SAFETY MODELING OF URBAN ROADS – A CASE STUDY OF TIRUCHIRAPPALLI CITY

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Road safety is the main concern in many developing countries including India. According to Ministry of Road Transport and Highways, Tamilnadu reported the maximum fatalities in the past year, accounting for about 10.7% of total fatalities in India. Rapid motorization accompanied by quick expansion in road network and urbanization seriously impacts the road safety levels of our country. In India, road accident is the major disaster that has taken 17 lives every hour over the past year. Lack of scientific analysis of accidents and non-adherence of general safety measures lead to undesirable results. Traffic safety on urban arterials is influenced by several key variables including geometric design features, land use, traffic volume, and travel speeds. This study aims to analyze the relationships among these variables. The classified accident data for six years (2010 to 2015) were collected from Tiruchirappalli Commissioner's Office and Police Records for urban arterials of Tiruchirappalli city. Geometric data was obtained from field investigations. Volume studies and spot speed studies were conducted on the study segments. Poisson-lognormal and Negative Binomial model was used to estimate the accident frequencies. The results show that Negative Binomial models had the best goodness- of-fit and efficiency with the lowest standard errors. The models explain that traffic volume, speed and geometric design features significantly affect the accident occurrence.

KEYWORDS

Fatalities, spot speed, Poisson-lognormal (PLN), Negative Binomial model

INTRODUCTION

Road safety is a major concern in many developing countries including India. Road accidents are responsible for an increase in deaths and disability throughout the world. Road accidents lead to loss of life, property and affect the general welfare of the people and the economy. According to World Health Organization, about 1.25 million die each year as a result of road accidents worldwide and if no action is taken, road accidents are predicted to be the 7^{th} leading cause of death by 2030. India accounts for 10% of global road accidents and has highest death rate in the world. Henceforth, it is essential to find solutions to mitigate the problem so that loss of life and property can be reduced. A better understanding of the factors associated with the occurrence of accident is required so that effective countermeasures can be identified and suggested to reduce road accidents.

Road accidents are an outcome of the interplay of various factors, some of which are the length of road network, vehicle population, human population and adherence/enforcement of road safety regulations, etc. According to WHO, low and middle income countries account for about 90% of the world's road fatalities. In India, traffic fatalities have increased by 4.6% from 2014 to 2015. The analysis of road accident data reveals that about 57 accidents and 17 deaths take place every hour on an average in Indian roads. About 5.01 lakh road accidents were reported during the year 2015. The number of persons killed in road accidents during the year 2015 was 1,46,133 which means an average of one fatality per 3.4 accidents.

Road accidents have been increasing alarmingly in Tamil Nadu, being a major state contributing to total no. of accidents in India. Tamilnadu reported the highest number of road accidents in 2015 sharing about 13.8% of the total accidents in the country. Tamilnadu accounts for about 10.7% and 15.9% of total road fatalities and injury accidents in the entire country. Tamilnadu ranked second highest and first in the country for fatalities and minor injury accidents. The number of persons killed in road accidents during the year 2015 was 15,642 that is an average of one fatality per 4.3 accidents. A case study of Tiruchirappalli city is considered for the present study. Tiruchirappalli city is situated at the geographical center of Tamilnadu. Every year, a number of people are killed or injured due to road accidents. The number of persons killed in road accidents during the year 2015 was 161 that is an average of one fatality per 5.1 accidents.

Predicting the exact cause for the road accident is complex. Studies were done relating the factors like traffic volume, speed, road characteristics, road geometrics etc., with the road accidents. Measures to rectify those factors might be difficult or very expensive in the field by means of its implementation and monitoring. This study focuses on analyzing road accident data and the relationship between various factors influencing road accidents so that suitable accident remedial measures can be suggested to enhance road safety. The main objective of the study is to analyze the relationship between road accidents and factors that are likely to influence the occurrence of accidents and also recommending strategies to reduce the number of accidents and their severity in order to enhance safety.

