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Bottleneck Effect Caused by Motorcyclist Presence in the Traffic Flow on Kerten Signalized Intersection

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Abstract The number of motorcycles in Surakarta has been increasing dramatically since several years ago. This condition was engendering several phenomena such as bottleneck and congestion including around an intersection. This research aims to determine the repercussions of motorcycles from the viewpoint of the traffic flow, timing signal, and the driver's behavior. The traffic flow was analyzed based on the Indonesian Highway Capacity Manual, the bottleneck analysis was determined using the Yuan model, and the behavior analysis was based on descriptive statistics. The traffic flow data consisted of secondary data sourced by a Local Government and primary data from a field survey at Kerten Intersection. Behavior data were obtained from questionnaires using Google Forms and the field survey reached 300 participants. The result of the research shows that from the traffic flow and driver`s behaviors point of view motorcycles are causing bottleneck and traffic congestion. It is because when motorcycle volume is added to the flow the bottleneck often exceeds 1, and the motorcycle's behavior and habits are affecting the driving's way of other riders and drivers. This research is expected to be a source of information as well as a basis for comparison for further research for authors and other researchers. This shall provide a viable data source with viability and advantages for those interested in the same subject of research.

Keywords Traffic Flow, Traffic Behaviour, Bottleneck Analysis

1. Introduction

Motorcycles are the most frequent means of transportation in most growing and developing countries in Southern and South-East Asia, as well as a few African countries. Motorcycles have a low weight factor when compared to other types of vehicles, which allows them to squeeze through any gaps between automobiles [1], [2]. This type of vehicle is also considered to be more flexible than other vehicles, cheaper and fuel efficient [3]. As a result, a rising number of people prefer to ride their motorcycles to work or school [1] instead of driving.

Approximately 88.7 million motorcycles were in circulation in 2015, with the number increasing to 115 million in 2020. This is according to the Indonesian Central Bureau of Statistics. The Java Islands experienced the fastest growth in the number of automobiles in the Indonesian archipelagos, with an annual growth rate reaching 9.28 percent [4]. This overwhelming number of motorbikes must have a substantial impact on traffic in metropolitan areas, where roads and streets are congested, there is limited space, freedom, and route choice, and there is a high risk of congestion, as well as in rural areas. The operation and administration of urban streets that are subjected to mixed traffic is a difficult challenge. Several academics have attempted to quantify the consequences of motorcycles, including at signalized junctions [5]–[8], but have come up short. The author [9] stated that an increase in the number of motorcycles in a mixed traffic flow will affect the total saturation flow.

When the volume of traffic exceeds the capacity of a road or when a number of things interfere with the flow of traffic, traffic congestion or jamming can occur frequently. At intersections, drivers experienced a decrease in speed, a lengthier trip, an increase in delay [10], and queuing [11], [12]. The intersection of the access road with the highway, known as a ramp, is designed to allow time for drivers to slow down before entering the main lane [13]. Based on actual data, it has been discovered that the worsening of traffic flow in free flow happens primarily at bottlenecks created by on and off-ramps, rather than at other points. When there is a lot of traffic, a moving jam is almost always present. Typically, bottlenecking affects only a few zones or a single portion of the entire system. However, if a road becomes crowded, the likelihood of subsequent downstream and upstream roads becoming clogged increases, particularly on major roads [14]. This condition needs to be antisipated in order to realize traffic safety for all road users, including those who don not use vehicles. The activity is known as traffic management. There are four principles in this management, i.e. Education, Engineering, Enforcement and Evaluation. In addition to ensuring traffic safety, the purposes of this management are to reduce congestion and delays, as well as increase road capacity. Traffic education includes training and licensing for drivers/riders, reorientation of road users, traffic information system and public particiation in policy [15]. Traffic engineering is a science which studies the interactions between transport demand and supply. In order for the interaction to take place safety, the infrastructure and vehicles need to be prepared. This is in accordance with the Global Plan of Action which is designed to provide the roadmap to reduce road traffic fatalities. The policy is known as the 5 pillars of traffic safety, consisting of road safety management, safer roads, safer vehicles, safer road users, and post crash response [16], [17]. Enforcement is the process of policing the entire traffic system to catch and punish violators of traffic regulations including penalties such as fines [15].

As a hub connecting East Java with West Java, the city of Surakarta is located in Central Java and serves as the city's main shopping mall. This is due to the fact that Surakarta serves as the primary gateway to these two provinces. Among the most recent toll roads to be built are the Solo-Kertosono and Solo-Semarang Toll Roads (SoKer and SoSem, respectively) [18]. As a result, Surakarta is an inevitable stopover point for travelers traveling between these two provinces. According to observations, a large number of vehicles (cars, trucks, and buses) transit the city every day, either transporting people or delivering products. The high number of traffic entering the city, particularly around rush hour, was generating gridlock. This condition can be seen on A. Yani Street Surakarta, precisely around Kerten Signalized Intersection [19].

While automobiles, lorries, and buses are already responsible for causing considerable traffic congestion during rush hour, motorbikes are accountable for creating a bottleneck in the traffic flow during peak hours. It can be seen when motorcycles slip through other vehicles to get to their destination and cause them to slow down. This behavior is the cause of the high number of traffic accidents involving motorcyclists [20].

In addition, when approaching a traffic signal, motorbikes are frequently found in the front of the automobiles' queue as well as in the green shared lane. Due to this, other types of vehicles are forced to stop and wait for motorbikes to go even when the light has already changed to green. If this is seen as a bottleneck, it leads to the occurrence of another phenomena known as Traffic Signal Offset [21].

