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Vehicle Headway Distribution Models on Two-Lane Two-Way Undivided Roads

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***Abstract*—The time headway between vehicles is an important flow characteristic that affects the safety, level of service, driver behavior, and capacity of a transportation system. The present study attempted to identify suitable probability distribution models for vehicle headways on 2-lane 2-way undivided (2/2 UD) road sections. Data was collected from three locations in the city of Semarang: Abdulrahman Saleh St. (Loc. 1), Taman Siswa St. (Loc. 2) and Lampersari St. (Loc.3). The vehicle headways were grouped into one-second interval. Three mathematical distributions were proposed: random (negative-exponential), normal, and composite, with vehicle headway as variable. The Kolmogorov-Smirnov test was used for testing the goodness of fit. Traffic flows at the selected locations were considered low, with traffic volume ranged between 400 to 670 vehicles per hour per lane. The traffic volume on Loc.1 was 484 vehicles per hour, that on Loc. 2 was 405 vehicles per hour, and that on Loc. 3 was 666 vehicles per hour. Random distribution showed good fit at all locations under study with 95% confidence level. Normal distribution showed good fit at Loc. 1 and Loc. 2, whereas composite distribution fit only at Loc. 1. It was suggested that random distribution is to be used as an input in generating traffic in traffic analysis at highway sections where traffic volume are under 500 vehicles per hour.**

***Keywords*—headway, undivided-road, traffic flow, probability distribution**

I. INTRODUCTION

The term headway is defined as the time interval between successive vehicles and expressed in time unit of seconds. Theoretical knowledge about the arrival and headway patterns of vehicles are very important in transportion engineering. Some mathematical distribution models have been used to describe the characteristics of the vehicle headway mathematically. Vehicle headway is an important micro characteristic of traffic flow that affects savety, level of service, driver behavior, and the capacity of the transportation system.

One of the reasons why mathematical description of vehicle headway should be understood is that it is needed as input for the simulation model of traffic flow on a digital computer, such as to simulate junctions, vehicle following, toll road gates, and other roadway traffic situations. As it is already known, one of the problems in simulations is the need for traffic data as input. At least there are two methods to solve this problem. The first methode is by observing the actual data in the field. This method has two drawbacks: 1) computer reading takes time, and it takes a long time to collect data, and 2) because only actual data is used, one of the advantage of simulation which is the ability to check the extreme conditions that difficult to observe in reality is lost.

The second methode is by internal data generation. This second method eliminates both of these weaknesses because it allows a computer to generate its own data. Thus the timing problem can be overcome, because the generation of data by a computer takes only a short time. In addition, by internal data generation, situations that are difficult to be observed in the field can be researched.

One of the problems with internal data generation is the need for knowledge of the mathematical model that can accurately generate data that fit with the actual situation. The purpose of this study was to identify the probability distribution model of vehicle headways on two-lane two-way undivided roads (2/2 UD).

II. THEORETICAL BACKGROUND

As describes in May [1], a microscopic view of traffic flows can be shown in Figure 1, where several vehicles traverse a road segment within a specific time period. The time of arrival of vehicles 1, 2, 3, and 4 at the observation point is expressed by t_1, t_2, t_3, and t_4. The time between the arrival of one vehicle and the next vehicle is defined as the time headway, so the time headway can be shown as,

$$(h)_{1\text{-}2} = t_2 - t_1, \quad (h)_{2\text{-}3} = t_3 - t_2, \quad \text{etc.}$$

It can be observed from Figure 1 that the headway (h) actually consists of two time intervals: the occupancy time, the time required by the physical vehicle to pass through the observation point, and the time gap, time interval between the rear-end of the vehicle and the front-end of the next vehicle.

An observer could record the arrival time of each vehicle at an observation point and then compute its headway for a certain volume or traffic flow conditions. The observed headways can be grouped for certain headway interval, and subsequently frequency distributions of headway groups can be made for specific traffic flow conditions.

The shape of the headway distribution change with the increase of the volume or flow of vehicles on the road. When the traffic flow is very low, the vehicles are free to move without interacting with other vehicles. As the traffic flow increase, some vehicles will be in platoons while the others move freely. If the traffic flow approaching the capacity of the road, the vehicle will move with almost constant headway. Between the these two extreme conditions, the intermediate headway distribution exists.

