Examining Safety Impacts of Road Cross-Sectional Elements and Land Use at Midblock Location in Addis Ababa

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ABSTRACT

Road safety issues are major causes for economic, social, and health problems, especially in the developing countries. Consequently, the city of Addis Ababa has taken big share of the road traffic crashes in the country of Ethiopia. Road traffic crash is the result of complex interactions between the roadway, road users, and vehicles. Therefore, the study was focused to examine the influence of road cross sectional elements on road traffic crashes occurrence in Addis Ababa. The count model was used to investigate the relationship between road traffic crashes and road's contextual factors. Twenty midblock locations were taken as samples based on a convenience sampling approach. Addis Ababa police reported crash and traffic data were collected from selected road segments. A total of 2596 crashes were collected to develop the Poisson and Negative Binomial regression crash models.

The results of this study revealed that there were strong association between road cross-sectional design parameters and road traffic crashes frequency. The modeling result indicated thatlog of average daily traffic, Pedestrian volume as dummy variable, length of midblock location, median width, median types, commercial and office area, number of lanes and sidewalks width were found to be positively associated with crash occurrence

in Poison regression model. The results of this research support transport planners, road designers, and road safety experts for consideration of road safety issues and factors to promote safe and sustainable road design standards.

Key Words: Road safety, Crash occurrence, Poisson regression Model, Negative Binomial regression Model, Addis Ababa.

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1. INTRODUCTION

Addis Ababa is the capital city of Ethiopia with a population of four millions, and is considered to be of diplomatic and political significance for the African continent (Alemu 2017). Road safety issues are major causes of economic, social and health problems, especially in the developing countries. According to the WHO report, an estimated 1.3 million people are killed in road crashes and up to 50 million injured worldwide every year, on average more than 2 people die per minute (WHO 2015).

Recent urbanization in Addis Ababa has brought about new urban challenges such as road traffic crashes. road crashes have increased at an alarming rate throughout the country, as well as in Addis Ababa (Tulu et al. 2013a; Tulu et al. 2017).

Even though The WHO and the Traffic Police Department of Addis Ababa have been working together since 2002 to reduce road traffic crashes, reports indicated that the trend of crashes is not declining but rather continues to rise at an alarming rate.Any given road traffic crash is the result of a complex interaction between the roadway, road users and vehicle. In study by Brodie et al, the causative factors for road injuries and fatalities were categorized under road factors, driver factors, vehicle factors and occupational factors (Brodie et al. 2009). The contribution of any given factor to the cause of the road traffic crashes could vary with the conditions. In developed countries, there are continuous efforts to meet the safe systems in road environments through safety audits during the planning, designing, execution, and operating stage. Africa's road network is expanding rapidly, maintenance standards have started improving lately, and there can be seen a potential for improving the safety standards of the roads going forward (Terje 1998).

Various road safety strategies and countermeasures have been used at different stages of network development. This efforts to prevent road crashes, mainly involves conscious planning, design, and operations of roads. However, the police have limited road and traffic engineering and management skills in developing countries and thus they underestimate the contribution of road design to traffic crashes (Bezabih 2004).

However, there is strong consensus in the highway engineering experts, that the design of cross sectional elements influence the safety of road way. The cross section of the road way is important to roadway safety. The characteristics of the cross section are often the determining factors in whether the driver and vehicles will crash or safely recover an errant maneuver. The portion of urban road cross-section, which is generally used just for pedestrian, Cyclist, transit and vehicular movement may serve multiple purposes, including future expansion and room for recovery from single vehicle crashes (NACTO 2017). Most Common elements of urban roadway cross section are the width of lane, number of lanes shoulder width, pedestrian crossings, crossing frequency, furniture zone, pedestrian sidewalk, median width, median type, median height, transit lane and bicycle lane (NACTO 2017; Rista et al. 2017).