Motorcycles are required to use the left-most lane in Indonesia, according to the country's laws and regulations [22]. At a signalized intersection, this can be seen as a lane narrowing situation. As a result, the majority of non-signalized and signalized traffic in Indonesia may be exposed to bottlenecks. This law not only reduces the amount of time a biker can spend operating on the street to a bare minimum, but it also has unintended implications. Cars are compelled to use the right lane, resulting in a significantly longer line of vehicles. The waving phenomena happens when a car approaching an intersection makes a left turn; in addition, motorcyclists will travel down the left side of the lane, resulting in the vehicle in the far-left lane being surrounded by motorbikes, as shown in the image below.

It can be seen from the sentences above that a number of occurrences are occurring along a road segment and at a traffic signal intersection, respectively. As a result, it is required to investigate phenomena such as bottlenecks induced by motorcycles at signalized junctions, while also taking into consideration the driving behaviors of the drivers [23], [24]. Driving is a difficult endeavor that necessitates the acquisition and processing of information as well as the ability to make quick decisions [25]. In order to accomplish this, the field of transportation studies is linked to a variety of disciplines, including sociology, psychology, the environment and economics [26], among others. Specifically, the purpose of this study is to identify how motorcycle riders behave on the roadway, particularly at intersections, and how this conduct impacts other vehicles. In addition, the degree of congestion along the route that is bordered by the Faroka and Kerten crossroads, as well as other phenomena produced by bottlenecks, are determined by this study.

2. Methods

The section of Slamet Riyadi Street between the Faroka and Kerten intersections has been selected as the subject area for this investigation (see Figure 1). This study makes use of secondary data from a Traffic Video Recording from Dishub Surakarta, as well as primary data from a perception survey conducted through a questionnaire. The video was taken on Wednesday in order to avoid recording on weekends and to capture the best possible period in between working days. After the video has been recorded, it must be extracted in order to obtain the traffic volume. In order to determine the geometric condition and component of the road, an infield survey will be carried out in the same way as documentation was carried out for the environment.

Surakarta was chosen as the location for the perception survey because it has a large number of people living in it. Google Forms was utilized in situations when a questionnaire was published and shared online. The targeted population consisted of anyone who held a valid driving license and was willing to take part in the study. Two versions of the questionnaire were published, one of which was filled out by motorcyclists and the other which was filled out by someone who used another form of vehicle. After the questionnaire was made public, everyone who was interested in participating had two weeks to complete it before the deadline. Because the number of responses fell short of the targeted sample, an interview was conducted in order to get the remaining samples that were not collected through the survey.

