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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Identification of road traffic crash black spot locations on a selected rural two-lane two-way road in Tigray Region, Ethiopia

Winta Gebre Mehari

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

SUPERVISOR :
Prof. dr. Gerhard WETS

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WINTA GEBRE MEHARI [1849976]

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Supervisor: **Prof. Geert Wets**

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PREFACE

The roadway safety management process is one of the systematic approaches for the improvement of road traffic safety which includes the identification of road traffic crash black spot locations as the first step of it. As being the first step, the general purpose of black spot identification is to identify high crash frequency locations on a road network for the improvement of road safety. This thesis presents an approach for the identification of road traffic crash black spot locations on the selected rural two-lane two-way road to come up with first attempt improvement measures. Thus, this paper can be used as an input for the roadway safety audit program of the region.

I would like to acknowledge and sincerely thank Professor Geert Wets and Nora Reinolsmann for their constructive feedback and guidance starting from the beginning and throughout the completion of Master thesis part 1. I am also grateful to Doctor Ashenafi Aregawi, Assistance Professor at Mekelle University, Ethiopia for his countless assistance throughout the completion of this paper. Finally, I am still grateful to the Flemish Inter-University Council (Vlaamse Interuniversitaire Raad/ VLIR-UOS) for providing me the full financial support for my Master’s degree at Hasselt University.

ABSTRACT

Even though the expansion of road transport has a remarkable contribution to the economic and social development of one nation, ineffective/deficient use of the transportation system generates some social and economic externalities. Road traffic crashes are one of the main negative externalities of road transport. Road traffic crashes are one of the most common causes of significant losses of human life and economic resources in low- and middle-income countries like Ethiopia. In Tigray region, Ethiopia, 56.4 percent of the total road traffic crashes have occurred in the rural area which is slightly higher than the crash occurred in the urban area. In addition to this, the study shown the percentage distribution for the causes of road traffic crashes. Accordingly, road defects are the leading causes of road traffic crashes which contributes to 47.4 percent of the total road traffic crashes in the Southern part of Tigray region. This problem calls up for some roadway safety improvement works. As a result to this, the general objective of this study is to identify the road traffic crash black spot locations on the selected rural two-lane two-way road to come up with a first attempt improvement measures. The approach used to identify black spot locations is based on the potential savings in crash costs. The selected rural two-lane two-way road is located in the Northern part of Ethiopia, Tigray region that extends from ***Zeban Zelemnay*** to ***Kale Azba.***

Mekelle-Abyi adi-Adwa rural road is one of the major rural roads in Tigray region, Ethiopia. The study area of this paper is also on this major rural road i.e. from ***Zeban Zelemnay*** to ***Kale Azba.*** The road traffic crash data of all districts in this zone are collected from 2014 – 2018 G.C for analysis. In addition to this, a field survey is made to observe the geometry, environment of the roadside, traffic flow regulators, and markings of the road sections. Based on the collected data, it is clear that there is an increase in the number of deaths and injuries due to road traffic crash.

The selected rural road has a length of 60 km. But, for the suitability of ranking, the rural road is divided into 12 equal sections. Accordingly, road section 10, road section 11, and road section 6 are identified as black spot locations along the selected rural road. Finally, after conducting field observation, possible improvement measures for the identified black spot locations are proposed. These include Installation of speed breakers, Widening of road in some locations,

Maintenance of some road surfaces, Installation of some guardrails and hazard lights, Removal of some roadside obstructions (Upgrading safety appurtenances, removing trees, mowing, flattening side slopes, removing or adding fill around headwalls, and increasing clear zone.

Keywords: Road traffic crash, Crash severity, Observed crash frequency, Predicted crash frequency, Estimated crash frequency, Black spot location

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CHAPTER 1: INTRODUCTION

1.1 Characteristics of Road Traffic Crashes in Ethiopia

Road Transport is one of the modes for the transportation of people and freight from one place to another. In Ethiopia, road transport accounts for 90 to 95 percent of those people and freight movements. Well-developed road transport in developing countries like Ethiopia facilitates the growth process of the development activities of the nation such as the creation of market access opportunities, expanding of education, health service provision, trade facilitation (both with in the country and export market), better public as well as private service provisions, and linkage to other modes of transportation. This clearly implies road transport plays a great role in the economic development of a country especially for landlocked countries such as Ethiopia (Worku 2011). In Ethiopia, the total road network coverage has shown a significant increment. The total road network coverage has increased from 26,550 km in 2000 to 113,066 km in 2016 (Ethiopian Roads Authority 2016).

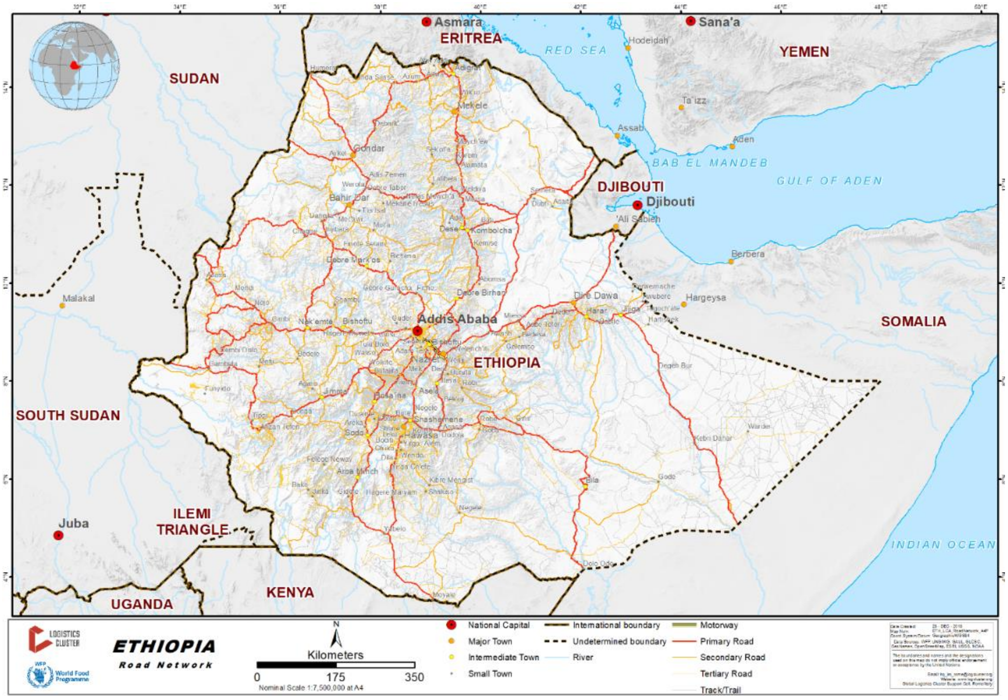

FIGURE 1: Road network coverage in Ethiopia (Ethiopia Road Network - Logistics Capacity Assessment - Digital Logistics Capacity Assessments)

Apart from the benefits of road transport, road traffic death and injuries have continued to be a critical concern of society. According to the report by the World

Health Organization WHO (2018), road traffic crashes are the cause of death for more than 1.35 million people worldwide. The report also added that the burden greatly varies between low-income countries and high-income countries (3 times higher death rates in low-income countries than in high-income countries). Apart from this, there also exists a difference in the progress of reducing the number of road traffic deaths among different regions. No reductions in the number of road traffic deaths were observed in any low-income country, whereas some reductions were observed in middle- and high-income countries (WHO 2018). For instance, according to the study conducted in Sub Saharan Africa Tarimo (2012), the total number of reported road traffic crashes in the Kilimanjaro region, Tanzania was 906 in 2008 while it was 1125 in 2009 indicating a significant increase in the number of road traffic crashes. As a result of this, nowadays the issues of road safety have become the most urgent issue worldwide, in particular, it is the main concern of low- and middle-income countries. Ethiopia also as low- and middle-income countries stand one of the worst countries with respect to road traffic death and injuries as it is estimated to be a fatal rate of 95 per 10,000 vehicles (United Nations Economic Commission for Africa 2009).

In Ethiopia, Road traffic crash is one of the most common causes of significant losses of human life and economic resources. The impacts of road traffic crashes are not only on individual life or his/her family but also on the government and society at large. According to the Ethiopian fiscal year in 2007/8, police-reported 15,086 road traffic crashes which has resulted in the losses of 2,161 lives and over ETB 82 million (US$7.3 million) (United Nations Economic Commission for Africa 2009). Even though there is a significant increase in road network development and motorized vehicles, the police reported road traffic crashes in Ethiopia are increasing at an alarming rate. Accordingly, the report from Ethiopian traffic police commission stated that in the past eleven years (2007/8 – 2017/18) on average around 9.16 % growth of road traffic fatalities were registered in the country annually (Deme 2019).

The chart below shows the relationship between the variables (road network coverage (RNC), motorized vehicle (MV), and road traffic crash (RTA)) and their growth rate in the past eleven years.

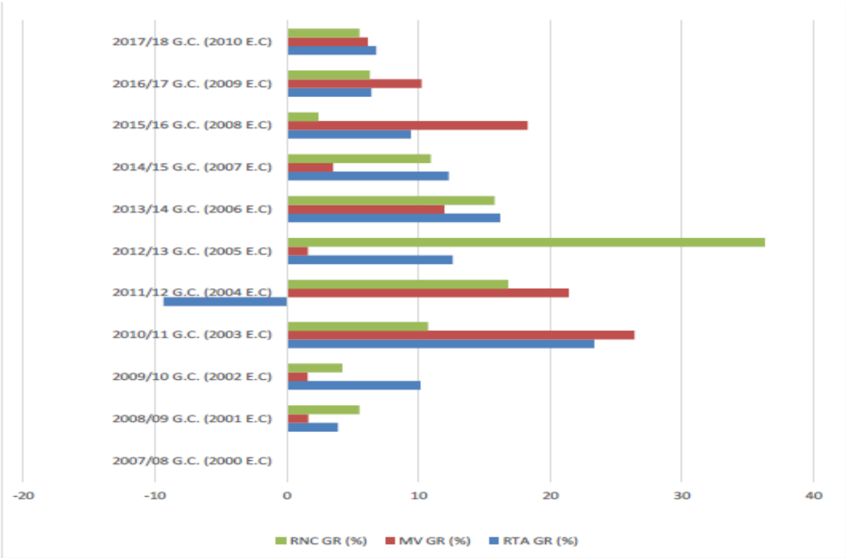

FIGURE 2: The Growth rate of RTC Vs MV Vs RNC in Ethiopia from 2007/8-2017/18 (Deme 2019)

As mentioned above, administratively Ethiopia is comprised of nine regional states and two cities. These regional states and cities have a different population, geographic area, economic activities, and culture. In addition to this, these regional states have significant dissimilarities in urban development, land use, and economic importance. As a result of the above-mentioned differences, these regional states have a different distribution of road traffic crashes (Tulu 2015). According to the Ethiopian traffic police commission report as cited in Wendimu (2017), the regions of Oromia, Addis Ababa, and Amhara had experienced the highest number of road traffic deaths and injuries in 2012/13, contributing 25.3%, 23.4%, and 22.2% of the total road traffic crash injuries in Ethiopia respectively. Addis Ababa is the economic and political center of Ethiopia where the Federal government and Oromia Regional State Government are located. In addition to this, it is the city where the United Nations Economic Commission for Africa (UNECA) and African Union (AU) are headquartered. Addis Ababa is the largest city in Ethiopia with an estimated population of 3.4 million and 524,444 registered vehicles which covers 70 percent of the total Ethiopian registered vehicles (Transport Programs Management Office (TPMO) 2018). Due to all the mentioned factors, Addis Ababa is one of the cities with a high number of road traffic crashes. There are different contributing factors for road traffic crashes in Addis Ababa. For example: according to the study Samson (2006), driver distraction, driver impairment (tiredness, illness, alcohol, and drug), mechanical failure (flat tires, brake failure, axle failure, and steering mechanism failure), road conditions (foreign obstacles or substances on the road surface, making the roads slick, and road damage including potholes), speed exceeding safe conditions, the speed of surrounding motorcyclists, and weather were identified among the main contributing factors for the road traffic crashes in Addis Ababa. The road traffic crash injuries distribution by the regional state in Ethiopia is shown in the table below.