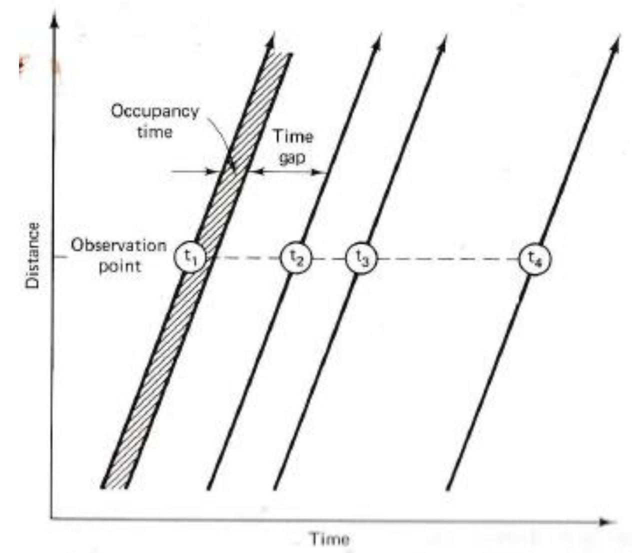

Figure 1. Microscopic view of traffic flow (May, 1990)

Adams [2] first reported that the number of vehicles passing through the observation point at the same time interval follows the Poisson distribution. Negative exponential distribution is a mathematical distribution which describes the distribution of the random interval. Two conditions must be met in order for headway truly random [1]: 1) at any time the possibility of the arrival of the vehicle are the same, and 2) the arrival of a vehicle at any one time does not affect the time arrival other vehicles.

The negative exponential distribution can be derived from the count Poisson distribution [1]. The negative exponential distribution is an interval distribution; that is, it is the distribution of the number of individual time headways in various time headway intervals. While the Poisson distribution is a count distribution; that is, it is the distribution of a number of time periods which contain different flow levels.

The equation to calculate the Poisson distribution can be expressed as follows.

$$P(x)=\frac{m^x e^{-m}}{x!}$$

Where: $P(x)$ = the chances of x vehicles arriving in a time interval t, m = the average number of vehicles arriving in a time interval t, x = the number of vehicles arriving in a time interval being observed, t = selected time interval, e = natural numbers (2.71828...).

Review the special case where x=0. That is a state in which no vehicle appeare during a specified time interval t. So the above equation becomes

$$P(0)=e^{-m}$$

If there are no vehicle appear in the time interval t, then its headway must be equal to or greater than t, so

$$P(0)=P(h>t)$$
$$P(h>t)=e^{-m} \quad (1)$$

As it is known that m is the average number of vehicles coming in the time interval t. If the vehicles flow in one hour is expressed in V, and t is in seconds, then

$$m=\frac{Vt}{3600}$$

and equation (1) become

$$\Pi (\eta > \tau) = \varepsilon^{-\varsigma\tau/3600} \quad (2)$$

Average headway t', in seconds, can be determined from vehicle flow in one hour, V,

$$t' = \frac{13600}{V} \quad (3)$$

Substitution of equation (3) in equation (2) produce an alternative equation

$$P(h>t) = e^{-t/t'}$$

With this equation, when the average headway t' is known, the observer can select intervals t, and then $P(h\geq t)$ can be calculated. Note that when $t=0$, $P(h\geq t)=1$. The higher t, the smaller $P(h>t)$ until finally when $t\rightarrow\infty$, $P(h\geq t)\rightarrow 0$. The probability of headway intervals are calculated by:

$$P(t\leq h \leq t+\Delta t)=P(h>t)-P(h\geq t+\Delta t)$$

Normal distribution occurs in cases where headways are uniform or if the drivers try to drive with the same headways but failed so that the headways are spread around the headway in question [1]. The normal distribution is determined based on the average headway and standard deviation of the headway distribution. In the case of a uniform headway, the average headway is:

$$t'=\frac{3600}{t}$$

While the standard deviation is zero. In the case of normal headway distribution, headway average is calculated by the equation as above, but the standard deviation is greater than zero. Because negative headway is not possible (in fact may not be less than 0.5 seconds), then the minimum headway is

$$\alpha = t - 2s$$

Where: α = minimum headway, t = the average headway, s = standard deviation of the distribution headway, 2 = constant, so that 2 standard deviations below the average headway will approach the theoretical minimum headway.

