Analysis of Factors Affecting Street Bottleneck Capacity through Oblique Cumulative Plots

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Abstract: This research unveils the factors that affect urban street bottleneck capacity through the use of oblique cumulative plots for traffic analysis on Henry Dunant Road, a busy urban street in Bangkok. Detailed observations on the street reveal that the street bottleneck capacity was affected by several factors such as illegal blocking parked cars, interrupted U-turns from the opposing direction, and interrupted crossover right turns from an access road. In order to analyze the quantitative effects from these factors, four days of traffic data at the study site were collected by video cameras, manually extracted, and plotted using the oblique cumulative curves such that traffic mechanism at the site can be examined by visualizing the changes in flow rates from each different measurement and comparing across observation days. The analysis results show the degrees of how these individual factors affect the street bottleneck capacity.

Key Words: *Traffic Flow Theory, Highway Capacity, Oblique Cumulative Plots, Traffic Bottleneck*

1. INTRODUCTION

Bangkok, as well as many other Asian large cities, has a lot of traffic congestion problems on local streets due to high traffic demand and limited supply of roadways. However, it is evident that some illegal driving and parking activities could result in a reduction of street capacity, or a traffic bottleneck, on a middle of street even without any geometric restriction or traffic control devices. Understanding the quantitative effect of these activities on the street capacity will lead to an appropriate policy and guideline for traffic engineers as well as transportation planners in design and operation of local street traffic efficiently.

This research's main objective is to understand the quantitative effect of traffic activities on the street that could result in the change of street capacity. The research was done by selecting a street bottleneck site that could be filmed by video cameras to record driver behaviors and traffic mechanism in details. The data were collected for four days and carefully extracted and plotted using an oblique cumulative plot technique. The graphical illustration from traffic data through the use of this technique has unveiled previously unreported details of how different conditions on a street bottleneck quantitatively affect street capacity

The remainder of the paper is organized as follows. Section 2 summarizes related background research. The sites used for this study and data collection method are described in Section 3. Section 4 presents the traffic mechanism at the study site on observation days. Section 5 summarizes the factors affecting street bottleneck capacity. Then, the sixth and final section contains concluding remarks as well as areas of further research.

2. BACKGROUND

Daganzo (1999) defines an active bottleneck as the point on a roadway system between two locations if the traffic is detected to be queued upstream of the location and unqueued downstream. Also, any improvement that results in the increase in bottleneck capacity would obviously alleviate traffic congestion and save delay for traffic commuters. While most traffic engineers know that bottleneck is claimed to be the main cause of traffic congestion, not enough experimental or observation work is being done to understand local-street bottlenecks caused by distinct local driver behaviors. Therefore, the knowledge about what affects capacity and causes an active bottleneck on a local street has been insufficient and inconclusive such that no regular method is available.

Although Transportation Research Board (2000) provides a methodology for analyzing the capacity of urban streets, this methodology does mainly take account of lane width and traffic control devices. This methodology could serve well for the U.S. and European countries' streets where their roadway design is in accord to the standard and most drivers follow traffic laws well. This is not the case in many Asian countries, where many drivers are not abiding by the law. Therefore, the methodology could not be used to analyze several evident conditions that significantly affect street capacity. Examples of these conditions are the presence of on-street parking, illegal multi-lane on-street parking, unpermitted turning movements from an access crossing the street, U-turns from the reverse direction at an open median, presence and operations of law enforcement personnel at the site, illegal pedestrian crossing, illegal bus/taxi passenger drop-offs and pick-ups, etc. The effects of these conditions on street capacity have been less attentive among researchers since they are site-specific. Also, each of the condition could happen simultaneously with another condition, resulting in difficulty in analyzing by any standard method. Fortunately, the conditions and traffic behaviors found at each site are mostly repetitive and could be predictable in the same peak period on each day.

