Speed–volume relationship and headway distribution analysis of motorcycle (case study: Teuku Nyak Arief Road)

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Abstract. In many developing countries, transportation modes are more varied than the other country. For example, in Jakarta, Indonesia, in some roadway, motorcycle is the most dominant vehicle, with total volume is four times higher than a passenger car. Thus, the traffic characteristic in motorcycle-dominated traffic differs from a common traffic situation. The purpose of this study is to apply the concept and theory developed to analyze motorcycle behaviour under motorcycle-dominated traffic condition. The survey is applied by recording the traffic flow movement of research location at specified time period. The macroscopic characteristic analyzed in this research is a speed-flow relationship based on motorcycle equivalent unit (MCU). Furthermore, a detail microscopic characteristic analyzed that is motorcycle time headway regarding traffic flow. MCU values computed were consists of motorcycle (MC), light vehicle (LV) and heavy vehicle (HV). Those values were calculated 1.00, 6.13 and 10.71 respectively. The speed and volume relationship result is showing a linear regression model with $R^2$ value is 0.58, it can be explained that the correlation between two variables is intermediate. The headway distribution of motorcycle is compatible with the negative exponential distribution which fitted with the proposed theory for a small vehicle such as a motorcycle.

Keywords: flow, headway distribution, motorcycle equivalent unit, transportation modes

1. Introduction
Congestion is the main problem occurred in developed country such as Indonesia, particularly in their capital city Jakarta. In Jakarta, for example, two-wheelers are the most dominant vehicle with the total volume is four times higher than a passenger car. Due to a high number, Jakarta has been suffering from a congestion problem, which is mostly caused by two-wheel vehicles. The high proportion of motorcycle in traffic will affect the traffic characteristic. Characteristic in motorcycle-dominated traffic is differ from a common traffic situation due to its mixed proportion of vehicles, it will convert the characteristic from a homogeneous traffic flow to heterogeneous traffic flow. Regarding heterogeneous characteristic, the homogeneous traffic concept has a limitation in the application for heterogeneous traffic [1].

There was a study conducted to identify traffic characteristic that has significant motorcycle proportion. Minh, Sano and Matsumoto [2] were developed a motorcycle unit equivalent known as MCU in order to estimate volume under heterogeneous traffic flow condition. MCU is developed with a consideration of the dynamic characteristic of moving vehicle [2].

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The present study is intended to adopt and applied the concept of motorcycle equivalent unit (MCU) as a proper method to analyze a characteristic of heterogeneous traffic flow at Indonesian roadways, specifically in Jakarta, which have a significant motorcycle proportion in traffic flow. MCU is considered due to the limitation of passenger car unit (PCU) as a common method used to analyze a characteristic of heterogeneous traffic flow. In order to conduct this study, site location used must have a sufficient motorcycle proportion. The objectives of the study are to obtain several parameters, such as MCU value for each type of vehicle in traffic, speed and flow relationship based on the MCU value obtained, and motorcycle headway analysis.

2. Research Method
There are two types of data used in this research, primary and secondary data. Primary consists of speed and volume of vehicles in traffic streams, motorcycle headway, and roadway geometry. Speed, volume, and headway were collected by using video camera and tripod located at the pedestrian bridge above site location. The video camera was recorded all the traffic flow at specified time period. Roadway geometry data was collected by measuring roller to measure length and width of the site location. To avoid any unusual behaviour by the driver, all of the data were collected under clear weather.

Secondary data consists of vehicle categories and vehicle dimension. In this study, vehicles are classified into three categories according to Indonesian Highway Capacity Manual (also known as MKJI 1997), there are light vehicle (LV), heavy vehicle (HV), and motorcycle (MC). Dimensions for each category were determined from domestic auto market data on 2016 in order to represent the real condition in Indonesia by showing the highest market for each category of the vehicles. Thus, the data obtained were used as a guideline for computing MCU. Domestic market data of light vehicle (LV) and heavy vehicle (HV) were obtained from the data that published by Association of Indonesia Automotive Industries (GAIKINDO). Meanwhile, the domestic market data of motorcycle (MC) were obtained from the data that published by Association of Indonesia Motorcycle Industries (AISI).

