Borneo Engineering: Jurnal Teknik Sipil
Vol. 10 No. 1. April 2026, pp. 83-94

ISSN 2685-7553
e-ISSN 2581-1134

Research Article

Estimation of Passenger Car Equivalent (PCE) Values in Heterogeneous Traffic Using The Time Headway Method on Timor Raya Road, Kupang City

Amy Wadu[1*], Mateus R. Sodanango[1], Ludofikus Dumin[1], and Angelita Laapen[1]

[1]Department of Civil Engineering, Politeknik Negeri Kupang, Kota Kupang, Indonesia

Corresponding author email: **amywadu@gmail.com**
DOI. 10.35334/be.v10i1.605

Article history:
Recieved:
Revised:
Accepted:

Keywords:
urban road;
Light Vehicleequivalent;
Light Vehicleunits;
capacity;
volume .

Abstract

Traffic on urban roads in Indonesia is generally heterogeneous, consisting of various types of vehicles with different characteristics. To analyze heterogeneous traffic flow, all vehicles are converted into Light Vehicleunits (PCU) and this concept forms the basis for the definition of Light Vehicleequivalent (PCE) in various guidelines. However, the standard PCE values from guidelines such as MKJI 1997 and PKJI 2023 can produce inaccurate traffic performance estimates because PCE values are not universal and are highly dependent on traffic conditions, road geometry, and driving culture in a particular region. This study aims to estimate PCE values using the time headway method on Jalan Raya Timor in Kupang, Indonesia, which has experienced rapid vehicle volume growth, especially motorcycles. The time headway method is considered more dynamic and sensitive in reflecting drivers' perceptions of vehicle spacing, thus providing more accurate PCE values than traditional methods. The results of the study show that the PCE value for motorcycles (MC) ranges from 0.64 to 0.98, while for heavy vehicles (HV) it ranges from 1.05 to 2.16. The vehicle headway time method proved to be more accurate in assessing the volume-capacity ratio (V/C) because it is more sensitive to the time interval between vehicles, resulting in a V/C estimate that is closer to field data compared to the standard PCE method from PKJI.

©The author(s). Published by BEJTS
This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA 4.0).

Introduction

Urban traffic in Indonesia is generally heterogeneous, consisting of a mix of various types of vehicles (private cars, motorcycles, public transportation, trucks, motorized rickshaws, etc.) with different characteristics (Yu et al., 2023) (Wadu, 2024). This situation makes it difficult to enforce lane discipline and poses challenges for traffic management (Azam et al., 2022) (Kotagi & Asaithambi, 2019). One solution for analyzing heterogeneous traffic flow is to convert all vehicles into Passenger Car Equivalent (PCE), thereby obtaining a standardized vehicle flow (passenger cars). This concept underlies the definition of Passenger Car Equivalent (PCE) in various guidelines. Standard PCE values

from guidelines such as the 1997 Indonesian Highway Capacity Manual (MKJI 1997), its updated version, the 2023 Indonesian Highway Capacity Guidelines (PKJI 2023), and the Highway Capacity Manual (HCM) have been used as references for traffic flow conversion. However, the PCE value is not universal, as it is highly dependent on traffic conditions, road geometry, and driving culture in each country or region (Sharma & Biswas, 2021). Conventional traffic management strategies were developed primarily for homogeneous, orderly traffic flows; in contrast, traffic modeling and control for vehicles with irregular lane behavior remain lagging. Consequently, the use of fixed PCE values from MKJI/PKJI/HCM under current conditions may yield inaccurate traffic performance estimates. A study conducted in Manado (Padang et al., 2024) indicates that PCE values from the 2014 PKJI no longer align with current traffic conditions. Similarly, a study in Aceh (Sugiarto et al., 2018) found significant differences between the old manual PCE values (MKJI 1997) and the new calibration results, as current traffic characteristics differ significantly from those when the old guidelines were developed. These findings highlight the urgency of updating the PCE values to align with current local conditions. In Kupang City (Wadu et al., 2024), an approach using PCE values calibrated based on occupancy rates and traffic composition was found to provide a more realistic estimate of the level of service (LOS C) compared to using the 1997 MKJI PCE, which indicates gridlock conditions (LOS F).

Kupang, the capital of East Nusa Tenggara Province, has experienced rapid growth in its economy, population, and number of motor vehicles—particularly motorcycles—which has increased by approximately 7–8% per year. However, this growth has not been matched by an increase in road capacity. On Timor Raya Road, the volume-to-capacity (V/C) ratio has reached 0.91, indicating that traffic is nearing maximum capacity (Sodanango et al., 2021). The accuracy of traffic planning parameters, such as the PCE value, is also a key focus in evaluating road performance in Kupang. Recent research at the Tirosa Roundabout in Kupang City has shown significant differences in analysis results when using the 1997 MKJI PCE compared to alternative PCE calculation methods tailored to local traffic characteristics (Wadu et al., 2024). revealed that the 2023 PKJI standard value for motorcycles (0.15) is only suitable for initial conditions and does not represent conditions at saturation. During the saturation phase, the actual PCE is only 0.08, indicating that the standard PKJI value is too high for heavy traffic conditions. This finding confirms that applying the MKJI 1997 PCE value directly can yield inaccurate performance estimates for traffic conditions with a highly diverse vehicle mix.

