# Measuring Passenger Car Unit at Four-Legged Roundabout using Time Occupancy Data Collected from Drone

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**Abstract** – This study aims to measure the values of passenger car unit (PCU) at a four-legged roundabout based on the time occupancy data in complex traffic operation. Within mixed traffic, the PCUs are needed as a equivalency factor to convert various type of vehicles to a standard unit. The unit of PCU was used to determine capacity and level of service of specific the traffic condition. The composition of vehicles going through the intersection, mostly varies and each type of vehicles tends to have diverse effects on capacity and level of services. Consequently, a conversion factor from various vehicles to a standard vehicle is required. The data of this study was collected using a drone at the investigated roundabout at one of the major roundabouts in Aceh Besar, Aceh province, Indonesia. The method used was the vehicle's time occupancy, in which calculated from the average time required by each vehicle to pass through the roundabout area. The results show that the PCU values obtained is 0.16 for motorcycle, 0.59 for rickshaw, 1.07 for pickup, 1.91 for a medium vehicle, and 3.76 for the heavy vehicle. These results should be utilized for converting various type of vehicles into PCUs to estimate capacity and level of services, especially at the roundabout trafict. This results may be suitable to revise the Indonesian Traffic Code, named Indonesian Highway Capacity Manual 1997, and useful for ongoing national-level efforts to upgrade the Indonesian Highway Capacity Manual

***Keywords:*** Intersection, roundabout, time occupancy, drone, passanger car unit

## Introduction

Car ownership and its usage have been growing rapidly in the last decade in Indonesia. Consequently, most of urban areas in Indonesia are suffering from transport-related problems such as excessive travel times, increasing vehicle operating cost, air pollution, unnecessary energy consumption, and even severe economic (Sugiarto *et al.*, 2017a). This induced traffic congestion problem in several cities in Indonesia has been investigated by several researchers such as Sugiarto *et al.* (2016; 2017b) in Jakarta and Sofyan *et al.* (2017) and Anggraini *et al.*, (2017) for Banda Aceh. Additionally, studies by Sugiarto *et al.*, (2012; 2013; 2015) examined and explained on how the traffic breakdown mechanism at urban arterial roads due to u-turn section and on-street parking activities using macroscopic parameters (i.e., volume, speed). These studies concluded that u-turn section and on-street parking activities are significantly affected by the traffic stream characteristics. However, studying traffic characteristic at an intersection in particular for the roundabout is quite valuable and necessary to accomplish to manage traffic situation at the junctions. Therefore this paper examined a study related to the roundabout, especially with the issue of calibrating passenger car equivalent unit at a roundabout.

A roundabout is an intersection area of a road segment that forms at least three-legs and plays an essential role in distributing traffic. This roundabout is located at the center of the intersection and, usually, has a higher reduced level than the road surface elevation, so a driver or a rider cannot pass through it. Under moderate traffic conditions, a roundabout may reduce delay and provide a safer movement in comparison with un-signalized intersections. There may be less potential for traffic accidents at this roundabout, since traffic flow merges and diverges at small angles and lower speeds (Troutbeck and Brilon, 2001). Currently, a roundabout has been widely accepted as an alternative to conventional intersection design in almost all countries under homogenous and heterogeneous traffic conditions. It provides better capacity as compared to a two-way-stop controlled or an all-way-stopped control intersection, under low-traffic

conditions (Sonu *et al.*, 2016)

Under mixed traffic conditions, the traffic volume unit of the vehicle per hour per lane is inappropriate as the traffic operates without lane discipline in the case of Indonesia. The composition of vehicles through the mixed traffic is generally diverse, consisting of light vehicles, heavy vehicles, motorcycles, rickshaws, and others. Each type of vehicles tends to have different effects on traffic. IHCM (1997) mentions that a traffic flow is a number of motor vehicles passing a point on the road per unit of time, expressed in vehicles/hours, passenger car equivalent (PCE)/hours, or annual average daily traffic (AADT). Therefore, a conversion factor from a vehicle to a reference vehicle, in this case, light vehicle (passenger car), is needed. The unit of the conversion factor is called passenger car unit (PCU) or passenger car equivalent (PCE). Hence, the PCU value is considered as the critical part of capacity estimation because the capacity is commonly expressed as PCU/h, and the estimation error changes as the value of the PCU changes (NCHRP, 2010). The term passenger car equivalent (PCE) was introduced in Highway Capacity Manual (HCM) 1965 and adapted to Indonesian highway capacity manual (IHCM, 1997).

