Traffic Congestion Evaluation at the Unsymmetrical Signalized Intersection of Sentul, Yogyakarta

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Abstract. Sentul intersection is the unsymmetrical signalized intersection located nearby the Sentul Market of Yogyakarta, which has a potential causing traffic congestion. The study aims to analyze the performance of an unsymmetrical intersection based on Indonesian’s regulation and to determine the congestion cost occurred at the Sentul signalized intersection. This study utilizes a quantitative method to evaluate the intersection performance by considering delay, vehicle queue, congestion cost, and level of service (LOS). The study included primary data collection from a traffic survey, a traffic modelling to assess the intersection performance, and a congestion cost analysis using software by considering three different conditions: Existing Condition, Alternative 1 and Alternative 2. The results showed that the performance of the existing condition was very poor with average delay of 106.71 second/vehicle, queue time of 134.42 seconds, LOS of F, and congestion cost of intersection was IDR 3,722,627 per hour. The 1st alternative was re-designing phase time of traffic light and the 2nd alternative involved re-designing green time, widening of approach area, applying left turn on red (LTOR) for the west-arm of intersection, and removing on-street parking area. The 2nd alternative is the best solution since it will reduce delay by 30\%, vehicle queue by 54\%, congestion cost decrease by 50\%, the LOS increase from F to E, and then improve intersection performance significantly.

1. Introduction
Traffic congestion often occurs on roads with mix traffic like in Yogyakarta, Indonesia where there is no separation lane between motorized and non-motorized vehicles. Traffic congestion does not only affect the increasing of total travel time, but it causes delay, long queue of vehicles, higher vehicle operating cost, and lower level of service at intersection. In addition, emissions arising from traffic congestion will become air pollution around congestion points which can harm the health of road users [1]. As a tourist and educational city, Yogyakarta has a fairly growth rate of vehicles that is potential to cause traffic congestion. The Centre for Transportation and Logistics Studies, Gadjah Mada University in [2] stated that each year the city of Yogyakarta has an average growth of 4.04\% for private vehicles. The growth of vehicles will increase traffic and significantly increase vehicle queues at intersections [3-4]. Moreover, the imbalance of traffic volume and road capacity can lead to traffic congestion and cost losses which are important considerations in a trip [5-6]. The references [7-9] explain that transportation costs consist of costs caused by transportation users (internal costs) and costs arose by society as a whole (external costs). Costs arising from traffic congestion greatly affect vehicle speed, so decreasing vehicle speed in traffic flow will have an impact on increasing congestion costs [10]. The congestion cost is defined as the difference between the costs incurred by the...
community (marginal social cost) and the costs incurred by private vehicle users (marginal private cost) on a trip [11-12]. The time loss on a trip due to congestion is the most basic loss because increasing travel time will have an impact on increasing fuel consumption which results in increased vehicle operating costs [13]. The study of Errampalli also concluded that traffic congestion greatly affects the increase in fuel consumption costs and travel time costs [14]. Therefore, this study aims to analyze the performance of unsymmetrical intersection and to determine the congestion cost occurred at Sentul signalized intersection as well as providing technical recommendations for improving level of service and reducing congestion costs.

2. Research method
This study utilized a quantitative method to evaluate the unsymmetrical signalized intersection of Sentul, Yogyakarta, by considering delay, vehicle queue, congestion cost, and level of service (LOS) as the important parameters. The stages of study are illustrated in figure 1. The location of study was chosen at Sentul, Yogyakarta city, Indonesia as shown in figure 2 and 3. This location was determined by considering the specific intersection of Sentul, which is an unsymmetrical intersection nearby a traditional market and potential to traffic congestion as well as traffic accident. The observations survey indicated that the maximum queue length at each intersection arm. Data collection in this study included data on environmental conditions and geometric, traffic volume, cycle times and signalized phases, and vehicle speed. Primary data collection was carried out on weekdays for 6 hours at the peak of the morning, afternoon, and evening. Secondary data in this study were the value of driving behaviour data for input values in the Vissim 10 software [15] and the result of Pribadi's research [16] to calibrate the model based on the actual road conditions in Indonesia. The congestion cost is calculated based on the research of Tzedakis [10] as shown in equation 1.

\[
CC = N \left[ VC. V_a + \frac{V_a}{V'} \right] QT
\]  

(1)

where:
- \(CC\) = cost of congestion (IDR per hour)
- \(N\) = volume of vehicle queues (pcu/hour)
- \(VC\) = vehicle operating costs (IDR/veh.km)
- \(V_a\) = actual speed (km/h)
- \(V'\) = ideal (design) speed (km/h)
- \(V\) = value of time per vehicle (IDR/hour)
- \(QT\) = queue time (hours)

Vehicle operating costs (VC) are calculated using equation 2 based on Sugiyanto [11]:

\[
VC = 0.4937v^2 - 60.218v + 2991.9
\]  

(2)

where \(v\) = speed of the vehicle (km/hour).
Figure 1. Stage of research utilizing quantitative method.