By rearranging the above equation, the standard deviation can be calculated by the following equation $s = (t - \alpha)/2$

Probability density function for normal distribution is expressed by equation

$$f(t) = \frac{1}{(2\pi s)^{1/2}} e^{-1/2\,[(t - \bar{t}) / s]^2}$$

Value headway t cumulative distribution, ie P(t<t) can be seen in the normal distribution table to look at the value of z/s, where z=t-t. Further opportunities headway h groups can be calculated by the equation

$$P(t<h<t+\Delta t)=P(t<h<t)-P(t+t<h<t)$$

Probability density function of Type III Pearson distribution [3] is expressed by the equation

$$f(t) = \frac{\lambda}{\Gamma(K)} [\lambda(t-\alpha)]^{K-1} e^{-\lambda(t-\alpha)}$$

Where:
$f(t)$ = probability density function
λ = intermediate parameter
K = shape parameter
α = shift parameter, that states the amount of shift of the distribution (seconds)
t = headway under review
e = constant, 2.71828
$\Gamma(K)$ = gamma function = $(K-1)!$

The probability of each headway group can be calculated as the following equation

$$P(t \le h \le t+\Delta t) = \frac{\lambda}{(K)} [\lambda(t-\alpha)]^{K-1} e^{-\lambda(t-\alpha)} + \frac{\lambda}{(K)} [\lambda(t+\Delta t)-\alpha)]^{K-1} e^{-\lambda|(t+\Delta t)-\alpha|}$$

Schuhl [1] proposed a composite exponential distribution in which a proportion of vehicles are classified as in restrained flow condition and the other proportion as in a free flow condition. A composite model combines normal headway distribution for the vehicles that are in the convoy (platoon) and negative exponential distribution that is shifted by α for free flow vehicles. Four independent parameters should be determined to apply composite distribution: the average and standard deviation for a normal distribution, the proportion of vehicles in platoon, and the minimum headway of vehicles that are not in platoon. Composite exponential probability distribution is expressed by the equation

$$P(h \ge t) = (1-n)(1-e^{-t/b_2^2}) + n[-e^{-(t-\alpha)/(b_1-\alpha)}]$$

Where:
n = vehicle proportion in platoon
1-n = free flow vehicle proporton
b_2 = average vehicle headway in platoon
= 3600/(sum of vehicle in platoon)
b_1 = average free flow vehicle headway
= 3600/(sum of free flow vehicles)
α = Minimum vehicle headway in platoon, second
t = headway, second

III. METHODE

The study was conducted at three two-lane two-way undivide (2/2UD) roads. The three location are on Abdurrahman Saleh St. (Loc. 1), Taman Siswa St. (Loc. 2) and Lampersari St. (Loc. 3), in the city of Semarang. Data collected were traffic volume, vehicle arrival times, and vehicle headways. Each selected location was observed for one hour period. Three headway distribution models were evaluated, that were random, normal, and composite distribution.

Model evaluation was done graphically as well as statistically. Graphical evaluation was done by displaying theoretical distribution against the distribution of actual data to see which theorical distribution close to the distribution of actual data. Statistical evaluation techniques were necessary to examine whether a mathematical model of a particular distribution is in accordance with actual conditions. Statistical technique that was used to test the suitability of the measured distribution and the theoretical distribution is Kolmogorov-Smirnov test. Kolmogorov-Smirnov test is a goodness-of-fit test, which tests whether there is a meaningful difference between the measured frequency distribution and the expected theoretical frequency distribution.

IV. RESULTS

One characteristic of Indonesian roadway traffic, as the case in many developing countries, is the heterogeneous composition of its traffic. Various types of vehicles, such as motorcycles, passenger cars, buses, trucks, and various other types of vehicles, operate on the same highway sections. Besides motorized vehicles, unmotorized vehicles such as bicycles, tricycles and wagons are also prevalent on highways. The main purpose the present study was to identify the model of vehicle headway on 2-lane two-way highways. The study only examined one type of vehicle, that is passenger cars, which included station wagon and multi-purpose vehicles (MPV). Motorcycles were not investigated because its arrival often clustered parallel in a single traffic lane. Meanwhile the number of other types of vehicles were limited to analyse.

