS3	125	+50
82	34.94	+250	Escarpment	DS3	125	
83	35.08	**-25**	Escarpment	DS3	125	-30
84	35.19	**+50**	Escarpment	DS3	125	+55
85	35.31	**+45**	Escarpment	DS3	125	+50
86	35.45	-400	Escarpment	DS3	125	
87	35.59	+200	Escarpment	DS3	125	
88	35.71	-200	Escarpment	DS3	125	
89	35.80	+250	Escarpment	DS3	125	
90	36.05	**-70**	Escarpment	DS3	125	
91	36.70	-900	Mountainous	DS3	175	
92	37.43	+500	Mountainous	DS3	175	
93	37.75	**-150**	Mountainous	DS3	175	-175
94	37.98	+200	Mountainous	DS3	175	
95	38.55	-400	Mountainous	DS3	175	
96	38.86	**+160**	Mountainous	DS3	175	+175
97	40.04	+1000	Mountainous	DS3	175	
98	40.48	-320	Mountainous	DS3	175	
99	40.89	**+160**	Mountainous	DS3	175	+175
100	41.14	-300	Mountainous	DS3	175	
101	41.82	+200	Mountainous	DS3	175	
102	42.82	+300	Mountainous	DS3	175	
103	43.04	**-100**	Mountainous	DS3	175	-175
104	43.40	-200	Mountainous	DS3	175	
105	43.72	**+38**	Escarpment	DS3	125	+40

APPENDIX E: Vertical Alignment for Mekelle -Hagereselam(10km) road segment

Curve No	Chainage	Gradient Ahead	Length of Gradient	Length of Vertical Curve	Type of Curve	K-Value	Type of Terrain
	(m)	(%)	(m)	(m)			
POB	0.00	2.33	63	-	-	-	
1	93.08	-1.73	59	61	Summit	15	Rolling
2	206.50	0.64	210	47	Sag	20	Rolling
3	526.78	3.21	123	172	Sag	67	Rolling
4	886.15	-3.30	51	300	Summit	46	Rolling
5	1,153.33	-0.89	257	132	Sag	55	Rolling
6	1,530.81	**-6.76**	270	109	Summit	18	Rolling
7	2,005.55	-3.32	411	300	Sag	87	Flat
8	2,683.16	**-5.05**	322	233	Summit	135	Flat
9	3,271.35	-3.37	268	300	Sag	178	Flat
10	3,839.48	-0.50	257	300	Sag	105	Flat
11	4,331.53	-2.67	374	170	Summit	78	Flat
12	4,890.03	-0.97	116	200	Sag	118	Flat
13	5,205.91	-3.49	55	200	Summit	79	Flat
14	5,392.59	0.71	47	63	Sag	15	Flat
15	5,507.14	-2.88	274	72	Summit	20	Flat
16	5,840.74	-0.52	297	47	Sag	20	Flat
17	6,228.82	-2.82	341	135	Summit	59	Flat
18	6,690.90	0.35	199	106	Sag	33	Flat
19	6,962.89	-2.27	213	39	Summit	15	Flat
20	7,209.83	-3.73	302	29	Summit	20	Flat
21	7,590.58	1.01	308	129	Sag	27	Flat
22	8,026.08	-3.09	314	127	Summit	31	Flat
23	8,598.42	0.54	697	391	Sag	108	Flat
24	9,647.69	-1.46	645	314	Summit	157	Flat

25	10,599.34	3.35	170	300	Sag	62	Flat