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CRASH PREDICTION MODEL FOR TWO-LANE RURAL HIGHWAYS IN THE ASHANTI REGION OF GHANA

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MPhil. Roads and Transportation Engineering and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Crash Prediction Models (CPMs) have been used elsewhere as a useful tool by road Engineers and Planners. There is however no study on the prediction of road traffic crashes on rural highways in Ghana. The main objective of the study was to analyse and develop a prediction model for road traffic crashes occurring on the rural sections of the highways in the Ashanti Region of Ghana. During the period 2005-2007, the Ashanti Region alone accounted for more than one-fifth of all road traffic fatalities in Ghana and majority (67.3%) of these fatalities occurred on the rural highways. The model was developed for all injury crashes occurring on selected rural highways in the Region over the three (3) year period 2005-2007. Data was collected from 76 rural highway sections and each section varied between 0.8 km and 6.7 km. Data collected for each section comprised injury crash data, traffic flow and speed data, and roadway characteristics and road geometry data. The Generalised Linear Model (GLM) with Negative Binomial (NB) error structure was used to estimate the model parameters. Crash rates were initially related to each explanatory variable in turn to ascertain if any relationships existed. Two types of models, the 'core' model which included key exposure variables only and the 'full' model which included a wider range of variables were developed. The results show that traffic flow, highway segment length, junction density, terrain type and presence of a village settlement within road segments were found to be statistically significant explanatory variables ($p < 0.05$) for crash involvement. Adding one junction to a 1 km section of road segment was found to increase injury crashes by 32.0% and sections which had a village settlement within them were found to increase injury crashes by 60.3% compared with segments with no settlements. The model explained 61.2% of the systematic variation in the data set. Road and Traffic Engineers and Planners can apply the crash prediction model as a tool in safety improvement works and in the design of safer roads. It is recommended that to improve safety, highways should be designed to by-pass village settlements and that the number of junctions on a highway should be limited to carefully designed ones. There is the need also to develop separate crash prediction models for specific crash types and also to conduct a similar study on a countrywide scale.

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LIST OF ABBREVIATIONS AND ACRONYMS

AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
BRRI	Building and Road Research Institute
CPM	Crash Prediction Model
DVLA	Driver and Vehicle Licensing Authority
GHA	Ghana Highway Authority
GLM	Generalized Linear Model
MAAP	Micro-computer Accident Analysis Package
NB	Negative Binomial
PHC	Public Health Risk
RTC	Road Traffic Crash
TRL	Transport Research Laboratory
UK	United Kingdom
WHO	World Health Organisation

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DIFINITIONS

Fatal Crashes: A fatal crash is one in which one or more persons are killed as a result of the crash, provided death occurs within 30 days (Ross Silcock and TRL, 2003).

Serious Injury Crashes: A serious crash is one in which there are no deaths, but one or more persons are detained in hospital as 'in patient' for more than 24 hours.

Slight (minor) Injury Crashes: A slight injury crash is one in which there are no deaths or serious injuries, but one or more persons are treated and discharge or detained for not more than 24 hours.

Injury Crashes: This is the sum of all fatal, serious and slight crashes i.e. crashes involving any kind of injury.

Damage-only Crashes: Damage only crash is one in which no one is injured, but damage to vehicles and or property occurred.

CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Road Traffic Crashes (RTCs) and their associated deaths and injuries have become a major socio-economic problem for most developing countries (Jacobs *et al.*, 2000; Ghee *et al.*, 1997). In Ghana, it is estimated that, road traffic crashes cost the nation 1.6% of its Gross Domestic Product (Afukaar *et al.*, 2006). Apart from the cost element, there are also other social effects of crashes such as suffering and loss of breadwinners and quality of family life. Crashes are also generally known to have a greater adverse effect on the poor (Ross Silcock and TRL, 2003).

Research on road traffic crashes have shown that crash severity tends to be mostly higher on rural highways than on urban roads (Afukaar *et al.*, 2008; Hamilton and Kennedy, 2005; Jacobs, 1976). Major factors that affect highway safety have been established and categorised as human factors, vehicle factors and the road environmental factors. All these factors have to be addressed in order to improve highway safety. Out of these factors, the most controllable one, at least from the viewpoint of the Transportation Engineers may be highway related factors. Nonetheless, any changes made to the highway related factors could have an impact on driver or vehicle related factors as well. Thus identification of highway related factors, which contribute towards total number of highway crashes on rural highways, is very important in improving safety.

1.2 Problem Statement and Justification of the Research

In Ghana statistics available indicate that about 1,900 people are killed and another 5,800 are seriously injured in road traffic crashes annually (Afukaar *et al.*, 2008). The Ashanti, Greater-Accra and Eastern Regions accounted for over 60% of road traffic crashes in the country. Whereas the road traffic fatality trends in the Greater-Accra and Eastern Regions appear to be gradually levelling-off, that of the Ashanti Region continues to increase sharply (Afukaar and Agyemang, 2006). Again, the Ashanti Region is one of the Regions with above average Public Health Risk (PHR) of road traffic crashes with a fatality index of 8.8 fatalities/100,000 population as against a national average of 8.5 fatalities/100,000 population (Salifu *et al.*, 2006).

The statistics further indicate that crashes in the non-urban environment (mostly on rural highways) account for about 70% of all road traffic fatalities. It is also evident from the data that whilst fatalities on roads in urban settlement areas follow a gradual upward trend, that for the non-urban areas follow a steep trend as shown in *Figure 1.1*. It is therefore apparent from the above that in order to stem the increasing road traffic fatalities in the country, there is the need to deal with the issue of non-urban road traffic fatalities.

For this purpose, relevant factors that affect the frequency and severity of crashes on the rural highways need to be identified. Research that has been carried out to address road safety issues in the rural areas is less when compared to the urban areas. Consequently education, enforcement and engineering measures to improve road safety have been concentrated in the urban road environment. Given this state of affairs, the rural road

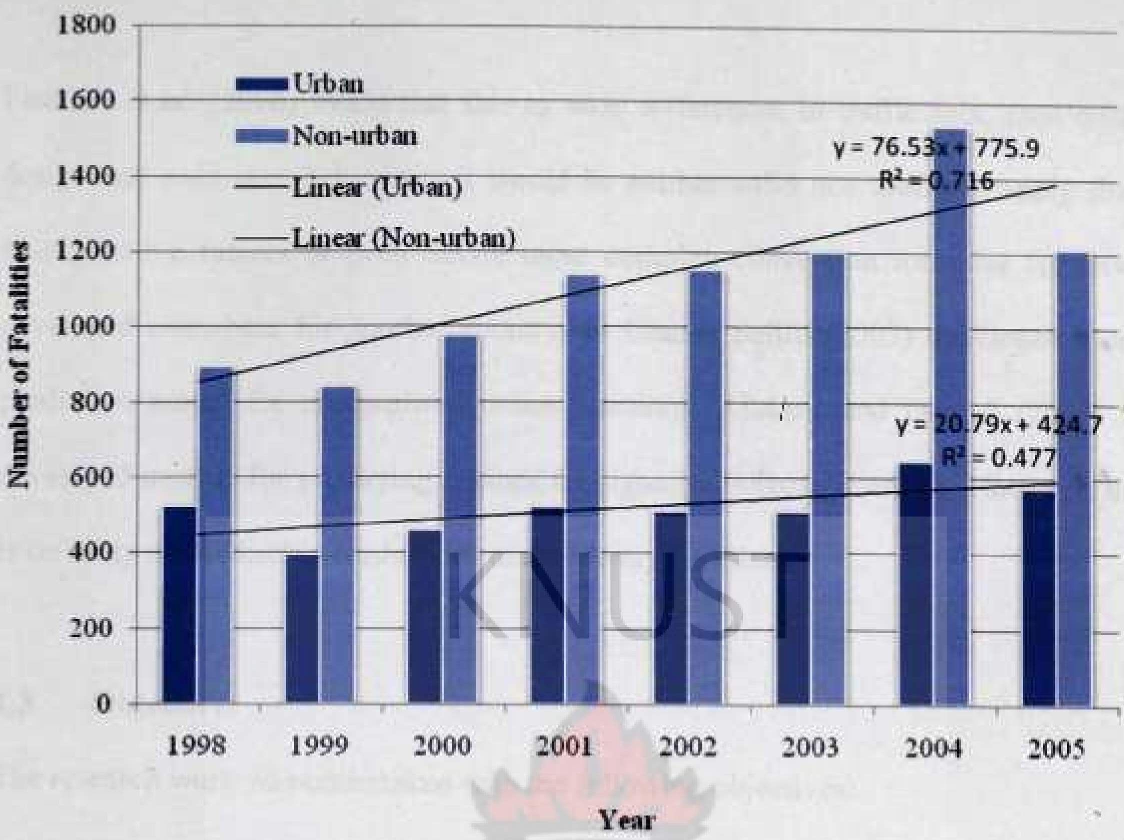

Figure 1.1: Changes in Fatalities by Road Environment
Source: Salifu et al., 2006

safety problem deserves a higher or equal priority in road safety policies as the efforts directed at reducing crashes in the urban areas.

The purpose of developing crash prediction models on highway facilities is to enable road engineers and planners to provide a realistic estimate of expected crash frequency as a function of traffic volume and roadway geometry. Development of such estimates is a critical component in the consideration of safety in highway planning and design. It helps in assessing accurate cost-benefit measures of highway safety alternatives. There has been a considerable international experience in applying multivariate models to determine the relationship between crash rates and road and traffic characteristics.

Fletcher *et al.* (2006) found that due to wide differences in traffic mix, road quality, design and road user behaviour, it would be neither valid nor useful to apply simple multiplicative factors or even devise more complex conversion formulae for models developed elsewhere for another country. In Ghana, Salifu (2003) developed a crash prediction model for unsignalised urban junctions. Afukaar and Debrah (2007) also developed models for predicting crashes for signalised urban junctions. However, there is no study on predicting crashes on rural highways in Ghana.

1.3 Objectives

The research work was undertaken with the following objectives:

- To analyse road traffic crashes occurring on the non-urban (rural) sections of the highways in the Ashanti Region of Ghana based on police crash reports.

- To develop a crash prediction model to identify contributory factors that are likely to affect injury crashes on the rural highways in the Ashanti Region of Ghana.

1.4 Scope of Study

The model was developed for all crashes resulting in death or injury over a three (3) year period 2005-2007 on selected rural highways in the Ashanti Region of Ghana. Damage only crashes were not included in the study because of the high level of under-reporting associated with this type of crashes in Ghana (Afukaar *et al.*, 2006).

In this report, a rural highway is defined as a highway passing through the non-urban environment i.e. passing through the village (population of not more than 5,000 inhabitants) and rural non-settlement areas.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Segment and Intersection Models

Substantial research has been conducted over the years on the development of Crash Prediction Models (CPMs) for highway facilities. To develop and validate a method for predicting crashes on main roads with minor junctions where traffic counts on the minor approaches are not available, Mountain and Fawaz (1996) used Generalized Linear Modelling to estimate regression coefficients and Empirical Bayes procedure was used to improve these estimates. Crashes on highway sections were shown to be a non-linear function of traffic exposure and minor junction frequency. For the purposes of estimating crashes, while the regression model estimates were shown to be preferable to crash counts, the best results were obtained using the Empirical Bayes method. The latter was the only method that produced unbiased estimates of expected accidents for high-risk sites.

Salifu (2003) developed prediction models for unsignalised urban junctions in Ghana. The results showed that the best models based exclusively on traffic exposure functions (i.e. traffic flow) explained 50 per cent more of the systematic variation in accidents at T-junctions than at X-junctions. In the extended models that included road geometric and other traffic variables it emerged that the absence of street lighting and dedicated left-turning lanes and the average standard deviation of approach spot speeds of vehicles on the major road were all positively correlated with accident frequency at both T- and X-junctions.

Afukaar and Debrah, (2007) used Negative Binomial technique to develop two models: pedestrian crash model and injury crash model for T- and X-junctions for signalised intersections in Ghana. The study found that generally, an increase in traffic flow, approach mean speed, number of lanes on the minor roads and junction location within commercial areas tended to increase crash frequency whilst more lanes on the major roads and presence of a median on the major road decreased crash frequency.

Dissanayake and Ratnayake, (2006) investigated the effect of highway geometrics and other related factors on frequency of rural highway crashes. The data was analysed using two different model formats (Negative Binomial and Poisson models). Negative Binomial models were found to be more effective in modelling crash frequencies especially since the dataset was over-dispersed. Model results showed amount of traffic, speed limit and highway geometry characteristics such as steep sideslopes, grades and sharp curves tend to increase the occurrence of crashes on rural highways.

Vogt and Bared, (1997) analysed and modelled crash and roadway data for two-lane rural highway segments and intersections. Variables used in the study included crash counts, traffic exposure, surface and shoulder width, roadside hazard rating, number of driveways, horizontal and vertical alignments, intersection angles, speed limits and commercial traffic percentage. Models of Poisson type and Negative Binomial type were developed, and advanced statistical techniques were applied to assess the explanatory value of the models in the presence of Poisson randomness and over-dispersion. The models derived from these data indicated that traffic volume and segment length are the key highway variables contributing to crashes, but that surface and shoulder width, roadside conditions, and alignments are also significant, especially in the segment models.

In a study that establishes the empirical relationship between truck crashes and geometric design of road sections, Miaou *et al.* (1993) proposed statistical frameworks based on Poisson regression and Negative Binomial regression. Preliminary models were then developed using crashes and road inventory data. Some encouraging relationships were developed for horizontal curvature, length of curve, vertical grade, length of grade, paved shoulder width, number of lanes, and annual average daily traffic (AADT) per lane. All except paved shoulder width showed a positive relationship with truck crashes. Goodness-of-fit test statistics indicated that extra variations (over-dispersion) existed in the data over the developed Poisson models.

Abdel-Aty and Radwan (2000) applied the Negative Binomial technique to model the frequency of crash occurrence and involvement on a principal arterial in Central Florida. The model illustrated the significance of the annual average daily traffic, degree of horizontal curvature, lane, shoulder and median widths, urban/rural environment, and the section's length on the frequency of crash occurrence. The results showed that heavy traffic volumes, high speeds, narrow lane width, large number of lanes, urban roadway sections, narrow shoulder width and reduced median width increase the likelihood for crash involvement.

Greibe (2003) had separate studies on crash prediction models for urban junctions and urban road links. Generalised linear modelling techniques were used to relate crash frequencies to explanatory variables. The estimated crash prediction models for road links were capable of describing more than 60% of the systematic variation ('percentage-explained' value) while the models for junctions had lower values. The study indicated that modelling crashes for road links is less complicated than for junctions, probably due to a more uniform crash pattern and a simpler traffic flow exposure or due to lack of adequate explanatory variables for junctions.

In a study that evaluated safety of urban arterials, Sawalha and Sayed (2001) used the Negative Binomial distribution to develop crash prediction models. They investigated large number of models with different combinations of traffic and roadway related variables to determine significant variables towards crash occurrence. The study concluded that longer section length, higher traffic volume, unsignalized intersection density, driveway density, pedestrian crossway density and number of traffic lanes tend to increase crash occurrence. However, the study estimated that conversion from an undivided arterial to one with raised-curb median could result, on average, in a 10% crash reduction.

2.2 Elements of Model Development

From the extensive review of literature, the following elements have been identified to be necessary for any model development:

- Appropriate model form
- Appropriate error structure
- Procedure for selecting the model explanatory variables
- Procedure for outlier analysis, and
- Methods for assessing model goodness of fit.

2.2.1 Model Form

Miauo and Lum, (1993) investigated the statistical properties of two conventional linear regression models and identified potential limitations of these models in developing vehicle crashes and highway geometric design relationships. It was demonstrated that the conventional linear regression models lack the distributional property to describe adequately random, discrete, non-negative, and typically sporadic, vehicle crash events on the road. As a result, these models were not appropriate to make probabilistic statements about the occurrences of vehicle crashes on the road, and the test statistics derived from these models were questionable. Several other literatures have supported the unsatisfactory property of ordinary linear regression models in developing vehicle crashes, traffic flow and highway geometric design relationships (Miaou, 1994; Kim *et al.,* 2005; Garber and Wu, 2001)

Currently, Generalized Linear Regression Model (GLM) is used almost exclusively for the development of Crash Prediction Models - CPMs (Sawalha and Sayed, 2006; Taylor *et al.*, 2002; Harnen *et al.*, 2004; Donnell and Mason, 2006). Sawalha and Sayed, (2006) said the mathematical form used for any CPM should satisfy two conditions:

1) It must yield logical results.

   This means that

   i. It must not lead to the prediction of a non-negative number of crashes and

   ii. It must ensure a prediction of zero crash frequency for zero values of the exposure variables, which for road sections are section length and traffic flow.

2) To use generalized linear regression in the modelling procedure, there must exist a known link function that can linearize this form for the purpose of coefficient estimation.

These conditions according to Sawalha and Sayed (2006) are satisfied by a model form that consists of the product of powers of the exposure measures multiplied by an exponential function incorporating the remaining explanatory variables. Such a model form can be linearized by the logarithm link function. Expressed mathematically, the model is of the form

$$E(Y) = a_o L^{a1} Q^{a2} \exp \sum_j b_j x_j \quad \ldots \quad \ldots \quad \ldots \quad (2.1)$$

Where $E(Y)$ is the predicted crash frequency, L is the section length, Q is some function of flow, x_j is any variable additional to L and Q, exp is the exponential function e = 2.718282 and a_0, a_1, a_2, b_j are the model parameters.

2.2.2 Error Structure

The occurrences of vehicle crashes are discrete random events. That is, the number of vehicles involved in crashes on a given road section during a period of time is probabilistic in nature. Researchers in this field say the Generalised Linear Model (GLM) mentioned above assumes an error structure (probabilistic structure) that is used in the data generation process (crashes). This distributional assumption is also used to obtain tests and confidence statements about the estimated regression coefficients.

2.2.2.1 Crash as a Bernoulli Trial

A crash is, in theory, the result of a Bernoulli trial (Lord *et al.,* 2004). Whenever vehicles enter highway segment, an intersection or any other type of entity (a trial) of a given transportation network, each vehicle may result in an outcome that may be classified as a success (crash) or failure (no crash).

If there are N independent trials (vehicles passing through a road segment, an intersection, etc.) that give rise to a Bernoulli distribution with the probability of successes (crashes) = p and $q = (1-p)$ is the probability of failure (no crash). The appropriate probability model that accounts for a series of Bernoulli trials is known as the binomial distribution (McClave and Sincich, 2003; Lord *et al.*, 2004), and is given as:

$$P(Y=n)=\binom{N}{n}p^{n}(1-p)^{N-n} \qquad \ldots \quad \ldots \quad \ldots \quad (2.2)$$

where Y is the random variable that records the number of success, $n = 0,1,2,\ldots,N$. The mean and variance of the binomial distribution are $E(Y) = Np$ and $Var(Y) = Npq$ respectively.