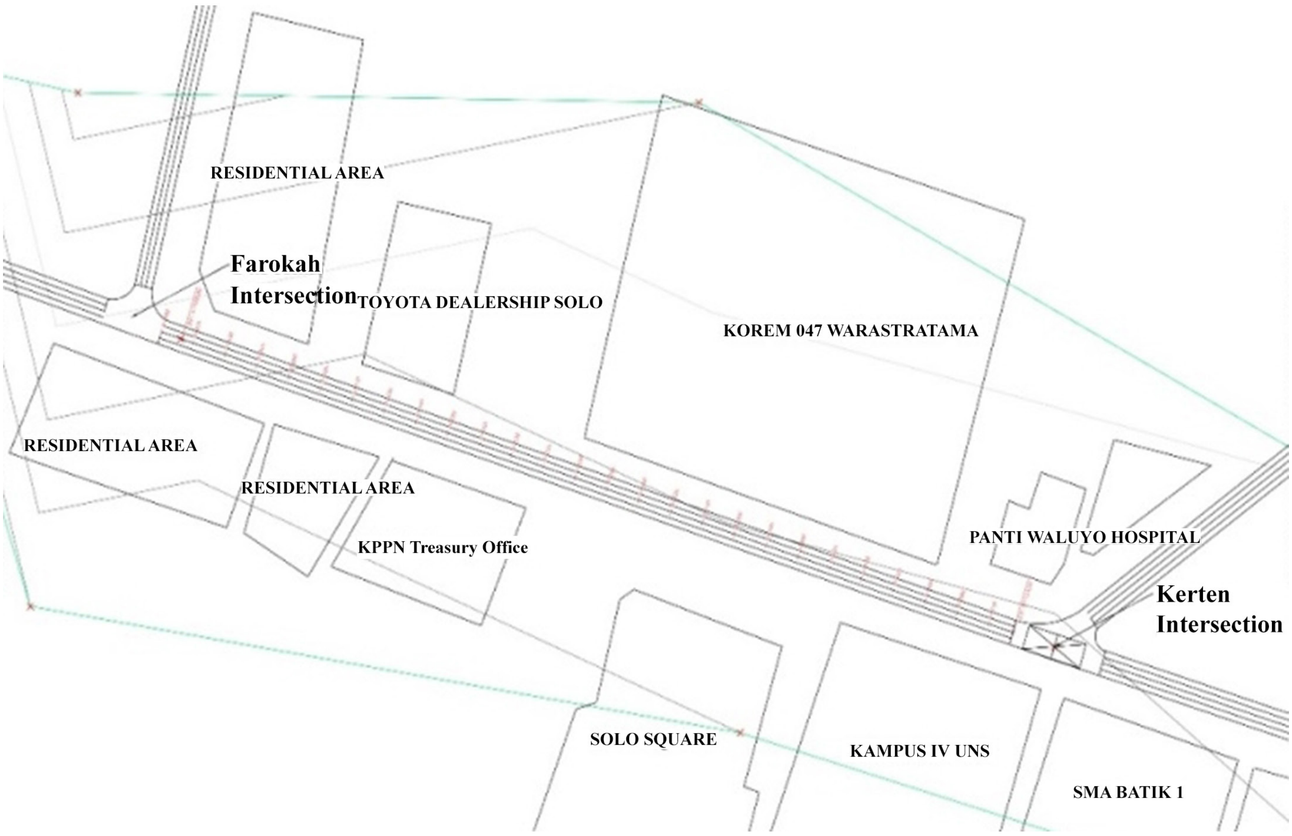

Figure 1. Location of Study

The collected data will be analyzed as follow. First by determining the need traffic stream parameter such as volume, a timing signal, environment, and geometric data needed for the research. Volume is one of the main parameters used to describe a macroscopic traffic flow [21], [23], [27]. For other analyses such as the capacity and the volume will be calculated based on the Indonesian Highway Capacity Manual (IHCM). The value of road capacity (C, pcu per hour) is obtained from the based capacity (Co) multiplied by all the adjustment factors as shown in Equation 1. The factors are carriageway width (FCw), directional split (FCsp), side friction (FCsf), and city size (FCcs) [28].

$$C = Co \times FCw \times FCsp \times FCsf \times FCcs \quad (1)$$

After the traffic parameters above were obtained, then bottleneck analysis was carried out by using Yuan et al Model. This model is to determine the presence of a bottleneck at a signalized intersection [29]. Here two case scenarios were analyzed, first, the traffic without a motorcycle in the flow, and then all types of vehicles are included in the flow. An overview of this formulation model can be seen in Figure 2, while the detailed information of the symbol is presented in Table 1[23].

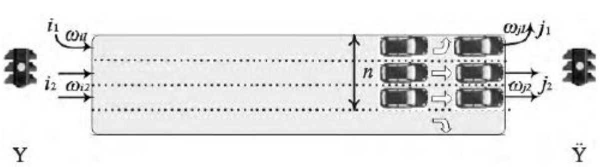

Figure 2. Road segment with signalized intersection [29]

Table 1. Symbol of geometric component of road Figure 2 [29]

Symbol	Meaning
Y (Ÿ)	Upstream/Downstream of road α.
i_1 (i_2)	The entry flows at the intersection
j_1 (j_2)	Exit flows at the intersection
n	Total number of left-turn exit lanes and straight-through
ω_{i1}, ω_{i2}	Number of left-turn and straight-through lanes of upstream roads, respectively
ω_{j1}, ω_{j2}:	Number of left-turn and straight-through lanes of roads, respectively

Road segment is not only affected by signal timing but also the geometric of the upstream roads. With δ the interval length of the period of the analysis numbered from 0 to the k^{th} interval is determined by (kδ,(k+1)δ). The discrete-time variable can be seen in Table 2, while the signal timing parameters are shown in Table 3. All of the formulas used in the bottleneck analysis of two-phase signals (signal timing plan Y2 ¥2) are shown in Equations 2 to 10.

Table 2. Discrete-time variables [29]

Symbol	Meaning
$\lambda_1(k)$ ($\lambda_2(k)$)	The ratio of effective green time of the phase that controls i_1 (i_2) to δ at interval k respectively
$\lambda_3(k)$ $\lambda_4(k)$	The ratio of effective green time of the phase that controls j_1 (j_2) to δ at an interval k respectively if the intersection downstream chooses a four-phase signal
$\lambda_5(k)$	The ratio of the effective green time of the phase that controls both j_1 and j_2 to δ at an interval k if the intersection downstream chooses a two-phase signal
$u_a'(k)$	Entry saturation flow at interval k
$z_a'(k)$	Exit saturation flow at interval k

$$u_a(k) = [\lambda_1(k)\omega_{i1} + \lambda_2(k)\omega_{i2}]C_a \quad (2)$$

C_a is the maximum number of vehicles per lane entering a road $\propto$ or at an interval of δ.

$$z_a(k) = \lambda_5(k)nC_a \quad (3)$$

Table 3. Signal timing parameters [29]

Symbol	Meaning
λ	$0<\lambda<1$, ratio of effective green time of the phase that controls flow j_1 and j_2 synchronously to cycle length
1/γ	$0<1/\gamma<1$, ratio of total effective green time of the phases that control flows i_1 or i_2 asynchronously to cycle length
1/μ	$0<1/\mu<1$, ratio of total effective green time of the phases that control flows j_1 or flows j_2 asynchronously to cycle length
η	The ratio of effective green time of the phase that controls flows i_1 to effective green time of the phase that controls flows i_2
φ	The ratio of effective green time of the phase that controls flows j_1 to effective green time of the phase that controls flows j_2

Based on Equations 2 and 3, the number of increased vehicles on road α at interval k can be calculated by using Equation 4.

$$u_a(k) - z_a(k) = [\lambda_1(k)\omega_{i1} + \lambda_2(k)\omega_{i2}]C_a - \lambda_5(k)n \tag{4}$$

If π_a is the least common multiple of two signals at the intersection Y and ¥. The number of increased vehicles in interval of Equation 5 can be determined by Equation 6.

$$\pi_a(k_t, k_t) = k_t + \left(\frac{\pi_a}{\delta}\right) \tag{5}$$

$$\sum_{k=k_t}^{k_t}[u_a(k) - z_a(k)] = \sum_{k=k_t}^{k_t}[\lambda_1(k)\omega_{i1}] + \sum_{k=k_t}^{k_t}[\lambda_2(k)\omega_{i2}] - \sum_{k=k_t}^{k_t}⟦[\lambda_5(k)n]\} \tag{6}$$

