THE IMPACT OF CHANGING FLOW OF FREIGHT TRANSPORT ON STOCHASTIC CAPACITY OF ROAD LINKS

D.M Priyantha Wedagama[1]*, Dilum Dissanayake[2], Fazilatulaili Binti Ali[3]
[1]Department of Civil Engineering, Faculty of Engineering, Universitas Udayana, Bukit Jimbaran, 80361, Bali, Indonesia
[2]School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom
[3]Defence Science Department, Faculty of Defence Science and Technology, Universiti Pertahanan Nasional Malaysia, 57000, Kuala Lumpur, Malaysia
*priyantha@civil.unud.ac.id

ABSTRACT
Although the number of freight vehicles on the road is increasing, little attention is paid to their impact on traffic flow. Due to their size and performance characteristics compared to non-freight vehicles, the transport of goods can have an impact on road traffic. At the same time, many studies conducted on road traffic give special value to the capacity of roads. However, in this study, road capacity is analyzed according to probability distribution. This study shows that reducing the number of light and heavy vehicles used to transport goods by 3 and 5 times, respectively, will increase the capacity of road routes by 8 times and 6.5 times. Although traffic flow is not uniform and the number of vehicles is reduced, freight vehicles still have a direct and significant impact on the arterial road capacity. This study was limited to morning rush hour traffic so that subsequent research could examine the total duration of mixed traffic conditions.

Keywords: arterial roads; freight transport; mixed traffic; stochastic road capacity

INTRODUCTION
There are very few freight vehicles compared to the number of passenger vehicles on the road, but the impact is especially evident in high-traffic areas. Freight vehicles, especially large vehicles, have different physical characteristics as well as operating characteristics compared to other vehicles, thus having a physical and psychological impact on surrounding traffic (Moridpour, et.al., 2014). Although the amount of goods transported by vehicles is increasing (de Bok et al., 2018), little attention has been paid to the impact of freight vehicles on traffic flows. Statistically, heavy and light vehicles in Bali account for 82% and 19% of the total number of heavy and light vehicles on the road respectively (Central Bureau of Statistics of Bali Province, 2021). Therefore, measuring these differences is of great importance for local governments and other authorities to address road design and traffic congestion challenges (Lu et al., 2020).

The different types of freight vehicles, especially heavy vehicles, exhibit relative to other vehicles in mixed traffic affects the road capacity and overall level of service (LoS) (Singh, et.al., 2020). Additionally, estimating lane capacity in mixed traffic and drivers' lack of traffic discipline create varying degrees of difficulty (Mehar, et.al., 2014). Therefore, the influence of freight vehicles on traffic flow characteristics deserves more attention because it directly affects transport capacity (Al-Kaisy et al., 2005). The number of goods transport vehicles in Bali, including trucks, increased by 5.66% (from 148,238 to 156,624) in the three years from 2018 to 2020 (Central Bureau of Statistics of Bali Province, 2021). This increase in the number of vehicles indicates that freight vehicles have increased the distance traveled on Bali's road network. However, since a single value of road capacity does not reflect the actual observed value, capacity must be considered as a random variable that is naturally stochastic (Brilon, et.al., 2005; Geistefeldt., 2009). To represent capacity in this way, capacity must be estimated as a probability distribution over a range of values (Brilon, et.al, 2005). The cumulative

distribution of the corresponding performance values is called the "capacity distribution function" and is considered a valuable tool for evaluating road performance and efficiency. Additionally, peak flow is considered an estimate of road capacity (Brilon, et al., 2005).

The high interaction rate between light vehicles (LVs) and HVs and the significant difference in their speeds can lead to mobility bottlenecks (Zhou et.al., 2018). This reduces the average speed and traffic volume on the road for operational reasons. Understanding the deterrent effect caused by freight transport vehicles is important in traffic analysis as it affects not only traffic speed but also traffic flow and ultimately traffic capacity and LoS. To better understand the phenomenon of the impact of freight transport vehicles on capacity reduction, this study investigated the mixed traffic situation at different speeds during peak hours on Bali's main roads. Previous research (Wedagama, et.al., 2022) also suggests that further research is needed on the influence of the presence of other transportation modes on express choices. Past studies (Shah and Gupta., 2016; Kumar, et.al., 2018; Salini and Ashalatha., 2020) have also shown that the method used to determine road capacity in developed countries cannot explain the traffic situation in developing countries. The Studies in developed countries do not consider the characteristics of mixed traffic flows, especially in Indonesia where motorcycles (MCs) constitute the majority of traffic. For example, the distribution of speed data follows a normal distribution under homogeneous traffic conditions in developed countries, but does not follow a normal distribution under heterogeneous/mixed traffic conditions (Shah and Gupta., 2016).

