

THE INFLUENCE OF MIXED TRAFFIC ON CONGESTION LEVEL AND MARGINAL ROAD CONGESTIONS

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ABSTRACT: Urban traffic in most developing nations is heterogeneous in which the impact of different types of vehicles on road congestion would not probably similar. The impact, therefore, should be analyzed independently considering the dimension, speed, and proportion of each vehicle within the traffic stream. In theory, different types of vehicles influence less congestion can be utilized as a reason for traffic management measures. This study aims to develop an alternative method other than the use of the Indonesian Highway Capacity Manual (MKJI) for analyzing congestion level and marginal congestions. The proposed methods determine the passenger car equivalent (PCE), estimate the maximum capacity of a type of vehicle on a road link and predict congestion level and marginal congestions. Three road links selected as the case study are Jl. Mahendradatta, Jl. Buluh Indah and Jl. Cargo in Denpasar, Bali. This study found that the high proportion of small vehicles on the road such as motorcycles may also have a high influence on marginal road congestion. This study suggested that the maximum capacity and marginal congestion of each type of vehicle on the road link should initially be considered prior to perform traffic management policy such as prohibiting the entry of light and heavy vehicles while at the same time allowing motorcycles to have the access on certain road lanes.

Keywords: Congestion level, Marginal congestion, Mixed traffic, Urban Transportation

1. INTRODUCTION

An attempt to minimize road congestion by means of road improvement is restricted with monetary and physical limitations. Meanwhile, focusing on the issue of urban traffic congestion on traffic management measures, for example, constraining or charging the typical types of vehicles to accessing roadways is viewed as a more satisfactory option [1-3]. Urban traffic in most developing nations, however, is mixed or heterogeneous, and the different types of vehicles would not probably have a similar influence on road congestion [4, 5]. It is necessary, therefore, to analyze the influence of various types of vehicles on road congestion under mixed traffic conditions.

The mixed traffic composition can be used to analyze the congestion levels prior to constructing a road congestion model [6]. In fact, the composition of traffic and volume levels differs as indicated by the observation period. Likewise, the increase in congestion due to the addition of new vehicles is exceptionally subject to the type of vehicle, the level of volume, the composition of traffic flow, the width of the highway, etc. The volume and composition of preceding traffic to the addition of new vehicles are defined as 'base volume' and 'basic composition' respectively.

The increase in congestion due to the addition of new vehicles at the base volume is called incremental congestion (IC). Incremental

congestion is apparently considered by all vehicles in traffic flows. Furthermore, the total additional congestion to traffic flow caused by the addition of a certain type of vehicle is defined as Marginal Congestion (MC) [4]. Meanwhile, past studies have investigated on traffic congestion level in an effort to reduce road traffic congestion. Road traffic congestion level apparently can be measured with level of service (LOS from A to F) and travel time index (TTI). These measures, however, were used only for current traffic congestion level and not for future occurrence [7, 8].

The idea of MC has been broadly utilized in the transportation economy, particularly with regards to traffic congestion costs. These past investigations have noteworthy contributions for examining road congestion costs by referring to MC [9, 10]. Nonetheless, the greater part of these investigations is based on homogeneous traffic streams that are dominated by light vehicles. There have been few examinations, however, concentrating on the use of traffic congestion costs under mixed traffic conditions in which the influence of different types of vehicles on traffic congestions is unique [10, 11].

To diminish MC caused by different types of vehicles, the given volume level can be examined and the entry of the type of vehicle that causes most extreme MC can be restricted. The idea of MC can be utilized as a reason for examining

vehicle types under mixed traffic conditions. In this way, MC can be resolved progressively in accordance to the traffic volume and its composition during peak hours for each predetermined time interval such as 5 minutes, 10 minutes and so forth [4].

