Traffic Flow Analysis Due to Road Narrowing (Case Study: Jatingaleh Underpass)

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***Abstract*—Jatingaleh Underpass is designed to solve congestion problem and reduce the rates at which accidents occur at intersections due to conflicts, but bottleneck can affect traffic performance. This study aims to determine in traffic movements, traffic performance after the existence of Underpass based on MKJI 1997, analyze density with the Greenshield linear approach, and analyze the effect of bottleneck. To be more effective, the survey is conducted by using drones. Based on the analysis, the road performance becomes better, but some segments should be optimized because degree of saturation (DS) > 0.75. The vehicle speed results are 52.29; 55.49; 29.87; 26.28 km/hour in segment A; B; C; D and Segment Density C; D = 155.71; 152.86 pcu/km. Vehicle speed on bottleneck Segment C and D, in Setia Budi Street does not achieve the Primary Arterial Road criteria at 60 km/hour with very high density result. Bottleneck causes increased density, raises new conflict points (weaving), decreases vehicle speed up to 42-46%, and causes queue length of 0,150 km. We propose that the Underpass it must be in accordance with the geometric requirements of MKJI, there should be no narrowing of the road in any segment.**
Keywords—congestion, traffic, bottleneck, underpass

I. INTRODUCTION

Jatingaleh is the center of activities and meeting point of Semarang's upper and lower regions. The increasing number of vehicles in this city especially in Jatingaleh, Teuku Umar and Setia Budi Section causes congestion. According to previous studies, traffic congestion can lead to an increase in local density, thereby negatively affecting the economy [1].

Traffic management and engineering has been conducted in order to resolve this problem without success, thereby, leading to the construction of an Underpass to help enhance this situation. A study conducted by Setiono, taking into account the road performance using MKJI 1997, lead to the Construction of Gilingan Underpass to improve road performance, reduce acute congestion at intersections and accident rates [2].

Based on previous study data in 2012 using Average Daily Traffic (ADT), the volume at street Teuku Umar is 10.497 pcu / hour with DS = 1.8, while in Setia Budi street it is 5,245 pcu / hour with DS = 0,9 [3,4]. As a result of this, the government resolved to take adequate measures to overcome congestion in the Jatingaleh region, by planning the construction of underpasses. Its several segments show that road performance still cannot solve the existing problems optimally [4].

The Jatingaleh Underpass consists of widening the Jatingaleh Bridge, and construction of narrowed C and D road segments (Figure 1) capable of creating potential differences in traffic performance.

Based on road geometry studies, diversity of these characteristics can cause differences in vehicle speed [5]. However, according to the speed study conducted by Gaca [6], it is necessary to adjust speed limit recommendations with respect to the developed road functions. This is in lieu with the acceleration value of the design currently used, to adjust the class and its function [6].

As a result of this, the development of Jatingaleh Underpass which is expected to overcome congestion needs owing to the narrowing of some segments.

Based on the existing phenomena, the purpose of this study is:

1) Analyzing changes in traffic movements.
2) Knowing traffic performance after the existence of Underpass with the MKJI 1997 analysis method [7].
3) Evaluating the speed, volume, and density relationship using the Greenshields linear method [8,9].
4) Examining narrow segments.

II. RESEARCH METHOD

Based on the congestion phenomenon in Jatingaleh and previous studies, research was conducted on the characteristics of traffic and the effect of road constriction. The survey tools used in this study are drones in order to cover large areas. According to H. Zhou [10], conventional traffic data collection is not only limited to local regions and thus, it is expensive and labor intensive to monitor traffic activities across broad areas [10].

However, assuming the survey is carried out conventionally, more surveyor workers are required and it will be less effective because due to numerous roads and intersections, thereby, making it more expensive. Therefore, the use of unmanned aircraft is considered more effective.