TABLE 1: Road traffic crash injury distribution by regional states in Ethiopia for 2012/13 (Tulu 2015)

Regional state	**Fatal**		**Serious injury**		**Slight injury**		**Total injury crashes**			
	Male	Female	Male	Female	Male	Female	Male	Female	Total	%
Tigray	189	11	272	144	201	160	662	418	1080	8.7
Afar	48	7	77	25	51	9	176	41	217	1.8
Amhara	531	157	535	222	1043	261	2109	640	2749	22.2
Oromia	856	374	633	216	889	171	2378	761	3139	25.3
Somali	58	14	81	23	50	14	189	51	240	1.9
Benishangul	11	13	49	32	81	24	141	69	210	1.7
Debub people	225	53	314	89	471	116	1010	258	1268	10.2
Gambela	14	10	27	25	35	27	76	62	138	1.1
Harar	23	3	22	12	66	10	111	25	136	1.1
Addis Ababa	333	78	1030	406	773	275	2136	759	2895	23.4
Dire Dawa	17	4	63	36	126	79	206	119	325	2.6
Total	2305	827	3103	1230	3786	1146	9194	3203	12397	100

In the above section, a brief summary of the burden, magnitude, and trend (characteristics) of the road traffic crashes in Ethiopia is presented. However, the detailed characteristics of road traffic crashes for the study area (Tigray region) is not well explained due to the limitation of reports and studies. Approximately 70 percent of the cars present in the country are registered in Addis Ababa (Transport

Programs Management Office (TPMO) 2018). As a result of this, most of the studies regarding road traffic crashes are conducted in that city. Specific to the Southern zone of Tigray region, based on the results of the study from 2010 G.C to 2015 G.C, 866 road traffic crashes have occurred and these crashes have resulted in an equivalent economic loss of 41,199,330.00 Ethiopian birrs (Wedajo et al., 2017). From the same report, the occurrence of road traffic crashes within that area is increasing at an alarming rate.

Different studies showed that there is a strong relationship between land use type and the occurrence of road traffic crashes. For instance, the most fatal and injury crashes in Ethiopia have occurred in and around cities, particularly in central business districts and rural village areas. The complexity of the road environment, mixed traffic, built-up property along these roads that attract mixed traffic were among the most common reasons for the high occurrence of road traffic crashes in these specified land-use types. Specific to rural areas, Even though the speed limit in these rural village areas is 30 kilometer per hour, most drivers drive on these road environments at a higher speed. This is one of the main reasons for the occurrence of road traffic crashes in rural village areas (Tulu et al., 2013). The table shown below summarizes the road traffic crash occurrences by land-use type for Ethiopia.

TABLE 2: Road traffic crash by land-use type (Tulu et al., 2013)

Land use	Fatal crashes	%	Injury crashes	%	Property damage	%
Rural village areas	3041	25	4737	16	4334	7.1
Agriculture areas	1948	16.1	3584	12.1	4360	7.1
School areas	892	7.4	1903	6.5	2379	3.9
Industrial	355	2.9	929	3.2	1554	2.5
Church areas	462	3.8	1369	4.7	2855	4.7
Market areas	820	6.8	3147	10.8	6720	10.9
Recreational areas	562	4.6	1908	6.4	4505	7.3
Hospital areas	342	2.8	617	2.1	2552	4.2
Central business district	1765	14.5	6290	21.4	24039	39.1
Urban residential	1597	13.2	4234	14.3	6955	11.3
Other	356	2.9	736	2.5	1183	1.9
Total	12140	100	29454	100	61436	100

In Ethiopia, a road traffic crash investigation is conducted by the authorized traffic police officers. The detail information regarding the crash incident has been collected by field observation in the actual road traffic crash scenarios supported by interviews in the few cases and questionnaires and documentation in most cases. In addition to this, the road traffic crash investigation process carried out by the city's authorized traffic police officers are only based on tire skid marks and measuring tape. The main investigation processes include arrival at the scene, describing the point of impact, moving vehicle and marking wheels, identify and preserve fragile evidence, take statements, tire marks, sketches, measurements, photography, investigating vehicular defects, and completing the investigation (Meresa et al.,2016). All the necessary information is collected manually on a printed paper form for each crash incident. The collected road crash data are reported to regional state administration (administratively Ethiopia is comprised of nine states and two cities). Regional traffic police administrators consolidate the regional reports and submit them to the Federal police commission.

1.2 Roadway Safety Management Process

Road traffic crashes occur as a result of factors related to road infrastructure, environment, vehicles, and road users and the way they interact (Peden et al. 2004).

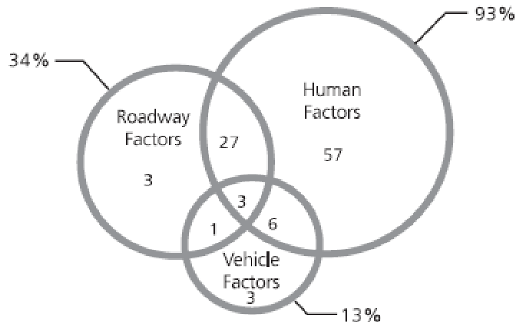

FIGURE 3: Road traffic crash contributing factors (AASHTO 2010)

Road infrastructure is one of the contributing factors for the occurrence of road traffic crashes. This is true because a road network determines how road users perceive their environment (Ahmed 2013). Accordingly, different road parameters affect road safety. These are cross-section of the roadway (width of the travel lane, width and type of shoulder, skid resistance of the surface of the travel way), roadside condition (clear zone, presence of median), the curvature of the roadway (radius of the curve, super elevation, length of the curve), sight distance (stopping sight distance (SSD), passing sight distance (PSD), decision sight distance (DSD)), and access management (Ahmed 2013). It is believed that the cross-section of the roadway (mainly lane width, shoulder width and type) is one of the main factors for the occurrence of road traffic crashes. Different studies have been conducted on the significance level of these roadway cross-sections on road traffic crashes. For instance: according to the study on the benefits expected from lane widening, shoulder widening, shoulder surfacing, and general roadside improvements Zegeer et al. (1987), the following key study results were found.

- Roadway cross-section parameters (lane width, shoulder width, shoulder type, and roadside characteristics) were found to be the most significant factors for the occurrence of road traffic crashes.
- The effects of lane widening on road traffic crashes were quantified. As a result, the widening of a lane by 2 feet (for example: widening lanes from 10 feet to 12 feet) resulted in a 23 percent reduction on road traffic crashes. These quantified reductions are applicable only for lane widths between 8 and 12 feet.
- The effects of shoulder widening were also determined. As a result, adding 2 feet of paved shoulder on 0 to 12 feet shoulder resulted in a 16 percent reduction on road traffic crashes. It was also found paved shoulders are more effective than unpaved shoulders.

There are two main transport engineering approaches for dealing with road traffic safety problems. These are proactive and reactive approaches. The proactive approach sometimes called a collision prevention approach is an approach that tries to prevent unsafe road conditions from occurring in the first place. This is done through an explicit priority in transportation planning, design, and construction in such a way that a minimum number of crashes take place. The reactive approach (retrofit approach), on the other hand, works based on the making necessary improvement measures to existing hazardous sites (black spots) for the reduction of the crash frequency and severity at these sites. This approach mainly focuses on identifying and remedying road safety problems in the existing road networks (Sayed et al. 2010). Therefore, the identification of road traffic black spot locations for providing some improvement measures is an example of a reactive safety management approach. According to AASHTO

(2010), the roadway safety management process and its steps are summarized as follows.

"Roadway safety management process is a quantitative, systematic process for studying roadway crashes and characteristics of the roadway system and those who use the system, which includes identifying potential improvements, implementation, and the evaluation of the improvements". The roadway safety management process includes six main activities. The first step in the roadway safety management process is road network screening, in other words, it is black spot analysis. This step includes reviewing of the road network to identify and rank sites to realize which sites are most likely advantageous in the reduction of the crash frequency with the implementation of a countermeasure. Those sites identified as most likely to benefit with the implementation of countermeasures are studied in more detail to identify the crash patterns, contributing factors, and appropriate countermeasures. There are five major steps in network screening. These are establish focus, identify the network and establish reference populations, select performance measures, select screening method, and screen and evaluate results. The next activity that follows network screening is diagnosis. The activities included in this step are mainly understanding the crash patterns, past studies, and physical characteristics of the sites selected in the network screening process before selecting potential improvement measures. This step includes three main steps. These are safety data review, assess supporting documentation, and assess field conditions. After a detailed diagnosis of sites selected in the network screening process, the next step in the roadway safety management process is selecting proper countermeasures for the reduction of crash frequency or severity at the selected sites. In this step, more than one different improvement measures are selected as a solution to the specified problems. The fourth step in the roadway safety management process is economic appraisal. In this step, the economic appraisals of the countermeasures selected in the previous step are conducted for the prioritization of projects. Economic appraisals are performed for the comparison between the benefits of countermeasures and their project costs. Two types of economic appraisal are available. These are benefit-cost analysis and cost-effectiveness analysis. After conducting the economic appraisals for different countermeasures selected, the next step is the prioritization of these countermeasures according to different methods. The three prioritization methods presented in the Highway Safety

Manual are ranking by economic effectiveness measures, incremental benefit-cost analysis ranking, and optimization methods.

The last step in the roadway safety management process is safety effectiveness evaluation. The main activity of this step is evaluating the change in a crash as a result of the implemented improvement measures.

1.2.1 A review of definitions of a road traffic crash black spot

A study has implied that there is no universally accepted definition of a black spot (K Geurts and Wets 2003). Road traffic crash black spots are defined in different ways by different countries and scholars. Some of the definitions of road traffic crash black spot by different countries are discussed below.

According to the Austrian guideline code for the planning, construction, and maintenance of roads (RVS 1.21) published in November 2002 as cited in Elvik (2007), identification of black spot and hazardous locations is based on their recorded crash history. In order to be classified as a black spot, a road section has to meet at least one of the following criteria:

1) The occurrence of 3 or more similar injury crashes within 3 years and a relative coefficient R_k of greater than or equal to 0.8. The value of this relative coefficient is calculated as follows (Elvik 2007):

$$Rk = \frac{U}{0.5 + 7 * 10^{-5} * AADT}$$

Where:

- U = Number of injury crashes within 3 years
- AADT = Annual Average Daily Traffic (vehicles/24 hours)

2) The occurrence of at least 5 crashes (including property damage only) of a similar type within a year.

In Austria, the Sliding window approach is being used for the identification of road traffic crash black spot locations. A sliding window with a length of 250 meters is being used for the identification of black spots. The sliding window follows the course of the road under observation and indicates each location where one of the two criteria for a black spot is met.

In Flanders, to identify black spot locations, the Flemish government analyses the crash data that are reported by the Belgian “analysis form for traffic accidents”. Based on these data, first, each site where in the last three years three or more crashes have occurred is selected. Then, a site is considered to be a black spot when its priority value (P), calculated using the following formula, equals 15 or more (Elvik 2007; Karolien Geurts et al. 2004b)

$$P = X + 3 * Y + 5 * Z$$

Where:

- P = Priority value
- X = Total number of light injuries
- Y = Total number of serious injuries
- Z = Total number of death

In Hungary, there are two different definitions of road traffic crash black spots. These are outside built-up area and within built-up area. According to the outside built-up area, a road traffic crash black spot is defined as a location where at least 4 crashes have occurred during 3 years on a road section no longer than 1000 meters. In another hand, within built-up areas, a road traffic crash black spot is defined as a location where at least 4 crashes have occurred in 3 years on a road section no longer than 100 meters (Elvik 2007; Szénási and Jankó 2017). The sliding window approach is being used for the identification of road traffic crash black spot locations. The window is either 1000 meters or 100 meters wide. After identification of these black spot locations, they are ranked for detailed engineering studies (Elvik 2007). In Hungary, the currently used tool for the ranking of road traffic crash black spot location is done by a software (Win-Bal) (Borsos et al. 2016). During ranking of these black spot locations, traffic volume (Average Annual Daily Traffic) is taken into consideration, in order to identify those black spots that have a higher crash rate with respect to the traffic volume.

In Norway, there is a distinction between black spots and black sections. For instance, a black spot is any location on the stretch of road (not more than 100 meters in length) where at least 4 injury crashes have occurred in the last 5 years. Whereas, a black section is any road section (not more than 1000 meters in length) where at least 10 injury crashes have occurred during the last 5 years. Black spot locations are identified using a sliding window, which is fitted to the location of the crashes and black sections are the collection of different black spots that are located near one another. Once black spots or black sections have been identified, they are ranked for detailed engineering studies. Ranking of these black spot locations consists of the following four tasks (Elvik 2007):

1) Estimation of the cost of road crashes based on the recorded number of crashes.

2) Estimation of the expected number of crashes and the cost of these road crashes for a similar spot or section that has the best possible road safety standard.
3) Estimation of the probability that the recorded number of crashes exceeds the number that can be expected at a similar site that has the best possible road safety standard.
4) Ranking of sites (spots or sections) according to the difference between the cost of road crashes estimated for the site and the cost of road crashes for a similar site that has the best possible road safety standard (the potential for reduction of road crash costs).

