Comparison analysis of unstandardized roundabout between MKJI 1997 and USHCM 2000 by simulation model

D Purwanto and K H Basuki

Department of Civil Engineering, Diponegoro University, Jl. Prof. Sudarto, SH., 50239, Tembalang, Semarang, Indonesia

kamiharibasuki@lecturer.undip.ac.id

Abstract. Roundabout affect adversely on traffic if they do not comply with predetermined standards. This study aims to compare the impact of traffic on non-standard roundabouts with two different methods. The analytical method used is the Indonesia Highway Capacity Manual (MKJI) 1997 [5] and the United State Highway Capacity Manual (USHCM) 2010 [6] using the Synchro7 software. The results of the analysis related to the geometric parameters of the road, calculating the Weaving Ratio (Pw), the Capacity (C), the Degree of Saturation (DS), delays in the weaving interfacing section, traffic delays at roundabouts (DTR), queuing opportunities (QP%) and all in unit a passenger car unit (pcu). The results of the analysis show that the analysis using the Synchro software for USHCM 2000 method, there are significant differences compared to the MKJI 1997 method. By using the Synchro7 software, the degree of saturation obtained is very large, this may be due to the inaccuracy of modeling in the application compared to the actual conditions. In conclusion, with these considerations and traffic behavior in Indonesia, the results of the analysis used are the MKJI 1997 reference method.

1. Introduction

Circle road traffic in the roundabout has a controls the method by limiting the transfer of vehicle motion into diverging, merging, crossing, and weaving movements to slow down the vehicle speed [1,2]. The weaving section is divided into two main types, the first is named the single weaving section and the second is called the circular weaving section that is considered as successive braids. Roundabouts are most effective when intersections between roads of the same size and flow rate are used. Roundabouts are therefore very suitable for crossing two-lane or four-lane roads [3,4]. For intersections between larger roads, the closure of the braided area is easy and the safety of the roundabout decreases [2,5].

The road network in many cities has roundabouts, but some of these are non-standard roundabouts. Semarang, as the capital of Central Java Province, constantly develops, the rise of population, private vehicle users are stepping up, the economy is increasing, and development is always continuing. Supposing that this development does not offset with infrastructure improvements, especially roads, gradually the road will no longer be able to serve the ever-increasing traffic flow. Diponegoro Park Roundabout at Semarang City is a road network that connects about 6(six) approaches that converge at the roundabout. It is not in accordance roundabout with predetermined standards based on Manual Kapasitas Jalan Indonesia (MKJI) 1997 also United State Highway Capacity Manual (USHCM) 2000. Unstandardized Roundabout described in Figure 1 and specification compared at Table 1.
Figure 1. Unstandardized roundabout Geometric Dimension (Case study: Diponegoro Park at Semarang City)

Table 1. Comparison Roundabout Geometric Standard between (MKJI 1997) and USHCM 2000

| Geometric Design element   | Constraint     | Specification Standard | MKJI 1997 | HCM 2000 | Case Study |
|----------------------------|----------------|------------------------|-----------|-----------|------------|
| Island Diameter R (meter)  | Minimum        | MKJI 1997              | 25.4      | 20.0      | 20.0       |
| Width of Approach W_A(meter)| Minimum        | HCM 2000               | 6.0       | 8.6       | 8.0        |
| Width of Weaving W_w (meter)| Minimum        |                        | 9.0       | 10.1      | 12.6       |
| Length of Weaving W_L (meter)| Minimum       |                        | 33.0      | 42.0      | 42.0       |
| Weaving Ratio P_w (Wv/Vt)  | Minimum        |                        | 0.32      | 0.40      | 0.29       |
| Island Shape               | Shape          | MKJI 1997              | Circle    | Circle    | Oval       |
| Alignment Approach         | Center point   | USHCM 2000             | All of Approach | All of Approach | 2/6       |

2. Objective
This study aims to evaluate the roundabout with predetermined standards performance using MKJI 1997 and US-HCM 2000 method. The objectives of this research are to describe unstandardized roundabout conditions according to the oval base shape and road section by the weaving segment. Roundabout performance analysis is compared between MKJI 1997 and US-HCM 2000 method based on existing condition and scenario task are improved by simulation Model using Synchro 7 Software.