How to use data obtained from drones:

1) The first step is for the surveyor to determine the strategic location to enable the drones camera to cover the area of study (covering the four road sections studied). The point of observation is the Jatingaleh Bridge to facilitate video captured to the Gombel Underpass.
2) The unmanned aircraft is flown by a surveyor within a certain height at one observation point.
3) Video recording is carried out for 1 hour. This is conducted to observe the movement of vehicle traffic on Setia Budi Street.
4) It easy to obtain traffic data in a wide area, and minimize the number of observers in the field.
5) Data includes number of vehicles, the time changes needed by vehicles to move from one reference point to another.
6) The recorded video is played back to calculate the volume of each type of vehicle, as well as the speed with

reference to distance, and the density of vehicles under study.

7) The data is then analyzed using MKJI 1997 and the linear Greenshields approach, taking into account the effect of road narrowing on traffic.

Vehicle speed is calculated using the Space Mean Speed method with the following steps:

1) Determine the starting and ending points to be traveled by along 100 m.
2) Record the start and end time needed to reach a predetermined point.
3) Calculated the speed for each type of vehicle.
4) The speed observed is in Segment A, B, C, and D.

Calculation of obstacle weights aims to determine the type of class of side barriers. These include pedestrians, parking vehicles, those coming in and out of the road side and slow moving vehicles. Analysis of traffic performance was done MKJI 1997 with the Greenshields linear method approach.

The location to be researched and analyzed is limited to those capable of narrowing the problem in Jatingaleh Underpass. It is stretched out from the bridge to the Gombel Underpass area, down to the end of Lama and Baru (Setia Budi Street).

The observed location is divided into 4 segments A, B in the middle line (above the Underpass) and C, D in the outer lane. The location of the observation can be seen in Fig. 1 as follows:

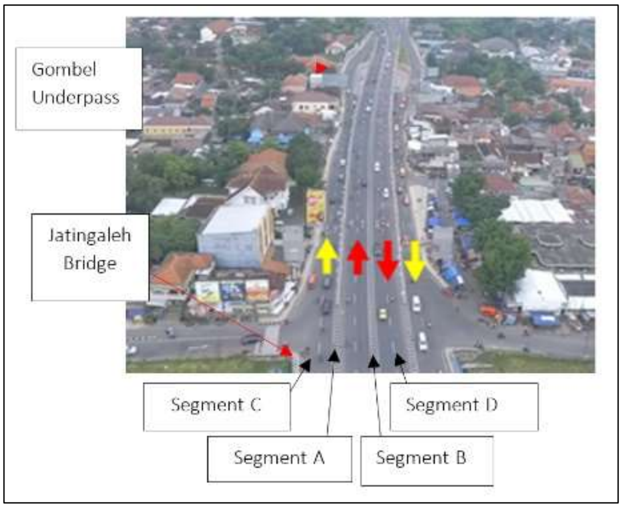

Fig. 1. Location of the Traffic Flow in Jatingaleh

In Setia Budi Street, segment A and B passes over the Underpass with Primary Arterial Road Types of width 14.00 m, and type 4/2 D. Segments C and D are on the Outer Lines with Primary Arteries of width 6.00 m, with Type Road 2/1.

III. RESULT AND DISCUSSION

A. Movement Pattern

Before the Underpass Development, there were lots of congestions associated with this location due to many points of conflict. Furthermore, in front of the Front Tax Office, the rotating vehicle was limited, causing congestion. After the construction of the Gombel Underpass, vehicles started moving freely and safely.

The movement of vehicles before and after its development can be seen in Figs. 2 and 3.