LITERATURE REVIEW

Road accidents are stochastic in nature and they are non-negative integers. Many statistical methods are available to model the data. Road section length, traffic volume; unsignalized intersection density, driveway density, pedestrian crosswalk density, the number of traffic lanes, median type and land use has a significant effect on accident occurrence (10). The effect of median type on road accident was studied in detail and it is found that 10% accident reduction can be achieved by improving undivided arterial with a raised curb median. Generalized linear model was developed (4) and identified that number of access roads and speed limits are the important variables in a road link model. The limitation of the study is that the model cannot take into account the internal correlation exists between the traffic flow variable and other variables like road width, number of lanes, etc. Poisson-lognormal models (PLN) incorporating corridor variation that is one model with variance function and the other with mean function was developed to analyze the occurrence of accidents (3). In the traditional PLN model, accident frequency is significantly influenced by section length, Annual average daily traffic (AADT), crosswalks density, land use, unsignalised intersection density and number of lanes between signals. The second extended model with mean function also shows significant results in incorporating random parameter and its effects on accident frequency.

Traditional Negative Binomial regression was applied to measure the relation between accident frequency, traffic volume, road length temporal distribution and road design characteristics (9). Accident frequency increases if drivers showed high interest to change lane. It was also explained that accident frequency decreases with lane width, however the condition varies when the traffic parameter is incorporated with lane width. The number of junction also increases the accident risk. The effect of regional level, site level, crash level and driver - vehicle unit on crash severity of single and dual carriageway roads was examined (6). Road length, lane width, traffic volume and road side obstructions have a positive influence on single carriageway crash frequency. Traffic volume has a positive influence where road length, lane width and road side obstructions roads have a negative influence on dual carriageway crash frequency. The crash severity at single and dual carriageway decreases with a wider shoulder width and traffic volume and also with the presence of road marking. The motorcycle accident fatalities on Malaysian primary roads was analyzed (7) and the number of motorcycle fatalities increases with increase in exposure to number of access points per kilometer. It was concluded that many service roads may be introduced to connect the access points in order to reduce fatalities.

A fatal crash prediction model has been developed for 218.6 km urban arterial roads of medium sized Indian city on the basis of 6 year crash data (8). The Negative Binomial regression model is developed and it was found that road segments with high traffic level have higher risk for fatal crashes. The fatal crashes increase with every kilometer exposure in road segment length and decreases as number of junction per kilometer increases. The risk is also high in divided roads. Safety analysis on urban single carriageway roads in Kerala was conducted (2). Crash frequency of urban midblock increases with increase in carriageway width, number of minor intersections and traffic volume, whereas decreases with an increase in the width of the shoulder and bus stop numbers along the roadway. Crash Modification Factors were developed to analyze and evaluate alternate safety treatment. Accident frequency is positively related with horizontal curvature, terrain type, heavy-vehicle traffic and access points while decreases with posted speed limit and shoulder width (5). The accident severity model explained that horizontal curvature, paved shoulder width, terrain type and side friction were associated with more severe accidents, whereas land use, access points and presence of median reduced the probability of severe accidents.

Safety analysis was carried for Chinese suburban arterials (11). According to the modeling results, four variables at the segment-level (access density, horizontal alignment, percentage of heavy vehicles, and area types) and two variables at the arterial-level (density of signals and standard deviation of signal spacing) have statistically significant impacts on minor injury crash occurrence. For severe injury and total crashes, four variables at the segment-level (access density, horizontal alignment, percentage of heavy vehicles, and area types) and one variable at the arterial-level (DOSP) were significant. A Bayesian joint model has been proposed and compared with the three site-level crash prediction model (Poisson model, Negative Binomial model and Conditional autoregressive model) for the road network in Hillsborough, Florida (13). It is inferred from the study that crash count subjects to increase with the number of lanes in road segment, more access roads, higher speed limits and poor pavement condition. Random Parameter Negative Binomial model (RPNB) and Semi-parametric Geographically Weighted Poisson Regression model (S-GWPR) was developed (12) to investigate the spatial heterogeneity in regional safety modeling. The different types of model was developed and compared to find the best fit model. It was concluded that S-GWPR model yields better result and it was estimated that Equal road length with more intersections, road segments with speed limit of 45mph, population density are positively related to total or severe accidents.

STUDY AREA AND METHODOLOGY

Tiruchirappalli city traffic has been categorized into two zones namely North zone and South zone. The North zone includes seven stations and the South zone comprises of five stations. Twenty four urban arterial/ sub-arterial road network of Tiruchirappalli City forming study area was considered for the present study. These are the major arterial and sub-arterial roads connecting major commercial areas, government offices, schools and residential areas of Tiruchirappalli city. The accident data was collected from Tiruchirappalli Police Commissioner's

Office. The data helps to analyze the accident scenario based on location, time, vehicles involved, persons involved and type of roads. The road geometric data like carriageway width, shoulder, footpath/sidewalk, median, safety barrier, parking, etc., are obtained from direct field survey. Volume counts were carried out for the arterial and sub arterial for twenty four hours of traffic by means of manual method and vehicle composition are plotted. Spot speed measurements were carried out for the selected road network using stop watch technique.