2.2.2.2 Poisson Distribution as a Limiting Form of Binomial

For typical motor vehicle crashes where the event has a very low probability of occurrence and a large number of trials exists, the binomial distribution is approximated by a Poison distribution. Under the Binomial distribution with parameters N and p, let $p = \lambda / N$, so that a large sample size N will be offset by the diminution of p to produce a constant mean number of events λ for all values of p. Then as $N \to \infty$

$$P(Y = n) = \binom{N}{n}\left(\frac{\lambda}{N}\right)^{n}\left(1-\frac{\lambda}{N}\right)^{N-p} \cong \frac{\lambda^{n}}{n!}e^{-\lambda} \quad \ldots \quad \ldots \quad \ldots \quad (2.3)$$

where, $n = 0,1,2,\ldots,N$ and λ is the mean of a Poisson distribution (Lord *et al.*, 2004).

The mean or expected value of the Poisson distribution Y is assumed to be equal to its variance. That is,

$$E(Y_i) = Var(Y_i) = \lambda \quad \ldots \quad \ldots \quad \ldots \quad (2.4)$$

where, $E(Y_i)$ is the expected number of crashes on section i and $Var(Y_i)$ is the variance of observed number of crashes. For a given set of explanatory variables (highway geometrics, speed, traffic and other data), λ can be estimated using the formulation.

$$\ln(\lambda) = \beta X_i \qquad \dots \quad \dots \quad \dots \qquad (2.5)$$

where, X is a vector of explanatory variables and β is a vector of parameters to be estimated.

However, in some cases this method has limitations in applying to real world data due to the assumption of equal mean and variance. When the data is over-dispersed or under-dispersed (i.e. variance is greater or less than the mean), the use of the Poisson regression models to make probabilistic statements about the occurrences of vehicle crashes will overstate or understate the likelihood of the crashes on the road (Miaou and Lum, 1993; Dissanayake and Ratnayake, 2006). Many previous studies have found that crash data tend to be over-dispersed in many situations with the variance being significantly higher than the mean. In such cases, any inferences made based on Poisson model estimation may lead to wrong conclusions. As a result of this, many researchers recommend using alternative methods in analysing crash data, when the data is over-dispersed (Miaou and Lum, 1993; Miaou, 1994; Lord *et al.*, 2004)

2.2.2.3 Negative Binomial (NB) Distribution

The Negative Binomial distribution does not require equal mean and variance assumption. In this method, the mean or expected value itself is assumed to be a random variable, which can be described by the gamma distribution. *Equation (2.5)* can then be written as:

$$\ln(\lambda) = \beta X_i + \varepsilon_i \quad \ldots \quad \ldots \quad \ldots \quad (2.6)$$

where ε_i is the unobservable error term with a gamma distribution. The variance of this distribution can be expressed as:

$$Var(Y_i) = E(Y_i) + \alpha E(Y_i)^2 \quad \ldots \quad \ldots \quad \ldots \quad (2.7)$$

where $E(Y_i)$ is the expected number of crashes on section i and α is called the Negative Binomial dispersion parameter. The over-dispersion occurs when the value of α is greater than 1 but when its value is zero, NB distribution reduces to Poisson distribution with which the variance is equal to the mean. The corresponding probability distribution under the NB assumption is given by,

$$P(Y_i = y_i) = \frac{\Gamma(y_i + 1/\alpha)}{\Gamma(y_i + 1)\Gamma(1/\alpha)} \frac{[\alpha E(Y_i)]^{\alpha}}{[1 + \alpha E(Y_i)]^{(y_i - 1/\alpha)}} \quad \ldots \quad \ldots \quad (2.8)$$

where $\Gamma(.)$ is a quantity that comes from gamma distribution function.

Dissanayake and Ratnayake, 2006 used Poisson distribution to identify critical factors that are likely to affect total number of crashes on rural highways in Kansas and found it not to be suitable due to over-dispersion in the crash data. Consequently, they used Negative Binomial (NB) which showed a better fit for the data and concluded that, NB distribution provided a reasonably satisfactory method for modelling crash frequency. Several other studies have advocated the use of NB distribution when the variance in the crash data is greater than the mean (Lord *et al.,* 2004; Donnell and Mason, 2006; Miaou, 1994; Miaou and Lum, 1993)

Lord *et al.,* (2004) in their paper "Poisson, Poisson-Gamma and Zero-Inflated and Regression Models of Motor Vehicle Crashes: Balancing Statistical Fit and Theory" concluded that:

i. Crash data are best characterized as Bernoulli trials with independence among crashes and unequal crash probabilities across drivers, vehicles, roadways, and environmental conditions. Because of the small probability of a crash and the large number of trials these Bernoulli trials can be well approximated as Poisson trials.

ii. Poisson and Negative Binomial models serve as statistical approximations to the crash process. Poisson models serve well under nearly homogenous conditions, while Negative Binomial models serve better in other conditions.

2.2.3 Selecting the Model Explanatory Variables

According to Sawalha and Sayed, (2006) model generality requires that a model be developed in accordance with the principle of parsimony, which calls for explaining as much of the variability of the data using the least number of explanatory variables. Deciding on which variables to include in a model is a multi-step process. First, variables believed to relate to the phenomenon in question have to be determined. This is usually based on previous studies, experience and engineering judgement based on available information (Sawalha and Sayed, 2006; Dissanayake and Ratnayake, 2006). The manner in which these variables will be used in the model must also be determined (whether as continuous, discrete or categorical variables). Last is the statistical determination as to which variables should remain in the model. Many studies have suggested that the t-ratio of its estimated parameter (equal to the parameter estimate divided by its standard error and equivalent to the Wald statistics) should be significant at the 95% confidence level, i.e. p-values < 0.05 (Sawalha and Sayed, 2006; Dissanayake and Ratnayake, 2006; Donnell and Mason, 2006; Harnen *et al.*, 2004).

2.2.4 Model Goodness of Fit Assessment

Researchers in this area have identified two major statistical measures used in assessing the goodness of fit in both Poisson and Negative Binomial approaches. The first statistic is called Pearson Chi-square statistic, which is defined as:

$$Pearson\ \chi^2 = \sum_{i=1}^{N} \frac{[y_i - E(Y_i)]^2}{Var(Y_i)} \quad \ldots \quad \ldots \quad \ldots \quad (2.9)$$

where y_i *and* $E(Y_i)$ are the observed and estimated crash frequencies on section i and $Var(Y_i)$ is the estimated variance of y_i.

The other goodness of fit statistic is called Deviance. The deviance is the likelihood ratio test statistic measuring twice the difference between the maximized log-likelihoods of the studied model and the full or saturated model. The full model has as many parameters as there are observations so that the model fits the data perfectly. Therefore, the full model, which possesses the maximum log-likelihood achievable under the given data, provides a baseline for assessing the goodness of fit of an intermediate model with p parameters (Sawalha and Sayed, 2006; Dissanayake and Ratnayake, 2006). McCullah and Nelder, (1989) have shown that if the error structure is Poisson distributed, then the scaled deviance is as follows:

$$D = 2\sum_{i=1}^{N} yi \ln\left(\frac{yi}{E(Yi)}\right) \quad \dots \quad \dots \quad (2.10)$$

While if the error structure follows the negative binomial distribution, the deviance is

$$D = 2\sum_{i=1}^{N}\left[y_i \ln\left(\frac{y_i}{E(Y_i)}\right) - (y_i + 1/\alpha)\ln\left(\frac{y_i + 1/\alpha}{E(Y_i) + 1/\alpha}\right)\right] \quad \dots \quad (2.11)$$

Both the Pearson Chi-square and scaled deviance have exact Chi-square distributions for normal theory linear models and for other models, asymptotic Chi-square distributions can be assumed with (N-p) degrees of freedom (Sawalha and Sayed, 2006; Dissanayake and Ratnayake, 2006; McCullar and Nelder, 1989). If the model assumption is correct then the estimated values of both Pearson Chi-square and deviance should be close to its degrees of freedom. In other words, the estimated value divided by its degrees of freedom should be close to 1 (i.e. $D/(N-p)$ or $\chi^2/(N-p) \approx 1$). Bauer and Harwood, (1998) have mentioned that if the values of these ratios are between 0.8 and 1.2 for a given model, then the model can be considered to be appropriate for representing the data (Sawalha and Sayed, 2006).

2.2.5 Coefficient of Determination (R^2)

To measure the overall goodness-of-fit in linear regression models, the coefficient of determination, R-squared is often used. The R-squared value indicates the amount of variability in the response variable explained by the variation in the selected set of explanatory variables. Different R-squared measures may yield substantially different answers, or even answers larger than 1, particularly for models that are not linear (Vogt and Bared, 1998; FridstrØm *et al.*, 1995; Kvalseth, 1985). In the estimation of model parameters in both the Poisson and Negative Binomial models, the Maximum Likelihood estimation method is usually used. To the extent that we want to use R-squared statistics as a basis for testing goodness-of-fit, the way the model parameters are estimated becomes relevant, since R-squared is maximized by ordinary least squares estimation but not by maximum likelihood. FridstrØm *et al.* (1995) developed several alternative goodness-of-fit methodologies for generalized Poisson regression models. Miaou (1996) also investigated different approaches to calculate R-squared values for different regression techniques using different distribution assumptions including Poisson and Negative Binomial. The R-squared estimation based on dispersion parameter for Negative Binomial models has the following form,

$$R_{\kappa}^{2} = 1 - \frac{\kappa}{\kappa_{\max}} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (2.12)$$

where κ and κ_{max} are the overdispersion parameters estimated using the model under consideration and the model with no covariates (only intercept) respectively. Based on simulations, Miaou (1996) concluded that this measure shows promise. It is simple to calculate, it yields a value between 0 and 1, it is independent of the choice of intercept term in the model and it has the proportionate increase property. Miaou (1996) proposes as a criterion that independent variables of equal importance, when added to a model, increase the value of the measure by the same absolute amount regardless of the order in which they are added.

2.2.6 Procedure for Outlier Analysis

Data collected may contain odd or extreme observations called outliers. Outliers occur in a set of data either because they are really different from the rest of the data or because errors took place during data collection and recording. These extreme observations may have effect on the model equation. Outlier analysis could be carried out to identify these influential observations. For this purpose, Cook's distances are calculated. The Cook's distance, c_i can be define as,

$$ci = \frac{h_i}{p(1-hi)}(r_{SP})^2 \qquad \ldots \qquad \ldots \qquad \ldots \qquad (2.13)$$

where h_i is the diagonal element of the projection matrix which maps yi into $E(Y_i)$, p is the number of model parameters and r_{SP} is the standardized Pearson residual of data point i. According to Sawalha and Sayed, (2006) the standardized Pearson residual for the Poisson and Negative Binomial regression models is given by:

$$r_{SP} = \frac{y_i - E(Y_i)}{\sqrt{(1-h_i)\,Var(y_i)}} \quad \ldots \quad \ldots \quad \ldots \quad (2.14)$$

Sawalha and Sayed, (2006) proposed the following three step procedure for identifying extremely influential outliers.

i. The data are sorted in descending order according to the c_i values.
ii. Starting with the data point having the largest c_i value, data points are removed one by one, and the drop in scaled deviance is observed after the removal of each point.
iii. Points causing a significant drop in scaled deviance are extremely influential outliers.

The difference between the deviances of two models has a Chi-square distribution with $(df_1 - df_2)$, where df_1 and df_2 are the corresponding degrees of freedoms for the models with all the observations (N) and the model with a data point removed (N-1) respectively. According to Maycock and Hall, (1984) and Dissanayake and Ratnayake, (2006) if the difference of two deviances is statistically significant at a given significance level, then the removed observation can be considered to cause a significance drop in deviance $\left(e.g.\ \chi^2_{(df_1-df_2)} > \chi^2_{0.05,1} = 3.84\right)$. However, Sawalha and Sayed, (2006) emphasized that excluding influential outliers from the development of a crash model is not synonymous with neglecting these outliers or removing them from the database. Rather, they should be investigated to determine what makes them different and whether any information can be extracted from them.

2.3 Delineation of Road Sections

Miaou and Lum, (1993) considered two (2) methods, i.e. fixed-length sections, say, every 2 km or homogeneous sections, defined as sections that are homogeneous in major geometric design and traffic characteristics. They found out that, short road sections (less than 1.6 km) had undesirable impacts on the estimation of their linear regression models. Longer sections (greater than 1.6 km) were, therefore, suggested to be preferred. However, given that most of the curved and graded sections were relatively short, the analysts oftentimes were unable to find a sufficient number of long and homogeneous road sections, which exhibited wide enough variations in geometric design variables to study the relationships. To overcome this problem, many analysts according to Miaou and Lum, (1993) have chosen to keep long road sections and not to insist on having homogenous road sections. Instead, they allowed road sections to be non-homogenous in horizontal curvatures and vertical grades. That is, one road section may have contained multiple curves and multiple grades.

Resende and Benekohal, (1997) reached the conclusion that, to get a reliable crash prediction model crash rates should be computed from 0.8 km or longer sections.

2.4 Segment Variables – Past Research Works

2.4.1 Average Daily Traffic (ADT)

Traffic flow function is one of the most significant variables in predicting crashes. Many models have used traffic exposure as a dependent variable although its relationship with crash count is not fully linear (Vogt and Bared, 1998). It is recommended to use traffic flow function as an independent variable for greater accuracy because it interacts with other controllable variables, and it measures the effect of traffic flow intensity (Vogt and Bared, 1998; Hauer, 1994)

2.4.2 Lane Width

Adequate lane width is important to provide sufficient lateral clearance between vehicles moving in the same or opposite directions. Generally it has been found that crash rates decrease when lane width increases (Vogt and Bared, 1998; Miaou *et al.*, 1993).

2.4.3 Shoulder Surface Type and Width

Adequate shoulder width is also important for increasing the chances for safe recovery when vehicles run off the road. Research findings suggest that crash rates decrease as paved shoulder width increases. Miaou *et al.*, (1993) found a reduction of 8% for a paved shoulder widening of 2 feet (0.6m) per side.

Shoulder type (paved vs. unpaved) is also important in terms of stability of vehicles when a vehicle goes off the road. Roads with paved shoulders are found to have lower crash and severity rates than similar highways having unpaved shoulders of the same width because the unpaved shoulders are unstable and vehicles find it difficult to recover on them when they run off the road.

2.4.4 Speed

Major studies have been done to find the relationship between crashes and speed (Kloeden *et al.*, 2001; Baruya, 1998; Taylor *et al.*, 2002; Lynam and Hummel, 2002). From all the studies there is a strong consensus on the evidence of the effect of speed on the severity of a crash, and the conclusion is well supported by the clearly understood physical mechanism that occurs during impact. However, researchers attest to the fact that, the relation between speeds and crash involvement is much more difficult to establish. Recent studies (Taylor *et al.*, 2002; Kloeden *et al.*, 2001; Quimby *et al.*, 1999) have concluded that crash involvement increases with speed on any particular road or for any particular driver.

2.4.5 Horizontal Curves

Crashes are more likely to happen on horizontal curves than on straight sections because of the vehicle dynamics and additional effort required by the driver to control the stability of the vehicle. Previous studies suggest that, as the degree of curvature increases, crash rate increases. For a fixed curvature degree, crash rate increases as the length of curve increases (Vogt and Bared, 1998; Miaou *et al.*, 1993). Elvik and Vaa, (2004) found that straightening horizontal curves reduces the number of crashes when the radius of the curve is less than 2000 metres. The effect is greatest in straightening sharp curves and it decreases gradually as the radius of the curve increases.

2.4.6 Vertical Grades

There is a greater risk of crashes on grades than on level sections. For heavy goods vehicles, downgrades may be more dangerous than upgrades because of their inferior deceleration capabilities compared to passenger cars (Miaou *et al.*, 1993). The problem on upgrade is different. Since goods vehicles cannot maintain normal, prevailing traffic speeds on upgrades, the drivers of other vehicles occasionally attempt to perform unsafe overtaking manoeuvres. Elvik and Vaa, (2004) concluded that reducing gradients reduces the number of crashes. The effect is greater for the steepest gradients and decreases thereafter. Sight distances are reduced at certain points along a crest curve. Reduced sight distances make it difficult to drive and give less time to react to unexpected events thereby increasing the risk of crashes (Elvik and Vaa, 2004).

2.4.7 Intersections

Approximately only 12% of crashes occur at intersections on the rural highways in Ghana (Afukaar *et al*, 2008). Elvik and Vaa, (2004) found an increase in crash rate with an increase in access (defined as any road connecting a private property to a public road) density. Many studies have not considered the number of intersections within segments in model development.

CHAPTER 3

3.0 METHODOLOGY FOR DATA COLLECTION

3.1 Range of Data Collected

Variables believed to relate to crashes on rural highways were identified. This was primarily based on literature and engineering judgement based on available information and exploratory analysis. The data collected for all sections for the study included:

- Injury crash data (for a 3 year period, 2005-2007)
- Traffic flow data
- Vehicle speed data
- Road characteristics
- Road geometry

This study was approved by the Institutional Review Board (IRB) of the Kwame Nkrumah University of Science and Technology, Kumasi.

3.2 Selection of Road Corridors

An extensive reconnaissance survey was carried out to identify suitable sites from which the sample of sites for the study was drawn. The road sections from which the samples were drawn were all two-lane single carriageway rural segments of road. The road sections were all under the jurisdiction of the Ghana Highway Authority (GHA). Stratified random sampling technique was used in the road selection process in order to select segments from the population to include roadways from the three (3) different highway categories namely: national roads, N (which link regional capitals to the national capital); inter-regional roads, IR (which link regional capitals to one another); and regional roads, R (which link the district capitals to the regional capitals) so as to avoid bias.

Only road sections which had not undergone any modification during the period (2005-2007) for which crash data were studied were included in the sample. Since the objective of the study was to establish the effects of the different variables on crashes, selection of segments were done in order to achieve variety in traffic volumes, speeds, road characteristics and geometry. The thick purple lines shown in *Figure 3.1* indicate the road corridors which were selected for the model development.