Based on the ranking of sites, those sites which are highly ranked will be selected for detailed engineering studies. This includes a detailed crash analysis, site visits, observation of road user behavior, etc. After the detailed analysis, first attempt improvement measures are proposed for the highly ranked sites (spots or sections). Finally, prioritization of these improvement measures will be done based on the benefit-cost ratio estimated for each site (Elvik 2007).

In Portugal, identification of black spots is done for the roads belonging to the National Road Network which is managed by the Portuguese Highway Agency. According to this agency, there are two definitions of road traffic crash black spots. Based on the first definition, road traffic crash black spot is a road section (intersections and non-intersection) with a maximum length of 200 meters, with the occurrence of 5 or more crashes and a severity index of greater than 20 during the year of analysis. The severity index is calculated by the following weighted sum (Ramos et al. 2015):

$$Severity\ Index = 100 * X + 10 * Y + 3 * Z$$

Where:

- X = Number of fatalities
- Y = Number of serious injuries
- Z = Number of slight injuries

Afterward, the identification of black spot locations is done using a sliding window moving along the road. According to the second definition, a black spot is a road section (site) where the expected crash frequency is greater than the expected crash frequency of similar sites.

1.2.2 Approaches for the identification of road traffic crash black spot

As mentioned in the above section, there are different definitions of road traffic crash black spot by different countries and scholars. The same is true for the identification of road traffic crash black spot, there are different approaches for the identification of black spots. Different performance measures (approaches) are available for the identification of road traffic crash black spot locations in a given stretch of highway. These are average crash frequency, crash rate, equivalent property damage only average crash frequency, relative severity index, critical rate, the expected average crash frequency with Empirical Bayes adjustment, etc. (AASHTO 2010). Montella (2010) assesses the different alternative approaches for the identification of road traffic black spot locations on a highway segment. The comparison of different approaches is discussed below.

1.2.2.1 Crash frequency

Crash frequency is one of the simplest methods for the identification of road traffic black spot locations. This method works based on the ranking of sites according to the descending order of observed crash frequencies. Crash frequency analysis (used with simple ranking) is one of the most traditional methods for the identification of black spot locations. Due to the fact that crash frequency analysis does not take into account the severity of crashes it analyzes, it can result in segments of the road with a low potential benefit being identified as black spots (Da Costa et al. 2015).

1.2.2.2 Equivalent property damage only crash frequency (EPDO)

The EPDO crash frequency method uses the crash severity (fatal, injury, and property damage) to develop a combined frequency and severity score for each site. This method uses a weighting factor for each crash severity based on the property damage only (PDO) crash costs. The resulting value summarizes the crash severity and costs. In the calculation, the weighting factors were developed from the road traffic crash cost estimates developed by the UK Department for Transport which is based on the willingness to pay method (Montella 2010).

1.2.2.3 Crash rate

The crash rate method for the identification of road traffic crash black spot is mainly based on the frequency of crashes with respect to exposure (mostly measures by traffic volume). Accordingly, this approach explains the crash risk for the individual road user (AASHTO 2010).

1.2.2.4 Empirical Bayes (EB) method

In the EB approach, it works based on the combination of the predicted number of crashes and the observed number of crashes for a given site. The predicted number of crash is the crash frequency from a crash prediction model that estimates the number of crashes that would be expected in the analysis period at sites with traffic volumes and other characteristics similar to the one being analyzed. Whereas, the observed number of crash is based on the recorded crash incidents in a given site. For a better estimate of the expected number of crashes, these two crash numbers are combined with a weighting factor of "w". Ghadi and Török (2017) compare different methods for the identification of road traffic black spot locations i.e. sliding window method, spatial auto-correlation method, and Empirical Bayes method. The sliding window method works based on the principle of moving a sliding window across the entire road network to identify segments that meet the criteria of the crash's threshold. While moving the window, when the criteria are met a black spot location is identified and the search for another black spot is continued from the next segment without overlapping. The threshold value is calculated according to the crash frequencies. The number of crashes for each sliding window (similar in length) is tabulated. In the end, the threshold value is calculated as the average observed number of crashes for all tabulated similar locations with a level of the confidence interval. As a result of this, any location "L" is unsafe when it's observed number of crashes exceeds the threshold value, as in the following equation (Ghadi and Török 2017).

$$Xi > Xave + CI * \frac{SD}{n}$$

Where:

- Xi = the number of crashes at any location i
- Xave = the average number of crashes for all similar locations
- CI = a confidence interval (99%, 95%, etc.)
- SD = the standard deviation
- n = the number of all measured locations

Accordingly, sliding window method was found to face some limitations of being used a fix length window whatever the real extension of the real black spot, rather than the problem of the rule "first come first serve" that could result in a deviation of the identified black spot from the real position (Ghadi and Török 2017). The spatial auto-correlation method for the identification of road traffic crash black spot locations is based on the spatial aggregation of contiguous spatial units (crashes) that are geographically approximate. This method works based on the global Maron's index I that measures the degree of co-variation between spatial units' values at each location and the nearby location. A positive value of Maron's index I indicate a positive association between variables and a higher co-variation. Whereas, a negative index value indicates a negative association between variables, and 0 value indicates no correlation between the variables (Ghadi and Török 2017)

1.2.3 Road traffic crash cost

Apart from human deaths and injuries due to road traffic crashes, the economic consequences of road traffic crashes are also very important. Evaluating the cost of road traffic crashes at a national level has a long history, with over 70 years of research. For instance, in 1938, a study on the estimation of road traffic crash costs in United Kingdom (UK) was conducted by a researcher called Jones. Later on, different researchers (Reynolds, Dawson, Jacobs, Miller, Ogden, and Elvik) have continued to study on the road traffic crash costing using different methodologies (as cited in Ahadi and Razi-Ardakani 2015). One of the findings showed that Peden et al. (2004), the cost of road traffic crash injuries is estimated roughly 1-3 percent of the gross national product in low- and middle-income countries. The economic values of road traffic crash injuries are different across countries due to the methodological differences between countries regarding the cost components that are taken into account and the methods used to estimate specific cost components (Wijnen and Stipdonk 2016). For example, based on the study García-Altés and Pérez (2007), the economic costs for road traffic crashes are between €7347 per injury in Portugal and €119,174 in Sweden, and between €105,546 per death in Holland and €2,160,000 in United States of America (USA). Estimating the cost of road traffic crash deaths and injuries has so many advantages for one country. Firstly, the estimation of the total cost of road traffic crashes makes the government be aware of the annual cost of road traffic crashes. This awareness can lead the government to analyze the economic benefits of investing in national road safety programs. As a result of this, there will be a greater opportunity to allocate resources at a national level to ensure road traffic safety (G. Jacobs 1995; Goff Jacobs et al. 2000; Silcock 2003). Secondly, the estimation of road traffic crash costs can be used to ensure the best use is made of any investment through an economic appraisal. This economical appraisal is made based on the cost-benefit analysis method. Cost-benefit analysis of potential road safety improvement measures can be used to predict the economic benefits of implementing the improvement measure (Goff Jacobs et al. 2000).

The different methodologies that can be used to estimate the cost of road traffic crashes have been discussed by Ahadi and Razi-Ardakani (2015; G. Jacobs (1995); Silcock (2003) as listed below:

- Lost output or Human capital method
- Net output method
- Life-insurance method
- Court award method
- Implicit public sector valuation method
- Value of risk change or Willingness-to-pay method

The human capital and willingness-to-pay methods are the most commonly used techniques for estimating the cost of road traffic crashes (Ahadi and Razi-Ardakani 2015). The human capital method estimates the cost of road traffic crashes based on the assumption of the output that an individual can produce over their productive life period (Luathep and Tanaboriboon 2005). The human capital method can be considered as a natural starting point for estimating the crash costs for developing countries. It is also the best approach to estimate the cost of road traffic crashes in developing countries like Ethiopia. In the human capital method, there are two categories of cost components. These are unit cost per casualty (hospital and medical cost, lost output, and human cost) and unit cost per crash (property damage cost, insurance administrative cost, emergency medical service cost, and police administrative cost) (Silcock 2003).

As defined in G. Jacobs (1995), "Willingness-to-pay approach is based on the fundamental premise that decisions made in the public sector concerning the allocation of scarce resources should reflect the preferences and wishes of those individual citizens who will be affected by the decisions". Therefore, the value of a reduction in road traffic crash risk is defined in terms of the cumulative amount that people are willing to pay for it. A number of developed countries like United States of America, United Kingdom, New Zealand, and Sweden have used the willingness-to-pay method for estimating the cost of road traffic crashes (Ismail and Abdelmageed 2010). The net output method of crash costing is similar to that of the human capital method. The only difference between them is the net output method deducts the discounted value of the victim's future consumption from the gross output figure (G. Jacobs 1995). The life-insurance method estimates the road traffic crash cost in relation to the total cost for which individual citizens are willing to insure their lives. This method is mainly dependent on the public's awareness of risk exposure and the consequences of a road traffic crash as a probable social danger. As a result of this, this method is not appropriate for developing countries where the population has less awareness of the risk avoidance concerns (Ahadi and Razi-Ardakani 2015). The court award method of estimating the road traffic crash cost is based on the court system. This estimation includes the award given by a judge to the family of a deceased or injured person, not the life value of that injured person. In United Kingdom, the total compensation awarded by the court depends on the negligence of the defendant, whether the person killed or injured was partly to blame, whether or not the employer of the injured person is continuing to pay them any wages and whether industrial injury benefits are to be paid. The implicit public sector valuation method determines the cost of road traffic crashes based on the accident prevention in safety legislation or in public sector decisions taken either in favor of or against investment programs that affect safety (G. Jacobs 1995).

1.3 Statement of the Problem

According to the study Wedajo et al. (2017), in Tigray region, 56.4 percent of the total road traffic crashes have occurred in the rural area which is slightly higher than the crash occurred in the urban area. In addition to this, the study has shown the percentage distribution for the causes of road traffic crashes. Accordingly, road defects are the leading causes of road traffic crashes which contributes to 47.4 percent of the total road traffic crashes in the Southern part of Tigray region. Some of the main causes of road traffic crashes are narrow road right of way, deficient lane width, section of the roads being almost escarpment and mountainous terrain, eroded shoulder, and pavement markings not visible. Specific to the study area, 61 fatalities, 62 major injuries, 16 slight injuries, and 148 property damage only were reported during the period of 2018 Tigray Traffic Police Commission (2018) which contributes to the highest number of crash in that region.

One of the systematic methods for the improvement of road safety is through the roadway safety management process (AASHTO 2010). The identification of road traffic crash black spot locations is the first step of the highway safety management process (Montella 2010). As being the first step, the general purpose of black spot identification is to identify high crash frequency locations on a road network for the improvement of road safety (Nguyen et al. 2018). It also helps to select the most cost-effective projects in order to ensure that the best use is made of the limited funds available (Montella 2010). According to the report Elvik (2007), in developed countries, the black spot management process has shown a significant improvement in road traffic safety. Even though there is also an urgent need for road safety improvement works in developing countries, it has been observed that safety improvement works are not taken up systematically (Ramesh Raju Buddharaju 2012). In Ethiopia, many studies focus on the police-reported descriptive presentation of fatalities, injuries and property damage. However, a systematic road safety improvement studies such as roadway safety management process could not be found. This is one of the main challenges for the improvement of road traffic safety.

From the above-mentioned data, it is clear that Tigray region, Ethiopia is facing an enormous loss of human life due to road traffic crashes. In addition to the loss of human life, there is also a significant economic loss for the country. Accordingly, Ethiopia lost an estimated economic cost of road traffic crash between 340 – 430 Million Ethiopian birrs which is 0.8 - 0.9 % of the total GDP in 2009 (United Nations Economic Commission for Africa 2009). These significant human lives and economic losses call up for some urgent road safety improvement tasks. However, it is impracticable for developing countries to treat all identified black spots due to economic/financial difficulties. Therefore, it is essential to establish an approach that can be used for both identification and prioritization of black spot. Consequently, the approach to identify road traffic crash black spots based on potential savings in crash costs can meet this requirement (Nguyen et al. 2016). As a solution to these problems, this research will focus on the identification of road traffic crash black spot locations based on the potential saving in crash costs. Thus the purpose of this study is to minimize the burden of road traffic crashes by improving road traffic safety through the identification of road traffic crash black spots and to come up with first attempt improvement measures to be implemented.

1.4 Research Questions

The following questions have been organized to seek answers in relation to the research objectives.