Various methods have been developed to determine the PCE value, including the time headway method, which captures drivers' perceptions of the distance between vehicles. Studies using the time headway method at various locations have yielded results that differ from standard guideline values. In a study (Irwandi et al., 2025), field time headway measurements and statistical modeling during peak hours on urban road segments indicated a PCE value of 0.413 for motorcycles and 1.416 for Heavy Vehicles. A study by (Ghanim & Abu-Lebdeh, 2022) also used empirical data and microscopic simulations to analyze the relationship between time headway and traffic density across different levels of vehicle composition. This approach yielded equivalence factors that varied with congestion level, with distance-based PCE being more sensitive to changes in the proportion of heavy vehicles than the traditional method. A literature review by (Sharma & Biswas, 2021) highlights that the PCE value is not static but depends on traffic volume and composition. Vehicle-to-vehicle distance-based methods are considered superior at reflecting drivers' perceptions of vehicle-to-vehicle distance, but they are rarely directly compared with speed- or density-based methods in the context of cross-cultural urban driving.

The advantage of the time headway method lies in its sensitivity to variations in traffic conditions and its ability to provide dynamic PCE values. This method can capture changes in driver behavior in response to different congestion levels, where the time headway between vehicles varies with congestion level and vehicle composition. Research shows that time-headway-based PCE is more sensitive to changes in the proportion of heavy vehicles than other methods, resulting in an equivalence factor that varies with congestion level (Khayam & Widyastuti, 2021).

In the context of microscopic simulations and heterogeneous traffic modeling, the time-headway method also offers advantages because it can be integrated with vehicle-following models and lane-changing behavior that underlie vehicle behavior in mixed traffic. The method's ability to accommodate

dynamic traffic characteristics makes it a suitable approach for heterogeneous traffic conditions in Indonesia, and the lack of discipline in lane usage (Sugiarto et al., 2024).

From previous studies on determining PCE using the time headway method, it can be concluded that this approach consistently provides estimates that are more dynamic and sensitive to traffic composition and operational conditions than traditional methods based on speed or density. The time headway method can capture changes in drivers' perception of the distance between vehicles, thereby adjusting the equivalence factor based on congestion level and the proportion of Heavy Vehicles, making it a more accurate alternative for analyzing heterogeneous traffic in Indonesia.

Methodology

Data Collection Methods

Observations were conducted on Mondays, Wednesdays, and Fridays (morning and afternoon) because these days represent the characteristic fluctuations in traffic at the beginning of the week, midweek, and toward the end of the workweek. The manual extraction of time headway data was performed through frame-by-frame analysis using video playback software (at 30 fps), allowing the reference point when the front bumper of a vehicle crossed the imaginary observation line to be recorded with high precision down to fractions of a second

Traffic Flow Monitoring Using UAVs

The recording was conducted by keeping the drone stable (in hover mode) at a single point for 15–30 minutes to capture variations in traffic flow. The drone was flown at an altitude of approximately 50–100 meters to cover a wide area while still capturing precise vehicle details, and the camera was set to 4K at 30 fps to ensure accurate data. A 50-meter-long road segment on Jalan Timor Raya was selected for traffic data collection via video recording. The selected road segment features two two-way lanes with a commercial environment, as shown in Figure 1. During video recording, the drone remained stationary in the center of the road segment to ensure recording of traffic flow from a downward vertical perspective

Extraction of Traffic Time Intervals

Data extraction was performed manually by reviewing video recordings, demonstrating high accuracy in vehicle counting (İlyas et al., 2024). The data will be categorized by vehicle type: motorcycles (MC), Light Vehicles (LV), and heavy vehicles (HV). For time headway data, various combinations of vehicle convoys were also observed manually, such as LV-LV (light vehicle followed by light vehicle), HV-LV (heavy vehicle followed by light vehicle), and so on, including MC-MC, MC-LV, LV-MC, HV-HV, and LV-HV as shown in Figure 2.

Calculation of the Passenger Car Equivalent (PCE)

The HV PCE value is calculated by dividing the average HV time headway by HV by the average LV time headway by LV. The result will be accurate if the HV time headway is independent of the vehicle in front or behind (Alenzi et al., 2022). This condition is met if the average time headway of LV, followed by LV, plus the average time headway of HV, followed by HV, is equal to the average time headway of LV, followed by HV, plus the average time headway of HV, followed by LV. The above can be expressed in (1):

$$ta + td = tb + tc \tag{1}$$

where ta is the average time headway between a Light Vehicle(LV) and the Light Vehicle(LV) following it, tb is the average time headway between heavy vehicle (HV) followed by heavy vehicle (HV), tc is the average time headway between light vehicle (LV) followed by heavy vehicle (HV), and td is the average time headway between heavy vehicle (HV) followed by light vehicle (LV).

The conditions required to satisfy the above equation are difficult to meet because every vehicle has different characteristics. Similarly, drivers have varying driving abilities. Therefore, adjustments to the average time-distance value are necessary using (2):

$$\left[ta-\frac{k}{na}\right]+\left[td-\frac{k}{nd}\right]=\left[tb+\frac{k}{nb}\right]+\left[tc+\frac{k}{nc}\right] \quad (2)$$

$$k=\frac{na.nb.nc.nd.(ta+td-tb-tc)}{nd.nb.nc+na/nb.nc+na.nd.nc+na.nd.nb} \quad (3)$$

Where na is the number of LV time headway data points followed by LV, nb is the number of HV time headway data points followed by HV, nc is the number of LV time headway data points followed by H, and nd is the number of HV time headway data points followed by LV.

