International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 4
ISSN: 2088-5334

The Effects of Bike Boxes on the Traffic Performance at Signalized Intersections in Yogyakarta City

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Abstract — **A bike box is an area at the head of a traffic lane at a signalized intersection that is designated for cyclists. It does not only provide safety and priority for cyclists, but it also influences the delay time and the queue length, which affect the traffic performance of an intersection. This study aims to analyze the effects of bike boxes at Senopati Intersection and Pojok Benteng Wetan Intersection in the city of Yogyakarta. The primary data that was collected for the study included traffic volume, vehicle speed, driving behavior, traffic signal, and intersection geometrics. Also, secondary data was taken, such as the image of the intersections from Google Earth Software. This research used a quantitative method with statistical techniques for data analysis using Microsoft Excel 2016 and VISSIM Software to simulate the intersections in three conditions: non-orderly bike boxes, orderly bike boxes, and without bike boxes. The results were Panembahan Senopati Intersection had the lowest delay time in a condition without a bike box and had the shortest queue length in a non-orderly bike box condition, while Pojok Benteng Wetan Intersection had the lowest delay time in an orderly bike box condition and had the shortest queue length in a condition without bike box. The level of intersections service for Panembahan Senopati Intersection and Pojok Benteng Wetan were in D and F, respectively. Further research is needed to learn about other factors that may cause a variation in intersections' performance.**

Keywords— **Bike boxes; signalized intersections; VISSIM software.**

Manuscript received 23 Apr. 2021; revised 4 Sep. 2021; accepted 15 Oct. 2021. Date of publication 31 Aug. 2022.

I. INTRODUCTION

The issue of sustainability is important for development because development should fulfill the needs of today without sacrificing the needs of future generations. It can be done by implementing many aspects such as environmental, social, and economical in every development to ensure the needs of future generations are not neglected [1]. In the transportation sector, to actualize sustainability is to reduce private vehicles, increase public transportation, or use eco-friendly modes such as bicycles.

Bicycle riding is a means of transportation, recreation, and exercise [2]. It improves public health directly by increasing physical activity and indirectly by reducing emissions from automotive transportation [3]. The bike-sharing program also indirectly improves public health by reducing congestion [4]. Many governments have advocated cycling by providing bicycle-exclusive road networks and full integration with public transportation as cycling has become an important transportation mode in urban life [5].

An increase in cyclists leads to an increasing trend in crashes, especially at intersections [6]. At mixed traffic intersections with high-density bicycle traffic flow, bicycle flow shows an obvious lateral dispersion tendency and frequent interactions with other road users within the shared space, leading to a lack of traffic safety and efficiency [7]. Environmental, traffic, and humans are the factors that affect bicycle safety. The environmental factors, land use, built environment, and road infrastructures can affect bicycle safety [8]. One of the causes of bicycle crashes is the lack of bicycle facilities or infrastructure at the road or the intersection [9]. Some types of bicycle facilities are bicycle tracks (separated from the road with curbs) and bicycle lanes (separated from the road with painted lines) [1], [10]. Implementing bike lanes is considered useful in improving both safety and operations of traffic flow on urban streets [11]. Bicycle facilities can improve the cycling experience and increase perceived and actual safety levels [12].

In 2008, the Governor of the Special Region of Yogyakarta, Sultan Hamengku Buwono X, and the former Mayor of Yogyakarta, Herry Zudianto, launched a program called "Sego Segawe". The program encourages people to bike to work and school. The government had provided bike lanes on the left streets with yellow lanes, signposts of alternative routes for bicyclists, and a bicycle waiting room in front of motorized vehicles waiting room at intersections to protect bicyclists from motorized vehicles.

A bike box is a designated area for cyclists to wait at an intersection. It is located at the head of the traffic lane in front of other vehicles and is usually painted in high contrast color (e.g., bright green) to increase the bikers' visibility [13],[14]. A bicycle waiting room or bike box is hypothesized to reduce conflict and encourage more bicycling by enhancing the perception of safety and priority at an intersection [14]. Some research has shown that bike box significantly increases the riders' perceived safety when crossing the intersection and effectively reduces their exposure to ultrafine particles [15], [16].

This study aims to analyze how bike boxes affect the traffic condition at Panembahan Senopati Intersection and Pojok Benteng Wetan Intersection under three different scenarios, namely (1) when bike users properly use the available bike boxes, (2) when bike users do not use the available bike boxes, and (3) when there are no bike boxes available. The software to help the simulation and analysis were Microsoft Excel 2016 and VISSIM.

II. Materials and Method

A. Signalized Intersection

The use of signals with three-color lights (green, yellow, and red) is applied to separate trajectories from conflicting traffic movements in the time dimension [17]. This is an absolute necessity for traffic movements coming from intersecting roads with major conflicts. Signals can also be used to separate the turning motion from the straight-line traffic or to separate the movement of the turning traffic from the crossing pedestrians as the second conflicts. The details can be seen in Figure 1.

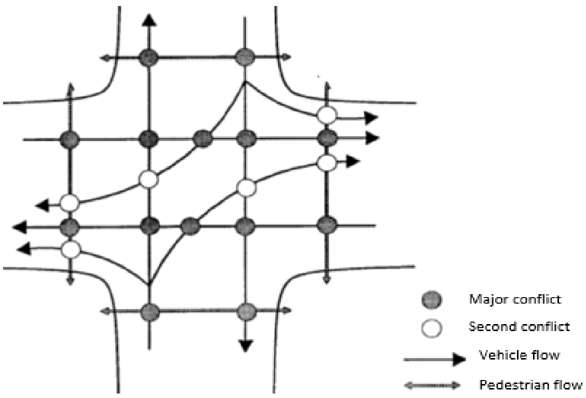

Fig. 1 Major and Second Conflicts at the Four-Way Signed Intersection [17]

The analysis of intersection performance is based on geometry, traffic flow, intersection capacity, determination of signal time, degree of saturation, queue length, stop number, delay, and index of intersection service level [17]. The queue length is the number of vehicles lining up in an approach at an intersection. If the degree of saturation is more than 0.5, then NQ1 is expressed by Equation 1, and if the degree of saturation is less than or equal to 0.5, then NQ1 is 0.