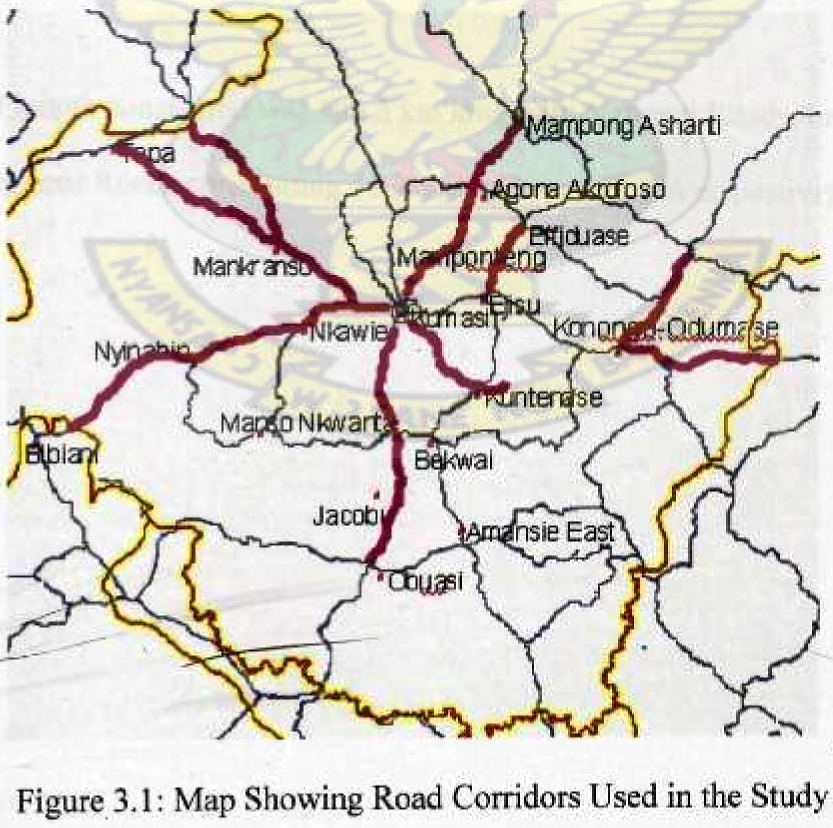

Figure 3.1: Map Showing Road Corridors Used in the Study

3.3 Selection of Road Links

A total of fourteen (14) road corridors were selected for the project. These road corridors were subdivided into seventy-six (76) links and studied for the purpose of model development. Lengths of links were not to be less than 0.8 km in order to get a reliable crash prediction model (Resende and Benekohal, 1997). Links were either taken as between two major junctions, between two towns, between a junction and a town or between a junction or town and any major landmark, for example, a river/bridge. The road corridors, number of links and length studied within each corridor are as presented in *Table 3.1*.

Thirty-one of the sites representing 40.8% were on National Roads, whilst 21(27.6%) were on Inter-Regional Roads and 24 (31.6%) were on Regional Roads.

The total road length considered was 186.3 km long with National Roads, Inter-Regional Roads and Regional Roads constituting 41.3%, 31.4% and 27.3% respectively.

Table 3.1: Road corridors, number of links and length studied within each corridor.

No.	Route Name	Road Corridor	No. of Links	Length (km)
National Highways				
1	N6	Dadieso-Konongo	9	33.0
2	N6	Abuakwa-Mankranso	7	10.5
3	N10	Obuasi Junction-Anhwiankwanta	9	22.8
4	N10	Anhwiankwanta-Pakyi	5	9.3
5	N10	Pakyi-Kumasi	1	1.4
Total			***31***	***77.0***
Inter-Regional Highways				
6	IR5	Abuakwa-Adiembra	7	20.2
7	IR5	Adiembra-Bibiani	6	20.2
8	IR4	Kumasi-Ntonso	2	4.0
9	IR4	Ntonso-Mampong Asante	6	14.1
Total			***21***	***58.5***
Regional Highways				
10	R65	Mankranso-Tepa	8	16.8
11	R104	Ejisu-Effiduase	6	11.2
12	R76	Konongo-Agogo	5	9.4
13	R106	Kuntenase-Abono	2	7.9
14	R106	Kumasi-Kuntanase	3	5.5
Total			***24***	***50.8***
All Roads			**76**	**186.3**

3.4 Road Traffic Crash Data

In Ghana, information on road traffic crashes is available at the National Road Traffic Crash Database at the Building and Road Research Institute (BRRI). The database is compiled from police files using a standard crash report form. This form includes information about the crash location, the vehicle(s) and casualties involved. In general, a police report contains additional information from casualties who survived the crash, witnesses, and report by a vehicle examiner from the Driver and Vehicle Licensing Authority (DVLA), a plan of the crash indicating the location and a general report by the investigator summarising the facts surrounding the crash. Most of the information has been coded and stored in computers at the BRRI using the Micro-computer Accident Analysis Package (MAAP, windows version) software developed by the Transport Research Laboratory (TRL), United Kingdom (UK).

For the purpose of this study, the relevant information for each crash was the location and date. Crash data were retrieved and analysed with the help of the cross tabulation and kilometre analysis facilities available in the MAAP software. The data consisted of all reported injury crashes occurring at the sites.

3.5 Traffic Flow Data

Traffic flow data including Average Daily Traffic (ADT) was obtained from the Traffic and Planning Unit of the Ghana Highway Authority (GHA) for the different road corridors for the study.

3.6 Procedure for Speed Measurement and Minimum Sample Size

Measurements of speeds were made with a radar speed gun at not less than three (3) locations within each segment in order to get a representative speed for the segments which oftentimes were un-homogenous. The data collection team was stationed in a parked vehicle and used the speed gun to measure spot speeds of vehicles. Effort was made to measure the speeds of all passing vehicles. In a situation where there was a platoon of vehicles, only the lead vehicle in the fleet was measured since vehicles following in a platoon do not travel at their desired speeds.

In order to measure the correct speeds of vehicles, attempt was made to place the radar gun directly in the line of travel of the target vehicle (collision course). This was to reduce the phenomenon of cosine effect. With radar guns, as the angle of incidence increases with lateral movement to either right or left from this direct line, its accuracy decreases. The measured speed will decrease as one moves off this centreline.

For all the road links considered for the modelling of crashes in this report, a minimum sample size of vehicles as shown in *Table 3.2* were surveyed for the speed study. This sample size was designed to provide a precision level of at least ±5% on the estimates at 95% confidence level and 0.5 degree of variability (Israel, 1992). The minimum sample size was based on the Average Daily Traffic (ADT) of the road corridors.

Table 3.2: Minimum required sample size for speed data

Road Corridor	Average Daily Traffic	Minimum Sample Size
Dadieso-Konongo	8,948	383
Abuakwa-Mankranso	5,310	372
Obuasi Junction-Anwiankwanta	2,171	338
Anwiankwanta-Pakyi	6,172	376
Pakyi-Kumasi	7,167	379
Abuakwa-Adiembra	3,849	362
Adiembra-Bibiani	3,678	361
Kumasi-Ntonso	3,792	362
Ntonso-Mampong Asante	3,081	354
Mankranso-Tepa	663	249
Ejisu-Effiduase	1,955	332
Konongo-Agogo	1,319	307
Kuntenase-Abonu	347	186
Kumasi-Kuntanase	3,288	357

3.7 Road Characteristics and Geometric Data

Field surveys were carried out for all selected road segments for the purpose of establishing the road characteristics. Measurement of link length was done on site. Carriageway and shoulder widths were also measured on site and at more than two (2) locations within a link in order to get a representative figure for the entire segment.

The following information was collected:

Categorical Variables

- Terrain type (Flat or Hilly/Rolling)
- Road marking (Present for roads with only centreline or both centreline and edgeline or Absent for no marking)
- Shoulder (Present or Absent)
- Should type (Paved or Unpaved)
- Village settlement within road segment (Present or Absent)
- Road surface type (Asphalt or Surface dressing)

Continuous Variables

Continuous variables comprised the following:

- Length of section
- Carriageway width
- Shoulder width
- Junction density within segment (Number of junctions/segment length)
- Access density within segment(Number of accesses/segment length)
- Horizontal curves density within segment (Number of horizontal curves/segment length)
- Vertical curves density within segment (Number of vertical curves/segment length)

Accesses were defined as any road connecting a private property to a public road. Junctions consisted of T-junctions, Y-junctions and X-junctions within segments.

CHAPTER 4

4.0 ANALYSIS OF DATA

4.1 General Crash Analysis

4.1.1 Road Traffic Crashes in the Ashanti Region

During the period 2005-2007, a total of 21,709 injury road traffic crashes occurred in Ghana resulting in 48,605 casualties. Of these crashes, 3,812 representing 17.6% occurred in the Ashanti Region of Ghana and resulted in 9,153 casualties representing 18.8% of all reported road traffic casualties in the country. Furthermore, the Ashanti Region alone accounted for more than one-fifth (20.5%) of all road traffic fatalities in Ghana as shown in *Table 4.1.*

Table 4.1: Distribution of Crashes/Casualties in the Ashanti Region of Ghana (2005-2007)

Crashes/Casualty Severity	National	Ashanti Region	Percentage (%) Ashanti Region
Crashes			
Fatal	4439	839	18.9
Hospitalised	8223	1565	19.0
Not Hospitalised	9047	1408	15.6
Total	***21709***	***3812***	***17.6***
Casualties			
Fatalities	5689	1167	20.5
Seriously Injured	17311	3297	19.0
Slightly Injured	25605	4689	18.3
Total	***48605***	***9153***	***18.8***

4.1.2 Urban Versus Rural Environment

In considering Ashanti Region alone, it was observed that over two-thirds (67.3%, n=785) of all road traffic fatalities occurred on the non-urban road environment as against 32.7% (n=382) in the urban areas.

4.1.3 Location of Crashes and Collision Type in the Rural Environment

Over ninety percent (90.2%) of all fatal crashes in the rural environment occurred on road sections outside junctions whilst only 9.8% occurred at junctions.

As presented in *Figure 4.1*, 'hit pedestrian' collision was the predominant collision type constituting 38.6% of all collisions on the rural road sections, followed by 'vehicle ran-off road' (20.4%), side swipe (8.5%) and head-on collision (8.4%). Further investigation into 'hit pedestrian' collisions revealed that majority (91.7%) of these collisions occurred within village settlements while 8.3% occurred at the rural non-settlement areas. Indeed, 'hit pedestrian' collision is a settlement related problem.

4.1.4 Vehicle Types Involved

Cars were most frequently involved in crashes in the non-urban road environment in Ashanti Region, accounting for 37% of the reported injury crashes. This was followed closely by bus/mini-buses (36%), with goods vehicle contributing 21% of the crashes. This is shown in *Figure 4.2*.

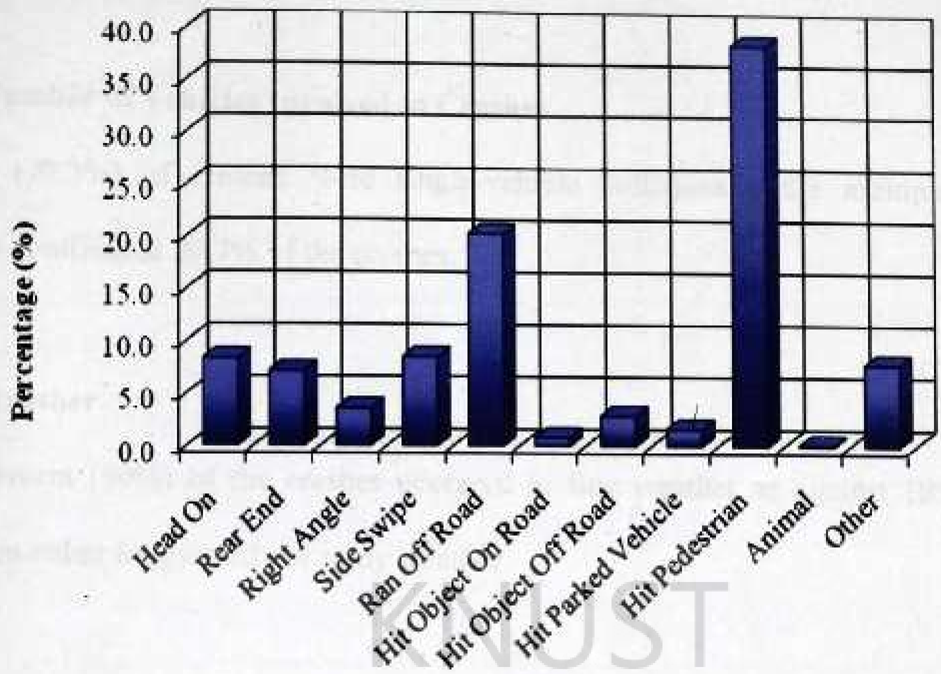

Figure 4.1: Distribution of Injury Crashes on Rural Road Environment in Ashanti by Collision Type

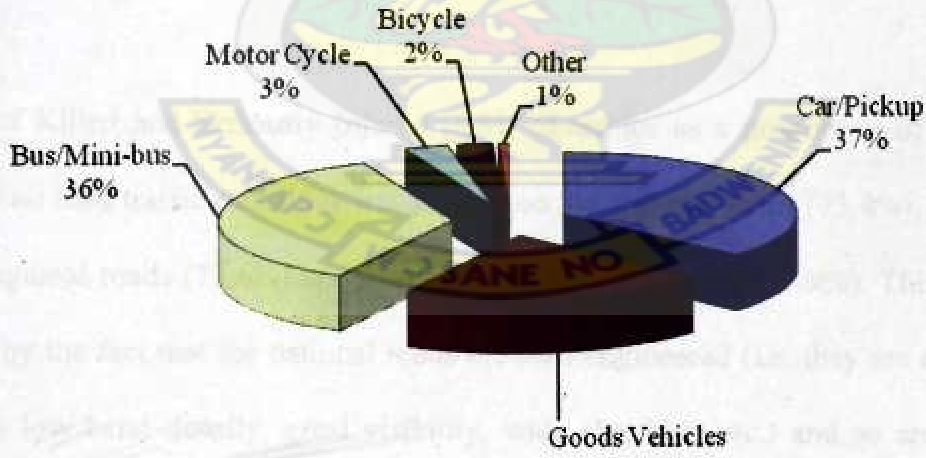

Figure 4.2: Distribution of Vehicles Types Involved in Crashes on Rural Roads in Ashanti

4.1.5 Number of Vehicles Involved in Crashes

Majority (70.3%) of crashes were single-vehicle collisions while multiple-vehicle collisions contributed 29.7% of the crashes.

4.1.6 Weather

Ninety percent (90%) of the crashes occurred in fine weather as against 10% which occurred in either foggy/misty or rainy weather.

4.2 Crash Data on Road Links Considered in the Study

Table 4.2 shows the number of personal injury crashes and their severity on road links sampled for the study. A total of 301 crashes were recorded of which 50.8% occurred on roads classified as National Highways, 30.2% occurred on the Inter-Regional Highways and 18.9% on the Regional Highways. The entire road traffic crash statistics for the different categories of roads have been presented in *Appendix A1*.

The risk of Killed and Seriously Injured (KSI) casualties as a proportion of the total number of all road traffic casualties was highest on the regional roads (75.4%), followed by inter-regional roads (73.6%) and lowest on the national roads (71.9%). This may be explained by the fact that the national roads are well engineered (i.e. they are relatively wide, with low bend density, good visibility, wide shoulder, etc.) and so are able to sustain the high traffic speeds with lower proportion of killed and seriously injured casualties. In contrast, the regional roads possess limited sight distances, are narrow and most often have weedy shoulders. The average crash rate (crashes per 10^8 vehicle-kilometres travelled) for the different highway categories are also shown in *Figure 4.3*.

The highest rates occurred on regional highways, followed by inter-regional highways with national highways having the lowest rates.

Table 4.2: Distribution of Crashes and Rates on Selected Segments by Road Category

Road Class	Crash Severity			All Crashes		Proportion
	Fatal	*Serious*	*Slight*	*n*	%	KSI (%)
National	60	50	43	153	50.8	71.9
Inter-regional	23	44	24	91	30.2	73.6
Regional	17	26	14	57	18.9	75.4
Total	100	120	81	301	100.0	73.1

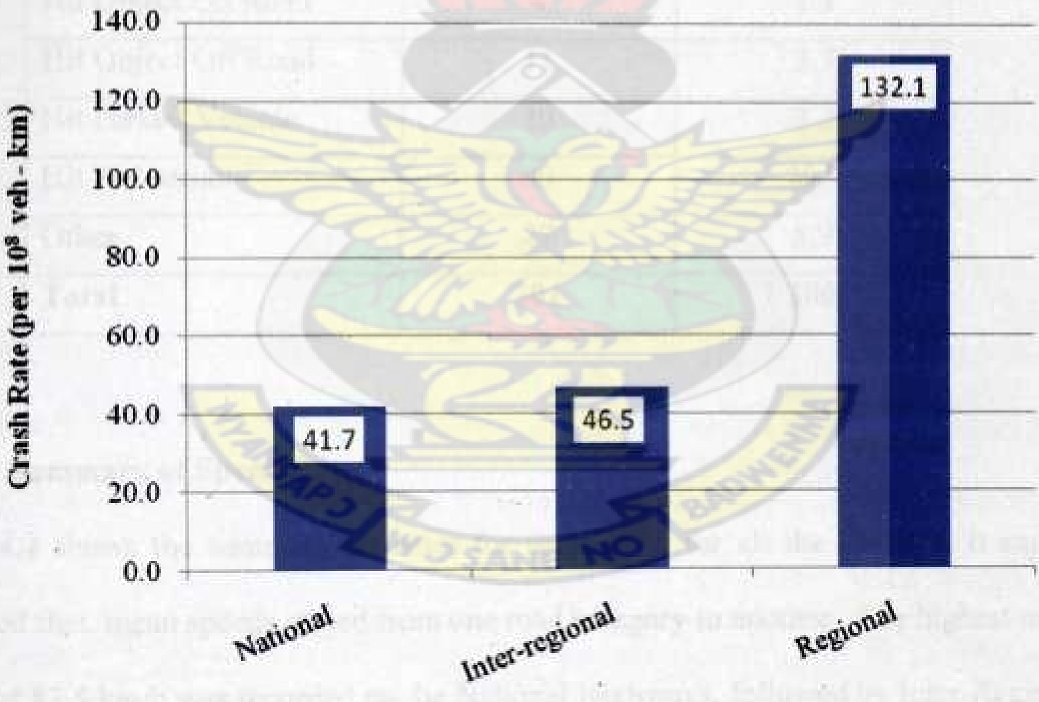

Figure 4.3: Crash Rate by Road Category

In considering the collision types, majority of the crashes on the segments sampled were 'hit pedestrian' collisions (29.9%), followed closely by 'vehicle ran-off road' collisions (24.3%) and right angle collisions (9.8%) as shown in *Table 4.3*.

Table 4.3: Distribution of crash types on road segments sampled for study

Collision Type	Number (n)	Percentage (%)
Head On	28	9.3
Rear End	16	5.4
Right Angle	29	9.8
Side Swipe	13	4.2
Ran off Road	73	24.3
Hit Object On Road	4	1.3
Hit Object Off Road	11	3.7
Hit Parked Vehicle	10	3.2
Hit Pedestrian	90	29.9
Other	27	8.9
Total	**301**	**100**

4.3 Summary of Speed Data

Table 4.4 shows the summary statistics for speed data for all the 76 sites. It can be observed that, mean speeds varied from one road category to another. The highest mean speed of 83.5 km/h was recorded on the National Highways, followed by Inter-Regional (81.3 km/h) and Regional Highways (69.2 km/h). The highest mean speed recorded on the national roads may be due to the fact that they have favourable geometric characteristics when compared with the inter-regional and regional roads. A mean speed of 78.7 km/h was recorded on all categories of roads.

