The Study of Adding Left Turn Lanes Effectiveness at Signalized Intersection with PKJI 2014 (Case Study Sarwo Edhie Wibowo - Sudirman Signalized Intersection, Magelang, Indonesia)

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Abstract. The signalized intersection on the case study area continued getting worse in recent times due to the increasing traffic volume. To increase the level of service, treatment is carried out by adding a special left turn lanes of Sarwo Edhi Wibowo Street (named sodetan road). The research was conducted to analyze the effectiveness of adding left-turn lane to increase the intersection capacity. Analysis method using Pedoman Kapasitas Jalan Indonesia (PKJI) 2014. Based on the analysis results, the snooze value and queue length decreased in the observation area (sodetan road), but the decrease in the average delay value of all approach lanes was not significant enough. Unfortunately, the level of service with or without the new road has not changed, still worse (F). Widening road in the form of the addition of sodetan road at this signalized intersections turns out not to be very effective in solving congestion problems. This research is expected to be a recommendation for related agencies in improving the performance of the signalized intersection and can be considered in the development of policies related to the effectiveness of widening the road or adding lanes at other intersections in reducing congestion at intersections.

1. Introduction
Signalized intersections are the main part of the road network that influence efficient roadway [1]. It’s used to serve directional flow and facilitated signal control [2]. Inappropriate intersection design can worsen road network conditions. Evaluation of intersection performance is also needed to ensure the intersection can serve traffic optimally. The evaluation at a signalized intersection is the key to planning, design, operation, and management of the transportation system [3]. The signalized intersection on the case study area continued getting worse in recent times due to the increasing traffic volume. It needs to be studied and evaluated due to the congestion that occurred on all of the approach lanes. The case study area was placed at Sarwo Edi Wibowo - Sudirman intersection. This location is also known as Simpang Artos. This intersection is the busiest in Magelang city. The queue length exceeds the normal condition, especially at peak hours. To improve the capacity of Sarwo Edi Wibowo lanes, the mayor of Magelang, Sigit Widyonindito on Thursday, May 17th 2018, officially opened Sodetan Road on Sarwo Edi Wibowo-Sudirman intersection. The road financed by the Regional Budget (APBD) of Magelang city in 2017 and 2018 worth Rp 3.5 billion and is expected to unravel the congestion that often occurs in the front junction of The Armada Town Square. Sodetan Road is about 250 meters long and about 12 meters wide. The head of Magelang City Public Works Office, Yonas Nusantrawan Bolla added that this one-way road is only for public and private vehicles, except trucks and buses. This road is especially for vehicles traveling towards Magelang City. The area of study case can be seen in Figure 1.
The Sodetan Road is adding left-turn lanes at this intersection. The left turn or right turn (at right-hand-drive countries) at signalized intersection plays an important role in improving traffic flow in the road network [4]. A good design left turn treatment can reduce vehicle delay and increase the operational efficiency at the signalized intersection [5][6]. The Sodetan Road also improved the safety performance in this intersection. This safety can increase by spatially separating the conflicting traffic volume at the signalized intersection [7]. This Sodetan Road was expected to be able to improve the mobility of traffic.

However, from the observations, Sodetan Road tends to be quiet from traffic and often seen as a public transport parking space. On the other hand, during rush hour and holidays, Sarwo Edhie Wibowo Road experienced a long delay. Therefore, this research proposed to analyze the effectiveness of Sodetan Road as adding left-turn lanes at Sarwo Edhie Wibowo-Sudirman intersection as a congestion solver.

2. Literature Review

Previous research was conducted research for modelling capacity at a signalized intersection with a left turn storage bay [8]. The additional turning lanes are used to increase the capacity at the intersection. However, the added turning lanes are limited by the road configuration. Therefore, turning lanes often exist in the form of a left turn storage bay. The paper proposed a probabilistic model to calculate the total capacity for a full through the lane and the additional left-turn lane. The model gives an advantage over current methodologies by considering both stochastic arrivals of vehicles and signal phasing sequence. The research results the capacities of the through and left-turn movements are related to the proportion of the through traffic volume, the length of the additional turning lane, and the effective green time of both through and left-turn signal phases. The model was verified using VISSIM as microscopic simulation software. The result was consistent with both theoretical models and simulated results.