Next, the average time headway of the vehicle pairs is corrected using (4), (5), (6), (7), and (8):

$$ta_k=ta-\frac{k}{na} \quad (4)$$

$$tb_k=tb-\frac{k}{nb} \quad (5)$$

$$tc_k=tc-\frac{k}{nc} \quad (6)$$

$$td_k=td-\frac{k}{nd} \quad (7)$$

Using the corrected average time headway value, it can be concluded from (8)

$$ta_k+td_k=tb_k+tc_k \quad (8)$$

where ta_k is the corrected average time difference between LV and LV, tb_k is the corrected average time difference between HV and HV, tc_k is the corrected average time difference between LV and HV, and td_k is the corrected average time difference between HV and LV.

If these conditions are met, the PCE HV value can be calculated using (9)

$$PCE_{HV}=\frac{td_k}{ta_k} \quad (9)$$

Meanwhile, the formula for calculating the PCE MC is the same as the formula for the PCE HV, but the HV variable is replaced with the MC variable. This equation also uses (1), where ta is the average time headway of an LV followed by an LV, te is the average time headway of an MC followed by an MC, tf is the average time headway of an LV followed by an MC, and tg is the average time headway of an MC followed by an LV.

The correction value for the average time headway is calculated using (2), and the correction factor k is calculated using equation (3), where na is the number of LV time headway data points followed by an LV, ne is the number of MC time headway data points followed by an MC, nf is the number of LV time headway data points followed by an MC, and ng is the number of MC time headway data points followed by an LV.

Next, the average time headway of vehicle pairs for MC is corrected using (10) through (14)

$$ta_k=ta-\frac{k}{na} \quad (10)$$

$$te_k = te - \frac{k}{ne} \tag{11}$$

$$tf_k = tf - \frac{k}{nf} \tag{12}$$

$$tg_k = tg - \frac{k}{ng} \tag{13}$$

Using the corrected average time headway value, the calculation must satisfy the mathematical equilibrium condition as shown in (14):

$$ta_k + te_k = tf_k + tg_k \tag{14}$$

Where ta_k is the average time interval corrected for LV-LV, te_k is the average time interval corrected for MC-MC, tf_k is the average time interval corrected for LV-MC, and tg_k is the average time interval corrected for MC-LV. Once the conditions of equation (14) are met, the PCE MC value can be calculated by dividing tek by ta_k.

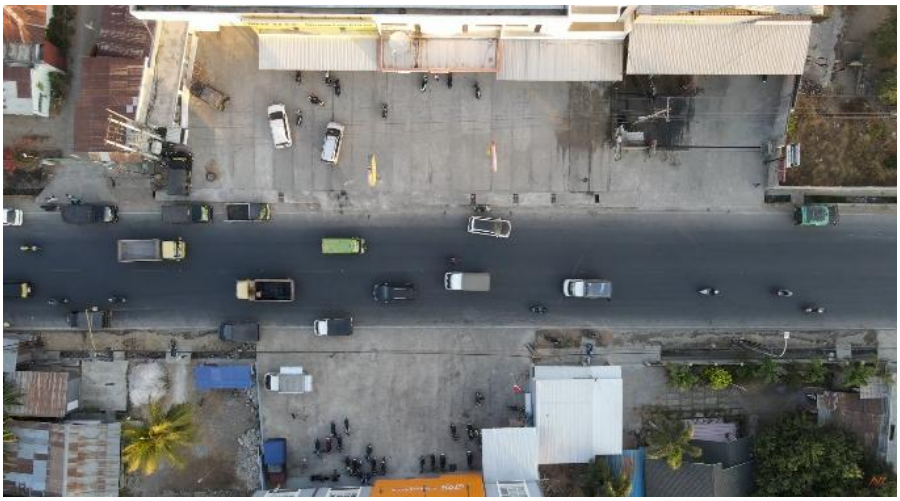


Figure 1. A frame captured from a video recorded by an unmanned aerial vehicle (UAV)