**Primary data:**
1. Environmental condition of intersection
2. Geometric data
3. Traffic volume
4. Phase time
5. Vehicle speed

**Secondary data:**
Parameters of Driving Behavior for Indonesian condition

- Delay
- Queue Time
- Queue Volume
- LOS
- Vehicle Number
The queue volume (N) is calculated by applying equation 3. The queue volume of vehicles uses passenger car units (pcu) in table 1, so that in determining the value of time (V') of each vehicle can be used table 2 provided by Ministry of Public Works and Settlement the Republic of Indonesia [17].

\[ N = (IV - OV) \times emp \]  \hspace{1cm} (3)

where:
- \( N \) = volume of vehicle queues (pcu/hour)
- \( IV \) = initial vehicle volume (vehicle/hour)
- \( OV \) = volume of vehicles passing the intersection (vehicle/hour)
- \( emp \) = the equivalent of a passenger car
Table 1. The equivalent of a passenger car unit (PCU) [17].

| Vehicle type     | PCU Protected | PCU Opposed |
|------------------|---------------|-------------|
| Passenger car    | 1.00          | 1.00        |
| Heavy vehicle    | 1.30          | 1.30        |
| Motorcycle       | 0.15          | 0.40        |

Table 2. Value of time for each vehicle type (V’) [17].

| Vehicle Type     | Value of time (IDR/hour) |
|------------------|-------------------------|
| Motorcycle       | 315                     |
| Passenger car    | 1,925                   |
| Small bus        | 7,385                   |
| Big bus          | 9,800                   |
| Small truck      | 4,970                   |
| Medium truck     | 4,970                   |
| Big truck        | 4,970                   |

3. Results and discussions

3.1. Existing condition
Based on the analysis, the peak hour traffic volume was in the period of 06.30-07.30 AM. The complete vehicle data are provided in table 3, which consists of trucks, buses, cars, motorcycle (MC) and non-motorized vehicles (NMV). In addition, the survey results of the phase timing and signal phase can be seen in table 4 and figure 4.

Table 3. Traffic volume at peak hour.

| Traffic movement directions | Truck | Bus | Passenger car (vehicle/hour) | Motorcycle (vehicle/hour) | NMV |
|-----------------------------|-------|-----|-------------------------------|---------------------------|-----|
| E-N                         | 1     | 0   | 126                           | 1,094                     | 10  |
| E-W                         | 1     | 3   | 263                           | 1,787                     | 12  |
| E-S                         | 1     | 0   | 162                           | 849                       | 7   |
| W-N                         | 0     | 0   | 15                            | 98                        | 5   |
| W-E                         | 3     | 8   | 180                           | 1,804                     | 35  |
| W-S                         | 0     | 3   | 10                            | 173                       | 6   |
| S-N                         | 1     | 1   | 208                           | 2,843                     | 2   |
| S-E                         | 1     | 0   | 77                            | 804                       | 3   |
| S-W                         | 1     | 1   | 8                             | 109                       | 6   |
Table 4. Phase timing.

| Arm of intersection | Green (second) | Amber (second) | Red (second) | All red (second) |
|---------------------|----------------|----------------|--------------|-----------------|
| West                | 26             | 3              | 120          | 13              |
| South               | 22             | 3              | 124          | 8               |
| East                | 63             | 3              | 83           | 8               |

Figure 4. The existing signal phases.

The simulation using Vissim 10 [15] for the existing conditions obtained a LOS F with a delay $D$ of 106.71 seconds/vehicle, and vehicle queue time $QT$ of 134.42 seconds. The queue volume for vehicles $N$ was 2,372.55 pcu/hour. Vehicle operating costs $VC$ as shown in table 5, obtained IDR 1,685/km for the west arm, IDR 1,754/km for the south arm, and IDR 1,757/km for the eastern arm. The result of the congestion cost analysis in the existing condition was IDR 3,722,627/hour.

Table 5. Analysis results of vehicle operating cost (VOC).

| Arm of intersection | Average speed (km/hour) | VOC (IDR/km) |
|---------------------|-------------------------|--------------|
| West                | 28.25                   | 1,685        |
| South               | 26.17                   | 1,754        |
| East                | 26.10                   | 1,757        |
3.2. 1st Alternative for improving intersection performance
The intersection improvement by applying the 1st alternative was carried out by re-designing the green time as shown in table 6.

| Arms   | Existing green time (second) | Proposed green time of the 1st alternative (second) |
|--------|------------------------------|---------------------------------------------------|
| West   | 26                           | 45                                                |
| South  | 22                           | 43                                                |
| East   | 63                           | 60                                                |

Table 6. Re-designing green time of the 1st alternative.