Currently, there are many studies related to roundabout with homogenous traffic condition (for example see Chandra and Kumar (2003); Lee (2015); Sonu *et al.* (2016)), but only a few study on roundabout under heterogeneous traffic conditions, as estimating roundabout's capacity is difficult because of the widely varying operational characteristics and also varying driver's responses in the mixed traffic stream. Chandra and Kumar (2003) suggested a methodology for the estimation of dynamic PCU value directly proportional to the ratio of clearing speed ratio of a standard car and subject vehicle category. Furthermore, PCU value is inversely proportional to the space occupancy ratio of a standard car and subject vehicle category. Moreover, several studies have been done by employed microscopic simulation technique in estimating PCU values for a wide range of traffic volume and roadway conditions under heterogeneous traffic conditions (see for examples Arasan and Arkatkar, 2010; Praveen and Arasan, 2013). Moreover, Lee (2015) developed passenger car equivalents for heavy vehicles at roundabouts, such a way that the variation in the entry capacity in a various mix of cars and heavy vehicles was minimized. The latest study by Sonu *et al.* (2016) was carried out to estimate the PCU values of different vehicle categories at a typical four-legged roundabout based on the concept of time occupancy. A stream equivalency factor (k) has also been developed based on the estimated the PCU to convert the heterogeneous traffic flow into a homogenous stream equivalent without making use of the PCU factors. Furthermore, a multiplicative adjustment factor is suggested for the use of the HCM 2010 equation directly in the field to estimate entry flow under mixed traffic condition.

This study was conducted at the largest roundabout in Aceh Besar, a capital city of Aceh province, Indonesia, the Lambaro roundabout. The roundabout is a four-legged roundabout, with three legs consist of four lanes and a median while the another leg has two effective lanes and no median. This study aimed to measure PCU value based on the local conditions.

## Materials and Methods
### Study area

This study was carried out at Lambaro roundabout which is suggested as the largest roundabout in Banda Aceh, Indonesia. The roundabout is a four-legged roundabout, with three legs consist of four lanes and a median. Another leg is with two effective lanes and no median. The Lambaro roundabout can be seen in Figure 1.

### Data collection

A preliminary survey was conducted so that the final survey can be carried out on scheduled target. The preliminary survey was conducted long before the primary data was collected. The preliminary survey is substantial to get a proper description of the distribution of traffic flow at the study area including the type of vehicles such as motocycle, rickshaw, light vehicle, pick-up, medium vehicle, and heavy vehicle. It is expected that an appropriate view of the research location obtained in which is used to determine survey schedule, observation post, drone placement, and a number of the surveyor. A pilot/preliminary survey was conducted on Monday, May 29th, 2017. This preliminary survey recommended that the primary data should be collected on weekdays at morning peak hour (07.30 - 09.30) and afternoon peak hour (16.30 - 18.30). The used equipment to support the data collection include:
1) Video camera to record traffic, with the help of drone flying at a certain altitude to get a good view and able to cover the entire roundabout area and record the entire movement of vehicles traveling through the roundabout;