$$\mathrm{NQ}_1 = 0{,}25 \text{ x C x } \left[(\text{DS-1}) + \sqrt{(\text{DS-1})^2 + \frac{8 \text{ x (DS -0,5)}}{C}} \right] \quad (1)$$

$$\mathrm{NQ}_2 = \text{ c x} \frac{\text{1 - GR}}{\text{1 - GR x DS}} \text{ x } \frac{Q}{3600} \quad (2)$$

$$\mathrm{NQ} = \mathrm{NQ}_1 + NQ_2 \quad (3)$$

Delay is an additional travel time required to go through an intersection when compared to a crossing without passing an intersection. Traffic Delays (DT) are waiting times caused by traffic interactions with conflicting traffic movements. Equation 4 is used to get the average traffic delay value (DT) for each approach due to the influence of reciprocity with fourth movements at the intersection.

$$\mathrm{DT} = \text{c x } \frac{0.5 \text{ x (1-GR)}^2}{\text{(1-GR x DS)}}) \text{ x } \frac{\text{NQ1 x 3600}}{c} \quad (4)$$

The level of intersection services can be seen in Table 1 [18].

TABLE I
LEVEL OF INTERSECTION SERVICE

Service Level Index	Delay Time (second)
A	≤ 5
B	5.1 - 15
C	15.1 - 25
D	25.1 - 40
E	40.1 – 60
F	> 60

B. Bike Box Overview

A bicycle waiting room or Advanced Stop Line for Cyclists (ASL) is a facility to place bicycle users in front of or beside a line of vehicles that are stopping at a signal intersection [19]. Bicycle users are specifically placed to be seen by motor vehicle users, thereby reducing the risk of conflict and making bicycle users cross the crossing safely.

Following the successful implementation of bike boxes in the Netherlands, the UK first introduced the bike box concept at Oxford in 1984, Newark in 1989, and Bristol in 1991 [20]. The results of research conducted in these three cities showed the application of Bike Boxes which was considered satisfactory and generally easily understood by road users. More than 75% of bicycle users at each location used the bike lane and waiting zone, and more than 90% of motor vehicle drivers stayed clear of the bike lane. 82% of motor vehicles arrived at the intersection when the red signal was outside the waiting area (reservoir). Bike boxes without the approaching lane can be seen in Figure 2.

Fig. 2 Bike boxes without the approaching lane [19]

The handling model applied in the four cities of Oxford, Newark, Bristol, and Manchester is a refinement of the design applied in the Netherlands. Compared to the first design, this model has additional signs for the motor vehicle stop lines, the motorbike lanes, and the complete signs. Similar to the result of the previous survey, most bicycle users were satisfied with the bike lanes and the improvement to the bike boxes [19]. This appears to be possible by improving the layout with a combination of making bicycle lanes, staining lanes, and bicycle waiting areas, as shown in Figure 3.

Fig. 3 Bike boxes with a nearside cycle lane [19]]

Wall et al [19] suggests that bicycle lanes should be considered in the middle between the left turn lane (turn right for Indonesian conditions) and the front ends of all vehicle lanes. The example of bike boxes with a central approaching cycle lane can be seen in Figure 4.

Fig. 4 Bike boxes with a central cycle lane [19]

This design is worth consideration, especially for the intersection segment with large left-turn vehicles and large continuous or straight) bicycle currents. Several studies have also shown that many bicycle users continuously use the nearside cycle lane to turn left or straight. Only a few bikes use the nearside lane close to the stop line to turn right. Most bicycles will turn right using some parts or not using bicycle lanes. It was also found that the bicycle lanes made in the middle, as shown in Figure 4, play a function for bicycles to queue up.

The skeleton bicycle boxes and green-colored bicycle boxes without site-specific variability are increasing the behavior of cyclists and motorcyclists at intersections [21]. The addition of bicycle boxes seems to have encouraged cyclists to take a more visible stopping position in front of the driver, which resulted in a substantial reduction in the percentage of cyclists waiting for a queue of motorized vehicles and a significant percentage increase in cyclists who left the first crossing.

In Indonesia, the application of a bicycle box needs to be used for motorcycles so that it is more appropriate to be called an exclusive stop space than a bicycle box. This special stop room (exclusive stop room) is one solution to solve the problem of motorcycle congestion at a signalized intersection.

Exclusive motorcycle stopping space is a stop space facility for motorbikes during the red phase, which is placed in front of a queue of four-wheeled motor vehicles and does not cross the end of the intersection approach line [20]. This exclusive stop zone is marked with a one-stop line for motorbikes and one for four-wheeled vehicles. These two-line markers are placed sequentially and separated by a space with a certain distance. Exclusive stopping space models for motorbikes were developed from bike boxes for bicycles. The model of exclusive stopping space consists of a lane approach and a waiting area (reservoir). The main function of this exclusive stopping space is to help the motorcycle move first from a four-wheeled vehicle so that it can make the intersection clean faster and reduce traffic conflicts caused by motorcycle maneuvers.

The research was conducted on the effectiveness of using a special stop room for motorbikes on the performance of the signalized intersection at Karanganyar Regency using VISSIM software. This research found that the west side of the intersection, which has no special stop area for motorbikes, has a better performance. This west side consists of two lanes; drivers can use the left to make a direct left turn.[22].

C. VISSIM

Researchers have widely used microsimulation modeling to evaluate existing transportation infrastructure and traffic operations. VISSIM is an advanced microscopic traffic simulation software that provides the flexibility to simulate jurisdiction-specific networks [23]. The VISSIM program is a program developed by PTV (Planung Transportation Verkehr AG) in Karlsruhe, Germany. The name comes from "Verkehr Städten - SIMulationsmodell" (German for "Traffic in the city - simulation model"). VISSIM began in 1992, and VISSIM is now used worldwide for microscopic simulation to model multimodal transport operations by the public sector, consulting firms, and universities [24].

The performance at the signalized intersections in the VISSIM modeling must be calibrated and validated. Calibration is the process of re-modeling the simulation model so that the simulation model accurately represents or closely resembles the real-life situation. In comparison, validation is a comparison of parameters obtained from the field with the simulation results using VISSIM. That is why calibration and validation are done by matching the results of the input volume data and output volume data that comes out. Most validation techniques, especially for signalized intersections, are volume to capacity ratios, vehicle delay, queue lengths, etc. [23]. For the calibration process, vehicle performance and driver behavior parameters need to be adjusted so that the model outputs are similar to observed data [25].

