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Modeling of the Effect of Toll Road Characteristics on Accident Rate

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ABSTRACT

A traffic accident is an event on the road that is unexpected and unintentional. Traffic accidents have an impact on the national economy as evidenced by the contribution of traffic accidents to economic losses in the form of a decrease in GDP by 2.9% – 3.1% or equivalent to USD 1.332 Billion – USD 1.465 Billion. So, to minimize accidents, an analysis is needed that is useful for anticipating accidents. This study intends to obtain the effect of the characteristics of intercity toll roads, as well as urban toll roads, on the accident rate. The stages conducted in this research are previous research studies, data collection, determining variables, and modeling. Based on the analysis that has been done in this study, a negative binomial distribution is used to determine the accident rate of inter–city toll roads and the Poisson distribution to determine the accident rate of toll roads within the city and the fatality rate of toll roads between cities and within cities. There are nine parameters used in this model, which can cover more things than similar studies that have been done before.

1. INTRODUCTION

A traffic accident is an event on the road that is unexpected and unintentional involving a vehicle with or without other road users resulting in human casualties and/or property loss [1]. Traffic accidents have an impact on the national economy. The contribution of traffic accidents to economic losses is in the form of a decrease in GDP by 2.9% – 3.1% or equivalent USD 1.332 Billion – USD 1.465 Billion [2]. Therefore, analysis related to accidents is an important thing to do to reduce the number of accidents. In this study, the classification of toll roads by region is divided into two, namely urban toll roads and inter–city toll roads with distinctive characteristics. Urban toll roads have different characteristics and facilities, especially in terms of the availability of rest areas and inter–city toll roads have a relatively high accident rate. The scope of the research is narrowed by analyzing the characteristics of toll roads based on their regional classification. The selection of the toll road used is based on the availability of accident data, traffic flow, and toll road characteristics. In the end, each of the 2 (two) toll roads were selected with the following in Table 1.

Based on previous studies, there are no studies that differentiate between the analysis of inter–city and inter–city toll roads, even though there are differences in the characteristics of the data and the accident rate. In addition, this research is designed in such a way that a more accurate, faster, and easier application is obtained for repairs in the field. So that the basic problem that must be solved is how the differences in the characteristics of the accident rate that occur on urban toll roads with intercity toll roads are described based on mathematical modeling.

Therefore, this research was conducted with the aim of obtaining the effect of the characteristics of intercity toll roads, as well as urban toll roads, on the accident rate. Broadly speaking, the stages to be fulfilled include obtaining the accident rate that occurred in each toll road case study, obtaining the factors related to the toll road characteristics of each case study, obtaining the toll road characteristic factors for the accident rate in each, a toll road case study, formulating a model of the influence of toll road characteristics on the accident rate, and applying a model of the influence of toll road characteristics on the accident rate to determine the location of black spots/black areas. In the end, it is hoped that this research can produce policy recommendations for stakeholders.

Table 1. Comparison of the ratio of number of accidents per km on urban toll roads to intercity toll roads

Toll Road Status	Location	Length (km)	Number of Accidents (2015–2019)	Number of Accidents per km
Urban	Pondok Aren – Serpong	12.5	310	25
	Surabaya – Waru	17.0	184	11
Inter–City	Cikopo – Palimanan	116.75	5.496	47
	Tangerang – Merak	72	3.141	44

2. LITERATURE REVIEW

The management, prevention, and control of accidents on toll roads is the obligation of the BUJT (Toll Road Business Entity). A prerequisite that must be met for the toll road to operate is that the initial toll road will be operated in the form of an audit process for the feasibility of the operation and when the toll road has been operated in the form of compliance with the Minimum Service Standards (SPM). In accordance with PM PU No. 16/PRT/M/2014 [3], the substance of toll road MSS can be measured from several elements, including toll road conditions; average travel speed; accessibility; mobility; first aid safety. In addition to the six factors above, in the process of managing safety and preventing traffic accidents on toll roads operationally also includes controls in the form of: Setting the V/C volume/capacity ratio, Setting PHV (Peak Hour Volume), Management of accident rate and fatality rate, Management of construction/pavement, Traffic engineering, Setting the distance of rest areas, Setting the distance of On and Off ramp/distance to toll gates [4]. In its implementation, the Management, Prevention and Control of traffic accidents is carried out as a preventive measure or corrective action.

According to Article 1 number 24 of Law Number 22 of 2009 [5], concerning Road Traffic and Transportation, a traffic accident is an unexpected and unintentional event on the road involving a vehicle with or without other road users resulting in human casualties and/or property loss. Meanwhile, according to WHO (1984), a traffic accident is an incident on road traffic involving at least one vehicle that causes injury or damage or loss to the owner (victim).