Equation 6 can be made more concise by changing the appearance as in Equations 7 to 9. Then, Equation 4 can be expressed as Equation 10.

$$\sum_{k=k_t}^{k_t}(\lambda_1(k)) + \sum_{k=k_t}^{k_t}(\lambda_2(k)) = \frac{\pi_a}{\delta} \tag{7}$$

$$\sum_{k=k_t}^{k_t}(\lambda_5(k)\delta) = \lambda\pi_a \tag{8}$$

$$\sum_{k=k_t}^{k_t}(\lambda_1(k)) = \sum_{k=k_t}^{k_t}(\lambda_2(k)) \tag{9}$$

$$\sum_{k=k_t}^{k_t}[(u_a(k) - z_a(k)] = \left[\frac{\eta\omega_{i1}+\omega_{i2}}{n+1} - \lambda_n\right] \times \frac{\pi_a C_a}{\delta} = \frac{\Delta_a\pi_a}{\delta} \tag{10}$$

With Δa is the bottleneck indicator to estimate the general bottleneck degree of the individual road during the period of δ in urban transportation networks.

As in the case of two-phase signal timing, for the timing plan of Y4 and ¥2 can be expressed as Equation 11. Similarly, for timing plan of Y4 ¥4 is stated in Equation 12, and for Y2 ¥4 is in Equation 13.

$$\sum_{k=k_t}^{k_t}[(u_a(k) - z_a(k)] = \left[\frac{\eta\omega_{i1}+\omega_{i2}}{\gamma(n+1)} - \lambda_n\right] \times \frac{\pi_a C_a}{\delta} = \frac{\Delta_a\pi_a}{\delta} \tag{11}$$

$$\sum_{k=k_t}^{k_t}[(u_a(k) - z_a(k)] = \left[\frac{\eta\omega_{i1}+\omega_{i2}}{\gamma(n+1)} - \frac{\varphi\omega_{j1}+\omega_{j2}}{\eta(\varphi+1)}\right] \times \frac{\pi_a C_a}{\delta} = \frac{\Delta_a\pi_a}{\delta} \tag{12}$$

$$\sum_{k=k_t}^{k_t}[(u_a(k) - z_a(k)] = \left[\frac{\eta\omega_{i1}+\omega_{i2}}{n+1} - \frac{\varphi\omega_{j1}+\omega_{j2}}{\eta(\varphi+1)}\right] \times \frac{\pi_a C_a}{\delta} = \frac{\Delta_a\pi_a}{\delta} \tag{13}$$

When a two-phase is chosen at intersection Y, $X_a^{\pi_a}$ which is the maximum number of vehicles entering road α during the total effective green time π_a, it can be calculated using by Equation 14, while for a four-phase is by Equation 15.

$$X_a^{\pi_a} = \frac{(\eta\omega_{i1}+\omega_{i2})\pi_a C_a}{(\eta+1)\delta} \tag{14}$$

$$X_a^{\pi_a} = \frac{(\eta\omega_{i1}+\omega_{i2})\pi_a C_a}{\gamma(\eta+1)\delta} \tag{15}$$

When a two-phase is chosen at intersection ¥, $\theta_a^{\pi_a}$ which is the maximum number of vehicles leaving road α during the total effective green time π_a, it can be calculated by Equation 16, while for a four-phase is by Equation 17.

$$\theta_a^{\pi_a} = \frac{\lambda n\pi_a C_a}{\delta} \tag{16}$$

$$\theta_a^{\pi_a} = \frac{(\varphi\omega_{j1}+\omega_{j2})\pi_a C_a}{\mu(\varphi+1)\delta} \tag{17}$$

Traffic bottleneck of road α is determined with the bottleneck indicator Δa, as the following condition.

If $\Delta_a > 0,\ X_a^{\pi_a} > \theta_a^{\pi_a}$, then road α is a traffic bottleneck.

If $\Delta_a = 0,\ X_a^{\pi_a} = \theta_a^{\pi_a}$, then road α is in a critical state.

If $\Delta_a < 0,\ X_a^{\pi_a} < \theta_a^{\pi_a}$, then α is a bottleneck-free road.

3. Results

The information gathered will be examined in the following ways. To begin, determine the necessary traffic stream parameters, such as volume, a timing signal, the surrounding environment, and geometric data, that will be used in the research. By using that as a starting point, we can use the Yuan et al. model to determine whether or not there is a bottleneck at a traffic signalized intersection. In this study, two case scenarios were investigated: the first involved traffic without a motorbike in the flow, and the second involved traffic with all types of cars in it. Other studies, such as the capacity and volume, will be calculated using IHCM as a base.

3.1. Traffic Signal Data

This data was obtained from the process of extracting the video recordings obtained by the Local Government. The data obtained is then processed and displayed in the form of a signal phase diagram as shown in Figures 3 until 5.