3. Research Methodology
In the calculation of the roundabout, it is necessary to observe and analyze the weaving section. These observations are used as input data in the calculation of capacity and road performance measures in the form of degrees of saturation, delays, and queuing opportunities for the roundabout section. The input data are city population, vehicles growth, traffic distribution, turning movement, traffic volume, major and minor roads based on traffic entries to roundabout and peak hour time. Analysis results related to
the geometric parameters of the road, calculating the weaving ratio (Pw), calculating the basic capacity (Co), calculating the capacity (C), calculating the degree of saturation (DS), the delay in the interlacing parts of the weaving, the delay in roundabout traffic (DTR), the opportunity to queue the interlacing parts of the roundabout (QP%) and all of them in passenger car units (pcu) so that later they will get a traffic resurgence and a delay [5-7].

3.1. Analysis using Manual Kapasitas Jalan Raya (MKJI) 1997 method

3.1.1. Degree of saturation. DS value is using the equation below:

\[ DS = \frac{C}{Q_{pcu}} \] (1)

- \( C \) = Capacity of roundabout
- \( Q_{pcu} \) = Total flow (pcu/hour) *pce = passenger car equivalent

3.1.2. Delay at weaving section. Based on DS value is described below:

\[
\begin{align*}
DT &= 2 + 2 \times 5.68982 \times DS - (1 - DS) \times 2, & DS \leq 0.6 \\
DT &= 1/(0.59186 - 0.52525 \times DS) - (1-DS) \times 2, & DS > 0.6
\end{align*}
\] (2) (3)

- \( DT \) = Delay weaving traffic (sec/pce)
- \( DS \) = Degree of saturation

3.1.3. Average delay at roundabout. According to DT, total flow into roundabout delay weaving section is assumed 4 sec/pce, the equation below:

\[
D_R = \frac{\sum (Q_i \times DT_i)}{Q_{in} + DG} \quad ; \quad i = 1 \ldots n
\] (4)

- \( D_R \) = Average delay at roundabout (sec/pce)
- \( i \) = weaving section i in roundabout
- \( n \) = amount of weaving section in roundabout
- \( Q_i \) = total flow at weaving section i (pcu/hour)
- \( DT_i \) = average traffic delay in the weaving section i (sec/pce)
- \( Q_{in} \) = total flow in into the roundabout (pcu/hour)
- \( DG \) = average geometric delay at weaving section (4 sec/pce)

3.1.4. Queueing Proportion. It is the chosen maximum number of proportion queue at the weaving, depend on DS value, proportion queue’s formula is:

\[
\begin{align*}
\text{Upper limit} \quad & QP = 26.65 \times DS - 55.55 \times DS^2 + 108.7 \times DS^3 \\
\text{Lower limit} \quad & QP = 9.41 \times DS + 29.967 \times DS^{4.619}
\end{align*}
\] (5) (6)

- \( QP \) = Proportion Queue (%)
- \( DS \) = Degree of Saturation

3.2. Analysis using US-HCM 2000 Method by Synchro Software

3.2.1. Calculation of Traffic Distribution Matrix. Traffic distribution matrix used for correction in processing traffic data also for forecasting traffic distribution [8]. In the Synchro Software data input, it needs balanced traffic data between the entrance and exit vehicles in the road, so that this calculation is necessary. Distribution matrix calculated using statistical equation; mean method as follows:

\[
T_{ij} = f_{ij} \times (E_i + E_j) / 2
\] (7)

Evidence:
- \( T_{ij} \) = Next iteration data value
- \( f_{ij} \) = Previous iteration data value
- \( E_i = O_i / O'_i \)
- \( E_j = D_j / D'_j \)
- \( O_i \) = Number of vehicles exit the weaving
\[ O_i = \text{Number of vehicles iteration result} \]
\[ D_j = \text{Number of vehicles entering the weaving} \]
\[ D_j' = \text{Number of vehicles iteration result} \]

3.2.2. Synchro Software. Trafficware Synchro Studio is a series of software for simulating, optimizing, and analyzing traffic data in 3D [7]. Synchro is an easy-to-use software that allows traffic experts to analyze traffic volume at intersections and crossings, and to model three-dimensional models of roads, private and public vehicles, sidewalks, and more. It has developed by the US-HCM 2000 method [6]. This application was designed and simulated to help with modeling. This application can also identify problems and provide a solution. Analysis using synchro needs geometric data of intersection used in modeling, also balanced traffic data as the input. The traffic data have to be balanced, which means the amount the vehicles in or out of the intersection have to be the same. If it is not, it will happen an error in the analysis. Flowchart of Synchro Software usage is shown in Figure 2.