Basically, road safety is an interaction between vehicles, people, and roads. It is common to blame the driver for a collision, or the condition of the vehicle being driven. If neither the driver nor the vehicle is to blame, then accidents are often seen as fate, or sheer bad luck. Since then, traffic accidents have always been described as destined collisions [6].

The accident rate is used to measure the accident rate on a road segment or a road point. There are various ways and methods to measure the Accident Equivalent Number (AEN). Some AEN is determined through the segment of the road. The other method is calculated based on the point of occurrence of the accident. Based on the Construction and Building Guidelines Pd T–09–2004–B concerning Handling of Traffic Accident Prone Locations from the Ministry of Public Works and Public Housing of Indonesia [7], the following is the calculation of the accident rate and fatality rate, AEN, and the determination of accident–prone locations (black spots).

(1) Accident rate (AR) [7]

$$AR=\frac{A\times 10^{8}}{day\times AADT\times T\times l} \tag{1}$$

(2) Fatality rate (FR) (Kementerian PUPR, 2004)

$$FR=\frac{VD\times 10^{8}}{day\times AADT\times T\times l} \tag{2}$$

The calculation of the equivalent accident number (EAN) is carried out using a weighting system. The accident rate weighted ranking uses a comparison of the monetary value of the accident cost to determine, which refers to the accident cost. The following is an accident weighting value based on the losses caused.

$$M:B:R:K=12:6:3:1 \tag{3}$$

The AEN value is then calculated for each section on the toll road under review. When you have finished calculating the AEN value in each toll road section, the AEN is sorted in a table starting with the highest number of values to the lowest. For the record, this method does not look at the number of victims, but only the incidence and frequency.

The beginning of determining the blackspot is to identify the location of the blackspot. To begin with, black spots can be intersections, middle block chunks, or cuts in the road. All locations have a history of accidents–some reported, others unreported. To formulate a blackspot, an Accident Equivalent Number (AEN) value is required, as previously explained. One method of determining accident–prone locations (blackspots) is the statistical approach to quality control for inter–city roads, using UCL (Upper Control Limit) as a control chart. A road segment with an accident rate that is above the UCL line is defined as an accident–prone location (blackspot).

$$UCL=\lambda+2.576\sqrt{\left(\frac{\lambda}{m}\right)+\left(\frac{0.829}{m}\right)+\left(\frac{m}{2}\right)} \tag{4}$$

The previous study model used as a reference in this study, the research that is close to this research is the research by Haryadi [8] entitled Exploration of the Toll Road Traffic Accident Rate Model with the GLM (Generalized Linear Modeling) technique. The study locations studied were the Jagorawi Toll Road (Jakarta – Bogor – Ciawi), the Jakarta – Cikampek Toll Road, and the Padaleunyi Toll Road (Padalarang – Cileunyi), with traffic volume and segment length as variables. The model results obtained are as follows:

Linear Regression

$$Total=24.59+5.217\times l+0.0001298\times AADT \tag{5}$$

Positive intercept indicates that although there is no traffic and the length of the segment is zero, the model predicts the occurrence of more than 24 accidents per two years. This is of course impossible, so this model cannot be used to show the relationship between the total number of accidents with the length of the segment and the volume of traffic. From statistical analysis, it is known that only the segment length parameter is significant (5%). The linear regression model is based on the assumption of a normal distribution which is a continuous distribution, while the traffic accident data on a road segment at a certain time period is discrete non–negative data that does not follow the normal distribution.

Poisson Regression

$$\ln(Total)=3.503+0.07792(l)+0.000002622(AADT) \tag{6}$$

The basic assumption of the Poisson distribution is that the mean and variance are the same. The model developed using the Poisson distribution shows a large overdispersion value, which is an indication that the mean value is much different from the variance value. This violates the most basic of assumptions. From the software output, R shows a large overdispersion symptom. The residual deviance value is 1677.6 with 54 degrees of freedom giving a ratio of deviance divided by degrees of freedom of 31.07. The greater the ratio value, the greater the difference in value between the mean and variance (overdispersion). It also indicates that the data does not match the type of function of the model.

Negative Binomial Regression

$$\ln(Total) = 0.427 + 0.075(l) + 0.382 \times \ln(AADT) \quad (7)$$

The use of negative binomial distribution to model segment length, traffic volume and total accident solves the problem of overdispersion. The resulting model is similar to the model generated with the Poisson distribution, but the problem of overdispersion is almost completely solved. The value of the deviation divided by the degrees of freedom is 1.1285 (a value of 1.0 indicates that there is no problem with a variance greater than the allowable).

In addition to the Haryadi's model [8], a study of the previous model that is relevant to this research was also conducted, so this research tries to fill the gap from previous studies with the following developments.

(1) This study tries to explain the relationship between the characteristics of urban toll roads and intercity toll roads on the accident rate by using the Generalized Linear Model (GLM), which includes a Poisson regression model, or a negative binomial distribution if overdispersion is found in the data distribution, namely the condition where the data variance is greater than the average value. Basically, overdispersion does not change conclusions about the relationship between accident rate and traffic volume and road geometry design [9].