2) Speed gun to calculate spot speed;
3) Laptop to extract video data;
4) Measuring tape to measure roundabout geometry such as intersection width, weaving section width, weaving section length, and roundabout radius; and
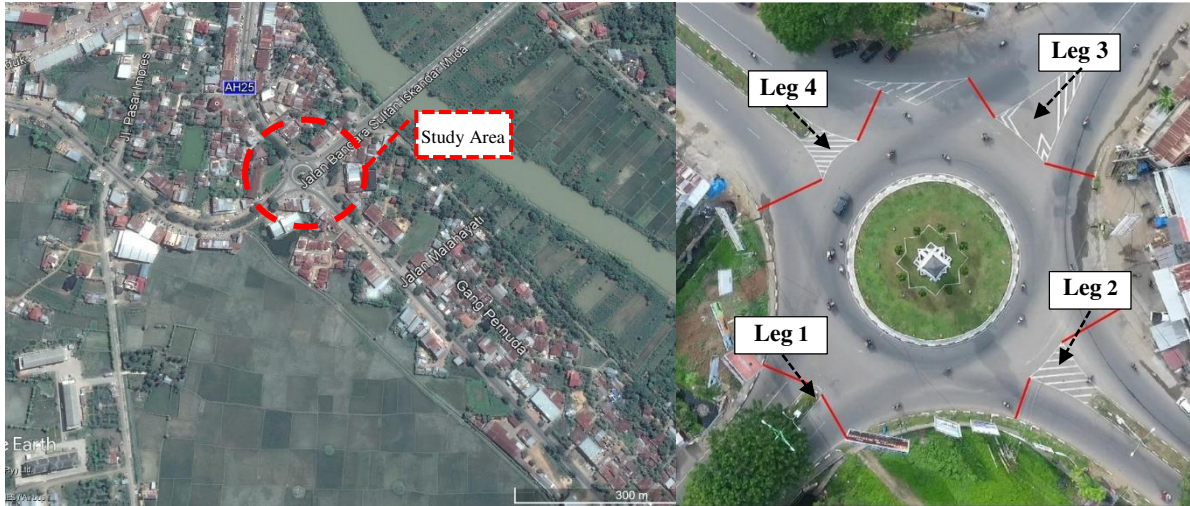5) Stationary for noting.



Figure 1 Location of Study Area

The data of this study were collected based on direct observation at the field. The directly collected data at the research location are as follow.

1) The geometry of the roundabout including intersection width, weaving section width, weaving section length, and roundabout radius which are measured using a tape meter;
2) Spot speed obtained from speed gun; and
3) Vehicles' time occupancy derived from video records.

The measurement of the roundabout geometric was carried out when the traffic flow was low The field data collection was performed for two weekdays during morning and afternoon peak hours.

**Traffic flow and composition**

There are three primary variables used to explain the traffic flow and its characteristics (Khisty and Lall 2003), namely:

1) Velocity, defined as a movement rate, such as distance per unit time, generally in miles/hours or kilometers/hours;
2) Volume, representing the actual number of vehicles observed or estimated through a point over a specified time range; and
3) Density, the number of vehicles occupying a certain length of lane or road, averaged over time, usually expressed by vehicles per mile.

The factual traffic composition in the traffic flow varies from pedestrians to heavy trucks. This factual composition will vary by the location of the road segment and the borders either based on the planning or based on the rules applied to certain roads. The DOH (2004) classifies vehicles based mainly on the size and configuration of the vehicle axis. Some types of vehicles are insignificant. Therefore, the types of vehicles taken into account in this study are only motorcycles (MC), rickshaw (RS), light vehicle (LV), pick-up (PU), medium vehicle MV), heavy vehicle (HV). LV represents passenger cars. MV is a two-axis truck, while HV includes buses and large trucks with a minimum of three axes. In this study, the pick-up (PU) is separated from LV because PU generally carries goods, while LV in this study is devoted to passenger cars.

**Traffic speed calculation**

Speed is the rate of vehicle's movement for a certain distance per a unit of time (Roess et al., 2004). Vehicles moving in traffic flow are in various speed, so that the traffic flow is in a range of speed instead of a single fixed speed. Speed can be divided into three types, which are the speed of movement, speed of

travel, and spot speed. There are two methods of processing spot speed data: time mean speed and space mean speed. Matthew and Rao (2007) suggested that time mean speed is the average speed of all vehicle passing through a point over a duration of time. Time mean speed is an arithmetic mean (AM) of the local velocity data. Time mean speed is formulated as shown in Eq. (1).

$$v_t \;\; = \;\; \frac{1}{\sum f_i} \sum f_i \cdot v_i \tag{1}$$

where $v_i$ is a spot speed of the vehicle, $f_i$ is a frequency and $v_t$ is a time mean speed.