ANALYSIS OF ACCIDENT DATA

The accident data collected from Tiruchirappalli Police Commissioner's Office gives an overview of number of fatal and non-fatal accidents that had occurred in Tiruchirappalli City for the past six years from 2010 to 2015. Road accident is an incident that occurs on public roads resulting in either injury or loss of life, or damage to property in which at least one moving vehicle is involved. The total fatal and non-fatal accidents for the selected arterial and sub-arterial roads in North zone and South zone for six years from 2010 to 2015 are presented in Figure 1 & Figure 2.

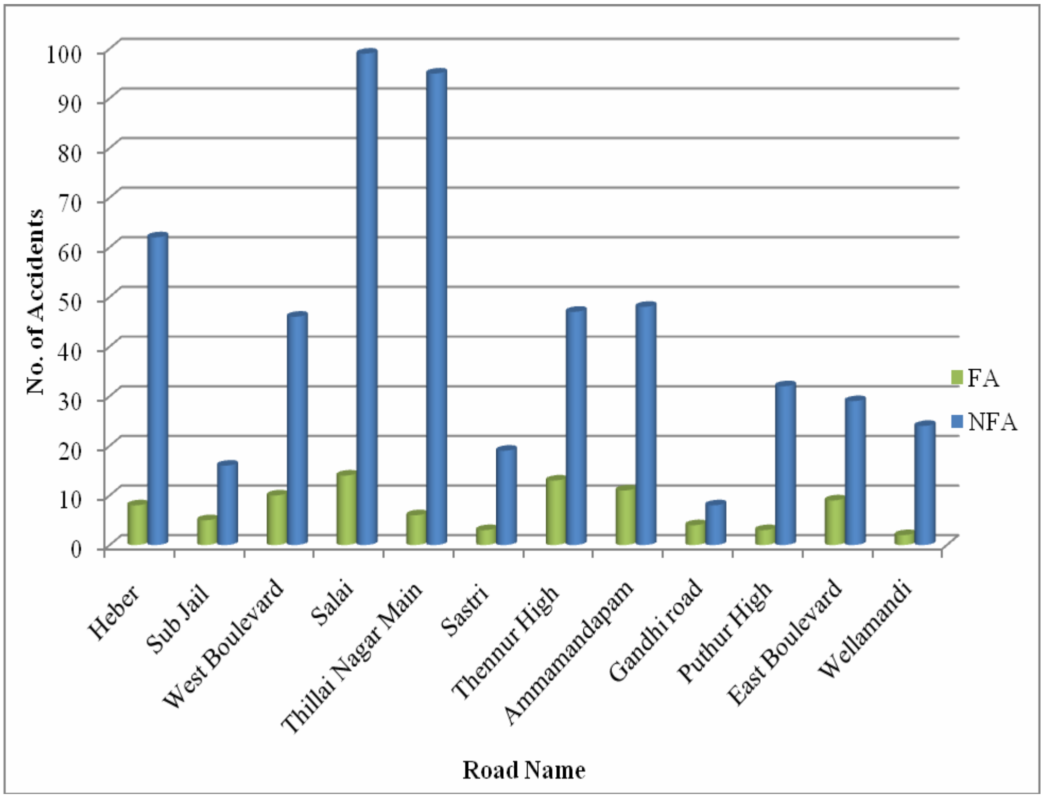

FIGURE 1 Total fatal and non-fatal accidents in North zone

It can be observed from the Figure 1 and 2 that more number of accidents were reported in 11 roads namely Collector Office Road, Bharathidasan Road, Puthur EVR Road, Simcometer Road, Heber Road, West Boulevard Road, Salai Road, Thillai Nagar Main Road, Thennur High Road and Ammamandapam Road in which Salai Road has the highest record of 113 accidents for the six years.

