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Calculation of the Level of Death Risk in Traffic Accidents Based On Aggregate Loss Costs

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Abstract

The transportation sector is undergoing transformative changes, driven by the emergence of autonomous vehicles and advancements in smart transportation systems. However, these innovations pose novel challenges, particularly in mitigating the risk of fatalities in traffic accidents. This study focuses on estimating death risk in traffic accidents by analyzing aggregate loss costs within the context of traffic safety. Employing a quantitative approach, the research utilizes the Poisson distribution to model the frequency of fatal incidents and the exponential distribution function to depict the distribution of associated losses. The study's objective is to calculate aggregate losses, offering insights into the potential severity of risks. Through a comprehensive analysis, the results affirm the efficacy of the Poisson and exponential distributions in assessing death risk in traffic accidents, with the highest estimated aggregate loss cost reaching Rp3,734,832.09.

Keywords: Traffic accidents, death risk, aggregate loss costs

1. Introduction

Traffic accidents are a leading global cause of death, ranking tenth among all causes and ninth as a major contributor (Gopalakrishnan, 2012). The number of traffic accidents and fatalities continues to rise, increasing from 5.1 million in 1990 to 8.4 million in 2020, marking a 65% surge. According to the World Health Organization (WHO), nearly 16,000 people die daily due to injuries, with thousands more experiencing permanent disabilities. Data indicates that road accidents dominate the global mortality rankings, especially in developing countries. Currently, the global road transport accident rate has reached 1.2 million fatalities and over 30 million injuries or disabilities per year. In Indonesia, there were 258,274 accidents during the 2003-2007 period, claiming 69,485 lives, averaging 13,877 deaths annually, making it a primary cause of death on the roads compared to other modes of transportation.

2. Literature Review

According to Bank Indonesia Regulation No. 5/8/PBI/2003, risk is defined as the potential loss resulting from a specific event. Furthermore, in accordance with Bank Indonesia Regulation No. 11/25/PBI/2009, risk is categorized into 8 types, including credit risk (Crouhy, 2000), market risk (Alexander, 2009), operational risk (Jarrow, 2008), liquidity risk (Goodhart, 2008), compliance risk (Losiewicz-Dniestrzanska, 2015), legal risk (Zetzsche, 2018), reputation risk (Larkin, 2002), and strategic risk (Emblemsvåg, 2002).

3. Materials and Methods

3.1. Materials

The research object used is traffic accident data obtained from the Directorate of Traffic in the city of Kupang. Table 1 is a list summarizing traffic accidents in the city of Kupang from January 2011 to December 2013 involving 10 road segments identified as locations where traffic accidents occurred.

Table 1: Fatalities Data in Traffic Accidents on the Roads of Kupang from 2011 to 2013

Name of Street	2011	2012	2013
Jl. Sudirman	4	0	0
Jl. Moh. Hatta	2	3	1
Jl. Cak. Doko	3	1	1
Jl. Eltari	3	2	1
Jl. Frans Seda	2	2	3
Jl. M. Praja	1	5	0
Jl. Adi Sucipto	5	1	2
Jl. Pahlawan	0	4	0
Jl. Jalur 40	1	3	3
Jl. H. R. Koroh	2	0	2
Jl. Soeharto	0	1	0
Jl. A. Yani	1	0	1

Source: Bolla, M. E., Blegur, J. T. R. N and Ramang, R. (2019)

3.2. Methods

3.2.1 Random Variable

Random variable is a variable whose values are determined randomly. Random variables consist of discrete random variables and continuous random variables. A random variable is said to be a discrete random variable if its sample space is limited or countable (Michael, 2017). Let X be a discrete random variable with sample space S, and its probability density function X is given by:

$$p_x(X) = P(X = x), x \,\epsilon\, S \tag{1}$$

satisfying two properties in equation (2):

$$\sum_{i=1}^{n} p_{xi}(x_i) = 1 \; and \; 0 \leq p_x(x) \leq 1 \tag{2}$$

Furthermore, a continuous random variable is a random variable that takes on all values within a continuous scale (Pratikno et al., 2020). The probability density function of a continuous random variable satisfies the conditions in equations (3) to (5):