1) What are the expected numbers of crash by severity level (fatal, major injury, minor injury, and property damage only) of the road sections (sites) on the rural two-lane two-way road?

2) Which road sections (sites) of the rural two-lane two-way road are identified as black spot locations?

1.5 Objective of the Study

The general objective of the study is to identify the road traffic crash black spot locations on the rural two-lane, two-way road based on the potential saving in crash costs for providing first attempt improvement measures.

The specific objectives of the study are to:

- Estimate the distribution of the expected number of crashes by severity level for the selected rural two-lane, two-way road using the Empirical Bayes method.
- Identify black spot locations for the selected rural two-lane, two-way road.
- Conduct field observation for diagnosis and providing first attempt improvement measures.

1.6 Scope of the Study

The scopes of this study are:

- According to Cheng and Washington (2005); Nguyen et al. (2016), the optimum length of period which is used to identify road traffic crash black spot locations varies from three years to six years. Hence, this study is limited to the crash database obtained from the traffic police for a period of 5 years (2014-2018).
- The study area of this research is limited to the two-lane two-way rural road of 60 km length that is found in the Tigray region, Ethiopia.
- The study is limited to the effects of road infrastructure on the occurrence of road traffic crashes. Therefore, other road traffic crash contributing factors (human factors and vehicle factors) are not discovere

1.7 The Framework of the Study

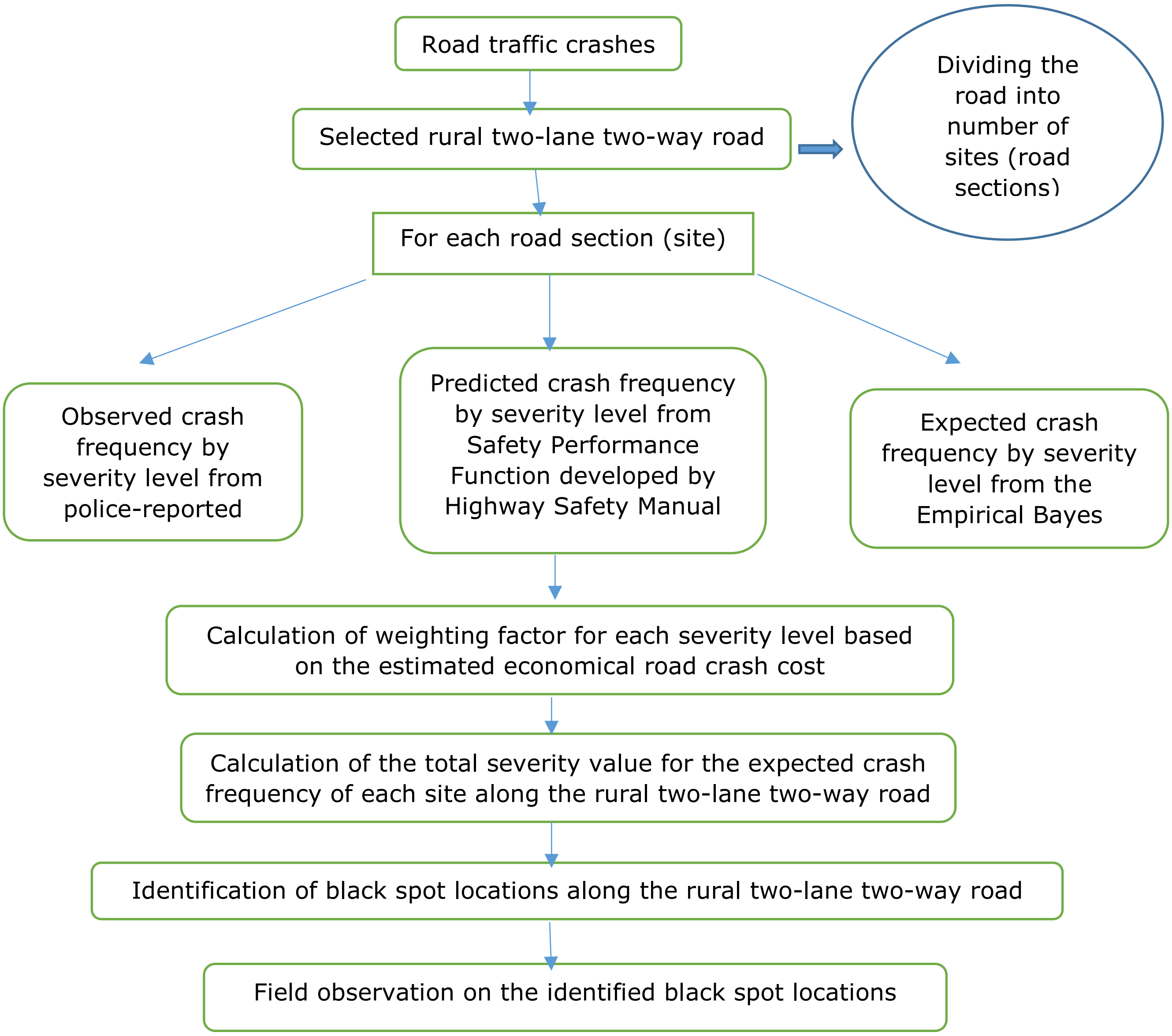

FIGURE 4: Framework of the study

CHAPTER 2: METHODOLOGY

2.1 Introduction

The major aim of this paper is to identify the road traffic crash black spot locations on the selected rural two-lane two-way road based on the potential saving in crash costs. Hence, the study is executed on a two-lane two-way rural road which has a total length of 60 km in the Tigray region, Ethiopia. The entire methodology that is adopted for accomplishing the objective of the study is based on data collection, analysis of crash data, identification of road traffic crash black spot locations, and field observation. Microsoft Excel, Google earth, UTM geo map, and Arc GIS 10.7 software are also used for accomplishing the objective of the study.

2.2 Study Area

Generally, the study is conducted in the Northern part of Ethiopia in Tigray region on a selected rural two-lane two-way road. The stretch of road is 60 km long that extends from ***Zeban Zelemnay*** to ***Kale Azba*** as it is shown in the figure below.

FIGURE 5: Study area for road traffic crash analysis (Google Maps, 2020)

2.3 Sampling Method

The sampling method used to select the rural two-lane two-way road is a purposive sampling technique. This study is conducted on the rural road on the basis of different criteria. The main criteria include:

- The availability of better road traffic crash database at the respective police stations compared to other road networks of the region.
- The potential susceptibility of the road to the occurrences of a frequent number of road traffic crashes. Specific to the study area of this paper, 61fatalities, 62 major injuries, 16 slight injuries, and 148 property damage only was reported during the period of 2018 (Tigray Traffic Police Commission 2018).
- High traffic volume on the selected rural two-lane two-way road due to its location. It is a district located on the major/national road network.

2.4 Data Collection Method

Different types of data is collected to achieve the main objective of the study. These data are both primary and secondary data as discussed below.

2.4.1 Road traffic crash data

Data on the road traffic crash is obtained from the Tigray region traffic commission. According to Cheng and Washington (2005; Nguyen et al. (2016), the optimum length of period which is used to identify road traffic crash black spot locations varies from three years to six years. Accordingly, a five years (2014 – 2018 G.C) road traffic crash data by severity (fatal, major injury, minor injury, and property damage only) on all sites within the rural two-lane two-way road is collected. The police-reported road traffic crash data includes the following variables:

- Crash date, month, and year
- Crash specific location
- Reason for the crash
- Crash type
- Driver- vehicle relation
- Driver’s age, driving experience, and gender
- Crash severity (fatal, major injury, minor injury, and property damage only)
- Vehicle type and service age in years
- The weather condition in the time of the crash
- Road condition in the time of crash

2.4.2 Road traffic data

The two important parameters that are used to determine the predicted number of crashes for the selected rural two-lane two-way road are the traffic volume and road geometric design features (AASHTO 2010). The two parameters listed below are used to determine the predicted number of crashes using the model developed by the Highway Safety Manual.

- Average annual daily traffic (AADT)
- Road geometric design features
    - Lane width
    - Shoulder width and type
    - Roadside hazard rating
    - Driveway density
    - Horizontal curvature
    - Vertical curvature
    - Centerline rumble strips
    - Passing lanes
    - Two-way left-turn lanes
    - Lighting
    - Automated speed enforcement
    - Grade level

2.5 Data Analysis

The approach for the identification of road traffic crash black spot locations based on the potential saving in crash costs can be divided into the following steps.

Step 1- Dividing the rural two-lane two-way road into a number of road sections (sites)

The first step of this method is to divide the rural two-lane two-way road into multiple road sections (sites). The fixed-length division method and non-fixed division method are the two commonly used methods for road divisions (Bi et al. 2014). Additionally, the study Hauer (2002) state that the appropriate division method is dividing a highway into a number of fixed length road sections and to consider each segment as a site. Accordingly, in this study, this approach is adopted to divide the selected rural two-lane two-way road.

Step 2- Data collection

As explained in the above section, the data collection is supposed to come up with the following two sets of data:

- Road traffic crash data by severity for each site within the rural two-lane two-way road.
- Traffic volume (AADT) and road geometric design features for each site within the rural two-lane two-way road.

Step 3- Estimating the expected number of crashes for each road sections within the rural two-lane two-way road.

Observed crash frequency analysis (used with simple ranking) is one of the most traditional methods for the identification of black spot locations. This is because the ranking of black spot locations based on historic count data is very sensitive to random variation in crash counts and to the regression to the mean problem (Karolien Geurts et al. 2004a). Additionally, due to the fact that observed crash frequency analysis does not take into account the severity of crashes, it can result in segments of road with a low potential benefit being identified as black spots (Da Costa, Qu, and Parajuli 2015). In order to address the above-mentioned problem, different scholars have started to use the expected crash frequency instead of the observed crash frequency. The expected crash frequency is the estimation of the crash frequency based on the combination of the observed crash frequency data for a given site with predictive crash frequency from many similar sites (AASHTO 2010). Nowadays, the expected number of crashes estimated using the Empirical Bayes method is used in road safety to identify black spot locations (Karolien Geurts et al. 2004a). Therefore, in this study, the Empirical Bayes method is used to estimate the expected crash frequency of all road sections within the rural two-lane two-way road. The observed number of crashes by severity and location for the selected rural two-lane two-way road is collected from police-reported crash data. On another hand, the predicted number of crash for all the sites within the rural two-lane two-way road is estimated using Safety Performance Function for rural two-lane two-way roadway segments developed by Highway Safety Manual.

According to AASHTO (2010)the Safety Performance Function for predicted average crash frequency for rural two-lane two-way roadway segments is shown in the equation below.

$$Nspf\ rs = AADT * L * 365 * 10^{-6} * e^{-0.312}$$

Where:

- Nspf rs = predicted total crash frequency for roadway segment base condition;
- AADT = average annual daily traffic volume (vehicles per day); and
- L = length of roadway segment (miles)

The base conditions for the above-mentioned equation are:

- Lane width = 12 feet
- Shoulder width and type = 6 feet and paved respectively
- Roadside hazard rating (RHR) = 3
- Driveway density = 5 driveways per mile
- Horizontal curvature, vertical curvature, centerline rumble strips, passing lanes, two-way left-turn lanes, lighting, and automated speed enforcement = None
- Grade level = 0%

Therefore, Crash Modification Factors (CMF) are applied to account for the effects of site-specific geometric design and traffic control features. Finally, the equation that will be used to estimate the predicted crash frequency for the selected stretch of highway is as shown in the equation below (AASHTO 2010).

$$Npredicted\ rs = Nspf\ rs * Cr * (CMF1r * CMF2r * \ldots * CMFnr)$$

Where:

- Npredicted rs: predicted average crash frequency for an individual roadway segment for a specific year;
- Nspf rs: predicted total crash frequency for roadway segment base condition
- C_r: calibration factor for roadway segments of a specific type developed for a particular geographic area; and
- CMF_{1r}*CMF_{2r}* … * CMF_{nr}: crash modification factors for rural two-lane two-way roadway segments

Highway Safety Manual has also provided the estimate of the predicted crash frequencies by crash severity level for rural two-lane two-way roadway segments.