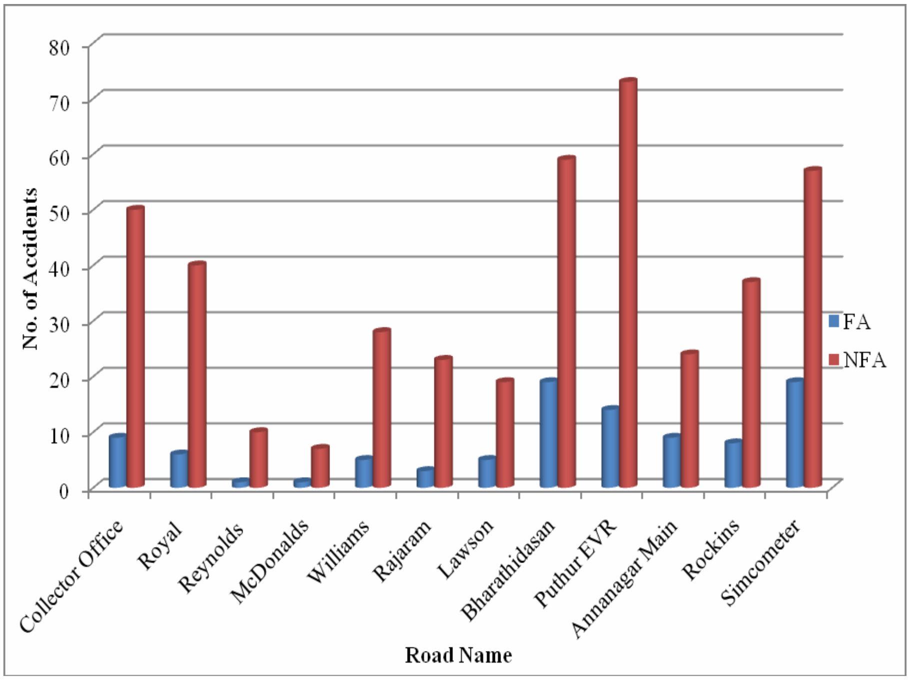

FIGURE 2 Total fatal and non-fatal accidents in South zone

Similarly, more number of fatal accidents have been observed in six roads namely Bharathidasan Road, Puthur EVR Road, Simcometer Road, Salai Road, Thennur High road and Ammamandapam Road. The accident data gives a clear indication of number of accidents which are increasing year by year. More number of fatal and non-fatal accidents is observed in 2-lane 2-way undivided roads which accounts for about 45% of the total accidents followed by 4-lane 2-way divided roads which shares about 25% of the total accidents. Vehicles involved in road accidents in terms of accused vehicle and victim vehicle explains that two wheelers are responsible for 42% of total road accidents followed by buses (22%), cars (16%), trucks (13%) and auto Rickshaws (7%). Two wheelers and pedestrians are the victim of more number of accidents accounting for about 48% and 40% of the total road accidents.

Road Inventory and Traffic Data

The road infrastructure elements like bus stops, speed breakers, number of lanes, presence of median, shoulder, drainage etc., that are likely to influence traffic accidents are identified from literature and field visit. The physical features and traffic controlling measures of the site are collected for all the 24 selected roads by field visits. Median is present in 10 roads. Width of the median ranges from 0.5 m to 1.2 m. Median openings is mostly observed in three-arm or four-arm junctions. Maximum number of median opening is present in simcometer road (7 nos.) followed by East Boulevard road (5 nos.). The openings are used for both pedestrian crossing and turnings movements for the vehicle. In some of the roads like West Boulevard road and Puthur road, safety barriers are used for dividing the roads instead of concrete median. Small median openings for pedestrian to cross is provided in Rockins road and Bharathidasan road but no cross walk marking is provided in these openings. Number of minor intersecting roads is more in Thillai Nagar Main road (22 nos.) and Sastri road (20 nos.). Road side parking is observed in 50% of the roads. In many roads, unauthorized road parking is observed. The traffic controlling measures such as road markings and speed breakers are observed in 12 roads near Central bus stand of Tiruchirappalli city. In these 12 roads, road markings are faded and centre line road markings are absent. Road markings are also not available for the full stretch of the roads. Road studs are not seen any of the roads. Proper road markings are not there near the junctions or minor intersecting roads.

Classified volume counts and spot speed measurements were carried out for 24 roads in Tiruchirappalli city. The details of traffic volume composition are given in Figure 3. Traffic volume composition shows that two wheelers share the maximum composition of 60% - 70% in almost all the urban road segments considered for the study followed by cars (11%-15%), auto-rickshaws, buses, cycles and trucks.