To analyze these traffic dynamic behaviors in details, the "oblique cumulative plots" technique, introduced by Cassidy and Windover (1995), was used in this research. This technique is a special time-series data treatment that could illustrate the changes in driver behavior and enable researcher to analyze the effects of activities that contribute to the change in street capacity. The oblique cumulative plots display the quantity $O(t) = N(t) - q_0 \times (t-t_0)$ versus t; i.e., the cumulative virtual vehicle count to time t, V(t), minus a background reduction, $q_0 \times (t-t_0)$; q_0 is a selected background flow. In this way, the oblique coordinate system amplifies changes in slopes. Since the slopes of the O-curves are proportional to the flows at each measurement location, these plots facilitated visual identification of the times when these flows actually changed. This technique has been generally used in numbers of traffic dynamic researches such as Cassidy and Bertini (1999), Cassidy and Rudjanakanoknad (2005), Ahn and Cassidy (2007), Chung, *et al* (2007), etc. Nevertheless, all of these researches were done on uninterrupted-flow-facility or freeway traffic only, the attempt of using this technique on an interrupted flow facility such as a local street has not yet been performed.

In conclusion, this research is an unprecedented study to analyze these traffic dynamic behaviors on a local street using the oblique cumulative plot technique to visually analyze the changes in flows, capacity, and activities on the street. The study site and data collection are described next.

3. STUDY SITE AND DATA COLLECTION

As described in Section 2, the sites used for studying street bottleneck capacity must be an active bottleneck. In addition, to collect high-resolution traffic data via videotape, vantage points (e.g., pedestrian crossing bridge or building) should be available near the site.

The data used in this study were collected by video cameras from the mid-section of Henri Dunant Road, a busy urban street in Bangkok, in the northbound direction between Rama I and Rama IV roads as shown in Figures 1. This short stretch of street has two vantage points, i,e., a pedestrian crossing bridge on the south and the tall Dentistry Building on the northwest side of the site. From both vantage points, multiple video cameras were positioned to view throughout northbound stretch. The high-resolution data extracted from this site and analyzed are described next.