The input and output volume of the vehicle must be close to the tolerance limit of approximately 10% [26]. After the results are close to the same, a trial and error will be carried out on the driving behavior to get the traffic behavior that occurs in the actual field. Some researchers used GEH statistics to prove the validation of VISSIM simulation. The GEH statistic gets its name from Geoffrey E. Havers, who invented it. GEH statistic is an empirical formula that has proven useful for a variety of traffic analysis purposes. GEH statistic equation can be seen in Equation 5. GEH less than 5% means that the validation of VISSIM simulation is accepted.

$$\text{GEH} = \sqrt{\frac{(q_{\text{simulated}} - q_{observed})^2}{0.5(q_{\text{simulated}} + q_{observed})}} \quad (5)$$

D. Method and Data

This type of research was conducted using quantitative methods. Quantitative research uses instruments that produce numerical data [27]. Data analysis was performed using statistical techniques to reduce and classify data, determine relationships, and identify differences between groups of data. Controls, instruments, and statistical analysis are used to produce research findings accurately.

The sampling technique used was non-random sampling with a purposive technique. Purposive sampling is a technique to determine samples with certain considerations by the desired objectives [27]. This sampling calculated the flow of vehicles per segment during peak hours by peak hour survey officers. This sampling was used because of the research's limited time, cost, and energy. Therefore, researchers determined their samples were taken with not only certain considerations but also followed the study's objectives. The sample was taken in the morning and evening, which estimated that many cyclist activities occur at the intersections understudy at these times.

Primary data in this study were traffic volume data, vehicle speed data, driving behavior data, traffic signal data, and intersection geometric data. Secondary data in this study were the image of the Panembahan Senopati Intersection and Pojok Benteng Wetan Intersection which were obtained from Google Earth Software.

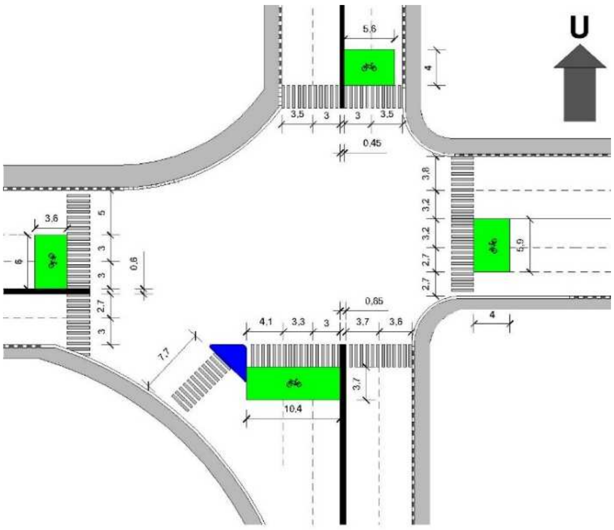

Fig. 5 Layout of Panembahan Senopati Intersection

The overall analysis of this research used Microsoft Excel 2016 software and VISSIM software, which refer to Indonesian Road Capacity Manual [17]. After that, an analysis used quantitative methods on the volume of traffic, delays, and opportunities in the queue. Then the discussion was carried out using the comparison method to compare traffic conditions at intersections with non-orderly bicycle waiting rooms, with orderly bicycle waiting rooms, and without bicycle waiting rooms on weekdays (represented by Monday and Wednesday) and weekends (represented on Saturday). The following figures and tables represent the layout, vehicle volume data, traffic signal diagram, and traffic signal phase at Panembahan Senopati Intersection and Pojok Benteng Wetan Intersection.

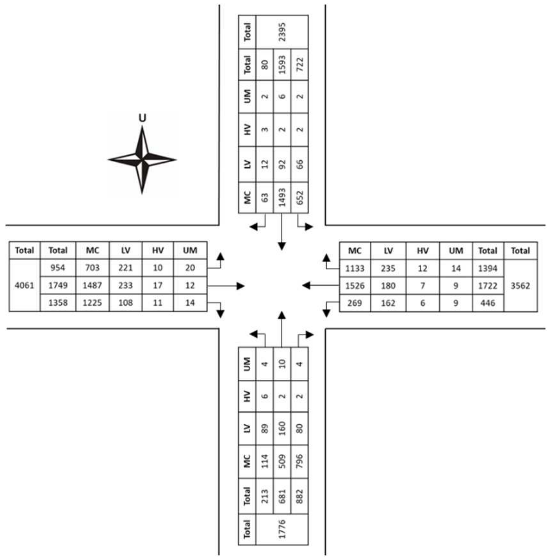

Fig. 6 Vehicle Volume Data of Panembahan Senopati Intersection

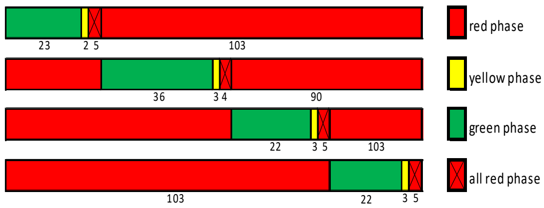

Fig. 7 Traffic Signal Diagram of Panembahan Senopati Intersection

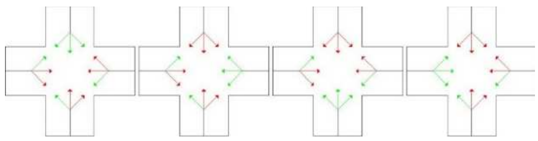
Fig. 8 Traffic Signal Phase of Panembahan Senopati Intersection