Technical guidelines for determining the capacity of roads and intersections currently refer to the Indonesian Road Capacity Manual/MKJI (Directorate General of Bina Marga, 1997). Considering the high proportion of MC in Indonesia, including Bali province, exceeding 85% (Central Bureau of Statistics of Bali Province, 2021), the MKJI methodology may need to be modified (Munawar et al., 2018). Therefore, in this study, we develop a model for analyzing the impact of freight vehicles on road capacity. Therefore, the research goal is to analyze the composition of freight transport vehicles that impact road capacity. If the relationship between freight transport vehicles with changing road capacity can be identified, the appropriate action can be performed to prevent or minimize the reduction, depending on the level of freight transport penetration. Understanding the impact of freight traffic on reduced road capacity can help traffic management achieve travel times by preventing congestion. Jl. Bypass Ngurah Rai towards Kuta, Sanur and Nusa Dua are examples of arterial roads in Bali frequently passed by freight transport vehicles. Therefore, performance from a traffic flow perspective can be improved through traffic management strategies. The scientific contribution of this study is to analyze the impact of freight transport on road capacity and contribute to general knowledge about other variables that influence road capacity reduction. The results of this study are intended to serve as a reference when formulating a strategy for freight transport impact on road traffic, for example, planning to locate cargo terminals near ports and airports.

Identifying the relationship between freight vehicles and changes in road transport capacity can help develop appropriate measures to prevent or minimize reductions. Understanding the impact of freight traffic on road capacity can help traffic management reduce travel times by avoiding congestion. Jl. Bypass Ngurah Rai towards Kuta, Sanur, and Nusa Dua are examples of Bali arterial routes commonly used by freight vehicles. Therefore, performance from a traffic flow perspective can be improved through traffic management strategies. The scientific contribution of this study is to analyze the impact of freight transport on road transport capacity and contribute to general knowledge about other factors affecting road transport capacity. The results of this study are intended as a reference when developing strategies on the impact of

freight transport on road traffic, for example planning the establishment of freight terminals near ports and airports.

METHOD

Data collection was performed using a video camera at three locations along the observation section, namely J1. Bypass Ngurah Rai towards Kuta, J1. Bypass Ngurah Rai towards Sanur, and J1. Bypass Ngurah Rai towards Nusa Dua. The data collected include traffic volume (Q) and travel time (t) to determine speed (V) and road geometry conditions. These three roads are four-lane two-way divided arterial roads. Traffic volume and travel times however, were measured only for one direction for each segment. The study area is the uninterrupted flow of traffic on straight and flat sections (0% grade) of the road. Also, the section should have no other access points near the data collection zone to have minimal or no lateral friction impact on traffic flow. Collected traffic speed and volume data were extracted for each 5-minute aggregation. All vehicles are classified and classified into three categories: motorcycle (MC), light vehicle (LV), and heavy vehicle (HV). Observation times are chosen during peak traffic hours, from 07:30 to 10:30 Bali local time. Based on the traffic data, the observed road segments refer to traffic flow conditions such as intensity (volume/capacity ratio), traffic distribution, and traffic composition.

Table 1 shows the site traffic characteristics and road geometry conditions. Observations were made when the pandemic period began to subside, but traffic conditions were still lower than in non-pandemic conditions. Observations of a few side frictions (few pedestrians crossing the road, vehicles parked or stopped on the side of the road, unmanned vehicles passing by the side of the road, vehicles entering and exiting the land use) were measured along the 200-meter road section). MC has the largest percentage among the three observed modes, in the range between 61.43% and 77.58%, LV in between 21.19% and 34.12%, and HV in the range of 1.23% to 4.45%. This transport mode ratio indicates a mixed traffic flow condition. A previous study concluded that the lane width effect is more pronounced under mixed traffic conditions where vehicles do not follow each other (Patel and Joshi., 2014). A negative association was found between reduced capacity and the number of lanes, showing a downward trend from 16.33% for 2-lane highways to 8.85% for 5-lane highways (Oh and Yeo., 2015).

