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Impact of On-street Parking on Urban Arterial Performance: A Quantitative Study on Travel Speed and Capacity Deterioration

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Abstract - Traffic congestion has been a serious social and technical problem since the early year's rapid motorization in Banda Aceh, Aceh Province of Indonesia. Urban arterial performance becomes the crucial concerns of many traffic engineers. Arterial performances were analyzed using oblique cumulative plots and breakdown method. The approaches are time series treatment between cumulative vehicles arrival versus time contracted from data recorded by video cameras. Investigations were conducted during both morning and evening peak hours on three regular weekdays for observing saturation condition in order to observe the maximum capacity under prevailing conditions. This study examined the impact of presence on-street parking on deterioration both travel speed and capacity. It found that capacity diminished slightly 10-13% (275-368vph) compared to the pre-breakdown condition. Likewise, during the breakdown, speed dropped about 13-19% (3-5kph) controlled by pre-breakdown as well. The simulation software so called VISSIM 5.30 was governed to estimate the measurement of effectiveness (MOEs) by removing on-street parking from a site of study. The MOEs reveal that removing on-street parking able to reduce average delay approximately 12 sec/veh (32%) and increase speed about 5kph (24%).

Keywords: Arterial performance, pre-breakdown, breakdown, travel speed, capacity, on-street parking, simulation, VISSIM 5.30, MOEs.

Introduction

Traffic congestion has been a serious social and technical problem since the early year's rapid motorization in Banda Aceh, Aceh Province Indonesia. Urban arterial performances namely travel speed and capacity becomes the crucial concerns of many traffic engineers. Present day, Banda Aceh is challenging by experiencing of traffic congestion problems particularly at urban arterial corridors. High traffic demand and limited supply of roadways are always the main factors produced traffic congestion. However, there are other sources of local and temporal congestion, such as uncontrolled access point, median opening and on-street parking activities, which are caused a reduction of roadway capacity during peak operations. Such locations create interruption smooth traffic flow along arterial streets, which in turns stimulate related problems, such as, excessive air pollution, additional energy consumption and driver's frustration due to stop and go traffic conditions. So far, traffic performance evaluation in Indonesia uses the traffic code so called Indonesian Highway Capacity Manual (IHCM, 1997).

Indonesian Highway Capacity Manual (IHCM, 1997) provides a static method for examining the capacity of the urban arterial. However, the methodology does not take into consideration of bottleneck activities on arterial roads, such as, uncontrolled access point, median opening and unrestricted on-street parking. This condition could happen simultaneously; mostly repetitive and predictable in same peak hour demands. Previous work, Sugiarto *et al* (2012) employed dynamic capacity approaches for examining speed and capacity drop at the section of median opening. Dynamic capacity methods are widely use in uninterrupted facilities such as Cassidy and Bertini (1999), Cassidy and Rudjanakanoknad (2005), Chung *et al.* (2007), Persaud *et al.* (1998), Elefteriadou *et al.* (2001), Zhang (2001) and Lertworawanich and Elefteriadou (2003).

Breakdown is defined as transitions of traffic from free moving to a congested condition when demand exceeds the capacity. The findings from previous studies concluded that under breakdown situation a capacity of the road is more reasonably analyzed using dynamic approaches. Nevertheless, most of the previous dynamic studies are commonly done for uninterrupted flow facilities. A recent study of Rudjanakanoknad (2009) and Sugiarto *et al* (2012) was perhaps the first studies which applied oblique cumulative plot method for assessing traffic mechanism at a u-turn section on the local street in Bangkok and Banda Aceh. Rudjanakanoknad (2009) was focused only in identifying general factors that are effecting of traffic in bottleneck section but less detail about how to quantify the breakdown parameters such as road capacity, vehicle speed and the period of breakdown. Furthermore, Sugiarto *et al* (2012) has

done on how to quantify the dropped of speed and capacity at the u-turn section in Banda Aceh. The objective of this study was to reveal the effects of on-street parking activities such as shoulder lane utilization and parking maneuvers on traffic performance deteriorations. The specific objectives include assessing the decrease in traffic capacity and speed caused by the above mentioned influencing factors. Understanding the quantitative effect of these activities on the roadway capacity and speed will lead to an appropriate policy and guideline for traffic analyst particularly for design and operation of urban arterial corridors.