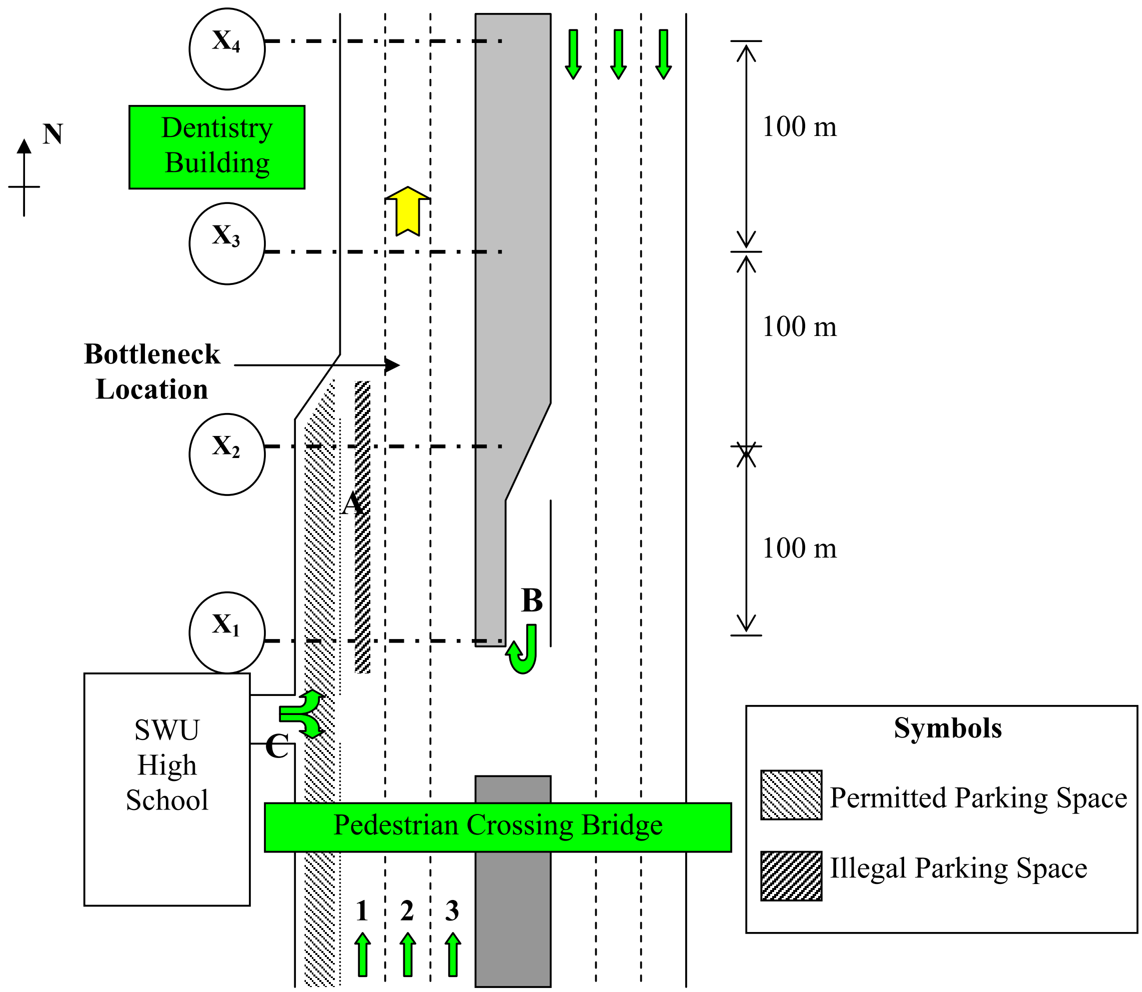

Figure 1 Study Site, Northbound Henri Dunant Rd, Bangkok, Thailand

Figure 2 shows the picture taken from the pedestrian crossing bridge during an uncongested period. This section permits parking on the left-most lane bay. However, during the peak period (when the SWU High School ends each day), illegal parking happens daily on an adjacent lane (denoted as **Lane 1** in Figure 1). These illegal parking cars could be extended for three lines, covering two traffic lanes (denoted as **A** in Figure 1), as shown in Figures 3(a) and 3(b) below.

Figure 2 Picture of Northbound Henri Dunant Road from a pedestrian crossing bridge

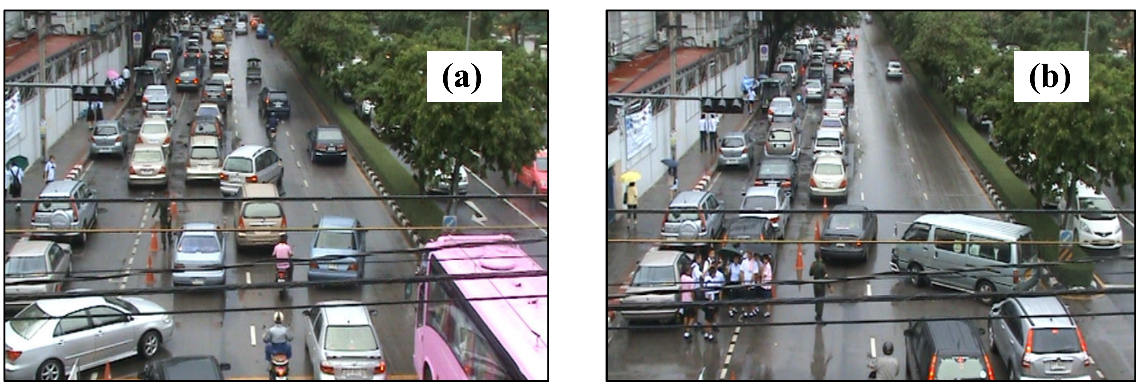

Figure 3 Multi-lane Parking at the study site when the bottleneck is active.
(a) Turning Movements from School Access
(b) U-Turns from opposing direction

Besides multi-lane parking, during the peak period, there were high turning movements (both left and right turns) from the school access as shown in Figure 3(a) and denoted as **B** in Figure 1, and high U-turn volumes from the opposing direction as shown in Figure 3(b) and denoted as **C** in Figure 1. Also, because of traffic congestion and illegal parking activity, law-enforcement personnel usually come to order the blocked parking cars to leave the site. However, in some circumstances, blocked cars remain parked even if a police officer was there. This was because only one police officer could not handle all parked cars at the same time.