Exit lanes for left-turn (EFL) as a newly proposed unconventional intersection design analyze by [9] and demonstrated to be very promising for improving the intersection capacity. The paper developed a saturation flow adjustment model for EFL control and calibrated based on field data. Median opening blockage, demand starvation, multilane interference, conflict with opposing vehicles, and lane changes are considered as five influencing factors. The reduction of saturation flow rate was 6% for the approach left-turn lanes caused by EFL, 31% for the left-turn lanes in the mixed-use area, and 19% for the left-turn lane at the presto line cause by EFL. The result of the research gave advantages for planning, design, and operation of the EFL intersection.

Research on the left-turn on the signalized intersection was evaluated by [10] located at Supriyadi T-Junction. This research determined the effectiveness of the application of directly Left Turn on Red (LTOR) and indirectly left turn (N-LTOR) with delay performance indicators. The method used was MKJI 1997, PKJI 2009, and Shock Wave method. The results showed the effectiveness of the directly left turn had 0.8 degree saturation, the tipping point was 20%, in the field by 26%. This indicated that
the intersection was appropriately enforced LTOR. The application of LTOR or N-LTOR simulation results in existing conditions was calculated with the value of DS. Calculation optimization by using a total cycle time reset from 105 seconds to 97 seconds following the optimal T junction cycle time conditions. Researched about the evaluation of Pahlawan-Raden Saleh Sarif Bustaman intersection was conducted in Bogor West Java, Indonesia [11]. This research was conducted to evaluate the intersection performance with the Indonesian road capacity manual (Manual Kapasitas Jalan Indonesia/MKJI) 1997. The result showed that the intersection cycle time was incompatible with the dimension of the approach lanes resulting in a high degree of saturation and low level of service.

From the above literature reviewed, this paper proposed the Indonesian Capacity Guidelines for Signalized Intersection/Pedoman Kapasitas Jalan Indonesia (PKJI) 2014 method. The condition of the case study area was also different from other research that the existence of the new left-turn lanes, namely Sodetan Road.

3. Methodology

Figure 2 illustrates the methodology of this research. The literature review was collected from previous studies that are related to this research and from Pedoman Kapasitas Jalan Indonesia (PKJI) 2014 (Indonesian Highway Capacity Guidelines 2014)[12]. The data collection stage consists of primary and supporting data collection. Primary data are traffic volume, traffic flow, environment condition, phase period, and traffic cycle. While the supporting data consist of a map, road segment, and other data from similar studies. The existing data of Traffic volume data was collected from the Local Department of Transportation. The data is then calculated by Pedoman Kapasitas Jalan Indonesia 2014. The calculation was used to analyze the traffic performance of Sarwo Edhie Wibowo Jenderal Sudirman intersection. After that, the analysis was continued to determine the level of service based on The Regulation of Minister of Transportation Number 96, 2015[13]. The analysis was also conducted to know traffic performance five years later. The projection analysis was also conducted with the same method. The analysis was continued to the Sodetan Road effectiveness evaluation by comparing the traffic performance of Sarwo Edhie Wibowo - Sudirman intersection with and without Sodetan Road.

Figure 2. Research method stages.
4. Result and Discussion

4.1. Analysis of existing signalized intersection with and without sodetan road

Environmental and intersection geometric data obtained from the Department of Transportation Magelang in 2019. It can be seen in Table 1 and Table 2.