(2) This study focuses only on the characteristics of toll roads that affect the accident rate. Based on the mapping of the previous study, no research has been found that has the effect of resting place locations, the distance between toll gates, and blackspot points on the number of accidents that occur. Therefore, in this study, the characteristics of the toll roads that will be reviewed in this study are as follows, taking into account the availability of data [10].

a. Traffic factor:

–Comparison between traffic volume and road capacity (volume capacity ratio).

b. Geometry factor (infrastructure):

–Number of available lanes.

–Toll road shoulder width.

–Location of blackspots.

c. Vehicle factor (means):

–Composition (class) of vehicles on toll roads.

d. Road complementary factors:

–Distance from rest area to toll gate.

–Availability of median barriers.

(3) The data to be used is secondary data obtained from the relevant agencies. Before developing the model, the data will be tested statistically first, namely with a partial test and a data fit test for the proposed model.

(4) In this study, a comparison will be made between the characteristics that affect the rate of accidents on urban toll roads with statistically significant inter–city toll roads.

3. METHODOLOGY

The approach used to solve the problem and achieve the research objectives is a visual approach and historical data, by observing conditions in the field directly, as well as reviewing the data on the number of accidents obtained from each toll road operator. In addition, a regression model approach was also carried out, with model development and Poisson regression analysis. If there is overdispersion, then a model is developed with a negative binomial model. Broadly speaking, the systematic work of this research consists of five main stages, namely the preparation stage, namely by formulating the introduction, literature review, and the research methodology used [11]. Second, the stage of data collection and processing, namely collecting data needed in research, both primary and secondary data. The data is processed according to the needs of the next analysis. Third, the descriptive statistical analysis stage, which is to group the data based on the variables studied from the entire sample. Furthermore, the data will be presented in the form of tables and graphs. Finally, the modeling and analysis stage, where the model of the influence of toll road characteristics on the accident rate is built using a Poisson regression model, or a negative binomial model if there is overdispersion. Then, the model is analyzed to get the factors that influence the accident rate on toll roads. In addition, a policy recommendation is prepared to be applied in the management and operation of toll roads.

Before collecting and processing data, it is necessary to identify the variables used in this study. A variable is an attribute or nature or value of a person, object, or activity that has a certain variation determined by the researcher to be studied and then drawn conclusions. There are two types of variables used in this study, namely the independent variable (X) and the dependent variable (Y). The independent variable, or what is commonly referred to as the independent variable, is the variable that affects or is the cause of the change or emergence of the dependent variable. Variable types can also be categorized into discrete data and continuous data. Discrete data is data obtained from the results of counting or counting, not measuring, so that there are no decimal numbers in the data, while continuous data is data obtained from measurement results, so that the amount of data can occupy all values that exist between two points or can have decimal numbers.

The purpose of this study was to obtain the effect of the characteristics of intercity toll roads, as well as urban toll roads, on the accident rate and fatality rate. Therefore, the variables classified as dependent variables are accident rate and fatality rate, while other variables act as independent variables. The variables chosen to be included in the model are those that have been described in previous studies and show an influence on the accident rate, show research gaps, and have data availability. The following table shows the group of variables for urban toll roads and intercity toll roads that will be used in this study.

The steps for modeling, model analysis, until policy recommendations are produced are as follows. First, it is necessary to identify and interpret variables and proceed with data collection and processing. Second, an analysis of the model development is carried out using the Poisson distribution, then it is necessary to check whether there is overdispersion. If there is overdispersion, the model needs to be recalibrated with the negative binomial method so that there is no overdispersion so that it can be continued with statistical tests. The statistical test was carried out using the goodness of fit, Wald test, and likelihood ratio (G–Test) methods [12]. After passing the statistical test, the owned model needs to be validated before it can be implemented for the formulation of recommendations as shown in Table 2.

Table 2. Variable definition

Variable	Parameter	Type
Dependent variable	Accident rate (AR)	Discrete
	Fatality rate (FR)	Discrete
Traffic factor	Volume Capacity Ratio (VCR)	Continue
Vehicle factor	Vehicle composition	Continue
Road factor (infrastructure)	Number of toll road lanes	Discrete
	Outer shoulder width	Continue
	Inner shoulder width	Continue
	Blackspot location	Discrete
Road complementary factor	Distance to rest area or toll gate	Continue
	To the toll gate before	Continue
	Distance to rest	Discrete

4. DATA PROCESSING

Secondary data collected from the management agency of each toll road is related to traffic volume, toll road characteristics data, and accident data that occurred on the toll road in a span of five years, namely 2015 – 2019. The data is then processed to become variables in modeling the effect of toll road characteristics on the accident rate. As an example, only one toll road section of the four roads studied will be shown. The following is data obtained from toll road managers that have been processed so that the characteristics of the road sections being reviewed can be known as shown in Table 3 and Table 4.