From the pedestrian crossing bridge, individual vehicle arrival times at two fixed locations (labeled X_1 and X_2 in Figure 1) along the street stretch were measured. The width of illegal parking blockage from the edge line of parking bay (**A**) were measured approximated from the stopped camera film every 5-second. The arrival times of individual turning vehicles from school access (**B**) and U-Turn vehicles (**C**) at the site were measured as well.

From the Dentistry Building, individual vehicle arrival times at two remaining fixed locations (labeled X_3 and X_4 in Figure 1) are measured.

These data were collected during an afternoon rush hour at the site, just before the school ends, i.e., 15:30-16:30, for four days in 2008, i.e., Friday July 18th, Monday August 25th, Monday October 27th, Wednesday November 13th. These four days represent a regular school day with good weather condition. The results of data analysis are shown in the following section.

4. TRAFFIC MECHANISM AT THE STUDY SITE

This section describes the details of traffic conditions and how they affect street bottleneck capacity through graphical presentation.

On all observation days, just a short period before 15:30, the traffic condition between X_1 and X_2, were always congested and the queue from this location propagated upstream. Until some time around 16:10-16:25, the demand dropped and no queue were present. In the meanwhile, the traffic condition between X_3 and X_4 were always free flowing and in absence of downstream queue.

Although not shown here (to reduce excessive lines in the figures), the researcher had proved the bottleneck activation by plotting all four oblique cumulative curves of X_1 through X_4 in the same axis, and shifted X_2-, X_3- and X_4- curves to the left with their respective free flow travel time between their measurement locations and X_1. For all observation days, it was found that the upstream-most curves at X_1 and X_2 diverged from their downstream counterparts at t = 15:30, while the downstream curves at X_3 and X_4 remain superimposed until the period around 16:15-16:25, these four curves converge and become superimposed again. These verify that an active bottleneck lied on the segment between X_2 and X_3.

Importantly, since X_3 is the location downstream of the bottleneck the slopes of the curve (plus the background flow in case of oblique cumulative plot) are thus corresponding to the bottleneck capacities until the demand drops happened.

To explain the traffic mechanism happening at the study site in details, the data from two observation days were selected to present in Figures 4 and 5. The remaining two days are not shown due to their similarity but will be discussed in the following section.

Figure 4(a) displays an oblique cumulative plot of vehicle count versus time, t, measured at X_3 (O-Curve), on Monday, October 27, 2008. The O-Curve figure shows that the street capacity increased from 1,600 vph to 1,900 vph at t = 15:42. Shortly thereafter, the high capacity of 1,900 vph can be sustained for 13 minutes until t = 15:55, when the capacity dropped back to 1,300 vph.

