Analysis of unsignalized intersection upgrading at constrained area in the city of Banda Aceh

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Abstract. The city of Banda Aceh is the capital city of Aceh province. The city’s population is 259,913, and the city’s annual population growth rate is 1.97% (BPS, 2018). Punge intersection is one of the intersections in Banda Aceh; this intersection is passed by the numerous and dense traffic. Based on the observation in certain hours at Punge intersection, it reveals several problems, namely: the intersection capacity and the performance level of the intersection. As a result, this study is aimed to evaluate the performance of Punge intersection. The intersection calculation was based on the Indonesia Highway Capacity Manual (MKJI, 1997). The benefit that can be obtained from this research is to eliminate traffic conflict. According to the survey, it was discovered that the dominant traffic (3,053 pcu/hours) was at the Sultan Iskandar Muda Street, D, from the central city to Ulee Lheu; on the contrary, only a few traffic (559 pcu/hours) passed on Cempaka Punge Jurong Street, A. By way of conclusion, the intersection capacity is inadequate because the degree of saturation has exceeded 0.85, viz 1.851. Therefore, Simpang Punge needs some improvements, such as repairing traffic lights and its geometric.

1. Introduction
The highway is one of the infrastructures for smoothing traffic either in a city or rural area. One part of the highway considered vitally important to be analyzed and evaluated is the intersection. The intersection is the meeting point of the highway network; this is because at the intersection often creates various traffic barriers.

The city of Banda Aceh is the capital city of Aceh province, with 259,913 citizens and an annual population growth rate reached 1.97% [1]. The origin-destination transportation occurred at Punge intersection was partly caused by the highway access permit of the city of Banda Aceh, access to offices, schools, historical sites, and tourist attractions. Such conditions cause a high concentration of movement to the Punge intersection area. The spatial pattern formed in that intersection consists of mixed areas filled with various types of activities such as trade in services, offices, public facilities, and settlements. At Punge intersection area, there is a node meeting for three secondary arterial roads, namely: Sultan Iskandar Muda Street, Punge Blang Cut Street, and Cempaka Punge Jurong Street.

From the mentioned problem, the purpose of the study is to evaluate the performance of the Banda Aceh Punge intersection to avoid traffic conflicts and discover intersection capacities, degree of saturation, delay and queue opportunities in 4-arm signal intersections, as well as solutions or alternative
solutions for traffic congestion problem at the intersection. The benefit of this research is to eliminate traffic conflicts disrupting traffic flow and driver safety. This is because there is no adequate infrastructure for road users at the intersection.

The scopes of the research are the capacity and performance level (degree of saturation and delay). Intersection calculations are based on the Indonesian Road Capacity Manual (MKJI 1997). Data retrieval is conducted for 3 days, namely: Monday, Thursday, and Sunday, in which the peak hours are in the morning office hours (07:00 – 09:00 WIB), noon (13:00 – 15:00 WIB), and afternoon (17:00 – 19:00 WIB).

2. Study literature

2.1. Intersection

The intersection is a point at which traffic flow conflict occurred. This is because the intersection commonly is a buildup of vehicles, especially during peak hours; this can cause congestion and accidents due to meeting one vehicle with another vehicle from the opposite direction [2]. The type of intersection based on the method of arrangement can be grouped into 2 (two) types, namely:

2.1.1. Unsignalized intersection. Intersections that do not use traffic signals. At this intersection road, users must decide whether they are safe enough to cross the intersection or must stop before passing the intersection [3].

2.1.2. Signalized intersection. At signalized intersections, road users can pass intersections according to the operation of traffic signals. So road users can pass it only when the traffic signal shows green on the arm of the junction.

Based on the type, the intersection, in general, consists of a plot of an intersection, intersection with splitting road lanes without a ramp, and interchanges. A plot of intersection is the intersection where two or more highways joined in which each highway leads out from a junction and forms part of it. These roads are called intersections [4].

2.2. The intersection point of conflict

In the intersection area, vehicles and pedestrians will intersect at a point of conflict; this conflict will reduce the movement and a potential location for accidents.

Traffic flow affected by the conflict at an intersection has a complex behavior: any movement turn left, turn right, or straight, each facing a different conflict and behavior associated with the movement [5]. The point and the kind of maneuver can be seen in figure 1 below.