The grouping of vehicle volumes on toll roads is carried out according to vehicle class based on Bina Marga standards. namely:

Group I: cars, small trucks. and buses;
Group II: trucks with two axles;
Group III: trucks with three axles;
Group IV: trucks with four axles;
Group V: trucks with five axles.

Table 5 and Table 6 show the volume of vehicles on each section of the Cipali Toll Road in 2015.

Table 3. Recapitulation of the characteristics of the Cikopo – Palimanan Toll Road

Segment	Number of Lane	Width of Outer Shoulder	Width of Inner Shoulder	Median Barrier
Cikopo – Kalijati	2	3.0	1.5	No
Kalijati – Subang	2	3.0	1.5	No
Subang – Cikedung	2	3.0	1.5	No
Cikedung – Kertajati	2	3.0	1.5	No
Kertajati – Sumberjaya	2	3.0	1.5	No
Sumberjaya – Palimanan	2	3.0	1.5	No

Table 4. Recapitulation of distance between Cikopo – Palimanan Toll Road facilities

Segment	Toll Gate (km)		Rest Area (km)	Distance from Rest Area to Gate 1 (km)	Distance from Rest Area to Gate 2 (km)	Distance Gate to Gate (km)
Cikopo – Kalijati	72	99				27
Kalijati – Subang	99	110	102	3	8	11
Subang – Cikedung	110	139	130	20	9	29
Cikedung – Kertajati	139	158				19
Kertajati – Sumberjaya	158	174	166	8	8	16
Sumberjaya – Palimanan	174	189				15

Table 5. Flow rate Tol Cikopo – Palimanan (Route A)

Direction	Flow Rate (10^6 Veh/Year)				
	2015	2016	2017	2018	2019
Cikopo – Kalijati	2.621	5.875	6.533	6.905	7.652
Kalijati – Subang	2.579	5.778	6.466	6.851	7.632
Subang – Cikedung	2.261	4.973	5.561	5.939	6.742
Cikedung – Kertajati	2.203	4.820	5.406	5.806	6.609
Kertajati – Sumberjaya	2.118	4.639	5.257	5.578	6.396
Sumberjaya – Palimanan	2.177	4.771	5.355	5.721	6.597
Total	13.961	30.858	34.580	36.802	41.630

Table 6. Flow rate Tol Cikopo – Palimanan (Route B)

Direction	Flow Rate (10^6 Veh/Year)				
	2015	2016	2017	2018	2019
Palimanan – Sumberjaya	2.297	4.883	6.214	5.902	6.687
Sumberjaya – Kertajati	2.247	4.776	6.173	5.800	6.537
Kertajati – Cikedung	2.355	4.971	6.277	6.047	6.781
Cikedung – Subang	2.454	5.102	6.249	6.153	6.864
Subang – Kalijati	2.773	5.864	6.817	7.054	7.744
Kalijati – Cikopo	2.825	6.034	7.061	7.132	7.771
Total	14.953	31.633	38.794	38.091	42.386

From Indonesian Road Capacity Manual [13] for toll road, road capacity can be calculated by the Eq. (8).

$$C = C_o \times FC_w \times FC_{SP} \quad (8)$$

The Cikopo – Palimanan Toll Road with an alignment terrain that tends to be flat. And the type of road divided into four lanes. the Cipali Toll Road has a basic capacity of 2,300 pcu/hour/lane. For each lane width of 3.6 meters. The adjustment factor due to the traffic lane width (FCw) used is 1.012. As for the adjustment factor due to the separation of directions, the value of 1.00 is used, considering that there is a median on the Cipali Toll Road. Therefore, the capacity of the Cipali Toll Road is based on these parameters, namely:

$$C = C_o \times FC_w \times FC_{SP}$$
$$\frac{C = 2300 \times 1.008 \times 1.00 = 23{,}184 \frac{pcu}{hour}}{lane} \quad (9)$$

Since 2015, the entire Cipali Toll Road section consists of two lanes for each direction. Therefore, the capacity of this toll road is 4,655 pcu/hour.

Table 7. AADT Tol Cikopo – Palimanan (Route A)

Direction	AADT (Veh/Day)				
	2015	**2016**	**2017**	**2018**	**2019**
Cikopo – Kalijati	13,043	16,053	17,899	18,919	20,965
Kalijati – Subang	12,834	15,787	17,716	18,771	20,911
Subang – Cikedung	11,251	13,588	15,238	16,272	18,473
Cikedung – Kertajati	10,961	13,170	14,812	15,908	18,109
Kertajati – Sumberjaya	10,541	12,677	14,404	15,283	17,525
Sumberjaya – Palimanan	10,832	13,038	14,673	15,677	18,074
Total	69,462	84,314	94,742	100,829	114,057