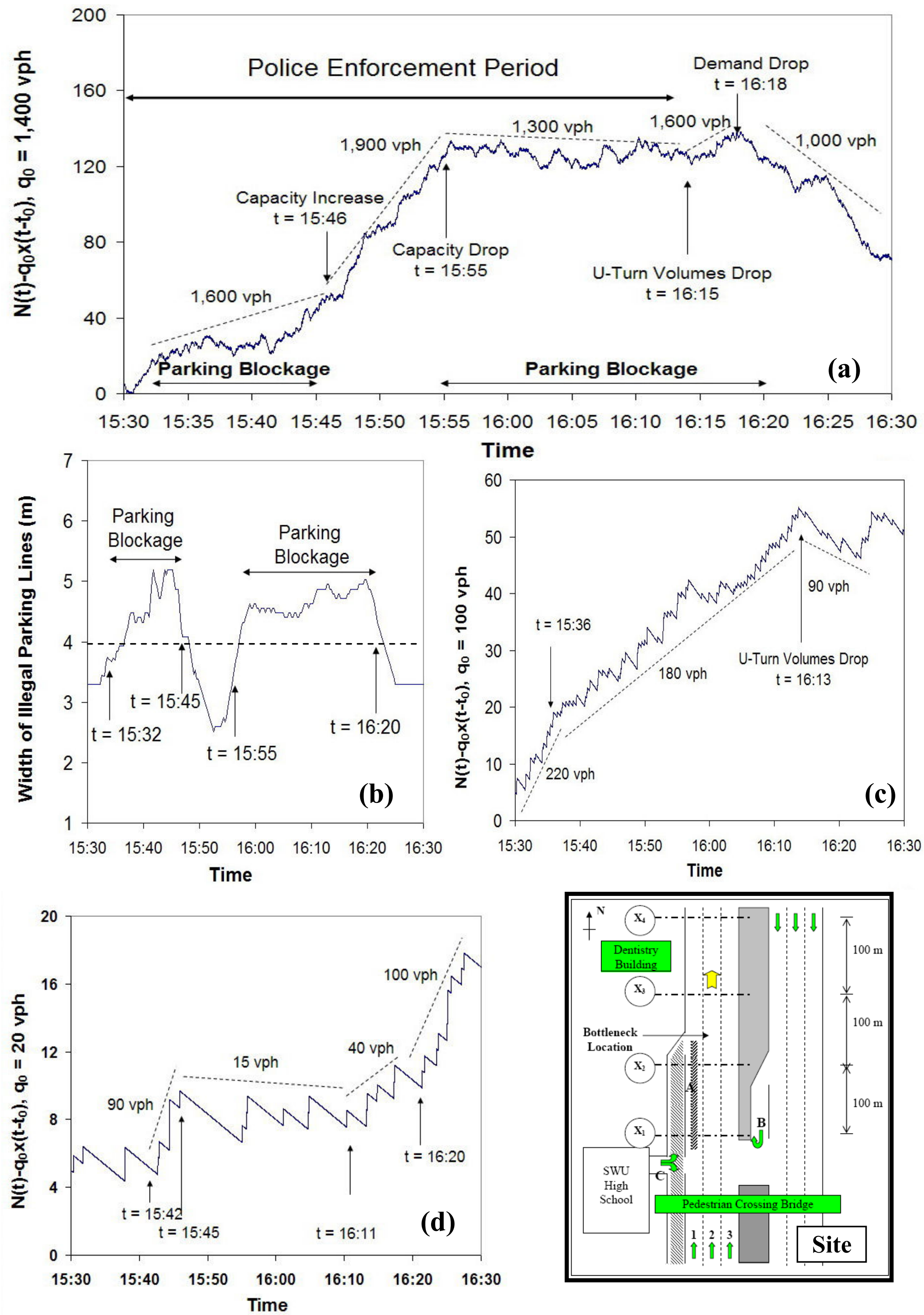

Figure 4 Traffic Data on Monday, October 27, 2008

(a) Oblique N-curve at X_3

(b) 5-min moving average of illegal parking width

(c) Oblique N-curve of U-Turns

(d) Oblique N-curve of right turns from access

The cause of capacity changes on this day is evidently corresponding with the blockages of parked vehicles as shown in Figure 4(b). Figure 4(b) shows that when the blockage width dropped below or increased above approximately 4 meters, the capacity immediately changes. Note that the clearance of parking blockage might not immediately happen once the police office came since he must spend some minutes (around 10-15 minutes, from t = 15:30-15:45) to clear the whole line of illegal blockage.

The change in capacity could not be explained alone by parking blockage. At time t = 16:15, the capacity returned to 1,600 vph even the blockage remained there. The cause of this change could be explained by the change in U-Turn volumes. Figure 4(c) displays an oblique cumulative plot of U-Turn volumes versus time, t. The Figure shows that U-Turn volumes had been as high as 180 vph since the period since time t = 15:36, and remained constant for 37 minutes. Then, at time t = 16:13, the U-Turn volumes dropped to 90 vph. This explains why the street capacity increased at this time.

Another possible cause of capacity changes at this site is the right turn movements from the school access; however, the effect is inconclusive on this day. Figure 4(d) displays an oblique cumulative plot of right-turn volumes versus time, t. The Figure shows that the right turn volumes were very low (around 30 vph, or 1 car every two minutes) except for some few minutes (t = 15:42-15:45). Due to extremely small periods of time, the effect on capacity is not clearly shown as a capacity change in Figure 4(a). Also, when the turning volumes surged to 100 vph after t = 16:20, there was no effect on street capacity either since the demand of traffic on the main street already dropped and the bottleneck was dissipated since t = 16:18 as noted in Figure 4(a).