In theory, limiting motorized vehicles or restricting certain types of motor vehicles to enter an area is intended to reduce road traffic congestion within that area. There are often restrictions applied for heavy and light vehicles entering roadways in cities in Indonesia. This prohibition, however, does not frequently apply to motorcycles because their size is relatively small and is considered capable of maneuvering on the roadways. This study, therefore, highlights two main issues as follows:

- a. Is this policy remaining relevant considering the existence of a large amount or high proportion of motorcycles within traffic stream?
- b. How do motorcycles influence or contribute to road traffic congestion level and marginal congestion?

As the high proportion of motorcycles in the traffic flows, the Indonesian Highway Capacity Manual (MKJI) is considered less appropriate to be used for a reference to analyze road congestion [12]. This study, therefore, aims to propose an alternative method other than the use of Indonesian Highway Capacity Manual (MKJI) in the analysis of congestion level and marginal congestions. The proposed method is performed following the study objectives as follows:

- a. To estimate the equivalency units of different vehicle types (passenger car equivalent/PCE) on the road links under mixed traffic conditions,
- b. To develop speed-density functions so that the maximum capacity/flows for different types of vehicles on the road links can be determined,
- c. To analyze the influence of various types of motor vehicles on congestion level and marginal congestion under mixed traffic conditions.

Because of the remarkable increase in the number of motor vehicles in particular motorcycles, these combined methods may provide a genuine work for traffic congestion analysis in an urban area.

2. METHODS

2.1 Passenger Car Equivalent and Road Traffic

In comparison to those in developing countries, different traffic conditions occur in developed countries tends to be nearly homogeneous

consisting only of heavy and light vehicles. Heavy vehicles are yet limited in traffic to enter urban areas so that, only light vehicles overlook in urban areas. Besides that, there is a strict limitation for motorized vehicles, which is to have a lane discipline. This condition, however, is rarely found in mixed traffic in developing countries such as Indonesia. For instance, a number of motorcycles in 1997 in Denpasar city was 267,234 units while in 2016 it reached 1,026,430 units [13]. There has been an almost four times increase in the number of motorcycles within the 19-year period in the city of Denpasar. In addition, based on the size of the vehicle and the motorcyclists' behavior, the motorcycle may reduce the speed of other motor vehicles which subsequently increase the traffic delay on the road [14]. As a result, this can reduce the level of road service.

In a lane discipline situation, vehicle occupancy on the road is managed by the length of the vehicle which is used afterward to examine passenger car units (PCU) [5]. However, in accordance with maneuvering characteristics under a mixed traffic condition, motorcycles run not on the available lane. As a consequent, vehicle occupancy is better formulated in a unit of area. In this study, the equivalent value of a passenger car (PCE), therefore, refers to the method below [5, 15] as follows:

$$PCE_i = \frac{V_{LV}/V_i}{A_{LV}/A_i} \quad (1)$$

where

PCE_i The equivalent value of passenger car for the ith type of vehicle

V_{LV}; V_i The average speed of light vehicles & of ith type of vehicle (km/hour) respectively

A_{LV}; A_i Area (length x width) of a light vehicle & of ith type of vehicle on the road (m²) respectively

Table 1 shows the average dimensions of motor vehicle classifications. The arranged vehicle classification incorporates small, medium and large vehicles adopted from the Guidelines for Inter-City Road Geometric Planning Procedures [16] while, the motorcycle dimension is taken from Chandra, et.al in [14]. A spot speed technique is utilized for evaluating the average speed of various types of vehicles (V_i). Traffic speed is resolved from the travel time observation and is changed over into kilometers per hour. Subsequent to calculating the size and the speed of each type of vehicle, the PCE can be resolved.

Table 1 Vehicle and Dimension Categories

No.	Type	Vehicle	Average dimension (m)	Area (m ²)
1.	Small vehicles	Passenger car	2.10 x 5.80	12.18
2.	Medium vehicles	Truck vehicles 2 axles and bus 2 axles	2.60 x 12.10	31.46
3.	Large vehicles	Semi-trailer trucks	2.60 x 21.00	54.60
4.	Motorcycles	Scooter, motorcycles, mopeds	1.87 x 0.64	1.20

A road is considered to have zero congestion values on free-flow traffic, 100% congestion at maximum flow and more than 100% congestion in unstable conditions or forced traffic flow. Consequently, traffic conditions will have a congestion value between zero and 100%.