Materials and Methods

Study site selection

The study was conducted at Jl. Teuku Umar, Banda Aceh City, Indonesia on the spot which is parking activities identified as the critical condition. This spot is located in front of Harapan Bunda General Hospital as can be seen in Figures 1 and 2. The study area is urban arterial road which is connecting suburban area to central of Banda Aceh city. An Average hourly traffic volume is approximately 2,800vph to 3,200vph. The area is mixed land use namely business area, private and public offices. Furthermore, mode of transport which are using this network mostly private car (35%), motor cycle (60%), and remaining are busses, truck and minibus (5%). Three days during peak hour periods of weekdays were selected for investigations. Video data were recorded by using video cameras operated from the vantage points. The observation data and time are summarized in Table 1.

At the study site, the roadway includes three lanes each direction namely median lane, central lane and shoulder lane. During peak demand, one and half lanes were utilized for parking and its maneuvers. It should be noticed that the object of the observation was the traffic on the main stream affected by shoulder lane space which is utilized for parking. Accordingly, the reduction of the effective lane for main stream was examined in this study by using performance metrics speed and capacity reduction.



Figure 1. Map of study site (Google earth, 2012)

Table 1. Timetable of data collections

No.	Road Name	Day(date of observation)	Time of observation	Bottleneck type
1.	T. Umar	Wednesday (11/04/ 2012)	07.15-08.15 am	Parking section
2.	T. Umar	Wednesday (11/04/ 2012)	04.30-05.30 pm	Parking section
3.	T. Umar	Friday (13/04/ 2012)	07.15-08.15 am	Parking section
4.	T. Umar	Friday (13/04/ 2012)	04.30-05.30 pm	Parking section
5.	T. Umar	Monday (16/04/ 2012)	07.15-08.15 am	Parking section
6.	T. Umar	Monday (16/04/ 2012)	04.30-05.30 pm	Parking section



Figure 2. Blocking and lane utilization at the study site.

Methodology of analysis

Oblique cumulative plots and breakdown plot methods were used as diagnostic tools in this study. Those methods are based on a cumulative arrival curve which is able to visualize of traffic observations collected directly from the video cameras. Data were extracted manually by using free software so called Timer Application. Time coding software was used for extracting traffic parameter data, and plotted by using Ms. excel 2007. Brief introduction of the above mentioned methods is described in following paragraphs.

The oblique cumulative plot is time-series data treatment between the cumulative vehicle arrival and time. The measurement of arrivals is conducted in a short time period such as one minute or even less, and the time interval selected can be influenced the magnitude of the flow. Oblique cumulative plots is a special time-series data treatment of $O(t)$ versus t , in which $O(t)$ denotes cumulative vehicle after re-scaled, and can be drawn as $O(t) = N(t) - q_0 \times (t - t_0)$. $N(t)$ is a cumulative vehicle counted during time t , q_0 is selected background flow, and t_0 is starting time. Background flow is determined by trial and error from the curve of the vehicle's arrival versus time arrival. Re-scaling curves of vehicle arrival by subtracting selected background flow created the oblique coordinate system amplifies changes in slopes, making possible to visually the flow changes at each measurement location. From the oblique cumulative plots, researchers estimate the slope of each increasing or decreasing the flow rate by time interval. The slopes are represented the dynamic capacity of the road section during the observation period.

Breakdown plot is also time-series data treatment which is powerful for detecting capacity and speed drop. The main purposes of using this method are listed by Lertworawanich *et al.* (2003), Elefteriadou *et al.* (2001) which is a breakdown probability function better for quantifying three capacities on the active bottleneck based on time series plots of flow and speed as following 1). Identify and quantify each transition interval from non-congested to congested flow, breakdown event, and document the corresponding breakdown flow. 2). Identify and document the maximum pre-breakdown flow. This flow is the maximum observed at the site prior to the occurrence of congestion. 3). Identify and document the maximum discharge flow.