How right turn movements affect the capacity can be proven by the data on another observation day. Figure 5(a)-5(d) show a series of traffic data in the same order as Figure 4(a)-4(d) on Friday, July 18, 2008. Like the previous day, the O-Curve figure (Figure 5(a)) shows that the street capacity was changed over time in the range of 1,240-1,740 vph due to several activities as follows.

Figure 5(a) displays that the first capacity change on this day happened at t = 15:42, when the capacity slightly dropped from 1,240 to 1,160 vph. This time was exactly when the U-turn volumes increased from 60 to 180 vph (see Figure 5(c)). The lower capacity of 1,160 vph remained almost constant and persisted through t = 16:05, matching well with the times of sustained high U-turn volumes of 180 vph. Nevertheless, Figure 5(b) shows that there was no significant effect of the parking blockage on street capacity on this day since there was no noticeable change in the Oblique N-curve at X_3 around t = 15:46 (see Figure 5(a)).

At t = 16:05, the right turn volumes surged very high from 30 vph to 120 vph (see Figure 5(d)), this high turning volumes stayed for 7 minutes until t = 16:12, when it dropped to only 20 vph. Coincidently, the capacity changed from 1,160 to 960 vph at t = 16:05, and reversed to 1,740 vph.

The capacity of 1,740 vph, sustained as long as 14 minutes until t = 16:26, was the highest capacity observed on this day. It happened when both the right turn from school access and U-turn volumes were low, as well as, there was no parking blockage on the roadway These conditions are considered to be ideal to maintain high capacity for this site study.