Traffic volume was considered low in all three locations. The traffic volume at Location 1 (Abdurahman Saleh St.) was 484 vehicles per hour (8 vehicles per minute). That at Location 2 (Taman Siswa St.) was 405 vehicles per hour (7 vehicles per minute). While the volume of vehicles in Location 3 (Lampersari St.) was 666 vehicles per hour (11 vehicles per minute).

The observed vehicle headway for the three selected locations are presented in Figure 1. Vehicles headways were grouped in one second intervals. Most of the headways fall in 0-1 seconds interval group at three observation sites. From the total 726 observed headways at Location 1, about 20.5 percent fall in 0-1 seconds interval and only about 6 percent had values more than 20 seconds. The average headway values at Location 1 is 7.43 seconds with a standard deviation of 7.32 seconds.

At the second location the total number of 666 headways was observed. The average headway value at this location was 5.40 seconds with a standard deviation of 5.65 seconds. A total of 27.3 percent of the headways had the size of one second or less, and only 2.2 percent are longer than 20 seconds.

From a total of 810 observed headways at third location, 23.8 percent had a size of 1 second or less, and nearly 20 percent had size between one and two seconds. The proportion of headways that were larger than 20 seconds was relatively larger than the other two selected locations, which is about 12.5 percent. The size of the average headway at this location was 8.89 seconds with a standard deviation of 14.4 seconds.

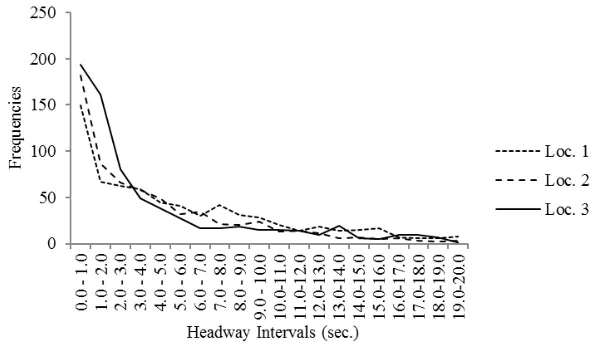

Figure 2. Measured vehicle headway frequencies at selected locations

The graphs of measured and theoretical headway probability distributions for Locations 1, 2 and 3 are presented in Figures 3, 4, and 5 respectively. These figures show the probability for each headway interval. Three mathematical distributions are shown as theoretical distributions, that are: random distribution, normal distribution, and composite distribution. Qualitative evaluation by comparing the graphs of measured probability distribution with the graphs of each theoretical probability distribution reveals that random distribution is closer to measured distribution than that of the other theoretical distributions. This is same for Location 1, 2 and 3.

The calculation of model fit tests for each location were conducted using the Kolmogorov-Smirnov (K-S) procedure. The results of goodness of fit using Kolmogorov-Smirnov test are presented in Table I. The test results show that random distribution fit to the headway distributions at all of the studied locations. While the composite distribution only fit to Location 1, and normal distribution fits to only Locations 1 and 2.

V. DISCUSSION

According to May [1], vehicle headway distribution model varies depending on the amount of traffic flow. This is due to the interaction between vehicles. The greater the traffic flow, the interaction between vehicles also increases. Vehicles move freely without the need to interact with other vehicles in very traffic low conditions. In other words, each vehicle could appear at any time. The only exceptions that occur on the actual condition is the required minimum headway for safety reason. The time headway distribution of that particular traffic conditions can be described as random headway distribution.

Situations where traffic flow is very low is one of two boundary conditions. Another boundary condition is a situation where the level of traffic flow is around capacity. In a such dense traffic conditions almost all vehicles interact so that the headways will be approximately constant. Between these two boundary conditions there intermediate condition, where a part vehicles move independently while the others interact each other.