![Flowchart of Synchro Software usage](image)

**Figure 2.** Analysis of Synchro 7 Software

4. Data Analyse and Results
Traffic analysis was carried out on all the weaving at the peak hour during weekdays and peak hours during the weekend. The analysis performed for existing condition and scenario condition is assumed by Hotel to operate, which is 2022.
4.1. Analysis of existing conditions using MKJI 1997 method

Result of analysis using MKJI 1997 for existing condition shows that performance of the roundabout during the weekday is quite bad, which have F level of service in the morning, E level of service in the noon, and F level of service in the evening. With this performance, it is likely to happen traffic jams in the morning at the W_{1-2} with a degree of saturation = 1.23. And in the evening, congestion will get worse with the worst condition at the W_{4-5} with the degree of saturation = 1.43.

During the weekend, the traffic is not as heavy as weekday, with the result that roundabout still capable enough to serve traffic flow which through it. The highest degree of saturation is in the evening, 0.92 at the W_{3-4} so that at this condition traffic in the roundabout is quite heavy but less likely to happen congestion. Weaving identities according to approach lane point name, for example, W_{1-2} is Weaving lane between approach lane point 1 and 2, it can be seen in Figure 3.

![Figure 3. Circulating traffic flow and Weaving Identities.](image)

Results of the roundabout’s existing performance during weekdays and weekends are shown in Table 2 and Table 3.

**Table 2. Result of Analysis on Weekday in Existing Condition**

| Time     | Weaving name | DS of Weaving | DS of Roundabout | Weaving Delay (second) | Delay of Roundabout (Second) | Queueing Proportion (%) | LOS of Weaving |
|----------|--------------|---------------|------------------|------------------------|------------------------------|------------------------|----------------|
| Morning  | W 1-2        | 1.23          | 1.23             | 15.01                  | 32.98                        | 90.47                  | F              |
|          | W 2-3        | 0.72          |                  | 4.10                   |                              | 13.28                  | C              |
|          | W 3-4        | 0.98          |                  | 12.84                  |                              | 36.38                  | E              |
|          | W 4-5        | 0.85          |                  | 6.51                   |                              | 21.94                  | D              |
|          | W 5-6        | 0.82          |                  | 5.82                   |                              | 19.63                  | D              |
|          | W 6-1        | 0.77          |                  | 4.90                   |                              | 16.31                  | D              |
| At Noon  | W 1-2        | 0.77          | 0.93             | 4.85                   | 29.60                        | 16.10                  | D              |
|          | W 2-3        | 0.67          |                  | 3.45                   |                              | 10.81                  | C              |
After Morning At Noon

Weaving Analysis of Projection performed using calculation of vehicles, it is necessary to project a volume of vehicles in the condition of the hotel in operation, it is necessary to project a volume of vehicles in

Table 3. Result of Analysis on Weekend in Existing Condition

| Time | Weaving name | DS of Weaving | DS of Roundabout | Weaving Delay (second) | Delay of Roundabout (Second) | Queueing Proportion (%) | LOS of Weaving | LOS of Roundabout |
|------|--------------|---------------|-----------------|------------------------|-----------------------------|------------------------|----------------|-----------------|
| W 3-4 | 0.93         |               |                 | 9.62                   |                             | 30.38                  | 64.41          | E               |
| W 4-5 | 0.88         |               |                 | 7.58                   |                             | 25.19                  | 54.99          | E               |
| W 5-6 | 0.72         |               |                 | 4.19                   |                             | 13.60                  | 31.49          | C               |
| W 6-1 | 0.69         | 1.43          |                 | 3.72                   |                             | 11.83                  | 27.46          | C               |
| W 1-2 | 0.69         |               | 3.76            | 15.01                  | 37.74                       | 11.98                  | 27.80          | C               |
| W 2-3 | 1.03         | 1.43          | 15.01           | 15.01                  |                             | 31.74                  | 234.28         | F               |
| W 3-4 | 1.42         |               | 15.01           | 15.01                  |                             | 162.43                 | 234.28         | F               |
| W 4-5 | 1.43         |               | 15.01           | 15.01                  |                             | 170.96                 | 243.17         | F               |
| W 5-6 | 1.19         |               | 15.01           | 15.01                  |                             | 78.82                  | 136.93         | F               |
| W 6-1 | 1.11         |               | 15.01           | 15.01                  |                             | 59.42                  | 110.27         | F               |
| W 1-2 | 0.69         |               | 3.76            | 15.01                  |                             | 11.98                  | 27.80          | C               |
| W 2-3 | 1.03         | 1.43          | 15.01           | 15.01                  |                             | 31.74                  | 234.28         | F               |
| W 3-4 | 1.42         |               | 15.01           | 15.01                  |                             | 162.43                 | 234.28         | F               |
| W 4-5 | 1.43         |               | 15.01           | 15.01                  |                             | 170.96                 | 243.17         | F               |
| W 5-6 | 1.19         |               | 15.01           | 15.01                  |                             | 78.82                  | 136.93         | F               |
| W 6-1 | 1.11         |               | 15.01           | 15.01                  |                             | 59.42                  | 110.27         | F               |