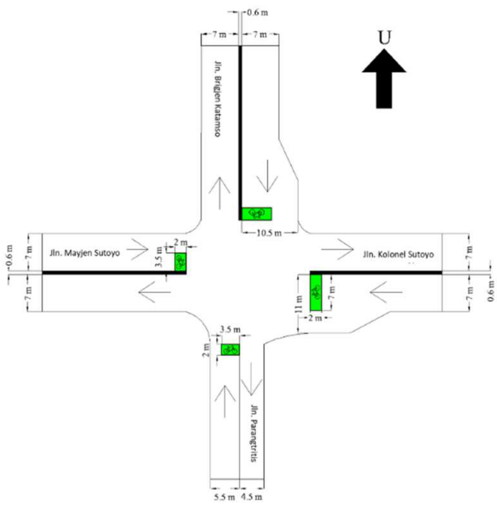

Fig. 9 Layout of Pojok Benteng Wetan Intersectrion

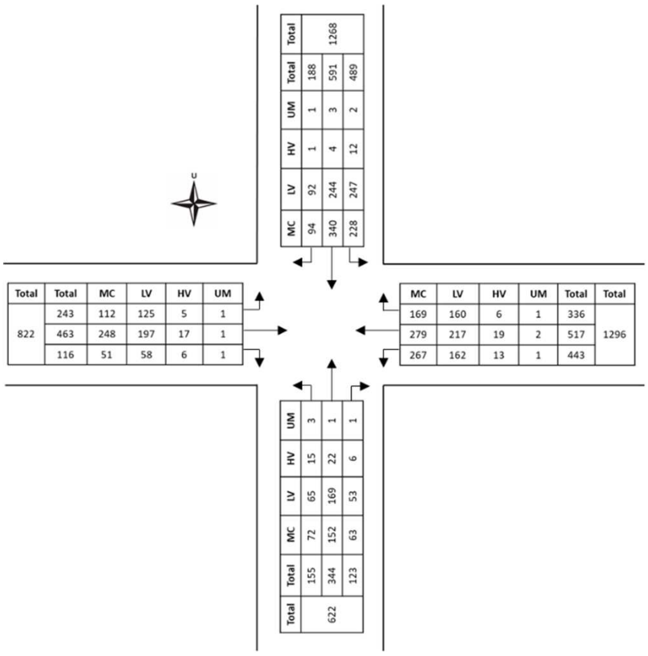

Fig. 10 Volume Data of Pojok Benteng Wetan Intersection

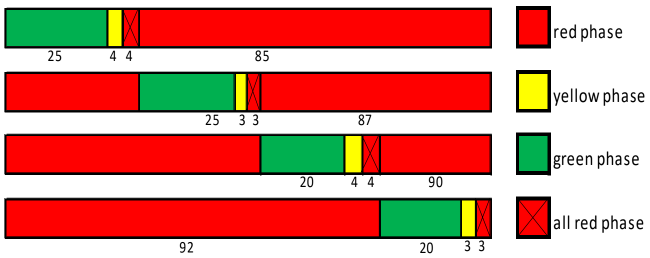

Fig. 11 Traffic Signal Diagram of Pojok Benteng Wetan Intersectrion

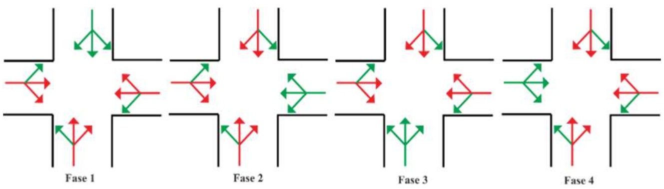

Fig. 12 Traffic Signal Phase of Pojok Benteng Wetan Intersection

III. Results and Discussion

Data from observations and surveys were analyzed using VISSIM software. The output of the evaluation parameter in the VISSIM software can determine the performance of the intersection. The following are the results of the Evaluation in VISSIM software that has been carried out.

A. Site 1: Panembahan Senopati Intersection

Driving behavior is a vehicle driver behavior that is one of the parameters of the VISSIM software. Driving Behavior data were obtained from direct observations and measurements in the field. Driving behavior must be adjusted to the original conditions on the ground. Table 2 shows the parameters performed during the calibration and trial and error processes.

Validation is the process of testing the calibration's accuracy based on the difference in the number of passing vehicles and the number of vehicles inserted into the VISSIM software. The data used in the calibration process is the Data Collection Point which can read the volume of a vehicle modulated in the VISSIM software, and data Collection Points were placed in the middle of a road segment in each approach segment.

TABLE II
Driving Behaviour Calibration of Panembahan Senopati Intersection

No	Driving Behavior Types	Driving Behavior Parameters	Value (meters)	
			VISSIM Default	Calibration
1	Car Following	Average Standstill Distance	2	0,3
2		Additive Part of Safety Distance	2	0,5
3		Multiplicative Part of Safety Distance	3	1,2
4	Lateral	Desired Position at Free Flow	Middle of Lane	Any
5		Minimum Distance Standing	1	0,1
6		Minimum Distance Driving	1	0,4

The results of the validation in the Panembahan Senopati Intersection can be seen in Table 1. Based on Table 1, the GEH calculation for all segments in Panembahan Senopati Intersection was below 5%. Therefore, the simulation using VISSIM met the requirement and can be used for the research.

TABLE III
VISSIM Validation for Panembahan Senopati Intersection

Segment	Vehicle Volume		GEH (%)
	Based on Survey	VISSIM Output	
North	2395	2279	2.4
East	3561	3454	1.8
South	1776	1763	0.3
West	4061	3993	1.1

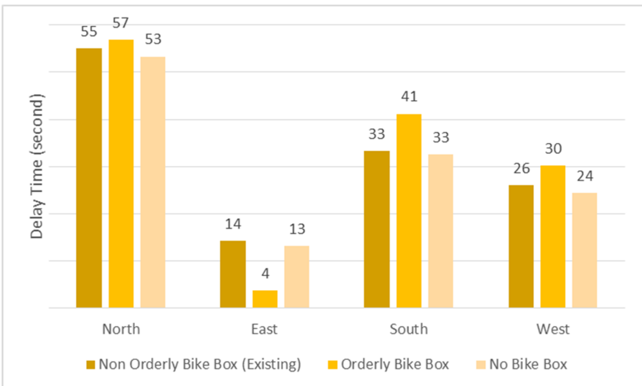

Fig. 13 Delay Time at Panembahan Senopati Intersection

The chart in Figure 13 shows that the delay time on the north, south, and west sides was the shortest when there were no bike boxes. In contrast, for the east side, the shortest delay time occurred when there was a properly used bicycle box. In the north segment, the difference value between a road segment with an orderly bicycle box condition and without a bicycle box condition was 3,518 seconds, or the condition without a bicycle box was more effective than with an orderly bicycle box by 6.19%. While the difference value between a non-orderly bicycle box condition and a condition without a bicycle box was 1,659 seconds or the condition without a bicycle box was more effective than a non-orderly bicycle box condition by 3.02%.