Table 8. AADT Tol Cikopo – Palimanan (Route B)

Direction	AADT (Veh/Day)				
	2015	**2016**	**2017**	**2018**	**2019**
Palimanan – Sumberjaya	11,432	13,344	17,025	16,172	18,321
Sumberjaya – Kertajati	11,179	13,052	16,913	15,891	17,912
Kertajati – Cikedung	11,718	13,584	17,199	16,568	18,579
Cikedung – Subang	12,211	13,940	17,123	16,858	18,807
Subang – Kalijati	13,801	16,022	18,679	19,328	21,218
Kalijati – Cikopo	14,055	16,488	19,347	19,541	21,292
Total	74,397	86,430	106,286	104,359	116,128

Table 9. PHV Tol Cikopo – Palimanan (Route A)

Direction	PHV (pcu/hour)				
	2015	**2016**	**2017**	**2018**	**2019**
Cikopo – Kalijati	1,459	1,845	2,055	2,196	2,433
Kalijati – Subang	1,434	1,811	2,031	2,176	2,423
Subang – Cikedung	1,256	1,557	1,743	1,885	2,140
Cikedung – Kertajati	1,221	1,506	1,690	1,840	2,095
Kertajati – Sumberjaya	1,173	1,450	1,646	1,767	2,028
Sumberjaya – Palimanan	1,206	1,490	1,674	1,809	2,089
Total	7,749	9,661	10,839	11,674	13,208

Table 10. PHV Tol Cikopo – Palimanan (Route B)

Direction	PHV (pcu/hour)				
	2015	**2016**	**2017**	**2018**	**2019**
Palimanan – Sumberjaya	1,306	1,535	1,945	1,878	2,132
Sumberjaya – Kertajati	1,277	1,502	1,932	1,845	2,084
Kertajati – Cikedung	1,339	1,563	1,967	1,927	2,165
Cikedung – Subang	1,403	1,606	1,961	1,961	2,191
Subang – Kalijati	1,587	1,847	2,146	2,249	2,473
Kalijati – Cikopo	1,618	1,905	2,224	2,277	2,485
Total	8,529	9,958	12,174	12,137	13,530

In order to determine the ratio of traffic flow to road capacity. Data on the volume of vehicles at peak hours is needed. Therefore, the annual traffic flow data in the table above needs to be converted into Annual Average Daily Traffic (AADT). AADT is the average number of vehicle traffic that passes one lane of the road for 24 hours which is obtained based on data for one year. An example of the AADT calculation for vehicles moving from Cikopo to Kalijati in 2015 is as follows. Considering that the Cipali Toll Road has been operating since June 13, 2015, the number of operational days for this toll road in 2015 is 201 days.

$$AADT_{cikopo-kalijati} = \frac{Flowrate_{Cikopo-kalijati}}{Number\ of\ day\ in\ a\ year}$$
$$AADT_{cikopo-kalijati} = \frac{2{,}621{,}686}{201} = 13{,}043\,\frac{vehicle}{day} \quad (10)$$

By performing a similar calculation as in the example above. The 2015 Cikopo – Palimanan (Cipali) Toll Road AADT is obtained as shown in Tables 7 and 8.

Due to data limitations which result in the unavailability of the number of vehicles per hour in one year. The above–mentioned Average Daily Traffic (AADT) data needs to be converted into peak hour vehicle volume using the k factor. The factor k represents the peak hour traffic flow of a road segment in a year, which is defined as the ratio between the hourly traffic volume occurring in the 30th busiest order (or another. For example, 50th or 200th order) to its AADT [14]. According to the Indonesian Road Capacity Manual [13], the k factor value commonly used in Indonesia is 11%.

Calculation of the volume capacity ratio (VCR) is carried out in passenger cars (pcu). Therefore, the peak hour vehicle volume must be multiplied by the passenger car equivalence factor (pcu) for expressways obtained from the Manual [13]. The emp factors used in this study are as follows.

MHV: 1.30 pcu

LB: 1.50 pcu

LT: 2.00 pcu

The following is a formula of calculating the peak hour volume from AADT to PHV in passenger cars unit (pcu). namely:

Peak Hour Volume (PHV)

$$PHV = AADT \times k \times emp \quad (11)$$

By performing a formula as listed above. The volume of vehicles during peak hours on the Cikopo – Palimanan Toll Road in 2015 is obtained as shown in Tables 9 and 10.

The VCR value can be determined by dividing the volume of vehicles at peak hours by the capacity of the road segment. Capacity of the Cipali Toll Road is 4655 pcu/hour/direction. With the peak hour volume (PHV) on the Cikopo – Kalijati section = 1459 pcu/hour, the following is the VCR value.

Volume Capacity Ratio (VCR)

$$VCR = \frac{PHV}{C} \quad (12)$$

In general, the accident rate is used to measure the accident rate on a road segment. Pignataro [15] revealed that the accident rate based on vehicle kilometers traveled can be calculated by Eq. (1).