Research done in USA (Milton and Mannering 1998), revealed the relationship between road geometry, traffic related elements and motor vehicles crashes. It was shown to include road cross sectional element variables such as number of lanes, roadway width, length of section, shoulder width by using negative binomial and Poisson regression model. The study indicated that an increase in length of the road segments increases the probability of crash for all functional classes of roads. Numbers of lanes in sectional design were also shown to have a significant with positive coefficient. As the number of lanes increase the amount of traffic with the section is likely increase and thereby increasing the possibility of driver error. Similarly, wider lane tends to increase number of crashes (Tulu 2007).

A PhD dissertation (Timur 2010) analyzed and evaluated safety impacts of median types and midblock left turn treatments for urban arterials. The result indicated that the segments with raised median have lower rear-end and sideswipe crash rates, 18.7% and 21.7%, respectively. The

reductions in dangerous crashes such as angular and head-on are larger compared to rear-end and sideswipe. The segments with raised median have lower rates by 37.2% and 39.6%, respectively, compared to segments with two-way left-turn lane (TWLTL).

A study investigated the safety effects of sidewalks constructed and found that sites with no sidewalks or pathways were the most hazardous for pedestrians. Factors such as width of sidewalk, clear path, and obstructions also play a role. This reveals that crashes at sites without sidewalks are more than twice as likely to occur as otherwise. Thus, sites with no sidewalks were found that it has an association with crashes with pedestrians, and sites where sidewalks were present on both sides of the road were least hazardous(Abdel-Aty et al. 2011) .

This study aims to explore the association of road traffic crashes with midblock cross sectional elements of the road. To achieve this aim a count-based econometrics model was applied to assess the association of urban road cross-sectional elements with road traffic crash counts and assessed how well the model fits a set observations (statistical goodness-of-fit, and consistency with the underlying theory of crash process and empirical credibility.

The significance of this study is to determine the relationship between road cross-sectional elements and road traffic crash occurrence which is vital to transport planners and urban road engineers, to understand the contribution of road cross sectional elements on the occurrence of road traffic crashes and develop remedial measures at various level of road project cycle. The following section presents methodology used in this study, and is followed by description of the data used as potential explanatory variables in the modeling process. The subsequent sections outline data analysis, and model estimation. Conclusions are presented in the final section.

2. METHODS

Modeling of crash count data is very important in road safety analysis, and in the past, researchers have proposed an analytical method for analyzing crash data. Previous researches attempted to estimate crash frequency classifications into two types. One type included conventional univariate regression models, such as the Poisson Regression model, Poisson Gamma (Negative Binomial) model, Poisson lognormal model, zero-inflated model, and Conway Maxwell Poisson model. The second type includes more specification based models such as generalized additive models, random parameters models, finite mixture, Markov switching models, and hierarchical models (Lord and Mannering 2010).

A Poisson regression model is sometimes known as a log-linear model, especially when used to model contingency tables. Poisson regression models are generalized linear models with the logarithm as the link function, and the Poisson distribution function as the assumed probability distribution of the response. Negative binomial regression is a popular generalization of Poisson regression because it loosens the highly restrictive assumption that the variance is equal to the mean made by the Poisson model (Washington et al. 2011).

The Poisson regression models have been used to describe the count data. It is a statistical modeling technique which is used to model the relationships between road geometry, site characteristics, and traffic variables, and the expected number of resulting crashes on roadway segments or intersections. Crash data is nonlinear, random, and non-negative (count) data, which approximately follows the Poisson distribution. Based on the test for the dispersion parameter and the goodness-of-fit measure for the accident data, the GPR model performs as good as or better than the other regression models (Famoye et al. 2004). Another study also confirmed the appropriateness of the generalized linear model (GLM) to establish the relationship among traffic flow, road geometry property and crashes (Maher and Summersgill 1996).

In the Poisson regression, the probability of mid-

block k having crashes per year is shown as follow (Washington et al. 2011).