In the east segment, the delay time of an orderly bicycle box was 9,487 seconds shorter than without a bicycle box condition or an orderly bicycle box condition was 71.74% more effective than without a bicycle box condition. While delay time without bicycle box condition was 1,002 seconds shorter than the non-orderly bicycle box condition or without bicycle box condition had a more effective condition than non-orderly bicycle box condition by 7.04%.

In the south segment, the difference value between an orderly bicycle box condition and a condition without a bicycle box was 8,589 seconds, and a condition without a bicycle box was 20.87% more effective than an orderly bicycle box condition. While the difference value of a non-orderly bicycle box condition and a condition without a bicycle box was 0.691 seconds, or the condition without a bicycle box was 2.08% more effective than a non-orderly bicycle box condition.

In the west segment, the delay time of an orderly bicycle box was 5,888 seconds longer than without a bicycle box condition or the condition without a bicycle box was 19.46% more effective than with an orderly bicycle box condition. While delay time of a non-orderly bicycle box condition was 1,725 seconds longer than without a bicycle box condition or the condition without a bicycle box was 6.61% more effective than with a non-orderly bicycle box condition.

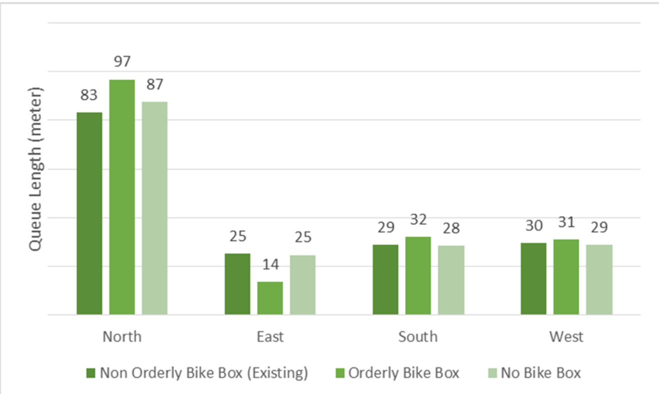

Fig. 14 Queue Length at Panembahan Senopati Intersection

Figure 14 shows that on the south and west sides, the queue was the shortest when there were no bicycle boxes. In contrast, the north segment had the shortest queue length in a non-orderly bicycle box condition, and the east segment had the shortest queue length in an orderly bicycle box condition.

In the north segment, the queue length of an orderly bicycle box was 9.33 meters longer than without a bicycle box condition, or the condition without a bicycle box was 9.64% more effective than with an orderly bicycle box condition. While the queue length of non-orderly bicycle box condition was 4.22 meters shorter than without a bicycle box condition or a non-orderly bicycle box condition was 4.83% more effective than the condition without a bicycle box.

In the east segment, the difference value of an orderly bicycle box condition and a condition without a bicycle box was 11,177 meters, or an orderly bicycle box condition was 45.28% more effective than a condition without a bicycle box. While the difference value of a non-orderly bicycle box condition and a condition without a bicycle box was 0.455 meters, or a condition without a bicycle box was 1.81% more effective than a non-orderly bicycle box condition.

In the south segment, the queue length of an orderly bicycle box was 3,502 meters longer than without a bicycle box condition, or the condition without a bicycle box was more effective than with an orderly bicycle box condition by 10.96%. While the queue length of the non-orderly bicycle box condition was 0.278 meters longer than without a bicycle box condition or the condition without a bicycle box was slightly more effective than a non-orderly bicycle box condition by 1%.

In the west segment, the difference value of an orderly bicycle box condition and a condition without a bicycle box was 2,396 meters, or condition without a bicycle box was more effective than an orderly bicycle box condition by 7.7%. While the difference value of a non-orderly bicycle box condition and a condition without a bicycle box was 0.943 meters, or condition without a bicycle box was more effective than a non-orderly bicycle box condition by 3.18%.

B. Site 2: Pojok Benteng Wetan Intersection

Table 4 shows driving behavior parameters in Pojok Benteng Wetan Intersection that were performed during the calibration and trial and error processes.

TABLE IV
DRIVING BEHAVIOUR CALIBRATION OF POJOK BENTENG WETAN INTERSECTION

No	Driving Behavior Types	Driving Behavior Parameters	Value (meters)	
			VISSIM Default	Calibration
1	Car Following	Average Standstill Distance	2 m	0,5 m
2		Additive Part of Safety Distance	2 m	1 m
3		Multiplicative Part of Safety Distance	3 m	1,5 m
4	Lateral	Desired Position at Free Flow	Middle of Lane	Any
5		Minimum Distance Standing	1 m	0,4 m
6		Minimum Distance Driving	1 m	0,8 m

The results of the validation in the Pojok Benteng Wetan Intersection can be seen in Table 5. Based on the data in Table 5, the GEH for all four sides of Pojok Benteng Wetan Intersection was calculated at below 5%. Therefore, the simulation using VISSIM has met the requirement and can be used for the research.

TABLE V
VALIDATION FOR POJOK BENTENG WETAN INTERSECTION

Segment	Vehicle Volume		GEH
	Based on Survey	VISSIM Output	(%)
North	1268	1216	4.1
East	1311.6	1291	1.5
South	619.4	607.6	1.9
West	821.4	823.2	0.2

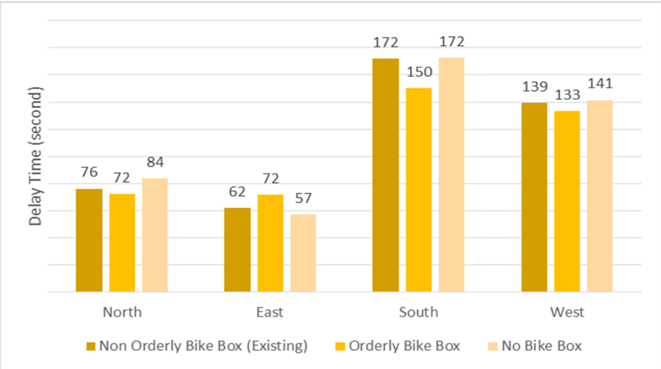

Fig. 15 Delay Time at Pojok Benteng Wetan Intersection

Based on Figure 15, delay time on the north, south, and west segment of the Pojok Bentang Wetan Intersection with an orderly bicycle box tends to be smaller than in other conditions. However, the east segment condition without a bicycle box had the smallest delay time for its segment.