From the number of accidents in each segment. The accident rate per kilometer for each section of the Cikopo – Palimanan Toll Road section can be calculated, which is shown in the following Table 11 and Table 12.

Table 11. Accident rate per kilometer Cipali Toll Road (Route A)

	Accident Rate (AR)					
Year	**Cikopo – Kalijati**	**Kalijati – Subang**	**Subang – Cikedung**	**Cikedung – Kertajati**	**Kertajati – Sumberjaya**	**Sumberjaya – Palimanan**
	27 km	**11 km**	**29 km**	**19 km**	**16 km**	**15 km**
2015	59.50	91.07	115.30	84.60	76.23	41.03
2016	87.62	88.11	113.02	94.99	90.25	82.43
2017	78.23	92.79	111.60	98.32	91.54	104.56
2018	77.77	63.69	96.38	76.14	80.67	67.58
2019	52.27	79.80	58.30	69.27	85.01	73.77

Table 12. Accident rate per kilometer Cipali Toll Road (Route B)

	Accident Rate (AR)					
Year	**Palimanan – Sumberjaya**	**Sumberjaya – Kertajati**	**Kertajati – Cikedung**	**Cikedung – Subang**	**Subang – Kalijati**	**Kalijati – Cikopo**
	15 km	**16 km**	**19 km**	**29 km**	**11 km**	**27 km**
2015	77.76	93.18	111.21	145.22	100.38	96.62
2016	66.89	117.75	93.16	160.85	93.02	113.54
2017	43.99	79.98	88.03	132.97	85.34	105.94
2018	40.66	76.51	93.13	100.87	81.18	85.68
2019	39.88	56.40	67.52	73.34	81.00	65.77

Table 13. Fatality rate per kilometer Cipali Toll Road (Route A)

	Fatality Rate (FR)					
Year	**Cikopo – Kalijati**	**Kalijati – Subang**	**Subang – Cikedung**	**Cikedung – Kertajati**	**Kertajati – Sumberjaya**	**Sumberjaya – Palimanan**
	27 km	**11 km**	**29 km**	**19 km**	**16 km**	**15 km**
2015	2.70	3.37	8.76	0.00	8.47	5.86
2016	1.89	1.57	5.55	3.28	2.69	2.79
2017	3.97	1.41	7.44	3.89	4.76	1.24
2018	3.22	1.33	5.81	2.72	5.60	2.33
2019	2.42	0.00	3.07	3.19	3.91	4.04

Table 14. Fatality rate per kilometer Cipali Toll Road (Route B)

Year	Fatality Rate (FR)					
	Palimanan – Sumberjaya 15 km	Kalijati – Subang 11 km	Palimanan – Sumberjaya 15 km	Cikedung – Kertajati 19 km	Palimanan – Sumberjaya 15 km	Sumberjaya – Palimanan 15 km
2015	2.78	2015	2.78	2015	2.78	2015
2016	2.73	2016	2.73	2016	2.73	2016
2017	3.22	2017	3.22	2017	3.22	2017
2018	2.26	2018	2.26	2018	2.26	2018
2019	1.99	2019	1.99	2019	1.99	2019

The fatality rate uses a calculation like the accident rate, only that the number of accidents that is considered is only fatal accidents or those that cause the victim to die. For example, on the Cikopo – Palimanan Toll Road section. The Cikopo – Kalijati section can be calculated using Eq. (2). The number of fatal accidents and the fatality rate per kilometer for each section of the Cikopo – Palimanan Toll Road section is then converted into fatality rates, as shown in Table 13 and Table 14.

The method of determining accident–prone locations (blackspots) used in this study is the UCL (Upper Control Limit) approach as a control–chart. The following is an example of the calculation steps for AEN and UCL as mentioned on Eq. (3) in identifying black spots on the Cikampek – Kalijati section of Route A.

$$\mathrm{AEN} = (\mathrm{M} \times 12 + \mathrm{B} \times 6 + \mathrm{R} \times 3 + \mathrm{K} \times 1) = 1419$$
$$UCL = 1046.5 + 2.576\sqrt{\left(\frac{\lambda}{AEN}\right) + \left(\frac{0.829}{\boldsymbol{AEN}}\right) + \left(\frac{\boldsymbol{AEN}}{2}\right)} = \mathbf{1115.15} \quad (13)$$
$$\boldsymbol{AEN}(= \mathbf{1419}) > \boldsymbol{UCL}(= \mathbf{1115.15}) \rightarrow \boldsymbol{Blackspot}$$

Because the AEN value in the Cikampek – Kalijati segment is higher than its UCL. The segment is classified as a blackspot are shown in Table 15.