| Road section           | Env. condition | Side barriers | median | slope (%) | LTOR |
|------------------------|----------------|---------------|--------|-----------|------|
| Sudirman               | Commercial     | Moderate      | No     | -         | Yes  |
| Semarang - yogya       | Commercial     | Moderate      | Yes    | -         | Yes  |
| Sarwo Edi Wibowo       | Commercial     | Moderate      | No     | -         | Yes  |
| Soekarno Hatta         | Commercial     | Moderate      | Yes    | -         | Yes  |

| Road section            | Approach lanes (m)                |                           |
|-------------------------|-----------------------------------|---------------------------|
|                         | Effective lane | Approach lane | Entrance lane | Exit lanes | LTOR lane |
| Sudirman                | 8                   | 8             | 8             | 10         | 1,7      |
| Semarang - yogya        | 7                   | 11            | 11            | 7          | 4,0      |
| Sarwo Edi Wibowo        | 7                   | 11            | 11            | 7          | 3,5      |
| Soekarno Hatta          | 7                   | 9,5           | 9,5           | 9          | 3,5      |

Based on Table 1 and Table 2, it can be seen that the case study area is a commercial area with moderate side barriers. Semarang-Yogya and Soekarno Hatta Road is equipped with a median, while for the other arms there do not have a median. There are Left On Turn Red (LOTR) facilities for each arm. On the other hand, intersection geometric data which includes effective width, approach width, entry width, exit width, and LTOR width can be seen in table 2. The effective width value was obtained from the provisions of the PKJI 2014. The effective width of Sarwo Edhie Wibowo without Sodetan Road equal to the exit width of 7.5 meters and the volume used in the calculation is $q_{LRS}$ and $q_{BKA}$. The effective width of Sarwo Edhie Wibowo with Sodetan Road based on PKJI 2014 is 7 m and the volume used in the calculation is $q_{LRS}$.

The next calculation includes the number of phases, the time for each phase, and the signal movement which includes red time, green time, all red time, and yellow time. In the existing conditions, the intersection is divided into 4 different signal phases with a cycle time of 232 seconds for each phase. The type of approach lane is the protected type (P) in each approach. There is an opposite type (O) in the eastern approach, namely Soekarno Hatta Road heading towards Purworejo. The calculation of traffic volume is divided into four types of vehicles, namely MC (Motorcycle), LV (Light Vehicle), HV (Heavy Vehicle), and UM (Un Motorized). The SIS-II form was used to calculate the traffic flow data. The SIS-II form can be seen in Table 3.

| Approach code | Direction | MV (Motorized vehicles) | UM (Unmotorized vehicles) |
|---------------|-----------|-------------------------|---------------------------|
|               | $Q_{KBM}$ | $R_{P}$ | $R_{O}$ | $Q_{KTB}$ | $Q_{KTB}$ |
|               | veh/h     | skr/h  | P  | O      | veh/h  | (veh/h) |

Table 3. Traffic flow calculation form.
North | LT/LTOR | 295 | 139 | 178 | 0.21 | 11 | 0.038
| ST | 713 | 315 | 415 |  | 12 | 0.017
| RT | 429 | 193 | 252 | 0.30 | 0 | 0.000
| Sum | 1437 | 646 | 846 |  | 24 | 0.016

South | LT/LTOR | 550 | 377 | 428 | 0.32 | 8 | 0.014
| ST | 689 | 401 | 474 |  | 11 | 0.016
| RT | 559 | 410 | 459 | 0.34 | 1 | 0.002
| Sum | 1798 | 1188 | 1360 |  | 19.78 | 0.011

East | LT/LTOR | 930 | 425 | 557 | 0.49 | 4 | 0.004
| ST | 797 | 312 | 435 |  | 0 | 0.000
| RT | 323 | 134 | 182 | 0.15 | 0 | 0.000
| Sum | 2050 | 872 | 1174 |  | 4 | 0.002

West | LT/LTOR | 506 | 223 | 294 | 0.25 | 11 | 0.022
| ST | 731 | 455 | 532 |  | 11 | 0.015
| RT | 519 | 225 | 301 | 0.25 | 11 | 0.021
| Sum | 1756 | 903 | 1126 |  | 33 | 0.019

After using the SIS-II table, the SIS-IV form was used to find the degree of saturation. In this form, the basic saturation (So) is calculated. The basic saturation was obtained by multiplying the effective width with 600. After that, we determine the city size adjustment factor (F_{UK}), side barriers adjustment factor (F_G), parking adjustment factor (F_P), right-turn adjustment factor (F_{bka}), and left-turn adjustment factor (F_{LT}). In the existing conditions, a variation of cycle time and green time is used to determine the real conditions. The cycle time used is green time and time lost. Before calculating the adjustment of the cycle time, it is necessary to find the value of the critical current ratio (R_{AS}), the cycle time before adjustment (C_{bs}), the adjustment green time (H_i), and the adjusted cycle time (c). The current ratio is calculated according to the reviewed approach lane. After that, determine the R_{QS} of each phase and R_{AS}.