Figure 1. Potential points on the intersection [2].
2.3. Intersection setting objectives
The main purpose of setting the intersection is to maintain the security of the current flowing, to provide clear instructions, so it does not cause any doubt. Traffic control at intersections can be achieved using traffic lights, markers and signs, directions, and traffic islands [6]. From the selection of the intersection, it can be found the objectives that are as follows:
1. Both reducing and avoiding the possibility of accidents from various conflict point conditions.
2. Maintaining the capacity of the intersection so that the intersection can be achieved in its operation as planned.
3. In its operation of a deviation arrangement, it must provide clear and definite simple instructions that direct traffic in a suitable and safe place.

2.4. Level of service (LoS)
The level of service is a measure of road work performance or intersection that is calculated based on the level of road use, speed, density, and obstacle occurred [7]. LoS can be seen in the following table:

| Level Of Service (Los) | Capacity reserve (Cr) |
|------------------------|-----------------------|
| A                      | > 400                 |
| B                      | 300 – 399             |
| C                      | 200 – 299             |
| D                      | 100 – 199             |
| E                      | 0 – 99                |
| F                      | -                     |

2.5. Unsignalized-intersection capacity
The capacity is the maximum traffic flow that can be maintained on a section of road under specific conditions expressed in vehicles/hour or pcu/hour [2]. The total capacity of an intersection can be expressed by multiplying the basic capacity (Co) and adjustment factors (F). The formulation according to MKJI intersection capacity (1997) is written as follows:

\[ C = C_o \times F_W \times F_M \times F_{CS} \times F_{RSU} \times F_{LT} \times F_{RT} \times F_{MI} \]  

Information:
\( C \) = Actual capacity (according to existing conditions),
\( C_o \) = The value of the base capacity,
\( F_W \) = Approach width adjustment factor,
\( F_M \) = The adjustment factor for the main street,
\( F_{CS} \) = The adjustment size of the city factor,
\( F_{RSU} \) = The adjustment types of side barrier road environment and unmotorized vehicles factor,
\( F_{LT} \) = Turn Left adjustment factor,
\( F_{RT} \) = Turn Right adjustment factor, and
\( F_{MI} \) = Minor road flow factor.

2.6. Degree of saturation (DS)
The degree of saturation (DS) is the ratio of actual traffic flow (pcu/hour) to capacity (pcu/hour). The most appropriate way to assess the results of the calculations that we do is to look at the degree of
saturation (DS) for the observed condition. If the saturation obtained exceeds the received value (DS > 0.85), it is necessary to correct the geometric of an intersection, control the total drift current and adjust the current with the signs to maintain the desired degree of saturation (DS < 0.85) [8]. The formulation according to MKJI degree of saturation (1997) is written as follows:

\[
DS = \frac{Q_{tot}}{C} \tag{2}
\]

Information:
- DS = Degree of saturation,
- C = Capacity (pcu / hour), and
- \(Q_{tot}\) = real total current (pcu / hour).

2.7. Delay (D)
The delay at the intersection is the total average of time obstacles experienced by the vehicle when passing an intersection [6]. This obstacle arises if the vehicle stopped because the queue is deviated until the vehicle exit the intersection due to the influence of inadequate intersection capacity. The delay value affects the value of the travel time of the vehicle. The higher the value of delay, the higher the travel time.

Delays in traffic are divided into 5 types, namely:

1. Average traffic delay for all intersections (DTi)
   - DTi traffic delay (seconds/pcu) is the average delay for all vehicles entering the intersection. Delay (DTi) is determined from the empirical relationship between delay (DTi) and degree of saturation.
   - For DS < 0.85:
     \[
     DTi = 2 + 8,2078 \times Ds - (1 - Ds) \times 2 \tag{3}
     \]
   - For DS > 0.85:
     \[
     DTi = \frac{1,0504}{(0,2742 - 0,2042 \times Ds) - (1 - Ds) \times 2}. \tag{4}
     \]
2. Average traffic delay for major roads (DTMA)
   - For DS < 0.85:
     \[
     DTMA = 1.8 + 5.8234 \times Ds - (1 - Ds) \times 1.8 \tag{5}
     \]
   - For DS > 0.85:
     \[
     DTMA = \frac{1.05034}{(0.346 - 0.246 \times Ds) - (1 - Ds) \times 1.8}. \tag{6}
     \]
3. Traffic delays average minor road (DTMI)
   - The minor road traffic delay is determined based on the average traffic delay (DTi) and the major road traffic delay (DTMA).
   \[
   DTMI = (Q_{TOT} \times DTi - Q_{MA} \times DTMA) / Q_{MI} \tag{7}
   \]
4. Geometric delay intersection (DG)
   - Geometric delay intersection is the average geometric delay of all motorized vehicles entering the intersection. DG is calculated using the equation:
   - For DS ≤ 1.0:
     \[
     DG = (1 - DS) \times (PT \times 6 + (1 - PT) \times 3) + DS \times 4 \tag{8}
     \]
   - For DS ≥ 1.0:
     \[
     DG = 4 \text{ seconds/pcu} \tag{9}
     \]
5. Intersection delay (D)
   - The intersection delay is calculated using the following equation:
     \[
     D = DG + DT \tag{10}
     \]
2.8. Opportunities queue (QP%)
The opportunities queue (QP %) is the possibility of a queue with two or more vehicles in any approaching area at an unsigned intersection. The limit of the opportunity queue value (%) is determined from the empirical relationship between the opportunity queue (%) and the degree of saturation (DS) [9]. Opportunities queue with an upper limit and a lower limit can be obtained using the following formula:

Upper limit:
\[ QPa = (47.71 \times DS) - (24.68 \times DS^2) + (56.47 \times DS^2) \]  
(11)

Lower limit:
\[ QPb = (9.02 \times DS) + (20.66 \times DS^2) + (10.49 \times DS^2) \]  
(12)

Information:
DS = Degree of saturation,
Qpa = Opportunity for upper queue (%), and
QPb = Opportunity for lower queue (%).

3. Research methods

3.1. Data processing and analysis methods
Data needed to analyze capacity and delays at the intersection of Punge are as follows:
1. Data on traffic volume for each group of crossings during rush hour
2. Geometric data of the road (width and number of lines)
3. Data about environmental conditions and land use in the intersection area.

Data collection was conducted at the Punge Banda Aceh intersection. At the intersection, there are 4 (four) arms. Each arm is placed in a post consisting of 3 (three) personnel. Each person must record the volume of the vehicle moving straight, the vehicle turning right, and the vehicle turning left, all on each crossing arm. For the calculation of non-signaled intersection, the MKJI 1997 form is used with the respective functions including:
1. Step A: input data.
   a. Geometric conditions.
   b. Traffic conditions.
   c. Environmental conditions.
2. Step B: capacity.
   a. The width of the approach and the type of the intersection.
   b. Basic capacity.
   c. The factor of median adjustment for the main road.
   d. The factor of city size adjustment.
   e. Adjustment factors for environmental types, side barriers, and non-motorized vehicles.
   f. The adjustment factor for turning left.
   g. The adjustment factor for turning the right.
   h. The minor road flows adjustment factor
3. Step C: level of performance.
   a. Degree of saturation.
   b. Delay

4. Results and discussion

4.1. Geometric intersection
This research was conducted by reviewing the volume of traffic flow vehicles on Sultan Iskandar Muda Street, Punge Blang Cut Street, Punge Jurong Street, and Punge intersection, in the city of Banda Aceh. The location is in the west of Banda Aceh which leads to tourist attractions, schools, and others. For more details, the location can be seen in figure 2. The intersection of geometric measurement results
obtained directly on a research location by measuring the width of the effective arm closers on each sleeve using a tape meter.

The roads that are studied in this research have different types. The main road, which is Sultan Iskandar Muda Street (from Ulee Lheu to the city center) has the type of 6/2D road and secondary arterial road. In terms of Sultan Iskandar Muda Street (from the direction of the city to Ulee Lheu), the type is 2/1UD and secondary arterial roads. For Punge Blang Cut Street (minor), the type is 2/1UD roads and secondary arterial roads. For Punge Blang Jurong Street (minor), the type is 2/1UD and secondary arterial roads.

4.2. Volume of traffic flow

Based on the results of a survey conducted for 3 (three) days, the peak traffic flow volume falls on Sundays, November 1, 2015, afternoon, at 17:00 – 19:00 WIB. The information is presented in Table 2.

| Intersection arm | MC number of vehicles (%) | LV number of vehicles (%) | HV number of vehicles (%) | UM number of vehicles (%) |
|------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| A                | 514 92                    | 40 7                      | 5 1                       | 0 0                       |
| B                | 2,028 68                  | 953 32                    | 5 0                       | 1 1                       |
| C                | 876 87                    | 129 13                    | 4 0                       | 0 0                       |
| D                | 2,283 75                  | 755 25                    | 6 0                       | 0 0                       |