After all the data that is owned is processed into variables that are used as the basis for making the model. The data is collected and compiled so that it can be entered and processed with the Python programming language to facilitate data processing. Modeling is intended to predict the AR and FR values, which are rates of the number of accidents or the number of fatal accidents that occur on a toll road. which are normalized by time, segment length, and traffic volume. To find out whether a data has a Poisson distribution or a negative binomial. The data will be tested to see if there is overdispersion, which is a condition when the variance of the response variable is greater than the mean value of the response variable. The estimated dispersion value, namely the residual deviance divided by the degree of freedom, which is greater than 1 indicates that the variance value is greater than the mean value. This indicates overdispersion in the data. After that, it is determined how capable the data is to fit into the model by measuring the deviance goodness of fit (GOF). A small p–value indicates that the model is not able to explain the dataset, which is measured from the deviance of the data, so, the hypothesis H0 is rejected, that the sample comes from a population with a Poisson distribution, so, the model will be developed with negative binomial regression. The results of the software output regarding the dispersion estimate and p–value for the GOF deviance for each modeling with a Poisson distribution are shown in Table 16.

Table 15. Identification of blackspots in every section of the Cipali Toll Road

Segment	Category
Cikampek – Kalijati	Blackspot
Kalijati – Subang	Not Blackspot
Subang – Cikedung	Blackspot
Cikedung – Kertajati	Not Blackspot
Kertajati – Sumberjaya	Not Blackspot
Sumberjaya – Palimanan	Not Blackspot

Table 16. Dispersion estimation dan deviance goodness of fit test

Model	Residual Deviance	DOF	Dispersion Estimation	Distribution	p–value	Goodness of Fit Test (>5%)
AR Inter–City	699.04	135	5.02	Poisson	0.000	Not OK
	202.80	135	1.50	Binomial negative	0.000	Not OK
AR Urban	89.64	76	1.05	Poisson	0.136	OK
FR Inter–City	158.92	135	1.24	Poisson	0.078	OK
FR Urban	34.19	76	0.45	Poisson	1.000	OK

5. DISCUSSION

The model is then tested as a whole to see whether the variables have a simultaneous effect on the response variable, by comparing the likelihood ratio of the model with constants only or without parameters (β1 = 0), to the likelihood ratio of the model with all variables. If the p–value is less than the level of significance (α = 0.05). The parameter is not worth 0 and the model is not affected by the constant alone. From the software, the p–value for each model is 0. So, it is evident that although some variables are not partially significant at the 95% confidence level, the variables still have a simultaneous effect on the model. After several statistical tests were carried out on the model, the following equation was obtained.

Model Inter–City Toll Road (binomial negative)

$$Ln_{\left(\frac{no.of\ accident}{exposure}\right)} = 5.251 - 1.121\,(VCR) - 0.358(No\ of\ Lane) - 0.013(Distance\ 1) + 0.421(Median\ Barrier) + 0.362(blackspot) \quad (14)$$

$$Ln_{\left(\frac{no.of\ Fatal\ accident}{exposure}\right)} = 1.118 - 2.616\ (VCR) + 3.324\ (\%I) - 0.788\ (No\ of\ Lane) - 0.018\ (Distance\ 1) + 0.641\ (blackspot) \tag{15}$$

Model Urban Toll Road (Poisson)

$$Ln_{\left(\frac{no.of\ accident}{exposure}\right)} = 23.70 - 33.287\ (\%I) - 1.18\ (No\ of\ Lane) + 10.119\ (Inner\ Shoulder\ Width) - 0.255\ (Distance\ 1) - 0.752\ (Distance\ 2) + 0.917\ (blackspot) \tag{16}$$

$$Ln_{\left(\frac{no.of\ Fatal\ accident}{exposure}\right)} = 66.561 - 114.47\ (\%I) + 28.038\ (Inner\ Shoulder\ Width) - 0.645\ (Distance\ 1) - 33.981\ (Distance\ 2) + 1.750\ (blackspot) \tag{17}$$

Ln(no. of Fatal accident/exposure) = 66.561 – 114.47 (%I) + 28.038 (Inner Shoulder Width) – 0.645 (Distance 1) – 33.981 (Distance 2) + 1.750 (blackspot)

This model was created based on the study locations used with 2 inner–city toll roads and 2 inter–city toll roads respectively. It is hoped that with the existing limitations. This model can be applied to all toll roads in Indonesia as a reference in improving toll road safety.

The proposal for providing recommendations for increasing the level of safety on toll roads based on this model can be ordered based on the sensitivity level of each predictor variable to the Accident Rate or Fatality Rate.

