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The Effect Of Road Narrowing On The Traffic Characteristics

Reza Yoga Widya Baskara*, Atik Wahyuni, Farida Hardanignrum

Department of Civil Engineering, Faculty of Engineering, Narotama University, Indonesia
**Corresponding author e-mail: rezayoga43@gmail.com*

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Abstract

A problem found in transportation is road narrowing. Road narrowing refers to a condition in which its downstream is smaller than the upstream. This research took place on *Ahmad Yani* Street at the front of *Royal Plaza*, Surabaya. The location of this research had a sufficiently high traffic flow. Thus, the road should be able to operate optimally. In fact, there is still a density caused by road narrowing. This research was intended to determine how much the maximum flow, maximum density and free speed on the road before, during and after the narrowing. Besides, this research was carried out to find out the relation of the flow, the traffic density and speed, determine the value of the shock waves during the road narrowing. This research was done on Wednesday and Saturday morning, at 06:00-08:00 and in the afternoon at 16:00-18:00. The calculation performed was based on Greenshield method. The analysis revealed that the largest maximum flow was on the fragment of road before narrowing, which was 2376.30 pcu/hour. The maximum density found on the fragment of road during narrowing was 322.33 pcu/hour, and the highest free speed regarding to the road condition before the narrowing was 57.21 km/hour. The relation between flow, speed and density showed a significant result (R2> 0.5). Shock waves obtained were in the mornings and afternoons on Wednesday and Saturday.

Keywords: *road narrowing, shock waves, free flow.*

1. Introduction

Surabaya which is located on the north coast in East Java province becomes the second largest city in Indonesia after Jakarta. The area of Surabaya city reaches around 326.81 km² along with 2,765,487 population of its inhabitants in 2017, it borders Madura Strait in the north and east, it borders Sidoarjo Regency on the south, and Gresik Regency in the west. There are a total of 160 urban villages around its 31 sub-districts [1].
The total of road network in Surabaya is 2,063.04 km. Similar to other Cities, the problem comes from the management of road infrastructure which is still being evaluated by the Surabaya Government. Road infrastructure plays an important role in Surabaya economic growth so that it is able to suffice and accommodate the high mobility of Surabaya citizens. Hence, the Surabaya Government puts in the efforts continuously for the improvement. For instance, the Surabaya Government has built the new roads and widened its certain sections. Regardless the efforts done by the Surabaya Government, the management had not been maximally done on several road points. For instance was Ahmad Yani street at the front of *Royal Plaza*.

2. Literature Review

The speed of traffic, known as “S” notation is the motion of vehicle within a time unit distance [2]. Volume is defined as the number of vehicle passing a certain point per unit time at a particular location [3]. Density means the average number of vehicles per unit length of a certain lane and time [4]. Greenshield model was the earliest model used to observe the traffic behavior. Greenshield (1934) conducted a research focusing on the road lane in Ohio, USA, whose the traffic conditions met the requirement since there were no interruption and free movement (study state conditions). Shock waves happened due to the changes of traffic density as it caused by the obstruction on free traffic flow, This condition found on roads due to certain construction such as traffic accidents, road repair and others incidental things or as the result of road lane narrowing which is permanent. Besides that it is also found whether or not at a signalized intersection. The normal shock waves at signalized intersection are caused by red and green lights that appear periodically [5].

3. Method

The field data collection was carried out on Wednesday and Saturday. It was conducted for 12 hours per day at 06:00-18:00 with observational time interval per 10 minutes. The data retrieval of volume and speed was done at 3 points namely normal road condition, road narrowing condition and road condition after narrowing. The primary survey was held to obtain the volume and speed data. The speed data were obtained by recording the travel time of vehicles on the fragment of observation road by taking the data of light vehicles randomly at 10 minutes interval. While the volume data were taken by recording all types of vehicles that cross the observation line at the research location with an observation time interval per 10 minutes. Then the data were summed up per 1 hour according to each type of vehicle and converted into passenger car unit (pcu) by multiplying each type of vehicle with the value of passenger car equivalent (pce). After knowing all the values of the model parameters by regression analysis, the researchers calculated the extent of the accuracy of the regression function by looking for the value of the coefficient of determination as well as the t test and F test significance.

4. Results and Discussion

The results of the analysis of the calculation of the value of speed, density and volume obtained from the results of research in the field were in the form of the number of vehicles and the average speed of the room. By using regression analysis from the above data, the mathematical relationship between density, speed and volume was obtained as follows:

Table 1. Relationship of average speed of time, volume, and density (Wednesday, February 19, 2020)