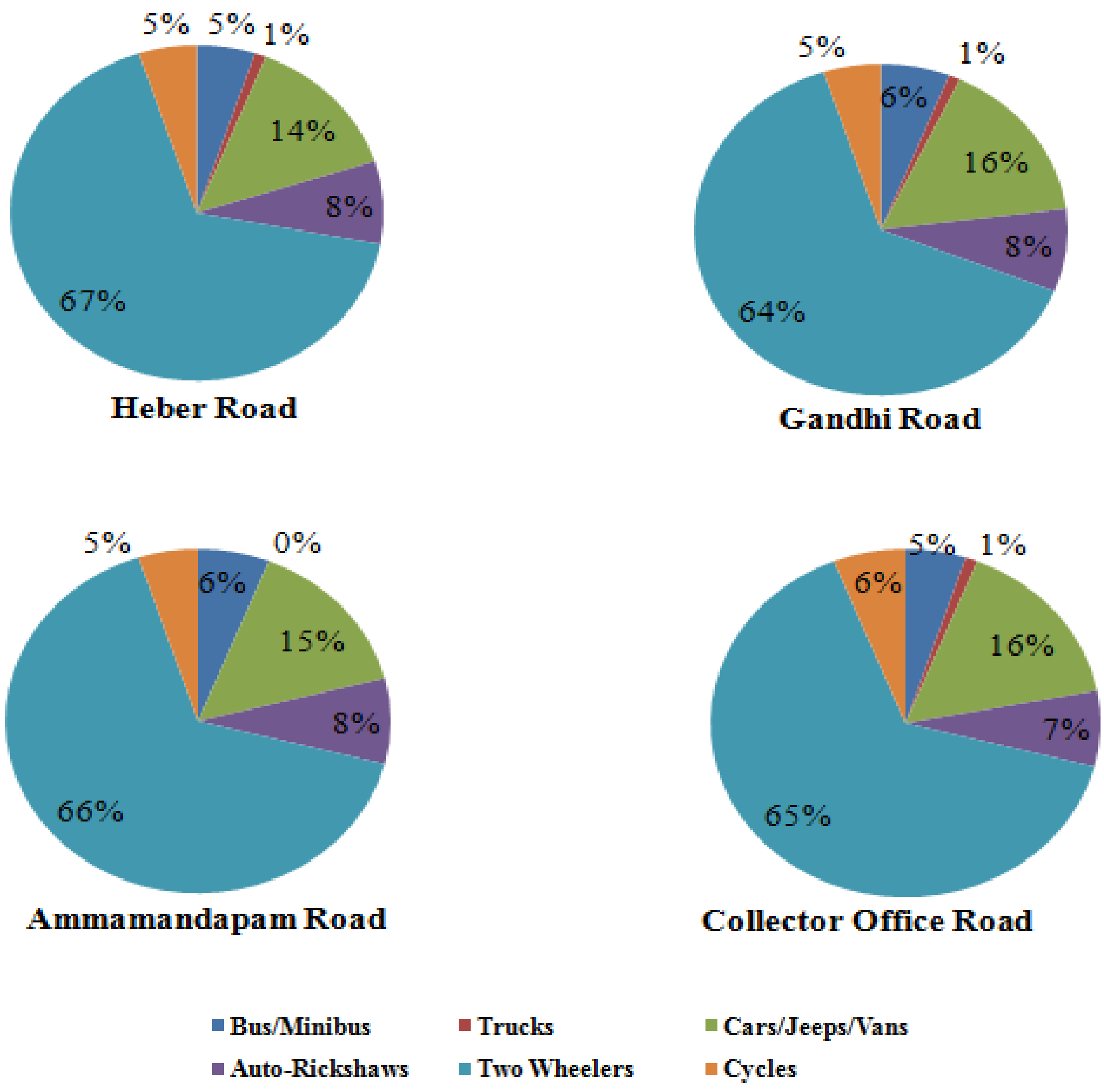

FIGURE 3 Traffic volume compositions at selected roads

Spot speed study was carried out on all the selected roads. The long base method was adopted for the study. The average speed was calculated from the arithmetic mean of the observed spot speed. The 85th percentile speed was calculated from the cumulative frequency graph. The minimum average speed is observed in Sub Jail road (27.1 kmph) and the maximum average speed is observed in Lawson road (43.2 kmph). The highest 85th percentile speed of 51 kmph is observed in three roads namely Rajaram road, Lawson road and Ammamandapam road followed by Thillainagar main road (47 kmph). Maximum speed of around 70 kmph is observed in Lawson road, Thillainagar main road and Ammamandapam road where as minimum speed of 15 kmph is observed in Sub jail road followed by West Boulevard road, Thennur high road and Gandhi road with a recorded speed of around 18 kmph.