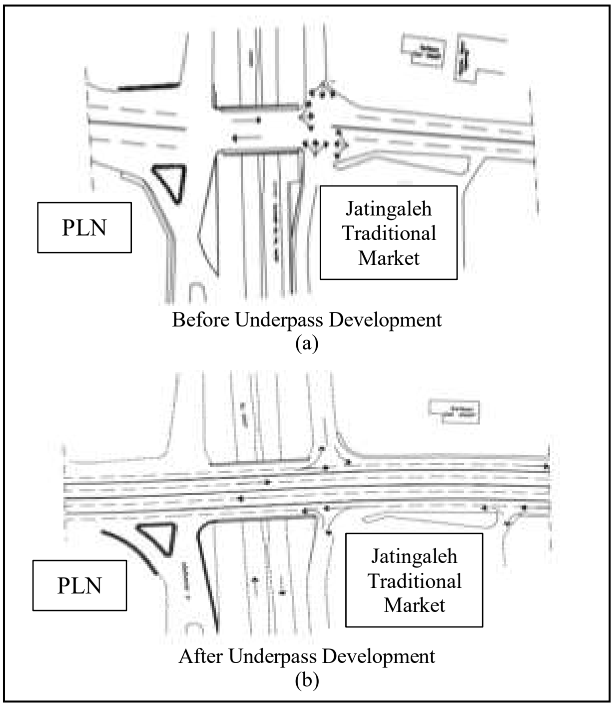

Fig. 2. Traffic Movement Patterns before (a) and after (b) Jatingaleh Underpass Development (Jatingaleh Bridge Location).

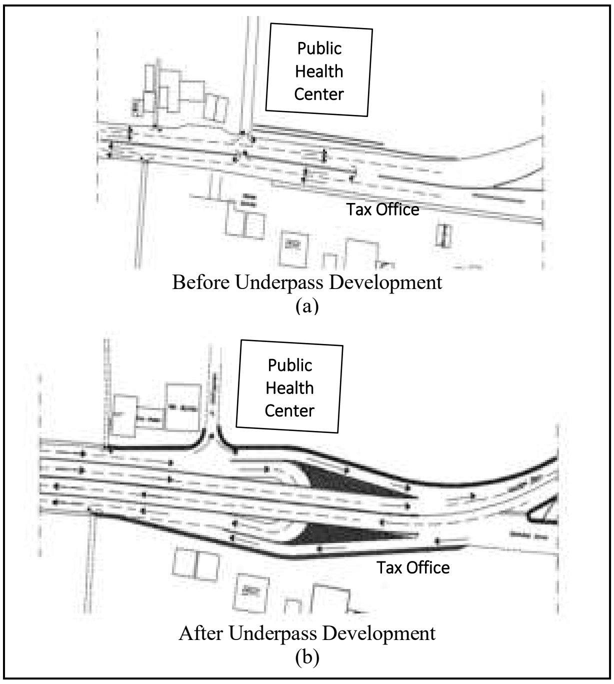

Fig. 3. Traffic Movement Patterns Before (a) dan After (b) Jatingaleh Underpass Development (Gombel Underpass Location)

As shown in Figures 2 and 3, the pattern of vehicle movements became more organized with the construction of the Underpass. Traffic movements before its existence appear to be very complex, giving rise to a point of conflict. Vehicles tend to divert, weave, and merge at intersections, thereby, leading to congestion and queues. After construction, traffic becomes more regular owing to the elimination of crossing points. The vehicle can also rotate safely because it has been facilitated by the existence of an Underpass.

B. Traffic Performance Analysis

In 2012, the saturation grades at Teuku Umar and Setia Budi were 1.8 and 0.9, respectively. In 2018, after constructing the Underpass Development, data was obtained according to the Table I as follows:

TABLE I. DATA RECAPITULATION IN ACCORDANCE WITH MKJI 1997

Data Recap	**Table Column Head**			
	A	***B***	***C***	***D***
Side Obstacles	39.2	31.6	797.1	418.1
C (junior/hour)	3135	3135	2368	2611
V (junior/hour)	2404	1926	1864	1660
DS	0.77	0.61	0.79	0.64
S (km/h)	52.29	55.49	29.87	26.28
FV (km/h)	57.00	57.00	41.00	46.00

Based on table I, the results of the analysis are as follows:

- With the construction of the Underpass Jatingaleh, traffic performance is better, as indicated by the decreasing value of saturation. However, some segments are still being optimized.
- In segment B and D, the degree of traffic saturation according to MKJI 1997 is less than 0.75, this indicates that it is able to accommodate passing vehicles properly. While in segment A and C on Setia Budi Street it exceeded 0.75, therefore, it is necessary to optimize it to enable the proper passage of vehicles.
- The delay beside Segment A, B is very small because the main road is restricted to vehicles moving in and out. Segment D is the frequency of medium side barriers, with the highest frequency in C owing to the large amount of vehicles moving out. Therefore further analysis is needed to examine the effect of side barriers.
- There is a considerable difference between the speed of the vehicle on the main line and in the outer lane because segments C and D act as the collecting lanes, therefore, it is greatly affected by the movement of other vehicles.
- The Criteria for Primary Arterial Road Speed are met in segments A and B only, while those that experience narrowing do not meet the speed of the primary artery. Therefore, a speed limit sign is needed to minimize accidents.
- There are clear differences between the performance of the main and outer road, such the density value, side barriers and vehicle speed in the field and the at free flow.