Table 1.
Traffic Composition and Road Geometry

Road Links	Coordinates (Easting, Northing)	Road Width(m)	Road Type	Median	MC (units)	LV (units)	HV (Units)
I	-8.733215,115.178745	14.50	4/2 D	Yes	10165 units (72.1%)	3556 units (25.2%)	376 units (2.7%)
II	-8.704213,115.248606	14.10	4/2 D	Yes	3426 units (61.4%)	1903 units (34.1%)	248 units (4.5%)
III	-8.785214,115.198730	14.10	4/2 D	Yes	4678 units (77.6%)	1278 units (21.2%)	74 units (1.2%)

Where:
HV = Heavy Vehicle; LV = Light Vehicle; MC = Motorcycle;
Road Links I: JL. Bypass Ngurah Rai towards Kuta; II: JL. Bypass Ngurah Rai towards Sanur; III: JL. Bypass Ngurah Rai towards Nusa Dua

RESULT AND DISCUSSIONS

Preliminary Data Analysis

Figures 1 to 4 show fluctuations in traffic volume and speed over the time of observation. The figure shows the fluctuations every hour with an interval of every five (5) minutes. The highest

volume and speed values on the graphs are set at 6,000 vehicles/hour and 60 km/hour respectively to facilitate the analysis of the initial data for traffic volume and speed in all observed road segments.Figure 1 shows the observed road segment in one direction at Jl. Bypass Ngurah Rai towards Kuta. The volume and speed of MCs are higher than the two other modes (LVs and HVs). The highest MC volume is at 3,990 vehicles/hour and the average MC speed is 23 km/hour. The speed of heavy vehicles on Jl. Bypass Ngurah Rai towards Nusa Dua is the highest (average 35 km/hour) than that on the other two road sections. The initial assumption was that a much higher volume of motorcycles on Jl. Bypass Ngurah Rai towards Kuta and Jl. Bypass Ngurah Rai towards Sanur could reduce the speed of heavy vehicles. For the road segments that do have a median, speed is not to be affected by traffic from the opposite direction. Traffic data are observed every 5 minutes to accommodate variations in flow and speed due to the heterogeneous nature of traffic. Table 2 shows that Jl. Bypass Ngurah Rai towards Kuta has the highest volume for all modes.

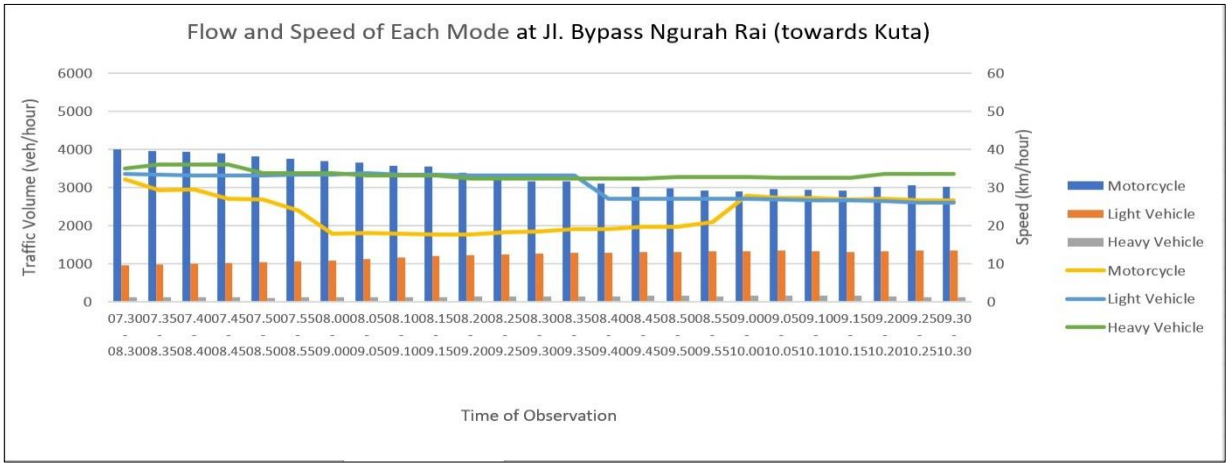
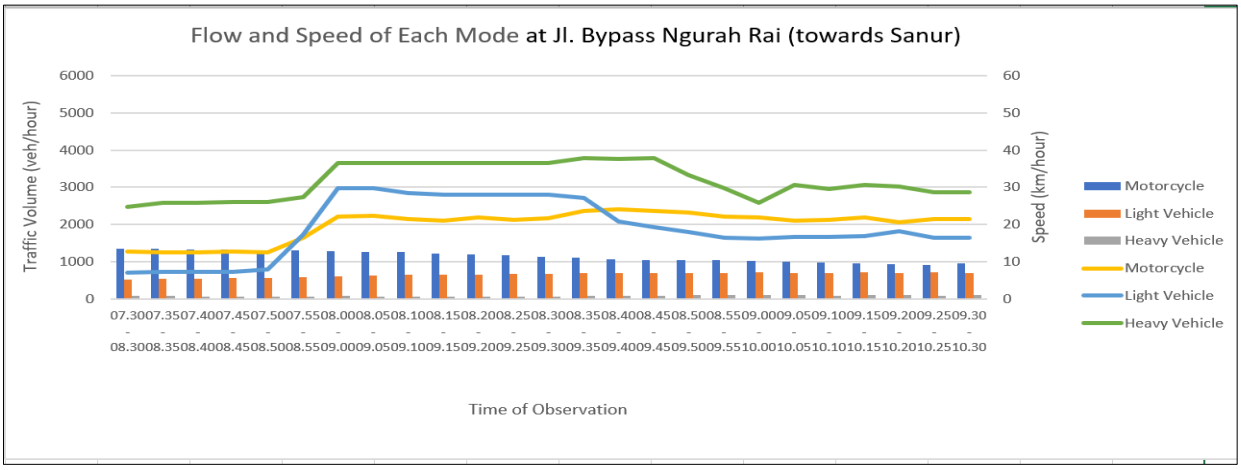