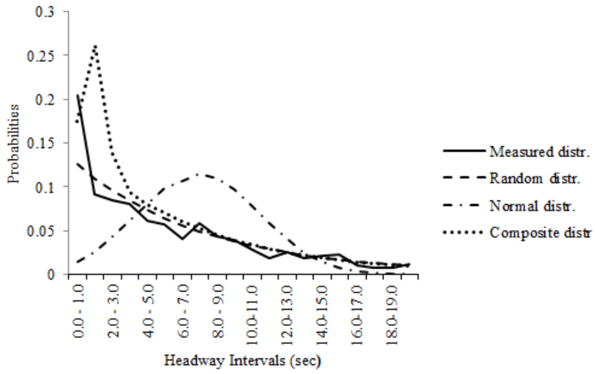

Figure 3. Probabilities of measured and theoretical vehicle headway at Location1

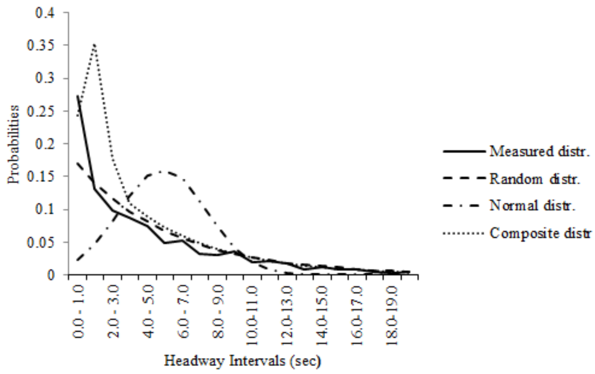

Figure 4. Probabilities of measured and theoretical vehicle headway at Location2

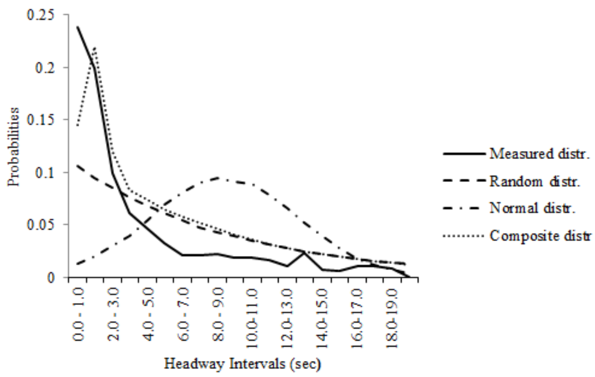

Figure 5. Probabilities of measured and theoretical vehicle headway at Location 3

The capacity of 2-lane 2-way undivided (2/2 UD) roads as the roads that been studied are about 2800 pcu (passenger car unit) per hour for two lanes [4]. The actual traffic volume at each location is 484, 1405 and 666 vehicles per hour for Location 1, 2, and 3 respectively. The traffic volume at the studied locations can be classified as low, because the volume of the traffic was far below the capacity of the road. Therefore, it can be expected the vehicle headway model for the studied locations was random distribution. The results of Kolmogorov-Smirnov goodness of fit tests with (Table I) confirm this, which vehicle headway distributions of all selected locations fit with random distribution with the 95% confidence level. Research conducted by Rangaraju and Rao [2] gave results that were consistent with what is discussed above. Where the Poisson distribution provides a fit to the pattern vehicle arrival when traffic volume is less than 500 vehicles per hour.

TABLE I. KOLMOGOROV-SMIRNOV GOODNESS OF MODEL FIT TESTS RESULT

Locations	Distributions	D_{max}	D_o	Remark
1	Random	0,078	0,29	Accept H_o
	Normal	0,140	0,29	Accept H_o
	Composite	0,273	0,29	Accept H_o
2	Random	0,113	0,29	Accept H_o
	Normal	0,134	0,29	Accept H_o
	Composite	0,378	0,29	Reject H_o
3	Random	0,269	0,29	Accept H_o
	Normal	0,363	0,29	Reject H_o
	Composite	0,323	0,29	Reject H_o

VI. CONCLUSIONS

The studied locations could be chategorized as having low traffic volume. Random distribution model indicated conformity to all selected locations based on Kolmogorov-Smirnov goodness of fit tests with a confidence level of 95%. Normal distribution model fits on two locations, while composite distribution model only fit in one location. Random distribution should be used in generating traffic data as input for traffic flow simulation model of highway sections with traffic volume of about 500 vehicles per hour or less.

ACKNOWLEDGMENT

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