Harmonic mean (HM) of spot speed is a value of space mean speed, which is calculated using Eq. (2) (Matthew and Rao, 2007)

$$v_s \;\; = \;\; \frac{\sum f_i}{\sum \dfrac{f_i}{v_i}} \tag{2}$$

where $v_s$ is space mean speed. In addition to the spot speed data processing, we can also generate speed percentiles that are at the cumulative frequency of 15% for recommended minimum speed and 85% for recommended maximum speed by using the speed profile to obtain the confidence interval.

## Weaving section

Weaving movement orders are giving a way to the left road users (IHCM (1997). Weaving is divided into two types which are a single weaving and roundabout. A roundabout is considered to be some sequential part of weavings. **Figure 2** sketches a roundabout section. The approach is the area of the road junction leg for the vehicle to queue before exiting past the stop line. The approximate width (Wx) is the width of traffic path measured in the narrowest entry area used by the moving traffic. X states the name of the approach. Physical width of each side with plenty of parking reduced by 2 m. The width of weaving (Ww) is the effective wide of the weaving section, also measured in the narrowest area. Length of weaving (Lw) is the effective length of the weaving section.

### Passenger car equivalent (PCE) and time occupancy

The time occupancy in a given direction as the time taken by the subject vehicle to clear the roundabout separately for left-movement, straight movement, or right-turn movement (Sonu et al., (2016. Time occupancy is the elapsed time starting from the front end of the vehicle entering the roundabout area to the rear end of the same vehicle exits from the roundabout area. A vehicle is considered to have entered the roundabout area when the front bumper of the vehicle passes through the stop line at the entry, and whereas when the same vehicle's rear bumper passes the exit line, it is declared that the vehicle has been out of the roundabout area. For more details see Figure 3. In this method, the vehicle is not only classified according to the type, but also categorized into the type of movement, in this case left turn, straight, and right turn.
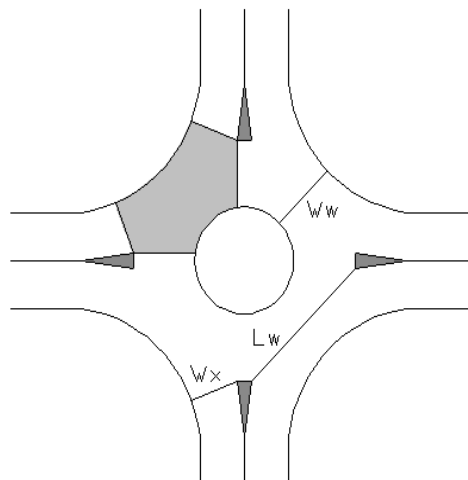


Figure 2 Weaving section instrument (IHCM, 1997)

Figure 3 Possible movements at a roundabout (Sonu *et al.*, 2016)

Sonu *et al.* (2016) formulated an equation for calculating the value of PCE using the vehicle's time occupancy method., as stated in Eq. (3).

$$PCE_i = \frac{T_i}{T_c} \frac{A_i}{A_c} \tag{3}$$

where $PCE_i$ represents PCE value of the subject vehicle, $T_i$ is an average time occupancy of the subject vehicle (s), $T_c$ is an average time occupancy of the passenger car (s), $A_i$ is a projected rectangular area of the subject vehicle (m²), $A_c$ is projected rectangular area of the passenger car (m²). Note that the projected area of vehicles is obtained by multiplying the length of the vehicle with the width of the vehicle. The respective length and width of vehicles can be referred to DOH (2004) or use representative vehicles which can be observed on site.

### Results and Discussions

**Table 1** shows the dimensions of the vehicles collected from field observation. The result of geometry measurement of Lambaro roundabout describes in Table 2.