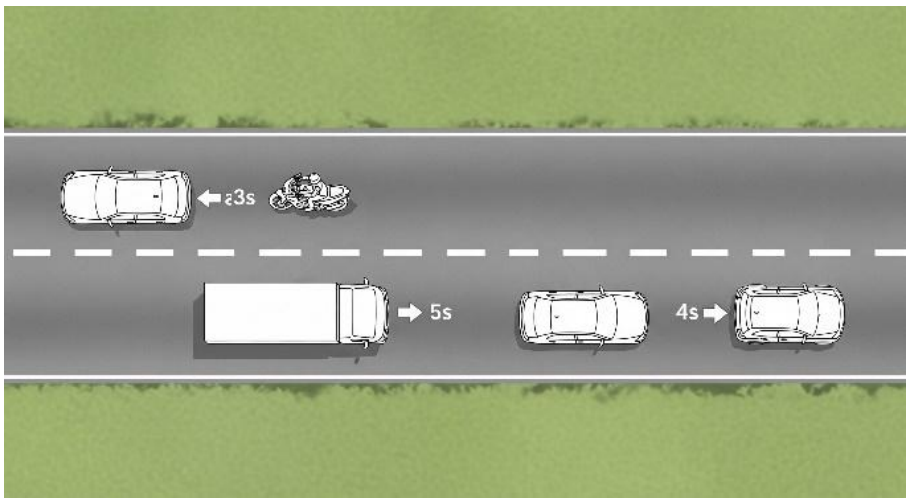


Figure 2. Illustration of Time Headway Measurement

Results and Discussion

The MC-MC combination (motorcycle with motorcycle) was recorded as the most common, with 854 instances on Friday morning. This suggests that interactions between motorcycles occur more frequently, or that more motorcycles were involved in the observations during that time. On the other hand, the LV-HV (Light Vehicle with Heavy Vehicle) and HV-LV (Heavy Vehicle with light vehicle, also referred to as a passenger car) combinations had relatively few samples, with fewer than 50 observations eac. This suggests that interactions between light and heavy vehicles occur less frequently than those between other vehicle types, or that the number of heavy vehicles involved in traffic during the overall observation period was simply lower. Table 1 provides an overview of the distribution of interactions between vehicles, which varies by vehicle type and observation time. More common combinations, such as MC-MC, show higher frequencies, while combinations such as LV-HV show less frequent interactions.

Table 1. Sample Size and Time Interval

Day, Direction	Number of Vehicle Samples						
	LV-LV	MC-MC	LV-MC	MC-LV	HV-HV	LV-HV	HV-LV
Monday Morning, Direction 1	113	633	97	66	17	8	20
Monday Morning, Direction 2	110	505	84	40	12	5	6
Monday Afternoon, Direction 1	168	844	197	130	23	33	39
Monday Afternoon, Direction 2	201	769	196	127	22	43	41
Wednesday Morning, Direction 1	134	823	168	109	23	18	12
Wednesday Morning, Direction 2	107	663	135	83	21	12	9
Wednesday Afternoon, Direction 1	147	497	148	100	24	15	16
Wednesday Afternoon, Direction 2	112	510	100	92	19	22	22
Friday Morning, Direction 1	202	854	178	110	12	13	16
Friday Morning, Direction 2	123	798	195	174	6	12	24
Friday Afternoon, Direction 1	182	801	167	95	30	28	31
Friday Afternoon, Direction 2	158	663	197	140	33	22	22

Table 2. General Characteristics

Headway	Mean (seconds)	Standard Deviation	Coefficient of Variation (%)
LV-LV	0.61	0.031	5.20%
MC-MC	0.71	0.075	10.60%
LV-MC	0.79	0.093	11.80%
MC-LV	0.86	0.073	8.40%
HV-HV	1.23	0.204	16.60%
LV-HV	1.21	0.344	28.40%
HV-LV	1.36	0.338	25.00%

This indicates a light vehicle's ability to maintain a stable, constant distance in traffic. On the other hand, motorcycles (MC-MC) also exhibit a relatively low time interval of 0.71 seconds, demonstrating their ability to maneuver in narrow gaps. Meanwhile, heavy vehicles (HV) exhibit the highest variability in interactions with other vehicles. The LV-HV combination had the highest coefficient of variation at 28.40%, followed by HV-LV at 25.00%. This variation indicates high uncertainty in the response time intervals between large and light vehicles, likely due to differences in vehicle dynamic characteristics, such as acceleration, braking, and the limited maneuverability of Heavy Vehicles. As noted in the study by (Durrani et al., 2016), differences in dynamic characteristics between medium-sized and light vehicles—such as limited acceleration and braking capabilities—can lead to

significant variability in reaction times between vehicles. These factors are exacerbated by heterogeneous traffic conditions, where the presence of heavy vehicles can create moving congestion and affect the overall stability of traffic flow (Wang et al., 2024).

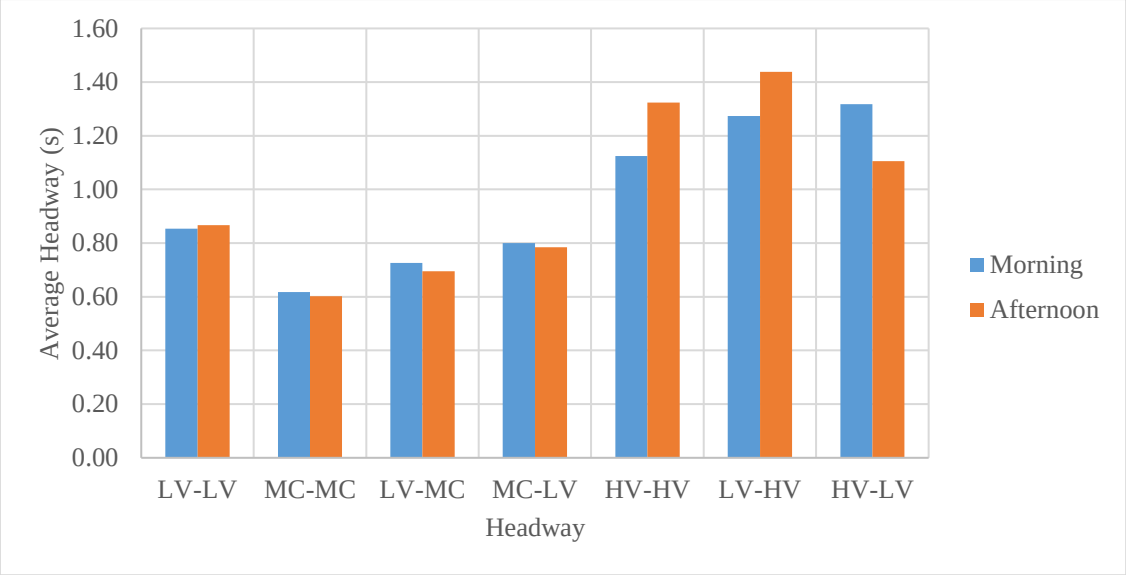


Figure 3. Average time headway by vehicle type during the morning and afternoon periods

