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Speed, Density, and Crash Relationship in Urban Arterial Roads

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ABSTRACT

Vehicle speed has an essential role in the occurrence of traffic accidents. Increasing the number of vehicles operating on the road will further increase the risk of traffic accidents because it is not balanced with discipline in driving. This study's purpose is to analyze the relationship between speed and traffic accidents that occurred in Gadjah Mada and Hayam Wuruk Road, Jember, through several variations of calculations. The independent variables used are average speed and 85th percentile speed and density, while the dependent variable used is the accident rate. The analysis used is a correlation test that determines the level of closeness of the relationship between the two variables and a regression test that helps estimate the relationship between the two variables through a regression equation model that will be selected based on conditions in the field. The results of this study indicate that speed and accident rate have a weak correlation, while density and accident rate have a strong correlation. Based on the regression analysis, lower speed is associated with a lower accident rate. Meanwhile, lower vehicle density leads to an increase in the accident rate. Speed management to improve traffic safety in Indonesia is needed. Direction for future research is presented

1. Introduction

The Traffic accidents causing deaths have been reaching an alarming level. The number of fatal crashes has not seen a declining trend since 2009. In 2016, there were 1.35 million people died on the road. Meanwhile, the World Health Organization (WHO) predicted that the trend would be tripled in 2030. It indicates that the implementation target of Sustainable Development Goals (SDGs) in 2020, which requires a 50% reduction of the traffic accident victim, becomes a problematic business. Although the declining trend in the number of traffic accidents causing death occurs in middle-and high-income countries (MHICs), the opposite pattern occurs in low-income countries (LICs). For example, WHO data for 2018 shows that the Southeast Asian and African regions, where most of the countries have low incomes, have the highest fatal accident number (accounting for 26.6 and 20.7 per 100,000 population, respectively). This accident rate is far above the world average (18.2 per 100,000 people). Countries in Europe and North America show contradictions, most of which are developed countries, with a traffic accident rate of only 15.6 and 9.3 deaths per 100,000 population. Moreover, Sulistyono et al. [1] stated that a program OK BOS (program focusing on blackspot management) initiated by Traffic Directorate Polda Jawa Timur did not show a significance level of reducing the crash frequency.

The human, vehicle, and environmental factor has been considered as the factors causing traffic accident [2]. However, human is the most significant factor causing traffic accidents [3]–[5]. The increasing number of motorized vehicles must be followed by the riders' discipline [6]. Moreover, the lack of a road environment and the limitation of safety features for protection have an essential role in increasing the traffic crash number [7]. Motorcycle (scooter) has inundated the LCIs for decades. Furthermore, motorcycles are responsible for 63.21% of crash frequency, whereas their behavior in driving is considered dangerous [8]. It is often exacerbated by the fact that riders in LCIs chaotically ride their vehicles. Therefore, dangerous driving behavior is essential to transport safety research [9]. However, the study related to travel behavior, especially in terms of speed choice, speed variations, and their relationship with accident numbers, is not yet studied comprehensively compared to the study conducted in MHICs.

Speeding has positive and negative effects on road users. Driving at high speed directly causes reduced travel time,

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increases mobility, and is good for road capacity. However, Lai et al. [10] state that driving at high speeds has negative consequences, namely the high number of accidents on urban roads and the increase in CO2 emissions. Furthermore, Wells [11] state that some motorists said that they are drivers who are reliable, safe, and do not have a negative record; therefore, the behavior of increasing speed does not affect the involvement in traffic accidents.

Speed management is an essential factor in road safety improvement strategies. In developing countries, statistically, high-speed driving behavior or commonly called speeding is responsible for around 60% of traffic accidents. The Indonesia National Police reported that 40% of fatal accidents were caused by speeding behavior.

Speed-related behavior has been identified as one of the leading causes of traffic accidents. The severity of traffic accident victims has a linear relationship to speed [12]–[14]. Nevertheless, some studies showed a different perspective in terms of a speed-accident relationship. Preliminary studies on the relationship conducted by Solomon [15] showed the relationship between speed and accident is a "U" shaped curve. However, most studies show a linear and exponential relationship. Some studies have even stated contradictions, where speed and accident are not statistically significant [16], [17]. The relationship between speed and accident must pay attention to factors from the simultaneous effect of traffic characteristics such as traffic flow/vehicle level [18], [19]. Meanwhile, the relationship between crashes and vehicle density or lane occupancy has not been investigated properly. It indicates that there are still different views about the relationship between traffic accidents and driving speed and a potential study to fill the gap in the relationship between crash rates and density.