Development of flow and speed profiles is the main requisite in order to examine traffic performance such as speed and capacity. As for capacity examination hourly flow profiles were constructed by using oblique cumulative plot and breakdown flow plot. By utilizing two methods, capacity was identified and the reduction of the capacity can be measured by comparing discharge flow rate to before breakdown. In addition to mentioned, speed reduction can be estimated by using selected critical speed. The critical speed used in this study is average speed. Speed below critical speed is respected to be breakdown speed, otherwise is normal speed. Reduction in speed is defined as percentage speed reduction which obtained by weighting breakdown speed to normal speed at the moments of pre-breakdown. Furthermore, to ensure unbiased estimation, moving average auto regression (MAAR) was employed for making smooth of speed and flow rate profiles. It could be helpful in visualizing magnitudes of speed and flow profiles.

Results and Discussions

Capacity and speed measurements

The oblique cumulative plots were firstly employed for analyzing the disorderly of traffic mechanism at on-street parking section as shown in Figure 3. It describes that the traffic behaviors slightly fluctuated both in the morning and evening peak observations. As for 11th April 2012, it was approximately 35 minutes period of breakdown in the morning peak. Longer breakdown occurred during evening peak compared to morning peak. It was about 45 minutes starting from 16:30 to 17:15pm. Figure 3 (top) shows that traffic demand was gradually increased to the maximum flow at 7:25am (2,763vph) just a moment before continually drop to 2,391vph (8:00am), then, after 8:00am the demand starts to decrease. Accordingly, the maximum capacity drop was 2,391vph (-372vph) or about 13 percent dropped compared to before breakdown flow as reference condition. Likewise pattern in evening peak observation as can be seen in Figure 3 (bottom). The maximum demand as recognized as before breakdown identified approximately 2,697vph (16:00pm), and as for maximum observed capacity dropped about 2,441vph (17:12pm) or can be calculated the flow diminished 280vph compared to before breakdown as well. To figure out clearly measures on capacity deterioration, three days morning and evening peak observations were examined using same approach which used in analyzing on 11th April 2012. Then, the average value was selected as performance measures arterial in terms of capacity diminished. It is assumed that the mean value represent the performance measures. It concluded that on-street parking by utilizing outer lane of road of way have significant effect on capacity. Thus, the evaluation of on-street parking must be considered on design and operation of urban arterial road in order to obtain better quality of services within urban network. The summary of capacity can be seen in Tables 2 and 3.

Aforementioned, the second method employed in this study is breakdown method. This method mainly used both dynamic capacity and speed of traffic streams. However, in this study, the method was used for defining speed propagations in the through traffic due to on-street parking. The patterns of traffic mechanism in site investigation were depicted in Figure 4. As it shown in the Figure 4 (top) the critical speed 25kph was selected to identify breakdown phenomena. The capacity in terms of flow rate at the moment before breakdown was approximately 2,669vph (7:22am) and continuing shift to 2,467vph (7:58am). A parallel with moving flow rate plot, it can clearly defined speed value corresponding to flow rate 2,669vph is 26kph. Accordingly, average speed within the breakdown period (from 7:25am to 8:08am) is approximately 22kph. It means that the speed dropped on the observed traffic conditions was about 4kph (15%) compared to pre-breakdown speed 26kph.

Let's consider to evening observations as can be seen in Figure 4 (bottom), the similar pattern was founded. The moving average curve clearly pointed that the reasonable flow rate pre-breakdown was about 2,605vph (16:32pm) before getting worsen to minimum flow rate 2,446vph (17:08pm). The speed reduction identically can be observed by same way as on morning observation. Pre-breakdown speed is corresponding to pre-breakdown flow rate and breakdown speed corresponds to breakdown flow rate. It can be easily measured from the moving average curve which was 28kph, 25kph and 22kph for pre-breakdown speed, critical speed and breakdown speed respectively. Thus, the speed dropped in the evening observation approximately 3kph or about 11 percent compared to before breakdown condition. In order to capture the variation of speed reduction, three days peak hour demand were analysis by using the same method, and average value selected as parameter of performance measures. The summary of speed observation defined by using the breakdown events method can be seen in Tables 4 and 5.

Table 2. The summary of capacity assessment during morning investigations.

No.	Date of observations	Breakdown period (minute)	Deterioration in Capacity, vph (%)	Pre-breakdown Capacity (vph)	Breakdown Capacity (vph)
1.	11/04/ 2012	35	-372 (-13)	2,763	2,391
2.	13/04/ 2012	37	-341 (-12)	2,825	2,484
3.	15/04/ 2012	18	-390(-14)	2,868	2,478
	Average Value	30	-368 (-13)	2,819	2,451

Table 3. The summary of capacity assessment during evening investigations.