Figure 1. Volume and Speed on JL Bypass Ngurah Rai towards Kuta



.Figure 2. Volume and Speed on Bypass Ngurah Rai towards Sanur

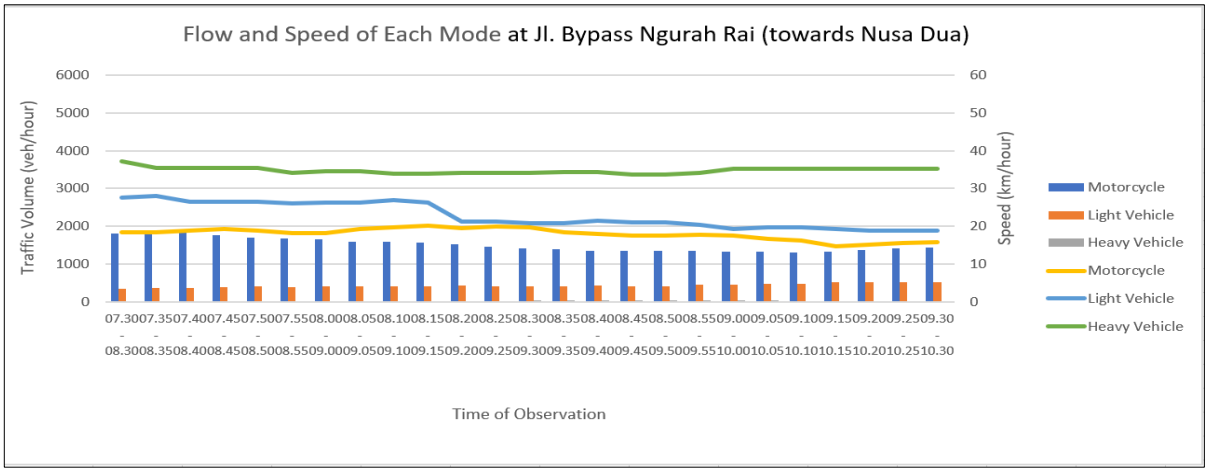


Figure 3. Volume and Speed on JL Bypass Ngurah Rai towards Nusa Dua

Table 2.
Max and Min Values of Volume and Speed

Road Links	Volume (Vehicles/hour)						Speed (km/hour)					
	MC		LV		HV		MC		LV		HV	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
I	3990	2899	1345	955	158	106	32	18	34	26	36	32
II	1355	922	718	527	104	65	24	13	30	16	38	25
III	1824	1318	518	343	36	16	20	15	28	19	37	34