$$F(x) \geq 0 \; \forall \; x \,\epsilon\, R \tag{3}$$

$$\int_{-\infty}^{\infty} f(x)dx = 1 \tag{4}$$

$$P(a < X < b) = \int_{-\infty}^{\infty} f(x)dx \tag{5}$$

3.2.2 Poisson Distribution

Poisson Distribution is used concerning the number of events occurring in a specific time interval or area. The Poisson Distribution is characterized by discrete random variables and information about the average value (μ) of an event in a specific time interval. According to Inouye (2017), the equation for the Poisson distribution is given by:

$$P(X = x) = \frac{\mu^x e^{-\mu}}{x!}, untuk \; x = 0,1,2, \ldots \tag{6}$$

where:
x : counting number
e : exponential number = 2.718281…
μ : average value of an event in a specific time interval.

The expectation and variance of the Poisson distribution are:

$$E[X] = \mu \tag{7}$$

$$Var[X] = \mu \tag{8}$$

3.2.3 Exponential Distribution

The exponential distribution describes the probability of the waiting time between events in a Poisson distribution. According to Inouye (2017), a continuous random variable X follows an exponential distribution with parameter $\lambda > 0$, if it has the following probability density function:

$$f(x) = \begin{cases} \lambda e^{-\lambda x}, x > 0 \\ 0, x \; lainnya \end{cases} \tag{9}$$

where:
$\lambda = \frac{1}{\mu}$: scale parameter of the exponential distribution

Its cumulative distribution function is given by:

$$F(X;\lambda) = 1 - e^{-\lambda x} \tag{10}$$

The expectation and variance of the exponential distribution are:

$$E(x) = \frac{1}{\lambda} \tag{11}$$

$$V(x) = \frac{1}{\lambda^2} \tag{12}$$

3.2.4 Chi-Square Test Procedure

Chi-Square is a continuous random variable related to an item or response that can be divided into several categories. The purpose of the Chi-Square test procedure is to test whether there is a significant difference between the observed number of specific object or response classifications and their expected values based on the null hypothesis. According to Allen (2009), the Chi-Square test procedure is as follows:

Formulate the hypotheses.
H_0 : The tested model follows a specific distribution.
H_1 : The tested model follows a different distribution.

Determine the significance level (α) and value X^2 with calculate the degrees of freedom using the formula $n - k - 1$.

Determine the critical value from the Chi-Square table.

Set the testing criteria.
Accept H_0 if the test statistic value is ≤ the critical Chi-Square value.

Calculate the test statistic value using the formula:

$$x^2 = \sum_{i=0}^{n} \left[\frac{(O_i - E_i)^2}{E_i}\right] \tag{13}$$

where:
O_i: observed value in category i.
E_i: expected value in category i.

Draw conclusions based on the testing criteria.

4. Results and Discussion

4.1. Fatalities Distribution Model

The goodness-of-fit test for the assumption of fatalities model following Poisson distribution yielded a test result in Table 2 with a chi-square statistic value (χ^2) equals to 5,64508 $\leq \chi^2_{(0,05)(10)}$ equals to 18,30704. This indicates that the fatalities of traffic accident model indeed follows a Poisson distribution.

Table 2: Goodness-of-fit Test for Fatalities Distribution Model Assumption

x_i	$p(x_i)$	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
0	0.00674	0	0.08086	0.08086
1	0.03369	1	0.40428	0.87783
2	0.08422	1	1.01069	0.00011
3	0.14037	0	1.68449	1.68449
4	0.17547	3	2.10561	0.37991
5	0.17547	1	2.10561	0.58053
6	0.14622	3	1.75467	0.88383
7	0.10444	2	1.25334	0.44481
8	0.06528	1	0.78334	0.05993
9	0.03627	0	0.43519	0.43519
10	0.01813	0	0.21759	0.21759

4.2. Risk Distribution Model

The goodness-of-fit test for the assumption of risk model following exponential distribution yielded a test result in Table 3 with a chi-square statistic value (χ^2) equals to 7,12648 $\leq \chi^2_{(0,05)(3)}$ equals to 7,81473. This indicates that the risk of traffic accident model indeed follows a exponential distribution.