No.	Date of observations	Breakdown period (minute)	Deterioration in Capacity, vph (%)	Pre-breakdown Capacity (vph)	Breakdown Capacity (vph)
1.	11/04/ 2012	42	-280 (-10)	2,697	2,417
2.	13/04/ 2012	25	-335 (-12)	2,754	2,419
3.	15/04/ 2012	38	-210 (-8)	2,512	2,302
	Average Value	35	-275 (-10)	2,654	2,379

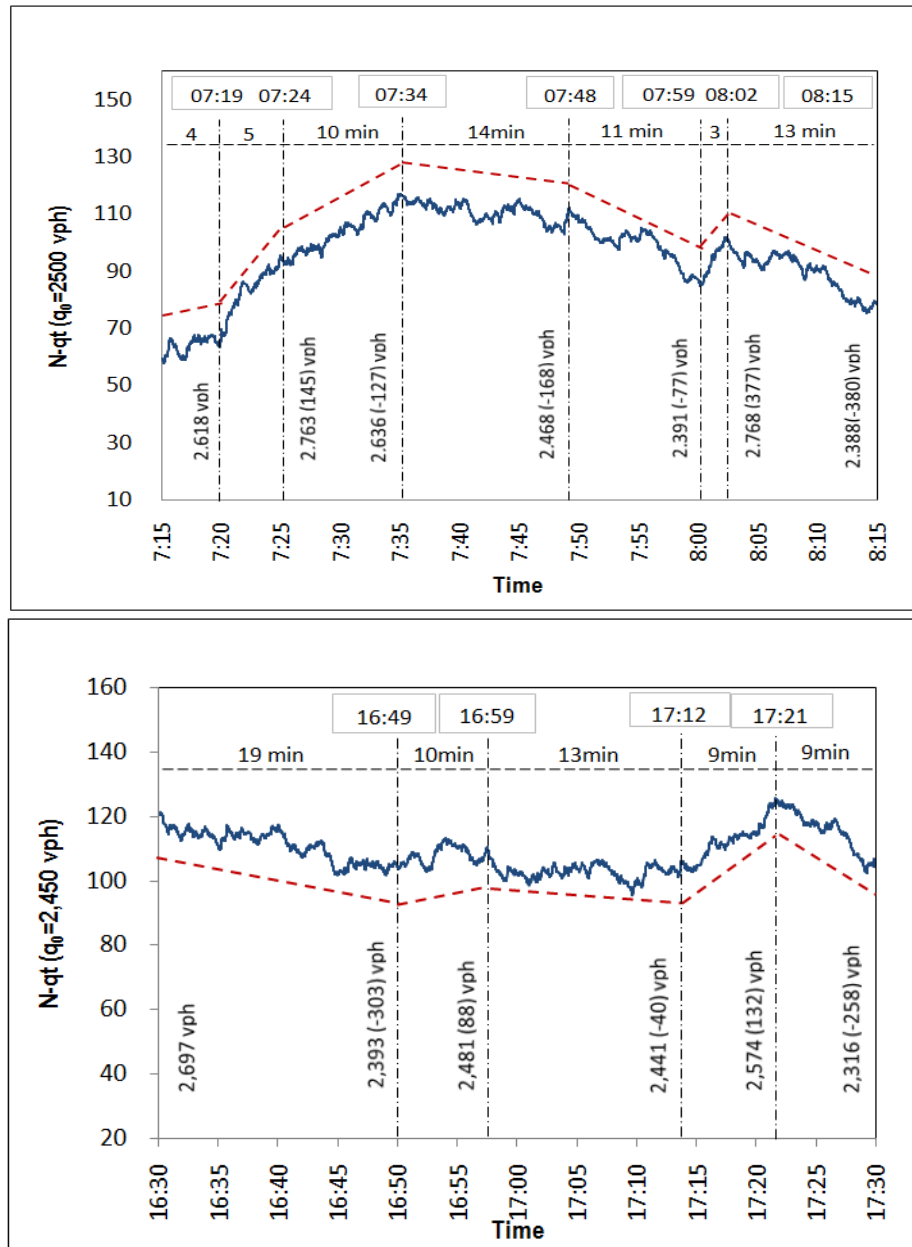


Figure 3. Oblique cumulative plots of morning (top) and evening (bottom) on peak demand 11th April 2012

Table 4. The summary of speed assessment during morning investigations.