The reason Primary Arterial Road Speed plan is not achieved in Segment C and D are as follows:

- The effective width of the outer Line is only 3.00 meters per lane so that it does not achieve the ideal width of urban roads of 3.50 meters.
- Lack of optimal land were provided on Outer Lines due to the problems associated with land acquisition were influenced by social factors leading to road narrowing in severing sections.
- The high number of vehicles passing, and volume from the exit of Jatingaleh Toll Road.
- The amount of side barriers and the fulfillment of public transit points.

C. Analysis of Relationships Speed – Density, Volume - Density

Analysis of relationships speed – density and volume – density attending the characteristic of each segment. The characteristics of each segment are as follows:

- Segment A: Small Side Constraints, Roads are not narrow, and they ascend
- Segment B: Small Side Constraints, Roads are not narrow, and they descend.
- Segment C: Large Side Obstacles, Roads have narrowed several segments due to limited land, and Flat Road.
- Segment D: Medium Side Obstacles, narrowing due to interchange, and Flat Road.

Based on the analysis, the relationship between velocity-density such as in Table II and the graph in Fig. 4 are as follows:

TABLE II. RELATIONSHIP OF SPEED (S) AND DENSITY (D) WITH THE GREENSHIELD LINEAR MODEL

Segment	**S-D**	R^2
Seg. A	S = -0.3069 D + 68.892	0.546
Seg. B	S = -0.3621 D + 68.253	0.588
Seg. C	S = -0.2366 D + 45.424	0.853
Seg. D	S = -0.1857 D + 38.838	0.646

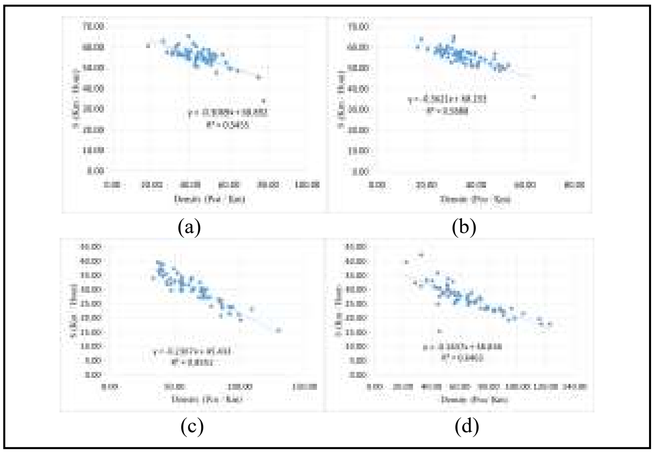

Fig. 4. Relationship of Speed – Density of Segment A (a), Segment B (b), Segment C (c), Segment D (d)

Based on table II, the analysis is as follows:

- The density affects the speed of the vehicle, especially in segments C and D, as a collecting path with low speed, the regression coefficient is 0.6-0.8.
- Linear Greenshields relationships are more suitable to be applied to collector or local lines, with low average velocities.

Based on the Greenshields linear equation, the parabolic volume (V) - Density (D) relationship is obtained, therefore, the equation in table III is obtained as follows:

TABLE III. VOLUME (V) RELATIONSHIP EQUATION – DENSITY (D) BASED ON THE GREENSHIELD EQUATION DERIVATIVE

Segment	V – D
Seg. A	$V = -0.3069\ D^2 + 68.892\ D$
Seg. B	$V = -0.3621\ D^2 + 68.253\ D$
Seg. C	$V = -0.2366\ D^2 + 45.424\ D$
Seg. D	$V = -0.1875\ D^2 + 38.838\ D$

Based on the Greenshields and MKJI 1997 method, the maximum capacity and free flow velocity obtained as shown in Table IV are as follows:

TABLE IV. MAXIMUM CAPACITY (C) AND SPEED OF FREE FLOW ACCORDING TO THE GREENSHIELD LINIEAR AND MKJI 1997

Segment	Maximum Capacity (pcu / hour)		Speed on Free Flow (km / h)	
	Greenshields	**MKJI**	***Greenshields***	**MKJI**
Seg. A	3066.42	3135	68.89	57.00
Seg. B	3216.29	3135	68.25	57.00
Seg. C	2180.60	2368	45.4	41.00
Seg. D	2052.79	2611	38.84	46.00

Data on maximum density at peak hours can be seen in Table V as follows:

TABLE V. MAXIMUM DENSITY (D) DURING PEAK HOURS

Segment	Dm (smp/jam)	
	Greenshields	**Observation**
Seg. A	83.79	117.14
Seg. B	94.25	90.00
Seg. C	96.04	155.71
Seg. D	105.71	152.86

Based on field observations, the density value in Segment C and D is very high compared to the maximum density obtained using a linear Greenshields where D = 96.04; 105.71 vehicles/km and D = 155.71; 152.86 vehicles/km. Traffic density analysis should be conducted directly in site.

Based on the Greenshields derivative equation the relationship of volume and density produces a parabolic graph. However, the volume relationship graph along with density calculated based on the formula V / S, shows the different behavior of segment C which has a narrowing like Fig. 5 as follows.

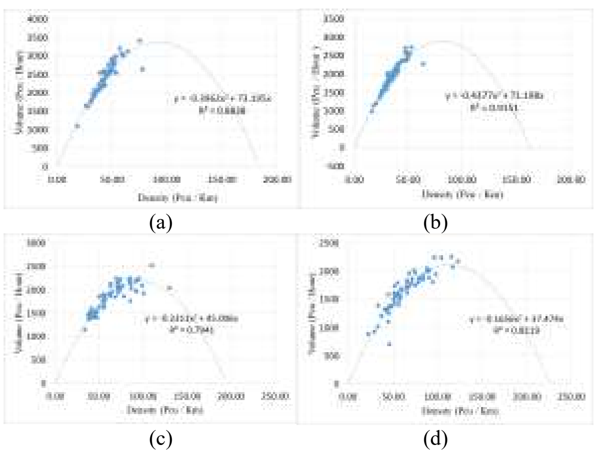

Fig. 5. Relationship of Volume – Density of Segment A (a), Segment B (b), Segment C (c), Segment D (d)

TABLE VI. RELATIONSHIP OF VOLUME (V) AND DENSITY (D) WITH THE GREENSHIELD LINEAR MODEL

Segment	V - D	R^2
Seg. A	$V = 0.3974\ D^2 + 73.24\ D$	0.880
Seg. B	$V = -0.4377\ D^2 + 71.198\ D$	0.915
Seg. C	$V = -0.2311D^2 + 45.066D$	0.794
Seg. D	$V = -0.1656\ D^2 + 37{,}474\ D$	0.812

Different behavior in segment C, which narrows roads with large side resistance value, produces a weak volume relationship with density. The influence of large side barriers and narrowing in C segment include:

- The speed of the vehicle is affected by changes in geometry due to the narrowing of the road.
- Vehicles entering into the new Gombel, must go through the right lane first because the left side is filled with vehicles coming in from tolls, and offices, owing to the stoppage of public transportation. This causes vehicles to undergo weaving leading to conflicting points. Similarly, vehicles from toll exit will enter the Gombel Underpass.
- The parabolic graph between volume and density shows a weak relationship in segment C.

Based on the analysis, the velocity-volume-density relationship can be concluded as follows:

- There is a significant difference between the data generated from Greenshields and MKJI 1997 analysis with regards to the calculation of the maximum capacity and free flow of the vehicle.
- The maximum density obtained using the Greenshields linear method is different from the location owing to the fact that the driving criteria in Indonesia is different from the countries used in the Greenshields research. Density in the location tends to be greater than the calculations.
- The speed and density relationship of Greenshields produces parabolic graphs. However, when compared to the graph of the volume and density relationship, calculated based on V / S, different behaviors can be seen in segment C. Therefore, further research is needed with regards to the relationship of volume and density on narrowed pathways.