The posted speed limit in the selected roads is 30 kmph. It is observed from the spot speed studies that average speed of five roads namely Thennur high road, Sub jail road, Royal road, Rockins road and McDonalds road is coming within the speed limit whereas the average speed of the vehicles in rest of 19 roads is exceeding the speed limit. The average speed of the divided and undivided roads also comes to 35 kmph which is higher than the posted speed limit. Strict enforcement should be made to control the speed in these roads. Thus, speed is considered as one of the important parameters in accident studies.

MODEL DEVELOPMENT

The occurrence of accident is stochastic in nature and it is a discrete random event. Predicting the occurrence of road accidents is a difficult task as accidents are affected by so many different factors. The linear regression models lack the distributional property (1) to describe adequately random, discreet, non-negative accident events on the road. Currently, count data models are mostly adopted for developing Accident Prediction Model. Poisson and Negative Binomial Model are traditional count data models. The model satisfying the conditions such as derives logical results and there must exist a link function that linearizes the model for the purpose of co-efficient estimation was developed (10). The main objective of modeling with many explanatory variables is to understand the complex relation or effect of different urban road variables with accidents.

Many parameters that are responsible for accident occurrence are identified based on the literature and field study. Correlation analysis shows that Number of Lanes, Road Marking Length, Parking Length and Traffic Volume correlate with accident frequency of divided and undivided roads. The variables with its significance value are given in Table 1.

TABLE 1 Model Parameters with their Significance

Sl. No.	Explanatory Variables	Significance
1.	No. of Lanes	0.007
2.	Carriageway Width in m	0.044
3.	Median Width in m	0.039
4.	Median Length per km	0.035
5.	No. of Median Opening per km	0.034
6.	Safety Barriers Length per km	0.791
7.	Parking Length per km	0.035
8.	No. of Minor Intersecting Roads per km	0.049
9.	Road Marking Length per km	0.013
10.	No. of Speed Breakers per km	0.048
11.	No. of Bus Stops per km	0.050
12.	Sidewalk Width in m	0.163

Sl. No.	Explanatory Variables	Significance
13.	Sidewalk Length per km	0.047
14.	Presence of Drainage	0.538
15.	Shoulder Width in m	0.015
16.	Shoulder Length per km	0.045
17.	Two Wheeler Volume in 1000 veh/day	<0.001
18.	Average Daily Traffic in 1000 veh/day	<0.001
19.	85th Percentile speed	0.083

Collinearity exists when two or more of the predictors in a regression model are moderately or highly correlated. The presence of correlation between the independent variables might limit the research conclusions. Variation Inflation factor (VIF) is determined to check the multicollinearity in the explanatory variables. From the correlation analysis, it is evident that there exists high inter-correlation among the explanatory variables. If any pair of independent variables is highly correlated, one of which should be removed from the analysis (9) to avoid the bias in parameter estimation. The variables showing significance at 95% and 99% are only considered for modelling.

Poisson Model

The accident occurrence is a random event and stochastic in nature. It is usually assumed that traffic accidents follow Poisson distribution and Poisson regression technique is employed to develop Accident Prediction Model. The mean and variance of this distribution can be given as:

$$E(Y_i) = VAR(Y_i) = \mu_i \quad (1)$$

In a Poisson regression model, the probability of the occurrence of y_i crashes for a given period of time on roadway segment $p(y_i)$ is given by,

$$p(Y_i = y_i) = p(y_i) = \frac{\mu_i^{y_i} e^{-\mu_i}}{y_i!}, i = 1,2, \ldots, n \quad (2)$$

Where, Y_i – the number of accidents for a given period for roadway segment i, μ_i – mean value of accidents occurred for a given period of time. The expected number of accidents per year can be given as:

$$\mu_i = EXP(\beta X_i) \quad (3)$$

Where, X_i is a vector of explanatory variables and β is a coefficient of explanatory variables. The model is estimated by standard maximum likelihood method and the estimate produce Poisson parameters that are consistent, asymptotically normal and asymptotically efficient. The constraint of the Poisson model is ‘variance = mean’ which may not always applicable for accident data. Since most of the time the accidents tend to be over-dispersed.