Where:

$$P(\gamma_k) = exp(-\phi_k)\phi_k^{\gamma_k} / \gamma_k! \quad (1)$$

ϕ_k :is the assigned Poisson parameter for midblock k, which is intersection k's expected crash frequencies,

Generally, the expected value of γ_k as a function of independent variables using a log-linear function is given by the following equation.

$$E(\gamma_k) = \sum_0^\infty \gamma_k P(\gamma_k) = \sum_0^\infty \gamma_k exp(-\phi_k)\phi_k^{\gamma_k} / \gamma_k! = \phi_k \quad (2)$$

The Poisson distribution constraints the variance and mean to be equal, that is

$$Var(\gamma_k) = E(\gamma_k) = \phi_k$$

The Negative Binomial regression model considers over dispersion parameter ofε_k. The probability density function for the Negative Binomial

$$p(Y_i = y_i) = \frac{\Gamma\left(y_i + \frac{1}{\rho}\right)}{\Gamma(y_i+1)\Gamma\left(\frac{1}{\rho}\right)}\left(\frac{\rho u_i}{1+\rho u_i}\right)^{y_i}\left(\frac{1}{1+\rho u_i}\right)^{1/\rho} \quad (3)$$

$$\phi_k = Exp(aX_k + \varepsilon_k) \quad (4)$$

$\varepsilon_k$is associated with a specific entity (midblock road segment) as opposed to a specific observation

Variables whose coefficients were insignificant were systematically removed from the model through stepwise procedure. Statistical significance was evaluated at a p-value of 10%. After systematically removing all insignificant variables, interpretation for each variable was made.

3. DESCRIPTION OF DATA

The convenience sampling technique was applied in the selection of the samples of roadway segments. Convenience sampling is a specific type of non-probability sampling method that relies on data collection from members of public who are conveniently available to participate in study. This sampling method involves getting participants wherever you can find them and typically whereever is convenient. Even though the non-probabilistic method of sampling was employed, the minimum size of the sample was calculated. The minimum sample size was calculated by assuming the estimate variance and acceptable margin of error for population were 0.1 and 5% respectively.

Accordingly, minimum sample sizes are 16 midblock road segments; however, 20 representative samples of midblock segments were selected from Arada and Kirkos sub cities of Addis Ababa city. From a total of 20 segments, 14 segments have a raised median and 6 segments have a painted median.

To establish the relationship between road cross-sectional elements and occurrences of road traffic crashes, data were collected on 20 midblock locations in Arada and Kirkos sub cities of Addis Ababa city. Detailed records of fatal crashes have been collected from the Addis Ababa Police Commissioner's office. Similarly, records of injury crashes and property damage only have been gathered from Kirkos and Arada sub cities Police stations. After excluding records with missing variables, a total of 2596 was included in the study of which, 45 were fatal, 261 were injuries and 2,290 were property damage, onlyin three years from July 2012 to June 2015 (Addis Ababa Police Commission 2015).

The explanatory variables included in the model were roadway characteristics and exposure variables. The average daily traffic has been captured. The road characteristics include median width, median height, number of lane, road segment length, type of median and sidewalk width were included in the explanatory variables.In addition to this, land use, median type, shoulder surface, pavement type and land use were considered in the modelling process. Table1 presents the descriptive statistics of the explanatory variables that have been identified.

4. RESULTS AND DISCUSSIONS

Among various explanatory variables that have been identified, some were associated to the road traffic crashes. For instance, Table 2 indicates

that the models were developed based on Poisson regression and negative binomial regression models. Again, the construction of the models in both cases reveal that Poison regression model were found more attractive than Negative Binomial regression due to the stability of estimates. The Pseudo R-squared was better in the case of Poisson regression model. In addition, the Akaike information criterion with divided number of observation shows the relative quality of statistical models. As a result, the two models were almost the same quality.

The log of average daily traffic, pedestrian volume (a dummy variable), length of midblock location, median width, median types, commercial and office area and numbers of lanes and sidewalks width were statistically significant in the poison regression model. As reported previously, these variables had significant effects on the occurrence of road traffic crashes. The results indicate that the model parameters have plausible signs and magnitudes. Below table depicts the discussion on each estimate.

