STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Mathematical Modeling Analysis of India's Accident & Use of Fly Ash and Polymers in Road Safety

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Abstract

Accident predicting models (APMs) are exceptionally strong tools for adaptation and mitigation strategies because they have the ability to predict both the severity and frequency of crashes. Road accidents are a major problem all throughout the world, especially in developing countries. Understanding the key variables that contribute can assist in reducing the frequency of traffic collisions. This study also discovered recent developments on fly ash, green composites, other polymer materials and their use in road stabilization and enhancement of binding properties. This article focuses on mathematical analysis and APM's development in India. Three models have been developed by using multiple linear regression analysis and nine models are developed using polynomial regression analysis. The reliability of models was examined by calculating the error between true and predicted values [accident model (0.76% error), injury model (1.06% error) and death model (1.48% error)]. The findings demonstrated that the proposed models are very capable of predicting road accidents in the country and it is expected that the work's outcome will benefit road safety professionals, technicians, and policymakers in making better decisions for people using the roadways.

Keywords: Accident predicting models (APM), road accidents, road safety, variables, regression analysis, polymer, Fly ash

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Received Date: April 23, 2024
Accepted Date: September 08, 2024
Published Date: December 17, 2024

Citation: Keshav Bamel, Saurabh Jaglan, Sachin Dass, Karuna Bamel, Amir Ali Khan, Parveen Berwal, Nakul Gupta. Mathematical Modeling Analysis of India's Accident & Use of Fly Ash and Polymers in Road Safety. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S488–S499p.

INTRODUCTION

A nation's transportation system is essential for its economic development. It governs the rate, uniformity, and trends of growth. According to recent research undertaken by the MORTH, the socio-economic consequences of road traffic crashes in India amount to Rs 1,47,114 Crores, approximately 0.77 percent of the country's GDP. Road safety is still a significant reason for concern due to its severity, magnitude, and unforeseen impacts on the well-being of people, and the national economy. It's an important issue that every country in the world must contend with. Today, a substantial number of hospitalizations and casualties across the globe are associated with traffic-related injuries, leading to detrimental social and economic repercussions. Traffic-related accidents and deaths lead to significant financial losses as well as considerable psychological anguish. In 2019, there were approximately 4,49,002 motor vehicle crashes in the Indian subcontinent, that led to 1,51,113 casualties and 4,51,36 injuries [1]. Polymer composite materials are highly beneficial for enhancing road safety as they can be utilized in the construction of crash barriers and high-strength components for vehicles & choice of materials for road construction is crucial for ensuring road safety, as the chemical composition and physical properties of the material directly impact factors such as friction, toughness, and fatigue of the road section. Fly ash after mixing with lime and water also impact the binding properties of the road, which further impact the durability and performance.

Enhanced safety protocols require implementation on national highways, which make up 2.03% of the entire road network and account for a significant number of casualties (35.7%) in 2019. Indicating the necessity for these roads to be safer. State highways are 3.01% of the total road length of the country but the contribution in casualties occurring due to road accident is more than 24%The remaining 39% of deaths were caused by other roads, which account for approximately 95% of all roadways. Riders on 'two wheelers' accounted for 38.0 percent of road accident victims, preceded by trucks, cars and buses, which contributed for 14.6 percent, 13.7 percent, and 5.9 percent of road accident casualties, respectively. The majority of road accidents (59.6%) were caused by "excessive speeding," which resulted in 86,241 deaths and 271,581 injuries. Excessive speed or overtaking were the factors in 25.7 percent of all road accidents, resulting in 42,557 deaths and 106,555 injuries. Additionally, only 2.6 percent of traffic accidents were caused by bad weather. Rural areas (260,379 incidents) and major cities (177,017 incidents) accounted for 59.5 percent and 40.5 percent of total road traffic accidents, respectively, while residential areas contributed for 29.9% (1,30,943 road crashes out of 4,37,396). [2] has shown that for the year 2019, the youngsters between the ages of 18 and 60 account for 84 percent of all traffic accident victims (1, 22, 350 persons). Numerous attempts have been made throughout the years (Table 1) to construct models for estimating the number of accidents on major highways or specific sections of highway. Population, number of motor vehicles, and length of constructed road are the primary factors for the variation in accidents taking place in a nation. As a result, it is crucial to analyze the fundamental variables that cause traffic accidents. [3] and [4] analyzed data on road deaths, vehicles, and population from 20 nations and the analysis discovered that one fatality value had an error of up to 67%, while 10 mortality values calculated by this algorithm were within fifteen percent of the real values and 19 values are within 40%. Because of the lack of model credibility, Andreassen questioned Smeed's analysis. He argued that Smeed’s equation was not relevant in all situations. Since Smeed's model did not manage to predict deaths in a number of developed and emerging economies, the author improved it by including additional variables. Road crash models were developed by [5] for the megacities in India. The primary finding of the study was that critical regulations and legislation need to be modified to curtail the expansion of individually owned automobiles and encourage the use of public transit in order to mitigate the number of fatal crashes

Table 1. Previous Accident Prediction Models.