The primary objective of this research is to develop a series of relationships between speed, crash number, and traffic density using statistical models. Correlation tests and regression analysis are performed on data collected on divided urban arterials in Jember, East Java, Indonesia to accomplish this objective.

2. Literature Review

Numerous studies have investigated travel speed and traffic accidents [12], [17], [20], [21]. However, there are only a few studies examined the relationship using statistical models. Moreover, some studies relied on a linear regression that is considered inappropriate for dealing with random events [22]. Therefore, this section focuses on the review of literature on a speed-accident relationship using several statistical methods.

Unlike the mean speed, speed variation is inconsistent along a segment. Speed variation has a similar estimation to standard deviation. It is found that traffic accident frequency and speed variation have a positive relationship, despite the variety of research methods, speed data, and traffic accident data collection [23]. Speed has a strong relationship with density and traffic volume, and the model developed by Underwood shows a more suitable value with Indonesia's condition [24].

Oh et al. [23] argue that speed variation was highly potential to cause a traffic crash. This study used freeway speed data incorporating the integrated real-time capabilities in advanced traffic management and information systems (ATMIS) and a nonparametric Bayesian model. Moreover, Lave [25] stated that the variation speed killed, not speed. However, a later study by Levy et al. [26] indicated that both average speed and speed variance has a positive relationship with the fatality rate at the 95% confidence level. Furthermore, Pei et al. [14], using a floating car data to determine the speed variation, indicate that speed variation is not significantly related to traffic accidents.

Generally, the average speed has a positive relationship with the accident number. A study by Taylor et al. [27] indicated that a 1 mile/h change in average speed was associated with a 5% change in the accident. Similarly, Levy et al. [26] employed the Bayesian approach and developed a relationship between average speed and fatalities, find that they have a positive relationship and are statistically significant. However, some literature reported inconsistent findings. Using GPS data, Pei et al. [14] indicated that higher mean speed caused shorter time exposure; thus, the traffic accident frequencies experienced a decrease. Furthermore, by developing generalized linear models, Garber and Gadiraju [28] inferred that the traffic accident rate was higher at lower mean speeds on the interstate, rural collector, and arterial roads. The different road geometric characteristics caused this. Moreover, they found that the total accident and fatality rate on the urban road was much higher than the other road types; thus, the safety of this road type needs more attention.

3. Material and Methods

3.1. *Urban Arterial Segments*

Some urban arterials were selected from Jember, East Java, Indonesia (Gajah Mada and Hayam Wuruk road), as given in **Figure 1**. Gajah Mada (segment 1 & 2) has four lanes and two ways, with a total length of 2.2 km. Meanwhile, Hayam Wuruk (segments 3 & 4) has six lanes and two ways, with a total length of 2.5 km. The selected arterials were divided into four segments, separated by the two signalized intersections. Furthermore, the traffic flow direction divides the segments. This results in a total of 16 one-way road segments.

The urban arterials are selected from the highest number of accidents in Jember. Based on Integrated Road Safety Management System (IRSMS) data, the traffic accident number on Gajah Mada road from 2014 to 2018 was 37, with the fatality rate of approximately 8%. Meanwhile, there were 118 crashes with a fatality rate of approximately 14% on Hayam Wuruk road.

3.2. *Road Geometric and Traffic Volume*

Road geometric design consists of the number of lanes, length of the segment, length of each lane, and presence of median. These data were obtained from field surveys. The walking distance was used to calculate the length of each lane. Meanwhile, the length of the segment was calculated using Google Earth.