Location	Observation	Formula Model	Field Model	R2
Fragment of the road before narrowing	St - V	$V= Dj.St-(Dj/St).St^2$	$V = 156{,}431\ St - 2{,}406\ St^2$	0,842
	V - D	$V= S_{ff}.D-(S_{ff}/Dj).D^2$	$V = 65{,}016\ D - 0{,}41562\ D^2$	0,958
	St - D	$S= S_{ff} - (S_{ff}/Dj).D$	$S = 65{,}016 - 0{,}41562\ D$	0,867
Fragment of the road during narrowing	St - V	$V= Dj.St-(Dj/St).St^2$	$V = 322{,}331\ St - 11{,}6036\ St^2$	0,480
	V - D	$V= S_{ff}.D-(S_{ff}/Dj).D^2$	$V = 27{,}778\ D - 0{,}08618\ D^2$	0,697
	St - D	$S= S_{ff} - (S_{ff}/Dj).D$	$S = 27{,}778 - 0{,}08618\ D$	0,904
Fragment of the road after narrowing	St - V	$V= Dj.St-(Dj/St).St^2$	$V = 265{,}550\ St - 5{,}33677\ St^2$	0,203
	V - D	$V= S_{ff}.D-(S_{ff}/Dj).D^2$	$V = 49{,}759\ D - 0{,}18738\ D^2$	0,916
	St - D	$S= S_{ff} - (S_{ff}/Dj).D$	$S = 49{,}759 - 0{,}18738\ D$	0,472

Table 2. Relationship of average speed of time, volume, and density (Saturday, February 22, 2020)

Location	Observation	Formula Model	Field Model	R2
Fragment of the road before narrowing	St - V	$V= Dj.St-(Dj/St).St^2$	$V = 145{,}124\ St - 2{,}20016\ St^2$	0,750
	V - D	$V= S_{ff}.D-(S_{ff}/Dj).D^2$	$V = 65{,}961\ D - 0{,}45451\ D^2$	0,918
	St - D	$S= S_{ff} - (S_{ff}/Dj).D$	$S = 65{,}961 - 0{,}45451\ D$	0,815
Fragment of the road during narrowing	St - V	$V= Dj.St-(Dj/St).St^2$	$V = 290{,}799\ St - 9{,}62083\ St^2$	0,724
	V - D	$V= S_{ff}.D-(S_{ff}/Dj).D^2$	$V = 30{,}226\ D - 0{,}10394\ D^2$	0,781
	St - D	$S= S_{ff} - (S_{ff}/Dj).D$	$S = 30{,}226 - 0{,}10394\ D$	0,955
Fragment of the road after narrowing	St - V	$V= Dj.St-(Dj/St).St^2$	$V = 169{,}767\ St - 3{,}0784\ St^2$	0,671
	V - D	$V= S_{ff}.D-(S_{ff}/Dj).D^2$	$V = 55{,}147\ D - 0{,}32484\ D^2$	0,876
	St - D	$S= S_{ff} - (S_{ff}/Dj).D$	$S = 55{,}147 - 0{,}32484\ D$	0,880

The value of coefficient of determination (R2) showed the influence of the independent variable (X) on the dependent variable (Y). The variable tested in this research was the t test, which was the control tool of the statistical analysis result, in this case linear regression, by comparing the values of F and t count and values of F and t table. The tests were considered true if the values of F and t count were greater than the values of F and t table.

Table 3. Results of F and t tests

Wednesday, February 19, 2020		**Saturday, February 22, 2020**	
Location	**Test result**	**Location**	**Test result**
Fragment of the road before narrowing	F= 424,426 t = 74,658	Fragment of the road before narrowing	F= 288,610 t = 56,916
Fragment of the road during narrowing	F= 615,545 t = 62,981	Fragment of the road during narrowing	F= 1334,76 t = 87,359
Fragment of the road after narrowing	F= 58,080 t = 41,657	Fragment of the road after narrowing	F= 475,544 t = 68,983

F table value = 3,14
T table value = 1,99714
It can be seen that the F and t count values were greater than the F and t table values at the 95% confidence level, thus the model can be used.

4.1. SHOCK WAVE VALUE

The value of the shock wave (ω) on the road narrowing began by plotting demand, upstream, and supply based on the selected maximum flow. Shock wave analysis can be done if demand exceeds supply [6].

$$\omega = \frac{V1-V2}{d1-d2}$$

ω = shock wave (km/hour)
V1 = traffic flow of area 1 (pcu/hour)
V2 = traffic flow of area 2 (pcu/hour)
D1 = traffic density of area 1 (pcu/km)
D2 = traffic density of area 2 (pcu/km)