From Table 2 above, at the intersection, the road most passed by vehicle is the Sultan Iskandar Muda Street (city center to Ulee Lheu), which coded as D. The most dominant vehicle passing the street is the motorized vehicle (MC) that number is 2,283 pcu/hour or 75% of total vehicles. The road, with the least amount of vehicles passing it, is Cempaka Punge Jurong Street, coded as A. The most dominant vehicle passing the street is the motorized vehicle (MC), which is 514 pcu/hour or 92%. The above table shows that the motorcycle (MC) still dominates on each arm closers while heavy vehicles (HV) are the smallest.
percentage number of vehicles on each arm closers.

4.3. Calculation of survey data

The survey data of Sunday (afternoon), November 1, 2015 and the comparison are as follows:

1. The intersection capacity
   a. Width of the approach
      \[ W_1 = \frac{(a/2 + b + c/2 + d/2)}{4} \] (the median exists in the B arm)
      \[ W_1 = \frac{(1.8/2 + 9 + 1.8/2 + 1.8/2)}{4} \]
      \[ W_1 = 2.93. \]
   b. Basic capacity (C_0)
      Because the intersection of Punge is not currently compatible with the type of intersection in MKJI (1997), the author considers that the type of intersection of Punge is suitable to the type of 422 which basic capacity value (C_0) is 2,900.
   c. Adjacent adjustment factor (F_W)
      FW value is obtained from the calculation of the average width-types closers with 422.
      \[ F_W = 0.70 + 0.0866 \times W_1 \]
      \[ F_W = 0.70 + 0.0866 \times 2.93 \]
      \[ F_W = 0.953. \]
   d. The main road median adjustment factor (F_M)
      As a result, the median type is narrow. F_M is 1.05.
   e. The size of the city of Banda Aceh is 249,282 people; the city size class (F_CS) is 0.1 – 0.5 million people (a small category). The value (F_CS) is 0.88.
   f. For adjustment factor type of commercial road environment, the obstacles = \( \frac{U_M}{MP} = 0.00 \), which is a medium side. Unmotorized vehicles (P_UUM) is 0.00, so F_RSU is 0.94.
   g. Turning left adjustment ratio \( (F_{LT}) \)
      \[ F_{LT} = 0.84 + 1.61 \times P_{LT} \] \hspace{1cm} (13)
      Information ;
      \[ F_{LT} = \text{Turning left adjustment ratio} \]
      \[ P_{LT} = \text{Turning left input variables (Form-I, using Line 20, Column 11).} \]
      Then:
      \[ F_{LT} = 0.84 + 1.61 \times P_{LT} \]
      \[ F_{LT} = 0.84 + 1.61 \times 0.14 \]
      \[ F_{LT} = 0.84 + 1.61 \times 0.14 \]
      \[ F_{LT} = 1.058. \]
   h. The turning right adjustment ratio (P_RT) is 1.
   i. The closers adjustment factor for the current minor road (F_MI).
      This condition is related to the code of 422 intersections with PMI values of 0.1845.
      \[ F_{MI} = 1.19 \times P_{MI}^2 - 1.19 \times P_{MI} + 1.19 \]
      \[ F_{MI} = 1.19 \times 0.1845^2 - 1.19 \times 0.1845 + 1.19 \]
      \[ F_{MI} = 0.011. \]
   j. Capacity (C)
      \[ C = C_0 \times F_W \times F_M \times F_{CS} \times F_{RSU} \times F_{LT} \times F_{RT} \times F_{MI} \]
      \[ C = 2,900 \times 0.953 \times 1.05 \times 0.88 \times 0.94 \times 1.058 \times 1 \times 1.011 \]
      \[ C = 2,569 \text{ pcu/hour} \]
The maximum capacity value at the intersection is 2,569 pcu/hour, which does not exceed the basic capacity of 2900 pcu/hour.

2. Level of performance

Level of performance includes:

a. The degree of saturation (DS)

\[ DS = \frac{Q_{tot}}{c} = \frac{4754}{2569} = 1.851 \]

From the calculation results, the DS value has exceeded the required DS value, namely DS > 0.85.

b. Delay (D)

- Delay traffic intersection

\[ DT_i = \frac{1.0504}{(0.2742 - 0.2042 \times Ds)} - (1 - Ds) \times 2 \]

\[ DT_i = -8.43 \text{ det/smp.} \]

The minus value (-) in calculating the traffic delay (DT) is obtained because the formula provided in MKJI is only valid for DS ≤ 1.2. Thus, the value of the actual delay is estimated to exceed 30 seconds/pcu.