Traffic volume data were obtained from Area Traffic Control System (ATCS) of the Department of Transportation Jember. The traffic volume used in this study is 24-hour traffic. The traffic volume of each segment is presented in **Figure 2**. It is worth noting that the traffic volume presented in **Figure 2**

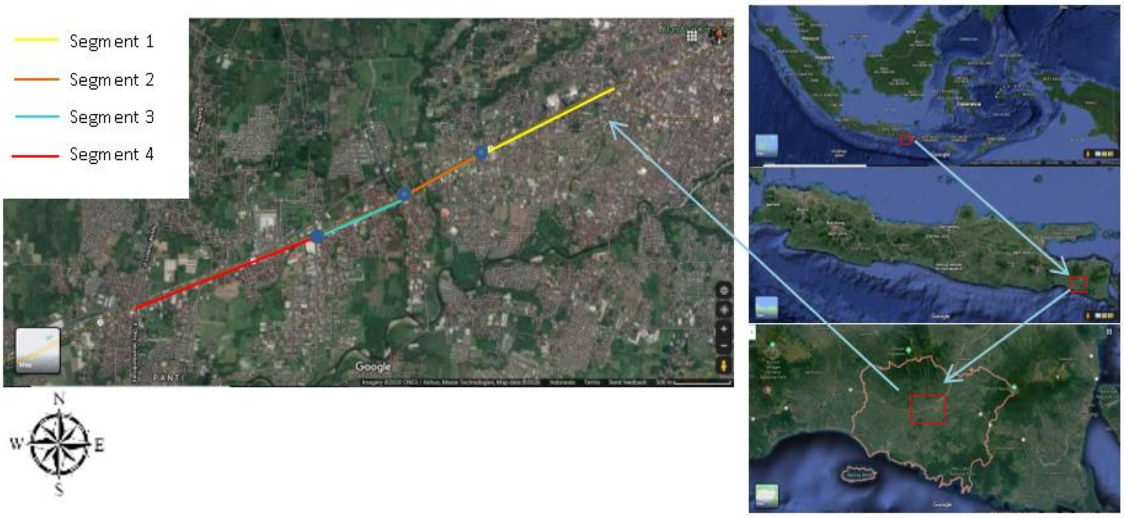
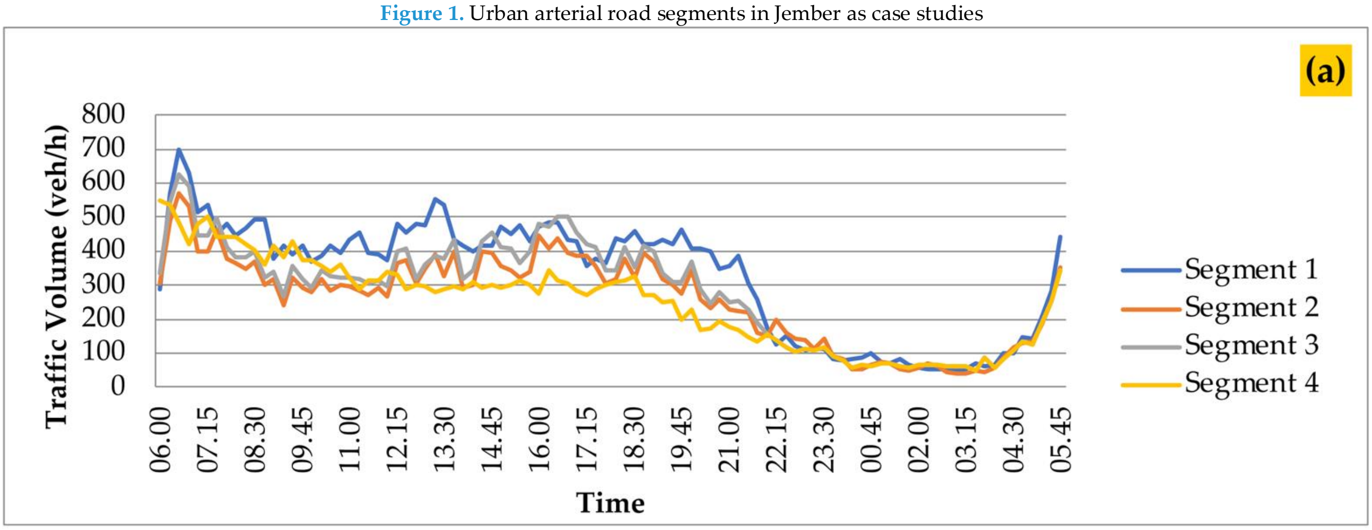