No.	Date of observations	Breakdown period (minute)	Deterioration Speed, kph (%)	in	Pre-breakdown Speed (kph)	Breakdown Speed (kph)
1.	11/04/ 2012	35	-4 (-15)		26	22
2.	13/04/ 2012	37	-3 (-11)		27	24
3.	15/04/ 2012	18	-3 (-12)		26	23
Average Value		30	-3 (-13)		26	23

Table 5. The summary of speed assessment during evening investigations.

No.	Date of observations	Breakdown period (minute)	Deterioration Speed, kph (%)	in	Pre-breakdown Speed (kph)	Breakdown Speed (kph)
1.	11/04/ 2012	42	-6 (-21)		28	22
2.	13/04/ 2012	25	-5 (-19)		26	21
3.	15/04/ 2012	38	-4 (-17)		24	20
Average Value		35	-5 (-19)		26	21

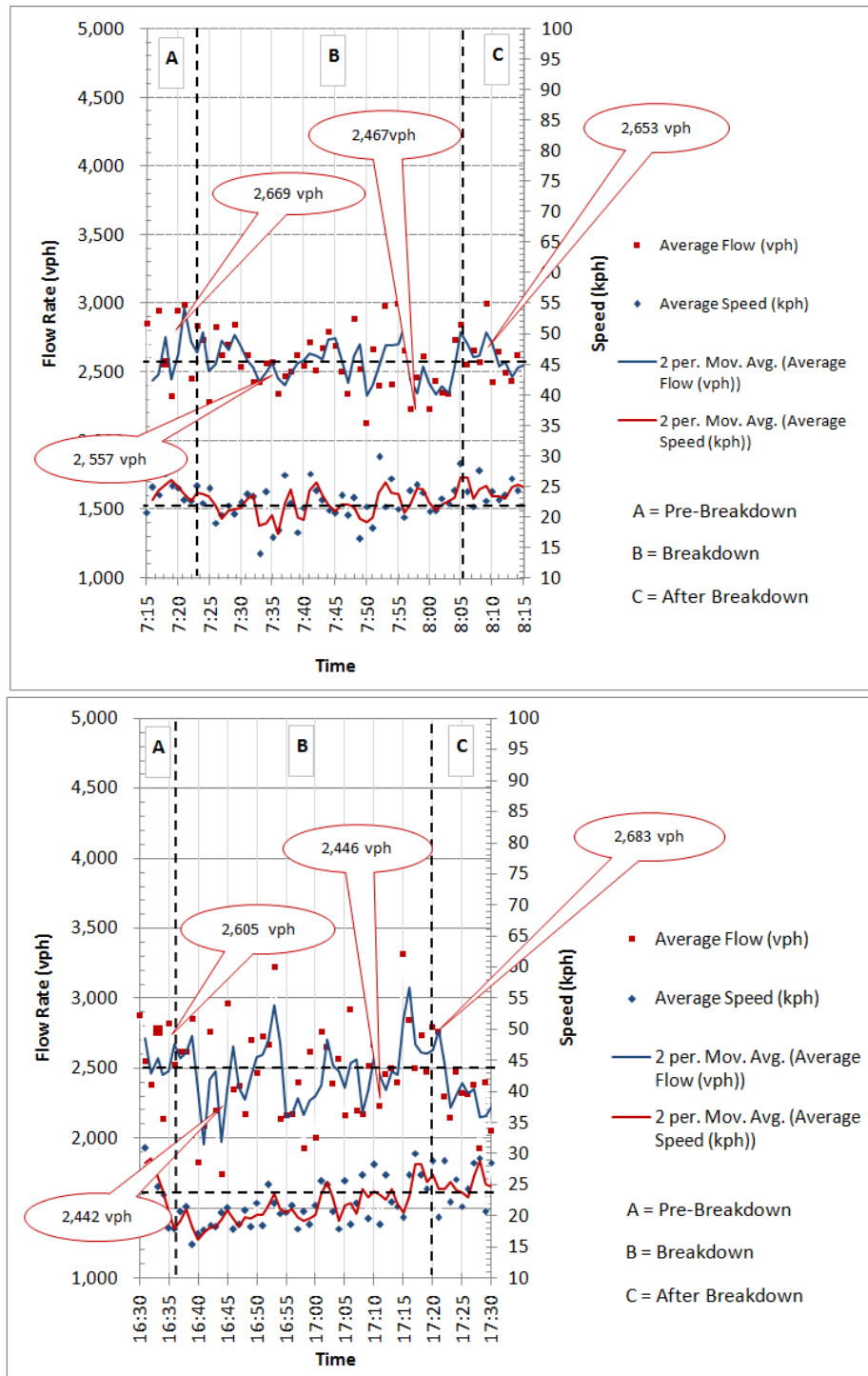


Figure 4. Moving average breakdown plots of morning (top) and evening (bottom) on peak demand 11th April 2012

VISSIM 5.30 traffic simulation

VISSIM is a microscopic, time step and behavior based simulation model developed to model urban traffic and public transit operations in Germany. The program able to analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops etc (PTV, 2010). This simulation tool was selected for examining either removing on-street parking during peak hour able to improve better operation or not.

VISSIM is a microscopic traffic simulation model which is widely used in current practice. In this work, VISSIM version 5.30 is selected for demonstrating traffic performance on the area of study. Consequently, set up scenarios of simulation is very necessary in order to ensure the simulation proficient manner in executing the existing and improvement scenario. Two scenarios were considered in this study namely existing condition (do nothing) and removing on-street parking during peak demand only (improvement). Then, the performance of measures (MOEs)

was selected for examining the efficiency of scenarios. In this regards, delay and travel speed were selected as performance measures. Speed and capacity were used as calibration parameters for running simulations. Due to the stochastic natures, one simulation run may produce significantly different results to other runs and replicating runs can overcome this deficiency. Practically, the replication method is performed by running the simulation for a number of independent runs. So far there have been no established standards to regulate the number of simulation runs. In this study 10 random seed numbers was selected to ensure unbiased MOEs, and average value obtained as the performance parameters. The result of simulation by employing 10 random seed number can be seen in Table 6. It soundly removes on-street parking able to reduce the delay from 38 sec/veh to 26 sec/veh, or approximately reduced 12sec/veh (32 %). Moreover, the speed also can be expected to get better with increment about 5kph or 24 percent compared to the existing one.