Table 4.4: Summary Statistics for Speed Data

Speed Parameter	National (N)	Inter-Regional (IR)	Regional (R)	All Roads
Mean Speed (km/h)	83.5	81.3	69.2	**78.7**
Standard Deviation (km/h)	18.7	18.7	14.5	**18.6**
85th Percentile (km/h)	102.0	100.0	82.9	**97.0**
Minimum Speed (km/h)	23.0	14.0	19.0	**14.0**
Maximum Speed (km/h)	184.0	154.0	127	**184.0**

Crash rate by mean speed is shown in *Figure 4.4*. There appear to be some indication of lower crash rate being associated with higher mean speed which is contrary to earlier studies (Taylor *et al.*, 2002; Kloeden *et al.*, 2001). Taylor *et al.* (2002) said the processes involved in the development of speed-crash models are far from straightforward. The complex inter-relationships between other variables mean that extensive databases and sophisticated statistical analysis techniques are required. A particular problem is that the key variables sometimes interact in such a way that the effect of interest (here the association between speed and crashes) is masked by correlations between these variables and a third variable (the 'masking' variable). In urban road study, pedestrian flow was found to be such a masking variable and its identification and quantification in the speed-crash model enabled a clear interpretation of the model to be made with respect to the effect of speed (Taylor *et al.*, 2000). A corresponding masking variable in this study could be the high frequency of pedestrian crashes in the settlement areas.

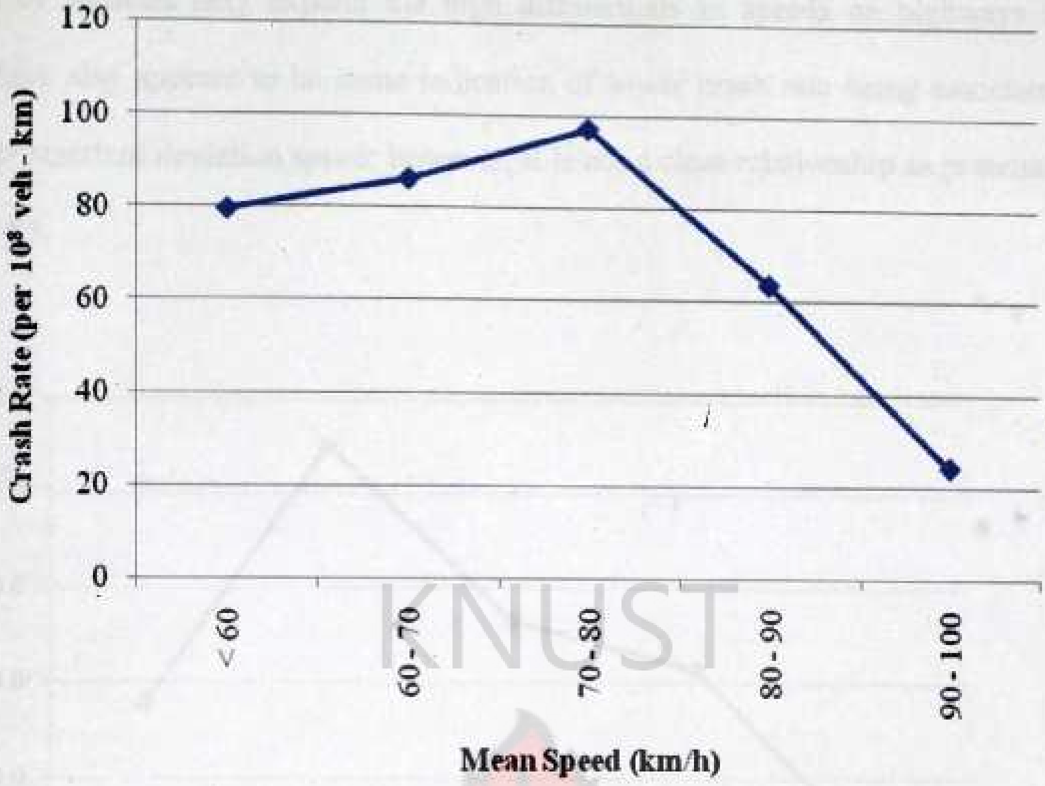

Figure 4.4: Crash Rate by Mean Speed (km/h)

Lave (1985) indicated that the prevailing standard deviation of speed in the USA varied from 8 to 12 km/hr depending on highway type. Speed dispersions as measured were 18.7 km/h on National and Inter-Regional Highways and 14.5 km/h on Regional Highways. In comparison, the existing standard deviation of between 14.5 and 18.7 km/hour on all highway categories in Ghana is extremely high. On all categories of roads, a speed dispersion of 18.6 km/hr was registered indicating that vehicle speeds are widely spread from the mean. Damsery-Derry *et al.* (2008) found that private cars were the fastest mode of transport in Ghana, travelling between 103 and 92 km/hr on rural non-settlement sections while trucks were the slowest and generally travelled between 69 and 73 km/h depending on the highway type. The differences in speed of the different categories of vehicles may explain the high differentials in speeds on highways in Ghana. There also appears to be some indication of lower crash rate being associated with higher standard deviation speed; however, it is not a clear relationship as presented in *Figure 4.5*.

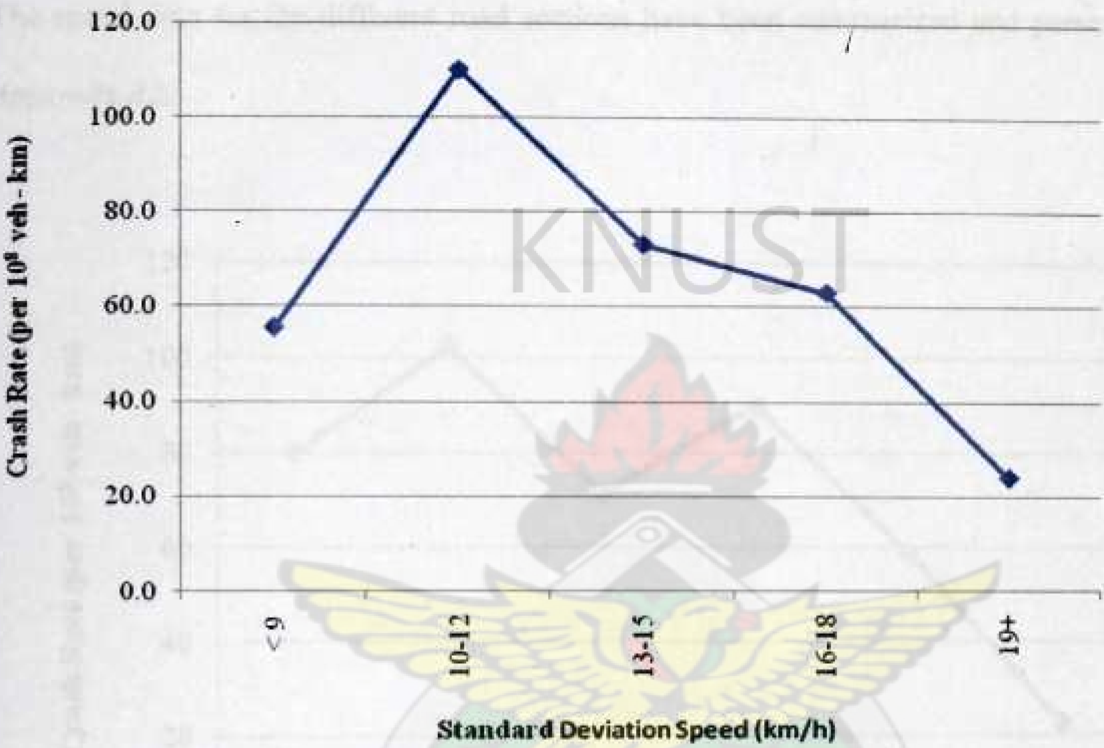

Figure 4.5: Crash Rate by Standard Deviation Speed (km/h)

The 85th percentile speeds are presented in *Table 4.3.* Mussa (2005), like most engineering literature has suggested the 85th percentile as a measure of fast driving and used it as a benchmark for determining maximum speed limits. Eighty-fifth (85th) percentile speeds of 102.0 km/h, 100.0 km/h and 82.9 km/h were recorded on the national, inter-regional and regional highways respectively. The overall 85th percentile speed was 97.0 km/h even though the maximum recommended speed limit on rural highways is 80 km/h depicting clearly that over speeding is rife on the rural two-lane, two-way highways in Ashanti Region. There appears to be no consistent trend in the effect of the 85th percentile speed on crash rate within road sections sampled for the study as shown in *Figure 4.6*.

The speed data for the different road sections have been summarized and presented in *Appendix A2*.

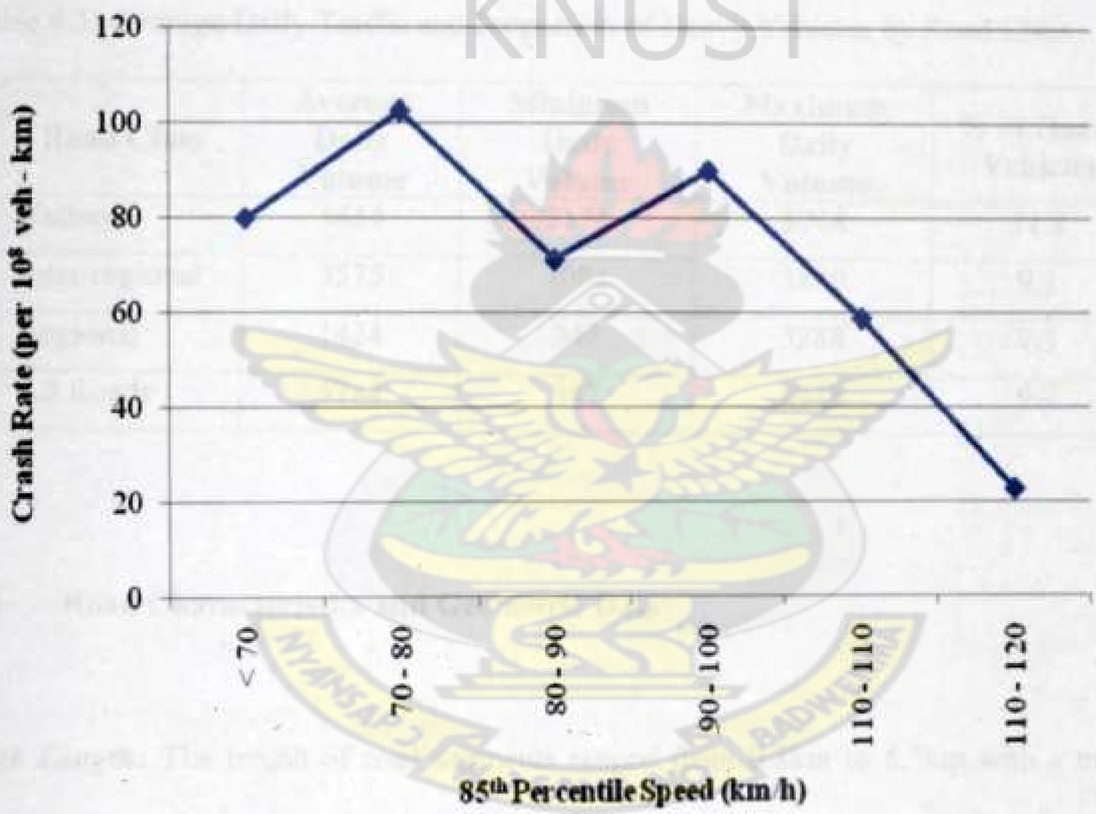

Figure 4.6: Crash Rate by 85th Percentile Speed (km/h)

4.4 Summary of Traffic Flow Data

The Average Daily Traffic (ADT) ranged from 347 to 8948 as illustrated in *Table 4.5*. Generally, traffic flow was highest on the national highways and lowest on the regional highways. Among the highway categories, the national roads had the highest proportion of heavy goods vehicles because road transport is the main form of transportation in Ghana and goods vehicles provide direct service between the national capital and other regional capitals and cities and even beyond the frontiers of Ghana. The detailed results of traffic flows (ADT) and the proportion of heavy vehicles have been presented in *Appendix A3.*

Table 4.5: Average Daily Traffic and Proportion of Heavy Vehicles by Road Class

Road Class	Average Daily Volume	Minimum Daily Volume	Maximum Daily Volume	% of Heavy Vehicles
National	5654	2171	8948	11.8
Inter-regional	3575	3081	3849	9.1
Regional	1424	347	3288	7.5
All Roads	3744	347	8948	9.7

4.5 Road Characteristics and Geometric Data

Link Length: The length of road segments ranged from 0.8km to 6.7km with a mean length of 2.5km.

Road Width: Road width varied from 7.0 m – 7.8 m with a mean value of 7.4m on all road types. Carriageway width varied from 7.0 m – 7.8 m on national roads, was 7.5 m on inter-regional roads and 7.0 m – 7.4 m on regional roads. Generally, the national and inter-regional roads which carry more traffic volume were wider than the regional roads.

However, all road widths were within the standards recommended by the Ghana Highway Authority (GHA, 1991).

A preliminary review of the data analysed showed that generally, average crash rate decreases as carriageway width increases as shown in *Figure 4.7*. Other studies elsewhere found similar results (Vogt and Bared, 1998; Miaou *et al.*, 1993).

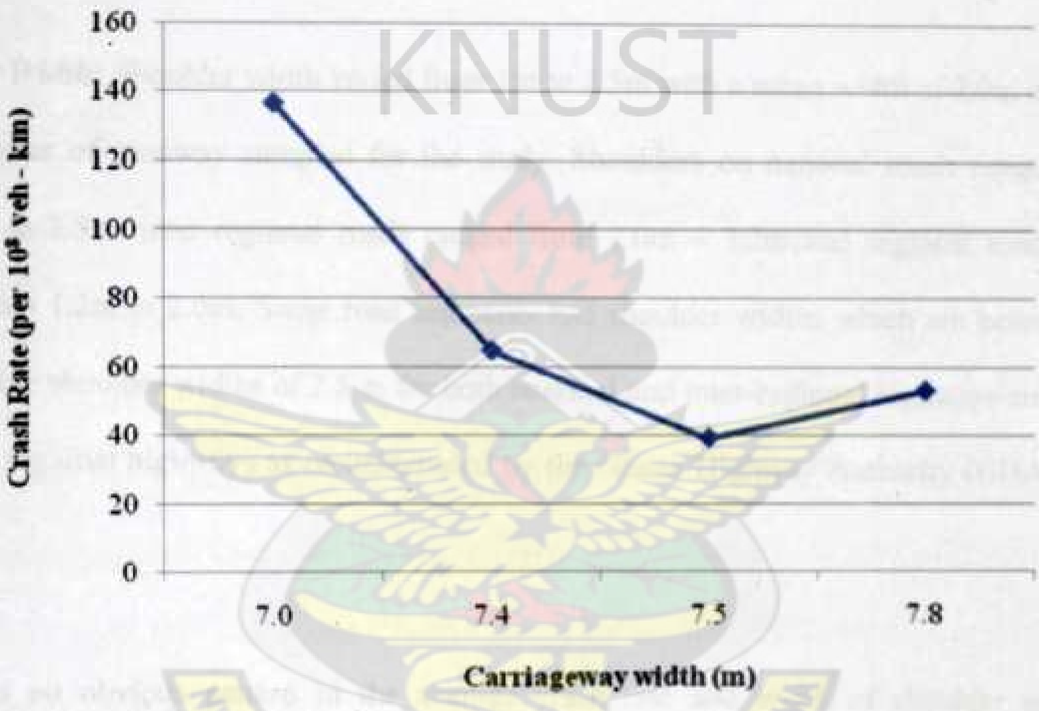

Figure 4.7: Crash Rate by Carriageway width

Terrain Type: Approximately 55% of all the sites were relatively flat whereas 45% were under rolling/hilly terrain conditions. Relatively, a higher percentage of rolling/hilly terrain type was found on the regional roads (54.2%), followed by inter-regional roads (47.6%) and national roads (35.5%).

Average crash rate was higher under flat terrain conditions than on rolling/hilly terrain conditions (91.2 crashes per 10^8 vehicle-kilometres vs. 47.3 crashes per 10^8 vehicle-kilometres)

Presence of Shoulder: Variability could not be assessed for the variable presence of shoulder as the entire road links sampled had shoulders.

Shoulder Width: Shoulder width varied from 1m to 2.5m with a mean width of 2.0m on all categories of roadway sampled for the study. Shoulders on national roads ranged from 1m to 2.5m, inter-regional roads ranged from 2.0m – 2.2m and regional roads ranged from 1.2m to 2.0m. Some road segments had shoulder widths which are below the desirable shoulder widths of 2.5 m for both national and inter-regional highways and 1.5 m for regional highways as recommended by the Ghana Highway Authority (GHA, 1991).

There was no obvious pattern in the average crash rate and width of shoulder as indicated by *Figure 4.8*. However, average crash rates were particularly low within segments with a shoulder width of more than 2.0 m. Wider shoulder widths have been found to be beneficial to road safety (Miaou *et al.*, 1993).

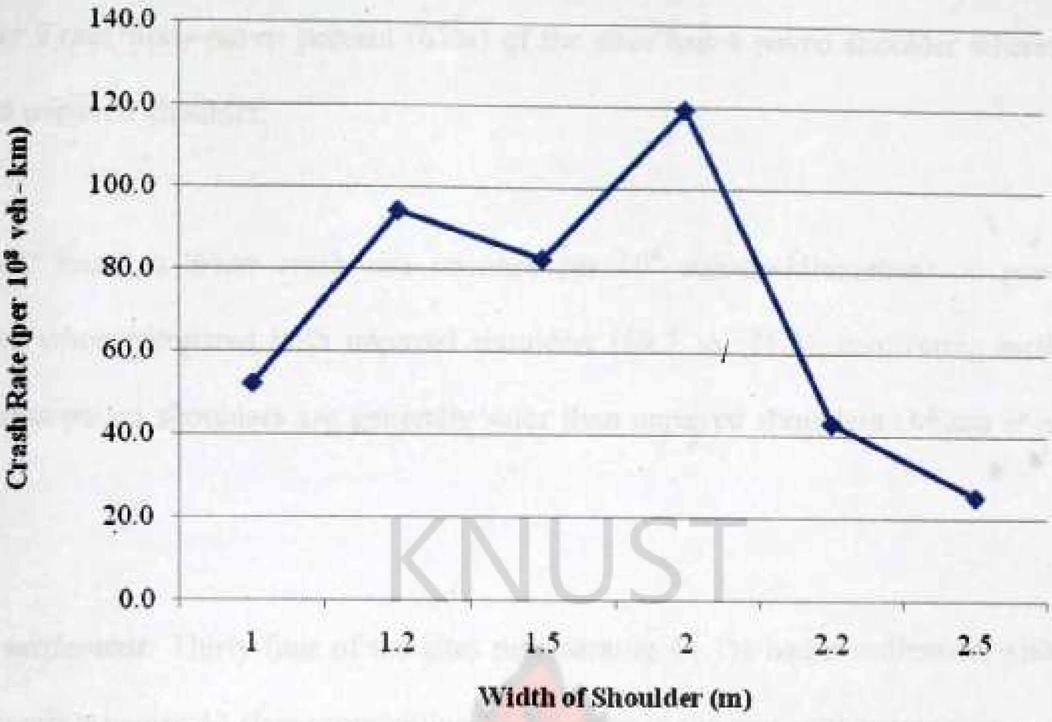

Figure 4.8: Crash Rate by Width of Shoulder

Road Marking: Approximately 82% of the sites were delineated (centreline only or centreline plus edges) whiles 18% had no marking at all. Fletcher *et al.* (2006) found similar results when they developed a model for Tanzania. This indicates a clear benefit in having road signs.