The level of congestion on a road segment (CG_Q) on a Q traffic volume is stated below [4]:

$$CG_Q = \left[\frac{Q}{Q_L} \right]^{\sum_{i=1}^n p_i + 1} \times 100 \quad (2)$$

where

- n Number of types of vehicles in mixed traffic flows
- i & p_i A type of vehicle (car; bus; truck, etc) & its proportion in mixed traffic flows
- Q_L Limited traffic volume which states 100% in congested traffic

When the hourly traffic volume employed in the congestion model in accordance to traffic data for a 15-minute period, the addition of one vehicle in 15-minute intervals results in an hourly volume increase of 4 vehicles (i.e. 4 times 15 minutes = 60 minutes), which is stated in passenger car units (PCUs). Traffic volume after the addition of an ith type of vehicle is obtained as follows (Q_i^{*}):

$$Q_i^* = Q + 4 PCU_i \quad (3)$$

Equation (4) shows that Q_{Li}^{*} restricts traffic volume to represent 100% congestion after changes in traffic composition after the addition of ith type vehicles. Meanwhile, MC for various types of vehicles and caused by the ith type of vehicle at the volume level Q is determined as given below [4]:

$$MC_{iQ} = \frac{[Q_i^* (\frac{Q_i^*}{Q_{Li}^*})^{\sum_{i=1}^n p_i^* + 1} - Q (\frac{Q}{Q_L})^{\sum_{i=1}^n p_i + 1}]}{4} \quad (4)$$

where:

- Q_{Li}^{*} 100% congestion after changes in traffic composition caused by Q_i^{*}
- Q_i^{*} Traffic volume after adding the ith type of vehicle to base volume Q
- p_i^{*} Traffic composition after adding the ith type of vehicle to the base volume Q

2.2 Case Study Area and Data Description

As shown in Table 2, road segments on single carriageways (four-lane two-way undivided) of Jl. Mahendradatta, Jl. Buluh Indah, and Jl. Cargo in Denpasar is employed as a case study. The selected road segments have various road widths as well as a high proportion of motorcycles representing mixed traffic. Motorcycle proportion for all segments is more than 64%, with the highest percentage exceeded 74% at Jl. Mahendradatta. The proportions of light and heavy vehicles on the case study were in between 23% and 35% and 1.5% and 2.7% respectively.

In order to minimize bias caused by the road and traffic parameters [17], the selected road segments, however, considerably have low side frictions such as few numbers of crossing pedestrians and non-motorised transport, no on-street parking, and few vehicles in and out to/from the frontage. They are more than 1800 vehicles/hour on average passing on these three roads so they are considered as having high traffic volume. Due to the physical dimensions and the existence of different motor vehicle composition, the road performance evaluation is necessary under mixed traffic conditions [5, 6].

Traffic data contains traffic volume and travel time of each vehicle involving motorcycles, heavy and light vehicles. Traffic data is collected by marking reference lines on the road. Video cameras put on either side of the road so as to record the vehicles across the observation point. Traffic volumes and travel time were surveyed on 24 May 2018, from 05.00 to 18.00 hours in which 15 minutes data were extracted manually from the video. A vehicle width that is over 50% crossing a particular lane involved in that lane will not be utilized in the other lane.

On the assumption that the traffic is less, the free travel flow is taken between 5.00 and 6.00 am [6]. The maximum capacity/flows for each type of vehicle on these three roads were obtained by constructing speed-density function so that maximum speed-flow curve as a point where oversaturated flow starts can be determined. These were conducted using the methods of Greenshield, Greenberg, and Underwood.

