Impact of dedicated mini roundabout on the capacity and level of services of the unsignalized intersection

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Abstract. This paper is aiming at investigating the impact of dedicated mini-roundabout on the capacity and level of services at a four-legged unsignalized intersection. The assessment was carried out based on two scenarios namely before the installation mini-roundabout (existing) and after installation (improvement). Datasets were collected at Ujung Stasiun KA unsignalized intersection, which is in the center of Bireuen City, Aceh province of Indonesia. A video-cameras are installed to observed traffic patterns including hourly volume, movement trajectories, and vehicle composition during three days on a morning, afternoon, and evening peak hour traffic. The Indonesian highway capacity manual (IHCM, 1997) is used to evaluate the capacity and level of service in existing conditions while the simulation approach using VISSIM is then performed to assess the scenario of virtual implementation dedicated mini roundabout. The result of analysis demonstrates that the capacity of unsignalized slightly increases by 5% while the delay and level of service are significantly reduced to 42% (31.02 sec to 18 sec), and improved from E to C, for delay and LOS, respectively. It can be concluded that the improvement of the existing condition by implemented a dedicated mini roundabout could improve the capacity and LOS in the study area.

1. Introduction

Unsignalized intersections are one of the major traffic facilities implemented in emerging cities including in Bireuen City, Aceh province of Indonesia. Such traffic facility has significantly affected the quality of services of urban road network especially traffic condition in the area highly consists of motorcycles and cars. Moreover, drivers' behaviors in developing countries are extremely complicated, for instances they do not follow lane discipline, easy to maneuver (lane changing) and ignoring safety gab during driving. This driving condition has significantly degraded the capacity and level of services of the unsignalized intersection. Several previous studies have noticed that the quality of services of urban corridors are noticeably dependent on how traffic mechanisms occur within the systematic [1] and virtual bottlenecks such as interference on median opening [2], disturbance on the on-street segment [3], driving maneuver at roundabout [4]. These findings decided that the U-turn and on-street parking behaviors are drastically influenced by the traffic mechanism on its segments.

A roundabout is one of the types of an intersection that forms at least three-legs and plays a vital role in delivering traffic [4]. The roundabout is mostly installed at the center of the intersection and normally has an elevated level compared to the normal road surface. This could avoid drivers passing through the roundabout. The roundabout is also one of an unsignalized intersection especially deal with moderate traffic volume. Troutbeck and Brilon [5] says that the roundabout may be less potential for traffic
accidents since traffic flow merges and diverges at small angles and lower speeds. Additionally, the roundabout has been widely implemented as a substitute for unsignalized intersection due to its benefit in decreasing delay and delivering a safer vehicle’s movement compared with ordinary unsignalized intersection. Lastly, the roundabout is also provided better capacity as contrasted to a two-way-stop controlled or an all-way-stopped control intersection, under low traffic demand [6].

The Indonesian Capacity Highway Capacity Manual (IHCM) 1997 [7] is a guide for engineers and planners for planning, designing and operating traffic facilities in Indonesia. This traffic code consists of urban street facilities, roundabout, highways and including signalized and unsignalized intersections. As regards to unsignalized intersection operation, the dynamic vehicles and driver’s behavior sometimes create irregularity movements within the conflict area of unsignalized intersection. The drivers mostly always rejected the and the role of priority movement at unsignalized intersection they ignored. This situation is repeatable and occurs most of the time particularly during peak hour traffic. It should be noted that traffic breakdown in emerging cities could be induced either by high traffic demand or the irregularity movement created by drivers within the conflict area. In this case, managing movements of the road users within the conflict area could improve the regularity traffic movements. Since roundabout able to circulate the movement, it should be reduced potential conflict by the driver and enhance the quality of service of the intersection.

To sum, therefore, this paper is aiming at investigating the impact of dedicated mini-roundabout on the capacity and level of services at a four-legged unsignalized intersection. The assessment was carried out based on two scenarios namely before the installation mini-roundabout (ex-ante) and after installation (ex-post). Datasets were collected at Ujung Stasion KA unsignalized intersection, which is in the center of Bireuen City, Aceh province of Indonesia. A video-cameras are installed to observed traffic patterns including hourly volume, movement trajectories, and vehicle composition during three days on a morning, afternoon, and evening peak hour traffic. IHCM 1997 is used to evaluate the capacity and level of service in existing conditions while the simulation approach using VISSIM is then performed to assess the scenario of virtual implementation dedicated mini roundabout. The remainder of this paper is organized as follows. The following section describes the area study, data collection, and processing. The next section explains the analysis method using IHCM and the setting of simulation using VISSIM. Lastly, discussions and conclusions are presented at the end of the paper.