Accordingly, 1.3 percent, 5.4 percent, 10.9 percent, 14.5 percent, and 67.9 percent of total roadway segment crashes are fatal, incapacitating injury, non-incapacitating injury, possible injury, and property damage only respectively. Finally, as mentioned above, the Empirical Bayes method is used to estimate the expected crash frequency of all sites within the rural two-lane two-way road. The Empirical Bayes method for estimating the expected crash frequency considering both the predictive model estimate and observed crash frequencies for an individual roadway segment or intersection is computed as follows (AASHTO 2010):

$$Nexpected = w * Npredicted + (1 - w) * Nobserved$$

$$w = \frac{1}{1 + k * (\sum_{all\ study\ years} Npredicted)}$$

Where:

- Nexpected = estimate of expected average crash frequency for the study period;
- Npredicted = predictive model estimate of average crash frequency predicted for the study period under the given conditions;
- Nobserved = observed crash frequency at the site over the study period
- w = weighted adjustment to be placed on the predictive model estimate
- k = over dispersion parameter of the associated SPF used to estimate Npredicted

Step 4- Calculating the weighting factors for each crash severity

The Equivalent Property Damage Only (EPDO) performance measure works by assigning weighting factors to each crash severity (fatal, major injury, minor injury, and property damage only) to develop a single combined severity score per location. The weighting factors is calculated relative to Property Damage Only (PDO) crash costs (AASHTO 2010).

Step 5- Calculating the severity index (EPDO score)

For each road section, in order to determine the severity index (SI), multiply the weighting factors with the corresponding number of fatal, major injury, minor injury as shown below.

$$SI\ (EPDO\ score) = Fk * Nfatal + Fmi * Nmi + Fsi * Nsi + Fpdo * Npdo$$

Where:

- SI = severity index
- fk, fmi, fsi, fpdo = fatal, major injury, minor/slight injury, and property damage only weighting factors respectively
- Nfatal, Nmi, Nsi, Npdo = number of fatal crashes, major injury, minor/slight injury, and property damage only respectively

Step 6- Ranking of the locations (road sections)

Finally, the locations (road sections) are ranked in descending order of the severity index (EPDO score). After ranking the locations, field observation is conducted on the selected black spot locations to provide first attempt improvement measures related to the road infrastructure.

CHAPTER 3: DATA ANALYSIS AND RESULTS

3.1 Introduction

Primarily, this chapter includes the detailed analysis of both primary and secondary data where the primary data analysis deals with computation and organization of data gathered from field observation, traffic volume studies, and geometric design data analysis. Whereas, secondary data analysis deals with the detailed analysis of the police-reported road traffic crash data. Subsequently, black spot locations along the selected rural two-lane, two-way road are identified. Field observation is also conducted on the identified black spot locations. Finally, some first attempt improvement measures are proposed for each black spot locations.

3.2 Characteristics of observed road traffic crash for the study area

This section presents the analysis of road traffic crash data obtained from respective traffic police stations. Hence, the collected crash data were sorted out and coded relevantly according to the objective of the study. Police reported road traffic crash data is collected on the selected rural road (from ***Zeban Zelemnay*** to ***Kale Azba)*** for 5 years (2014 – 2018 G.C). In total, 130 different crash data are collected on the selected rural road for the specified period. Most of the crashes happened in 2018 G.C. The increment of a road traffic crash on the selected rural two-lane, two-way road is shown in the figure below.

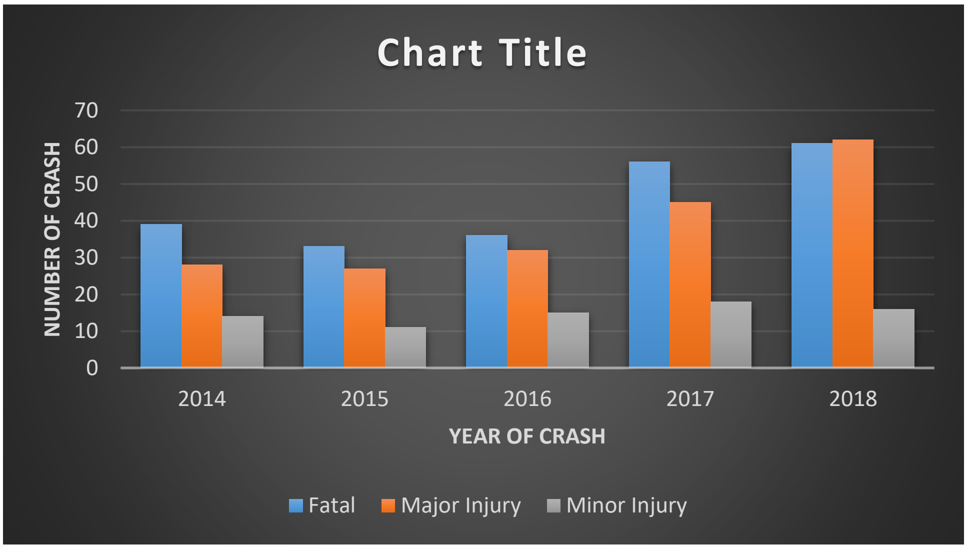

FIGURE 6: Year of crash vs Number of crash chart

In Ethiopia, a road traffic crash investigation is conducted by the authorized traffic police officers. All the necessary information is collected manually on a printed paper form for each crash incident. As a result of this, it was the responsibility of the researcher to locate the exact crash location. Consequently, the researcher used UTM geo map application software to collect the crash locations. The collected crash locations (X, Y, Z coordinate) is shown in the appendix below.

The collected crash location coordinates are analyzed using the ArcGIS 10.7 software to look at the distribution of the crashes along the selected rural two-lane two-way road as shown in the figure below.

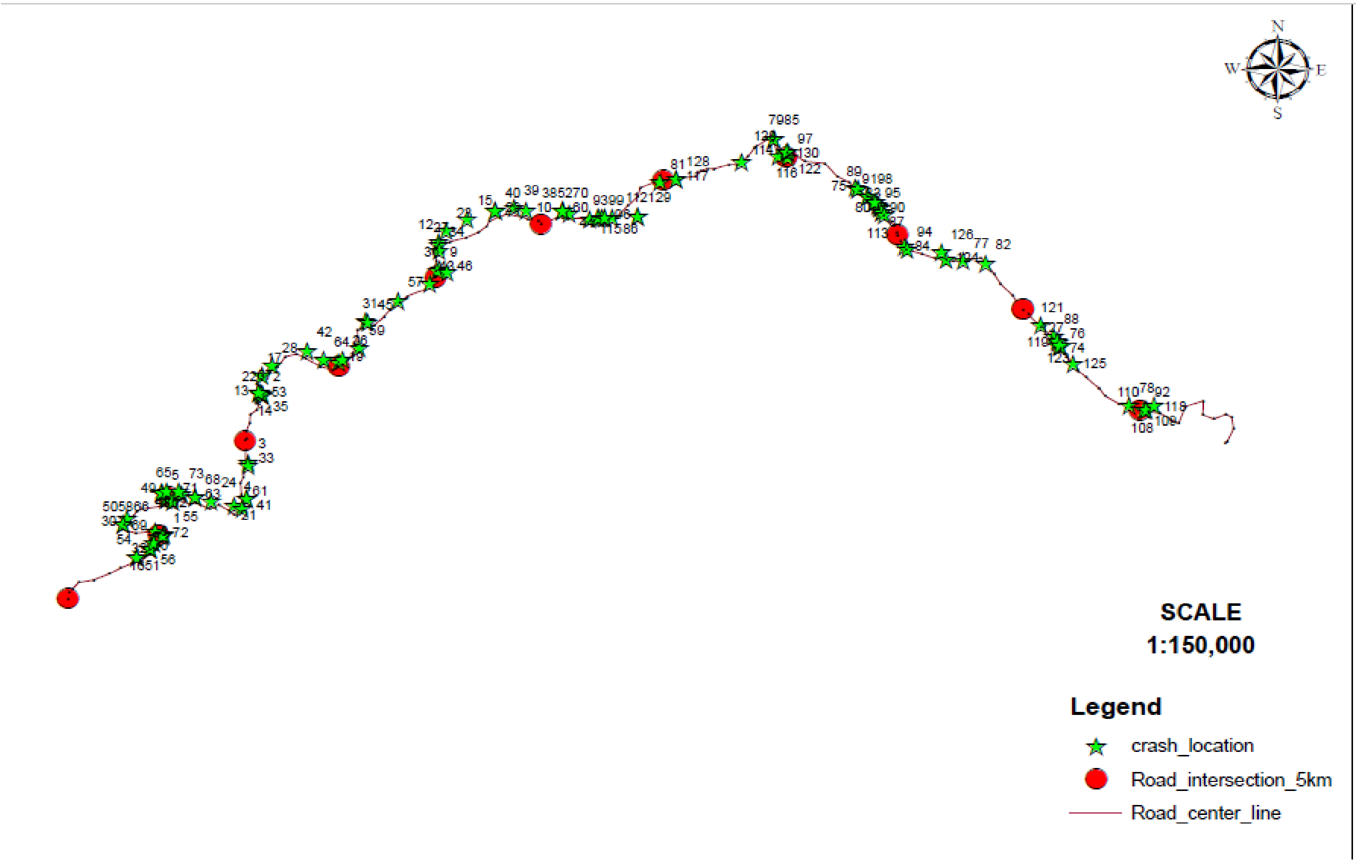

FIGURE 7: Road traffic crash map for the study area

The police reported road traffic crashes of the rural road for a period of 5 years is distributed as shown in the above figure. For each road section, the total number of fatalities, major injuries, minor injuries, and property damage only are computed from the above figure. The observed crash frequency of the selected rural two-lane two-way road for the period of the 2014-2018 is summarized as shown in the table below.

TABLE 3: Observed crash frequency for the study area

Road Section	**Observed crash frequency per year**			
	Fatal	**Major injury**	**Minor injury**	**PDO**
1	1.0	0.8	0.4	0.6
2	3.4	3.6	1.6	1.8
3	2.2	2.4	1.0	1.0
4	4.0	4.0	1.6	1.8
5	2.0	1.8	0.6	1.4
6	4.0	4.4	1.4	2.2
7	1.8	3.2	1.0	1.6
8	1.0	1.2	1.0	1.2
9	3.6	3.2	1.2	1.6
10	5.8	4.8	1.6	3.0
11	5.6	3.8	0.4	1.8
12	3.6	3.4	1.0	1.4

3.3 Predicted crash frequency for the study area

Mekelle-Abyi adi-Adwa rural road is one of the major rural roads in Tigray region, Ethiopia. The study area of this paper is also on this major rural road i.e. from ***Zeban Zelemnay*** to ***Kale Azba.*** This section covers the predicted crash frequency of the selected rural road. This predicted crash frequency is estimated based on the safety performance function for rural two-lane, two-way road developed by Highway Safety Manual.

The length of the selected rural road is 60 km i.e. from ***Zeban Zelemnay*** to ***Kale Azba*** on the major rural road of *Mekelle – Abi Adi – Adwa* road project. For the suitability of data analysis, the selected rural road is divided into equal length of 5 km. Therefore, the selected rural road has 12 different sections. Additionally, the Average Annual Daily Traffic (AADT) of the major rural road is reported by the Ethiopian Roads Authority (ERA) (Ethiopian Roads Authority 2016) as shown in the table below. The study area is found on the major rural road i.e. from 15 km to 75 km.

TABLE 4: Average Annual Daily Traffic (AADT) (Ethiopian Roads Authority 2016)

Section			**AADT**
No.	From - To	Km - Km	
1	Messebo – Hagere selam	5.1 – 49	2721
2	Hagere selam – Agbe Jct.	49 – 77	1627

As mentioned earlier, the predicted crash frequency of the selected road is estimated from the Safety Performance Function for rural two-lane, two-way road developed by Highway safety manual. According to AASHTO (2010)the Safety Performance Function for predicted average crash frequency for rural two-lane two-way roadway segments is shown in the equation below.

$$Nspf\ rs = AADT * L * 365 * 10^{-6} * e^{-0.312}$$

Where:

- Nspf rs = predicted total crash frequency for roadway segment base condition;
- AADT = average annual daily traffic volume (vehicles per day); and
- L = length of roadway segment (miles)

The base conditions for roadway segments on rural two-lane, two-way roads are:

- Lane width = 12 feet
- Shoulder width and type = 6 feet and paved respectively
- Roadside hazard rating (RHR) = 3
- Driveway density = 5 driveways per mile
- Horizontal curvature, vertical curvature, centerline rumble strips, passing lanes, two-way left-turn lanes, lighting, and automated speed enforcement = None
- Grade level = 0%

Therefore, Crash Modification Factor should be applied in the estimation to account for the effects of site-specific geometric design and traffic control features.

The summary of the Crash Modification Factors required for the rural two-lane, two-way road is presented in the table below.

TABLE 5: Crash Modification Factors (AASHTO 2010).