Figure 1. Urban arterial road segments in Jember as case studies



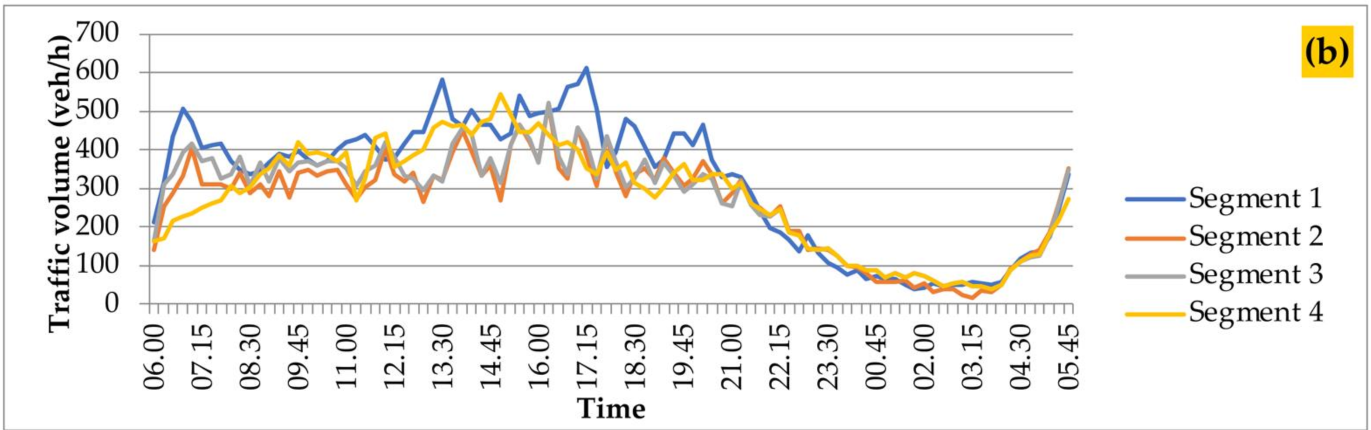


Figure 2. A pattern of traffic volume (a) direction A (b) direction B

are the cumulative number of light vehicle and motorcycle traffic.

3.3. *Spot Speed*

Spot speed surveys are conducted to know the vehicle's average speed at the location where electronic devices named radar speed guns are used. Spot speed surveys are performed on two segments with two directions, namely the direction towards the city and out of town—determination of spot speed survey locations is based on the number of accidents that occurred in the segment. The sample size of spot speed data is 100, for each type of vehicle (motorcycle, light vehicle), for each segment, every hour. The sample size for each vehicle type is based on the Slovin's formula, where the acceptable margin error is 0.1. The maximum volume per hour for motorcycle is around 4,000 while for car is 1,000; thus, resulting the sample size of 100.

The normality test was performed to understand whether the speed data have a normal distribution. Some normality tests (P-Plot, Kolmogorov-Smirnov) are used to check the normality of the data. Furthermore, the speed data is analyzed based on mean, median, modus, and 85% percentile.

3.4. *Crash Data*

The crash data is derived from IRSMS from 2014 to 2018. The IRSMS crash data consists of a specific crash location (using the coordinate of GPS), number of victims, type of crash, and type of vehicle. In this study, crash data are classified into three time periods (morning, afternoon, and evening). Nevertheless, crashes that were located in intersections were excluded. Crashes in intersections are mostly caused by some factors such as signal phase and the various design features of the intersections such as the curvature [28].

3.5. *Data Analysis*

A correlation test is performed to understand how close the relationship is between the two variables, namely the independent variable and the dependent variable. Correlation analysis used in this research is the product-moment analysis. Product moment correlation is a statistical analysis that is useful for analyzing research data as following Eq. (1)

$$r_{xy} = \frac{N.\Sigma xy - \Sigma x.\Sigma y}{\sqrt{[(N.\Sigma x^2) - (x)^2][(N.\Sigma y^2) - (y)^2}} \quad (1)$$

Meanwhile, the relationship between accident number with speed and density are identified using the regression analysis. The most suitable regression is assessed using the value of R^2.