Sodetan Road which is located on Sarwo Edhi Wibowo intersection is intended to flow the traffic from Sarwo Edhi Wibowo Road to the center of Magelang City. The calculation of capacity and degree of saturation is carried out at the intersection with and without Sodetan Road, then described in tables 4 and 5, namely Form SIS-IV at Artos Junction with Sodetan and Form SIS-IV at Artos Junction without Sodetan.

**Table 4.** Capacity and degree of saturation calculation form with sodetan road.

| Year: 2019 | Intersection: Artos |
| --- | --- |
| Place : Magelang | City Size: 0.12 million inhabitans |
| Traffic Flow Distribution, skv/h | |
| Phase 1 | U |
| Phase 2 | U |
| Phase 3 | U |
| Phase 4 | U |

**Table 4.** Capacity and degree of saturation calculation form with sodetan road.
Approach lane code | Green in phase: Saturation, S | Adjustment factor | S | Q | R/QS | H_i | C_i | D_j |
|-----------------|-----------------|-----------------|---|---|------|------|-----|-----|
| U 1             | 4800            | 0.83 0.94 1 1   | 1.08 1 | 4045 | 641 0.16 | 35 610 1.05 |
| S 3             | 4200            | 0.83 0.94 1 1   | 1.08 1 | 3277 | 683 0.21 | 35 494 1.38 |
| T 2             | 3600            | 0.83 0.94 1 1   | 1.08 1 | 2809 | 292 0.10 | 45 545 0.54 |
| T 2             | 2568            | 0.83 0.94 1 1   | 1.08 1 | 1872 | 187 0.09 | 35 304 0.61 |
| B 4             | 4200            | 0.83 0.94 1 1   | 1.08 1 | 3277 | 402 0.12 | 20 282 1.42 |

Total lost time = 97 s Pre-adjustment cycle time \( c = 232 \) s Intersection current ratio (RAS) = 0.69

**Table 5.** Capacity and degree of saturation calculation without sodetan road.

Year: 2019 | Intersection: Artos
Place: Magelang | City Size: 0.12 million inhabitants

Based on Table 4 and Table 5, it can be seen the degree of saturation in Simpang Artos has insignificant change. Sudirman Road with a value of 1.05, Semarang-Jogja with a value of 1.38, Soekarno hatta for a protected lane with a value of 0.54, Soekarno Hatta for the opposing lane with a value of 0.61. Meanwhile, the saturation rate for Sarwo Edhie Wibowo without Sodetan Road is 2.48 and decreased by 1.06 with the presence of Sodetan Road to 1.42.

The determination of Queue Length, Number of Vehicles Stopped, and traffic delays are carried out following SIS-V PKJI 2014 form. Calculation of queue length based on the number of skr remaining from the previous green phase \( (N_{Q1}) \) and the skr that came during the red phase \( (N_{Q2}) \). Stop vehicles or stop values \( (N_{KH}) \) is calculated on each lane as the average number of vehicle stops per skr.
Table 6. Queue length and number of stop vehicles delay calculation form with sodetan road.