4.2. Analysis of Scenario condition is assumed by hotel operates at 2022 using MKJI 1997 method

In analyzing the condition of the hotel in operation, it is necessary to project a volume of vehicles in 2022. Projection performed using calculation of vehicles, which then multiplied by the volume of existing vehicles. The formula used in calculating the vehicle volume projection is as follows:

\[ Qt = Q_0 \times (1 + r)^n \]  

(8)
Evidence: \( Qt = \) Volume of the vehicle in the year-\( n \)
\( Qo = \) Existing vehicle volume
\( r = \) Vehicle growth
\( n = \) Amount of year

The hotel has an impact in the form of generation and attraction of vehicles, which will burden the traffic on the roundabout. Calculation of generation performed with based on some other research. Recapitulation of generation calculation that performed shown as Table 4.

**Table 4. Representation of Trip Generation cause by Land Use Development Scenario**

| Guideline | Value of Generation |
|-----------|---------------------|
| Transportation Planning and Modeling [9] | 96 pcu/hour |
| Hotel Trip Production based on generate trip/100m\(^2\) [10] | minimum = 55 pcu/hour, maximum = 71 pcu/hour |
| Analysis of Traffic Impact Caused by Construction of Best Western Star Hotel and Star Apartment Semarang on-road section nearby [11] | Based on the amount of rooms = 319.2 pcu/hour, Based on building area = 523 pcu/hour |
| The Land Use/ Transport System [12] | 44 pce/hour |

Based on the result of the analysis, it chose generation based on Trip Generation Hotel. In the next analysis, the value of generation is assumed about 69 pcu/hour. The result of analysis using MKJI 1997 on weekday conditions when hotel operates shows the performance of roundabout when Hotel operates is atrocious. In each peak of our condition; morning, afternoon, and evening, the value of the degree of saturation is more than one. In each condition; morning, afternoon, and evening, the level of service of the roundabout are on F level.

**Table 5. Result of Analysis on Weekday in Scenario Condition**

| Time     | Weaving name | DS of Weaving | DS of Roundabout | Delay of Weaving | Delay of Roundabout | Queueing Proportion | LOS of Weaving | LOS of Roundabout |
|----------|--------------|---------------|------------------|------------------|---------------------|---------------------|-----------------|------------------|
| Morning  | W 1-2        | 1.39          | 1.39             | 15.01            | 34.84               | 149.57              | 220.57          | F                |
|          | W 2-3        | 0.80          | 5.51             | 18.51            |                     |                     |                 |                  |
|          | W 3-4        | 1.09          | 15.01            | 55.63            |                     |                     |                 |                  |
|          | W 4-5        | 0.95          | 10.63            | 32.51            |                     |                     |                 |                  |
|          | W 5-6        | 0.92          | 8.92             | 28.74            |                     |                     |                 |                  |
|          | W 6-1        | 0.86          | 6.91             | 23.18            |                     |                     |                 |                  |
| At Noon  | W 1-2        | 0.87          | 7.14             | 23.91            |                     |                     |                 |                  |
|          | W 2-3        | 0.74          | 4.46             | 14.66            |                     |                     |                 |                  |
|          | W 3-4        | 1.04          | 15.01            | 45.87            |                     |                     |                 |                  |
|          | W 4-5        | 0.99          | 13.80            | 37.79            |                     |                     |                 |                  |
|          | W 5-6        | 0.81          | 5.67             | 19.10            |                     |                     |                 |                  |
Afternoon