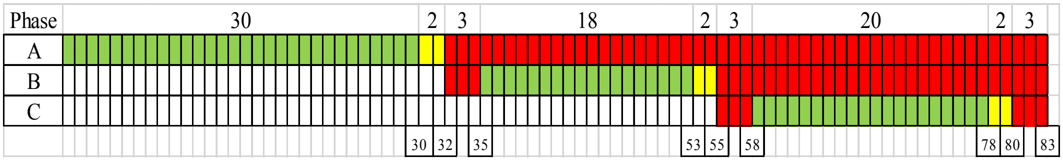

Figure 3. Signal timing at Kerten (6 AM to 9 AM)

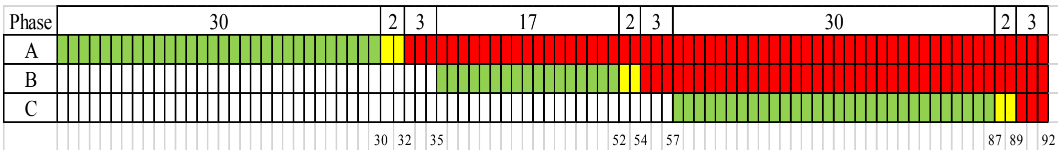

Figure 4. Signal timing at Kerten (9 AM to 3 PM)

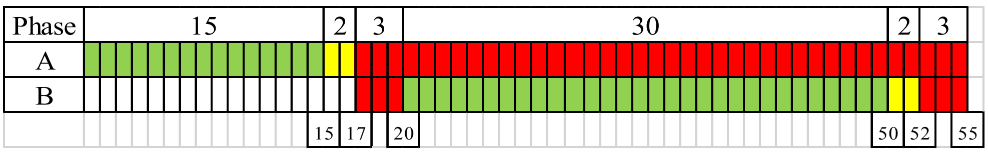

Figure 5. Signal timing at Faroka (6 AM to 3 PM)

Figures 3 and 4 show that Kerten Intersection is arranged in 3 phases with the inter-green time consisting of 2 seconds of yellow and 3 seconds of red. In the morning session, the green time for each phase is 30,18 and 20 seconds, respectively, while for the afternoon session is 30, 17, and 30 seconds. Slightly different from the above, the Faroka Intersection is arranged in 2 phases. Figure 5 shows that this intersection has a green time for each phase of 15 and 30 seconds, with the inter-green time being the same as Kerten.

3.2. Capacity Analysis

When there are geometric data and environmental factors available, a capacity analysis can be performed. According to the observations, the side friction around the site was classified as high in intensity. This level has a side friction adjustment factor of 0.89, which is a good value (Fsf). As evidenced by the presence of pedestrians, public transportation vehicles that stop to allow people to onboard and off board, and automobiles that pull out into the traffic lane, this condition can be observed.

It was possible to calculate the capacity adjustment factor for city size based on Surakarta's population numbers at the time, which came out to 0.94 based on those facts. Undivided four-lane two-way traffic is classed as the road stretch under consideration for the site study. Thus, the basic capacity of this road was 1500 pcu/hour per lane of traffic (Co). The geometric data in the form of lane width can be used to calculate the 1.13 of carriageway width adjustment factor, which can be found in Table 1. (Fw). Furthermore, based on the information presented above, the directional split correction factor is calculated to be 0.94. (Fsp). If we use Equation 1 with all of the numbers listed above, the road capacity for two lanes is 2665.9 pcu/hour.

3.3. Volume

The volume data was mainly composed of secondary data taken from 06:00 AM to 12:00 PM from two surveillance cameras located at Faroka and Kerten Intersection then divided into shorts ten (10) minutes of videos. These videos were recorded by DisHub Surakarta. From the recorded the traffic volume was extracted for only the vehicle traveling from Faroka to Kerten. The traffic Flow was first counted by grouping the vehicles by their type, namely: Motorcycle (MC), LV (Light Vehicle), Medium Vehicle (MV), and Heavy Vehicle (HV) expressed in the vehicle per hour per type with a time interval the length of the video. The volume per time interval is then converted into a passenger car unit by multiplying the volume to the passenger car equivalent of each type. For easy interpretation of the results, a graphical representation was done, which can be seen in Figure 6.

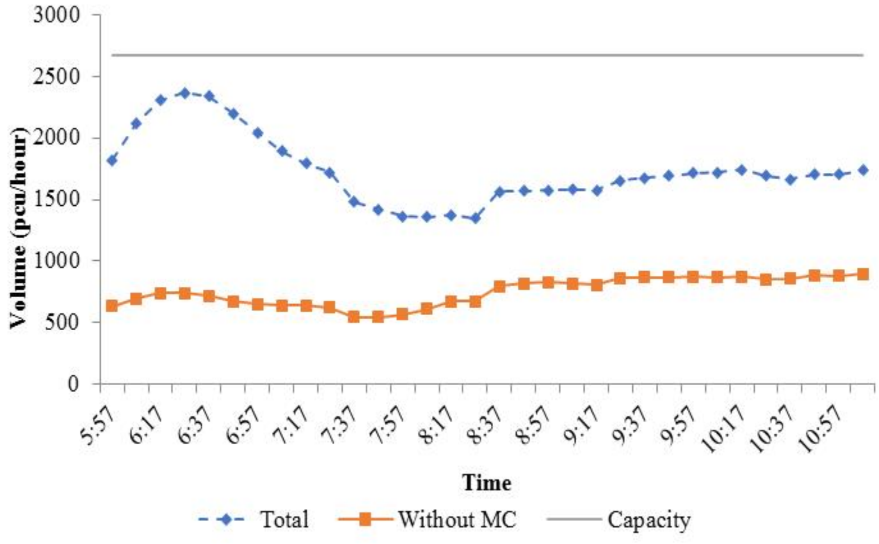

Figure 6. The traffic volume pattern

Figure 6 depicts the pattern of traffic volume for each of the three cases. The center line represents the overall volume of actual traffic flow, and the bottom line represents the volume of traffic flow that does not include motorcycles. At the time of the survey, the total volume at the location was still below the capacity of the roadway or the road segment's capacity. From 05:57 to 06:27, the total volume increased, and then began to decline fast until 08:27, as seen in the diagram. Following a precipitous decrease, the volume gradually climbed until the conclusion of the data collection period was reached. On the basis of Figure 6, it can be concluded that the volume of traffic in the absence of motorbikes tends to fluctuate continuously. In this particular instance, the volume is less than 900 pcu/hour. This condition demonstrates that there was a big number of motorcycles in the area at the time.