The logarithm of the average daily traffic is positively associated with road traffic crash frequency. Exposure to crash risk was directly related to the average daily traffic and hence road traffic crash frequency was likely to increase with average daily traffic. This was consistent with the assumption since more interactions between vehicles together with many potential conflicts in mid block locations can cause more crashes. High traffic volumes on major roads may increase the probability of crash occurrence (Zhenyu et al. 2011). A study (Milton and Mannering 1998), found that an increase of average annual daily traffic led to an increase in crash occurrence. The study conducted in Ethiopia shows that the log of the product of daily pedestrian crossing volume and AADT was statistically significant and positively associated with expected pedestrian injury crashes (Tulu et al. 2015). Another study done in Europe (Elvik 2009), suggested that there was a positive correlation between frequency of pedestrian crashes and exposure variables even though their relationships are nonlinear.

The study classified the pedestrian volumes as high, medium and low based on the close observation on each midblock location. Accordingly, high pedestrian volume road segments were highly associated with high crash frequency with p-value of less than 1%. Many studies have already verified the association of the increase of pedestrian volume with crashes (Lee and Abdel-Aty 2005; Elvik 2009; Miranda-Moreno et al. 2011; Galanis et al 2017). This implies that the risk of pedestrian crashes is high when the pedestrian volume increases. In addition, high pedestrian volume in Addis Ababa is found in the Central Business District area, which attracts more pedestrians and motorists. The land use in the city were not well planned and organized and consequently you may find pubs and restaurants in Central Business District of the city (Tulu et al. 2017). As a result, driving under influence of alcohol and careless speeding could be the root cause of crashes with pedestrians. Again, this is in line with the study done by the city (Tulu et al. 2017).

The length of midblock locations was found significant parameter, which has been positively associated with crash frequency. This study found an increase in length of the road segments increases crash occurrence. Thus, the greater length of road increases the likelihood of crash occurrences in the city. The second reason is, as the length of the road increases, number of driveways increases, which tends to increase crash occurrence. Generally, longer length of roads have more opportunities for interaction among road environment, vehicles and pedestrians that lead to complex and challenging for a driver to face crashes. This find is in line with the study done on a four-lane median-divided Italian motorway (Caliendo et al. 2007).

The results of the model show that the median width has impacts on road traffic crash frequency. The negative coefficients in the model indicate that crash frequency decreases with the increases of median width. A study done in State of Utah and Illinois (Karlaftis and Golias 2002), the effect of median width on crash rate using negative binomial regession model reveled that crash rate decreases as median width increases because of

wider median decreases head on/sideswipe opposite crashes and rollover crashes. Hauer (2000), reviewed various studies relating to median safety and he found that road traffic crashes decreases for medians wider than 30 ft (9meters).

Compared to the crashes that occurred at the road segment with raised median, crashes were positively associated with road segment with painted median and significant with p-values of less than 1%. The result implies that higher number of crashes resulted more form a mid-block segment with painted median than those with raised median. This result confirmed, the findings in Las Vegas Valley which concludes the segments with raised median have lower rear-end, sideswipe and injury crash rates by 18.7%, 21.7% and 23.7%, respectively (Timur 2010).

Commercial centers and offices are located at the Central Business District in the city. These areas were strongly associated with the occurrence of crashes with p-value of less than with 1%. It is true from the observation made during data collection as the pedestrian volumes were very significant. On the other hand, the street venders and other activities are being performed on sidewalk. As a result, pedestrians compete with the motorist to use the outer travel lane of the roadway. Crossing at the midblock section without pedestrian road markings were common, which also aggravates the exposure to crash risk. Similarly, study done in City of Charlotte, Mecklenburg County, North Carolina (Pulugurtha et al. (2013) found that the land use characteristics especially commercial, and office district were highly associated with the level of crashes. The findings of this study were in line with the previously mentioned publication.

The estimated coefficient for the number of lanes is observed to be positive. It implies that the mid-block segments with more number of lanes had an increased number of crash occurrence. This is due to vehicles on mid-block segments with more lanes operated at higher speed which lead to higher crashes. Another reason is that vehicles traveling along the midblock locations with more number of lanes have more lane changing and overtaking opportunities. The study conducted on the relationship between highway geometrics, traffic related element and motor vehicles accident by federal highway administration showed that as width of lane for the roadway increases, the driver can also be expected to drive faster, and this has a tendency to increase the probability of crashes (Milton and Mannering 1998). These factors may have contributed to having more crashes occurred on them. The finding is consistent with the study conducted (Xuecai 2010) in Las Vegas which included number of lanes as one of roadway characteristics is critical to the safety. The study concluded that the more the number of lanes, the higher traffic volume which leads to more crashes. Similarly, the study conducted in Florida also suggested that wide pavement surface and multiple lanes had significant weaving maneuvers on major approaches, leading to increase the risk of crashes frequency (Zhenyu et al. 2011).