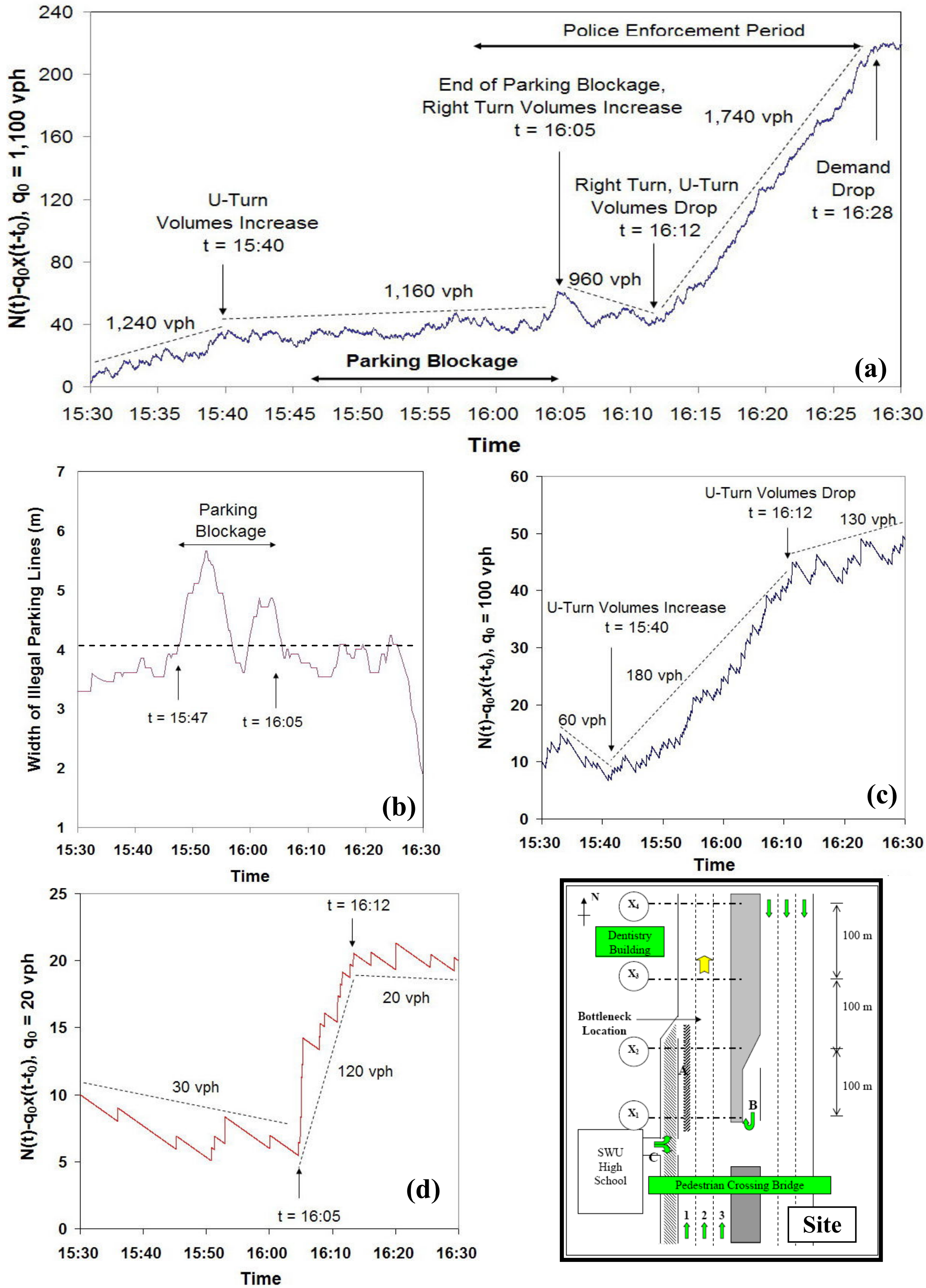

Figure 5 Traffic Data on Friday, July 18, 2008

(a) Oblique N-curve at X_3
(b) 5-min moving average of illegal parking width
(c) Oblique N-curve of U-Turns
(d) Oblique N-curve of right turns from access

5. FACTORS AFFECTING STREET BOTTLENECK CAPACITY

This section summarizes and compares each of the factors affecting street bottleneck capacity from all four observation days. These data were took out from series of oblique cumulative plots that were shown earlier in Section 4. Since the changes of street bottleneck capacity might occur during the time when one or more factors changes, only the changes that were caused by only one factor are summarized here to eliminate the combined effects. Therefore, the effects from some factors might not be found or separated out from the others on some observation days.

This section is organized based on the different factors as follows, parking blockage and unblockage, U-turns from the opposing direction, Right-turns from the school access, police enforcement, as follows.

5.1 Parking Blockage and Unblockage

Parking blockage and unblockage were well corresponding with the changes in street bottleneck capacity. Table 1 and 2 show the effects of these events, respectively. From Table 1, the average capacity reduction due to the blockage (of wider than 4 meter from permitted parking lane) was 460 vph. On the other hand, once the blockages were removed, the average capacity was returned by 330 vph. These numbers were accounted for about 20-25% of the bottleneck capacity without blockage.

Table 1 Effect of parking blockage on street bottleneck capacity

Observation Day	Time of event	Bottleneck Capacity (vph)		
		Before	After	Change
July 18, 2008	Individual effect of this event was not found.			
August 25, 2008	16:02	1,620	1,300	-320
October 27, 2008	15:55	1,900	1,300	-600
November 13, 2008	Individual effect of this event was not found.			
			Average	**-460**

Table 2 Effect of removing parking blockage on street bottleneck capacity

Observation Day	Time of event	Bottleneck Capacity (vph)		
		Before	After	Change
July 18, 2008	Individual effect of this event was not found.			
August 25, 2008	15:50	1,330	1,620	+290
October 27, 2008	15:45	1,600	1,900	+300
November 13, 2008	16:07	1,260	1,670	+410
			Average	**+330**

5.2 U-Turns from the Opposing Direction

U-Turns from the opposing direction also play a major role in street bottleneck capacity change. The effects of this event were found on three observation days as shown in Table 3. On July 18, the increase of U-Turns by 120 vph caused a capacity drop of 80 vph. In contrary, the drop of U-Turn volumes by 90 and 50 vph increase the capacity by 300 and 410 vph on October 27, and November 13, respectively.