3. Results and Discussion
The site location chosen was located at Teuku Nyak Arief Road, Jakarta, Indonesia. It’s a two-lane roadway with 3 m width for each lane. The observed length was measured 40 m. It can be noted that the distance measured should have a clear sight from camera perspective in order to obtain a good data. Furthermore, the percentage of motorcycle (MC), light vehicle (LV) and heavy vehicle (HV) are 74.29%, 24.55% and 1.16% respectively.

3.1. Motorcycle unit
Motorcycle equivalent unit (MCU) was calculated based on a dynamic characteristic of moving vehicle. This characteristic represents the correlation between speed and occupied space of vehicles in the lane. The maneuver is one of the main characteristic of motorcycle behaviour in traffic, due to its small size of the vehicle. Regarding this characteristic, the motorcycle does not move in the lane. Meanwhile, in traffic with lane discipline, the occupancy is controlled by the length of the vehicle. However, in the condition where vehicles do not follow lanes strictly, the occupancy is better reflected by area [3]. The equation for determining MCU is described below:

\[
MCU_i = \frac{V_{mc}/V_i}{A_{mc}/A_i}
\]

Where
- MCU\_i = Motorcycle equivalent unit of type i vehicle;
- \(V_{mc}\) = Mean speed of motorcycles (km/hr);
- \(V_i\) = Mean speed of type i vehicle (km/hr);
- \(A_{mc}\) = Projected rectangular area of motorcycles (m\^2);
- \(A_i\) = Projected rectangular area of type i vehicle (m\^2).
Table 1. Vehicle categories and sizes.

| No. | Category               | Dimension (m) | Area (m²) |
|-----|------------------------|---------------|-----------|
|     |                        | Length        | Width     |           |
| 1   | Motorcycle (MC)        | 1.856         | 0.666     | 1.236     |
| 2   | Light Vehicle (LV)     | 4.190         | 1.660     | 6.955     |
| 3   | Heavy Vehicle (LV)     | 6.026         | 1.945     | 11.721    |

Table 1 is showing vehicle dimension for each type respectively. The length and width of all vehicles were obtained from domestic auto market data that published by Association of Indonesia Automotive Industries (GAIKINDO) and Association of Indonesia Motorcycle Industries (AISI) in 2016. It represents the highest market for each type of vehicles, then the length and width of those vehicles were used as a guideline for computing MCU.

Mean speed of all vehicles was determined by using spot speed technique. To obtain the speed of the vehicle, the time required for travelling observation distance was counted by stopwatch. Stopwatch begins counting when vehicle entry an observed point and stop counting when the vehicle passes the end-point. Then, all of the speed obtained was converted into kilometer per hour. Furthermore, MCU value can be calculated by using the equation above.

Table 2. MCU value for each type of vehicle.

|                  | Motorcycle (MC) | Light Vehicle (LV) | Heavy Vehicle (LV) |
|------------------|-----------------|--------------------|--------------------|
|                  | 1.00            | 6.13               | 10.71              |

The computed results of MCU from equation (1) are shown in Table 2. The value of MCU for each category of vehicle is affected by the ratio between mean speed and the projected area of the motorcycle and another type of vehicle. Therefore, if the motorcycle has a significant difference mean speed than another type (i.e. light vehicle and heavy vehicle), MCU value will be increased as well.

3.2. Speed–volume relationship

There are three macroscopic characteristics of traffic flow: speed, volume, and density. In order to calculate the capacity of the carriageway, speed–volume relationship is usually applied due to the flexibility of collecting the data needed. The data should be collected at non-congested traffic and no traffic flow data was collected at or over the capacity [2].