Model	Equation	Remarks
Smeed’s forecasting model (1949)	$X/V = 3\times10^{-4}\ (V/Y)^{-0.67}$	X= Total number of deathsV= Number of registered vehiclesY= Total populationC= Total number of accidentsZ= Total number of Injuries
Andreassen’s prediction Model (1991)	$C= e^{21.26}\times V^{0.495}\times Y^{-0.83}$ $X= e^{13.47}\times V^{0.613}\times Y^{-0.63}$ $Z=e^{13.47}\times V^{0.604}\times Y^{-0.54}$	
Valli’s equation (2004)	$C/V= 8\times10^{-4}(V/Y)^{-0.75}$ $X/V= 3\times10^{-4}\ (V/Y)^{-0.58}$ $Z/V= 14\times10^{-4}\ (V/Y)^{-0.57}$	

According to [6]. human elements account for 95.38 percent of all Road Traffic Accidents (RTAs). During the day (6 a.m. to 6 p.m.), 60 percent of the collisions were logged. Between 12 and 6 p.m., the peak period (38.46 percent) was recorded. The months of July–September saw the most accidents (32.30 percent). [7] provided equations derived from different linear and Poisson regression models that relate volume of traffic and geometry elements to the truck-related accidents every year at an identified section of road. According to [8]. Five key variables were found to be liable for boosting the gravity of crashes involving pedestrians on rural roads. The study revealed that the first variable influencing the frequency of fatal pedestrian crashes was road condition, accident season, and climate. The second component featured variables such as accident time and the daytime condition, with accident time bringing an enormous effect on diminishing accidents and daytime condition having a positive and growing effect on accident cases. The third element was identified as pedestrian sexual identity and accident day, while the fourth factor was discovered as the reason for the collision and the geometry of the accident location. In guilan, pedestrian age and type of vehicle is the fifth important factor in pedestrian accidents [9]. proposed two models for braking and steering that mathematically explain cyclist action in smooth obstacle avoidance. Their research also illustrated how these models may be used to support active safety and road infrastructure, as well as new product assessment processes. Because new electric vehicles for personal transportation are becoming more prevalent, while autonomous cars are expected to enter the traffic system in the near future, the framework could be beneficial in determining the feasibility of the new modal split as a result of the new interactions between road users. In road safety research, determining and comprehending the environmental elements that contribute to road traffic accidents is critical [10]. developed an accident cost forecasting algorithm using STELLA software and road accident data obtained from 2006 to 2012 via Chennai city traffic police. Research revealed that after every bit of planning and preparation done by governments, the financial burden of accidents is still growing at an alarming pace, and it is an unnecessary strain on Indian economy [11]. utilized only mortality data for analyzing accidents and the author discovered that there is an immediate need to overhaul data collection systems of police, so that vital information is attainable for scientific study [12]. utilized machine learning concept- K-Means to uncover the variables causing accidents. Spyder and python tools are utilized to examine the accident data. The author ultimately created a prototype that illustrates the probability of accidents either high or low at any place, so that individuals may take measures before traveling to that region [13]. used a predesigned questionnaire which was filled out by the interviewer. Data was evaluated with the statistical tool of social sciences version 24.0 (IBM Inc. Chicago, USA) software. Research indicated that there should be control over individuals driving vehicles under the effect of alcohol and operators over-speeding and recklessly maneuvering on metropolitan roads as well as remote rural roads [14]. demonstrated that Andhra Pradesh has 7.5% of the nation's inhabitants but 10.4% deaths in road accidents [15]. examined the Hulasur-Basavakalyana (S.H) section of Karnataka and concluded that predominantly inadequate visibility contributes to collision of cars [16]. concluded that severity of collision might be decreased by using prediction model with accurate input of variables [17]. examined data in the SPSS version 16 and Chi-square test was carried out for analysis purpose and it was found that state of Haryana endured the biggest loss of human life and most impacted were pedestrians. [18] generated moving average to negate the periodic fluctuations in the data, following which exponential graph was drawn to examine the trend and curve of the total number of RTAs demonstrates elevated trend between 2000–2015 in India. [19] concluded that, on comparison, referring to the data presently accessible, Kernel Density may be viewed as a more acceptable approach of accident data analysis [20]. created Accident forecasting model and it was tested by Chi squared test and found to have a decent linear correlation between the dependent and independent variable [21]. discovered that fractures were the most common injury across the patients of non-fatal road accidents which frequently involved powered two wheelers and light automobiles, accompanied by various injuries such blunt injury, Abrasive wounds and lacerations [22]. Studied NH-1 during the year 2007 to year 2010, which encompasses the period when the expansion of the stretch took place and they noticed that more crashes occur during daylight hours (61%) than in night time (39%) [23]. examined three prominent classification methods i.e. decision tree (CART), SVM and Naïve Bayes on PTW accident data set. It was noticed that CART's performance in districts having high accident reports was quite good.