Where:
MC = Motorcycle; LV = Light Vehicle; HV = Heavy Vehicle
Road Link I: JL. Bypass Ngurah Rai towards Kuta; Road Link II: JL. Bypass Ngurah Rai towards Sanur; Road Link III: JL. Bypass Ngurah Rai towards Nusa Dua

The purpose of this study is to analyze the impact of changes in the percentage of freight vehicles on the probability of road capacity reduction. The capacity is the limit where below the limit value the traffic volume is still operating and above the limit value, the traffic volume breaks down into stop-and-go traffic. Capacity in this sense is by no means a constant value. In several previous studies (Asgharzadeh and Kondyli., 2018; Laflamme and Ossenbruggen., 2018) empirical analysis of traffic flow patterns calculated at 5-minute intervals, clearly shows that the capacity of the Weibull distributed road segment with almost constant shape parameters, which represents the value of the variance.

Road Capacity Distribution

The mathematical type of road capacity distribution function is studied by referring to a past study (Brilon, et.al., 2005) as follows:

$$F(x) = 1 - (\exp. - ((\frac{x}{\beta}))^{\alpha}) \quad \text{for x} \gg 0 \qquad (2)$$

Where

α : shape parameter

β : scale parameter

For parameter estimation of the distribution function, the maximum likelihood method, the probability function, or the natural logarithm (log-likelihood) is maximized to calibrate the distribution function. Figure 6 - 9 shows the probability of the arterial road capacity if there is a change in the percentage of the number of HVs in the traffic flow. The probability is

determined based on the parameters of the Weibull distribution function. The summary of the decrease in probability is shown in Table 4. Based on the standard deviation of the traffic volume shown in the table, the traffic volume on Jl. Bypass IB Mantra, both eastbound and westbound, have a higher variation than that on Jl. Gilimanuk and Gatot Subroto. This can cause a large difference in the shape parameter of the Weibull distribution value on Jl. Bypass IB Mantra compared to that on Jl. Denpasar-Gilimanuk and Jl. Gatot Subroto

The shape parameters in the Weibull distribution range from 8 to 30. The Denpasar-Gilimanuk and Gatot Subroto roads are arterial roads without a median, i.e 2 lane-2 way undivided road, have almost the same shape parameter values, which are between 28-30. Meanwhile, the bypass Ngurah Rai is an arterial road of type 4-lane 2-way divided road. For roads with a median, the speed in each direction has no influence on that in the opposite direction. The shape parameter values are almost the same, 8 and 11 for the eastbound and westbound traffic respectively. This is probably because the traffic volume (including the volume of HVs) in eastbound traffic is much smaller than that of westbound traffic. For a 5-minute observation, the road capacity is in the range of 1.00-1.02 times the capacity for an hour. This is in line with a past study by Lu, et al (2020) that concluded HVs use more road space than LVs and MCs and have a greater effect on traffic flow. Similarly, a past study (Singh, et.al., 2020) found that the impedance caused by different HVs to other vehicles in mixed traffic flows affects the overall road capacity and LoS.

Table 3.
Weibull Distribution Parameters

Road Links	Shape Parameter α		Scale Parameter β (pcu/hour)		σ standard deviation (pcu/hour)	
	Existing Flows	Existing-Freight Flows	Existing Flows	Existing-Freight Flows	Existing Flows	Existing-Freight Flows
I	2008.825252	1648.607372	8.293366	9.559927	140	123
II	1039.594396	812.082617	15.981091	27.932893	82	65
III	662.072957	591.813116	24.074550	27.932893	47	45

Where:
Road Link I: JL. Bypass Ngurah Rai towards Kuta; Road Link II: JL. Bypass Ngurah Rai towards Sanur; Road Link III: JL. Bypass Ngurah Rai towards Nusa Dua