Crash rates (crashes per 10^8 vehicle kilometres travelled) of 58.9 and 74.4 were recorded on segments with and without delineations respectively indicating that marked roads are safer than unmarked roads.

Shoulder Type: Sixty-seven percent (67%) of the sites had a paved shoulder whereas 33% had unpaved shoulder.

The study found a lower crash rate (crashes per 10^8 vehicle-kilometres) on paved shoulders when compared with unpaved shoulders (69.7 vs. 75.5), confirming earlier studies that paved shoulders are generally safer than unpaved shoulders (Miaou *et al.*, 1993).

Village settlement: Thirty-four of the sites representing 44.7% had a settlement within the segments whereas 42 sites representing 55.3% were in the non-settlement areas.

Average crash rate was higher within links with the presence of village settlement when compared with links without a village settlement (100.7 crashes per 10^8 vehicle-kilometres vs. 48.0 crashes per 10^8 vehicle-kilometres). It could be inferred that, it is twice as safer driving on trunk roads in non-settlement areas than on trunk road segments passing through a settlement.

Junction Density within Segment: Close to 53% of the road links considered in the study had at least one junction. T-junctions constituted 94.8% of all junctions whilst X-junctions constituted only 5.2%. Total junction density (number of junctions per section length) ranged from 0 to 1.7 per km with a mean value of 0.3 per km. Most (87%) of the sites sampled for the study had a junction density of 0.8 or less per km. Considering the different road categories, the highest average junction density of 0.4 per km was recorded on national roads, followed by 0.3 per km on regional roads and 0.2 per km on inter-regional roads.

Figure 4.9 shows that, there was no clear consistent trend in the effect of junction density on crash rate.

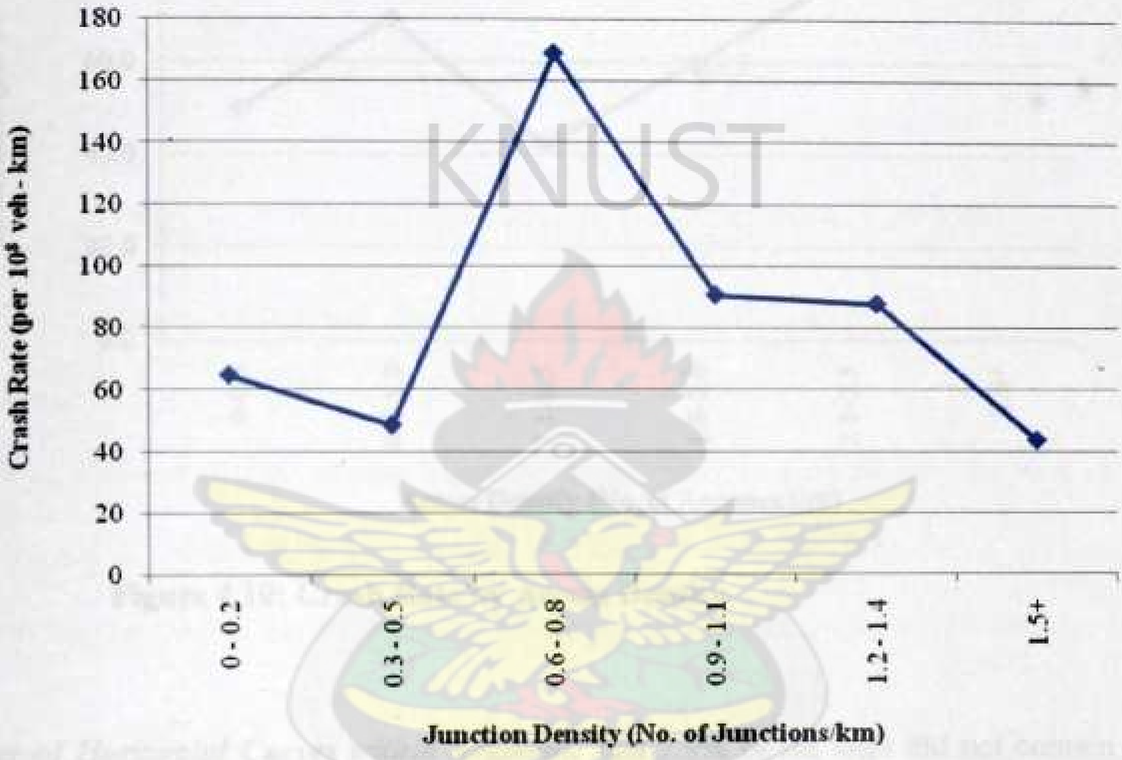

Figure 4.9: Crash Rate by Junction Density

Accesses Density: Over 90% of the sites had at least one access. Access density (number of accesses per section length) varied from 0 to 17.5 per km with a mean value of 1.8 per km. Most (74%) of the sites sampled for the study had a junction density of 2.5 or less per km. Access densities of 2.2 per km, 1.6 per km and 1.5 per km were recorded on national, regional and inter-regional roads respectively.

Generally, there appear to be some indication of higher crash rate being associated with higher access density within a segment as shown in *Figure 4.10*.

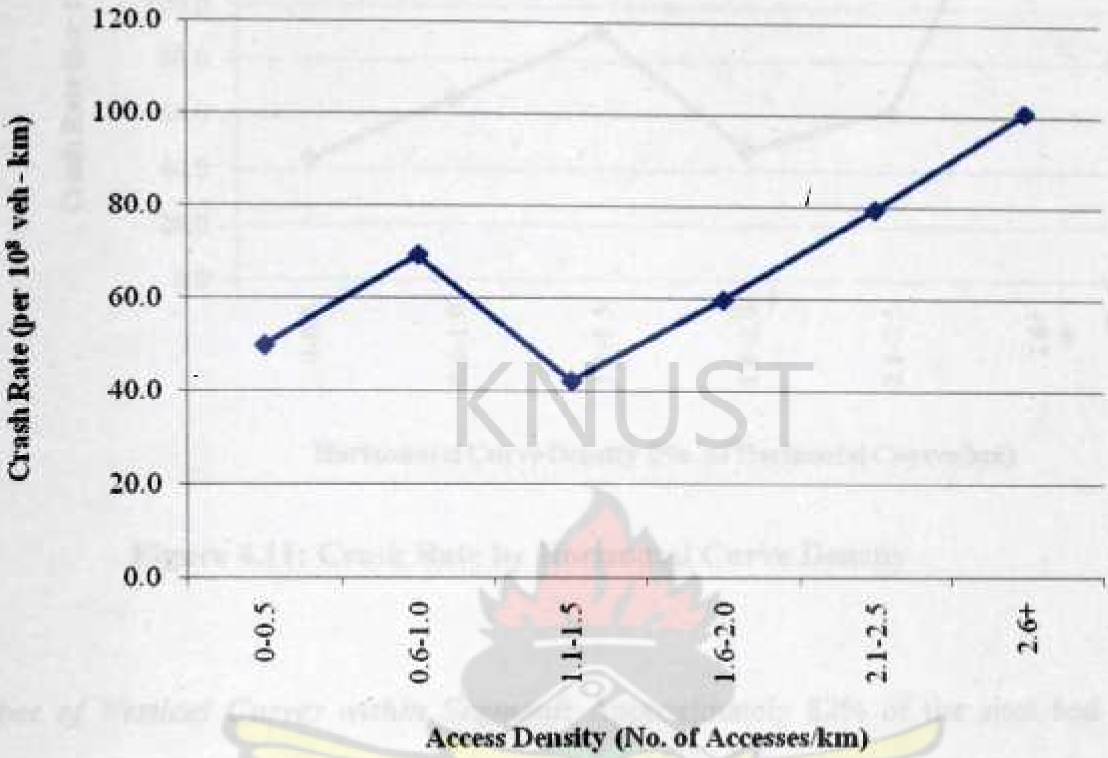

Figure 4.10: Crash Rate by Access Density

Number of Horizontal Curves within Segment: Just 7.9% of the sites did not contain horizontal curve within the segment. Horizontal curve density (number of horizontal curves per section length) varied from 0 to 6.4 per km with a mean value of 1.4 per km.

Generally, there appear to be some indication of higher crash rate being associated with higher horizontal curve density within segments as shown in *Figure 4.11*.

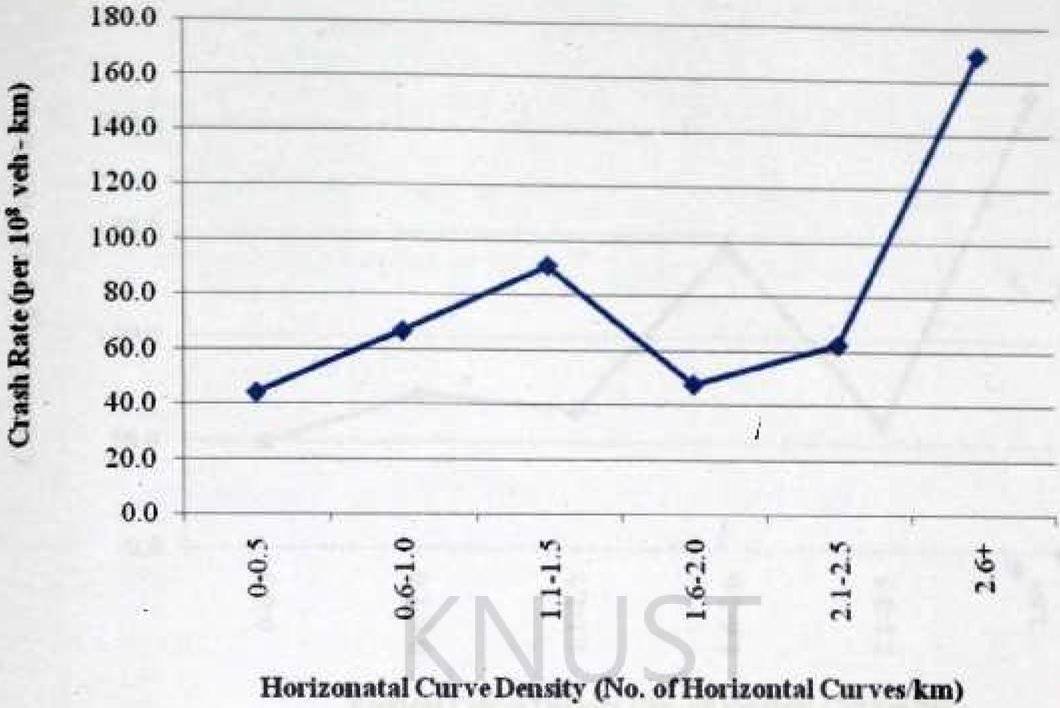

Figure 4.11: Crash Rate by Horizontal Curve Density

Number of Vertical Curves within Segment: Approximately 82% of the sites had at least one vertical curve within the segment. Vertical curve density (number of vertical curves per section length) varied from 0 to 3.6 per km with a mean value of 0.8 per km.

Generally, there appear to be some indication of higher crash rate being associated with higher vertical curve density within segments as shown in *Figure 4.12.*

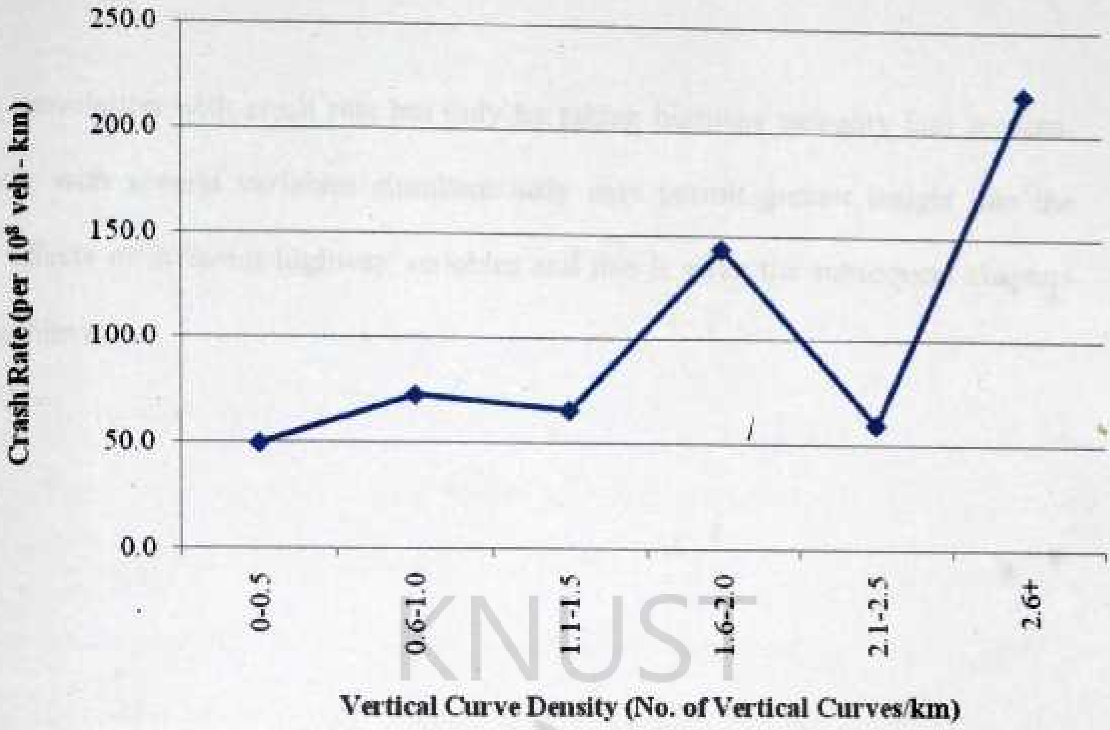

Figure 4.12: Crash Rate by Vertical Curve Density

Road Surface Type: Asphaltic surfacing represented 55.3% of the sites surveyed whilst surface dressed roads constituted 44.7%.

Road geometry data for all 76 sites have been presented in detail in *Appendix A4*.

The initial analysis has looked at the average crash rate for each factor level in turn. A major limitation of bivariate statistics is that the relationship between one variable and another may be masked or appear in misleading light and should be interpreted with caution (Vogt and Bared, 1998; Fletcher *et al.*, 2006). Factors interact with one another and hence a more complex analysis is also required in order to obtain a better understanding of what factors influence crashes, for example mean speed may show a positive correlation with crash rate but only by taking highway category into account. Modelling with several variables simultaneously may permit greater insight into the relative effects of different highway variables and this is what the subsequent chapters seek to achieve.

CHAPTER 5

5.0 MODEL DEVELOPMENT

5.1 Multiple Regression Analysis

The main objective of modelling with several variables simultaneously was to permit greater insight into the relative effects of the different highway variables on crashes. Modelling was undertaken at two stages – the 'core' model and the 'full' model all within the framework of Generalised Linear Models (GLMs). The 'core' model included exposure variables only which in this case were the traffic flow and section length. Apart from the fact that 'core' models have the advantage of being simple in form, they are also useful as a rough guide for identification of locations with a high frequency of crashes (blackspots), as well as for the prediction of the effect of traffic flow changes on crash occurrence (Salifu, 2004).

It is also important to know that there are a large number of variables apart from traffic flow and length that might contribute to crashes. These variables will not be in the list of factors included in the 'core' model. The 'full' model which was developed included a wider range of other important causal variables.

Following the knowledge established from the review of previous work the general form of the 'core' and 'full' models developed under this study were:

'Core Model'

$$E(Y) = a_o L^{a1} Q^{a2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5.1)$$

'Full Model'.

$$E(Y) = a_o L^{a1} Q^{a2} \exp \sum_j b_j x_j \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5.2)$$

where: $E(Y)$ = predicted crash frequency,

L = section length (km),

Q = ADT (per day),

x_j = is any variable additional to L and Q, and

exp = exponential function, e = 2.7183

a_0, a_1, a_2, b_j = are the model parameters

In accordance with the GLM framework, *Equations - (5.1)* and - *(5.2)* are transformed into the prediction mode using a log-link function as follows:

'Core Model'

$$\ln[E(Y)] = \ln(a_o) + a_1 \ln(L) + a_2 \ln(Q) \quad \ldots \quad \ldots \quad \ldots \quad (5.3)$$

Full Model'

$$\ln[E(Y)] = \ln(a_o) + a_1 \ln(L) + a_2 \ln(Q) + \sum_j b_j x_j \quad \ldots \quad \ldots \quad (5.4)$$

5.2 Modelling Procedure

The mean and variance for the crash data presented in *Appendix A1* were 3.96 and 8.28 respectively which indicated that the data set was over-dispersed since the variance is greater than the mean. Initial modelling using Poisson error structure also showed that the estimated dispersion parameter (Φ) defined as:

$$\Phi = \frac{Pearson\ \chi^2}{(N - p)}$$

where N is the total number of sections and p is the number of parameters in the model was greater than one (1) indicating that the data set was over-dispersed (McCullagh and Nelder, 1989). That means Poisson distribution is not capable of explaining the true distribution underlying the crash frequency.

Generalised Linear Model (GLM) was used to estimate the model coefficients using the STATA software package and assuming a Negative Binomial error distribution, all consistent with earlier research works in developing these models. By specifying the dependent variable, the explanatory variables, the error structure (in this case the Negative Binomial) and the link function (in this case log), the model is fitted. Model parameters (coefficients) were estimated using maximum likelihood approach. The procedure which was adopted in the model development was the forward procedure in which the variables were added to the model one by one.

5.3 Model Evaluation

In consonance with earlier studies, the decision on which variables should be retained in the model was based on two criteria. The first criterion was whether the t-ratio of the estimated parameter was significant at the 95% confidence level (p-value less than 5%). The second criterion was whether the addition of the variable to the model cause a significant drop in the scaled deviance at the 95% confidence level.

Two statistical measures were used in assessing the validity of the model developed. These were the Pearson Chi-square statistic and Deviance statistic. The coefficient of determination (R^2) was also employed to determine the amount of variability in the response variable explained by the variation in the selected set of explanatory variables. The R-squared estimation was carried out by the method recommended by Miaou (1996).