The modelling results of the 1st alternative obtained a service level (LOS) F with a delay of 95.53 seconds vehicle. The queue time for the vehicles was 115.78 seconds and the queue volume of vehicles at the intersection was 2,362.45 pcu/hour. The analysis results of congestion cost at intersection was IDR 3,163,927 /hour. The LOS was similar with the existing condition however the congestion cost decreased 15 percent. In general, there was an improvement for the intersection performance in the 1st alternative.

3.3. 2nd alternative for improving intersection performance
The improvement of intersections in the 2nd alternative was carried out by eliminating the parking area on the road (on street parking), re-designing the green time, widening each of the approaches and north arms of the intersection, and LTOR for continues traffic flow from the west arm to the north arm. The results of the re-designing the green time are as shown in table 7. The signalized phase with the application of turning left of the road continues for the west arm can be seen in figure 5. The widening of the intersection approach can be seen in table 8 and figure 6. Based on the results of the 2nd alternative, the LOS was obtained E with a delay of 74.23 seconds/vehicle. The queue time for vehicles was 61.70 seconds. The volume of the vehicle queue (N) at the intersection of the 2nd alternative was 2,297.60 pcu/hour. The analysis result of the congestion cost was IDR 1,876,757 per hour. It means there was an improvement of the intersection performance resulting from the 2nd alternative solution.

| Arms   | Existing green time (second) | Proposed green time of the 2nd alternative (second) |
|--------|------------------------------|---------------------------------------------------|
| West   | 26                           | 50                                                |
| South  | 22                           | 70                                                |
| East   | 63                           | 40                                                |

Table 7. Re-designing green time of the 2nd alternative.
Figure 5. Implemented phase of left turn on red of the 2nd alternative.

Table 8. Results of the approach widening of the 2nd alternative.

| Arms     | Traffic direction  | Existing width (m) | Proposed width of the 2nd alternative (m) |
|----------|--------------------|--------------------|------------------------------------------|
| West     | West to East       | 4.6                | 8.75                                     |
| South    | South to North     | 6.1                | 7.8                                      |
| East     | East to West       | 7.0                | 7.5                                      |
| North    | South to North     | 7.8                | 8.0                                      |
3.4. Comparison of the results

Based on the analysis, the 2nd alternative is the best option for improving intersection performance. It reduced delay, shortened vehicle queue time, reduced queuing volume of vehicles, thereby reduced the cost of congestion as well as increased the LOS at Sentul signalized intersection. The result also showed that the delay was reducing from 106.71 seconds/vehicle to 74.23 seconds/vehicle, vehicle queuing time from 134.42 seconds to 61.70 seconds, vehicle queue volume from 2,373.55 pcu/hour to 2,297.60 pcu/hour, congestion costs at the intersection which were originally IDR 3,722,627 per hour decreased to IDR 1,876,757 per hour, and intersection LOS increased from F to E. It means that the 2nd alternative can reduce the congestion cost by 50 percent and then improve the intersection performance significantly. A detailed comparison of the results is shown in table 9.

Table 9. Comparison of analysis results for all conditions.

| Parameter                      | Existing  | 1st Alternative | 2nd Alternative |
|--------------------------------|-----------|-----------------|-----------------|
| Delay (second/vehicle)         | 106.71    | 95.53           | 74.23           |
| Vehicle queuing time (second)  | 134.42    | 115.78          | 61.70           |
| Vehicle queue volume (pcu/hour)| 2,372.55  | 2,361.45        | 2,297.60        |
| Congestion cost (IDR per hour) | 3,722,627 | 3,163,927       | 1,876,757       |
| Level of service (LOS)         | LOS_F     | LOS_F           | LOS_E           |
4. Conclusions
The evaluation of the unsymmetrical intersection of Sentul, Yogyakarta was performed by considering delay, vehicle queue, congestion cost, and level of service as the important parameters. The analysis showed the existing condition at intersection was very poor with average delay of 106.71 second/vehicle, queueing time of 134.42 seconds, congestion cost of intersection was IDR 3,722,627 per hour, and LOS F. Two alternatives to improve the intersection performance were investigated using Vissim10: Alternative 1 and Alternative 2. The 1st alternative was re-designing green time of traffic light and the 2nd alternative were consisted of re-designing green time, widening of approach area, applying LTOR for the west-arm of intersection, and removing on-street parking area. The 1st alternative obtained LOS of F, average delay of 95.53 second/vehicle, queue time of 61.70 seconds, and congestion cost of intersection was IDR 3,163,927 rupiah per hour. The 2nd alternative resulted performance was increasing with average delay of 74.23 second/vehicle, queue time of 61.70 seconds and congestion cost became IDR 1,876,757 per hour with LOS of E. Alternative 2 is considered the best solution, this option will reduce delay by 30 %, queue time by 54 %, decrease the congestion cost by 50 %, and increase LOS. In general, the 2nd alternative improves the intersection performance significantly.

5. References

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