In the north segment, the difference value between condition without a bicycle box and condition with an orderly bicycle box was 11.75 seconds, or the condition with an orderly bicycle box was more effective than without a bicycle box by 13.97%. While the difference value between the condition without a bicycle box and the condition with a non-orderly bicycle box were 7.56 seconds or the condition with a non-orderly bicycle box was more effective than without a bicycle box by 9.02%.

In the east segment, the delay time of an orderly bicycle box was 14.35 seconds longer than without a bicycle box condition, or a condition without a bicycle box condition was more effective than an orderly bicycle box condition by 20.01%. While delay time of a non-orderly bicycle box was 4.72 seconds longer than without a bicycle box condition, or condition without a bicycle box condition was more effective than a non-orderly bicycle box condition by 7.6%.

In the south segment, the delay time of an orderly bicycle box was 22.11 seconds shorter than without a bicycle box condition, or an orderly bicycle box condition was 12.82% more effective than without a bicycle box condition. While delay time of a non-orderly bicycle box was 0.54 seconds shorter than without a bicycle box condition, and a non-orderly bicycle box condition was slightly more effective than without a bicycle box condition.

In the west segment, the difference value between condition without a bicycle box and condition with an orderly bicycle box was 8.03 seconds, or the condition with an orderly bicycle box was 56.79% more effective than without a bicycle box. While the difference value between the condition without a bicycle box and the condition with a non-orderly bicycle box were 2.3 seconds or the condition with a non-orderly bicycle box was 1.63% more effective than without a bicycle box.

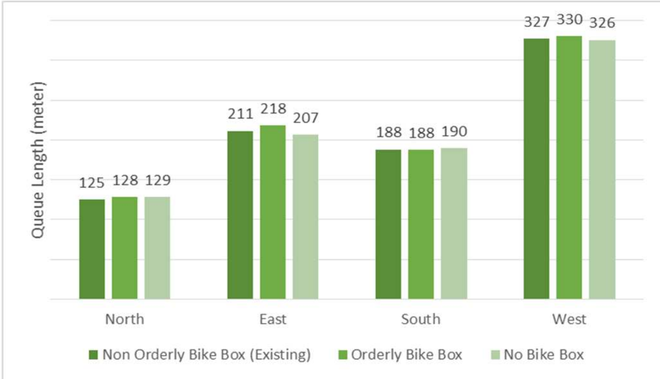

Fig. 16 Queue Length at Pojok Benteng Wetan Intersection

Figure 16 shows that the queue on the east and west sides was the shortest when there was no bicycle box. In contrast, the north segment had the shortest queue length in a non-orderly bicycle box condition, and the south segment had the shortest queue length in an orderly bicycle box condition.

In the north segment, the queue length of an orderly bicycle box was 0.645 meters shorter than without a bicycle box condition, or an orderly bicycle box condition was 0.5% more effective than the condition without a bicycle box. While the queue length of the non-orderly bicycle box condition was 3.54 meters shorter than without a bicycle box condition or a non-orderly bicycle box condition was 2.75% more effective than the condition without a bicycle box.

In the east segment, the difference value between an orderly bicycle box condition and a condition without a bicycle box was 11.29 meters, and a condition without a bicycle box was 5.18% more effective than an orderly bicycle box condition. While the difference value of a non-orderly bicycle box condition and a condition without a bicycle box was 4.6 meters or condition without a bicycle box was 2.18% more effective than a non-orderly bicycle box condition.

In the south segment, the queue length of an orderly bicycle box was 2.002 meters shorter than without a bicycle box condition, or an orderly bicycle box condition was slightly more effective than the condition without a bicycle box by 1.06%. While the queue length of the non-orderly bicycle box condition was 2 meters shorter than without a bicycle box condition or a non-orderly bicycle box condition was slightly more effective than the condition without a bicycle box by 1.05%.

In the west segment, the difference value of an orderly bicycle box condition and a condition without a bicycle box was 4.3 meters, or a condition without a bicycle box was more effective than an orderly bicycle box condition by 1.31%. While the difference value of a non-orderly bicycle box condition and a condition without a bicycle box was 1.69 meters or condition without a bicycle box was more effective than a non-orderly bicycle box condition by 0.52%.

C. Traffic Performances at Both Site

The results of the data obtained from the four segments are then calculated to obtain the average delay time and the maximum queue length.

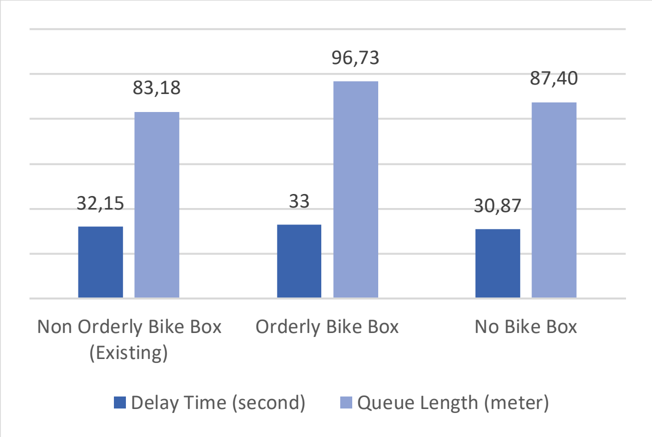

Fig. 17 Traffic Performances at Panembahan Senopati Street

Based on the average delay time of all segments from Figure 17, it can be concluded that the condition without a bicycle box was the most effective in Panembahan Senopati Intersection. The condition without a bicycle box was more effective than a non-orderly bicycle waiting room (existing conditions) at 3.98%. The condition without a bicycle box was also more effective than an orderly bicycle box condition at 6.45%.