Table 3: Goodness-of-fit Test for Risk Distribution Model Assumption

p	Class interval	x_p	$q(x_p)$	$Q(x_p;\lambda)$	O_p	E_p	$\frac{(O_p - E_p)^2}{E_p}$
1	0-3	3	0.10976	0.45119	2	1.35357	0.30872
2	3-5	5	0.07358	0.63212	4	2.52848	0.85639
3	5-7	7	0.04932	0.75340	5	4.52042	0.05088
4	7-10	10	0.02707	0.86466	1	7.78198	5.91048

4.3. Aggregate Loss Distribution Model

Based on the model assumptions and goodness-of-fit tests as indicated in Tables 2 and 3 have obtained Poisson distribution with parameter μ and exponential distribution with parameter λ. These parameters will be utilized in the calculation of aggregate loss distribution by combining both distributions, resulting in aggregate loss distribution that follows either Poisson or exponential distribution. The aggregate loss as follows:

$$f(K_x, L_x) = \frac{e^{-\mu}\mu^{K_x}}{K_x!} + (\lambda e^{-\lambda L_x}) \tag{14}$$

where:

μ : average death in traffic accident

K_x : the number of occurrences of death in traffic accident

L_x : the magnitude of the risk distribution

Simulations were conducted using Poisson parameter (μ = 5) and exponential parameter (λ = 0,2). Subsequently, random number generation was performed to represent the number of occurrences of death in traffic accidents and the magnitude of the risk distribution. The calculation of the total aggregate loss is presented in Table 4.

Table 4: Results of Aggregate Loss Cost Simulation

No.	K_x	L_x	$P(x = K_x)$	$P(x = L_x)$	$f(K_x; L_x)$	Total Aggregate Loss Cost (Rp)
1	4	0,30972	0,17547	0,18799	0,36345	3.634.546,45
2	8	0,43570	0,06528	0,18331	0,24859	2.485.876,11
3	4	0,80049	0,17547	0,17041	0,34588	3.458.795,46
4	1	0,63636	0,03369	0,17610	0,20979	2.097.884,34
5	10	0,26364	0,01813	0,18973	0,20786	2.078.603,90
⋮	⋮	⋮	⋮	⋮	⋮	⋮
29	4	0,04985	0,17547	0,19802	0,37348	3.734.832,09
⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	3	0,11500	0,14037	0,19545	0,33583	3.358.264,55

After examining 100 calculations of simulation, the highest total aggregate loss cost obtained is Rp3.734.832,09.

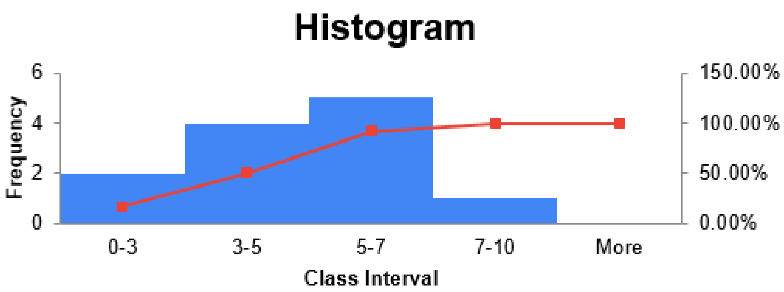

Figure 1: Histogram Visualization of Data Distribution

Figure 1 illustrates the distribution of fatalities data in traffic accidents. Based on Figure 1, it can be observed that the highest number of occurrences of death in traffic accidents falls within the range of 5-7 incidents with cumulative percentage of 91.67%.

5. Conclusion

The research results indicate that the Poisson distribution model and the exponential distribution model can be used for assessing death in traffic accidents risk based on aggregate loss costs. The goodness-of-fit test calculations using the chi-square test show that the frequency of events can be modeled following the Poisson distribution, and the risk distribution can also be modeled following the exponential distribution. Therefore, the aggregate loss distribution can be calculated following the Poisson and exponential distribution model. Subsequently, based on simulation calculations, an estimate of the potential losses incurred by due to traffic accidents is determined to be Rp3,734,832.09. By knowledge of this potential loss magnitude, Jasa Raharja company can optimize operational models for increased effectiveness.

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