4. Result and Discussion

4.1. *Normality Test on Speed Data*

The normality test is performed using namely histogram graph analysis, p-p plot graph analysis, and Kolmogorov-Smirnov test. The results of normality tests are presented in Figure 3, Figure 4, and Table 1.

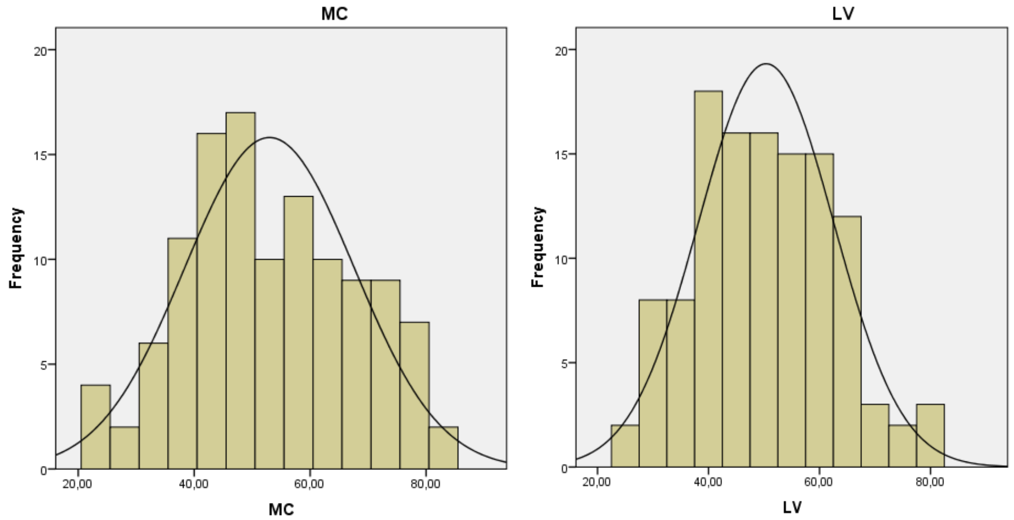


Figure 3. Normal distribution of speed data

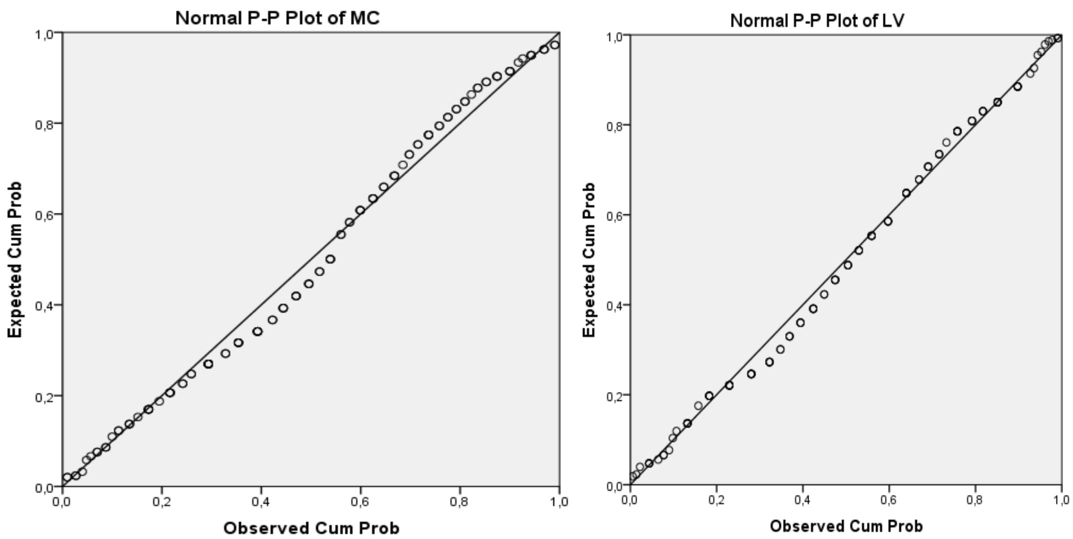


Figure 4. P-Plot graph on speed data

Table 1. Normality test

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Motorcycle (MC)	0.072	116	0.193	0.978	116	0.052
Light Vehicle (LV)	0.067	116	0.200	0.987	116	0.355

The graph shows the data follows the bell-curved line. Therefore, the data is normally distributed. Figure 4 shows the data distribution follows a diagonal line; thus, the data is normally distributed. Table 1 illustrates the Kolmogorov-Smirnov test using statistical tools. The table shows that the significance of the data is above 0.05; therefore, the data is normally distributed. It can be concluded that the speed data obtained can be used for further analysis.