![Figure 1. Speed–Volume relationship.](image)

Figure 1 is showing speed and volume relationship at Teuku Nyak Arief Road. The lowest traffic flow at site location is 7468 MCU/hr, and the highest flow is 11756 MCU/hr. The average stream speed of traffic on minimum flow and peak condition at site location does not have a significant
The speed varies approximately 4 km/hr. The average stream speed is affected by the driver behaviour. According to the data collected, the motorcycle has the highest average stream speed with 34.13 km/hr, while light vehicle and heavy vehicle are 31.31 km/hr and 30.21 km/hr respectively. Light vehicle and heavy vehicle tend to reduce their speed on traffic in order to reduce the risk of accidents due to motorcycle behaviour of maneuvering.

3.3. Motorcycle headway distribution

Researcher [4] described that time headway distribution varied considerably as the traffic flow rate increased due to the increasing interactions between vehicle and traffic streams. He proposed three classifications of time headway distribution based on traffic flow rate; random headway state for low flow condition, intermediate headway state for moderate flow condition, and constant headway state for high flow condition. The negative exponential distribution represents the random headway state flow. The normal distribution can be used when time headways are all constant. Meanwhile, intermediate headway state is a state lies between those two previous headway states (random and constant), and the mathematical distribution model approach proposed is Pearson type III distribution [4].

However, researcher [5] suggested negative exponential distribution represents its compatibility to a traffic flow that consists of a significant percentage of smaller vehicles such as a motorcycle. From the study conducted, the motorcycles arrivals are in the random state even during medium and high flow condition. Therefore, the negative exponential distribution is applied in order to obtain the best-fitted distribution for motorcycles. Slovin’s method with 5 percent margin of error was used to determine the observation sample number. Thus, from the total flow 3600 veh/hr, 360 motorcycles were observed.

Table 3. Statistical parameters of motorcycle headway.

| Min (s) | Max (s) | Mean (s) | St. Dev (s) | Median (s) | Mode (s) | Range | Number of classes | Interval |
|---------|---------|----------|-------------|------------|----------|-------|-------------------|---------|
| 0.22    | 8.84    | 1.15     | 0.81        | 0.53       | 8.62     | 9     | 1                 |

Table 3 is showing statistical parameters of motorcycle headway taken from the observed sample. The negative exponential distribution can be derived from Poisson distribution. If there are no vehicle arrivals in an interval \( t \), there must be a headway greater than or equal to \( t \) [6]. The equation is described below:

\[
Prob \text{(headway > } t \text{)} = \exp(-qt) \tag{2}
\]

Where,

\( q \) = Mean time headway (veh/sec);
\( t \) = Time interval (sec).

Table 4. Observed and theoretical headway data of motorcycle.

| Class | Time headway classes (s) | Observed frequency (fo) | Cumulative observed frequency (fo c) | Observed frequency percentage (%) | Theoretical frequency percentage (%) | Cumulative theoretical frequency (ft c) | Theoretical frequency (ft) |
|-------|--------------------------|-------------------------|-------------------------------------|-----------------------------------|--------------------------------------|----------------------------|--------------------------|
| 0     | 0.0 – 0.9                | 230                     | 360                                 | 100.00                            | 100.00                               | 360.00                    | 227.56                   |
| 1     | 1.0 – 1.9                | 77                      | 130                                 | 36.11                             | 36.79                                | 132.44                    | 83.72                    |
| 2     | 2.0 – 2.9                | 35                      | 53                                  | 14.72                             | 13.53                                | 48.72                     | 30.80                    |
| 3     | 3.0 – 3.9                | 7                       | 18                                  | 5.00                              | 4.98                                 | 17.92                     | 11.33                    |
| 4     | 4.0 – 4.9                | 7                       | 11                                  | 3.06                              | 1.83                                 | 6.59                      | 4.17                     |
The computed results between observed and theoretical frequencies of motorcycle headway are shown in Table 4. The calculation of theoretical frequency percentage is obtained from equation (2) and multiplied by 100, where $q = 3600/3600 = 1$ veh/sec and $t = 0, 1, 2, ..., 8$. Then, the value multiplied by a total amount of headway observed in order to obtain cumulative theoretical frequency ($f_{tc}$). Theoretical frequency headway in class ($f_t$) can be obtained from the difference between successive values of cumulative theoretical frequency.