| Time   | Weaving name | DS of Weaving | DS of Roundabout | Delay of Weaving | Delay of Roundabout | Queueing Proportion | LOS of Weaving |
|--------|--------------|---------------|------------------|-----------------|---------------------|---------------------|----------------|
|        |              |               |                  |                 |                     |                     |                |
| W 6-1  | 0.77         | 4.86          |                  |                 |                     |                     |                |
| W 1-2  | 0.78         | 5.13          |                  |                 |                     | 17.14               | 39.11          | D              |
| W 2-3  | 1.15         | 15.01         |                  |                 |                     | 67.88               | 122.18         | F              |
| W 3-4  | 1.58         | 15.01         |                  |                 |                     | 263.58              | 332.42         | F              |
| W 4-5  | 1.60         | 15.01         |                  |                 |                     | 279.48              | 346.66         | F              |
| W 5-6  | 1.33         | 15.01         |                  |                 |                     | 126.16              | 194.63         | F              |
| W 6-1  | 1.24         | 15.01         |                  |                 |                     | 93.23               | 155.41         | F              |

Table 6. Result of Analysis on Weekend in Scenario Condition

On weekends in condition the hotel operates shows the roundabout is no longer can provide good service. In the evening peak hour, the degree of saturation is 1.02, which means traffic that passed through it is over capacity. With proportion queue = 42.84% - 85.24%, it is possible to happens traffic jam.

4.3. Analysis of existing conditions using US-HCM 2000 method

4.3.1. Traffic Distribution Matrix, the result of calculation of distribution matrix shows that in the morning peak hour happened massive movement from Approach 1 to Approach 2, and from Approach
1 to Approach 4. While in the evening peak hour, massive movement comes from Approach 2 to Approach 1.

Table 7. Traffic Distribution Matrix on Morning during Weekday

| Origin Approach | Destination Approach | 1  | 2  | 3  | 4  | 5  | 6  | Oi |
|-----------------|----------------------|----|----|----|----|----|----|----|
| 1               | 0                    | 2135| 164| 1418| 542| 4  | 4270|
| 2               | 579                  | 0  | 1  | 20  | 4  | 0  | 602 |
| 3               | 129                  | 7  | 0  | 3   | 0  | 0  | 139 |
| 4               | 729                  | 49 | 1  | 6   | 0  | 0  | 782 |
| 5               | 726                  | 49 | 1  | 26  | 0  | 0  | 799 |
| 6               | 3                    | 0  | 0  | 0   | 0  | 0  | 3   |
| Dj              | 2174                 | 2236| 166| 1464| 551| 4  |

Table 8. Traffic Distribution Matrix on Afternoon during Weekday

| Origin Approach | Destination Approach | 1  | 2  | 3  | 4  | 5  | 6  | Oi |
|-----------------|----------------------|----|----|----|----|----|----|----|
| 1               | 0                    | 955 | 33 | 387 | 207| 1  | 1583|
| 2               | 1952                 | 0  | 116| 944 | 562| 6  | 3580|
| 3               | 69                   | 63 | 0  | 17  | 6  | 0  | 155 |
| 4               | 556                  | 557| 14 | 0   | 106| 0  | 1233|
| 5               | 249                  | 236| 2  | 80  | 0  | 0  | 567 |
| 6               | 4                    | 4  | 0  | 1   | 0  | 0  | 8   |
| Dj              | 2830                 | 1814| 165| 1429| 880| 8  |

4.3.2. Analysis using Synchro Software Method, US-HCM 2000 analysis using Synchro Software shown as in Table 9 and Table 10.

Table 9. Result of Analysis in Existing Condition

| Time            | Approach | ICU    | LOS | DS  | DS  |
|-----------------|----------|--------|-----|-----|-----|
|                 |          |        |     |     |     |
|                 |          |        |     | Approach | Weaving |
| Morning         | Approach 1| 238.8% | H   | 0.89| 0.85|
|                 | Approach 2| 238.8% | H   | 0.18| 0.97|
|                 | Approach 3| -      | -   | -   | -   |
|                 | Approach 4| 122.0% | H   | 0.23| 1.03|
|                 | Approach 5| 100.2% | G   | 0.24| 1.17|
|                 | Approach 6| -      | -   | -   | -   |
| Afternoon       | Approach 1| 238.8% | H   | 1.11| 0.31|
|                 | Approach 2| 296.1% | H   | 1.00| 1.05|
|                 | Approach 3| -      | -   | -   | -   |
Table 10. Result of Analysis in Condition Hotel Operates