4.2. *Safety and Speed Relationship*

There are two analyses in modeling the relationship between speed and accident: the correlation test and the regression test. The correlation test is between the number of accidents with 85th percentile speed, traffic density, and accident rate. Table 2 shows that the accident rate and speed have a positive low correlation. Meanwhile, the correlation between speed and density shows a negative high value.

From Figure 5, it can be concluded that higher speed leads to an increased accident rate. Meanwhile, according to the R-square value, the exponential regression shows the best for describing the relationship between speed and accident rate. This finding is supported by previous studies [29], [30].

4.3. *Safety Impact of Traffic Density*

Table 2 shows that the accident rate and density have a strong correlation (*r* =-0.772). The Pearson correlation shows a negative value, meaning density has a negative relationship with the accident rate.

As can be seen from Figure 6, it is concluded that lower density leads to an increased accident rate. However, the accident rate remains stable after the density reaches the value of 20 veh/km. According to the R-square value, the power regression best describes the relationship between density and accident rate.

Table 2. Correlation test

		Accident Rate	Speed	Density
Accident Rate	Pearson Correlation	1	0.494*	-0.772*
	Sig.		0.000	0.000
Speed	Pearson Correlation	0.494*	1	-0.625*
	Sig.	0.000		000
Density	Pearson Correlation	-0.772*	-0.625*	1
	Sig.	0.000	000	

*Correlation is significant at the 0.01 level (2-tailed)