| Approach Lane Codes | Traffic Flow Q (skr/h) | Average Number of Vehicles (stop/skr) | Queue Length P_A (m) | Number of Stop Vehicles Ratio R_KH | Number of Stop Vehicles N_KH (skr) | Delay |
|---------------------|------------------------|--------------------------------------|---------------------|-----------------------------------|-----------------------------------|-------|
|                     |                        |                                      |                     |                                   |                                   | T_L (s/skr) | T_G (s/skr) | T = T_L + T_G (det/skr) | Total Delay TxQ (skr.s) |
| U                   | 641                    | 2,06                                 | 161.40              | 1.41                              | 902                               | 234.24 | 4.00          | 238.24 | 152,771.56 |
| S                   | 683                    |                                      | 411.27              | 2.94                              | 2010                              | 809.91 | 4.00          | 813.91 | 556,104.16 |
| T                   | 292                    |                                      | 56.33               | 0.81                              | 236                               | 84.09  | 3.97          | 88.06  | 25,676.58  |
| T                   | 187                    |                                      | 37.55               | 0.84                              | 157                               | 92.17  | 3.37          | 95.54  | 17,845.89  |
| B                   | 402                    |                                      | 254.33              | 3.09                              | 1243                              | 900.68 | 4.00          | 904.68 | 363,948.05 |
| LTOR                | 1,092                  |                                      | Total               | 4,548                             |                                   | 0.0    | 6.0           | 6.0    | 6550.99    |
| Total Flow          | 2,205                  |                                      | Average Number of Vehicles (stop/skr) 2.06 | Total 4,548 | Average Intersection Delay (s/skr) 509.22 |

Table 7. Queue length and number of stop vehicles delay calculation form without sodetan road.

| Approach Lane Codes | Traffic Flow Q (skr/h) | Average Number of Vehicles (stop/skr) | Queue Length P_A (m) | Number of Stop Vehicles Ratio R_KH | Number of Stop Vehicles N_KH (skr) | Delay |
|---------------------|------------------------|--------------------------------------|---------------------|-----------------------------------|-----------------------------------|-------|
|                     |                        |                                      |                     |                                   |                                   | T_L (s/skr) | T_G (s/skr) | T = T_L + T_G (det/skr) | Total Delay TxQ (skr.s) |
| U                   | 641                    | 2,06                                 | 161.40              | 1.41                              | 902                               | 234.24 | 4.00          | 238.24 | 152,771.56 |
| S                   | 683                    |                                      | 411.27              | 2.94                              | 2010                              | 809.91 | 4.00          | 813.91 | 556,104.16 |
| T                   | 292                    |                                      | 56.33               | 0.81                              | 236                               | 84.09  | 3.97          | 88.06  | 25,676.58  |
| T                   | 187                    |                                      | 37.55               | 0.84                              | 157                               | 92.17  | 3.37          | 95.54  | 17,845.89  |
| B                   | 750                    |                                      | 749.07              | 5.23                              | 3923                              | 2,796.75 | 4.00          | 2,800.75 | 2,099,330.63 |
| LTOR                | 1,092                  |                                      | Total               | 4,548                             |                                   | 0.0    | 6.0           | 6.0    | 6,550.99   |
| Total Flow          | 2,205                  |                                      | Average Number of Vehicles (stop/skr) 2.06 | Total 4,548 | Average Intersection Delay (s/skr) 1,585.42 |

From Table 6 and Table 7, it can be compared to the length of the queue at the Artos Intersection with the existence of Sodetan Road and without Sodetan Road. The queue length that occurred was 749 meters on Sarwo Edhie Wibowo intersection without Sodetan Road and decreased by 494.74 meters due to Sodetan Road to 254 meters. Meanwhile, other approaches did not experience a change in the queue length. Based on the calculation of existing conditions with the Sodetan Road in Table 6 and without the Sodetan Road in Table 7, the average delay value is 509.16 s/skr, which decreased from the condition before the existing of The Sodetan Road, which was 1,585.42 s/skr. According to Minister of Transportation Regulation Number 96, 2015, the Level Of Service (LOS) indicates the value of F which means the intersection performed low speed, long queue, and the intersection capacity is below the traffic flow (Q>C). However, the decreased value in the average delay and queue length is not significant enough to improve the LOS. The LOS with and without Sodetan Road has an F level.