D. Analysis of Road Narrowing

- The Degree of Saturation in Setia Budi in 2012 was 0.9 with a width of 7.00 meters. After the Underpass its outer path (segments C and D) was narrowed to 6 meters in one direction.
- Despite a narrowing of 1.00 meters, the DS value becomes 0.79 and 0.64 in the C and in D Segments. This does not cause an increase in the DS value, because addition of the path divides the vehicle flow into 2 Outer lanes.
- While designing the blueprint the width of Setia Budi street, and Gombel Baru is planned in two directions. The DS value is 0.56 (based on the survey results). However, with 2 directions, it becomes 1.123, as in Fig. 6.

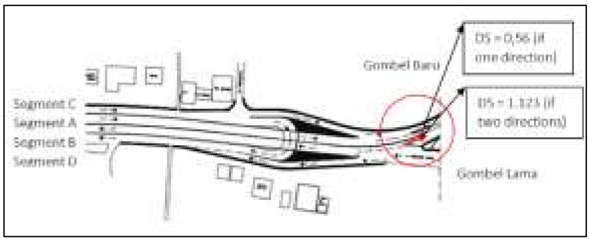

Fig. 6. Degree of Saturation on a narrowing path.

The interchange and merging of vehicles in segment D, can be seen in Fig. 7 as follows:

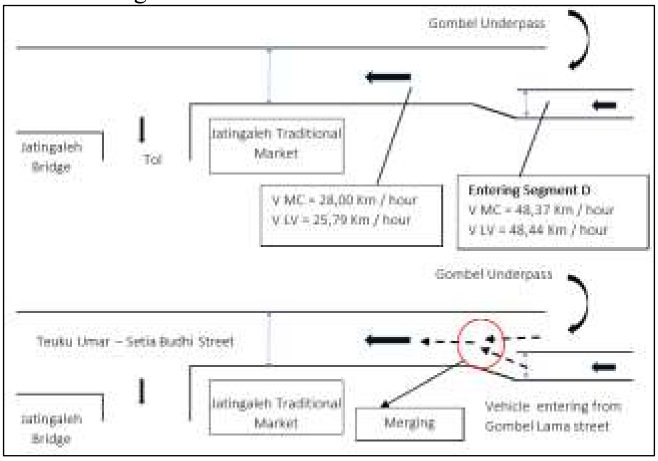

Fig. 7. Segment interchange narrowing D.

Based on the analysis of Fig. 7, the vehicle speed on Segment D (interchange) decreases. The original MC speed at 48.37 Km / Hour changes to 28.00 Km / Hour and the original LV at 48.44 Km / Hour changes to 25.79 Km / Hour. Based on observation the speed reaches 175 m due to the vehicle stopping at narrow areas.

The study conducted by Ognjenovic et al. [12] shows that lane changes affect vehicle speed. The operation (process) of their entering into the main traffic flows (on the highway) is more greater collisions assuming the entering lanes are not properly dimensioned and formed. The capacity depends on the intensity of traffic on the main direction and on the temporary gaps (critical interval) [12].

Based on field observations, the maximum queue is affected by merging, and narrowing the road (bottleneck) causing it to adjust its speed. The road capacity becomes smaller thereby, slowing down the emergence of a vehicle queue.

Speed in segment D has slowed due to the following:

- Adjustment of the movement of vehicles experiencing merging at the meeting point.
- The speed is affected by the vehicle in front which alternately enters the outer lane.
- Capacity of the road becomes smaller.