Table 2 Description of the road links

Jl. Mahendradatta (Mahendradatta Road Link)				
	Southbound Outer lane (m)	Southbound Inner lane (m)	Northbound Outer lane (m)	Northbound Inner lane (m)
Road width	3.30	3.70	3.90	3.30
Site location	330 m to the north of the junction of Jl. Teuku Umar Barat-Jl. Mahendradatta.			
Jl. Buluh Indah (Buluh Indah Road Link)				
	Southbound Outer lane (m)	Southbound Inner lane (m)	Northbound Outer lane (m)	Northbound Inner lane (m)
Road width	2.40	2.40	3.20	3.00
Site location	210 m to the south of Buluh Indah gas station.			
Jl. Cargo (Cargo Road Link)				
	Southbound Outer lane (m)	Southbound Inner lane (m)	Northbound Outer lane (m)	Northbound Inner lane (m)
Road width	3.40	2.80	3.10	3.25
Site location	350 m from the junction of Jl. Cargo Permai-Jl. Gunung Galunggung and 610 m to the north of Citraland access road.			

These models are the popular speed-density model. Greenshield, Greenberg, and Underwood proposed linear, logarithmic and exponential speed-density relationships. Density explains the contiguity among motor vehicles and maneuver within the traffic stream.

In contrast to speed, density is influenced by flow rates in the range of flows [18]. The models of Greenshields, Greenberg, and Underwood, therefore, can be used irrespective of the portion of speed-flow-density under mixed traffic conditions [5, 19].

3. STUDY RESULTS AND ANALYSIS

Due to the different traffic composition of vehicles in the study area, traffic volumes are converted to passenger car unit (PCU). Table 3 shows the passenger car equivalent (PCE) resulting from Eq. (1) for motorcycle and heavy vehicle on each road link. The PCE of motorcycle for all roads has the same value because of low variation of the average motorcycle speed for all of these segments. The speed variation, however, is relatively high for the heavy vehicles so that PCE for heavy vehicles differs for each road link. This is in line with a previous study finding that various equivalency factors indicating the increase in heterogeneity [19]. In other words, these road links of Jl. Mahendradatta, Jl. Buluh Indah and Jl. Cargo has apparently represented road traffic under heterogeneous conditions.

The Greenshields, Greenberg and Underwood models were constructed to accommodate Eqs. (2) and (4). The relationship between traffic density (D) and speeds (Vs) was investigated among these three models.

The Greenberg method was selected to model the relationship between traffic density (D) and speed (Vs) for these three types of vehicles as it has the highest r^2 compared to the other two models. As the results, the limited traffic volumes which state 100% in congested traffic (Q_L) were obtained for each type of vehicles on these three road links as shown in Table 4.

These models whose Pearson correlation coefficients (r^2) less than 0.7 were statistically considered less significant [20]. Subsequently, congestion level and marginal congestion models for the three road links and three types of motor vehicles were predicted and were shown in Figure 1. Similarly, these models having determination coefficients (R^2) less than 0.7 were also not further presented and analyzed.

It has been examined that congestion levels go up with the extra number of traffic flow. This is due to the fact that as the traffic volume increases, more number of vehicles run in the roadway and lead to a decrease in the speed of vehicles. The larger the vehicle's dimension the higher the congestion level. However, as shown in Figure 1 the motorcycles on Jl. Cargo increase at four (4) units per 15 minutes, its congestion level is higher than light vehicles. In addition, the congestion level of motorcycles for the addition of 10 vehicles per 15 minutes was about 4% higher than light vehicles. The reason is that the maximum capacity of motorcycle flows (Q_L) on Jl. Cargo was the least compared to light and heavy vehicles (refers to Eq. (2) and the Greenberg model results in Table 4).