Table 6. Average MOEs parameters (10 random seed, 3600s) performed by VISSIM 5.30

No.	Simulation scenarios	Delay (sec/veh)	Speed (kph)	Delay reduction Sec/veh (%)	Speed increment kph (%)
1.	Existing condition	38	21	0 (0)	0 (0)
2.	Removing peak hour parking	26	26	12 (32)	5 (24)

Conclusions

To sum up, as for the aim of this study was to examine the effects of on-street parking activities such as shoulder lane utilization and parking maneuvers on traffic performance deteriorations by governed the applicability of the dynamic capacity methods. Therefore, employing two dynamic tools namely oblique cumulative plot and the breakdown event was clearly and effectively manner in analyzing traffic characteristics and mechanisms during peak demand at the on-street parking segment. Additionally, the methodology in this research could be used as a guideline to conduct further research study at other study sites. As the result of quantitative study, it found that capacity diminished slightly 10-13% (275-368vph) compared to the pre-breakdown condition. Likewise, during the breakdown, speed drops about 13-19% (3-5kph) controlled by pre-breakdown as well. VISSIM 5.30 employed for estimating measurement of effectiveness (MOEs) which considering removing on-street parking at site of study. The MOEs explicated that able to reduce approximately 12 sec/veh (32%), increase 5kph (24%) tuned to existing condition for delay and speed respectively. It concluded that on-street parking at arterial corridors during peak hour demands produced a significant impact on deterioration of arterial performances. Thus, it is highly recommended that removing on-street parking at urban arterial network is necessary in particular for improving the quality of services of the network. It is also recommended that public services such as hospitals, government/private offices and shopping facilities should provide private parking lots. Local government must commence the policy to provide off-street parking facilities particularly for public building services since the city continuously suffers from increasing private autos and motorcycles.

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