Materials and Methods

Following the collection of data from 2011 to 2019, it was further examined on the basis of numerous accident characteristics. After that, data was subsequently categorized and organized into Tables in preparation for analysis. Multiple analyses and comparisons were conducted to illustrate the fluctuation of accident rates over time and to identify the pattern. ASI was calculated and then each data set of accident, fatality, and injury was assessed using polynomial, linear, exponential, power, and logarithmic equations. The R^2 values of the equations were compared, and the two equations with the highest R^2 values were used to develop accident and death prediction models. While developing forecasting models population, No. of registered vehicles and road length were considered as independent variables and then multiple linear regression analysis, and polynomial linear regression analysis was performed to make models to predict the accident, death and injuries for the country of India.

Accident severity index (ASI): Number of individuals killed per one hundred accidents. Polynomial regression analysis: Polynomial equations are equations that contain variables, exponents, and coefficients. It can have different exponents, with the higher one referred to as the equation's degree. In most cases, the polynomial equation is written as $ß_n(x^n)$ where,
'ß'= coefficient
'n'= exponent
'x'= variable

We get the following when we expand the polynomial equation:
$F(x) = ß_n x^n + ß_{n-1} x^{n-1} + ß_{n-2} x^{n-2} + + ß_1 x + ß_0$

Multiple regression analysis: This equation serves as a continuation of linear regression with a different slope coefficient (B) for each predictor. The value of Y in the absence of all predictors or if all X terms are zero, is represented by the first B term (Bo), which is also known as the intercept constant. X terms serve as the related input variables, and Y is the output variable.
$Y= B_0 + B_1X_1 + B_2X_2 ++B_nX_n$

Y denotes a dependent variable, B_0 denotes the y-intercept, B_1X_1= the first independent variable's regression coefficient and B_nX_n = the last independent variable's regression coefficient. Homoscedasticity, independence of observations, normality and linearity are some of the assumptions made while performing multiple regression analysis.

RESULTS AND DISCUSSION

ASI comparison was done between India and some other developing countries that are suffering from the problem of road safety

It can be clearly seen from Figure. 1 that India has the highest severity index (31.37) in 2018 among all the countries and has the highest number of deaths taking place per year as compared to any other nations. ASI is increasing in India throughout the analysis period irrespective of the steps taken by government to improve the road safety conditions of India. There has been a minor decrease in 2012 other than that the ASI has been increasing with an alarming rate and reached to a value of 33.36 in 2019. [24]. has also done a similar kind of study on a section of national highway-3 by gathering Data from 2009 to 2011 and transformed it into Average Daily Traffic (A.D.T.) after that ASI (20.8) was calculated and reported as highest for year 2011 but his results of ASI presents a much lower value when compared to [25]. who studied Dahod to Jhalod portion of N.H.113 and it was noticed that ASI (31.62) was maximum for year 2012 and altogether his results are matching the results of present study

As it can be seen in Figure 2, accident, death and injury per 10 lakh of road length; Accident, Injury and Death per lakh registered vehicles; Accident, Injury, and Death per thousand population are falling due to the increasing variables (population, no. of vehicles registered and total road length) used to compare in the following manner: population (8.432%) < road length (32.884%) < number of registered vehicles (109.486 %) during the study period. Accident, injury, and mortality was highest per lakh road length among the studied variables, since the road length is quite minimal when compared to registered vehicles and population of the country. Deaths per one lakh population had reduced by a small number because population of India is increasing with a birth rate of 2.22 per women and number of deaths are also rising with almost the same rate. A lot work is needed to reduce the mortality rate in road accidents as India is registering approximately 1.5 lakh death per year constantly throughout the decade 2011-2020