2. Area of Study, data Collection and processing

Figure 1 shows the area of study in which the targeted location is one of the most congestion and irregular traffic movement within the city of the Bireuen. The intersection named Ujung Stasiun KA in which this intersection has four-legged with no priority roles are operated. It is observed that the traffic movements at the targeted intersection mostly consists of passenger car and motorcycle, and a few of them are heavy vehicles such as bus or truck.

Regarding the data collection method, the geometric condition including approach width, lane width, the dimension of intersection and conflict area was measured directly onsite by surveyors. As for geometric was observed during off-peak hour traffic to avoid obstacles due to high traffic. These geometric data were measured directly and filled to the form of the survey by surveyors. In addition to this, the side friction data has also collected directly on site. It is observed that the targeted intersection was considerably had medium to high side friction. This partially due to the location of intersection is located in the dense urban road which pedestrian, entry-exit vehicle at parking lots, the slow-moving vehicle is quite significant even if non-motorized transport is less observed. Furthermore, Traffic stream data such as trajectory movements, signs, and typical potential traffic conflict were observed directly at the location. Moreover, traffic stream data such as volume, vehicle composition, and type of vehicle movements were recorded using a video camera for each approach. The cameras were mounted on the high-rise building at the location of the survey. Traffic stream characteristic was recorded during peak hour traffic within the morning peak (07:15-08:50), afternoon (12:00-14:00) and evening (16:30-18:00).
The traffic data was extracted in the traffic system laboratory from the recorded video camera. At first, recorded video data was extracted to get traffic volume and composition for each approach of the intersection. Then, the trajectories of vehicle movements have also observed by replaying recorded videos in traffic laboratories. Finally, all processed data related to traffic stream characteristics within the intersection were tabulated in Ms. Excel before used in the analysis. As mentioned before, the analysis in this study is focused on capacity and level of services considering two scenarios, that is the existing condition (unsignalized intersection) and implemented dedicated mini roundabout (improvement of an existing. The method used for the analysis will be described in the following section.
3. Analysis method

In this study, as mentioned above, the data analysis consists of two scenarios namely (1) assessing the capacity and level of service considering unsignalized intersection (existing scenario), and (2) determining new capacity and level of services when the dedicated mini roundabout implemented. As for evaluating the existing scenario, the IHCM 1997 is used for evaluating the capacity of the unsignalized intersection. The level of service is then determined using the Ministry of Transportation Decree [8]. The level of service (LOS) for unsignalized intersection is based on the average delay (second/PCU) and classified them as LOS A to F (see Table 1). It should be noted that according to the Ministry of Public Work Decree [9] the upper limit of degree of saturation (DS) is 0.85, and 0.9 for arterial/collector, and local road, respectively. As regards to the second scenario, the evaluation of a dedicated mini roundabout is assessed using the microsimulation approach implemented in VISSIM. The radius and diameter of the mini roundabout were modelled using VISSIM and then observed traffic demand is tested into the VISSIM simulation model.

Table 1. The Level of Service (LOS) Criteria.

| Criteria | Average Delay (Second/PCU) |
|----------|---------------------------|
| A        | < 5                       |
| B        | 5-10                      |
| C        | 11-20                     |
| D        | 21-30                     |
| E        | 31-45                     |
| F        | > 45                      |

Source: The Ministry of Transportation Decree [8]

The IHCM 1997 defines the capacity of unsignalized intersection consists of a multiplicative model among base capacity \( C_0 \) with adjustment factors such as adjustments factor for approach width \( F_W \), type of median \( F_M \), city size \( F_CS \), the ratio of unmotorized \( F_RSU \), the ratio left turn vehicle \( F_LT \), the ration right turns vehicle \( F_RT \) and the ratio of flow from the minor road \( F_MI \), as it is written in Equation (1).

\[
C = C_0 \times F_W \times F_M \times F_CS \times F_RSU \times F_LT \times F_RT \times F_MI
\]  

(1)