Sidewalk width is also a significant predictor with P values of less than 1% in explaining crash occurrence with negative estimated coefficient. The finding suggested that crash occurrence decreased as the width of sidewalk increased. One of the reasons were the city uses walking as the primary means of transportation accounting for about 60% of the trips within the city (Tulu, et al. 2013b). In addition to this, pedestrian sidewalks were insufficient or absence in the most part of the city. The lack of separation between vulnerable road users and motorized traffic led to a considerably expose pedestrians to potential crash risk (Tulu et al. 2013b). Lack of sidewalks can increase the risk of crashes compared to roads that have sidewalks (Abdel-Aty et al. 2011). Therefore, as the width of sidewalk decrease the pedestrians were forced to use roadways with motorized traffic. As a result providing the wider sidewalks may reduce the conflict between pedestrians and vehicles which improves road safety.

5. SENSITIVITY ANALYSIS

The sensitivity factor α is a kind of index to estimate the contribution of the uncertainty of x_i to the uncertainty of u. Since the objective function (is given, the effects of random variables can be determined as follows (Tsubaki et al. 1992):

$$\alpha_i = \frac{\partial u}{\partial x_i}\frac{\bar{x}_i}{\bar{u}} \qquad (i = 1,2,3,\ldots,n) \qquad (5)$$

$$U_i = \alpha_i (COV)_i \qquad (i = 1,2,3,\ldots,n) \qquad (6)$$

where, α_i: sensitivity factor of random variable i

U_i: uncertainty of random variable i

u: function with statistical variations

$\bar{u}$: mean of u

x_i: random variable i

$\bar{x}_i$: mean of x_i

COV_i: Coefficient of variation of random variable i

The model u is given in Eq. (5) and the uncertainty of random variables for the total road traffic crashes is shown in Fig. 1.

$$u = \exp(\beta + \sum_{i=}^{n=} \beta_i x_i) \qquad (7)$$

Where:

u :the model (Road traffic crash)

x_i:random variables (road charateristics)

As shown in Fig. 1, the largest contributions to the road traffic crashes occurrence in Addis Ababa are the ADT and pedestrian volume. The contribution of median width and type is insignificant as compared to other variables.

6. CONCLUSIONS

This research study investigated the effect of road cross-sectional elements on road traffic crash occurrence using a data set of road traffic crashes from Addis Ababa Police Commission archive. Urban Streets are very complex and as many studies showed, the design of street variables could be cautiously selected to minimize crash frequencies. Even though this work may not include many cross sectional variables of urban street that may influence the safety performance and capacity of urban street. Lane width and segregation of non-motorized and motorized traffic might be good examples. Accordingly, the Global Street Design Manual (NACTO 2017), gives much emphasis on the people and the place, as context of street and road user behaviors vary substantially within a few meters distance.

However, Poisson regression model was used to relate traffic crash frequency to a log of average traffic volume and road cross sectional elements (e.g., log of average daily traffic, pedestrian volume as dummy variable, length of midblock location, median width, median types, commercial and office spaces, number of lanes and sidewalks width) of 20 representative mid-block locations in Addis Ababa city. Moreover, sensitivity analysis was conducted to study the contribution of random variables to the road traffic crashes occurrence in Addis Ababa.

The results of this study revealed that there is a strong association between road cross sectional element and road traffic crashes. The finding proved that increasing number of lanes, longer midblock location, painted median type, higher pedestrian volume, and higher influence on traffic. However, variables that were found to decrease crash frequency are: wider sidewalk, wider median width and lesser number of lanes, which are considered to have a weak association with the crashes. Moreover, these results provide valuable information for transport planners, road designers, and road safety expert in the future consideration of road safety issue to promote safety standard road design and targeted countermeasures to address crash frequency in country particularly in Addis Ababa.