| Time     | Approach | ICU   | LOS | DS Approach | DS Weaving |
|----------|----------|-------|-----|-------------|------------|
| Morning  | Approach 1 | 266.2% | H   | 0.95        | 0.99       |
|          | Approach 2 | 266.2% | H   | 0.20        | 1.08       |
|          | Approach 3 | -     | -   | -           | -          |
|          | Approach 4 | 135.8% | H   | 0.27        | 1.14       |
|          | Approach 5 | 111.0% | H   | 0.28        | 1.31       |
|          | Approach 6 | -     | -   | -           | -          |
| Afternoon| Approach 1 | 212.6% | H   | 0.79        | 0.80       |
|          | Approach 2 | 212.6% | H   | 0.41        | 0.67       |
|          | Approach 3 | -     | -   | -           | -          |
|          | Approach 4 | 131.6% | H   | 0.33        | 1.09       |
|          | Approach 5 | 103.8% | G   | 0.17        | 1.35       |
|          | Approach 6 | -     | -   | -           | -          |

Based on the result of the analysis, there are two intersections that the result is unidentified. It is the intersection of Approach 3 and Approach 6. It is happened because there was a fault during the modeling and/or because geometrically it cannot apply to Synchro Software. With this consideration, therefore the result of the analysis used is based on the MKJI 1997 method.

The chosen alternative handling based on the analysis is restricting median at Approach 1 and applying a contra flow system on the W1-2. It was chosen because the contraflow system delivers the smallest ICU number than other alternatives also by restricting the entrance and exit direction of the roundabout.

5. Conclusion

According to the analysis of the results at the roundabout with predetermined standards, based on data survey at the research’s location, few problems affect the performance of the roundabout. It is not standard causing a traffic jam at the roundabout and the congestion get worse, geometric of the roundabout which inconsistent in every weaving caused lame road capacity. The degree of saturation is 1.43 with F level on of service at the afternoon make traffic flow tends to congested, vehicles go with low velocity, and likely happens traffic jam. In the existing and scenario condition happens saturated traffic flow, traffic jam, quite long queues, and vehicles stuck.

From the results of the analysis using Synchro software for the US-HCM 2000 method, there is a significant difference compared to the MKJI 1997 method. By using Synchro Software, the degree of saturation obtained becomes very large, this may be due to the inaccurate modeling in the application compared to the actual conditions. Conclusion with these considerations in mind and traffic behavior in Indonesia, the results of the analysis used are the 1997 MKJI reference method.
To overcome the problems in Roundabout, traffic engineering is needed. Based on design analysis, the most appropriate engineering is arranging entrance and exit movement in Approach 1 and applying contraflow at $W_{1-2}$. This decreases ICU numbers at the intersection of Approach 1 and Approach 2, from 296.1% to 121.4%. It also reduces conflict points in all approaches.

References
[1] Pande A and Wolshon B 2016 *Traffic Engineering Handbook 7th Edition* (New Jersey: John Wiley & Sons)
[2] Findley D J, Smith M S, Carwile R W, Gulden J and Garza J D L 2015 *Traffic Engineering Studies* in *Traffic Engineering Handbook* (New Jersey: John Wiley & Sons) p 109–148
[3] Pignataro L J and Cantilli E J 1973 *Traffic Engineering: Theory and Practice* (New Jersey: Prentice-Hall)
[4] Rodegerdts L 2004 *NCHRP 3-65: Applying Roundabouts in the United States* (Information for the Highway Capacity and Quality of Service Committee)
[5] Directorate General Bina Marga 1997 *Manual Kapasitas Jalan Indonesia* p 564
[6] Transportation Research Board 2016 *Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis* (Washington, DC: The National Academies Press)
[7] Cubic ITS Inc 2019 *Synchro Studio 11 User Guide* (Texas: Cubic ITS Inc.)
[8] Kim B -I and Jeong S 2009 *Comput. Ind. Eng.* 56 70–76
[9] Tamin O Z 2000 *Perencanaan dan pemodelan transportasi* (Bandung: Penerbit ITB)
[10] Sigit T A 2017 *Analisis dampak lalu lintas akibat pembangunan hotel ibis yogyakarta dengan pendekatan four step model* (Final Project Universitas Muhammadiyah Yogyakarta)
[11] Rahayu H, Wijaya M H, Setiadji B H and Kushardjoko W 2013 *J. Karya Tek. Sipil.* 2 174–181
[12] Blunden W R and Black J A 1984 *The land-use/transport system* 2nd Edition (Australia: Pergamon Press)