5.4 Variables Included in the Model

Although a large number of variables were collected and considered for inclusion in the 'full' model development, only variables with significant estimated parameter coefficients (p-values less than 5%) were maintained in the model. This method is similar to the one used by Vogt and Bared (1998).

The variables shown in *Table 5.1* were thus, used in the full model development. Variables such as mean speed, 85[th] percentile speed, percentage of heavy goods vehicles, horizontal curve density, vertical curve density, access density, carriageway width, shoulder width and the presence of road marking were found not to be significant explanatory variables ($p > 0.05$) as indicated in *Appendices A5.1 – A5.9* and were therefore excluded from the full model developed.

Table 5.1: Description of Variables and Symbols Used for Crash Prediction Models

No.	Variable Name	Description	Variable Type	Symbol
1	lnvolume	The Logarithm of Average Daily Traffic	Continuous	Q
2	lnlengthkm	The Logarithm of Link Length (km)	Continuous	L
4	juncdensity	Junction Density	Continous	JDen
5	terraintype	Terrain Type	Categorical (1 – flat, 0 - otherwise)	TerTyp
6	presenc~ment	Presence of Village Settlement	Categorical (1 - present, 0 – absent)	VSet

CHAPTER 6

6.0 MODEL RESULTS AND INTERPRETATION

6.1 'Core' Model

Parameter estimations for the log-linear equation for the 'core' model using Negative Binomial error structure are as shown in *Table 6.1*.

Table 6.1: Parameter estimation for 'core' model as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -163.95823
Iteration 1:   log likelihood = -163.89316
Iteration 2:   log likelihood = -163.89315

Generalized linear models                    No. of obs        =        76
Optimization     : ML                        Residual df       =        73
                                             Scale parameter   =         1
Deviance         =  77.72004149              (1/df) Deviance   =  1.064658
Pearson          =  79.62984854              (1/df) Pearson    =   1.09082

Variance function: V(u) = u+(0.08)u^2        [Neg. Binomial]
Link function    : g(u) = ln(u)              [Log]

                                             AIC               =  4.391925
Log likelihood   = -163.8931477              BIC               = -238.4235

------------------------------------------------------------------------------
             |                 OIM
injurycras~s |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    lnvolume |   .3710732   .0906441     4.09   0.000      .193414    .5487323
    lnlength |    .366611    .141817     2.59   0.010     .0886549    .6445672
       _cons |  -1.927247   .7320971    -2.63   0.008    -3.362131   -.4923635
------------------------------------------------------------------------------
```

The resulting 'core' model has been determined to be as follows:

$$E(Y) = 0.1 \times L^{0.3666} \times Q^{0.3711}$$

where: $E(Y)$ = expected crashes along the road segment for 3 years,

L = length (km) of road segment and

Q = Average Daily Traffic (ADT)

The goodness-of-fit statistics for the model shows that the model fits reasonably well with the data. The Pearson Chi-square and deviance statistics divided by its degrees of freedom were estimated to be 1.09 and 1.06 respectively as shown in *Table 6.1*. The values are within the permissible range of 0.8 and 1.2 (Dissanayake and Ratnayake, 2006) indicating that the Negative Binomial distribution assumption is acceptable.

The Average Daily Traffic (ADT) and segment length were statistically significant ($p < 0.05$) with positive estimated model parameters in the 'core' model. This indicates that the crash frequency increases with an increase in the traffic flow or segment length whilst the other variables are held constant. The exponent on segment length was 0.37. Since distance travelled is a measure of exposure, it follows that the more distance travelled, the more likely one could be involved in a crash. The exponent on traffic flow (ADT) was also estimated to be 0.37. This figure seems to be small when compared with other studies elsewhere (Dissanayake and Ratnayake, 2006; Qin *et al.*, 2004; Vogt and Bared, 1998) and considering the importance of traffic flow as a major determinant of road traffic crashes. Qin *et al.*, 2004 when they analysed different crash types found the lowest exponent of 0.4 on Average Annual Daily Traffic (AADT) when they considered only single-vehicle crashes. In the crash statistics on rural highway segments sampled for the study, over two-thirds (68.1%) involved single-vehicles and this may partly explain the rather low exponent value for the ADT.

Using the R-squared value, the variables in the flow based model ('core' model), namely traffic flow and segment length could only explain 31.3% of the total variation in the crash data. According to Salifu (2004), 'core' models may be regarded as relatively coarse and rough estimators of crash frequency.

6.2 'Full' Model

Parameter estimations for the log-linear equation for the 'full' model using negative binomial error structure are as shown in *Table 6.2*.

Table 6.2: Parameter estimation for 'full' model as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -144.05758
Iteration 1:   log likelihood = -143.43351
Iteration 2:   log likelihood =  -143.4325
Iteration 3:   log likelihood =  -143.4325

Generalized linear models                    No. of obs      =          76
Optimization     : ML                        Residual df     =          70
                                             Scale parameter =           1
Deviance         =  56.84761615              (1/df) Deviance =    .8121088
Pearson          =  56.67047211              (1/df) Pearson  =    .8095782

Variance function: V(u) = u+(0.0002)u^2      [Neg. Binomial]
Link function    : g(u) = ln(u)              [Log]

                                             AIC             =    3.932434
Log likelihood   = -143.4325036              BIC             =   -246.3037

------------------------------------------------------------------------------
             |                 OIM
injurycras~s |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    lnvolume |   .2479325   .0812996     3.05   0.002     .0885883    .4072767
  lnlengthkm |   .5059926   .1330352     3.80   0.000     .2452483    .7667368
 juncdensity |   .2778617    .141237     1.97   0.049     .0010422    .5546811
 terraintype |    .455121   .1286608     3.54   0.000     .2029504    .7072915
presenc~ment |    .471743   .1359147     3.47   0.001     .2053551     .738131
       _cons |  -1.688964   .6415961    -2.63   0.008    -2.946469   -.4314587
------------------------------------------------------------------------------
```

The resulting 'full' model has been determined to be as follows:

$$E(Y) = 0.1847 \times L^{0.5060} \times Q^{0.2479} \times EXP^{(0.2779\ JDen + 0.4551\ TerTyp + 0.4717\ VSet)}$$

where: *E(Y)* = expected crashes along the road segment for 3 years,

L = length (km) of road segment and

Q = Average Daily Traffic (ADT)

JDen = Junction Density

TerTyp = Terrain Type (1 – flat, 0 – otherwise)

Vset = Presence of Village Settlement (1 – present, 0 – absent)

EXP = Exponential function, e = 2.718282

The goodness-of-fit statistics for the full model shows that, the model fits reasonably well with the data. The Pearson Chi-square and deviance statistics divided by its degrees of freedom were estimated to be 0.81 as shown in *Table 6.2*. In other words, the estimated values of the Pearson Chi-square and deviance divided by the degrees of freedom were within the permissible range (i.e. between 0.8 and 1.2) indicating that the negative binomial distribution assumption is acceptable.

The R-squared value for the full model seems to be reasonable as it could explain 61.2% of the variation in the crash data. Dissanayake and Ratnayake (2006) have said the coefficient of determination is significant if found to be greater than 0.45. Approximately 39% of the systematic variations in the data set remain unexplained by the model developed. The 'percentage unexplained' may be attributed to human behaviour which has increasingly been acknowledged as one of the predominant factors in road traffic crashes and factors relating to the vehicle.

The following sections consider the significant variables identified through the 'full' model results.

6.2.1 Traffic Flow and Safety

The Average Daily Traffic (ADT) in the 'full' model was also significant with positive estimated model parameter. From the model, an increase in the traffic flow by 50% is expected to cause an increase in road traffic crashes by 11% whilst doubling the number of vehicles on the road is expected to cause an increment of 19%. Meanwhile, the proportions of heavy goods vehicles were found not to have a significant effect on crashes in this study (*Appendix A5.6*).

6.2.2 Road Segment and Safety

The length of road segment, the other important exposure variable aside traffic volume was the most significant predictor in the 'full' model with a positive estimated exponent of 0.51. This was as expected as distance travelled is a measure of exposure therefore it follows that the longer the distance travelled, the more likely one is involved in a crash.

6.2.3 Junction Density and Safety

The number of junctions per unit length within a road segment has a considerable influence on the crash risk as indicated by the estimated model parameter. In general, the more the number of junctions per unit length of segment, the higher the crash risk. For example, for all other variables held constant, adding one junction to 1 km section of road segment increases crashes by 32.0%. The number of junctions on a highway should therefore be limited to carefully designed ones to improve road traffic safety in Ghana

6.2.4 Terrain Type and Safety

The analysis suggests that, flat terrains record more injury crashes when compared with rolling or hilly terrains. An increase of 57.6% in injury crashes occurred at links with flat terrain compared with links with rolling or hilly terrain. This probably had to do in part, with the fact that drivers tend to travel at higher speeds on straight and flat road sections than on rolling or hilly terrains.

6.2.5 Presence of Village Settlement and Safety

The explanatory variable for presence of village settlement proved to be very important in the model. An increase of 60.3% in injury crashes were found for sections which had a village settlement within them compared with segments with no settlements.

From the crash data used in the model development, 90 (29.9%) were 'hit pedestrian' collisions of which 81.1% occurred in the settlement areas. It was presumed that the variable 'presence of village settlement' represents the level of pedestrian interference with vehicles on the highways. The interaction between fast moving vehicles and pedestrians is undesirable and contribute to the high number of injury crashes in the settlement areas.

CHAPTER 7

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Injury road traffic crashes on the rural highway sections in the Ashanti Region of Ghana have been analysed and statistical models developed to identify contributory factors that are likely to affect these crashes. Generalised Linear Model (GLM) with Negative Binomial (NB) error structure was used to estimate the model parameters. Two types of models, the 'core' model which included key traffic exposure variables only and the 'full' model which included a wider range of variables were developed.

The Ashanti Region alone accounted for more than one-fifth of all road traffic fatalities in Ghana and majority (67.3%) of these fatalities occurred on the rural highways. 'Hit pedestrian' collision was the dominant collision type (38.6%) and significant proportion (91.7%) of them occurred within village settlements. Majority (70.3%) of crashes in the Ashanti Region were identified to be single-vehicle collisions

From the model developed, traffic flow, segment length, junction density, terrain type and presence of village settlement within road link are significant explanatory variables that influence the prediction of injury crashes on the rural highways in the Ashanti Region of Ghana. The study proved that, passing a highway through settlement areas, traffic volume, provision of long straight and flat sections and increasing number of junctions per unit road length tend to worsen road traffic safety.

Road and Traffic Engineers and Planners can apply the crash prediction model as a tool in safety improvement works and in the design of new safer roads.

7.2 Recommendation

From the model developed and subsequent discussions above, the following recommendations are drawn:

- Safety situations on the highways should be improved through the provision of by-passes around the village settlements.

- The number of junctions on a highway should be limited to carefully designed ones to improve road traffic safety in Ghana.

- Road Engineers should as much as possible avoid provision of long straight and flat sections on highways to improve traffic safety. Intermittent graceful curves could be introduced to break the monotony.

7.3 Limitations of Study

The models developed in the study apply to segments of rural two-lane highways between 0.8 km and 6.7 km in the Ashanti Region of Ghana. The data base, particularly for traffic volume ranged from 347 – 8,948 vehicles per day. Outside these ranges the model predictions can be considered to be less robust. Again, the application of the model is considered valid for predicting only injury road traffic crashes.

7.4 Further Research

It is hoped that predominant crash types on the rural highway sections such as 'hit pedestrian' collisions and 'vehicle ran-off road' collisions could be modelled separately to establish the causal relationships. Such separate crash prediction models for specific crash types on the rural highways will offer opportunities to gain in-depth knowledge about these types of crashes and their collision mechanism

It would also be desirable to repeat the study for the entire country to help determine the key risk factors associated with traffic crashes on rural highways in Ghana.

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APPENDICES

Appendix A1: Road Traffic Crash Characteristics for Segments

No.	Section Name	Crash Severity			Injury Crashes
		Fatal	Serious	Slight	
	NATIONAL ROADS				
1	Dadieso - Four Junction	3	1	2	6
2	Four Junction - Bereku	3	2	1	6
3	Bereku - Asankare Barrier	1	1	1	3
4	Asankare Barrier - Atwedie	6	6	1	13
5	Atwedie - Water Works Town	2	1	1	4
6	Water Works Town - Cognac Guest Hse	4	1	3	8
7	Cognac Guest House - Juaso Cemetery	2	1	2	5
8	Juaso Cemetery - Sawmill	4	6	3	13
9	Sawmill - Adom Hospital	2	1	4	7
10	Topman Farm Jxn - Messiah Voc Inst, Mfensi	4	3	3	10
11	Diasempa Pig Farm - Dwenewoho	2	1	2	5
12	1st Mankranso Jxn - Bronikrom	2	3	4	9
13	Bronikrom - Attakrom	0	1	0	1
14	Attakrom - Kwadwokrom	1	0	0	1
15	(Biemso No. 1 Jxn - Filling St.) Adugyaman	2	2	2	6
16	Adugyaman - Potrikrom	0	0	1	1
17	Kyekyewere - Star Oil	0	3	0	3
18	Star Oil - Kwapia	1	1	1	3
19	Kwapia - Next Turn Farm(Akrokeri Jxn)	0	0	1	1
20	Next Turn Farm(Akrokeri Jxn) - Biribiwomang Jxn	3	1	3	7
21	Biribiwomang Jxn - Hemang	3	1	1	5
22	Hemang - Jacobu Jxn	1	1	0	2
23	Jacobu Jxn - Afoako	4	1	0	5
24	Ahwiaa - Daa	3	1	1	5
25	Daa - Anwiankwanta	0	1	1	2
26	CEPS Barrier, Anwiankwanta - Senfi Jxn	0	0	1	1
27	Senfi Jxn - Poultry Farm, Ofoase Kokoben	0	1	0	1
28	Poultry Farm, Ofoase Kokoben - Sharp Curve, Dominase Jxn	1	1	0	2
29	Sharp Curve, Dominase Jxn - Adjamesu	1	2	1	4
30	Adjamesu - Pakyi No. 1	3	2	1	6
31	Pakyi No. 1 - Pakyi No. 2	2	4	2	8

Appendix A1: Road Traffic Crash Characteristics for Segments *Cont'd*

No.	Section Name	Crash Severity			Injury Crashes
		Fatal	Serious	Slight	
	INTER-REGIONAL ROADS				
32	Cattle Range, Afari - Nkawie	1	2	1	4
33	Mpasatia - Goldfields	0	2	0	2
34	Goldfields - Anyinamso No. 1	0	0	1	1
35	Anyinamso No. 1 - Anyinamso No. 2	4	3	3	10
36	Betinko - Mmofranfaadwen	2	4	0	6
37	Mmofranfaadwen - Amangoase	0	0	1	1
38	Amangoase - Adiembra	1	1	0	2
39	Asibe Nkwanta - Abrokyire Junction	6	3	3	12
40	Nyinahin - Akoraboukrom	0	1	2	3
41	Akoraboukrom - Otaakrom	2	0	0	2
42	Otaakrom - Atwima Takoradi	0	2	3	5
43	Atwima Takoradi - River Nkontankontan	0	4	0	4
44	River Nkontankontan - Antwi Adjei Jxn	1	2	1	4
45	Mamponteng - Toll Booth	1	4	1	6
46	Aboaso - Ntonso	1	1	0	2
47	Ntonso - Mountain High School	2	3	0	5
48	Mountain High School - Kona	0	0	2	2
49	Kona - Tano Odumasi	0	3	1	4
50	Tano Odumasi - Agona	0	3	2	5
51	Agona - Jamasi	1	4	1	6
52	Mampong Scarp starts - Scarp ends	1	2	2	5

Appendix A1: Road Traffic Crash Characteristics for Segments *Cont'd*

No.	Section Name	Crash Severity			Injury Crashes
		Fatal	Serious	Slight	
	REGIONAL ROADS				
53	Sikafremogya Jxn, Mankranso - Kunsu	2	1	2	5
54	Kunsu - Nyameadom	0	1	0	1
55	Nyameadom - Okroase	0	2	2	4
56	River Adwuku - Suro Nyame Akura	1	1	1	3
57	Suro Nyame Akura - Barniekrom	2	0	0	2
58	Onyinamfo - Awadua	0	1	0	1
59	Awadua - Wioso	0	2	2	4
60	Hwebaa - Jacobu	1	0	1	2
61	River Afieso - Akyawkrom	2	2	1	5
62	Akyawkrom - Asotwe	1	3	0	4
63	Asotwe - Bonwire Jxn	2	0	0	2
64	Bonwire Junction - Yaw Nkrumah	0	1	1	2
65	Yaw Nkrumah - Juaben	1	1	0	2
66	Juaben - Effiduase	1	0	1	2
67	Atonsu Jxn - Nyaboo	0	2	0	2
68	Patriensa - Biama	0	0	1	1
69	Biama - Kyekyebiase	0	1	0	1
70	River Owere - Agogo Curve Begins	2	1	0	3
71	Agogo Curve Begins - Curve Ends	1	0	0	1
72	Abono - Patrensa	1	0	0	1
73	Patrensa - Dept of Food and Agric, Kuntenase	0	1	1	2
73	Abrankese - Pramso	0	1	0	1
75	Jachie - Abidjan Nkwanta	1	3	0	4
76	Abidjan Nkwanta - Pledge Tex Plywood	1	0	1	2