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Table 1: Descriptive Statistics of Variables used in the model

Variables	Mini-mum	Maxi-mum	Aver-age	Std. Deviation
Total crashes (number)	34	322	129.7	67.17
Road segment length (m)	390	2,000	910.35	400.78
Median width(m)	0	4.7	1.15	1.16
Median height (m)	0	0.5	0.25	0.2
Sidewalk width(m)	2.8	10	4.03	1.55
Average daily traffic	7,615	38,61	17,89	7,887.46
Number of Lane	4	9	5.75	1.54
Median Type (Raised=1,otherwise=0)	0	1	0.7	0.47
Sidewalk condition (paved=1,otherwise=0)	0	1	0.65	0.49
Number of median opening per segment	2	6	3.8	1.24
Pedestrian volume (high)	0	1	0.45	0.5
Pedestrian volume (medium)	0	1	0.3	0.46
Pedestrian volume (low)	0	1	0.25	0.43
Land use-commercial area	0	1	0.25	0.43
Land use-office area	0	1	0.15	0.36
Land use-school/hospital area	0	1	0.05	0.22
Land use-residential area	0	1	0.55	0.5

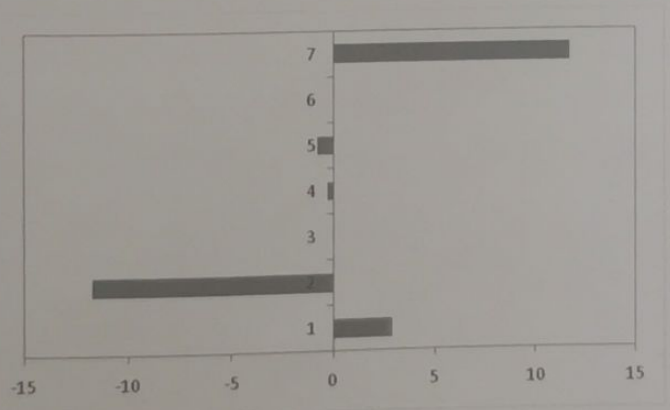


Table 2: Model estimates of total road traffic crashes

Description	Poisson Regression Model						Negative Binomial Regression Model					
	Coefficient	Standard error	z	Prob. /z/>Z	95% confidence Interval		Coefficient	Standard error	z	Prob. /z/>Z	95% confidence Interval	
Constant	0.18892	0.84854	0.22	0.8238	-1.47	-1.85	-0..56531	2.11002	-.27	0.7888	-4.7009	3.57025
LOG of ADT	0.92462***	0.21511	4.36	0.000	0.50301	1.34624	1.11507**	0.52859	2.11	0.0349	0.07906	2.15107
Pedestrian volume (high, medium and low)	0.46516***	0.04552	10.22	0.000	0.37594	0.55438	0.41101**	0.19327	2.13	0.0334	0.03222	0.78981
Road Length	0.00030***	0.7629D-04	3.87	0.0001	0.00015	0.00044						
Median width	0.07634***	0.02415	3.16	0.0016	02900	0.12368						
Median type	0.18796**	0.08253	2.28	0.0228	.02620	0.34972	0.52767***	0.15788	3.34	0.0008	0.21823	0.83711
Commercial area	0.36604***	0.06479	2.71	0.0068	0.23906	0.49302	0.34718**	0.17333	2.00	0.0452	0.00745	0.68691
Office area	0..46575***	0.09576	4.86	0.0000	0.27807	0.65343						
Number of lane	0.04664**	0.02257	2.07	0.0388	0.00239	0.09088						
Sidewalk	-0.13921***	0.02424	-5.74	0.000	-0.186	-0.0916						
Dispersion parameter for count data model							.07606	.06586	1.15	0.2481	-0.0530	0.20514
McFadden Pseudo R-squared	0.7457950						0.4203286					
Log likelihood function	-99.62789						-98.72228					
Restricted log likelihood	-391.91942						-170.30731					
AIC/N =	11.063						10.472					