**Table 1**. Vehicle dimensions

| Vehicle types | Width (m) | Length (m) |
|---|---|---|
| Motocycle (MC) | 0,68 | 1,92 |
| Rickshaw (RS) | 1,45 | 2,67 |
| Light vehicle (LV) | 1,66 | 4,19 |
| Pick-up (PU) | 1,83 | 3,72 |
| Medium vehicle (MV) | 2,06 | 6,03 |
| Heavy vehicle (HV) | 2,43 | 8,52 |

**Table 2**. The geometry of Lambaro Roundabout

| Leg | 1 (toward Banda Aceh) | 2 (toward airport) | 3 (toward Medan) | 4 (toward Meulaboh) |
|---|---|---|---|---|
| Type | 4/2D | 4/2D | 2/2UD | 4/2D |
| Entry width (m) | 8.3 | 8.8 | 6.5 | 7.0 |
| Exit width (m) | 8.0 | 9.5 | 7.7 | 9.0 |
| Weaving width (m) | 11.7 | 11.0 | 11.0 | 10.2 |
| Weaving length (m) | 33.2 | 22.5 | 28.8 | 33.8 |
| Radius (m) | 12.7 | | | |

## Speed profile and vehicle's time occupancy

The used data in analyzing the speed profile is spot speed. Speed profile comprised of minimum speed, maximum speed, time mean speed, and space mean speed is summarized at **Table 4**. **Figure 5** reveals that the average vehicle time's occupancy for the right-turn movement is almost four times the average left-turning vehicle's time occupancy. Whereas, the average through vehicles has shown about 250% higher in time occupancy compared to the left-turn vehicles. Moreover, the average vehicle's time occupancy of RS, PU, and MV is not much different. Moreover, it can be seen that the lowest of an average time occupancy is of MC while the highest is HV's. It because of time is inversely proportional to the speed. That is the higher the speed is, the smaller the travel time will be. Hence this corresponds to the speed profile which reveals that among all vehicles, the average MC speed is the fastest, while the HV is moving at the slowest.

**Table 4** Recapitulation of the speed profile

| Vehicle | Motorcycle | Rickshaw | Light vehicle | Pick-Up | Medium vehicle | Heavy vehicle |
|---|---|---|---|---|---|---|
| Minimum speed (km/h) | 19.74 | 17.86 | 18.85 | 17.98 | 18.01 | 17.14 |
| Maximum speed (km/h) | 26.09 | 22.57 | 24.05 | 22.72 | 23.99 | 21.51 |
| Time mean speed (km/h) | 23.34 | 20.88 | 22.07 | 21.06 | 21.43 | 19.71 |
| Space mean speed (km/h) | 22.99 | 20.68 | 21.78 | 20.80 | 21.04 | 19.53 |