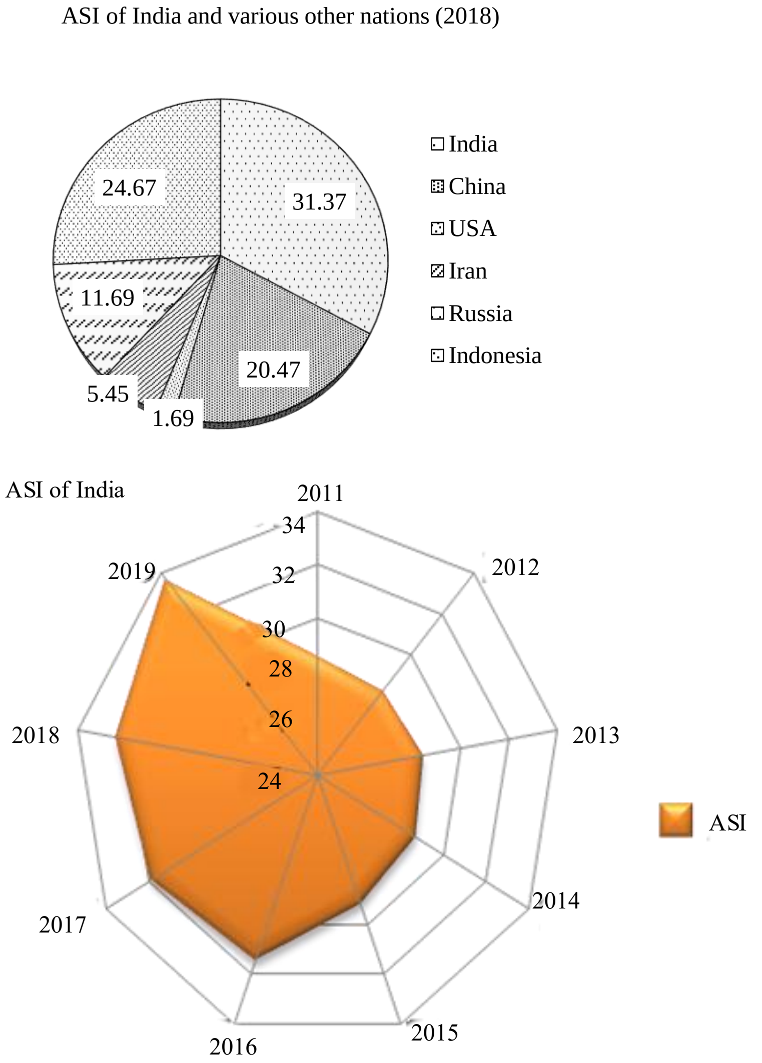


Figure 1. Asi of India and various other nations.

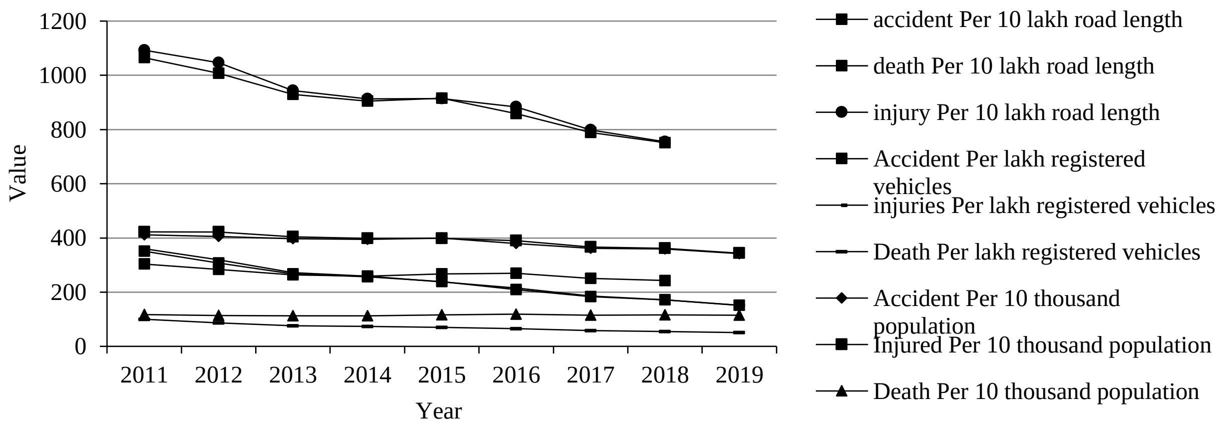


Figure 2. Trends of accident data w.r.t various variables.

Table 2. Accident data analysis using various equations.

Type	Analysis	Equation	R^2	Average R^2
Polynomial	Accident	$y = -0.977x^2 + 4.522x + 489$	0.834	0.829
	Death	$y = 0.077x^2 + 0.987x + 137.6$	0.756	
	Injury	$y = -0.794x^2 + 1.210x + 507.2$	0.898	
Linear	Accident	$y = -5.25x + 506.9$	0.708	0.765
	Death	$y = 1.766x + 136.1$	0.749	
	Injury	$y = -6.733x + 521.7$	0.838	
Exponential	Accident	$y = 507.7e^{-0.01x}$	0.71	0.762
	Death	$y = 136.3e^{0.012x}$	0.745	
	Injury	$y = 522.9e^{-0.01x}$	0.833	
Logarithmic	Accident	$y = -17.2\ln(x) + 505.1$	0.526	0.592
	Death	$y = 5.891\ln(x) + 136.6$	0.574	
	Injury	$y = -23.0\ln(x) + 520.8$	0.677	
Power	Accident	$y = 505.7x^{-0.03}$	0.524	0.587
	Death	$y = 136.7x^{0.040}$	0.571	
	Injury	$y = 521.8x^{-0.04}$	0.666	