4.2. Analysis of five years later projection

For the next 5 years traffic predicted, the traffic growth rate data is required. Vehicle growth data is obtained from the Local Police Traffic Division. Traffic growth can be calculated by simple linear regression and obtained a growth rate of 8.8%. Predictive volume is used to analyse the performance
of the intersection over the next 5 years. The traffic flow data of 5 years prediction is then included in the SIS-II form as previously calculated.

The volume of vehicles obtained on the SIS-II form will then be used for the calculation of the degree of saturation on the SIS-IV form. The geometric state of the Artos Intersection is considered unchanged then the saturated flows (S) are on the same value. Other calculation parameters such as current traffic flow ratio (R/Q) change because of the increasing value of traffic flow (Q), while the saturated flows remained constant. The degree saturation in each approach lane is increasing each year while the capacity is still in the fixed value.

The degree of saturation at Sudirman Lane increased by 0.91 to 1.74, Semarang-Jogja Lane increased by 0.35 to 1.38, Soekarno-Hatta Road increase by 0.35 on the protected lane to 2.29, and for the opposite lane increased by 0.44 to 1.10. While on Sarwo Edhie Wibowo Street has the highest saturation degree in 2025 compared to others. The value of DS in this section is 2.36, increased by 0.94 compared to the calculation in 2020.

The calculation of queue length and traffic delays in 2025 with the Sodetan Road is also done with the SIS-V form. Increased value of the degree of saturation led to changes in queue length each year and service levels in 2025. Sarwo Edhie Wibowo Road has the highest saturation level in 2025 compared to other lanes, along with 694.60 meters. This value increased by 440.26 meters compared to the calculation in 2020. The increased value in the queue length will increase the delay that occurs in this intersection. The average vehicle delay occurring in 2025 increased by 1182.15 sec/s to 1691.43 sec/smp. The average delay rate affects the Level Of Service (LOS). Referred to The Regulation of Transportation Minister No. 96, 2015, the LOS has an F level that indicates a forced flow, low speed, long queue (Q>C).

4.3. Sodetan road effectiveness evaluation
The calculation results using Pedoman Kapasitas Jalan Indonesia (The Indonesian Road Capacity Guidelines) 2014 (PKJI 2014) obtained the value of the length of queues and delays that occur in Artos intersection with the absence of Sodetan Road and without the Sodetan Road. Reviewed from overall approach lanes at the intersection, there was no change in the length of the queue or delays on the north, south, and east arms. Sodetan Road only changes the length of queues and delays on the western arm as well as the average delay value of intersections. However, the Level Of Service does not change that is worth F. Conditions worsened as traffic volume increased with a vehicle growth rate of 8.8% and projected into 2025. Conditions in 2020 with the lowest service rates also result in a low LOS for 5 years to come. Increasing the capacity of the intersection by adding the left turn lane namely Sodetan Road does not have a significant impact on the performance of the intersection. Sodetan Road does not improve the performance of Simpang Artos effectively.

5. Conclusion
Based on the results, it can be concluded that the queue length and delay on the north, south, and east approach lane with the treatment of adding a left turn lane called Sodetan Road remains the same. Sodetan Road only changes the queues length and delays on the western arm and the average delay value of the intersection. This reduction does not change the Level of Service (LOS) which remains F. The traffic projection was conducted in 2025, with a growth of 8.8% per year. The average vehicle delay in 2025 increased. The average delay rate affects the LOS. LOS in 2020, which is already at the lowest level, remains at level F.

This research has some limitations. One of them is conducted during the Covid19 pandemic. This caused the surveys couldn’t be conducted directly. Nevertheless, this limitation was solved by secondary data from the Local Transportation Department. Another limitation is that the analysis was conducted with manual procedures based on PKJI 2014.

Research using micro-simulation software can provide an overview of intersection performance with several alternative modelling to increase the level of service. The alternative of adding a left turn lane is traditional treatments for increasing capacity. This is a common practice to increase intersection performance. On the other hand, there are other alternative solutions such as re-time
traffic signals, combinational optimization of geometric design, and signal timings that can be applied in the intersection to improve the level of service.

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