Effect of narrowing on vehicle speed due to limited land in segment C can be seen in Figs. 8 and 9 as follows:

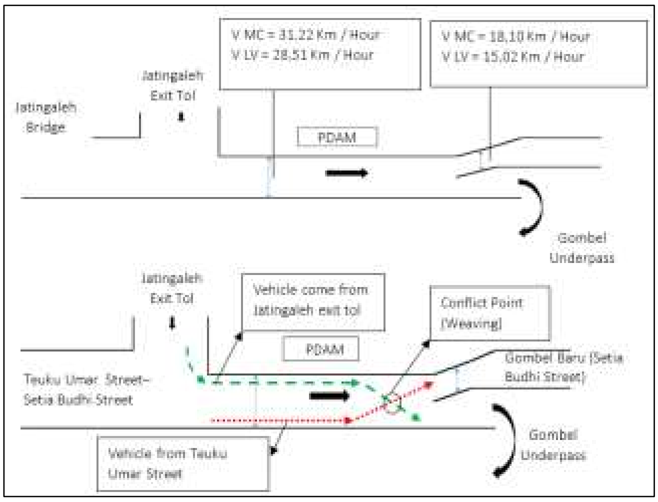

Fig. 8. Change in Speed on Road Narrowing in Segment C

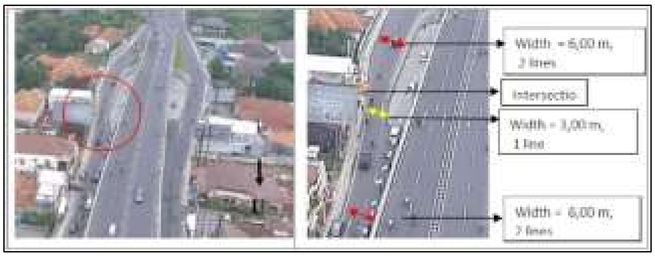

Fig. 9. Narrowing of Spots

Based on Fig. 8, the Vehicle Speed on Segment C, before entering the narrowing lane is 31.22 Km / Hour to 18.10 Km / Hour and the original LV speed is 28.51 Km / Hour to 15.02 Km / Hour.

The speed in Segment C has slowed due to the following:

- Adjusting vehicle movements merging, diverging, and weaving in areas near constriction. The most critical aspect of operation is whitening a segment of lane changing. This is to ensure that weaving vehicles, which must cross the road from the left to right or vice versa, are properly managed [13].
- The speed of the vehicle is influenced by those in front. This is because the speed fluctuation of each car creates a greater value with those behind it. This increase in fluctuations causes vehicle congestion. The physical mechanism of traffic jams with and without bottle necks shows that congestion occurs spontaneously [14]. This is similar to the narrowing effect in segment C, which can cause congestion due to changes in the speed of vehicles in front.
- The vehicles speed is affected by large side barriers in Segment C.
- Adjusting the roads capacity that changes becomes smaller.

IV. CONCLUSION

After the construction of Jatingaleh Underpass, vehicle movements became more organized owing to the decrease in the points of conflict.

- Based on the evaluation results, the degree of saturation (DS) in Segments A, B, C, D is 0.77; 0.61; 0.79; 0.64, respectively, with average speed of 52.29; 55.49; 29.87; 26.28 Km / hour. DS studies conducted on Setia Budi Road resulted to 0.9. This shows that road performance has increased, but optimization still needs to be conducted because some segments have DS> 0.75. Vehicle speed on narrow roads in segments C and D, on Setia Budi Road, which is the Primary Arterial Road (PUPR Minister Decree No: 284 / KPTS / M / 2015) does not meet the criteria for plan speed of 60 km / h, due to the influence of side barriers and narrow roads.
- Based on the analysis, the density value with Greenshields Segment A; B; C; D is 83.79; 94.25; 96.04; 105.71 pcu / hour, respectively with 117.14; 90.00; 155.71; 152.86 densities pcu/hour. Density should be carried out by on-site observations because there are significant differences with the calculation of the Greenshields model. This case is due to differences in road characteristics and user traffic behavior in Indonesia.
- Road Narrowing in Segment C (Outer lane of city direction) and Segment D (outer lane towards city direction) consists of high side barriers, which creates new conflict points (weaving vehicles), with decreasing vehicle speed of up to 42-46%. The speed of C Segment which was originally at MC; LV = 31.22; 28.51 Km / hour moved to18.10; 15.02 Km/hour, and the D segment originally at MC; LV = 48.37; 48.44 Km/hour migrated to 28.00; 25.79 Km/hour. The narrowing of the road creates an opportunity for queues with a maximum length of 0,150 Km.

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