Figure 3 shows that in the afternoon, heavy vehicles tend to have longer inter-vehicle distances, particularly for HV-HV, which increased by 0.200 seconds from morning to afternoon, thereby reducing lane capacity and slowing down Heavy Vehicle traffic. These wider HV-HV intervals easily trigger long queues at congestion points and cause backward-propagating speed fluctuations (Beigi et al., 2025). Conversely, motorcycle interactions show slightly shorter travel times in the afternoon. Motorcycles take advantage of narrow gaps with closer spacing; these conditions increase density in the motorcycle lane, reduce reaction space, and increase the risk of sudden braking or rear-end collisions (Yuen et al., 2011).

Table 3. PCE Values Based on Time Headway and PKJI 2023

Day, Direction	Time Headway		PKJI 2023	
	MC	HV	MC	HV
Monday Morning, Direction 1	0.77	1.31	0.25	1.2
Monday Morning, Direction 2	0.81	1.05	0.25	1.2
Monday Afternoon, Direction 1	0.88	1.28	0.25	1.2
Monday Afternoon, Direction 2	0.69	1.19	0.25	1.2
Wednesday Morning, Direction 1	0.95	2.08	0.25	1.2
Wednesday Morning, Direction 2	0.88	2.16	0.25	1.2
Wednesday Afternoon, Direction 1	0.98	1.30	0.25	1.2
Wednesday Afternoon, Direction 2	0.91	1.62	0.25	1.2
Friday Morning, Direction 1	0.91	1.93	0.25	1.2
Friday Morning, Direction 2	0.93	1.18	0.25	1.2
Friday Afternoon, Direction 1	0.64	1.68	0.25	1.2
Friday Afternoon, Direction 2	0.94	1.85	0.25	1.2

Based on Table 3, there is a very clear difference in characteristics between the Passenger car equivalent (PCE) values from the Time Headway method and those from the 2023 PKJI standard. This comparison is key to understanding the differences in road performance estimation results (V/C ratio) in Figure 6. The PKJI 2023 method uses static, constant values at all observation times: 0.25 for

Motorcycles (MC) and 1.2 for Heavy Vehicles (HV). In contrast, the Time Headway method produces dynamically fluctuating values because it directly responds to actual vehicle intervals in the field.

Meanwhile, for Heavy vehicles (HV), the PCE-based time headway fluctuates significantly between 1.05 and 2.16. Although under heavy traffic conditions, the value may fall below the PKJI standard (such as 1.05 on Monday Morning Direction 2 because vehicles are forced to close the gap), at certain times, the value can spike drastically to 2.16 (Wednesday Morning Direction 2). This demonstrates that heavy vehicles often force surrounding vehicles to maintain an extra-long safe distance, thereby occupying more than twice the space of a standard car.

Meanwhile, for Heavy vehicles (HV), the PCE-based time headway fluctuates significantly between 1.05 and 2.16. Although under heavy traffic conditions, the value may fall below the PKJI standard (such as 1.05 on Monday Morning Direction 2 because vehicles are forced to close the gap), at certain times, the value can spike drastically to 2.16 (Wednesday Morning Direction 2). This demonstrates that heavy vehicles often force surrounding vehicles to maintain an extra-long safe distance, thereby occupying more than twice the space of a standard car.