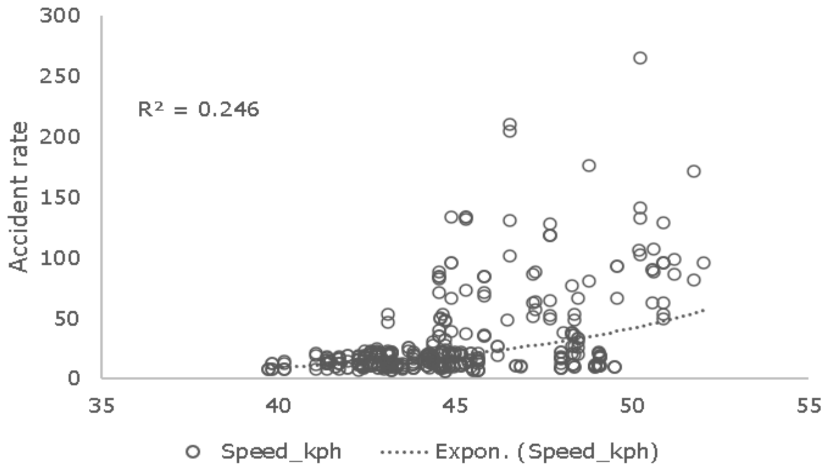


Figure 5. Regression analysis on accident rate and speed

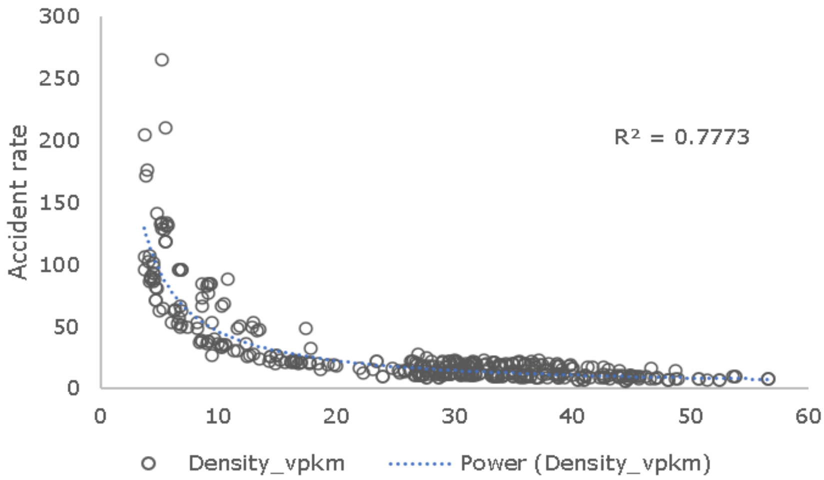


Figure 6. Regression analysis of accident rate and density

4.4. *Discussion*

At a minimum category of speed, when the speed increased by 1%, then the expected accident rate increased by 1.7%. However, the trend rises constantly, following the natural behavior of exponential regression. At a maximum 85th percentile speed, a 1% rise of speed led to 17.9% increase in the accident rate. A previous study in Shanghai [30] shows that, in urban arterials, a 1% increase in mean speed led to a 0.7% increase in crash frequency. A study in Canada [31] stated that a 1% higher average speed was responsible for 0.018% higher crash frequency. This confirms that the probability of crashes with regard to speed is higher on Indonesian urban arterial. This result is generally in line with the findings of [32], in which the 1% increase in mean speed would lead to a 1.36% higher crash frequency.

Meanwhile, it is generally argued that crash rates and the V/C ratio relationship typically follow a U-shaped diagram [33], [34]. The finding of this paper, however, concludes that lower density leads to an increased accident rate. A study [35] argues that crash occurrence decreased as the percentage of lane occupancy increased. Furthermore, the findings of this study are supported by research [36], which describes how a decrease in Level of Service (LOS) leads to an increase in crash rates.

In terms of the model produced in this study, a relationship between accident rate and speed follows an exponential pattern. This finding is in line with some previous studies. Meanwhile, a relationship between accident rate and density follows a power relationship. It is supported by a previous finding [37] that studies more than 200 predictive models for rural roads in Egypt. The author states that half of the predictive models followed a power relationship. However, Garber and Subramanyan [35] find that the predictive models of the relationship between crash occurrence and lane occupancy followed a polynomial of the third order.

Some policies could be suggested based on the current study's findings. Since speed mainly shows a positive relationship with accident rate, efforts to make drivers obey the speed limit should be made. Clear speed limit signs could play an important role in reducing the increase in collision frequency. The installation of cameras monitoring the vehicles' speeds, occupied with signs of "Speed camera is in operation" and strict law enforcement could also be a good idea.

A potential concern with the analysis carried out in this study is that speed data is not explored into speed variations. Furthermore, the density data are not separated by each lane. Lane-changing behavior is a factor causing the accident. A finding reported that crashes increase as traffic volume rises, especially in the segments with more than three lanes per direction. It is also stated that 6-lane freeways have a higher probability of crash rates. Therefore, any future study shall consider speed variation and the number of lanes to develop prediction models of crash.

The key findings from this paper can be used for formulating a relevant policy of speed management. The lower speed is associated with a lower accident rate. Therefore, it is important to make an appropriate speed on urban arterials, for example, the speed limit sign installation. Furthermore, a study [38] confirms that police presence reduced mean speed and estimated fatal casualty on dual and single carriageways.

5. Conclusion

In terms of the speed-crash relationship, the exponential regression shows the fittest value for describing the relationship between speed and accident rate vehicles on arterial roads. Furthermore, where several studies implied that there is no strong relationship between speed and crashes, this study shows a positive relationship. Following the natural behavior of the exponential model, a 1% increase in speed leads to a 1.7% increase in the accident rate. Nevertheless, the accident rate rises significantly at maximum speed.

Meanwhile, the density-crash relationship shows the power model is the fittest model describing the relationship. Lower density leads to a lower accident rate, and the accident rate is constantly stable at a density of 20 veh/km.

This study addresses an essential understanding of the knowledge gap in current studies of crash modeling, especially in Indonesia. Findings from this paper show the essential role of speed management in improving traffic safety in Indonesia. Furthermore, traffic management on the level of density is needed because lower density is often associated with higher speed and accident rates.

Further research should consider focusing on the crash fatality rate. Studying the relationship between speed, road environment, and fatality rate could bring a better understanding of establishing appropriate policies. A longer data series could be combined to facilitate the lack of data on fatal accidents.

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Author Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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