Table 3 PCE for motorcycle and heavy vehicle on each road link

Road Link	V _{LV}	V _{MC}	A _{LV}	A _{MC}	PCE _{MC}	V _{LV}	V _{HV}	A _{LV}	A _{HV}	PCE _{HV}
Jl. Cargo	41	43	12.18	1.2	0.09	41	37	12.18	31.46	2.86
Jl. Mahendradatta	38	42	12.18	1.2	0.09	38	35	12.18	31.46	2.80
Jl. Buluh Indah	39	42	12.18	1.2	0.09	39	39	12.18	31.46	2.58

where

- PCE_{MC}, PCE_{HV} : The equivalent value of passenger car for motorcycle and heavy vehicle respectively
 V_{LV}, V_{HV}, V_{MC} : The average speed of the light and heavy vehicles, and motorcycle (km/hr) respectively
 A_{LV}, A_{HV}, A_{MC} : Area (length x width) of the light and heavy vehicles and motorcycle (m²) respectively

Table 4 Model results

Motorcycles			r ²	Q _L (Vehicles/hour)
Greenshields	M	V _s = 64-0.956xDj	0.55	1064
	BI	V _s = 67-1.371xDj	0.62	823
	C	V _s = 66.801-1.716xDj	0.55	650
Greenberg	M	V _s = 13+ln(516/D)	0.81	2553
	BI	V _s = 14+ln(349/D)	0.87	1819
	C	V _s = 17+ln(180/D)	0.78	1100
Underwood	M	V _s = 63 x exp(D/-59)	0.55	1363
	BI	V _s = 67 x exp(D/-40)	0.66	980
	C	V _s = 66 x exp(D/-32)	0.56	786
Light vehicles			r ²	Q _L (Vehicles/hour)
Greenshields	M	V _s = 62-1.302xDj	0.80	326
	BI	V _s = 65-2.096xDj	0.61	498
	C	V _s = 67.808-3.61xDj	0.75	318
Greenberg	M	V _s = 15+ln(101/D)	0.88	567
	BI	V _s = 17+ln(118/D)	0.77	745
	C	V _s = 12+ln(214/D)	0.84	980
Underwood	M	V _s = 65 x exp(D/-15)	0.80	369
	BI	V _s = 65 x exp(D/-24)	0.59	571
	C	V _s = 68 x exp(D/-15)	0.74	370
Heavy Vehicles			r ²	Q _L (Vehicles/hour)
Greenshields	M	V _s = 71-36.812xDj	0.39	34
	BI	V _s = 59-33.588xDj	0.24	26
	C	V _s = 59-23.069xDj	0.41	38
Greenberg	M	V _s = 22+ln(4/D)	0.80	36
	BI	V _s = 13+ln(13/D)	0.34	62
	C	V _s = 18+ln(7/D)	0.51	46
Underwood	M	V _s = 63x exp(D/-2)	0.44	40
	BI	V _s = 57 x exp(D/-2)	0.26	34
	C	V _s = 60 x exp(D/-2)	0.39	43

Note : M (Mahendradatta); BI (Buluh Indah); C (Cargo)