3.3. Bottleneck Analysis

Refer to Equation 2 – Equation 17, the bottleneck degree of each period can be determined as shown in Table 4 to 5 and Figure 7.

Table 4. Result of bottleneck degree for overall type of vehicle.

k	Time Interval		Total Volume		Ca	Δ_a	$X_a^{\pi a}$	$\theta_a^{\pi a}$
			Exit	Entry				
First Cycle Time								
0	5:57	6:56	1819	1706	303	0.81	1258	500
1	6:07	7:06	2118	1956	353	0.94	1465	583
2	6:17	7:16	2302	2099	384	1.02	1592	633
3	6:27	7:26	2365	2124	394	1.05	1636	650
4	6:37	7:36	2335	2075	389	1.03	1615	642
5	6:47	7:46	2200	1924	367	0.97	1521	605
6	6:57	7:56	2040	1792	340	0.90	1411	561
7	7:07	8:06	1891	1679	315	0.84	1308	520
8	7:17	8:16	1790	1631	298	0.79	1238	492
9	7:27	8:26	1719	1591	286	0.76	1189	473
10	7:37	8:36	1483	1536	247	0.66	1026	408
11	7:47	8:46	1421	1280	237	0.63	983	391
12	7:57	8:56	1366	1215	228	0.61	945	376
13	8:07	9:06	1356	1207	226	0.60	938	373
14	8:17	9:16	1377	1250	229	0.61	952	379
15	8:27	9:26	1349	1283	225	0.60	933	371
16	8:37	9:36	1562	1319	260	0.69	1080	430
17	8:47	9:46	1570	1576	262	0.70	1086	432
18	8:57	9:56	1575	1585	263	0.70	1090	433
Second Cycle Time								
19	9:07	10:06	1578	1588	263	0.99	1210	410
20	9:17	10:16	1578	1567	263	0.99	1210	410
21	9:27	10:26	1653	1583	276	1.04	1268	429
22	9:37	10:36	1676	1577	279	1.05	1285	435
23	9:47	10:46	1692	1588	282	1.06	1297	440
24	9:57	10:56	1715	1574	286	1.07	1315	445
25	10:07	11:06	1719	1560	287	1.08	1318	446
26	10:17	11:16	1743	1557	291	1.09	1337	453
27	10:27	11:26	1695	1533	282	1.06	1299	440
28	10:37	11:36	1667	1528	278	1.04	1278	433
29	10:47	11:46	1705	1260	284	1.07	1307	443
30	10:57	11:56	1703	1281	284	1.07	1306	442
31	11:07	12:06	1739	1276	290	1.09	1334	452

Table 5. The result of bottleneck degree for traffic flow without motorcycle.

k	Time Interval		Total Volume		Ca	Δ_a	$X_a^{\pi a}$	$\theta_a^{\pi a}$
			Exit	Entry				
First Cycle Time								
0	5:57	6:56	633	648	106	0.28	803	147
1	6:07	7:06	696	702	116	0.31	883	192
2	6:17	7:16	739	767	123	0.33	937	203
3	6:27	7:26	743	770	124	0.33	942	204
4	6:37	7:36	718	761	120	0.32	911	198
5	6:47	7:46	675	717	113	0.30	856	186
6	6:57	7:56	652	695	109	0.29	826	179
7	7:07	8:06	644	687	107	0.29	816	177
8	7:17	8:16	638	661	106	0.28	810	176
9	7:27	8:26	622	654	104	0.28	788	171
10	7:37	8:36	547	659	91	0.24	694	151
11	7:47	8:46	545	559	91	0.24	691	150
12	7:57	8:56	568	572	95	0.25	721	156
13	8:07	9:06	614	612	102	0.27	779	169
14	8:17	9:16	672	684	112	0.30	852	185
15	8:27	9:26	672	734	112	0.30	852	185
16	8:37	9:36	794	766	132	0.37	1055	218
17	8:47	9:46	819	919	136	0.51	1149	225
18	8:57	9:56	832	946	139	0.51	1134	229
Second Cycle Time								
19	9:07	10:06	818	942	136	0.99	1149	212
20	9:17	10:16	807	928	134	0.99	1134	210
21	9:27	10:26	861	936	144	1.04	1211	224
22	9:37	10:36	871	934	145	1.05	1224	226
23	9:47	10:46	868	933	145	1.06	1220	225
24	9:57	10:56	874	919	146	1.07	1229	227
25	10:07	11:06	872	907	145	1.08	1225	226
26	10:17	11:16	875	881	146	1.09	1230	227
27	10:27	11:26	851	862	142	1.06	1196	221
28	10:37	11:36	856	864	143	1.04	1203	222
29	10:47	11:46	887	712	148	1.07	1246	230
30	10:57	11:56	881	736	147	1.07	1239	229
31	11:07	12:06	899	739	150	1.09	1264	234