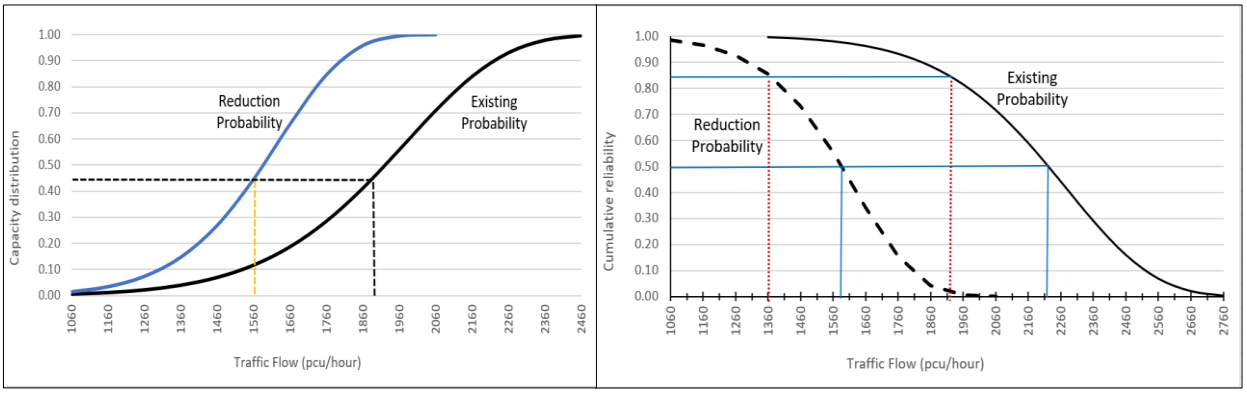


Figure 5. Weibull Distribution-Probability of Road Capacity on JL. Bypass Ngurah Rai towards Kuta

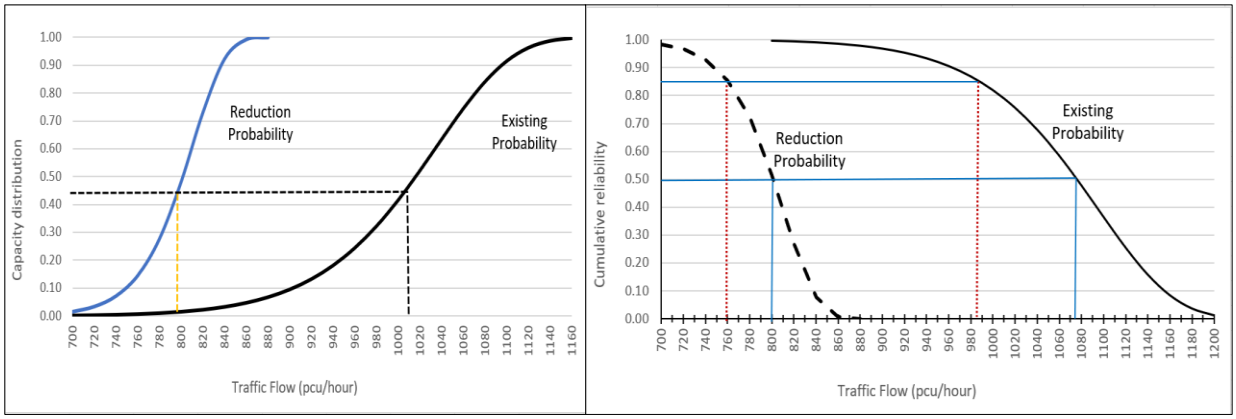


Figure 6. Weibull Distribution-Probability of Road Capacity on JL. Bypass Ngurah Rai towards Sanur

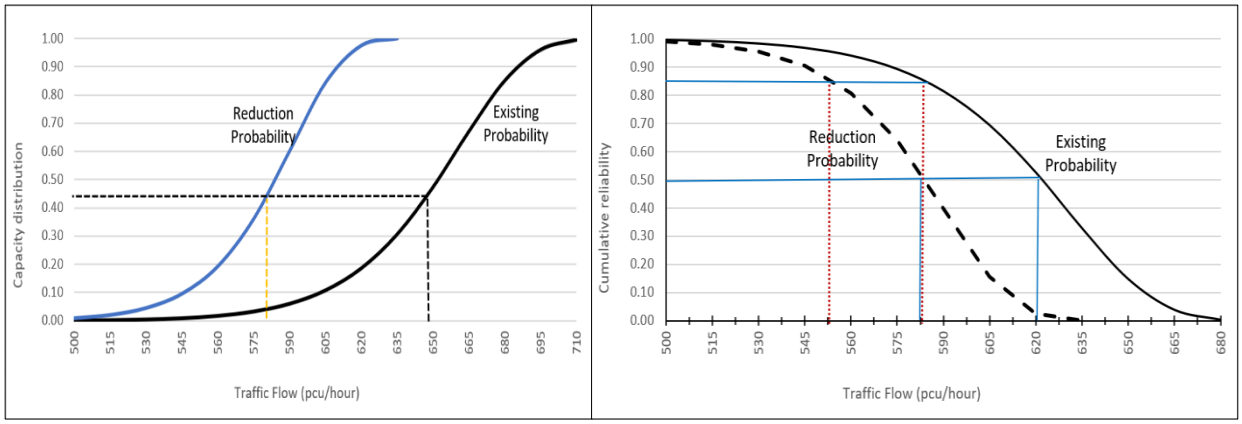


Figure 7. Weibull Distribution-Probability of Road Capacity on JL. Bypass Ngurah Rai towards Nusa Dua