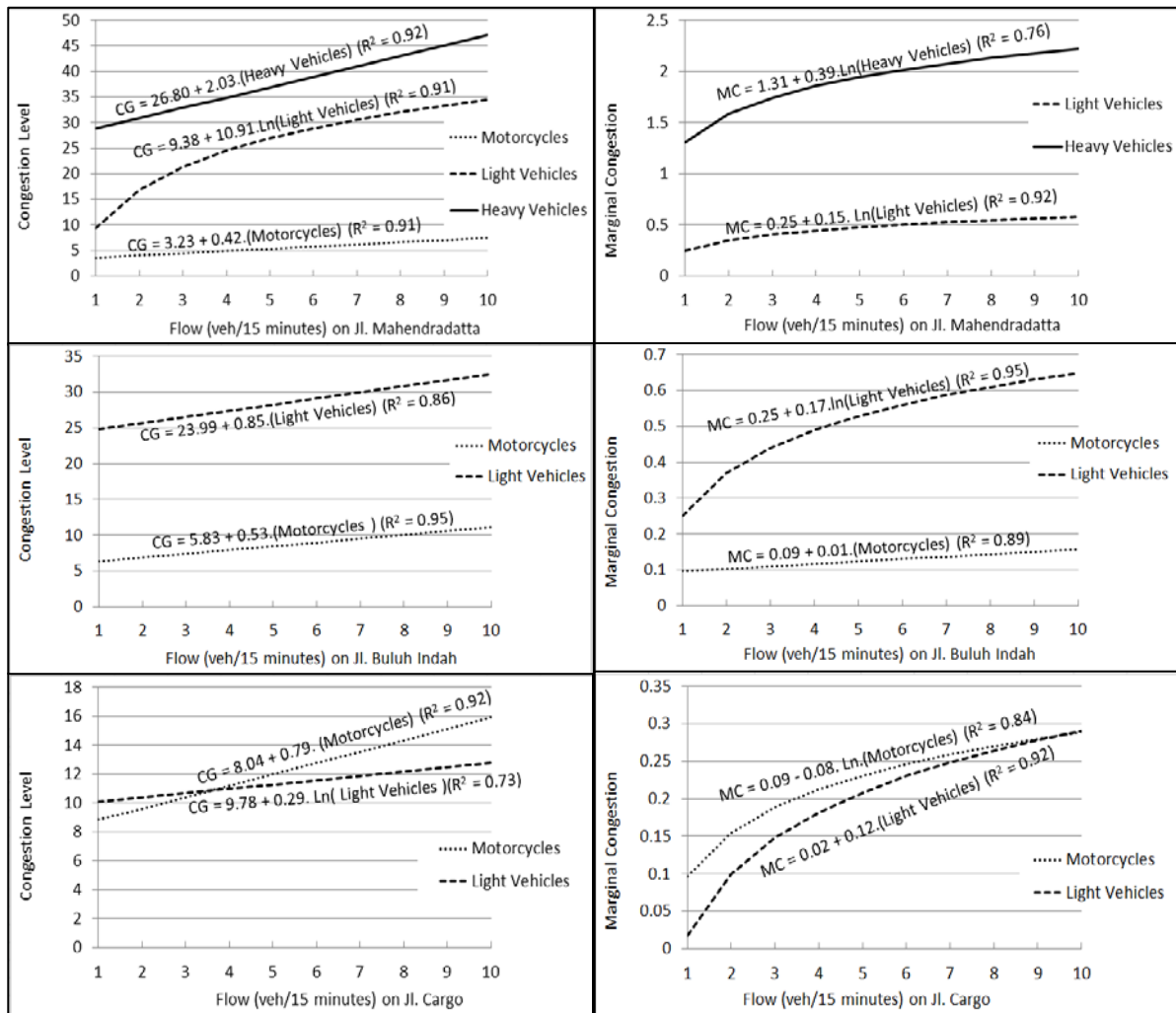


Fig. 1 Congestion level (left side) and marginal congestion (right side)

These findings suggest that urban transportation policy such as prohibiting motor vehicles from entering the road lane may not necessarily be appropriate and must be implemented carefully as a greater dimension of vehicles compared to the smaller ones may not result in higher marginal road congestion. Therefore, the maximum capacity for each vehicle for each road link initially must be taken into account.

Meanwhile, motorcycle and light vehicle models on Jl. Mahendradatta and Jl. Buluh Indah respectively was statistically accepted to be further analyzed as shown in Figure 1. The figure shows that the congestion level pattern of motorcycle and light vehicles was relatively similar for these two road links.

As the flow increases the congestion level escalates. The congestion levels for light vehicles and motorcycles on Jl. Mahendradatta were between approximately 20% and 35% and between approximately 4% and 8% respectively for the addition of 1-10 vehicles/15 minutes. The motorcycle, therefore, has less influence than light vehicles on congestion level on Jl. Mahendradatta.

In addition, as the congestion level of motorcycle is lower (between 6%-11% for the addition of 1-10 vehicles/15 minutes) than the light vehicle (between approximately 25%-33% for the addition of 1-10 vehicles/15 minutes), the increase in MC for motorcycle is less (between 0.1%-0.15% for the addition of 1-10 vehicles/15 minutes) than that for light vehicle (between 0.25%-0.65% for the addition of 1-10 vehicles/15 minutes) on Jl. Buluh Indah. This is due to the fact that the maximum capacity for motorcycles on Jl. Mahendradatta and Jl. Buluh Indah is much larger (2.5-5 times) than these for light vehicles (refer to

Eq. 3 and the Greenberg model results in Table 4). This is in line with a past study finding [6] describing that the value of MC is more significant at higher than lower traffic volume.