Where \( C \) represents the capacity (PCU/hr), and \( C_0 \) is base capacity defined using default value in IHCM 1997 chapter 2 (unsignalized intersection). As for the delay, the IHCM has consisted of two delay namely delay due to traffic stream (DT) and delay due to geometric condition (DG). The DT must be determined using the delay curve versus the degree of saturation Figure C-2:1 and Figure C-2:2 (IHCM, Chapter 2, page 3:40-41). The DG can be calculated using equation (2) for \( DS < 1 \), and equation (3) for \( DS \geq 1 \).

\[
DG = (1-DS) \times (PT \times 6 + (1-P_T) \times 3) + DS \times 4 \quad \text{(second/PCU)}
\]  

(2)

\[
DG = 4
\]  

(3)

The simulation method is employed to analyze the implementation of the mini roundabout. Traffic simulation is distinguished into three categories mainly microscopic, mesoscopic, and macroscopic. Microscopic models predict the state of individual vehicles and primarily focus on individual vehicle speeds and locations. Macroscopic models aggregate the description of traffic flow, and the measures of effectiveness, which are speed, flow, and density [10].

The VISSIM has been widely used to simulate traffic performance based on the improvement scenario, for example testing roundabout improvement [11-13]. The VISSIM is a microscopic, time step
and a behavior-based simulation model developed to model urban traffic and public transit operations. The VISSIM stands for “Verkehr Städten–SIMulationsmodell” which is developed by Planung Transport Verkehr AG (PTV-AG) in Karlsruhe Germany. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops, and it makes uses tool for the evaluation of various alternatives based on the transportation engineering and planning measures of effectiveness.

In this study, the simulation model using VISSIM is involved in several steps such as (1) proposed a new type of traffic operation, (2) coding network/calibrated geometric condition, (3) establish the measurement of effectiveness (MOEs), (4) generating several numbers of seeds for multiple runs, usually 5 to 10 times, (5) established a value of simulation time, the default value of 3600 seconds for VISSIM, (6) running simulations to obtain the MOEs. These steps practically can be done by several instructions namely (1) input background, (2) network coding, (3) building link-connector, (4) vehicle/traffic input, (5) inputting desire speed, (6) inputting vehicle compositions, (7) assigning vehicle route, (8) calibrating driving behaviour’s, (9) setting simulation runs and random seeds, (10) simulation runs, (11) establishing MOEs, (12) evaluating assessment of new proposed traffic operation.

4. Analysis of results and discussion

After conducting field observation, the aggregation of traffic flow data has shown maximum flow obtained during evening peak hours (16:30-18:00). Therefore, the analysis explained in this section is based on the evening peak hours data set observation. Figure 3 depicts traffic flow during evening observation in PCU/h for each of the approaches. The composition of the vehicle is classified into three types of common vehicles namely motorcycle (MC), light vehicle (LV) and heavy vehicle (HV). To convert the mixed traffic condition into the homogenous one, the term of passenger equivalent unit (PCU) is used. The PCU is a unit to measure various vehicles into a unit of LV by multiplying them with passenger car equivalent (PCE). The PCEs used in this study are based on the value in IHCM 1997.

Figure 3 shows that the traffic flow has shown about 763, 635, 515, and 286 PCU/h for Yoesoef Bahroen, Pemuda, Prof. A. Majid Ibrahim, and Gampong Geudong, respectively. The traffic flow has considerably dominated at Pemuda and Yoesoef Bahroen approaches. Looking at vehicle composition, Figure 4 has presented the distribution of vehicle composition among MC, LV, and HC. Notably, the
MC has dominated the traffic accounting for 95, 83, 89, and 74% for Gampong Geudung, Pemuda, Prof. A. Majid Ibrahim, and Yoesoef Bahroe approaches. Following by LV approximately accounted for an average between 10-21% for all approaches, and less than 5% of them are HV observed in study.