Facility type	Crash Modification Factor (CMF)	CMF description
Rural Two-lane Two-way roadway segments	CMF1r	Lane width
	CMF2r	Shoulder width and type
	CMF3r	Horizontal curves
	CMF4r	Horizontal curves: Superelevation
	CMF5r	Grades
	CMF6r	Driveway density
	CMF7r	Centerline rumble strips
	CMF8r	Passing lanes
	CMF9r	Two-way left-turn lanes
	CMF10r	Roadside design
	CMF11r	Lighting
	CMF12r	Automated speed enforcement

In addition to Crash Modification Factor, there is another factor called the Calibration factor that is used to adjust the predictive models which were developed with data from one jurisdiction for application in another jurisdiction. Calibration provides a method to account for differences between jurisdiction in factors such as climate, driver populations, crash reporting thresholds, and crash reporting system procedures (AASHTO 2010). According to this report, the calibration procedure involves five steps:

- Step 1- Identify facility type for which the applicable predictive model is to be calibrated.
- Step 2- Select sites for calibration of the predictive model for each facility type.
- Step 3- Obtain data for each facility type applicable to a specific calibration period.

- Step 4- Apply the applicable predictive model to predict total crash frequency for each site during the calibration period as a whole.
- Step 5- Compute calibration factor for use in predictive model.

Having all the necessary data, the predicted crash frequency of the selected rural road is presented in the table below. The detail table regarding the predicted crash frequency of the study area is presented in the appendix below.

TABLE 6: Predicted crash frequency of the study area

Road Section	**Predicted crash frequency per year**			
	Fatal	**Major injury**	**Minor injury**	**PDO**
1	0.056	0.231	0.620	2.903
2	0.052	0.216	0.580	2.715
3	0.045	0.196	0.527	2.469
4	0.049	0.202	0.541	2.534
5	0.054	0.225	0.605	2.831
6	0.053	0.221	0.593	2.775
7	0.053	0.219	0.589	2.758
8	0.026	0.110	0.294	1.377
9	0.027	0.110	0.296	1.388
10	0.032	0.131	0.352	1.648
11	0.031	0.127	0.341	1.599
12	0.034	0.141	0.379	1.776

3.4 Expected crash frequency for the study area

As mentioned above, the Empirical Bayes method will be used to estimate the expected crash frequency of all sites within the rural two-lane two-way road. The Empirical Bayes method for estimating the expected crash frequency considering both the predictive model estimate and observed crash frequencies for an individual roadway segment or an intersection is computed as follows (AASHTO 2010):

$$Nexpected = w * Npredicted + (1 - w) * Nobserved$$

$$w = \frac{1}{1 + k * (\sum_{all\ study\ years} Npredicted)}$$

Where:

- Nexpected = estimate of expected average crash frequency for the study period;
- Npredicted = predictive model estimate of average crash frequency predicted for the study period under the given conditions;
- Nobserved = observed crash frequency at the site over the study period
- w = weighted adjustment to be placed on the predictive model estimate
- k = over dispersion parameter of the associated SPF used to estimate Npredicted

The expected crash frequency for the study area is summarized as shown in the figure below.

TABLE 7: Expected crash frequency for the study area

Road Section	Observed crash frequency per year				Predicted crash frequency per year				w	Expected crash frequency per year			
	Fatal	Major injury	Minor injury	PDO	Fatal	Major injury	Minor injury	PDO		Fatal	Major injury	Minor injury	PDO
1	1	0.8	0.4	0.6	0.056	0.231	0.62	2.903	0.321	0.7	0.62	0.47	1.33
2	3.4	3.6	1.6	1.8	0.052	0.216	0.58	2.715	0.337	2.27	2.45	1.25	2.1
3	2.2	2.4	1	1	0.045	0.196	0.527	2.469	0.355	1.43	1.62	0.83	1.52
4	4	4	1.6	1.8	0.049	0.202	0.541	2.534	0.347	2.63	2.68	1.22	2.05
5	2	1.8	0.6	1.4	0.054	0.225	0.605	2.831	0.331	1.5	1.27	0.6	1.86
6	4	4.4	1.4	2.2	0.053	0.221	0.593	2.775	0.335	2.67	3	1.13	2.4
7	1.8	3.2	1	1.6	0.053	0.219	0.589	2.758	0.338	1.2	2.2	0.86	2
8	1	1.2	1	1.2	0.026	0.11	0.294	1.377	0.362	0.65	0.8	0.73	1.26
9	3.6	3.2	1.2	1.6	0.027	0.11	0.296	1.388	0.361	2.3	2.08	1.12	1.52
10	5.8	4.8	1.6	3	0.032	0.131	0.352	1.648	0.359	3.72	3.11	1.14	2.5
11	5.6	3.8	0.4	1.8	0.031	0.127	0.341	1.599	0.357	3.61	2.48	0.35	1.72
12	3.6	3.4	1	1.4	0.034	0.141	0.379	1.776	0.349	2.35	2.25	0.78	1.53

3.5 Identification of black spot locations on the rural two-lane two-way road.

It is impracticable for developing countries to treat all identified black spots due to economic/financial difficulties. Therefore, it is essential to establish an approach that can be used for both identification and prioritization of black spot. Consequently, the approach to identify road traffic crash black spots based on potential savings in crash costs can meet this requirement (Nguyen et al. 2016). In addition to this, many scholars recommend that the concept of crash severity should be included in any road traffic crash analysis using point weightage approach where it offers the opportunity to include all crashes in the identification process. Consequently, this study used the weighting factors developed by Ethiopian scholar Deme, Debela. According to (Deme 2019), the weighting factors for the corresponding crash severities for Ethiopia are calculated based on the estimation of the road traffic crash costs. Accordingly, the weighting factors for the corresponding fatality, major injury, minor injury, and property damage only are 4, 3.4, 1.4, and 1.

Based on the weighting factors estimated above, the severity index of each road section along the study area is summarized as shown below.

TABLE 8: Severity index of the road sections along the study area

Road section	**Expected crash frequency per year**				**Severity Index**	**Rank**
	Fatal	**Major injury**	**Minor injury**	**PDO**		
1	0.70	0.62	0.47	1.33	6.88	**12**
2	2.27	2.45	1.25	2.10	21.25	**5**
3	1.43	1.62	0.83	1.52	13.90	**9**
4	2.63	2.68	1.22	2.05	23.38	**4**
5	1.50	1.27	0.60	1.86	13.01	**10**
6	2.67	3.00	1.13	2.40	24.86	**3**
7	1.20	2.20	0.86	2.00	15.48	**8**
8	0.65	0.80	0.73	1.26	7.60	**11**
9	2.30	2.08	1.12	1.52	19.35	**7**
10	3.72	3.11	1.14	2.50	29.55	**1**
11	3.61	2.48	0.35	1.72	25.09	**2**
12	2.35	2.25	0.78	1.53	19.66	**6**

According to (Karolien Geurts et al. 2004), a sensitivity analysis is performed to investigate the impact on the identification and ranking of black spot locations of three different weighting value combinations representing a different attitude towards the traffic safety problems: avoiding all crashes, avoiding all deadly crashes, and avoiding all crashes with serious or deadly injuries. This study also performed a sensitivity analysis of the weighting factors on the ranking of black spot locations by applying three different weighting factor value combinations i.e. avoiding all crashes (1_1_1_1), avoiding all deadly crashes (10_1_1_1), and avoiding all property damage only crashes (1_1_1_10). The sensitivity analysis of the weighting factor combinations on the ranking of black spot locations is presented in the table below.

Table 9: Sensitivity analysis

Expected crash frequency per year				Severity Index							
Fatal	Major injury	Minor injury	PDO	4_3.4_1.4_1	Rank	1_1_1_1	Rank	10_1_1_1	Rank	1_1_1_10	Rank
0.7	0.62	0.47	1.33	6.88	12	3.12	12	9.42	11	15.09	11
2.27	2.45	1.25	2.1	21.25	5	8.07	5	28.5	5	26.97	4
1.43	1.62	0.83	1.52	13.9	9	5.4	9	18.27	9	19.08	10
2.63	2.68	1.22	2.05	23.38	4	8.58	3	32.25	4	27.03	3
1.5	1.27	0.6	1.86	13.01	10	5.23	10	18.73	8	21.97	7
2.67	3	1.13	2.4	24.86	3	9.2	2	33.23	3	30.8	2
1.2	2.2	0.86	2	15.48	8	6.26	8	17.06	10	24.26	5
0.65	0.8	0.73	1.26	7.6	11	3.44	11	9.29	12	14.78	12
2.3	2.08	1.12	1.52	19.35	7	7.02	6	27.72	7	20.7	8
3.72	3.11	1.14	2.5	29.55	1	10.47	1	43.91	1	32.97	1
3.61	2.48	0.35	1.72	25.09	2	8.16	4	40.65	2	23.64	6
2.35	2.25	0.78	1.53	19.66	6	6.91	7	28.06	6	20.68	9

3.6 Field observation on the identified black spot locations

The safe and efficient movement of traffic is greatly influenced by the geometric features of the road. Road traffic crash black spot maps normally show that crashes tend to cluster on curves, particularly on very sharp curves. Furthermore, it can be shown that two-lane rural roads pose the highest crash risks and severities. Therefore, this portion of the road network should be given special emphasis, and it appeared necessary to develop a practical procedure that considers driving behavior and safety rules for the evaluation of new designs; redesigns; and rehabilitation, restoration, and resurfacing (RRR) projects (Lamm, et al. 2002). This study also added the three basic quantitative safety criteria. These criteria aim to provide rural two-lane highway with design consistency, operating speed consistency, and driving dynamic consistency.

According to (Lamm, et al. 2002), the impact of the design parameters curvature change rate of the single curve, length of curve, superelevation rate, lane width, shoulder width, sight distance, grades, and traffic volume between 1,000 and 12,000 vehicle per day on two-lane rural highway sections was investigated in the United States, Germany, Greece, and Italy. This investigation showed, that the most successful parameter in explaining much of the variability in operating speeds and accident rates was the new design parameter curvature change rate of the single curve. All the other design parameters revealed insignificance in the regression models at the 95%-level of confidence.

3.6.1 Locations and features of the black spot locations

a) Section 10 (*Simret District)*

Simret district is one of the road sections along the study area that is located 50 km away from the starting point of the study area. Out of this road section extending in this district, there are some specific locations in which road traffic crashes are happening frequently. These road sections are Miheno, Maygua, and Agerbea which are located along this district. The feature of this road section is sharp curved (both horizontally and vertically) with short sight distance and covered with vegetation and mountainous on the roadside as shown in the figure below.

Figure 8: Road section map for Simret district (Google maps, 2020)

Field observation is conducted in this district to observe some problems associated with the road infrastructure. During the field observation, different road defects were observed. In this district, some of the road surfaces were observed with damaged pavement that forces the drivers to use the improper lane which is not allowed near sharp curves. In addition to this, there is no traffic regulation signs or signals that will help to regulate the traffic flow. During field observation, a large number of potential risk factors are observed. Some of these are:

- Fixed objects (Trees, rocks, culverts, and road equipment)
- Road alignment and layout: steep slopes (cuts/fills), steep ditches, steep gradients, sharp bends, narrow roadway, narrow and improper shoulder,
- Road signs: relatively, this road section has no road traffic signs for the regulation of the traffic flow.
- Pedestrians: no sidewalk as it is rural road.
- Others: missing road lighting, guardrails

Some features of this road section are shown in the figure below.

Figure 9: Some features of Simret district road section (Researcher)

b) Section 11 (*Menewe District)*

Menewe district is also one of the major black spot locations along the study area. This road section is highly characterized by both sharp horizontal and vertical curves with dangerous escarp road. It can be seen that some of the gradients of the road section are even beyond the allowed design standard as shown in the figure below. For example, According to the road design report of the study area, in this district 7 different sections were observed to exceed the gradient limit for DS4.

Figure 10: Road section map for Menewe district (Google maps, 2020)

During field observation, a large number of potential risk factors are observed. One of the common road infrastructure failure in this road section is improper shoulder. This road section is also located on the highland. As a result to this, this road section is subjected to weather influence such as rain, fog, and sometimes snow. Some road features and road defects of this road section is presented below.

Figure 11: Some features of Menewe district (Researcher)

Figure 12: Some features of Menewe district (Researcher)

3.6.2 Improvement measures to minimize road traffic crashes on the identified black spot locations

In each road section, there are different patterns of a road traffic crash and the illustrations cannot generalize the whole black spot sections. Different activities are applied by district road traffic officers that aim at the reduction of road traffic crashes in the identified black spot locations. Most of the measures taken are installing roadside traffic warnings which deliver information about road geometry, slope, severity of crash, speed limit, and the existence of bridges. However, all of these are not sufficient to minimize the damage of road traffic crashes. Thus, additional measures should be implemented for the further reduction of road traffic crashes. The possible improvement measures to minimize the road traffic crashes at the identified black spot locations is presented in the table below.