The polynomial and linear equations had the highest R^2 values, as shown in Table 2, indicating that data fits these two equations better than any other equation applied in the analysis. The polynomial equation's graphs are plotted (Figure 3) to visualize the trends in the accident data. Only deaths are increasing while the number of accidents and injuries are declining, which is alarming situation and same is illustrated by the increasing ASI of the country. [26] developed Accident models using regression analysis for Vadodara, Gujarat, and author discovered that the driver's negligence and the 2-W type of vehicle in city streets were the primary causes of the accident. and our study also shows that accidents per lakh registered vehicles have decreased but only up to a certain level, whereas accident have decreased with a steep slope in case of accidents per lakh road length and population. [27] and [28]. also used regression analysis and produced good results

Multiple Linear Regression Models

All of our models (Table- 3, 4 and 5) have a very high R^2 value mostly over 0.99 which means that the independent variable explains the variance of dependent variable up to 99%. [29] carried out modelling analysis using linear regression analysis where density and roadside features are used as variables, but his model have not produced similar result to our study as the R^2 value of present study is much higher.

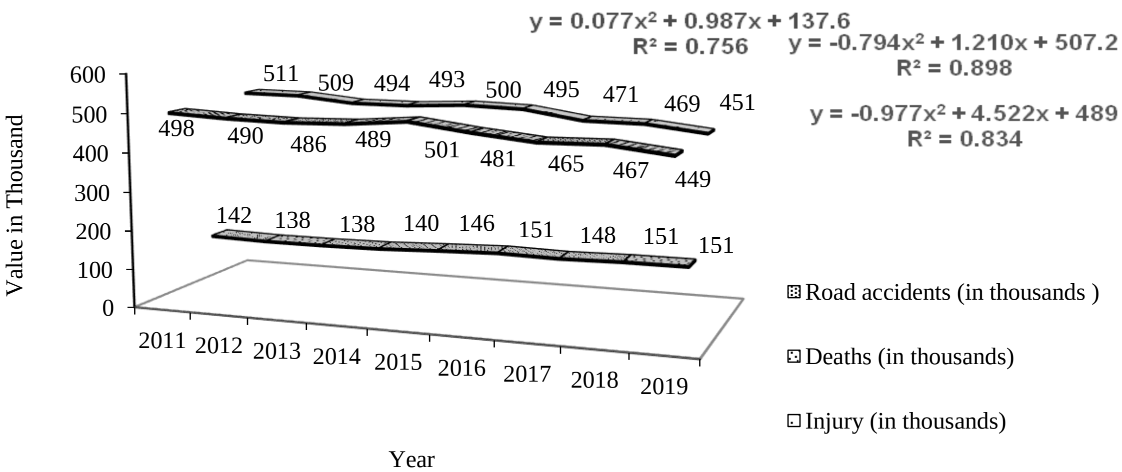


Figure 3. Polynomial equations for accident data pattern.

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Table 3. Accident Prediction Model.

Regression Statistics								
Multiple R	0.999901							
R Square	0.999803							
Adjusted R Square	0.83307							
Standard Error	8.271359							
Observations	9							
ANOVA								
	D f		***SS***		***MS***	***F***	***Significance F***	
Regression	3		2081288		693762.5	10140.45	7.05E-10	
Residual	6		410.4922		68.41537			
Total	9		2081698					
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RL	0.028465	0.030324	0.938706	0.384115	-0.04573	0.102664	-0.04573	0.102664
RV	-0.00087	0.000252	-3.45233	0.013594	-0.00148	-0.00025	-0.00148	-0.00025
P	0.000407	9.2E-05	4.421616	0.004463	0.000182	0.000632	0.000182	0.000632

Table 4. Death Prediction Model.