TABLE 2 Poisson Regression Model Estimates

	Model - 1			Model - 2		
Parameter Estimates	**β**	**Sign.**	**IRR**	**β**	**Sign.**	**IRR**
Intercept	1.259	<0.0001	3.523	2.169	<0.0001	8.746
CW	0.035	0.011	1.035	-	-	-
SL	-0.332	0.027	0.717	-0.712	0.001	0.491
ADT	0.017	<0.0001	1.018	-	-	-
PL	-	-	-	0.960	0.0003	2.611
Pearson Chi-Square	4.638			11.210		
Likelihood Ratio test	70.216	<0.0001		23.289	<0.0001	
Alkaline's Information Criterion (AIC)	76.735			81.792		
Finite Sample Corrected AIC (AICC)	80.372			83.792		
Bayesian Information Criterion (BIC)	79.826			84.110		

The model form is given as,

Accident Frequency = exp [1.259 + 0.035(CW) - 0.332(SL) + 0.017(ADT)] (4)

The parameter estimate of the Poisson Model is given in Table 2. The intercept has positive sign which indicates that for every 1 unit exposure there is an increase in risk. Carriageway width and traffic level also has significant effect on accidents which indicates that accident increases with increase in carriageway width and traffic by 1.03 times and 1.02 times respectively. Presence of shoulder decreases the chances of accidents by a factor of 0.8. The limitation in this model is that the assumption of mean and variance are equal but the mean and variance of the accident frequency is 8.75 and 22.19 respectively which indicates the large variance in the data set and hence Poisson Model was not chosen for further modelling.

Negative Binomial Model

In Poisson regression, the mean and variance of the target variable is assumed to be equal but in case of accident data the mean and variance of the data may not be always equal. To overcome this limitation Negative Binomial regression model can be developed, since it includes dispersion parameter that accounts for unnoticed heterogeneity in the accident data. The equation for developing Negative Binomial regression model is given as follows:

$$\mu_i = EXP(\beta X_i + \varepsilon_i) \tag{5}$$

Where $EXP(\varepsilon_i)$ is a Gamma-distributed disturbance term with mean 1 and variance α. Thus, this term allows the variance to differ from mean as follows:

$$VAR(y_i) = E(y_i)\big(1 + \alpha E(y_i)\big) = E(y_i) + \alpha E(y_i^2) \tag{6}$$

The term 'α' is referred as the dispersion parameter. The Poisson regression model is the limiting model of the Negative Binomial model as α approaches zero, hence the type of model to be adopted is decided based on this parameter. The Negative Binominal distribution takes the following form:

$$p(y_i) = \frac{\Gamma((1/\alpha) + y_i)}{\Gamma(1/\alpha) y_i!} \left(\frac{1/\alpha}{(1/\alpha) + \mu_i}\right)^{1/\alpha} \left(\frac{\mu_i}{(1/\alpha) + \mu_i}\right)^{y_i} \quad (7)$$

Where, Γ(.) is a gamma function. The likelihood function of this model is formulated as follows:

$$L(\mu_i) = \prod_i \frac{\Gamma((1/\alpha) + y_i)}{\Gamma(1/\alpha) y_i!} \left(\frac{1/\alpha}{(1/\alpha) + \mu_i}\right)^{1/\alpha} \left(\frac{\mu_i}{(1/\alpha) + \mu_i}\right)^{y_i} \quad (8)$$

When the data are over-dispersed, the variance estimated becomes larger and the standard error of estimable parameter gets inflated. Thus, Negative Binomial regression model has greater flexibility in developing Accident Prediction Model. Accident frequency expressed as accidents/km/year is the dependent variable in the model. The explanatory variables that shows significant at 0.01 levels and 0.05 level is considered for modelling. The parameter estimates for models developed are given in Tables 3.