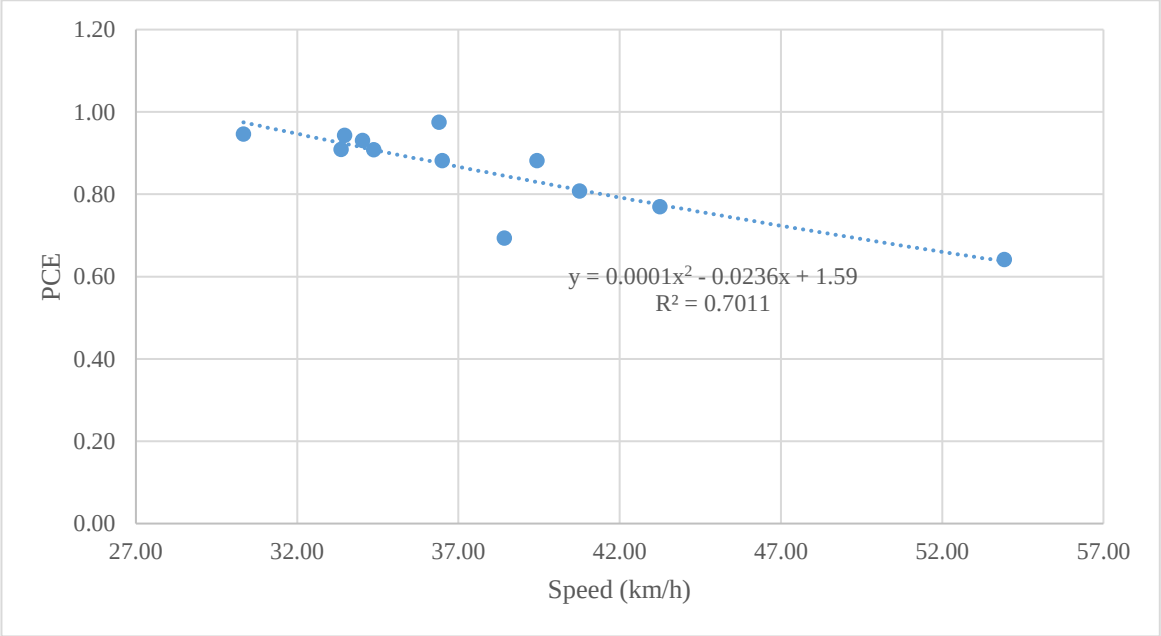


Figure 4. Relationship Between PCE and MC Speed

In Figure 4, the model shows a negative relationship between motorcycle speed and the Passenger car equivalent (PCE), meaning that higher motorcycle speed is associated with lower PCE. This indicates that motorcycles traveling at higher speeds require less road space than when traveling at low speeds. In other words, the efficiency of motorcycle road-space utilization increases with speed, so that at high speeds, motorcycles are more optimal in utilizing road space. Thus, increasing motorcycle speed not only enhances operational speed but also improves road space efficiency as measured by PCE. This aligns with research by (Syaiful & Akbar, 2020) which suggests that higher motorcycle speeds are associated with reduced road space requirements. Consequently, higher speeds not only improve operational efficiency but also optimize the utilization of road space. Therefore, studies (Putra, 2011) (Do et al., 2010) (Sugiarto et al., 2021) also suggest that the PCE value for motorcycles is not static and is influenced by dynamic traffic factors such as speed, depending on the time of the study.

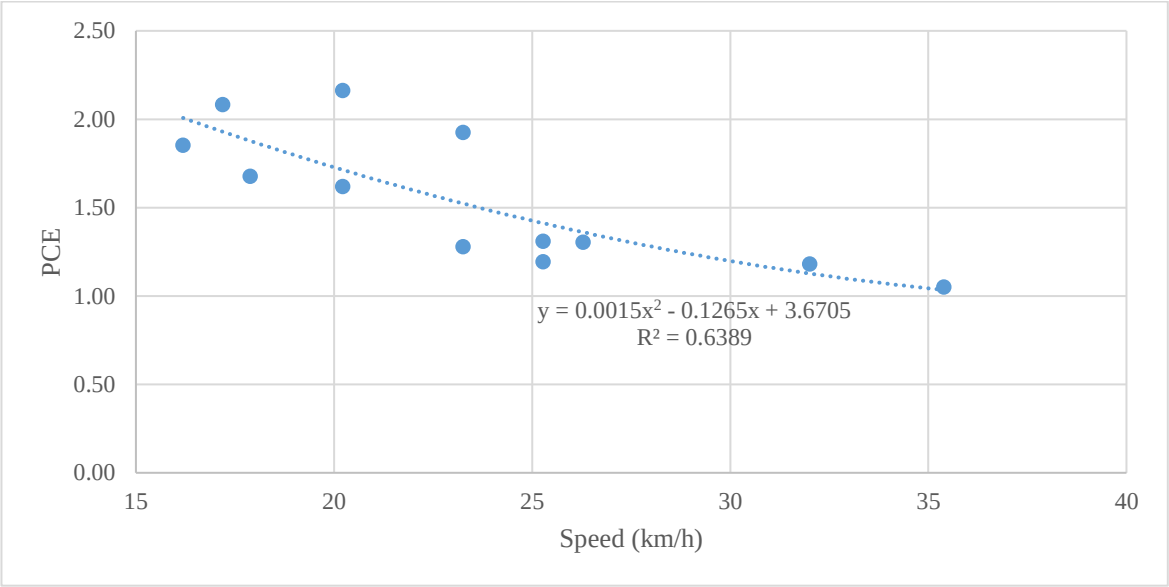


Figure 5. Relationship Between PCE and LV Speed

In Figure 5, the model shows a negative relationship between the PCE of heavy vehicles (HV) and HV speed. This means that the lower a heavy vehicle's speed, the higher its PCE, because it requires more road space at low speeds. Research (Roh et al., 2021) (Lu et al., 2020) (Singh & Santhakumar, 2022) also confirms that heavy vehicles require more road space at low speeds, so that a single Heavy Vehicle is equivalent to more passenger vehicles in terms of its impact on traffic capacity and density. The differences in PCE values generated by these two methods result in differences in road performance assessment results, as shown in Figure 6.