TABLE 10: Possible improvement measures for the identified black spot locations.

Road section	District	Possible improvement measures
10	Simret	• Installation of warning posts which shows the road section is sharp and steep curve • Removal of some road side obstructions (Upgrading safety appurtenances, removing

		trees, mowing, flattening side slopes, removing or adding fill around headwalls, and increasing clear zone • Maintenance of road markings • Installation of hazard light to prevent road traffic crashes during night • Minimizing the traffic flow on this road section by relocating the bus stations at the entrance of the zone. • Improving the road geometry of the section • Pavement surface treatments
11	Menewe	• Installation of warning posts which shows the existence of bridges. • Installation of guardrails • Increasing the sight distance of the road segments. • Employing stop/yield control • Providing proper shoulder material and width • Removal of road side obstruction • Speed breaker at the entry of bridges • Improvement of road carriageway • Signs to alert drivers of wildlife • Additional lane improvements • Pavement edge drop-off improvements • Side slope flattening
6	Al-Asa	• Recovery distance improvements • Advance warning for horizontal curves • Delineation • Shoulder maintenance • Sight obstruction reduction • Installation of speed breaker

CHAPTER 4: CONCLUSION AND RECOMMENDATION

The paper has identified the road traffic crash black spot locations on the selected rural two-lane two-way road. For the identification of black spot locations, the police reported road traffic crash data is analyzed for the whole study area. Severity Index (S.I) is used to rank the road traffic crash locations. Based on the analysis, the features of the black spot locations are distinguished and discussed. During field observation, this study also found the major contributing road factors along the identified black spot locations. These include sharp horizontal curves, high number of pedestrians directly access the road at a place where the road passes through village settlement, poor coordination of horizontal and vertical alignments, terrain type being escarpments, improper shoulder. Accordingly, simple and cost effective countermeasures such as provision of warning sign with recommended speed, road surface marking, construction of painted guardrail outside the curve, provision of rumble strips, and others are proposed for the purpose of reducing the expected crash frequency.

In general, road traffic crash countermeasure implementation is divided into two major categories; i.e. high cost crash countermeasure which is a long term countermeasure and the other one is low cost countermeasure which is a short term countermeasure (Azwan Ezzany Azmi, Sm Amirullah Zainal, 2005). But this paper mainly discusses the low cost countermeasures at the identified road traffic crash blackspots which can significantly improve road safety problems at hazardous sites. The improvement measure selection has been made by evaluating the potential for safety improvement if appropriate countermeasures are applied. To minimize the occurrence of road traffic crash at the identified black spot locations, the following improvement measures should be applied:

- The study investigated that grade length, shoulder width, and length of curve are major factors affecting road traffic crashes on the selected rural road. It is therefore recommended to install warning posts informing drivers on the presence of hazardeous sharp curve and down grade.
- The study indicated that on some road sections, the existing lane width is not wide enough for the effective traffic flow operation. It is therefore recommended to widen the narrow road segments.

- The study identified some damagedroad surfaces along the study area. It is therefore imperative to maintain the damaged road surfaces for the effective traffic flow.
- It is recommended to install some guardrails and hazard lights
- Removal of some road side obstructions (Upgrading safety appurtenances, removing trees, mowing, flattening side slopes, removing or adding fill around headwalls, and increasing clear zone

4.1 Limitations and future research suggestions

As said earlier, this study is conducted in Ethiopia. Under-reporting of road traffic crashes is very common in low- and middle-income countries. Ethiopia as one of the low-income country is facing such kind of problem. According to the study in Ethiopia (Abegaz et al. 2014), in that study period, traffic police independently reported 224 deaths and 446 injuries/billion vehicle kilometer, while hospitals reported 123 deaths and 1046 injuries/billion vehicle kilometer. Therefore, this study is expected to face some difficulties related to the under-reporting of road traffic crashes. This study is conducted during the COVID-19 crisis in 2020. This global health crisis has had an impact on the (writing) process, the research activities, and the research results that are at the basis of this study.

This study is limited to the effects of road infrastructure on the occurrence of road traffic crashes. Whereas, other road traffic crash contributing factors (human factors and vehicle factors) are not discovered. Therefore, this paper suggests further studies on human factor and vehicle factor. In addition to this, this paper recommends implementing the improvement measures proposed by the researcher on the rural road and to evaluate the effectiveness of the proposed improvement measures.

REFERENCES

AASHTO. 2010. *Highway Safety Manual*. AASHTO.

Abegaz, Teferi et al. 2014. "Road Traffic Deaths and Injuries Are Under-Reported in Ethiopia: A Capture-Recapture Method." *PLoS One* 9(7): e103001.

Ahadi, Mohammad Reza, and Hesamoddin Razi-Ardakani. 2015. "Estimating the Cost of Road Traffic Accidents in Iran Using Human Capital Method." *International Journal of Transportation Engineering* 2(3): 163–78.

Ahmed, Ishtiaque. 2013. "Road Infrastructure and Road Safety." *Transport and Communications Bulletin for Asia and the Pacific* 83: 19–25.

Bi, Hezheng, Linjun Lu, Jian Lu, and Chen Wang. 2014. "Study on Evaluation Models of Highway Safety Based on Catastrophe Theory." *Mathematical Problems in Engineering*. https://www.hindawi.com/journals/mpe/2014/403560/ (December 31, 2019).

Borsos, A., S. Cafiso, C. D'Agostino, and D. Miletics. 2016. "Comparison of Italian and Hungarian Black Spot Ranking." *Transportation Research Procedia* 14: 2148–57.

Cheng, Wen, and Simon P. Washington. 2005. "Experimental Evaluation of Hotspot Identification Methods." *Accident Analysis & Prevention* 37(5): 870–81.

Da Costa, Stephen, Xiaobo Qu, and Partha Mani Parajuli. 2015. "A Crash Severity-Based Black Spot Identification Model." *Journal of Transportation Safety & Security* 7(3): 268–77.

Deme, Debela. 2019. "Road Traffic Accident in Ethiopia from 2007/08-2017/18." *American International Journal of Sciences and Engineering Research* 2(2): 49–59.

Elvik, Rune. 2007. "State-of-the-Art Approaches to Road Accident Black Spot Management and Safety Analysis of Road Networks." : 126.

Ethiopian Roads Authority. 2016. "Road Sector Development Program 17 Years Performance Assessment." : 65.

García-Altés, A., and Katherine Pérez. 2007. "The Economic Cost of Road Traffic Crashes in an Urban Setting." *Injury prevention* 13(1): 65–68.

Geurts, K, and G Wets. "Black Spot Analysis Methods: Literature Review." : 30.

Geurts, Karolien, Geert Wets, Tom Brijs, and Koen Vanhoof. 2004a. “Identification and Ranking of Black Spots.” *Transportation Research Record* 1897.

“Identification and Ranking of Black Spots: Sensitivity Analysis.” *Transportation Research Record: Journal of the Transportation Research Board* 1897(1): 34–42.

Ghadi, Maen, and Árpád Török. 2017. “Comparison Different Black Spot Identification Methods.” *Transportation Research Procedia* 27: 1105–12.

Hauer, Ezra. 2002. “Hauer: Screening the Road Network for Sites with Promise - Google Scholar.”

Ismail, Mohamed A., and S. M. Abdelmageed. 2010. “Cost of Road Traffic Accidents in Egypt.” *World Academy of Science, Engineering and Technology* 42: 1308–14.

Jacobs, G. 1995. “Costing Road Accidents in Developing Countries.” *OVERSEAS ROAD NOTE 10*.

Jacobs, Goff, Amy Aeron-Thomas, and Angela Astrop. 2000. “Estimating Global Road Fatalities.”

Lamm, Ruediger, Basil Psarianos, and Salvatore Cafiso. 2002. “Safety Evaluation Process for Two-Lane Rural Roads: A 10-Year Review.” *Transportation Research Record: Journal of the Transportation Research Board* 1796(1): 51–59.

Luathep, Paramet, and Yordphol Tanaboriboon. 2005. “Determination of Economic Losses Due to Road Crashes in Thailand.” *Journal of the Eastern Asia Society for Transportation Studies* 6: 3413–25.

Meresa, Assefa Bekele, Jin Xu, and Shao Yiming. 2016. “Improvement of Traffic Accident Investigation Process: A Case Study in Mekelle City, Ethiopia.” *International Journal of Traffic and Transportation Engineering* 5(4): 91–95.

Montella, Alfonso. 2010. “A Comparative Analysis of Hotspot Identification Methods.” *Accident Analysis & Prevention* 42(2): 571–81.

Nguyen, Huy Huu, Pichai Taneerananon, Csaba Koren, and Paramet Luathep. 2018. “The Evolution of Criteria for Identifying Black Spots and Recommendations for Developing Countries.”

Nguyen, Huy Huu, Pichai Taneerananon, and Paramet Luathep. 2016. “Approach to Identifying Black Spots Based on Potential Saving in Accident Costs.” *Engineering Journal* 20(2): 109–22.

Peden, Margie et al. 2004. *World Report on Road Traffic Injury Prevention*. World Health Organization Geneva.

Ramesh Raju Buddharaju. 2012. "Predicting Road Accidents and Prioritizing Road Safety Improvement Measures in India Using Adapted Traffic Conflict Techniques."

Ramos, Luís, Luís Silva, Maribel Yasmina Santos, and João Moura Pires. 2015. "Detection of Road Accident Accumulation Zones with a Visual Analytics Approach." *Procedia Computer Science* 64: 969–76.

Samson, Fanueal. 2006. *Analysis of Traffic Accident*.

Sayed, Tarek, N. Saunier, Gord Lovegrove, and P. de Leur. 2010. "Advances in Proactive Road Safety Planning." In *Proceedings of the 20th Canadian Multidisciplinary Road Safety Conference*,.

Silcock, Ross. 2003. "Guidelines for Estimating the Cost of Road Crashes in Developing Countries." *London, Department for International Development Project* 7780: 2003.

Szénási, Sándor, and Domokos Jankó. 2017. "A Method to Identify Black Spot Candidates in Built-up Areas." *Journal of Transportation Safety & Security* 9(1): 20–44.

Tarimo, Hipolite Thomas. 2012. "Motor Traffic Injuries in Sub-Saharan Africa." *Dar Es Salaam Medical Students' Journal* 19(1): 13–16.

Tigray Traffic Police Commission. 2018. "Road Traffic Crash Data for Tigray Region, Ethiopia."

Transport Programs Management Office (TPMO). 2018. *Analysis of the Walking and Cycling Environment in Addis Ababa*.

Tulu, Getu Segni. 2015. "Pedestrian Crashes in Ethiopia: Identification of Contributing Factors through Modelling of Exposure and Road Environment Variables." Queensland University of Technology.

Tulu, Getu Segni, Simon Washington, and Mark J. King. 2013. "Characteristics of Police-Reported Road Traffic Crashes in Ethiopia over a Six Year Period." In *Proceedings of the 2013 Australasian Road Safety Research, Policing & Education Conference*, Australasian College of Road Safety (ACRS), 1–13.

United Nations Economic Commision for Africa. 2009. "Case Study: Road Safety in Ethiopia." http://repository.uneca.org/handle/10855/5250 (October 4, 2019).

Wedajo, Teyba, Emer T. Quezon, and Murad Mohammed. 2017. "Analysis of Road Traffic Accident Related of Geometric Design Parameters in Alamata-Mehoni-Hewane Section."

Wendimu, Tefari. 2017. "Run-off-The Road Crash Severity and Crash Severity-Based Black Spot Identification in Oromia Region, East Wallega Zone." AAU.

WHO, World Health Organization. 2018. *Global Status Report on Road Safety 2018: Summary*. World Health Organization.

Wijnen, Wim, and Henk Stipdonk. 2016. "Social Costs of Road Crashes: An International Analysis." *Accident Analysis & Prevention* 94: 97–106.

Worku, Ibrahim. 2011. "Road Sector Development and Economic Growth in Ethiopia." : 41.

Zegeer, Charles V. et al. 1987. "SAFETY EFFECTS OF CROSS-SECTION DESIGN FOR TWO-LANE ROADS - VOLUME I - FINAL REPORT."