TABLE 3 Negative Binomial Regression Model Estimates

	Model - 1			**Model - 2**		
Parameter Estimates	**β**	**Sign.**	**IRR**	**β**	**Sign.**	**IRR**
Intercept	1.593	<0.0001	4.920	1.595	<0.0001	4.930
SL	-0.329	0.046	0.718	-0.335	0.045	0.716
ADT	-	-	-	0.019	<0.0001	1.019
TW	0.029	<0.0001	1.029	-	-	-
Pearson Chi-Square	13.000			13.000		
Likelihood Ratio test	43.802	<0.0001		42.722	<0.0001	
Alkaline's Information Criterion (AIC)	109.370			109.382		
Finite Sample Corrected AIC (AICC)	111.370			111.382		
Bayesian Information Criterion (BIC)	111.687			111.700		

The model is given in the following equation,

$$\text{Accident Rate} = \exp\,[1.593 - 0.329(SL) + 0.029(TW)] \quad (9)$$

From the equation (9), it is clear that Two Wheeler traffic has positive effects on occurrence of accidents whereas presence of shoulder is negatively associated with the frequency of accidents. Incidence Rate Ratio (IRR) is used to interpret the variable and also if the value of IRR is less than 1, an increase in variable value refers to reduction in accident frequency and vice versa. The results show that traffic volume has significant effect on accidents which indicates that accident increases with increase in exposure to traffic by 1.03 times and presence of shoulder along the road segment decreases the chances of accidents by a factor of 0.7

Measure of 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. These are Pearson Chi-square statistic and Deviance. Model - 3 which has less Alkaline's Information Criterion (AIC) and Finite Sample Corrected AIC is considered as the final model. The Pearson Chi-square (value/df) is greater than 0.05 which indicates that the model is good fit.

Validation of Negative Binomial Model

The model validation is done on the one third of the data which was not considered in the model calibration. The validation is done by comparing the observed and expected accident count. The plot between observed and expected is shown in Figure 4.

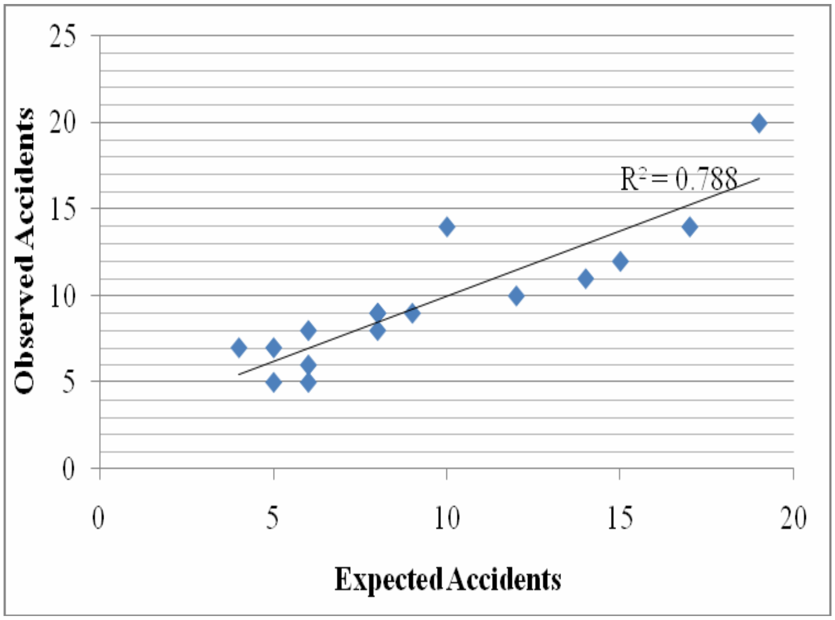

FIGURE 4 Model validation

According to Figure 4, it can be observed that the R^2 = 0.78 for the Negative Binomial Model and hence the model has better performance. Also, the remaining 8 roads that are not included in the model can be used for specifying the error rate in observation and model validating. The error term comes to 1.724% and the model is fit to predict the accident in future.

CONCLUSIONS

Safety analysis was carried out for the urban roads of Tiruchirappalli City. Accident Prediction Model (Negative Binomial) is developed to predict the rate of accidents in the divided and undivided urban roads of Tiruchirappalli City. The study recommends that increasing shoulder width to 2.5 m in all the road segments reduces the occurrence of accidents by 2.3 % since it provides buffer space for vehicle or pedestrian movement. Avoiding bus stops near the intersections and by regulating the access from minor roads, collisions can be reduced. Providing speed breakers near intersections helps to reduce speed of the vehicles and thus accidents can be avoided.

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