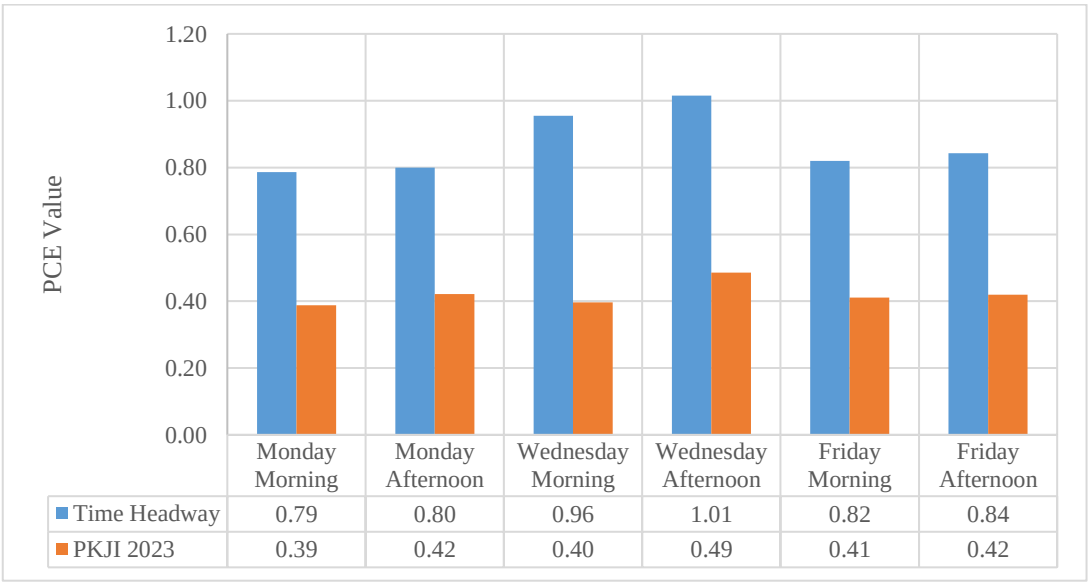


Figure 6. Comparison of v/c based on PCE from PKJI and the Time Headway Method

As shown in Figure 6, there is a striking difference: the V/C ratios derived from the Time Headway method are consistently much higher (ranging from 0.79 to 1.01) compared to those based on the 2023 PKJI standards (ranging from 0.39 to 0.49). The high V/C ratio in the Time Headway method is due to the much larger motorcycle PCE conversion value (0.64–0.98) compared to the PKJI static value (0.25). Since the motorcycle population heavily dominates traffic volume on Jalan Timor Raya, these high empirical PCE values significantly boost the total vehicle volume equivalence (veh/hr).

These results indicate that using the constant PKJI 2023 standard tends to underestimate actual traffic volume. The PKJI standard creates the illusion that the road is still relatively empty (V/C below

0.5), whereas in reality, the dense, maneuvering, and overtaking movement of motorcycles has consumed a significant portion of the road's capacity. Conversely, the Time Headway method successfully captures this reality dynamically, showing that at certain times (such as Wednesday Afternoon with a V/C of 1.01), the road has in fact reached saturation. This phenomenon suggests that conventional standards, such as PKJI, may not fully reflect the actual traffic dynamics on roads dominated by motorcycles, which require an empirical approach for determining a more adaptive PCE (Khayam & Widyastuti, 2021)

Conclusion

This study critically demonstrates that the Passenger car equivalent (PCE) value is not a universal constant and varies significantly, ranging from 0.64 to 0.98 for motorcycles and 1.05 to 2.16 for Heavy Vehicles, as it is influenced by mixed traffic conditions, road geometry, and driver behavior. This variability confirms that using standard PCE values from national guidelines (such as MKJI 1997 or PKJI 2023) tends to yield inaccurate estimates of road performance. Furthermore, this study identifies a dynamic relationship between speed and PCE: PCE decreases as speed increases for motorcycles and increases as speed decreases for Heavy Vehicles. Therefore, the time headway method is recommended as a more adaptive analytical approach for heterogeneous traffic in Indonesia.

Aknowledgments

We would like to thank the Kupang State Polytechnic for its full support of this research, both in the form of funding and moral support. This support has served as a source of motivation and a crucial foundation for the successful completion of this research. Special thanks go to the Department of Civil Engineering for the facilities and cooperation provided throughout the research process.

Conflict of Interest

The authors declare no conflict of interest. The funding sponsor (DIPA Politeknik Negeri Kupang) had no role in the design of the study, in the collection, analysis, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

References

A'yuni, Q., Sugiarto, S., Saleh, S. M., & Darma, Y. (2024). A preliminary analysis for determining passenger car equivalent value for motorcycle during first lost time and saturation time at pretimed signalized intersections. *E3S Web of Conferences*, *476*. https://doi.org/10.1051/e3sconf/202447601044

Azam, M. S., Bhaskar, A., & Haque, M. M. (2022). Driving behaviour modelling in the context of heterogeneous traffic and poor lane discipline conditions: the state of the art and beyond. *Transportmetrica A: Transport Science*, *18*(3). https://doi.org/10.1080/23249935.2020.1870581

Beigi, P., Hamdar, S., Talebpour, A., & Mahmassani, H. (2025). Impact of Heavy Vehicles on Headway Distributions: Study Using Naturalistic Urban Expressway Trajectories. *Transportation Research Record*, *2679*(7), 222–235. https://doi.org/10.1177/03611981251324198

Do, N. H., Le, Q. L. N., & Nam, K. C. (2010). An estimation of passenger car equivalent of motorbikes. *Proceedings - 24th European Conference on Modelling and Simulation, ECMS 2010*. https://doi.org/10.7148/2010-0098-0103

Durrani, U., Lee, C., & Maoh, H. (2016). Calibrating the Wiedemann's vehicle-following model using mixed vehicle-pair interactions. *Transportation Research Part C: Emerging Technologies*, *67*. https://doi.org/10.1016/j.trc.2016.02.012

Ghanim, M. S., & Abu-Lebdeh, G. (2022). Characterization of heavy vehicle headways in oversaturated interrupted conditions: Towards development of passenger car equivalency factors. *International Journal of Transportation Science and Technology*, *11*(3). https://doi.org/10.1016/j.ijtst.2021.07.002

Irwandi, Sutandi, A. C., & Mukti, E. T. (2025). The Value of Passenger Car Equivalent using the Time Headway Method on Urban Roads. *Civil Engineering Dimension*, *27*(1), 33–46. https://doi.org/10.9744/ced.27.1.33-46