![Figure 4. Distribution of traffic composition.](image)

**Table 2. The Capacity of Unsignalized Intersection (Existing).**

| Performance Measures* Descriptions | Average Approach Width (m) | Base capacity $C_0$ (PCU/h) | Calculated Capacity | Hourly Volume (PCU/h) | Calculated Total Delay (sec) | *Degree Of Saturation (DS) | **Level of Services (LOS) |
|------------------------------------|---------------------------|----------------------------|---------------------|-----------------------|-----------------------------|---------------------------|--------------------------|
| Value of Performance Measures     | 4.275                     | 2,900                      | 3,834               | 4382                  | 31.02                       | 1.14                      | E                        |

*traffic performance calculated using [7] and LOS using [8]

As mentioned in section 3, the capacity was calculated utilizing the IHCM formula [7] as it is shown in equation (1) and delay calculation using equation (2-3). The calculated delay is utilized to determine the level of service using the Ministry of Transportation Decree [8]. Table 2 summarizes the calculation of capacity, delay, and level of service in existing conditions before simulating using dedicated mini roundabout. Considering an existing condition with an unsignalized intersection the capacity can be obtained as much as 3,834 PCU/h and the total delay has shown 31.02 sec. The DS value can be computed by dividing the observed hourly volume to capacity, the DS value is about 1.14. Using the Ministry of Transportation Decree [8], then the LOS criteria of E is determined. The LOS of E has meant that the traffic performance using unsignalized intersection has been considerably oversaturated and certain improvement must be proposed.
Figure 5. Simulation dedicated roundabout using PTV Vissim (Academic licensed to Universitas Syiah Kuala).

Table 3. The capacity dedicated mini roundabout.

| Simulation Run/Seed Number | Simulation Interval (sec) | Queue Length (QlenMax) | Dynamic capacity (PCU/h) | Total Delay (sec) | Level of Services (LOS) Value | Level of Services (LOS) |
|---------------------------|--------------------------|------------------------|--------------------------|-------------------|-------------------------------|------------------------|
| 1                         | 900-4500                 | 47.36                  | 4,012                    | 18.06             | 3                             | C                      |
| 2                         | 900-4500                 | 50.89                  | 4,028                    | 18.65             | 3                             | C                      |
| 3                         | 900-4500                 | 42.05                  | 4,058                    | 17.31             | 3                             | C                      |
| 4                         | 900-4500                 | 28.94                  | 3,946                    | 17.88             | 3                             | C                      |
| 5                         | 900-4500                 | 40.48                  | 4,040                    | 18.10             | 3                             | C                      |
| Average                   |                          |                        |                          | 41.95             | 4,017                         | 18.00                  | 3                      | C                      |
| Standard Deviation        |                          |                        |                          | 8.37              | 43                            | 0.48                   | -                      | -                      |
| Maximum                   |                          |                        |                          | 50.89             | 4,058                         | 18.65                  | 3                      | C                      |

As regards the improvement for an existing condition, the dedicated mini roundabout with 4 m diameter is testing and simulating to obtain related traffic performance measures. Figure 5 illustrates the simulation setting and process using PTV VISSIM. The procedures of simulation using VISSIM has been explained in section 3. To ensure the consistency of stochastic nature, the simulation has considered generating 5 random seed as recommended by [2-3], [14]. Table 3 summarizes the measurement of effectiveness (MOE) obtained from the simulation. The MOEs consists of a maximum of queue length, the capacity, and obtained LOS. The average value of MOEs is 41.95 sec, 4,017 PCU/h, and C for a maximum of queue length, the capacity, and obtained LOS, respectively.

Comparing the performance measures among existing (unsignalized intersection) with the improvement (implemented roundabout) has considerably improved the performance in terms of capacity and LOS. The capacity seems to increase from 3,834 PCU/h to 4,017 PCU/h or improve about 5% compared to the existing condition. While the delay has dropped for about 42% (31.02 sec to 18...
This enhances the value of delay leads to an increase in the LOS from E to C. The LOS of C is considerably excellent services for the urban street facility. Therefore, it can be concluded that the improvement of the existing condition by implemented a dedicated mini roundabout could improve the capacity and LOS in the study area.

5. Conclusion
This paper investigates the impact of dedicated mini-roundabout on the capacity and level of services at a four-legged unsignalized intersection. The Indonesian highway capacity manual (IHCM, 1997) is used to evaluate the capacity and level of service in existing conditions while the simulation approach using VISSIM is then performed to assess the implementation dedicated mini roundabout. The result of analysis demonstrates that the capacity of unsignalized slightly increases by 5% while the delay and level of service are significantly reduced to 42% (31.02 sec to 18 sec), and improved from E to C, for delay and LOS, respectively. It can be concluded that the improvement of the existing condition by implemented a dedicated mini roundabout could improve the capacity and LOS in the study area.

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