Regression Statistics								
Multiple R	0.999904							
R Square	0.999807							
Adjusted R Square	0.833076							
Standard Error	2.468436							
Observations	9							
ANOVA								
	D f	***SS***		***MS***		***F***	***Significance F***	
Regression	3	189438.4		63146.15		10363.42	6.68E-10	
Residual	6	36.55904		6.093174				
Total	9	189475						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RL	-0.01306	0.00905	-1.44323	0.199062	-0.0352	0.009083	-0.0352	0.009083
RV	0.000113	7.51E-05	1.508854	0.18207	-7E-05	0.000297	-7E-05	0.000297
P	0.000153	2.75E-05	5.585852	0.001399	8.62E-05	0.000221	8.62E-05	0.000221

Table 5. Injury Prediction Model

Regression Statistics								
Multiple R	0.999918							
R Square	0.999836							
Adjusted R Square	0.833115							
Standard Error	7.658923							
Observations	9							
ANOVA								
	Df	***SS***		***MS***	***F***		***Significance F***	
Regression	3	2147163		715721	12201.36		4.44E-10	
Residual	6	351.9546		58.6591				
Total	9	2147515						
	Coefficients	***Standard error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RL	0.000215	0.028078	0.00765	0.994144	-0.06849	0.06892	-0.06849	0.06892
RV	-0.00073	0.000233	-3.14397	0.019967	-0.0013	-0.00016	-0.0013	-0.00016
P	0.000513	8.52E-05	6.025671	0.000943	0.000305	0.000722	0.000305	0.000722

In a model analysis, the following results are possible: -

Null hypothesis: We presume that the dependent and independent variables have no statistical relationship.

Hypothesis: The dependent and independent variables have a strong relationship.

MODEL-1 $A= (0.028465\times RL) + (-0.00087\times RV) + (0.000407\times P)$

MODEL-2 $D= (-0.01306\times RL) + (0.000113\times RV) + (0.000153\times P)$

MODEL-3 $I= (0.000215\times RL) + (-0.00073\times RV) + (0.000513\times P)$

The total number of Accident, Death, and Injuries (dependent variable) are 'A', 'D' and 'I' respectively. Whereas, the total population of India (P), Registered vehicles (RV) and Road length (RL) are the independent variables. A 95% confidence level was maintained throughout the model-development process. The models fit the hypothesis because the significance-F and P-values are both less than 0.05. The t-statistic value is highest for population variable (average of 3 models = 5.34), indicating that population has the highest effect on the road accidents and strong correlation is present between the two variables.

Polynomial Regression Analysis

All of our polynomial models (Table 6) produced good results and all of them are having a very high value of R^2& t-stat with an average prediction error of 0.76% in accident models and 1.48% and 1.06% in death and injury models respectively (Table 7), indicating that there is a strong correlation between the dependent and independent variables and models can be used to predict accidents and same is reflected in Figure (4 & 5) which shows the validation of the given models. Multiple linear regression models produced similar results, but they were slightly more accurate than polynomial models.

Table 6. Polynomial Models.

S N.	Model name	R^2	Standard error	Significance -F	P-Value	t-Stat	Model Equation
1	Accident & Population	0.999704	9.374	1.60E-11	3.4E-06 & 5.03E-05	13.166 & -8.775	$A= 0.001145\times P - 6.1E\text{-}10\times P^2$
2	Accident & Road length	0.99976	8.409	8.47E-12	3.47E-09 & 1.55E-07	35.761 & -20683	$A= 0.203537\times RL - 2.1E\text{-}05\times RL^2$
3	Accident & Registered vehicles	0.99796	24.598	5.31E-09	3.74E-08 & 1.7E-06	25.403 & -14.583	$A= 0.004822\times RV - 1.1E\text{-}08\times RV^2$
4	Death & Population	0.99975	2.599	9.80E-12	0.004 & 0.5164	4.10 & 0.6832	$D=9.91E\text{-}05\times P + 1.31E\text{-}11\times P^2$
5	Death & Road length	0.99945	3.848	1.03E-10	5.81E-07 & 0.0002	17.068 & -7.050	$D=0.04446\times RL - 3.3E\text{-}06 \times RL^2$
6	Death & Registered vehicles	0.99797	7.411	5.20E-09	9.65E-08 & 1.07E-05	22.153 & -11.09	$D= 0.001267\times RV -2.6E\text{-}09 \times RV^2$
7	Injury & Population	0.99978	8.162	6.45E-12	6.83E-07 & 8.2E-06	16.672 & -11.553	$I = 0.001263\times P - 7E\text{-}10\times P^2$
8	Injury & registered vehicles	0.99765	26.822	8.13E-09	5.58E-08 & 2.23E-06	23.980 & -13.927	$I = 0.004963\times RV - 1.2E\text{-}08\times RV^2$
9	Injury & Road length	0.99983	7.045	2.67E-12	7.04E-10 & 2.65E-08	44.955 & -26.699	$I = 0.214368\times RL - 2.3E\text{-}05\times RL^2$