A higher level of sensitivity can be predicted as the most influential variable in changes in AR and FR values and can be used as a basis for making recommendations with priority variables that need to be improved in general as follows:

·The priority of providing recommendations for each variable for the Accident Rate model is as follows:

–Reduce the number of blackspot location points

–Increase the number of lanes

–Increasing the distance from the resting place to the previous toll gate

·Priority for providing recommendations for each variable for the Fatality Rate model are as follows:

–Reduce the number of blackspot location points

–Increasing the distance from the resting place to the previous toll gate

Table 17. Variable corridor

Variable	Urban Toll Road	Inter–City Toll Road
Volume Capacity Ratio (VCR)	0.7 – 0.9	0.5 – 0.8
Percentage of goal volume. I (%)	0.58 – 0.70	0.5 – 0.7
Number of toll road lanes	2 – 4	2 – 4
Outer shoulder width (m)	2 – 3.5	2 – 2.5
Shoulder width in (m)	1 – 1.2	1 – 2.0
Distance from rest area to previous toll gate / distance 1 (km)	15 – 20	25 – 35
Distance from rest area to toll gate after / distance 2 (km)	5 – 10	25 – 35
Unavailability of median barrier	Yes/No	Yes/No
Blackspot location	0 – 5	0 – 5

The limitations are used as limitations so that this model can be used. Thus, in the application of this model a corridor is needed as a limitation in the use of this model so that the validity of the model is maintained. Corridor model obtained by trial & error on the data segment owned as shown in Table 17.

Traffic accidents have an impact on the national economy as evidenced by the contribution of traffic accidents to economic losses in the form of a decrease in GDP by 2.9% – 3.1% or equivalent to USD 1.332 Billion – USD 1.465 Billion. Modeling is intended to predict the AR and FR values, which are rates of the number of accidents or the number of fatal accidents that occur on a toll road, which are normalized by time, segment length, and traffic volume. This model can be applied to all toll roads in Indonesia as a reference in improving toll road safety.

6. CONCLUSIONS

Based on the available data from both traffic data and geometric data from the study location, it is possible to calculate the Accident Rate (AR) and Fatality Rate (FR) with the following equations for inner–city toll roads and inter–city toll roads.

Inter–City Toll Road

$$Ln_{(AR)} = 5.251 - 1.121 \cdot x_1 - 0.358 \cdot x_3 - 0.013 \cdot x_6 + 0.421 \cdot x_8 + 0.362 \cdot x_9 \tag{18}$$

$$Ln_{(FR)} = 1.118 - 2.616 \cdot x_1 + 3.324 \cdot x_2 - 0.788 \cdot x_3 - 0.018 \cdot x_6 + 0.641 \cdot x_9 \tag{19}$$

Urban Toll Road

$$Ln_{(AR)} = 23.70 - 33.287 \cdot x_2 - 1.18 \cdot x_3 + 10.119 \cdot x_5 - 0.255 \cdot x_6 - 0.752 \cdot x_7 + 0.917 \cdot x_9 \tag{20}$$

$$Ln_{(FR)} = 66.561 - 114.47 \cdot x_2 + 28.038 \cdot x_5 - 0.645 \cdot x_6 - 33.981 \cdot x_7 + 1.750 \cdot x_9 \tag{21}$$

where,
X_1: VCR; (ICT=0.5–0.8), (UT=0.7–0.9)
X_2: % Veh. Type I; (ICT=0.5–0.7), (UT=0.58–0.70)
X_3: Number of toll road lanes; (ICT/UT=2–4)
X_4: Outer shoulder (m); (ICT=2–2.5), (UT=2–3.5)
X_5: Inner shoulder (m); (ICT=1–2.0), (UT=1–1.2)
X_6: Distance I (km); (ICT=25–35), (UT=15–20)
X_7: Distance II (km); (ICT=25–35), (UT=5–10)
X_8: Median barrier; (ICT/UT=Yes=1; No=0)
X_9: Blackspot location; (ICT/UT=0–5)
ICT: Variable for Intercity Toll Road
UT: Variable for Urban Toll Road

With the results of this study, it is expected that the analysis of the calculation of Accident Rate (AR) and Fatality Rate (FR) can be more easily used in improving toll road facilities both on urban toll roads and on intercity toll roads. In addition, each parameter can also provide recommendation to toll road operators to remain focused on traffic safety so that potential accidents can be avoided.

For road planners, especially for toll roads. The results of this study can be used to evaluate the design owned against potential traffic accidents that may occur so that, in the future, sensitivity to traffic safety can be further improved.

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NOMENCLATURE

A	number of accidents per year
AADT	annual average daily traffic
AR	accident rate
B	serious injury
C	road capacity
C_o	base capacity (pcu/hour)
FA	number of fatal accidents per year
FC_w	adjustment factor for traffic lane width
FC_{sp}	adjustment factor due to direction separation
FR	fatality rate
K	accidents with material loss
k	peak hour factor
l	length of road (km)
LB	long bus
LT	long truck
M	died
m	equivalent accident number (AEN) in accident units
MHV	medium heavy vehicle
PHV	peak hour volume
R	minor injuries
T	observation period time
UCL	upper control limit
VCR	volume capacity ratio
VD	victim died
λ	accident rate in each segment