## PCEs estimation

The PCEs estimation uses the time occupancy method referred to Eq. 3. The result of PCE values calculated using the time occupancy method is shown in Table 5. It shows the value of the respective vehicle PCE per movement varies, but in general, the difference is not significant, such as PCE of motorcycle (MC), which ranges from 0.16 to 0.17. The average PCE value is the arithmetic mean of the PCE value for left, straight, and right turn. The average PCE value is avowed as the PCE value of each vehicle type without distinguishing the movement again. Hence, it can be concluded the PCE value at Lambaro roundabout as shown in Table 5. It encourages PU's PCE value almost equal to LV's. It indicates that the load to which each vehicle carries tends to be different, the effect pick-ups have on the traffic is approximately is similar to that of light vehicles. HV's PCE value is the greatest because its size is the largest of all and it takes more time for HV to clear the roundabout area than any other vehicles.
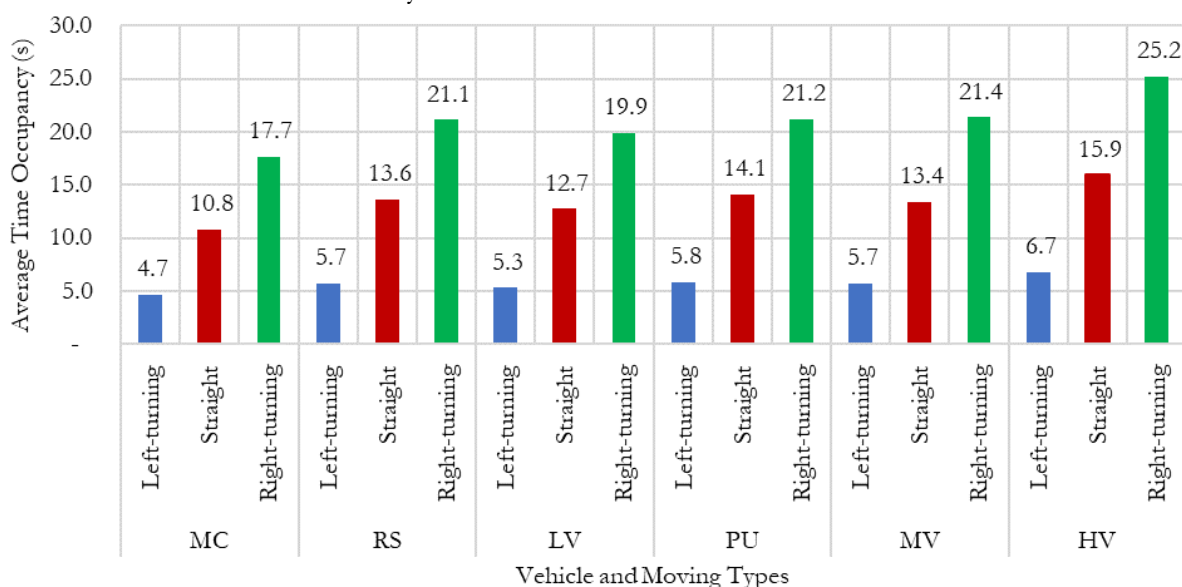
**Figure 4**. Average vehicle's time occupancy

**Table 5.** PCEs value for each type of vehicles at Lambaro roundabout

| Vehicle | MC | RS | PU | MV | HV |
|---|---|---|---|---|---|
| PCE value | 0.16 | 0.59 | 1.07 | 1.91 | 3.76 |

IHCM (1997) mentioned that passenger car equivalent (PCE) is a conversion factor of various types of vehicles to passenger cars or other light vehicles relevant to their respective impact on traffic. The PCE value for the roundabout according to IHCM (1997) is 1 for LV, 1.3 for HV, and 0.5 for MC. Regarding time occupancy, Mohan and Chandra (2016) sugested that time occupancy is the total time required by a vehicle passing through a conflict area. Time occupancy depends on the behavior of the rider, intersection geometry, type of vehicle, opposing vehicular traffic, the manner in which conflict area is cleared, and many other factors. Since the occupancy time is affected by the vehicle's size, it will be higher for longer vehicles such as trucks and buses.

**Conclusions**

The result of the passenger car equivalent values from this study are 0.16 for motorcycles , 0.59 for rickshaw, 1.07 for pick-up, 1.91 for a medium vehicle, and 3.76 for a heavy vehicle. Hereafter, speed profile shows that amongst all vehicles, the motorcycle is the quickest, while the heavy vehicle is the slowest, which are relevant to the average time occupancy which discloses that motorcycles has the most time occupancy while heavy vehicle has the least one. Furthermore, as a future direction of this work, the obtained passenger car equivalent value from this study should be used in the roundabout performance analysis in future. The present study results may be suitable for revising the Indonesian Traffic Code and useful for ongoing national-level efforts of upgrading Indonesian Highway Capacity Manual. As for future work, the calculation of passenger car equivalent values may be better to be compared to other methods such as potential capacity method and queue clearance rate to gain more reliable and comparable results of passenger car equivalent

**References**

Anggraini, R., Sugiarto, S., Pramanda, H. 2017. Factors affecting trip generation of motorcyclist for the purpose of non-mandatory activities. AIP Conference Proceedings 1903, 060011.

Arasan, V. T., Arkatkar, S. S., 2010. Micro-simulation study of effect of volume and road width on pcu of vehicles under heterogeneous traffic. Journal of Transportation Engineering, 136(12), 1110–1119.