The probabilities of the increasing road capacity due to the decrease in freight transport vehicles at the cumulative probability of 85% and 50% are shown in Table 5. The road capacity increases between 39% and 41% on Jl. Bypass Ngurah Rai towards Kuta at 85% and 50% cumulative reliabilities respectively. Meanwhile, the road capacity increases between 29% and 35% on Jl. Bypass Ngurah Rai towards Sanur and the road capacity increases between 5% and 7% on Jl. Bypass Ngurah Rai towards Nusa Dua. The increase in road capacity varies in terms of the reduction of freight transport vehicles on all observed road segments. This variation may be explained by the difference numbers of light and heavy vehicles on each observed road segment (refer to Table 1).

Table 5.
Road Capacity Increase Due to Decreasing Proportion of Freight Transport

Road Links	85% Cumulative Reliability	50% Cumulative Reliability (Median Value)
	Capacity Increase	Capacity Increase
I	40.44%	39.43%
II	29.61%	34.38%
III	5.43%	6.44%

Where:
HV = Heavy Vehicle

Road Link I: JL. Bypass Ngurah Rai towards Kuta; Road Link II: JL. Bypass Ngurah Rai towards Sanur; Road Link III: JL. Bypass Ngurah Rai towards Nusa Dua The smallest probability of increasing capacity is on Jl. Bypass Ngurah Rai towards Nusa Dua among the observed roads. This can be due to the smaller proportion of light and heavy vehicles in this segment compared to the other two road sections. In mixed traffic conditions, the estimation of road capacity poses different levels of difficulty with the flow and lane discipline (Mehar, et.al., 2014). Therefore, the influence of light and heavy vehicles used for freight transport on traffic flow characteristics requires greater attention because of its direct effect on road capacity (Al-Kaisy, et.al., 2005).

The influence of the speed of traffic flows has an indirect effect on determining the cumulative probability. This is because speed is only used when determining the PCE value. This is consistent with a previous study (Zhou et al., 2018) that summarized that high interaction rates between each mode with significant speed differences can cause traffic congestion. As a result, the average speed of freight vehicles may be reduced due to their operating characteristics. The analysis shows that the impact of light and heavy vehicles used to transport goods is imperative as it affects traffic speed, traffic volume, and ultimately road traffic capacity. This study only focuses on analyzing mixed traffic situations during rush hours. Therefore, further research is needed to take into account the full duration of mixed traffic flow conditions.

CONCLUSIONS

Despite their smaller percentage in the traffic stream, freight transport vehicles are considered to have significant impacts on road traffic capacity. A single road capacity value, however, does not reflect real mixed traffic conditions in developing countries, so the capacity should be considered an inherently stochastic random variable. To do this, the capacity must be determined and estimated as a probability distribution over a range of values. The cumulative distribution of the corresponding capacity values is referred to as the "capacity distribution function" and is considered a valuable tool in evaluating the performance and efficiency of arterial roads.This study found that the decrease of light and heavy vehicles used for freight transport between 3 times and 5 times respectively will increase the arterial road capacity by between 8 times and 6.5 times respectively. Despite traffic heterogeneity and smaller portions of vehicles, freight transport vehicles have direct and significant influences on arterial road capacity. In particular heavy vehicles, as their ratio increases, however, the speed difference between vehicle types decreases. The speed of heavy vehicles and other modes concluded to have an indirect effect on arterial road capacity. This study was used only for the peak hours of traffic flow conditions. A further study, therefore, needs to be conducted considering the overall period of traffic flow conditions so that capacity reduction due to freight transport vehicles can be captured comprehensively.

REFERENCES

A. Al-Kaisy, Y. Jung, H. Rakha. Developing passenger car equivalency factors for heavy vehicles during congestion, Journal of Transportation Engineering, Vol. 131, No. 7, 514–523, 2005.