However, there was a slightly different case on Jl. Cargo in which motorcycles have more influence on MC than light vehicles. Marginal congestion (MC) of motorcycles is gradually lower than light vehicles as motorcycles reaching 10 units per 15 minutes. Past studies [4, 6] evidently show that marginal congestion varies with vehicle type and traffic volume. These past studies found that all types of vehicles cause more marginal congestion at higher traffic volume while the effect is significant for vehicles that have a larger dimension. In contrast to these past studies findings, this study found that the high proportions of the small vehicle on the road such as motorcycle may also have a high influence on marginal road congestion.

Meanwhile, Table 2 shows that various road widths are observed on Jl. Mahendradatta, Jl. Cargo and Jl. Buluh Indah respectively. From the highest to the lowest road capacities on the studied road segment are successively on Jl. Mahendradatta, Jl. Cargo and Jl. Buluh Indah. From the highest to the lowest number of traffic flows (vehicles/hour) during peak hours are these on Jl. Buluh Indah, Jl. Mahendradatta and Jl. Cargo respectively. Considering its road width and its proportion of motorcycles, Jl. Cargo is in the middle order between these on Jl. Mahendradatta and Jl. Cargo. Traffic flows on the road segment of Jl. Cargo, however, were the lowest compared to these on the other two road segments. Interestingly, congestion levels and marginal congestions of motorcycles are higher than light vehicles on Jl. Cargo.

Past studies results [4, 6] indicated that vehicles with larger dimensions have a greater influence on congestion level and marginal congestion than these with smaller dimensions on wider roadways (i.e. higher road capacity). This study, however, suggests that a vehicle dimension does not necessarily influence congestion level and marginal road congestion on such wider roadways. Speed and proportion of each type of vehicle in mixed traffic condition apparently may have a higher influence than vehicle size on road congestion. Further studies, therefore, should more be focused on speed and proportion of each type of vehicle on different road types under mixed traffic conditions.

4. CONCLUSION

The impact of various types of vehicles on road congestion is required for detailing the objective of traffic management under mixed/heterogeneous

traffic conditions. This study proposes an elective strategy other than the utilization of Indonesian Highway Capacity Manual (MKJI) in the investigation of congestion level and marginal congestion (MC). The consolidated technique was to determine the equivalent value of passenger car (PCE) for each type of vehicle, to estimate the maximum capacity of a type of vehicle on a road link using the Greenshield, Greenberg and Underwood models and to predict congestion level and MC.

This study found that PCE for heavy vehicles differs for each road link. Various equivalency factors on these road links of Jl. Mahendradatta, Jl. Buluh Indah and Jl. Cargo has apparently confirmed that the traffic was under heterogeneous (mixed) conditions. In accordance with the Greenshield, Greenberg and Underwood models, this study demonstrated that a high proportion of motorcycles can produce a higher capacity of motorcycles than light and heavy vehicles on a road link. In this study, the impact of various types of vehicles on road congestion has been caught through MC. It has been demonstrated that on a road, the measure of MC changes in a coherent way with the vehicle type and flow level. In this manner, MC could shape a reason for planning traffic management measures.

In other words, this research found that the high proportion of small vehicle on the road such as motorcycle may also have a high influence on marginal road congestion. The traffic management policy, therefore, needs to be performed with caution, for instance when prohibiting the entry of light and heavy vehicles while at the same time allowing the motorcycle on certain road lanes requires an initial consideration on the maximum capacity and MC of each type of vehicle on the road link.

It might be noticed that the estimations of MC obtained from congestion model are basically traffic based measurement. Such measures are very helpful, however, depending on a hypothetical viewpoint. Further, the influence of the other road capacity measures such as side friction, traffic separation, and city size is not considered in the present study and may be considered in the future works.

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