Based on the maximum queue length of all segments seen in Figure 17, it can be concluded that the condition with a non-orderly bicycle box was the most effective in Panembahan Senopati Intersection. The condition with a non-orderly bicycle box (existing condition) was more effective than the condition without a bicycle box at 4.82%. While the condition with a non-orderly bicycle box (existing condition) was more effective than an orderly bicycle box condition at 14.01%

In Panembahan Senopati Intersection, the level of intersection services based on time delays in the three scenarios (Non-Orderly Bike Box, Orderly Bike Box, and No Bike Box) was in category D with a delay time between 25.1 - 40 seconds.

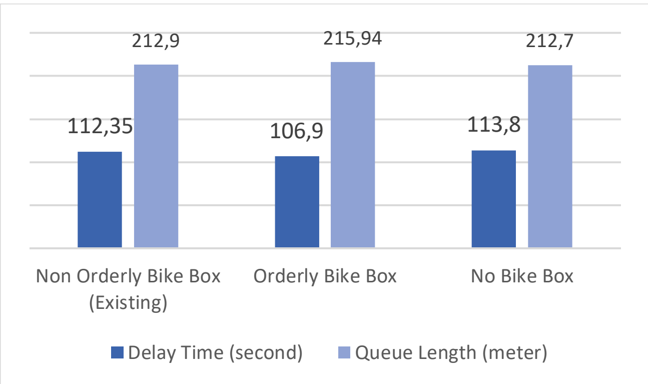

Fig. 18 Traffic Performances at Pojok Benteng Wetan Intersection

Based on the average delay time of all segments from Figure 18, it can be concluded that the condition with an orderly bicycle box was the most effective in Pojok Benteng Wetan Intersection. The condition with an orderly bicycle box was more effective than a non-orderly bicycle box at 4.85%. The condition with an orderly bicycle box was also more effective than without a bicycle box condition at 6.06%.

Based on the maximum queue length of all segments that can be seen in Figure 18, it can be concluded that the condition without a bicycle box was the most effective in Pojok Benteng Wetan Intersection. The condition without a bicycle box was more effective than the condition with an orderly bicycle box at 1.5%. While the condition without a bicycle box was slightly more effective than a non-orderly bicycle box condition (existing conditions) at 0.09%.

In Pojok Bentemg Wetan Intersection, the level of intersection services based on time delays in the three scenarios (Non-Orderly Bike Box, Orderly Bike Box, and No Bike Box) was in category F with a delay time of more than 60 seconds.

From the data research, every scenario (Non-Orderly Bike Box, Orderly Bike Box, and No Bike Box) had variations in the intersection performance, especially for the delay time and the queue length. For example, Panembahan Senopati Intersection had the lowest delay time in a condition without a bicycle box and had the shortest queue length in a non-orderly bicycle box condition. However, Pojok Benteng Wetan Intersection had the lowest delay time in an orderly bicycle box and had the shortest queue length in a condition without a bicycle box.

In contrast, although an intersection with a properly used bike box tends to perform poorer compared to an intersection with a disorderly bike box or with no bike box, from the aspect of cyclist safety, it is still the preferred condition. Because when the green phase begins, cyclists can move first, and other riders behind can know and predict the movements of the cyclists in front.

Other factors may contribute to the variation in intersection performance, such as the geometric data of the intersection, the traffic signal diagram, the traffic signal phase, the vehicle volume, and the types of the vehicles. Further research is required to study more about these additional factors and the effect that they have on intersection performance. A better understanding of the factors that affect the performance of an intersection can advance the design of a bicycle box that is not only good for safety but also good for traffic performance.

IV. Conclusions

Panembahan Senopati Intersection had the lowest delay time value of 30.87 seconds in a condition without a bicycle box. While the condition with the shortest queue length was the condition with a non-orderly bike box (existing) at 83.184 meters. On the other hand, Pojok Benteng Wetan Intersection had the lowest delay time value of 106.9 seconds in a condition with an orderly bicycle box. In comparison, the condition with the shortest queue length was the condition without a bike box at 212.7 meters. The level of intersection services based on time delays in the three scenarios (Non-Orderly Bike Box, Orderly Bike Box, and No Bike Box) for Panembahan Senopati Intersection and Pojok Benteng Wetan Intersection were in category D and category F, respectively.

Every scenario (Non-Orderly Bike Box, Orderly Bike Box, and No Bike Box) had variations in the intersection performance, especially for the delay time and the queue length. In further research, it is important to know other factors that may cause the variation in intersection performances and how much they affect the intersection performances.

NOMENCLATURE

NQ1	number of the passenger car unit remaining from the previous green phase	pcu
DS	degree of saturation	
GR	green ratio	
C	capacity	pcu/hour
NQ2	number of the passenger car unit arrivals during the red phase	pcu
c	cycle time	second
Q	traffic flow at entry points outside LTOR	pcu/hour
NQ	number of vehicles in the queue	vehicle
DT	average time delay	second/pcu
GEH	Geoffrey E. Havers equation	percentage
q	traffic flow volume	veh/hour

REFERENCES

[1] H. Hendrawan and S. Amelia, "Evaluation of The Effectiveness Bike Lanes on Urban Roads," in *Conference: 14th Road Engineering Regional Conference*, 2018, pp. 317–327, [Online]. Available: https://www.researchgate.net/publication/339840395.

[2] Z. Bin Lin, Y. H. Ji, Q. Y. Xiao, L. B. Luo, L. P. Li, and B. Choi, "Risk factors of bicycle traffic injury among middle school students in chaoshan rural areas of China," *Int. J. Equity Health*, vol. 16, no. 1, pp. 1–9, 2017, doi: 10.1186/s12939-016-0512-8.

[3] K. Wang and G. Akar, "The perceptions of bicycling intersection safety by four types of bicyclists," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 59, pp. 67–80, Nov. 2018, doi: 10.1016/j.trf.2018.08.014.

[4] T. L. Hamilton and C. J. Wichman, "Bicycle infrastructure and traffic congestion: Evidence from DC's Capital Bikeshare," *J. Environ. Econ. Manage.*, vol. 87, pp. 72–93, 2018, doi: 10.1016/j.jeem.2017.03.007.