- Delay the main street on traffic (DTMA)

\[ DT_{MA} = \frac{1.05034}{(0.346 - 0.246 \times Ds)} - (1 - Ds) \times 1.8 \]

\[ DT_{MA} = -8.08 \text{ det/smp.} \]

- Delay minor road on traffic (DTMI)

\[ DT_{MI} = \frac{(Q_{TOT} \times D_{TI} - Q_{MA} \times DT_{MA})}{Q_{MI}} \]

Information:

\[ Q_{MA} = \text{taken from the cabbage USIG-I form.} \]

\[ Q_{MI} = \text{taken from the cabbage USIG-I form.} \]

\[ DT_{MI} = (Q_{TOT} \times D_{TI} - Q_{MA} \times DT_{MA}) / Q_{MI} \]

\[ DT_{MI} = (2.569 \times -8.43 - 3.876.5 \times -8.08) / 877 \]

\[ DT_{MI} = -9.96 \text{ det/smp.} \]

value minus (-) in the calculation of the main road traffic delays (DTMA) obtained for DTi and DTMA.

- Delay geometric of intersection (DG)

\[ DG = 4 \]

- Intersection Delay (D)

\[ D = DG + DT_{I} = 4 + (-8.43) = -4.43 \text{ second/pcu.} \]

The minus value (-) in calculating the traffic delay (D) is obtained because the DTi value is minus (-).

3. Opportunities queue (QP%)

Upper limit : \[ QPa = (47.71 \times DS) - (24.68 \times DS^2) + (56.47 \times DS^2) \]

\[ = (47.71 \times 1.851) - (24.68 \times 1.851^2) + (56.47 \times 1.851^2) \]

\[ QPa = 326 \text{ %}. \]

Lower limit : \[ QPb = (9.02 \times DS) + (20.66 \times DS^2) + (10.49 \times DS^2) \]
\[
Q_{Pb} = (9.02 \times 1.851) + (20.66 \times 1.851^2) + (10.49 \times 1.851^2)
\]

By the value of \(Q_{Pa}\) and \(Q_{Pb}\) above 100\%, it can be concluded that the queues are inevitable at this intersection.

4. Level of services

The level of service at the intersection of Punge is categorized as B, which is the stable flow characteristics (speed slightly limited by traffic, the volume of services is used for the design of the outside lane of the city). Based on calculations, the intersection of Punge has a very high DS value which already exceeds 1.851 and DS that exceeds 0.85. If the width of the approach of Sultan Iskandar Muda Street (city center to Ulee Lheu), coded as D, is changed or equal to the width of the approach to Sultan Iskandar Muda Street (Ulee Lheu to city center), coded as B, the DS value still does not meet the requirements (DS > 0.85).

5. Conclusions and suggestions

5.1. Conclusions

From the analysis carried out, the following conclusions are obtained:

1. For traffic volume on Sunday (afternoon at 17:00 – 19:00 WIB), the highest number of vehicles is 3,053 pcu/hour, which passed on Sultan Iskandar Muda Street (city center to Ulee Lheu), and the road having the least traffic was the Cempaka Punge Jurong Street, with a total number of 559 pcu/hour.

2. On Sunday, the highest DS degree of saturation was occurred in the afternoon, at 17:00 – 19:00 WIB, which is equal to 1.851.

3. The maximum capacity value is 2,569 pcu/hour; it does not exceed the basic junction capacity that is equal to Co of 2,900 pcu/hour.

4. At the Banda Aceh Punge intersection, there is a chance of queuing at certain hours, especially in the afternoon.

5. Based on the results and observations obtained, the Punge Banda Aceh intersection is unable to accommodate traffic flows with conditions that do not have traffic control arrangements.

5.2. Suggestions

From the analysis carried out, the authors obtained some suggestions as follows:

1. A better traffic control system is needed at the intersection, such as repairment of the marker lines and installment of traffic signs.

2. It is necessary to reduce the conflict point at the intersection, by increasing the number of lanes at the intersection, the type of arrangement at the intersection, and the number of the direction of movement.

3. The personal awareness of drivers in driving vehicles and knowing traffic regulations, especially at the unsignalized intersections, is needed.

4. The junction capacity needs to be maintained.

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