Table 4. Shock wave calculation on Wednesday, February 19, 2020

Time Period	Traffic Flow of Area I	Traffic Flow of Area II	Traffic Density of Area I	Traffic Density of Area II	Shock Wave Speed
	(pcu/hour)	(pcu/hour)	(pcu/km)	(pcu/hour)	(km/hour)
06:00 - 07:00	2376,3	2238,46	57,21	322,33	-0,51992
06:10 - 07:10	2390,7	2238,46	56,08	322,33	-0,57180
06:20 - 07:20	2390,2	2238,46	56,07	322,33	-0,56990
06:30 - 07:30	2399,6	2238,46	56,29	322,33	-0,60570
06:40 - 07:40	2406,2	2238,46	54,96	322,33	-0,62737
06:50 - 07:50	2403,3	2238,46	54,89	322,33	-0,61637
07:00 - 08:00	2378,5	2238,46	55,79	322,33	-0,52542
07:10 - 08:10	2348,4	2238,46	53,64	322,33	-0,40918
07:20 - 08:20	2321,4	2238,46	54,45	322,33	-0,30963
07:30 - 08:30	2300,3	2238,46	51,12	322,33	-0,22803
07:40 - 08:40	2269,8	2238,46	51,84	322,33	-0,11588
07:50 - 08:50	2242,2	2238,46	49,83	322,33	-0,01374
08:00 - 09:00	2209,4	2238,46	51,83	322,33	0,10742
16:00 - 17:00	2323,9	2238,46	43,78	322,33	-0,30675
16:10 - 17:10	2338,2	2238,46	46,29	322,33	-0,36133
16:20 - 17:20	2361,4	2238,46	41,54	322,33	-0,43785
16:30 - 17:30	2373,5	2238,46	41,54	322,33	-0,48094
16:40 - 17:40	2397,6	2238,46	42,63	322,33	-0,56898
16:50 - 17:50	2409,9	2238,46	41,54	322,33	-0,61057
17:00 - 18:00	2070	2238,46	41,54	322,33	0,59993

Table 5. Shock wave calculation on Saturday, February 22, 2020

Time Period	Traffic Flow of Area I	Traffic Flow of Area II	Traffic Density of Area I	Traffic Density of Area II	Shock Wave Speed
	(pcu/hour)	(pcu/hour)	(pcu/hour)	(pcu/hour)	(km/hour)
06:00 - 07:00	2323,60	2197,43	46,29	290,80	-0,51601
06:10 - 07:10	2323,80	2197,43	43,78	290,80	-0,51160
06:20 - 07:20	2329,60	2197,43	42,63	290,80	-0,53259
06:30 - 07:30	2324,30	2197,43	41,54	290,80	-0,50899
06:40 - 07:40	2314,40	2197,43	41,54	290,80	-0,46928
06:50 - 07:50	2308,80	2197,43	40,50	290,80	-0,44496
07:00 - 08:00	2299,60	2197,43	41,54	290,80	-0,40990
07:10 - 08:10	2282,50	2197,43	41,54	290,80	-0,34130

07:20 - 08:20	2267,70	2197,43	41,54	290,80	-0,28192
07:30 - 08:30	2249,20	2197,43	41,54	290,80	-0,20770
07:40 - 08:40	2230,80	2197,43	41,54	290,80	-0,13388
07:50 - 08:50	2212,40	2197,43	42,63	290,80	-0,06033
08:00 - 09:00	2181,80	2197,43	41,54	290,80	0,06270
16:00 - 17:00	2260,80	2197,43	43,78	290,80	-0,25655
16:10 - 17:10	2249,00	2197,43	43,78	290,80	-0,20878
16:20 - 17:20	2249,40	2197,43	43,78	290,80	-0,21040
16:30 - 17:30	2261,40	2197,43	42,63	290,80	-0,25778
16:40 - 17:40	2276,50	2197,43	45,00	290,80	-0,32169
16:50 - 17:50	2285,40	2197,43	38,57	290,80	-0,34878
17:00 - 18:00	1966,30	2197,43	40,50	290,80	0,92341

As an example, the calculation was done to the data taken on Wednesday on the period of time 06:00-07:00:

a. A demand of 2376.30 pcu/hour with the road capacity of traffic flow of area 2 as much 2238.46 pcu/ hour resulted in a backward forming shock waves.
b. From the model, the equation obtained was $V = 65{,}016\ D - 0{,}41562\ D^2$ the value of traffic density of area 1 was obtained by adding the value of traffic flow of area 1 to the equation and the value of traffic density of area 2 was obtained by adding the value of traffic flow of area 2. Therefore, the values of traffic density of area 1 obtained = 57.21 pcu/km and traffic density of area 2 = 322.33 pcu/ km.

5. Conclusion

From all of the calculations, the data processing, and the discussion, the following conclusions were drawn:

1. The largest free speed (S_{ff}) was on the fragment of road before narrowing and decreased on the fragment of road during narrowing and increased one more time on the fragment of road after narrowing. The biggest density (D_j) was on the fragment of road during narrowing and then decreased on the fragment of road after narrowing. The highest maximum volume (Vm) was found on the fragment of road after narrowing.
2. There was a significant correlation ($R^2 > 0.5$) between flow, speed, and density.
3. Based on the survey conducted on Wednesday and Saturday, there were shock waves as follows: on Wednesday at 06:00 to 09:00 (the backward forming shock wave was 0.51992 km/hour, the forward recovery shock wave was 0.10742 km/hour), 16:00 - 18:00 (the backward forming shock wave was 0.30675 km/hour, the forward recovery shock wave was 0.59993 km/hour). Moreover, on Saturday 07:00 - 09:00 (the backward forming shock wave was 0.51601 km/hour, and the forward recovery shock wave was 0.06270 km/hour), 16:00 - 18:00 (the backward forming shock wave was 0.25655 km/hour, the forward recovery shock wave was 0.92341 km/hour).

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