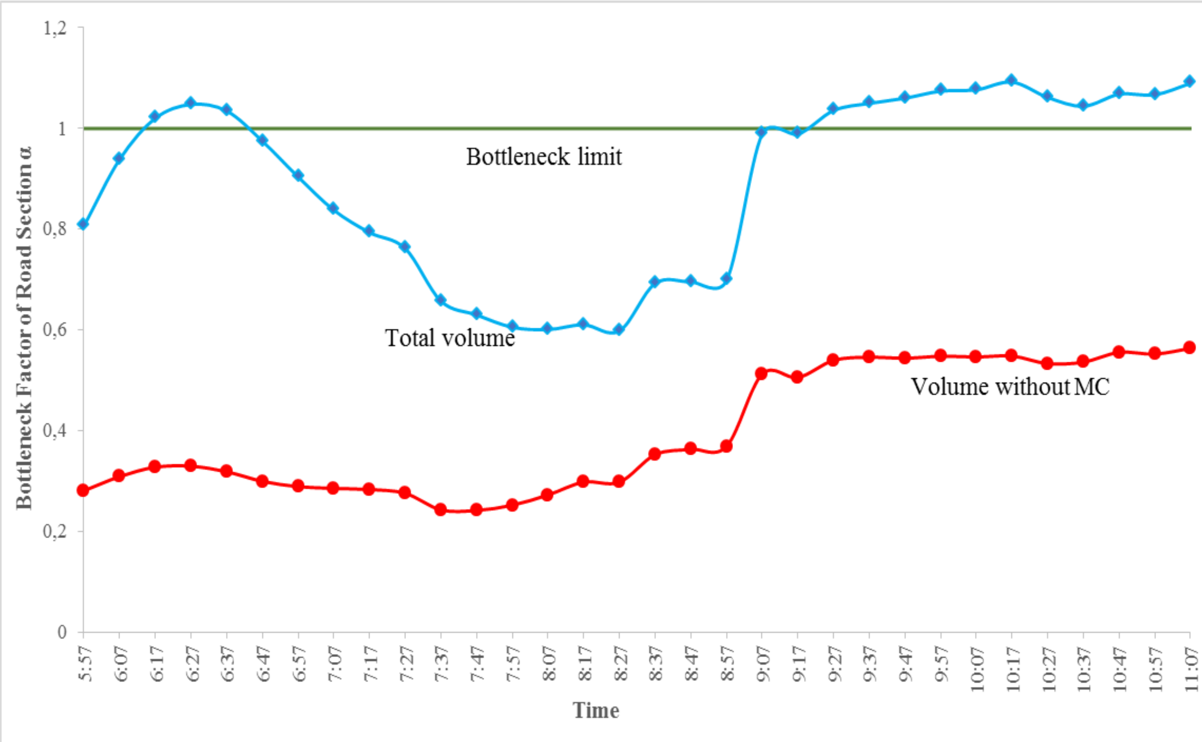

Figure 7. Bottleneck degree each case

Each case scenario is demonstrated in Figure 7 as the outcome of the bottleneck degree occurring each hour along the road as represented by the figure. In a similar vein to the preceding graph, the center line represents the degree to which a bottleneck has developed as a result of the actual total volume. The bottom line represents the degree to which a bottleneck has developed as a result of the total volume being decreased by motorcycles.

Table 4 shows the result of bottleneck analysis with total volume of vehicle, while Table 5 presents the result without the number of motorcycles. The degree to which a bottleneck exists was determined as a function of the flow of traffic entering and exiting the bottleneck. As a result of this condition, it is possible to conclude that the fluctuation of both graphs in Figures 6 and 7 is comparable. When motorbikes are kept apart from the rest of the flow, a bottleneck does not form because the bottleneck degree an is always smaller than one, as illustrated in Figure 7. However, as soon as motorcycles are introduced into the mix, a bottleneck occurs twice during the course of the trial, each time with an a bigger than one value. These are the hours of 06:17-06:37 and 09:27-12:00. As a result, it is possible that a bottleneck will form when the volume of traffic is high enough.

When there is a high volume of traffic, the road appears crowded, and lineups begin to form. Vehicles begin to use the shared lane when the light is green during this time. In addition to the presence of bikers, vehicles that use the slow lane were also a contributing factor to congestion. Because of the off-ramp, where the slow lane was regarded an exit and entry, the impediment was not an obstruction as had been assessed previously, but rather a detour.

3.4. Traffic Behaviour Analysis

This section will discuss the behavior of road users who are classified into 2 categories, namely motorcyclists and car drivers. This is intended to find out how the behavior or tendencies of each when approaching, at, and leaving the intersection. Based on the IBM-ISPSS v25 software, the results of the analysis related to traffic above can be seen in Table 6 (motorcycle's user), and Table 7 (car's user).

Table 6 reveals that the vast majority of respondents are licensed drivers with more than five years of driving experience, as shown by the majority of responses. However, less than half of those surveyed have less than five years of professional experience. The table also shows that the majority of respondents (40.1 percent) stated that they occasionally feel uncomfortable when driving in a car and side by side on the road alongside a motorbike. When asked about their preferred position when approaching a junction when there are automobiles already present, the majority of respondents (61.5 percent) said they preferred to remain in line and behind the already present vehicle.