Appendix A2: Speed Characteristics for Road Segments

No.	Section Name	Mean Speed (km/h)	Standard Deviation (km/h)	85th Percentile (km/h)	Minimum Speed (km/h)	Maximum Speed (km/h)
	NATIONAL ROADS					
1	Dadieso - Four Junction	93.1	23.9	119.5	46	158
2	Four Junction - Bereku	91.6	18.1	111.4	47	133
3	Bereku - Asankare Barrier	86.2	19.7	106.2	28	132
4	Asankare Barrier - Atwedie	94.9	21.2	117.0	38	163
5	Atwedie - Water Works Town	92.0	18.7	111.3	53	184
6	Water Works Town - Cognac Guest Hse	96.3	20.1	118.0	25	161
7	Cognac Guest House - Juaso Cemetery	69.3	19.0	90.0	25	129
8	Juaso Cemetery - Sawmill	89.2	18.8	108.0	48	149
9	Sawmill - Adom Hospital	88.2	18.7	105.7	49	141
10	Topman Farm Jxn - Messiah Voc Inst, Mfensi	76.7	15.6	93.5	37	120
11	Diasempa Pig Farm - Dwenewoho	83.1	16.9	98.0	23	154
12	1st Mankranso Jxn - Bronikrom	87.6	18.1	103.0	45	155
13	Bronikrom - Attakrom	84.2	16.7	100.3	45	124
14	Attakrom - Kwadwokrom	91.4	16.4	106.0	48	140
15	(Biemso No. 1 Jxn - Filling St.) Adugyaman	83.8	17.0	100.3	46	132
16	Adugyaman - Potrikrom	89.6	18.4	110.0	39	141
17	Kyekyewere - Star Oil	77.5	15.1	90.2	36	127
18	Star Oil - Kwapia	84.9	16.4	101.6	55	134
19	Kwapia - Next Turn Farm(Akrokeri Jxn)	81.3	16.6	97.0	46	138
20	Next Turn Farm(Akrokeri Jxn) - Biribiwomang Jxn	88.9	15.2	104.0	47	132
21	Biribiwomang Jxn - Hemang	78.1	15.4	93.0	23	121
22	Hemang - Jacobu Jxn	70.9	13.7	84.0	29	104
23	Jacobu Jxn - Afoako	76.6	14.1	93.6	46	104
24	Ahwiaa - Daa	82.4	16.5	99.0	33	122
25	Daa - Anwiankwanta	79.7	12.0	91.7	44	110
26	CEPS Barrier, Anwiankwanta - Senfi Jxn	74.3	12.9	87.1	42	115
27	Senfi Jxn - Poultry Farm, Ofoase Kokoben	77.9	15.4	93.5	50	123
28	Poultry Farm, Ofoase Kokoben - Sharp Curve, Dominase Jxn	71.0	11.2	83.0	46	99
29	Sharp Curve, Dominase Jxn - Adjamesu	77.8	13.1	89.1	45	117
30	Adjamesu - Pakyi No. 1	91.5	16.4	106.0	55	142
31	Pakyi No. 1 - Pakyi No. 2	77.9	13.8	91.0	42	126

Appendix A2: Speed Characteristics for Road Segments *Cont'd*

No.	Section Name	Mean Speed (km/h)	Standard Deviation (km/h)	85th Percentile (km/h)	Minimum Speed (km/h)	Maximum Speed (km/h)
	INTER-REGIONAL ROADS					
32	Cattle Range, Afari - Nkawie	80.1	13.9	93.0	52	133
33	Mpasatia - Goldfields	86.4	15.5	103.3	41	131
34	Goldfields - Anyinamso No. 1	82.5	18.2	101.0	47	144
35	Anyinamso No. 1 - Anyinamso No. 2	82.1	18.5	103.0	33	130
36	Betinko - Mmofranfaadwen	92.6	20.5	111.7	53	154
37	Mmofranfaadwen - Amangoase	84.7	18.2	108.0	52	129
38	Amangoase - Adiembra	93.6	16.9	111.0	58	138
39	Asibe Nkwanta - Abrokyire Junction	86.8	16.9	103.2	34	134
40	Nyinahin - Akoraboukrom	87.9	17.3	105.0	51	129
41	Akoraboukrom - Otaakrom	91.1	18.1	107.7	61	151
42	Otaakrom - Atwima Takoradi	81.4	17.2	96.4	48	136
43	Atwima Takoradi - River Nkontankontan	93.3	15.8	107.3	64	141
44	River Nkontankontan - Antwi Adjei Jxn	83.3	16.5	96.0	45	123
45	Mamponteng - Toll Booth	79.7	13.4	94.1	41	111
46	Aboaso - Ntonso	71.3	11.1	82.0	42	99
47	Ntonso - Mountain High School	87.9	18.3	105.8	39	142
48	Mountain High School - Kona	69.7	15.1	83.0	24	106
49	Kona - Tano Odumasi	86.5	14.7	102.0	53	125
50	Tano Odumasi - Agona	75.2	13.1	86.0	47	128
51	Agona - Jamasi	85.0	15.5	100.0	34	139
52	Mampong Scarp starts - Scarp ends	48.6	9.2	58.0	14	66

Appendix A2: Speed Characteristics for Road Segments *Cont'd*

No.	Section Name	Mean Speed (km/h)	Standard Deviation (km/h)	85th Percentile (km/h)	Minimum Speed (km/h)	Maximum Speed (km/h)
	REGIONAL ROADS					
53	Sikafremogya Jxn, Mankranso - Kunsu	77.3	16.5	91.0	35	125
54	Kunsu - Nyameadom	80.8	15.5	94.8	53	126
55	Nyameadom - Okroase	68.5	11.9	79.0	27	95
56	River Adwuku - Suro Nyame Akura	74.8	15.4	93.4	39	104
57	Suro Nyame Akura - Barniekrom	88.7	15.2	102.0	46	124
58	Onyinamfo - Awadua	83.3	12.2	94.0	50	109
59	Awadua - Wioso	85.9	13.7	97.7	59	127
60	Hwebaa - Jacobu	84.7	12.8	99.7	54	116
61	River Afieso - Akyawkrom	55.0	8.2	64.0	35	80
62	Akyawkrom - Asotwe	67.5	12.7	79.0	23	108
63	Asotwe - Bonwire Jxn	67.3	13.6	80.0	28	109
64	Bonwire Junction - Yaw Nkrumah	75.0	12.3	85.0	32	111
65	Yaw Nkrumah - Juaben	73.3	10.6	83.0	44	107
66	Juaben - Effiduase	64.0	9.8	73.0	36	91
67	Atonsu Jxn - Nyaboo	72.5	11.5	83.0	37	113
68	Patriensa - Biama	69.2	10.8	77.0	35	103
69	Biama - Kyekyebiase	60.6	14.3	75.6	22	102
70	River Owere - Agogo Curve Begins	71.7	12.1	82.0	26	110
71	Agogo Curve Begins - Curve Ends	67.0	8.7	76.0	42	85
72	Abono - Patrensa	44.0	8.8	54.0	19	62
73	Patrensa - Dept of Food and Agric, Kuntenase	70.4	12.9	82.0	26	113
73	Abrankese - Pramso	68.4	8.7	77.0	38	90
75	Jachie - Abidjan Nkwanta	61.4	10.2	70.2	32	90
76	Abidjan Nkwanta - Pledge Tex Plywood	65.9	9.6	74.5	44	96

Appendix A3: Vehicular Flow Characteristics for Road Segments

No.	Section Name	Traffic Flow (ADT)	Percentage (%) of Heavy Vehicles
	NATIONAL ROADS		
1	Dadieso - Four Junction	8948	22.2
2	Four Junction - Bereku	8948	22.2
3	Bereku - Asankare Barrier	8948	22.2
4	Asankare Barrier - Atwedie	8948	22.2
5	Atwedie - Water Works Town	8948	22.2
6	Water Works Town - Cognac Guest Hse	8948	22.2
7	Cognac Guest House - Juaso Cemetery	8948	22.2
8	Juaso Cemetery - Sawmill	8948	22.2
9	Sawmill - Adom Hospital	8948	22.2
10	Topman Farm Jxn - Messiah Voc Inst, Mfensi	5310	2.7
11	Diasempa Pig Farm - Dwenewoho	5310	2.7
12	1st Mankranso Jxn - Bronikrom	5310	2.7
13	Bronikrom - Attakrom	5310	2.7
14	Attakrom - Kwadwokrom	5310	2.7
15	(Biemso No. 1 Jxn - Filling St.) Adugyaman	5310	2.7
16	Adugyaman - Potrikrom	5310	2.7
17	Kyekyewere - Star Oil	2171	3.4
18	Star Oil - Kwapia	2171	3.4
19	Kwapia - Next Turn Farm(Akrokeri Jxn)	2171	3.4
20	Next Turn Farm(Akrokeri Jxn) - Biribiwomang Jxn	2171	3.4
21	Biribiwomang Jxn - Hemang	2171	3.4
22	Hemang - Jacobu Jxn	2171	3.4
23	Jacobu Jxn - Afoako	2171	3.4
24	Ahwiaa - Daa	2171	3.4
25	Daa - Anwiankwanta	2171	3.4
26	CEPS Barrier, Anwiankwanta - Senfi Jxn	6172	19.3
27	Senfi Jxn - Poultry Farm, Ofoase Kokoben	6172	19.3
28	Poultry Farm, Ofoase Kokoben - Sharp Curve, Dominase Jxn	6172	19.3
29	Sharp Curve, Dominase Jxn - Adjamesu	6172	19.3
30	Adjamesu - Pakyi No. 1	6172	19.3
31	Pakyi No. 1 - Pakyi No. 2	7167	20.1

Appendix A3: Vehicular Flow Characteristics for Road Segments *Cont'd*

No.	Section Name	Traffic Flow (ADT)	Percentage (%) of Heavy Vehicles
	INTER-REGIONAL ROADS		
32	Cattle Range, Afari - Nkawie	3849	11.4
33	Mpasatia - Goldfields	3849	11.4
34	Goldfields - Anyinamso No. 1	3849	11.4
35	Anyinamso No. 1 - Anyinamso No. 2	3849	11.4
36	Betinko - Mmofranfaadwen	3849	11.4
37	Mmofranfaadwen - Amangoase	3849	11.4
38	Amangoase - Adiembra	3849	11.4
39	Asibe Nkwanta - Abrokyire Junction	3678	12.4
40	Nyinahin - Akoraboukrom	3678	12.4
41	Akoraboukrom - Otaakrom	3678	12.4
42	Otaakrom - Atwima Takoradi	3678	12.4
43	Atwima Takoradi - River Nkontankontan	3678	12.4
44	River Nkontankontan - Antwi Adjei Jxn	3678	12.4
45	Mamponteng - Toll Booth	3792	5.7
46	Aboaso - Ntonso	3792	5.7
47	Ntonso - Mountain High School	3081	4.8
48	Mountain High School - Kona	3081	4.8
49	Kona - Tano Odumasi	3081	4.8
50	Tano Odumasi - Agona	3081	4.8
51	Agona - Jamasi	3081	4.8
52	Mampong Scarp starts - Scarp ends	3081	4.8

Appendix A3: Vehicular Flow Characteristics for Road Segments *Cont'd*

No.	Section Name	Traffic Flow (ADT)	Percentage (%) of Heavy Vehicles
REGIONAL ROADS			
53	Sikafremogya Jxn, Mankranso - Kunsu	663	8.7
54	Kunsu - Nyameadom	663	8.7
55	Nyameadom - Okroase	663	8.7
56	River Adwuku - Suro Nyame Akura	663	8.7
57	Suro Nyame Akura - Barniekrom	663	8.7
58	Onyinamfo - Awadua	663	8.7
59	Awadua - Wioso	663	8.7
60	Hwebaa - Jacobu	663	8.7
61	River Afieso - Akyawkrom	1955	14.0
62	Akyawkrom - Asotwe	1955	14.0
63	Asotwe - Bonwire Jxn	1955	14.0
64	Bonwire Junction - Yaw Nkrumah	1955	14.0
65	Yaw Nkrumah - Juaben	1955	14.0
66	Juaben - Effiduase	1955	14.0
67	Atonsu Jxn - Nyaboo	1319	4.9
68	Patriensa - Biama	1319	4.9
69	Biama - Kyekyebiase	1319	4.9
70	River Owere - Agogo Curve Begins	1319	4.9
71	Agogo Curve Begins - Curve Ends	1319	4.9
72	Abono - Patrensa	347	0.1
73	Patrensa - Dept of Food and Agric, Kuntenase	347	0.1
73	Abrankese - Pramso	3288	0.3
75	Jachie - Abidjan Nkwanta	3288	0.3
76	Abidjan Nkwanta - Pledge Tex Plywood	3288	0.3

Appendix A4: Road Geometry Characteristics for Road Segments

No.	Section Name	Length (km)	Road Surfacing Type	Carriageway Width (m)	Road Marking	Type of Road Marking	Presence of shoulder	Shoulder Type (If any)	Width of shoulder (m)
NATIONAL ROADS									
1	Dadieso - Four Junction	2.0	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
2	Four Junction - Bereku	6.0	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
3	Bereku - Asankare Barrier	4.7	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
4	Asankare Barrier - Atwedie	6.3	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
5	Atwedie - Water Works Town	1.6	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
6	Water Works Town - Cognac Guest Hse	3.4	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
7	Cognac Guest House - Juaso Cemetery	2.0	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
8	Juaso Cemetery - Sawmill	3.8	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
9	Sawmill - Adom Hospital	3.2	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.5
10	Topman Farm Jxn - Messiah Voc Inst, Mfensi	2.1	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
11	Diasempa Pig Farm - Dwenewoho	1.9	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
12	1st Mankranso Jxn - Bronikrom	2.3	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
13	Bronikrom - Attakrom	1.3	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
14	Attakrom - Kwadwokrom	0.8	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
15	(Biemso No. 1 Jxn - Filling St.) Adugyaman	0.8	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
16	Adugyaman - Potrikrom	1.3	Asphalt	7.8	Present	CL & Edges	Yes	Paved	2.2
17	Kyekyewere - Star Oil	2.4	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.2
18	Star Oil - Kwapia	1.8	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.0

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	No. of Horizontal Curves	Presence of Sharp Curve	No. of Vertical Curves	Presence of Steep Gradient	Terrain Type	No. of Junctions	Presence of Village Settlement	Accesses
	NATIONAL ROADS								
1	Dadieso - Four Junction	1	Present	3	Present	Flat	1	Absent	3
2	Four Junction - Bereku	6	Present	7	Present	Rolling	2	Present	4
3	Bereku - Asankare Barrier	2	Present	4	Present	Rolling	1	Present	6
4	Asankare Barrier - Atwedie	3	Present	3	Absent	Flat	2	Present	11
5	Atwedie - Water Works Town	1	Absent	0	Absent	Flat	0	Absent	1
6	Water Works Town - Cognac Guest Hse	3	Absent	1	Present	Rolling	0	Present	9
7	Cognac Guest House - Juaso Cemetery	1	Absent	1	Absent	Flat	3	Present	7
8	Juaso Cemetery - Sawmill	1	Absent	1	Absent	Flat	1	Present	7
9	Sawmill - Adom Hospital	1	Absent	2	Absent	Flat	1	Absent	7
10	Topman Farm Jxn - Messiah Voc Inst, Mfensi	1	Absent	1	Absent	Flat	2	Present	12
11	Diasempa Pig Farm - Dwenewoho	1	Absent	0	Absent	Rolling	0	Present	4
12	1st Mankranso Jxn - Bronikrom	1	Present	0	Absent	Flat	1	Present	3
13	Bronikrom - Attakrom	1	Present	1	Absent	Rolling	0	Absent	1
14	Attakrom - Kwadwokrom	1	Present	0	Absent	Flat	0	Absent	2
15	(Biemso No. 1 Jxn - Filling St.) Adugyaman	0	Absent	1	Absent	Flat	1	Present	14
16	Adugyaman - Potrikrom	1	Present	1	Absent	Flat	0	Absent	0
17	Kyekyewere - Star Oil	5	Present	1	Absent	Rolling	1	Present	4
18	Star Oil - Kwapia	2	Present	0	Absent	Flat	0	Absent	3

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	Length (km)	Road Surfacing Type	Carriageway Width (m)	Road Marking	Type of Road Marking	Presence of shoulder	Shoulder Type (If any)	Width of shoulder (m)
				NATIONAL ROADS					
19	Kwapia - Next Turn Farm(Akrokeri Jxn)	0.9	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.0
20	Next Turn Farm(Akrokeri Jxn) - Biribiwomang Jxn	4.0	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.5
21	Biribiwomang Jxn - Hemang	2.3	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.2
22	Hemang - Jacobu Jxn	2.7	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.2
23	Jacobu Jxn - Afoako	2.6	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.2
24	Ahwiaa - Daa	4.0	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.0
25	Daa - Anwiankwanta	2.1	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.0
26	CEPS Barrier, Anwiankwanta - Senfi Jxn	1.1	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.5
27	Senfi Jxn - Poultry Farm, Ofoase Kokoben	1.4	Asphalt	7.0	Present	CL & Edges	Yes	Paved	2.5
28	Poultry Farm, Ofoase Kokoben - Sharp Curve, Dominase Jxn	2.9	Asphalt	7.0	Present	CL & Edges	Yes	Paved	2.5
29	Sharp Curve, Dominase Jxn - Adjamesu	1.8	Asphalt	7.0	Present	CL & Edges	Yes	Paved	2.5
30	Adjamesu - Pakyi No. 1	2.1	Asphalt	7.0	Present	CL & Edges	Yes	Paved	2.5
31	Pakyi No. 1 - Pakyi No. 2	1.4	Asphalt	7.0	Present	CL & Edges	Yes	Paved	2.5

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	No. of Horizontal Curves	Presence of Sharp Curve	No. of Vertical Curves	Presence of Steep Gradient	Terrain Type	No. of Junctions	Presence of Village Settlement	Accesses
				NATIONAL ROADS					
19	Kwapia - Next Turn Farm(Akrokeri Jxn)	2	Absent	0	Absent	Flat	0	Absent	1
20	Next Turn Farm(Akrokeri Jxn) - Biribiwomang Jxn	6	Absent	3	Absent	Flat	2	Absent	7
21	Biribiwomang Jxn - Hemang	3	Absent	2	Present	Flat	2	Present	3
22	Hemang - Jacobu Jxn	4	Absent	2	Present	Rolling	1	Absent	1
23	Jacobu Jxn - Afoako	5	Absent	2	Absent	Flat	3	Present	7
24	Ahwiaa - Daa	6	Present	2	Absent	Flat	2	Present	5
25	Daa - Anwiankwanta	4	Present	0	Absent	Rolling	0	Absent	1
26	CEPS Barrier, Anwiankwanta - Senfi Jxn	1	Absent	0	Absent	Flat	0	Absent	1
27	Senfi Jxn - Poultry Farm, Ofoase Kokoben	3	Present	1	Absent	Rolling	0	Present	4
28	Poultry Farm, Ofoase Kokoben - Sharp Curve, Dominase Jxn	2	Absent	1	Absent	Rolling	1	Absent	2
29	Sharp Curve, Dominase Jxn - Adjamesu	2	Present	1	Absent	Rolling	3	Present	11
30	Adjamesu - Pakyi No. 1	2	Absent	2	Present	Flat	1	Absent	6
31	Pakyi No. 1 - Pakyi No. 2	0	Absent	2	Present	Flat	2	Present	19

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	Length (km)	Road Surfacing Type	Carriageway Width (m)	Road Marking	Type of Road Marking	Presence of shoulder	Shoulder Type (If any)	Width of shoulder (m)
	INTER-REGIONAL ROADS								
32	Cattle Range, Afari - Nkawie	2.9	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
33	Mpasatia - Goldfields	2.7	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
34	Goldfields - Anyinamso No. 1	3.6	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
35	Anyinamso No. 1 - Anyinamso No. 2	1.9	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
36	Betinko - Mmofranfaadwen	4.0	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
37	Mmofranfaadwen - Amangoase	2.7	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
38	Amangoase - Adiembra	2.4	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
39	Asibe Nkwanta - Abrokyire Junction	3.3	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
40	Nyinahin - Akoraboukrom	3.8	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
41	Akoraboukrom - Otaakrom	2.5	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
42	Otaakrom - Atwima Takoradi	1.9	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
43	Atwima Takoradi - River Nkontankontan	5.9	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
44	River Nkontankontan - Antwi Adjei Jxn	2.8	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.2
45	Mamponteng - Toll Booth	2.4	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
46	Aboaso - Ntonso	1.6	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
47	Ntonso - Mountain High School	1.5	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
48	Mountain High School - Kona	1.6	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
49	Kona - Tano Odumasi	1.3	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
50	Tano Odumasi - Agona	3.1	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
51	Agona - Jamasi	2.1	Asphalt	7.5	Present	CL & Edges	Yes	Paved	2.0
52	Mampong Scarp starts - Scarp ends	4.5	Asphalt	7.5	Present	CL & Edges	Yes	Paved	1.0