A. Mehar, S. Chandra, S. Velmurugan. Highway capacity through Vissim calibrated for mixed traffic conditions, KSCE Journal of Civil Engineering, Vol. 18, No. 2, 639–645, 2014.

A. Munawar, M.Z. Irawan, A.G. Fitrada. Developing Indonesian Highway Capacity Manual Based on Microsimulation Model (A Case of Urban Roads), In: Proceeding Transactions on Engineering Technologies: 25th World Congress on Engineering, 153- 163, 2018.

C.G. Roh, H. Jeon, B. Son. Do heavy vehicles always have a negative effect on traffic flow? Applied Sciences, Vol. 11, 5520, 2021.

C.R. Patel, G.J. Joshi. Mixed traffic speed–flow behavior under influence of road side friction and non-motorized vehicles: a comparative study of arterial roads in India, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, Vol.8, No.11, 1203-1209, 2014.

Central Bureau of Statistics of Bali Province. Bali in Figures, Bali Provincial Government, Denpasar, 2021.

D.M.P. Wedagama, I.W. Suweda, N.L.G. Astariyani. The influence of side friction on speed-mixed flow behavior on arterial roads in tourism area in Bali, Civil Engineering and Architecture, Vol. 10, No. 1, 27-44, 2022.

Directorate General of Bina Marga. Indonesian Road Capacity Manual, Ministry of Public Works, Jakarta, 1997.

E.M. Laflamme, P.J. Ossenbruggen. Estimation of stochastic traffic capacity using extreme value theory and censoring: a case study in Salem, New Hampshire, Archives of TransportVol. 48, No. 4, 61-75, 2018.

J, Geistefeldt. Estimation of passenger car equivalents based on capacity variability, Transportation Research Record Journal of the Transportation Research Board, 2130, 1-6, 2009.

J. Zhou, L. Rilett, E. Jones, Y. Chen. Estimating passenger car equivalents on level freeway segments experiencing high truck percentages and differential average speeds, Transportation Research Record, Journal of the Transportation Research Board, Vol. 2672, No. 5, 44–54, 2018.

M. de Bok, B. Wesseling, J. Kiel, O. Miete, F. Jan. A sensitivity analysis of freight transport forecasts for the Netherlands, International Journal of Transport Economics, Vol. 45, No. 4, 567-584, 2018.

M.A. Asgharzadeh, A. Kondyli. 2018. Comparison of highway capacity estimation methods, Transportation Research Record Journal of the Transportation Research Board, Vol. 2672, No. 9, 1-10, 2018.

P. Kumar, S. Arkatkar. G. Joshi. New approach for estimating passenger car units on multilane urban roads with heterogeneous traffic conditions, Journal of Transportation Engineering, Part A: Systems, Vol.144, No.3, 1-14, 2018.

P. Lu, Z. Zheng, D. Tolliver, D. Pan. Measuring passenger car equivalents (PCE) for heavy vehicle on two lane highway segments operating under various traffic conditions, Journal of Advanced Transportation. Article ID 6972958, 1-9, 2020.

P.M. Shah, N. Gupta. Analysis of speed parameters of mixed traffic flow on the sections of arterial streets (Jalandhar and Chandigarh Cities), Indian Journal of Science and Technology, Vol.9, No. 47, 1-6, 2016.

S. Moridpour, E. Mazloumi, M. Mesbah. Impact of heavy vehicles on surrounding traffic characteristics, Journal of Advanced Transportation, Vol. 49, No. 4, 535-552, 2014.

S. Oh, H. Yeo. Impact of stop-and-go waves and lane changes on discharge rate in recovery flow, Transportation Research Part B: Methodological, Vol. 77, 88-102, 2015.

S. Salini, R. Ashalatha. Analysis of traffic characteristics of urban roads under the influence of roadside frictions, Case Studies on Transport Policy, Vol.8, Issue 1, 94-100, 2020.

S. Singh, R.K. Panda, D.K. Saw, M.S. Selvaraj. Effect of Heavy Transport Vehicles on Speed-Flow Characteristics of Mixed Traffic on Multi Lane Divided Intercity Highways, In : Conference : 13th Asia Pasific Transportation Development Conference, 176-185, 2020.

W. Brilon, J. Geistefeldt, M. Regler. Reliability of Freeway Traffic flow: A Stochastic Concept of Capacity, In: Proceedings of the 16th International Symposium on Transportation and Traffic Theory, 125-144, 2005.