Table 6. Frequency and percentage of answers from motorcyclist's questionnaire

Questions	Response	Frequency	Percent	Valid Percent
1. Do you own a full driving license?	Yes	174	84.1	84.1
	No	33	15.9	15.9
2. How long have you been riding?	Less than a year	18	8.7	8.7
	Between 1 to 5 year	69	33.3	33.3
	more than 5 year	120	58	58
3. Does it bother you to ride side by side a car or other motorcycle?	Not at all	51	24.6	24.6
	A little bit	64	30.9	30.9
	Sometime	83	40.1	40.1
	Very Disturbing	9	4.3	4.3
4. While approaching an intersection and cars are already present at the intersection. Where do you stop?	Side by side the car	20	9.7	9.8
	Behind cars	126	60.9	61.5
	in front of cars	59	28.5	28.8
	Total	205	99	100
	Missing	2	1	
5. Do you wait for the light to be green to depart?	Yes, I wait for the green light	183	88.4	88.4
	No, I depart directly when the light is yellow	24	11.6	11.6
6. Do you depart as soon as the light is green or wait for the cars to free the way?	No, I wait	120	58	58.5
	Yes, I depart as soon as the light is green	85	41.1	41.5
7. Are you changing lanes before entering an intersection?	Yes	115	55.6	56.1
	No	90	43.5	43.9
8. When there is a left-turn signal do you still stay on the most left lane?	Yes	124	59.9	59.9
	No	83	40.1	40.1
9. In your opinion do motorcycles need a special lane?	Yes	166	80.2	80.2
	No	41	19.8	19.8

Table 7. Descriptive statistical analysis of car user questionnaires

Questions	Response	Frequency	Percen t	Valid Percent
1. Do you own a full driving license?	Yes	94	80.3	80.3
	No	23	19.7	19.7
2. How long have you been driving?	Less than a year	14	12	12
	between 1 to 5 year	36	30.8	30.8
	More than 5 year	67	57.3	57.3
3. It is known that motorcycle is omnipresent in the traffic flow. Does this presence disturb you or change your manner of driving	Not at all	22	18.8	18.8
	A little bit	27	23.1	23.1
	Sometime	61	52.1	52.1
	Very disturbing	7	6	6
4. While approaching an intersection and motorcycles are present at the intersection. Where do you stop?	Side by side motorcycle	2	1.7	1.7
	Behind motorcycle	74	63.2	63.8
	In front of motorcycles	40	34.2	34.5
5. When the light is green what your first reaction is? Do you wait for the motorcycle to free the way?	Yes	100	85.5	85.5
	No	17	14.5	14.5
a. If yes, why?	Motorcycles. are blocking the way	55	47	57.9
	It is not safe to depart before the motorcycles.	34	29.1	35.8
	Because of any other reason	6	5.1	6.3
b. If not why?	Usually, most motorcyclists depart as soon as the light is yellow	26	22.2	47.3
	Motorcycles will depart at the same time as other	29	24.8	52.7
6. When you want to turn left at an intersection, do the motorcycles present on the left lane often block you the way?	Yes	80	68.4	68.4
	No	37	31.6	31.6
7. In your opinion do motorcycles need a special lane?	Yes	96	82.1	82.1
	No	21	17.9	17.9

Table 6 also indicates the tendencies of motorcyclists who leave signalized junctions when they are not stopped. The vast majority of respondents (88.4 percent) claimed that they waited for the green light before departing, while only 11.6 percent stated that they left as soon as the light turned green. In connection with the aforementioned habit, the majority of motorcycle riders (58.5 percent) wait for the car to start before leaving, while 41.5 percent leave as soon as the green light turns on. The vast majority of motorcyclists (80.2 percent) agree on the importance of designated motorcycle lanes.

In accordance with motorcycle riders, the majority of vehicle drivers are licensed and have more than five years of driving experience, as shown in Table 7. In this survey, the majority of respondents (52 percent) stated that they are occasionally bothered when traveling side by side with a motorcycle. Respondents prefer to remain in line and behind an existing vehicle when approaching an intersection and a motorbike comes to a stop at the intersection, with 74 percent stating that they will do so. When leaving the signalized intersection, the vast majority of automobile drivers (85 percent) waited for the motorcyclist to be the first to go. Because of the above-mentioned departure behaviors, most automobile drivers waited for motorbikes to leave the road because motorcycles frequently obstruct their path. While some would go immediately after the green light because they anticipated that the motorcycle would depart shortly, others would wait until the light turned red. In the last question, the vast majority of drivers (more than 80 percent) agreed that motorbikes should have their own dedicated lanes on the highway.

4. Conclusions

Based on the results of the analysis, it can be concluded that motorbikes are one of the main causes of traffic jams that occur at the research location. This can be seen from when motorcycles are added to the total current, the number increases even though it is still below capacity. The behavior and habits of motorcyclists are some of the main causes of the above problems. Its small size can slip through the remaining spaces between vehicles and make it easier for them to reach the front of the queue.

However, congestion is not only caused by the behavior of motorcyclists, but other types of vehicles also contribute to this. It can be seen that when motorcycles are included in the total flow, the degree of road congestion is exceeded 1. This is considered prone to congestion. Based on behavioral analysis, it is known that motorcyclists prefer to stop behind cars and other types of vehicles but once there is an opportunity to reach the front queue they will take it. When approaching an intersection, motorcyclists prefer to stop behind a car but as soon as there is an opportunity to reach the front of the queue they will take it. All road users including motorcyclists agreed that it would be better for them if there was a dedicated lane for motorcycles.

Many phenomena are associated with traffic behavior at intersections, including moving speed at a starting green phase, and positioning in a lane when turning. For traffic safety at the intersection to be realized, it is necessary to conduct other traffic behavior studies. Although traffic safety education programs have been carried out, socialization still needs to be carried out periodically by reaching all road users. Socialization includes how to be safer road users, and the consequences if it is neglected for themselves and those around them. In addition, related to traffic conditions in Indonesia which are mixed between small and large vehicles, and also the high composition of motorcycles, it is necessary to think about planning separate traffic lanes.

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