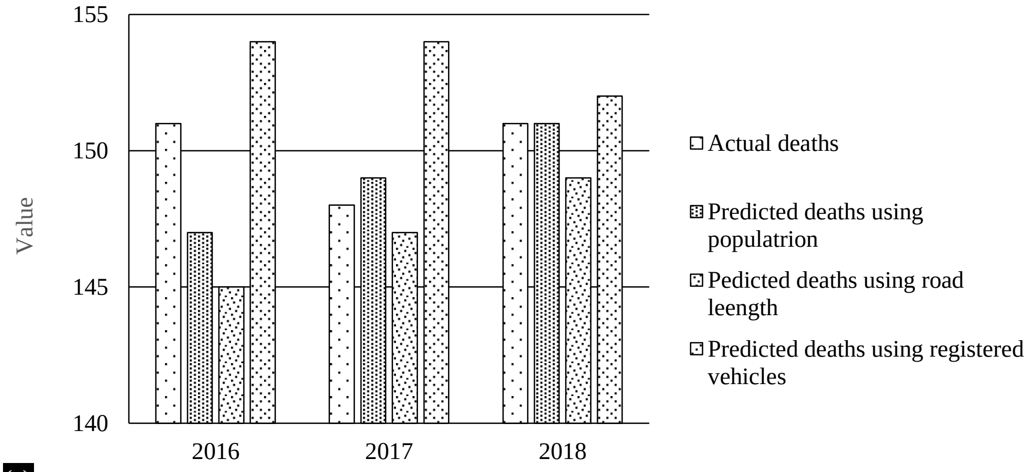
Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Validation of Models

Validation graph is plotted (Figure 4 & 5) to analyze the predicting power of the models. The error shown by the models is in the following order: Accident model (0.85%) < injury model (1.07%) < death model (1.526%). In polynomial regression analysis highest error was shown by the 'Registered vehicle - Accident Model' i.e. (8.93%) and least error is shown by the 'Population-Death model' i.e. (1.54%). The data on road traffic accidents in India is extremely limited. Many minor accidents are never recorded, while others are compensated discreetly. It is impossible to conduct routine analyses based on police data, making it virtually impossible to implement safety measures. RTAs can be avoided, and in order to tackle the problem, close synchronization and teamwork across many different disciplines, using a comprehensive and integrated strategy, is required.

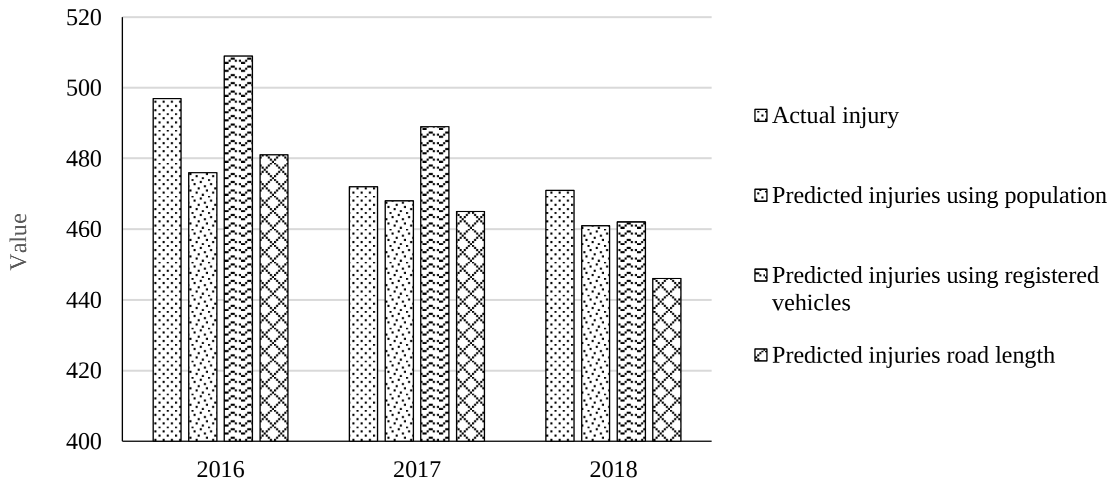
Table 7. Error In Prediction of Accident, Injury and Death.

% Error in prediction			
Year	**Accident**	**Death**	**Injury**
2016	1.07	2.66	2.16
2017	1.06	0.008	0.81
2018	0.15	1.8	0.22



(a)