Khayam, S., & Widyastuti, H. (2021). Studi Penentuan Nilai Ekivalensi Mobil Penumpang (EMP) Pada Sepeda Motor Untuk Ruas Jalan 4/2D di Sidoarjo. *Jurnal Aplikasi Teknik Sipil*, *19*(3). https://doi.org/10.12962/j2579-891x.v19i3.9241

Kotagi, P. B., & Asaithambi, G. (2019). Microsimulation approach for evaluation of reversible lane operation on urban undivided roads in mixed traffic. *Transportmetrica A: Transport Science*, *15*(2). https://doi.org/10.1080/23249935.2019.1632387

Lu, P., Zheng, Z., Tolliver, D., & Pan, D. (2020). Measuring Passenger Car Equivalents (PCE) for Heavy Vehicle on Two Lane Highway Segments Operating under Various Traffic Conditions. *Journal of Advanced Transportation*, *2020*. https://doi.org/10.1155/2020/6972958

Putra, S. (2011). The correction value of passenger-car equivalents for motorcycle and its impact to road performance in developing countries. *Procedia - Social and Behavioral Sciences*, *16*. https://doi.org/10.1016/j.sbspro.2011.04.461

Roh, C. G., Jeon, H., & Son, B. (2021). Do heavy vehicles always have a negative effect on traffic flow? *Applied Sciences (Switzerland)*, *11*(12). https://doi.org/10.3390/app11125520

Sharma, M., & Biswas, S. (2021). Estimation of Passenger Car Unit on urban roads: A literature review. In *International Journal of Transportation Science and Technology* (Vol. 10, Number 3). https://doi.org/10.1016/j.ijtst.2020.07.002

Singh, S., & Santhakumar, S. M. (2022). Assessing the impacts of heavy vehicles on traffic characteristics of highways under mixed traffic platooning conditions. *European Transport - Trasporti Europei*, (86). https://doi.org/10.48295/ET.2022.86.3

Sodanango, M. R., Wadu, A., Lada, Y. A. A., & Rafael, J. W. M. (2021). Effect of Oesapa Commercial Activities Towards Traffic Performance on Timor Raya Street Kupang. *International Conference on Innovation in Science and Technology (ICIST 2020)*, *208*(Icist 2020).

Sugiarto, S., Apriandy, F., Darma, Y., Saleh, S. M., Rusdi, M., & Miwa, T. (2021). Determining passenger car equivalent (PCEs) for pretimed signalized intersections with severe motorcycle composition using Bayesian linear regression. *PLoS ONE*, *16*(9 September). https://doi.org/10.1371/journal.pone.0256620

Sugiarto, S., Apriandy, F., Faisal, R., & Saleh, S. M. (2018). Measuring Passenger Car Unit (PCU) at Four Legged Roundabout using Time Occupancy Data Collected from Drone. *Aceh International Journal of Science and Technology*, *7*(2). https://doi.org/10.13170/aijst.7.2.8587

Sugiarto, S., Saleh, S. M., Darma, Y., Rusdi, M., A'yuni, Q., Fazila, T. S., & Rahma, R. (2024). Base saturation flow rate (BSFR) and its effect on performance of pretimed signalized intersection with non-lane based urban heterogeneous traffic. *PLoS ONE*, *19*(7 July). https://doi.org/10.1371/journal.pone.0306112

Syaiful, S., & Akbar, L. (2020). ANALISIS PENGARUH KECEPATAN LALU LINTAS TERHADAP KEBISINGAN YANG DITIMBULKAN KENDARAAN BERMOTOR. *Astonjadro*, *4*(1). https://doi.org/10.32832/astonjadro.v4i1.818

Wadu, A. (2024). Penanganan Kemacetan Lalu Lintas Yang Ditimbulkan Akibat Pergerakan Putar Balik (U-Turn) Pada Jalan Perkotaan. *Borneo Engineering : Jurnal Teknik Sipil*, *8*(2). https://doi.org/10.35334/be.v8i2.5290

Wadu, A., Sodanango, M., Nenobais, O., Dumin, L., Teknik Sipil, J., & Negeri Kupang, P. (2024). Evaluasi Nilai Ekivalen Mobil Penumpang (EMP) Berdasarkan Okupansi dan Komposisi Kendaraan pada Bundaran Tirosa Kota Kupang. *Jurnal Aplikasi Teknik Sipil*, *22*(1), 17–22.

Wang, S., Dong, C., Shao, C., Luo, S., Zhang, J., & Meng, M. (2024). Traffic state estimation incorporating heterogeneous vehicle composition: A high-dimensional fuzzy model. *Frontiers of Engineering Management*, (2020), 1–19. https://doi.org/10.1007/s42524-024-3148-1

Yu, W., Hua, X., & Wang, W. (2023). Stability and capacity for heterogeneous traffic flow mixed with vehicles in multiple controls. *Transportmetrica B*, *11*(1). https://doi.org/10.1080/21680566.2022.2113476

Yuen, C. W., Tan, A. Y., Karim, M. R., & Abdullah, A. S. (2011). Time headway study on exclusive motorcycle lane. *Proceedings of the Eastern Asia Society for Transportation Studies Vol. 8 (The 9th International Conference of Eastern Asia Society for Transportation Studies, 2011)*, *8*(1995), 398.