Appendix

Appendix 1 – Observed crash data for the study area

Police reported road traffic crash data of the rural two-lane two-way road from Zeban Zelemnay to Kale Azba (2014 - 2018 G.C)

Crash number	Year of crash	Weather condition	Crash severity				Crash location (Coordinate)			Road condition
			Fatal	Major injury	Minor injury	PDO	X	Y	Z	
1	2018		3	2	0	1	510256	1499507	2020	Sharp curve
2	2014		1	0	1	1	513292	1504041	2602	Steep slope
3	2016		3	2	1	1	512856	1501885	2639	Straight road
4	2017		2	2	1	1	512419	1500489	2590	Sharp curve
5	2015		2	1	0	1	510215	1500888	2394	Sharp curve
6	2015		4	1	0	1	509876	1499092	1918	Sharp curve
7	2015		2	1	1	1	509473	1498807	1857	Sharp curve
8	2017		1	2	1	1	509876	1499092	1918	Sharp curve
9	2017		0	0	1	0	518677	1508070	2590	Straight road
10	2018		1	3	0	1	521296	1509988	2598	Slight curve
11	2018		2	2	1	1	510287	1499543	2025	Sharp curve
12	2014		2	2	0	1	518643	1508965	2643	Straight road
13	2017		3	5	1	1	513195	1504107	2602	Steep slope
14	2014		6	4	0	1	513195	1504107	2602	Steep slope
15	2018		1	4	1	1	519504	1509718	2670	Slight curve
16	2015		1	2	1	1	509876	1499092	1918	Sharp curve
17	2016		1	0	0	1	513265	1504654	2626	Straight road
18	2016		2	4	1	1	510215	1500888	2394	Slight curve
19	2016		0	1	1	0	515590	1505096	2599	Slight curve
20	2014		2	3	1	1	509980	1499271	1971	Slight curve
21	2015		1	4	2	1	512800	1500709	2630	Straight road
22	2017		2	3	1	1	513251	1504080	2605	Slight curve
23	2018		1	1	0	1	518878	1509330	2662	Straight road
24	2017		5	2	0	1	511723	1500628	2534	Sharp curve
25	2015		3	2	1	1	510215	1500888	2394	Sharp curve
26	2015		1	0	0	1	515706	1505199	2608	Straight road
27	2016		1	2	1	1	518635	1508881	2635	Slight curve
28	2016		0	0	1	0	513577	1504981	2617	Steep slope
29	2014		1	0	0	1	520358	1509963	2628	Straight road
30	2018		5	5	0	1	509177	1500069	2235	Sharp curve
31	2016		0	3	2	0	516424	1506438	2562	Steep slope
32	2014		1	2	1	1	510016	1499652	2070	Sharp curve
33	2017		1	0	0	1	512859	1501779	2636	Straight road
34	2018		0	1	0	0	518647	1508708	2632	Straight road
35	2014		1	1	1	1	513292	1504041	2602	Slight curve
36	2018		0	0	1	0	518590	1508054	2580	Straight road
37	2017		3	1	0	1	510287	1499543	2025	Sharp curve
38	2014		1	0	0	1	522412	1509964	2512	Slight curve
39	2014		1	1	0	1	520928	1510082	2609	Slight curve
40	2018		0	1	1	0	520358	1509963	2628	Straight road
41	2017		2	2	1	1	512800	1500709	2630	Sharp curve
42	2014		1	0	0	1	514637	1505482	2609	Steep slope
43	2018		2	1	0	1	518359	1507635	2561	Straight road
44	2018		0	1	0	0	522602	1509888	2460	Straight road
45	2015		0	1	0	0	516485	1506385	2564	Straight road
46	2016		0	0	1	0	518896	1507992	2609	Slight curve
47	2018		3	2	1	1	510348	1500656	2331	Sharp curve
48	2017		4	3	1	1	510824	1500865	2438	Sharp curve
49	2017		2	1	1	1	510382	1500719	2371	Sharp curve
50	2018		3	1	0	1	509057	1499864	2212	Slight curve
51	2016		6	4	1	1	509876	1499092	1918	Sharp curve
52	2017		0	1	1	0	522412	1509964	2512	Slight curve
53	2018		1	2	1	1	513251	1504080	2605	Steep slope
54	2018		4	5	0	1	509473	1498807	1857	Sharp curve
55	2018		2	1	1	1	510554	1500619	2357	Slight curve
56	2017		3	4	0	1	509876	1499092	1918	Sharp curve
57	2016		1	0	0	1	517405	1507094	2545	Straight road
58	2016		3	1	0	1	509057	1499864	2212	Slight curve
59	2017		1	1	1	1	516224	1505560	2622	Slight curve
60	2018		3	4	0	1	522412	1509964	2512	Slight curve
61	2018		2	1	0	1	512671	1500369	2606	Slight curve
62	2015		2	2	1	1	510215	1500888	2394	Sharp curve
63	2015		1	3	1	1	511239	1500753	2492	Steep slope
64	2017		1	0	0	1	515151	1505167	2588	Steep slope
65	2014		2	1	0	1	510368	1500947	2414	Slight curve

66	2018		3	0	0	1	509057	1499864	2212	Straight road
67	2015		3	1	0	1	513180	1504123	2603	Steep slope
68	2016		1	0	0	1	511239	1500753	2492	Steep slope
69	2018		3	2	0	1	509980	1499271	1971	Sharp curve
70	2016		1	1	0	1	522412	1509964	2512	Slight curve
71	2014		1	1	0	1	510554	1500619	2357	Slight curve
72	2018		2	2	1	1	510256	1499507	2020	Sharp curve
73	2015		1	1	0	1	510739	1500936	2439	Straight road
74	2014		4	3	2	1	537518	1505625	1887	Sharp curve
75	2014		2	3	1	1	531377	1510666	2173	Slight curve
76	2018		0	2	1	0	537523	1505619	1887	Straight road
77	2014		3	2	0	1	534594	1508376	1959	Sharp curve
78	2014		2	1	1	1	539631	1503697	1820	Steep slope
79	2016		1	1	0	1	528835	1512309	2420	Steep slope
80	2018		0	1	1	0	532107	1509927	2093	Straight road
81	2017		0	0	1	0	525372	1510913	2440	Steep slope
82	2015		4	2	1	1	535265	1508289	1946	Sharp curve
83	2014		2	1	0	1	531311	1510733	2180	Slight curve
84	2018		0	2	1	0	532810	1508822	2019	Steep slope
85	2017		1	2	0	1	528835	1512309	2420	Steep slope
86	2016		1	1	1	1	523926	1509772	2448	Slight curve
87	2018		2	2	1	1	532018	1510134	2112	Sharp curve
88	2017		4	3	0	1	537337	1505916	1883	Sharp curve
89	2016		2	3	1	1	531377	1510666	2173	Slight curve
90	2018		5	4	0	1	532044	1510091	2108	Sharp curve
91	2017		0	2	1	1	531672	1510446	2149	Straight road
92	2016		0	1	1	0	540099	1503564	1798	Straight road
93	2017		2	2	0	1	523496	1509744	2432	Steep slope
94	2018		3	2	1	1	532876	1508722	2019	Slight curve
95	2016		1	2	1	1	531907	1510251	2128	Straight road
96	2016		3	2	1	1	523690	1509754	2433	Sharp curve
97	2018		2	1	0	1	529247	1511718	2344	Slight curve
98	2017		4	1	0	1	531672	1510446	2149	Sharp curve
99	2015		0	1	1	1	523496	1509744	2432	Steep slope
100	2014		0	0	1	0	531984	1510167	2121	Straight road
101	2018		1	0	1	1	532058	1510083	2109	Steep slope
102	2014		1	0	2	1	537473	1505721	1885	Slight curve
103	2017		0	1	3	0	531907	1510251	2128	Straight road
104	2015		4	1	0	1	532116	1509924	2094	Sharp curve
105	2018		2	3	0	1	523596	1509752	2435	Slight curve
106	2014		1	1	0	1	523496	1509744	2432	Steep slope
107	2015		3	2	1	1	531902	1510258	2127	Slight curve
108	2018		0	0	1	1	540148	1503547	1800	Steep slope
109	2018		1	1	0	1	540073	1503573	1799	Straight road
110	2014		1	1	0	1	540148	1503547	1800	Steep slope
111	2017		1	1	1	1	523687	1509757	2435	Slight curve
112	2018		2	1	0	1	524690	1509818	2453	Sharp curve
113	2016		1	2	1	1	532185	1509830	2085	Sharp curve
114	2017		3	1	0	1	527848	1511564	2459	Sharp curve
115	2017		5	2	0	1	523229	1509727	2432	Slight curve
116	2018		0	0	1	0	528968	1511746	2394	Straight road
117	2015		1	0	0	1	525861	1510993	2423	Straight road
118	2016		2	1	0	1	540390	1503682	1814	Slight curve
119	2017		1	1	0	1	537517	1505622	1887	Steep slope
120	2018		0	2	1	0	529242	1511904	2335	Straight road
121	2014		1	2	1	1	536943	1506280	1900	Sharp curve
122	2014		2	1	1	1	529255	1511900	2332	Sharp curve
123	2017		3	2	1	1	537441	1505794	1884	Sharp curve
124	2018		0	1	0	0	534061	1508399	1956	Straight road
125	2017		2	2	1	1	537929	1505048	1875	Steep slope
126	2014		0	1	0	1	533926	1508644	1977	Straight road
127	2016		2	1	0	1	537517	1505627	1887	Steep slope
128	2015		0	1	1	1	525861	1510993	2423	Straight road
129	2016		4	2	0	1	524690	1509818	2453	Sharp curve
130	2018		2	1	0	1	529206	1511888	2334	Slight curve

Appendix 2 – Predicted crash data for the study area

Section	Nspf rs	Crash Modification Factors		Cr	Npredicted rs			
			CMF values		Fatal	Major injury	Minor injury	PDO
1	2.26	CMF1r = 1.026	1.026	1.45	0.056	0.231	0.620	2.903
		CMF2r = 1.08	1.08					
		CMF3r = 1.015	1.015					
		CMF4r = 1	1					
		CMF5r = 1.16	1.16					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
2	2.26	CMF1r = 1.026	1.026	1.45	0.052	0.216	0.580	2.715
		CMF2r = 1.08	1.08					
		CMF3r = 1.00097	1.00097					
		CMF4r = 1	1					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
3	2.26	CMF1r = 1.026	1.026	1.45	0.047	0.196	0.527	2.469
		CMF2r = 1.08	1.08					
		CMF3r = 1.0012	1.0012					
		CMF4r = 1	1					
		CMF5r = 1	1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
4	2.26	CMF1r = 1.026	1.026	1.45	0.049	0.202	0.541	2.534
		CMF2r = 1.08	1.008					
		CMF3r = 1.0011	1.0011					
		CMF4r = 1	1					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
5	2.26	CMF1r = 1.026	1.026	1.45	0.054	0.225	0.605	2.831
		CMF2r = 1.08	1.08					
		CMF3r = 1.0018	1.0018					
		CMF4r = 1.042	1.042					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
6	2.26	CMF1r = 1.026	1.026	1.45	0.053	0.221	0.593	2.775
		CMF2r = 1.08	1.08					
		CMF3r = 1.002	1.002					
		CMF4r = 1.021	1.021					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
7	2.26	CMF1r = 1.026	1.026	1.45	0.053	0.219	0.589	2.758
		CMF2r = 1.08	1.08					
		CMF3r 1.017	1.017					
		CMF4r = 1	1					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					

8	1.35	CMF1r = 1.02	1.02	1.45	0.026	0.110	0.294	1.377
		CMF2r = 0.9	0.9					
		CMF3r = 1.026	1.026					
		CMF4r = 1	1					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
9	1.35	CMF1r = 1.02	1.02	1.45	0.027	0.110	0.296	1.388
		CMF2r = 0.9	0.9					
		CMF3r = 1.034	1.034					
		CMF4r = 1	1					
		CMF5r = 1.1	1.1					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
10	1.35	CMF1r = 1.02	1.02	1.45	0.032	0.131	0.352	1.648
		CMF2r = 0.9	0.9					
		CMF3r = 1.108	1.108					
		CMF4r = 1.051	1.051					
		CMF5r = 1.16	1.16					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
11	1.35	CMF1r = 1.02	1.02	1.45	0.031	0.127	0.341	1.599
		CMF2r = 0.9	0.9					
		CMF3r = 1.104	1.104					
		CMF4r = 1.023	1.023					
		CMF5r = 1.16	1.16					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					
12	1.35	CMF1r = 1.02	1.02	1.45	0.034	0.141	0.379	1.776
		CMF2r = 0.94	0.94					
		CMF3r = 1.102	1.102					
		CMF4r = 1.09	1.09					
		CMF5r = 1.16	1.16					
		CMF6r = 1	1					
		CMF7r, CMF8r, CMF9r, CMF10r, CMF11r, CMF12R = 1	1					