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	No. of Horizontal Curves	Presence of Sharp Curve	No. of Vertical Curves	Presence of Steep Gradient	Terrain Type	No. of Junctions	Presence of Village Settlement	Accesses
	INTER-REGIONAL ROADS								
32	Cattle Range, Afari - Nkawie	4	Absent	2	Absent	Flat	0	Present	12
33	Mpasatia - Goldfields	0	Absent	2	Present	Rolling	0	Absent	2
34	Goldfields - Anyinamso No. 1	2	Present	4	Present	Rolling	0	Absent	4
35	Anyinamso No. 1 - Anyinamso No. 2	0	Absent	0	Absent	Flat	2	Present	3
36	Betinko - Mmofranfaadwen	2	Absent	2	Present	Rolling	1	Present	4
37	Mmofranfaadwen - Amangoase	1	Present	2	Absent	Flat	1	Absent	1
38	Amangoase - Adiembra	1	Present	0	Absent	Flat	0	Absent	1
39	Asibe Nkwanta - Abrokyire Junction	1	Absent	2	Present	Flat	2	Present	9
40	Nyinahin - Akoraboukrom	2	Present	3	Present	Rolling	0	Absent	2
41	Akoraboukrom - Otaakrom	0	Absent	1	Absent	Flat	0	Absent	0
42	Otaakrom - Atwima Takoradi	2	Absent	1	Absent	Flat	2	Present	14
43	Atwima Takoradi - River Nkontankontan	1	Present	1	Absent	Rolling	0	Present	5
44	River Nkontankontan - Antwi Adjei Jxn	0	Absent	4	Absent	Rolling	0	Present	3
45	Mamponteng - Toll Booth	2	Absent	0	Absent	Flat	1	Absent	4
46	Aboaso - Ntonso	3	Absent	1	Absent	Flat	0	Absent	4
47	Ntonso - Mountain High School	1	Absent	2	Present	Flat	0	Present	4
48	Mountain High School - Kona	3	Present	1	Present	Rolling	0	Absent	1
49	Kona - Tano Odumasi	1	Absent	3	Present	Flat	0	Absent	3
50	Tano Odumasi - Agona	2	Absent	4	Absent	Rolling	0	Absent	6
51	Agona - Jamasi	5	Present	0	Absent	Rolling	1	Absent	6
52	Mampong Scarp starts - Scarp ends	23	Present	1	Present	Rolling	0	Absent	1

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	Length (km)	Road Surfacing Type	Carriageway Width (m)	Road Marking	Type of Road Marking	Presence of shoulder	Shoulder Type (If any)	Width of shoulder (m)
				REGIONAL ROADS					
53	Sikafremogya Jxn, Mankranso - Kunsu	1.4	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.0
54	Kunsu - Nyameadom	2.7	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.0
55	Nyameadom - Okroase	1.1	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.0
56	River Adwuku - Suro Nyame Akura	1.8	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.0
57	Suro Nyame Akura - Barniekrom	1.2	S. Dressing	7.0	Present	CL & Edges	Ycs	Paved	2.0
58	Onyinamfo - Awadua	2.0	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.0
59	Awadua - Wioso	3.3	S. Dressing	7.0	Present	CL & Edges	Yes	Paved	2.0
60	Hwebaa - Jacobu	3.3	S. Dressing	7.0	Present	CL & Edges	Yes	Pavcd	2.0
61	River Afieso - Akyawkrom	1.4	S. Dressing	7.4	Present	CL & Edges	Yes	Unpaved	1.5
62	Akyawkrom - Asotwe	1.6	S. Dressing	7.4	Present	CL & Edges	Yes	Unpaved	1.5
63	Asotwe - Bonwire Jxn	1.8	S. Dressing	7.4	Present	CL & Edges	Yes	Unpaved	1.5
64	Bonwire Junction - Yaw Nkrumah	1.9	S. Dressing	7.4	Present	CL & Edges	Yes	Unpaved	1.5
65	Yaw Nkrumah - Juaben	2.4	S. Dressing	7.4	Present	CL & Edges	Yes	Unpaved	1.5
66	Juaben - Effiduase	2.1	S. Dressing	7.4	Present	CL & Edges	Yes	Unpaved	2.0
67	Atonsu Jxn - Nyaboo	1.9	S. Dressing	7.4	Absent	None	Yes	Unpaved	3.0
68	Patriensa - Biama	1.4	S. Dressing	7.4	Absent	None	Yes	Unpaved	2.8
69	Biama - Kyekyebiase	1.9	S. Dressing	7.4	Absent	None	Yes	Unpaved	3.0
70	River Owere - Agogo Curve Begins	3.0	S. Dressing	7.4	Absent	None	Yes	Unpaved	1.5
71	Agogo Curve Begins - Curve Ends	1.2	S. Dressing	7.4	Absent	None	Yes	Unpaved	2.0
72	Abono - Patrensa	6.7	S. Dressing	7.0	Present	CL & Edges	Yes	Unpaved	1.2
73	Patrensa - Dept of Food and Agric. Kuntenase	1.2	S. Dressing	7.0	Present	CL & Edges	Yes	Unpaved	1.2
73	Abrankese - Pramso	1.0	S. Dressing	7.0	Present	CL & Edges	Yes	Unpaved	1.2
75	Jachie - Abidjan Nkwanta	1.6	S. Dressing	7.0	Present	CL & Edges	Yes	Unpaved	1.2
76	Abidjan Nkwanta - Pledge Tex Plywood	2.9	S. Dressing	7.0	Present	CL & Edges	Yes	Unpaved	1.2

Appendix A4: Road Geometry Characteristics for Road Segments *Cont'd*

No.	Section Name	No. of Horizontal Curves	Presence of Sharp Curve	No. of Vertical Curves	Presence of Steep Gradient	Terrain Type	No. of Junctions	Presence of Village Settlement	Accesses
	REGIONAL ROADS								
53	Sikafremogya Jxn, Mankranso - Kunsu	2	Absent	5	Present	Flat	1	Present	1
54	Kunsu - Nyameadom	2	Absent	5	Present	Rolling	0	Absent	5
55	Nyameadom - Okroase	3	Present	1	Absent	Flat	0	Present	4
56	River Adwuku - Suro Nyame Akura	1	Absent	1	Absent	Flat	0	Present	4
57	Suro Nyame Akura - Barniekrom	1	Absent	0	Absent	Rolling	1	Absent	0
58	Onyinamfo - Awadua	4	Absent	3	Absent	Flat	0	Absent	1
59	Awadua - Wioso	7	Present	2	Absent	Flat	1	Absent	2
60	Hwebaa - Jacobu	4	Present	3	Present	Rolling	1	Absent	1
61	River Afieso - Akyawkrom	1	Present	2	Present	Rolling	1	Present	5
62	Akyawkrom - Asotwe	2	Present	5	Present	Rolling	1	Present	4
63	Asotwe - Bonwire Jxn	3	Present	2	Present	Flat	0	Present	8
64	Bonwire Junction - Yaw Nkrumah	7	Present	4	Present	Rolling	0	Absent	3
65	Yaw Nkrumah - Juaben	6	Present	6	Present	Rolling	2	Absent	0
66	Juaben - Effiduase	4	Present	1	Absent	Flat	1	Absent	2
67	Atonsu Jxn - Nyaboo	5	Present	1	Absent	Flat	0	Absent	3
68	Patriensa - Biama	3	Present	4	Present	Rolling	1	Absent	1
69	Biama - Kyekyebiase	4	Present	0	Absent	Flat	0	Absent	0
70	River Owere - Agogo Curve Begins	7	Present	4	Present	Rolling	1	Absent	1
71	Agogo Curve Begins - Curve Ends	6	Present	2	Present	Rolling	0	Absent	0
72	Abono - Patrensa	43	Present	5	Present	Rolling	1	Absent	5
73	Patrensa - Dept of Food and Agric, Kuntenase	5	Present	2	Absent	Flat	0	Present	4
73	Abrankese - Pramso	2	Present	2	Absent	Rolling	0	Absent	0
75	Jachie - Abidjan Nkwanta	4	Absent	2	Absent	Flat	2	Present	13
76	Abidjan Nkwanta - Pledge Tex Plywood	4	Absent	1	Absent	Rolling	1	Present	12

Appendix A5.1: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -163.12614
Iteration 1:   log likelihood = -163.07059
Iteration 2:   log likelihood = -163.07058

Generalized linear models                    No. of obs      =        76
Optimization     : ML                        Residual df     =        72
                                             Scale parameter =         1
Deviance         =  76.07491333              (1/df) Deviance =  1.056596
Pearson          =   77.6705906              (1/df) Pearson  =  1.078758

Variance function: V(u) = u+(0.08)u^2        [Neg. Binomial]
Link function    : g(u) = ln(u)              [Log]

                                             AIC             =  4.396594
Log likelihood   = -163.0705836              BIC             = -235.7379
```

injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.3139483	.1003774	3.13	0.002	.1172123	.5106843
lnlengthkm	.3325705	.1448436	2.30	0.022	.0486822	.6164587
mean	.0094967	.0074734	1.27	0.204	-.0051509	.0241442
_cons	-2.200501	.7636866	-2.88	0.004	-3.697299	-.7037024

Appendix A5.2: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -162.87331
Iteration 1:   log likelihood = -162.82108
Iteration 2:   log likelihood = -162.82108

Generalized linear models                  No. of obs      =        76
Optimization     : ML                      Residual df     =        72
                                           Scale parameter =         1
Deviance         =  75.57590023            (1/df) Deviance =  1.049665
Pearson          =  76.61179455            (1/df) Pearson  =  1.064053

Variance function: V(u) = u+(0.08)u^2      [Neg. Binomial]
Link function    : g(u) = ln(u)            [Log]

                                           AIC             =  4.390028
Log likelihood   = -162.8210771            BIC             = -236.2369
```

injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.2941496	.103927	2.83	0.005	.0904565	.4978427
lnlengthkm	.3218934	.1456385	2.21	0.027	.0364472	.6073396
tile	.0087411	.0060251	1.45	0.147	-.0030679	.0205501
_cons	-2.103425	.7388961	-2.85	0.004	-3.551635	-.6552151

Appendix A5.3: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -163.05698
Iteration 1:   log likelihood = -163.00504
Iteration 2:   log likelihood = -163.00503

Generalized linear models                     No. of obs        =         76
Optimization      : ML                        Residual df       =         72
                                              Scale parameter   =          1
Deviance          =  75.94381553              (1/df) Deviance   =   1.054775
Pearson           =  75.61565319              (1/df) Pearson    =   1.050217

Variance function: V(u) = u+(0.08)u^2         [Neg. Binomial]
Link function    : g(u) = ln(u)               [Log]

                                              AIC               =   4.394869
Log likelihood    = -163.0050347              BIC               =   -235.869

------------------------------------------------------------------------------
             |                 OIM
injurycras~s |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lnvolume |   .3057518    .1009703     3.03   0.002     .1078536      .50365
   lnlengthkm |   .3593127    .1418673     2.53   0.011     .0812579    .6373674
 shoulderty~y |   .2335032    .1758033     1.33   0.184    -.111065     .5780714
        _cons |  -1.561887    .7656322    -2.04   0.041   -3.062498   -.0612749
------------------------------------------------------------------------------
```

Appendix A5.4: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -163.81092
Iteration 1:   log likelihood =  -163.7504
Iteration 2:   log likelihood = -163.75038

Generalized linear models                     No. of obs        =         76
Optimization     : ML                         Residual df       =         72
                                              Scale parameter   =          1
Deviance         =  77.4345149                (1/df) Deviance   =   1.075479
Pearson          = 78.47356752                (1/df) Pearson    =   1.089911

Variance function: V(u) = u+(0.08)u^2         [Neg. Binomial]
Link function    : g(u) = ln(u)               [Log]

                                              AIC               =   4.414484
Log likelihood   = -163.7503844               BIC               =  -234.3783

------------------------------------------------------------------------------
             |                 OIM
injurycras~s |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    lnvolume |   .3335051   .1139029     2.93   0.003     .1102595    .5567507
  lnlengthkm |   .3629392   .1420081     2.56   0.011     .0846084    .6412701
widthofsho~m |   .1024094   .1923425     0.53   0.594    -.2745749    .4793937
       _cons |  -1.826459    .749171    -2.44   0.015    -3.294807   -.3581109
------------------------------------------------------------------------------
```

Appendix A5.5: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -163.91656
Iteration 1:   log likelihood = -163.85093
Iteration 2:   log likelihood = -163.85092

Generalized linear models                  No. of obs      =        76
Optimization     : ML                      Residual df     =        72
                                           Scale parameter =         1
Deviance         =  77.63558416            (1/df) Deviance =  1.078272
Pearson          =  79.58876635            (1/df) Pearson  =    1.1054

Variance function: V(u) = u+(0.08)u^2      [Neg. Binomial]
Link function    : g(u) = ln(u)            [Log]

                                           AIC             =  4.417129
Log likelihood   =  -163.850919            BIC             = -234.1772
```

injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.3785783	.0943239	4.01	0.000	.1937069	.5634497
lnlengthkm	.3738142	.1440653	2.59	0.009	.0914515	.656177
verticalde~y	.0295194	.1013813	0.29	0.771	-.1691842	.228223
_cons	-2.017556	.796152	-2.53	0.011	-3.577985	-.4571265

Appendix A5.6: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -163.85415
Iteration 1:   log likelihood = -163.74789
Iteration 2:   log likelihood = -163.74784
Iteration 3:   log likelihood = -163.74784

Generalized linear models                   No. of obs      =        76
Optimization     : ML                       Residual df     =        72
                                            Scale parameter =         1
Deviance         =  77.42942597             (1/df) Deviance =  1.075409
Pearson          =  79.45846011             (1/df) Pearson  =   1.10359

Variance function: V(u) = u+(0.08)u^2       [Neg. Binomial]
Link function    : g(u) = ln(u)             [Log]

                                            AIC             =  4.414417
Log likelihood   = -163.7478399             BIC             = -234.3834
```


injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.4013137	.1070724	3.75	0.000	.1914558	.6111717
lnlengthkm	.3922464	.1495054	2.62	0.009	.0992212	.6852716
tageofheav~s	-.0061145	.0113425	-0.54	0.590	-.0283453	.0161164
_cons	-2.132044	.8300375	-2.57	0.010	-3.758887	-.5052001

Appendix A5.7: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -142.98013
Iteration 1:   log likelihood = -142.39197
Iteration 2:   log likelihood = -142.39115
Iteration 3:   log likelihood = -142.39115

Generalized linear models                          No. of obs      =        76
Optimization     : ML                              Residual df     =        69
                                                   Scale parameter =         1
Deviance         =  54.76491606                    (1/df) Deviance =  .7936944
Pearson          =  54.33320555                    (1/df) Pearson  =  .7874378

Variance function: V(u) = u+(0.0002)u^2            [Neg. Binomial]
Link function    : g(u) = ln(u)                    [Log]

                                                   AIC             =  3.931346
Log likelihood   = -142.3911535                    BIC             = -244.0557
```

injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.1899327	.0927885	2.05	0.041	.0080706	.3717948
lnlengthkm	.5099579	.1332717	3.83	0.000	.2487502	.7711657
juncdensity	.3260166	.1467148	2.22	0.026	.038461	.6135723
terraintype	.4278448	.1304843	3.28	0.001	.1721002	.6835894
presenc~ment	.4595933	.1369448	3.36	0.001	.1911864	.7280002
carriagewa~m	.4212934	.2949945	1.43	0.153	-.1568852	.9994719
_cons	-4.337458	1.962904	-2.21	0.027	-8.18468	-.4902372

Appendix A5.8: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -143.53575
Iteration 1:   log likelihood = -142.90763
Iteration 2:   log likelihood = -142.90659
Iteration 3:   log likelihood = -142.90659

Generalized linear models                    No. of obs       =         76
Optimization     : ML                        Residual df      =         69
                                             Scale parameter  =          1
Deviance         =  55.79578548              (1/df) Deviance  =   .8086346
Pearson          =  54.98155507              (1/df) Pearson   =   .7968341

Variance function: V(u) = u+(0.0002)u^2      [Neg. Binomial]
Link function    : g(u) = ln(u)              [Log]

                                             AIC              =    3.94491
Log likelihood   = -142.9065883              BIC              =  -243.0248
```

injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.2145981	.085935	2.50	0.013	.0461686	.3830276
lnlengthkm	.5310693	.1352859	3.93	0.000	.2659138	.7962247
juncdensity	.3029906	.142958	2.12	0.034	.022798	.5831832
terraintype	.467446	.1293985	3.61	0.000	.2138295	.7210624
presenc~ment	.4554676	.1361421	3.35	0.001	.1886339	.7223013
roadmarking	.1844471	.1823677	1.01	0.312	-.1729871	.5418813
_cons	-1.604772	.6357508	-2.52	0.012	-2.850821	-.3587235

Appendix A5.9: Parameter estimation for explanatory variables as estimated by STATA statistical software

```
Iteration 0:   log likelihood = -145.23161
Iteration 1:   log likelihood = -144.64974
Iteration 2:   log likelihood = -144.64886
Iteration 3:   log likelihood = -144.64886

Generalized linear models                          No. of obs      =        76
Optimization     : ML                              Residual df     =        70
                                                   Scale parameter =         1
Deviance         =  59.28031949                    (1/df) Deviance =  .8468617
Pearson          =  59.59380249                    (1/df) Pearson  =    .85134

Variance function: V(u) = u+(0.0002)u^2            [Neg. Binomial]
Link function    : g(u) = ln(u)                    [Log]

                                                   AIC             =  3.964444
Log likelihood   = -144.6488553                    BIC             =  -243.871
```

injurycras~s	Coef.	OIM Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnvolume	.2489637	.0823764	3.02	0.003	.087509	.4104183
lnlengthkm	.5226683	.1478138	3.54	0.000	.2329586	.812378
accessdens~y	.0281516	.0233426	1.21	0.228	-.017599	.0739022
terraintype	.4816812	.1280289	3.76	0.000	.2307492	.7326132
presenc~ment	.5048988	.1383751	3.65	0.000	.2336887	.776109
_cons	-1.704133	.6418894	-2.65	0.008	-2.962214	-.4460531