Chandra, S. and Kumar, U. 2003. Effect of lane width on capacity under mixed traffc conditions in India. Journal of Transportation Engineering, 129(2), 155–160.

DOH. 2004. The traffic enumeration survey guideline (*in Bahasa*). Ministry of Public Work, Jakarta.

IHCM. 1997. Indonesian Highway Capacity Manual (*in Bahasa*). General Directorate of Bina Marga. Jakarta.

Khisty, C. J., B. K. Lall. 2003. Basics of transportation engineering Volume 1 Third Edition (in Bahasa), Erlangga. Jakarta.

Lee, C., 2015. Developing passenger-car equivalents for heavy vehicles in entry fow at roundabouts. Journal of Transportation Engineering, 141(8), 04015013.

Matthew, T. V., Rao, K. V. K. 2007. Introduction to transportation engineering. NPTEL.

Mohan, M., Chandra., 2016. Three method of pcu estimation at un-signalized Intersections. Transportation Letters: the International Journal of Transportation Research, 10(2), 68-74.

Praveen, P. S., Arasan, V. T., 2013. Influence of traffc mix on pcu value of vehicles under heterogeneous traffc conditions. International Journal for Traffic and Transport Engineering, 3(3), 302–330.

Roger P. Roess., Elena S. Prassas., William R. McShane. 2004. Traffic Engineering. Third Edition, Pearson Education Inc. New Jersey.

NCHRP., 2010. Roundabouts: an informational guide (NCHRP Report 672). Transportation Research Board, Washington, DC.

Saleh, S.M., Sugiarto, S., Hilal, A., Ariansyah, D. 2017. A study on the traffic impact of the road corridors due to flyover construction at surabaya intersection, Banda Aceh of Indonesia. AIP Conference Proceedings 1903, 060005.

Soedirdjo, T. L. 2002. Traffic Engineering (*in Bahasa*). General Directorate of Higher Education Nasional Education Department. Bandung.

Sonu, M., Dhamaniya, Ashish., Shriniwas., Joshi, Gaurang. 2016. Time occupancy as measure of pcu at four legged roundabouts. Transportation Letters: the International Journal of Transportation Research. *Online First.*

Sugiarto, Limanond, T. and Nakatsuji, T., 2012. Dropped in capacity and traffic speed of urban Arterial: a case study at u-turn section in Aceh Province, Indonesia. Aceh International Journal of Science and Technology, (3): 86-92.

Sugiarto, S., Limanond, T., 2013. Impact of on-street parking on urban arterial performance: A quantitative study on travel speed and capacity deterioration. Aceh International Journal of Science and Technology, 2(1): 63-69.

Sugiarto, S., Lulusi, Saleh, M.S., 2015. An assessment of the capacity drops at the bottleneck segments: a review on the existing methodologies. Aceh International Journal of Science and Technology, 4(1): 64-77.

Sugiarto, S., Miwa, T., Sato, H., Morikawa, T., 2014. Congestion charging: Influence of public consciousness on acceptability in Jakarta Metropolitan Area. Proceedings of 21st World Congress on Intelligent Transport Systems, Detroit, USA.

Sugiarto, S., Miwa, T., Sato, H., Morikawa, T., 2017a. Explaining differences in acceptance determinants towards congestion charging policies in Indonesia and Japan. Journal of Urban Planning and Development (ASCE), 143(2): 1-12.

Sugiarto, S., Miwa, T., Morikawa, T., 2017b. Inclusion of latent constructs in utilitarian resource allocation model for analyzing revenue spending options in congestion charging policy. Transportation Research Part A: Policy and Practice, 103: 36–53.

Tamin, O. Z. 2008. Planning, Modelling, and Engineering of Transportation (*in Bahasa*). Institute Technology Bandung, Bandung.

Troutbeck R., Brilon W., 2001. Unsignalised Intersection Theory Chapter 8, Traffc Flow Theory, A State-of-the-Art Report, Organized by the Committee on Traffc Flow Theory and Characteristics.