[5] N. Guo, R. Jiang, S. C. Wong, Q. Y. Hao, S. Q. Xue, and M. Bin Hu, "Bicycle flow dynamics on wide roads: Experiments and simulation," *Transp. Res. Part C Emerg. Technol.*, vol. 125, no. September 2020, p. 103012, 2021, doi: 10.1016/j.trc.2021.103012.

[6] A. D. Rostami, A. Katthe, A. Sohrabi, and A. Jahangiri, "Predicting critical bicycle-vehicle conflicts at signalised intersections," *J. Adv. Transp.*, vol. 2020, 2020, doi: 10.1155/2020/8816616.

[7] Y. Li, Y. Ni, and J. Sun, "A modified social force model for high-density through bicycle flow at mixed-traffic intersections," *Simul. Model. Pract. Theory*, vol. 108, no. August 2020, p. 102265, 2021, doi: 10.1016/j.simpat.2020.102265.

[8] H. Ding, N. N. Sze, Y. Guo, and H. Li, "Role of exposure in bicycle safety analysis: Effect of cycle path choice," *Accid. Anal. Prev.*, vol. 153, no. August 2020, p. 106014, 2021, doi: 10.1016/j.aap.2021.106014.

[9] A. Houz, "Evaluation of Bike Boxes and Protected Intersections with Bicycle Signal Treatments for Improving Safety and Multimodal Mobility at Urban Signalized Intersections," Western Michigan University, 2018.

[10] T. K. O. Madsen and H. Lahrmann, "Comparison of five bicycle facility designs in signalised intersections using traffic conflict studies," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 46, pp. 438–450, 2017, doi: 10.1016/j.trf.2016.05.008.

[11] Z. Pu, Z. Li, Y. Wang, M. Ye, and W. Fan, "Evaluating the Interference of Bicycle Traffic on Vehicle Operation on Urban Streets with Bike Lanes," *J. Adv. Transp.*, vol. 2017, 2017, doi: 10.1155/2017/6973089.

[12] E. Robartes, E. Chen, T. D. Chen, and P. B. Ohlms, "Assessment of local, state, and federal barriers to implementing bicycle infrastructure: A Virginia case study," *Case Stud. Transp. Policy*, vol. 9, no. 2, pp. 488–496, 2021, doi: 10.1016/j.cstp.2021.02.004.

[13] N. Fournier *et al.*, "Accounting for drivers' bicycling frequency and familiarity with bicycle infrastructure treatments when evaluating safety," *Accid. Anal. Prev.*, vol. 137, no. July 2019, p. 105410, 2020, doi: 10.1016/j.aap.2019.105410.

[14] J. Dill, C. Monsere, and N. McNeil, "Evaluation of Bike Boxes at Signalized Intersections," Portland, Jan. 2011. doi: 10.15760/trec.138.

[15] T. Götschi, A. Castro, M. Deforth, L. Miranda-Moreno, and S. Zangenehpour, "Towards a comprehensive safety evaluation of cycling infrastructure including objective and subjective measures," *J. Transp. Heal.*, vol. 8, no. December 2017, pp. 44–54, 2018, doi: 10.1016/j.jth.2017.12.003.

[16] J. Luengo-Oroz and S. Reis, "Assessment of cyclists' exposure to ultrafine particles along alternative commuting routes in Edinburgh," *Atmos. Pollut. Res.*, vol. 10, no. 4, pp. 1148–1158, 2019, doi: 10.1016/j.apr.2019.01.020.

[17] Directorate General of Highways of the Republic of Indonesia, "Indonesian Road Capacity Manual." Jakarta, Indonesia, 1997.

[18] Minister of Transportation of the Republic of Indonesia, *Guidelines for Implementing Traffic Management and Engineering Activities*. 2015.

[19] G. T. Wall, D. G. Davies, and M. Crabtree, "Capacity Implications of Advanced Stop Lines for Cyclist (Transport Research Laboratory (TRL) Reports, TRL585)," Wokingham, UK, 2003. [Online]. Available: https://eprints.soton.ac.uk/53269/.

[20] M. Idris, "The Effect of a Motorcycle Special Stop Room on Traffic Conflicts at a Signal Intersection in Bandung," Institut Teknologi Bandung, 2007.

[21] J. Loskorn, A. F. Mills, J. F. Brady, J. C. Duthie, and R. B. Machemehl, "Effects of bicycle boxes on bicyclist and motorist behavior at intersections in Austin, texas," *J. Transp. Eng.*, vol. 139, no. 10, pp. 1039–1046, 2013, doi: 10.1061/(ASCE)TE.1943-5436.0000584.

[22] C. M. Sari and B. Kushari, "Effectiveness of the Use of a Special Stop Room Motorcycle Against the Performance of the Signalized Intersection in Lawu Karanganyar Regency," in *Prosiding Konferensi Nasional Inovasi Lingkungan Terbangun*, 2017, pp. 199–209, [Online]. Available: https://ilt.uii.ac.id/wp-content/uploads/2017/10/PROSIDING_ILT_OK.pdf.

[23] M. Arafat, S. R. Nafis, E. Sadeghvaziri, and F. Tousif, "A data-driven approach to calibrate microsimulation models based on the degree of saturation at signalised intersections," *Transp. Res. Interdiscip. Perspect.*, vol. 8, 2020, doi: 10.1016/j.trip.2020.100231.

[24] T. Kučera and J. Chocholáč, "Design of the city logistics simulation model using PTV VISSIM software," *Transp. Res. Procedia*, vol. 53, no. 2019, pp. 258–265, 2021, doi: 10.1016/j.trpro.2021.02.033.

[25] S. S. Leal, P. E. MacIel De Almeida, and R. G. Ribeiro, "Calibrating Traffic Microscopic Simulation Model Parameters Using an Evolutionary Approach," *Transp. Res. Procedia*, vol. 48, no. 2018, pp. 1038–1045, 2020, doi: 10.1016/j.trpro.2020.08.131.

[26] Roads and Traffic Authority of New South Wales Government, *Paramics microsimulation modelling - RTA manual*. New South Wales: Roads and Traffic Authority of New South Wales Government, 2009.

[27] Sugiyono, *Quantitative and Qualitative Research Methods and R&D*. Bandung, Indonesia: Alfabeta, 2012.