Table 3 Effect of changes in U-Turn volumes on street bottleneck capacity

Observation Day	Time of event	U-Turn Volumes (vph)			Bottleneck Capacity (vph)		
		Before	After	Change	Before	After	Change
July 18, 2008	15:40	60	180	+120	1,240	1,160	-80
August 25, 2008	Individual effect of this event was not found.						
October 27, 2008	16:15	180	90	-90	1,300	1,600	+300
November 13, 2008	16:07	120	70	-50	1,260	1,670	+410

Based on these numbers, it implies that the increase of U-Turns volumes might not significantly reduce the bottleneck capacity but the U-Turn restriction at this study would likely increase the bottleneck capacity with the average ratio of U-turns to through cars about 1:5, i.e., one U-Turn vehicle is equivalent to about five through-movement vehicles.

5.3 Right Turns from the Access

Right turning movements from the access cross over all through movements such that they reduced street bottleneck capacity. Table 4 shows the proof of this argument. On two observation days, average right turn volume increased by 68 vph, resulting in the average drop of 200 vph in street bottleneck capacity. Therefore, the average ratio of right turn volumes to capacity change is about 1:3, i.e., one right-turn vehicle is equivalent to about three through-movement vehicles.

Table 4 Effect of changes in right turns from the access on street bottleneck capacity

Observation Day	Time of event	Right-Turn Volumes (vph)			Bottleneck Capacity (vph)		
		Before	After	Change	Before	After	Change
July 18, 2008	16:05	30	120	+90	1,160	960	-200
August 25, 2008	16:10	30	75	+45	1,300	1,110	-190
October 27, 2008	Individual effect of this event was not found.						
November 13, 2008	Individual effect of this event was not found.						

5.4 Police Enforcement

Although not specifically shown in this paper, a presence of law enforcement personnel would significantly affect the street bottleneck capacity. In some indirect ways, an officer is there to order overly blocking vehicle s to leave the site, as well as, control the movements of U-Turns and right-turns from the access in some orderly ways. These effects would subsequently result in capacity changes as shown in the previous subsections.

In research practice, it is difficult to evaluate the effectiveness of enforcement personnel at the site in a quantitative way. Each different officer or even the same person in different day controls traffic at the site differently based on distinct daily traffic situation.

5.5 Other Possible Factors

Besides the aforementioned factors, other factors that affect street bottleneck capacity include on-street pedestrian crossing, walking people on the street to their parked vehicles, weather and lighting. These factors have not been investigated yet in this research.

6. CONCLUSION

To this end, this research has demonstrated the methodology of how to analyze the effects of different factors that could change street bottleneck capacity by using oblique cumulative plot technique. With limited data based on scenarios founded during observation periods, the research nevertheless shows degrees of how these individual factors affect the street bottleneck capacity.

Due to a unique nature of each local street facility, the results of this research could not be generalized and applicable at other site. Nevertheless, the methodology in this research could be used as a guildline to conduct further research study at other study sites. Once more careful research was done, some conclusive generalization of study results could be a base for updating standard design manuals as well as capacity analysis handbooks of street capacity analysis for traffic engineering professionals.

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REFERENCES

Ahn, S. and Cassidy, M. J. (2007) Freeway traffic oscillations and vehicle lane-change maneuvers. **17th International Symposium of Transportation and Traffic Theory**, London.

Chung, K., Rudjanakanoknad, J., and Cassidy, M. J. (2007), Relationship between traffic density and capacity drops at three freeway bottlenecks, **Transportation Research (Part B) Journal**, Vol 41, pp. 82-95.

Cassidy, M. J. and Bertini, R. L. (1999), Some traffic features at freeway bottlenecks, **Transportation Research (Part B) Journal**, Vol 33, pp. 25-42.

Cassidy, M. J. and Rudjanakanoknad, J. (2004), Increasing the capacity of an isolated merge by metering its on-ramp, **Transportation Research (Part B) Journal**, Vol 39, pp. 896-913.

Cassidy, M. J., and Windover, J. R. (1995), Methodology for assessing dynamics of freeway traffic flow, **Transportation Research Record 1484**, TRB, Washington D.C., pp. 73-79.

Daganzo, C.F. (1999) Remarks on traffic flow modeling and its applications, in traffic and mobility, **Proceedings of the Traffic and Mobility Simulation, Economics and Environment Conference**, pp.105-115.

Transportation Research Broad (2000) **Highway Capacity Manual, Special Report 209**, Washington D.C., National Research Council, Chapter 15.