To compare the observed distribution with the probability distribution, the non-parametric goodness of fit Chi-Square test was applied. The equation of the test is described below:

$$\chi^2 = \sum \frac{(obeserved\ frequency-theoretical\ frequency)^2}{theoretical\ frequency}$$  

(3)

| Class | Time headway classes (s) | Observed frequency ($f_0$) | Cumulative observed frequency ($f_{0c}$) | Observed frequency percentage (%) | Theoretical frequency percentage (%) | Cumulative theoretical frequency ($f_{tc}$) | Theoretical frequency ($f_t$) |
|-------|--------------------------|----------------------------|----------------------------------------|-----------------------------------|--------------------------------------|--------------------------------|-----------------------------|
| 5     | 5.0 – 5.9                | 1                          | 4                                      | 1.11                              | 0.67                                 | 2.43                           | 1.53                        |
| 6     | 6.0 – 6.9                | 1                          | 3                                      | 0.83                              | 0.25                                 | 0.89                           | 0.56                        |
| 7     | 7.0 – 7.9                | 1                          | 2                                      | 0.56                              | 0.09                                 | 0.33                           | 0.21                        |
| 8     | 8.0 – 8.9                | 1                          | 1                                      | 0.28                              | 0.03                                 | 0.12                           | 0.12                        |

Table 5. Chi-Square test.

| Observed frequency ($f_0$) | Theoretical frequency ($f_t$) | $\frac{(f_0 - f_t)^2}{f_t}$ |
|----------------------------|-------------------------------|-----------------------------|
| 230                        | 227.56                        | 0.026                       |
| 77                         | 83.72                         | 0.539                       |
| 35                         | 30.80                         | 0.573                       |
| 7                          | 11.33                         | 1.655                       |
| 11                         | 6.59                          | 2.945                       |
| Total                      |                               | 5.738                       |

Table 5 is showing the Chi-Square calculation. The last five classes of a theoretical frequency have a value less than 5, therefore, the remaining classes should be combined. According to the Chi-Square distribution tables, with the 5 percent significant level ($\alpha$) and 3 degrees of freedom (df), the value is 7.815. Thus, $\chi^2$ calculated < $\chi^2$ table, so there is no significant difference between observed and theoretical frequency. Consequently, the headway distribution of motorcycle at Teuku Nyak Arief roadway is negative exponential distribution. The goodness of fit of the negative exponential distribution to the observed values is shown in the graphic below.
4. Conclusion

MCU values computed were consists of motorcycle (MC), light vehicle (LV) and heavy vehicle (HV). Those values were calculated 1.00, 6.13 and 10.71 respectively. The MCU values considerably affected by the dynamic characteristic of moving vehicle. In this case, the parameters are speed (km/hr) and projected rectangular area (m²). The speed and volume relationship result is showing a linear regression model with $R^2$ value is 0.58, it can be explained that the correlation between two variables is intermediate. The lowest traffic flow at site location is 7468 MCU/hr, and the highest flow is 11,756 MCU/hr. Meanwhile, the average stream speed of the motorcycle, light vehicle and heavy vehicle are 34.13, 31.31 km/hr and 30.21 km/hr respectively. The headway distribution of motorcycle is compatible with the negative exponential distribution which fitted with the proposed theory for a small vehicle such as a motorcycle. The average time headway of traffic flow is 1.15 sec, while the headway ranges from 0.22 to 8.84 sec, and the standard deviation is 1.07 sec. The present study providing an information that can be used in the future as a simulation model for developing the traffic operation, particularly in the developed country like Indonesia, due to a significant proportion of motorcycle in traffic flow.

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