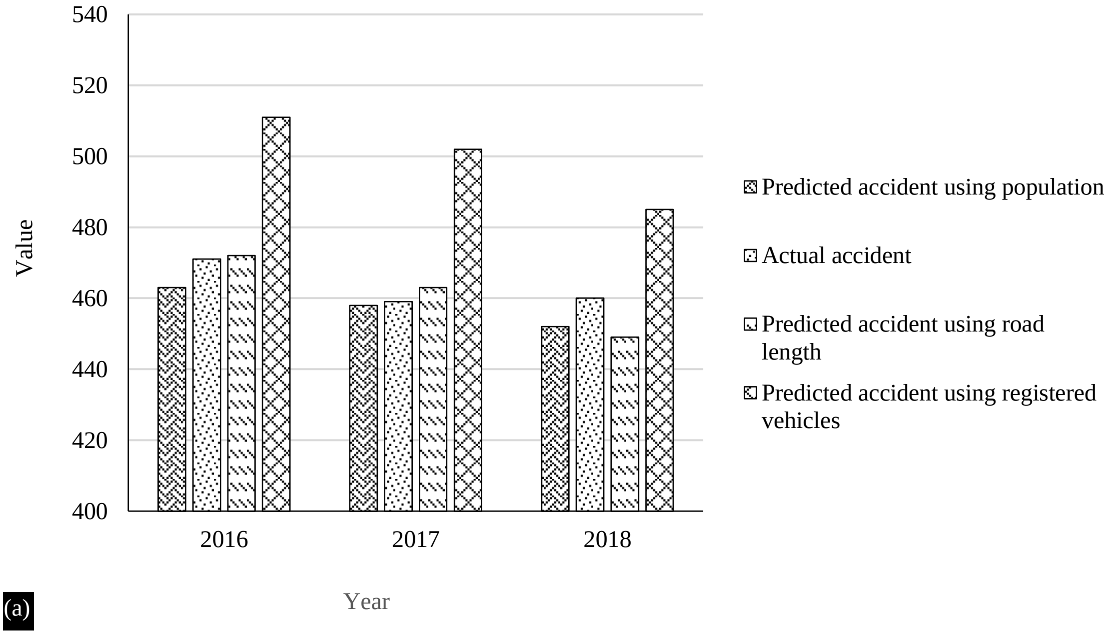
Year



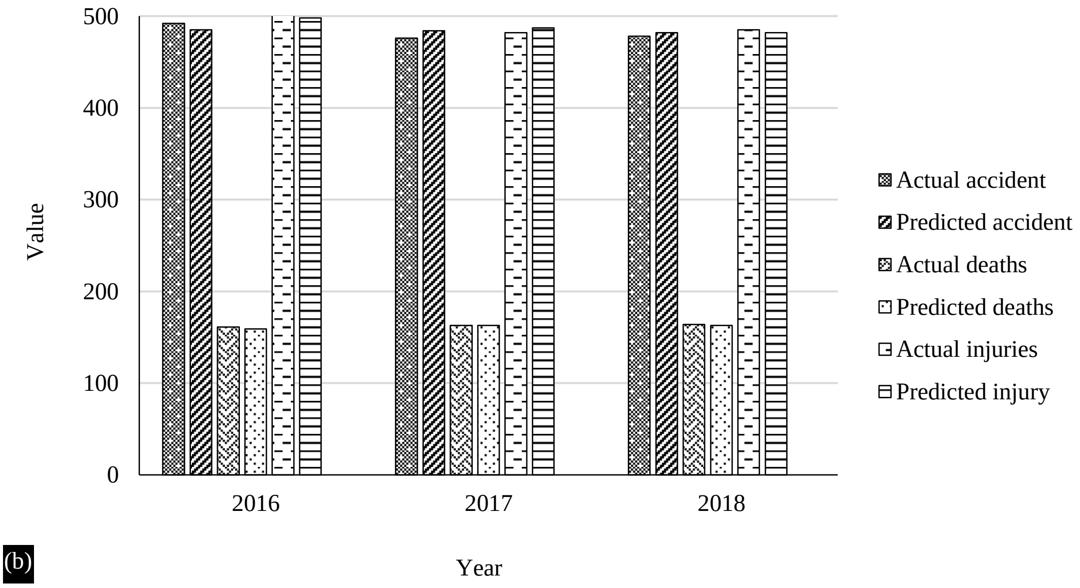
(b)

Year

Figure 4. Validation of polynomial injury and death models.



(a)



(b)

Figure 5. Validation of polynomioal accident and multiple regression analysis model.

CONCLUSIONS

1. In 2018, accident severity index of India (31.37) was highest among all the countries.
2. Accidents per lakh population are highest in 2011 (41.15) and lowest in year 2019 (34.21) during study period.
3. Number of accidents per lakh road length was at its lowest in 2019 (7514.07).
4. In India, the number of accidents per lakh registered vehicles is lower in 2019 (151.08) than it was in 2011 (351.03).
5. The findings of the research were applied to develop models that forecast number of road accident, fatalities, injuries in India. Three models were created using multiple linear regression, and nine models were created using polynomial regression analysis. Because these models offered good results, they can be used to forecast subsequent years fatalities and traffic accidents. It was discovered that multiple linear regression analysis was more accurate than polynomial regression analysis.

Acknowledgement

We will like to thank all members of the department of civil engineering DCRUST, Murthal for their support throughout the research.

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