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Research Article

Modeling the Relationship between On-Street Parking Characteristics and through Traffic Delay

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Abstract: : In performing regulation concerning the on-street parking prohibition, Jakarta transport authority bases its decision on the Level of Service of link under consideration. It does not make use explicitly of the dynamic of parking, i.e., the variables of parking characteristics whereas in some cases parking is prohibited while indeed the contribution of parking to the traffic jam is not quite significant. The purpose of this study is to examine the effect of on-street parking on the through-traffic by modeling the relationship between the various variables that represent parking characteristics and the variables associated with the traffic flow, with a case study on West Jatinegara Street, Jakarta. Parking variables are represented by parking turnover, parking index, flow-in and flow-out, while the traffic flow is represented by the delay time, i.e. the difference of travel time of with-parking state and the one of without-parking state to pass particular segment before the parking area. The model shows that there is a fairly strong relationship between parking turnover and the delay of vehicles that move toward the parking location, and the volume of the through-traffic also affects such relationship. Local authorities can take advantage of the model as a guideline in performing parking prohibition policy.

Keywords: Parking Characteristics, Parking Turnover, Delay Time, Through Traffic.

1. INTRODUCTION

Parking problems are faced by almost all big cities, including Jakarta, Indonesia. The business district in the city center generally has high on-street parking demand, especially on weekdays. During office hours, half of the vehicles in the downtown streets of big cities are in a condition of cruising for parking [1]. However, due to its interference to the through-traffic flow, on-street parking in many places in the city center is often prohibited by the local administrator. On the other hand, there are still lacks parking space, particularly in the city center. Indeed, office or shop owners in these areas need adequate parking space to provide the best service to their customers, while the road users expect the least possible disturbance on their trip, and the local government is stipulated for the livable and wealthy city.

To satisfy the parking demand, constructing new parking facilities is one of the possible choices. However, construction of new facilities is not always possible due to lack of money, human time, and land resources. Another solution that might be applied to meet the demand for parking is the optimization of parking facility usage. This approach seems to be more efficient since it consumes fewer resources [2]. In this context, parking management has an important role and it is related to the multiple objectives of the inhabitants of the city. Indeed, proper parking management should be able to generate a positive impact on the results of the trade-off between their objectives. The key is to find a method for effective management to maximize opportunities and reduce the difficulties related to the use of on-street parking [3]. Three specific objectives are frequently perceived to conflict parking management, namely the desire to use parking measures as a means of regenerating a specific part of the urban area such as the town center (i.e. providing more parking to attract business); the desire to use parking controls as a means of restraining vehicle traffic and improving

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environmental quality or to encourage the use of non-car models; and the need to secure sufficient revenue from the parking operation to cover costs or to make a surplus to fund other activities [4].

In performing parking regulation, especially of on-street parking prohibition, local authorities generally base their decisions by considering the road width, traffic volume, traffic speed, parking vehicle dimensions, parking type and the nature of land use. Jakarta Transport Authority makes use of Level of Service of link under consideration to decide the parking prohibition policy. In contrast, in some cases, the contribution of parking activities to the traffic jam is not quite significant indeed. Usually, the authorities do not make use of the variables of parking characteristics, such as parking turnover, parking index, parking duration, etc. For example, the characteristics of the on-street parking of the retail market are different from the ones of the wholesale market, although their characteristics of traffic and their road geometrics are similar. Parking turnover of the wholesale market may be lower than the rate of the retail market as a result of the process of loading and unloading and also due to the maneuvering of the heavy vehicles of commercial activities.

Consequently, both types of parking generator are likely to have different impacts on traffic flows that pass through it. In order to achieve the best result on parking management, the city government needs to consider the most appropriate conditions carefully to impose parking prohibition, by considering the parameters that describe the parking characteristics, besides the factors related to traffic flow of the through-traffic, and the road geometric. In this case, for two parking areas that have the same conditions of traffic characteristics and road geometric, it is possible to apply different parking policies or parking management. It may be expected to be one of the solutions to the problem of limited parking space in the major cities, including Jakarta.

The purpose of this study is to examine the effect of on-street parking on the through-traffic by modeling the relationship between various variables that represent parking characteristics and variables associated with the traffic flow, with a case study on West Jatinegara Street, Jakarta. It is an old business district in the city center equipped with two-lane one direction road and parallel parking system.

Naseri [5] analyzed the impact of on-street parking on the traffic flow variables in several cities of Iran. Traffic flow variables that were used are the speed, delay time, and traffic volume, while the parking variable was represented by the percentage of use of parking space. This study examined the effect of percentage of parking space usage on the average delay on different road types and V/C ratio. It proposed delay adjustment factor and equation models of the effects of both types of variables. The study showed that the higher the percentage of parking space usage, and the larger the V/C ratio, the higher the delay adjustment coefficient was. It was found that commercial area has the highest delay adjustment coefficient among the one of highway, arterial road and local residential street.

Thirayoot and Sugiarto [6] examined the impact of on-street parking, particularly the impact of road shoulder usage and parking maneuver on the performance of urban artery road in the city of Banda Aceh. The artery road performance was analyzed using dynamic capacity model. It showed that due to the presence of on-street parking, the road capacity was reduced by 10-13% (275-368 vhc/h) and the speed was reduced by 13-19% (3-5 km/h). Simulations were conducted using VISSIM 5:30 program to get the estimated effectiveness measurement by eliminating the on-street parking from the study site. The simulation showed that the absence of on-street parking could make the average delay time reduced by 12 sec/vhc (32%) and the speed can be increased by 5 km/h (24%).

Roza [7] described the characteristics of on-street parking in the area of Petaling Jaya City Council (MBPJ) Malaysia. It made use of some variables, i.e. number of parking lots, parking volume, average number of parking vehicles per hour, maximum parking vehicle per hour, parking turnover, parking duration and parking capacity per hour. The result showed that the differences in the parking characteristics were caused by land use, parking systems, different purpose and behavior of riders.

Portilia [8] examined the effect of on-street parking on the artery road or main road on the entire traffic flow. The study examined the effect of vehicle maneuver and bad position parking against the average travel time by using queuing model M/M/∞, where the arrival and departure took the form of Poisson distribution. The model was validated using a calibrated micro-simulation through local field measurements taken on the road segments in the city of Santander Cantabria, Spain. Microsimulation was used to calculate the reduction of capacity of road segments for each case study and the addition of the average travel time for each road user. Simulation of the model M/M/∞ showed that the on-street parking maneuver and wrong parking position affected the traffic flow.

Borovskoy and Yakovleva [9] studied parking turnover impact on traffic flow delay. The study method is based on the development of a simulation model depending on the mobility plan; in the course of full-scale studies, using data on the intensity of vehicle movement and the time of vehicle entry to and exit from the parking space. The path of vehicle movement, depending on various positions of the vehicle during parking, was performed with the help of Vehicle Tracking application for AutoCAD. It was noted that the increase in the turnover leads to an increase in delays in traffic flows.

Those previous studies focused more on the influence of parking angle and vehicle maneuvering characteristics to the reduction of road segment capacity, as well as their impact on the traffic delay. Since the measurement of parking characteristics is relatively more comfortable due to the standard procedures in the data collection rather than the measurements of vehicle maneuvers or other variables that are less commonly used in the parking study and traffic study, this research is aimed to see the effect of parking characteristics to the through-traffic, especially in Jakarta. It is intended to take into account the parking characteristics in the justification of parking prohibition regulation in a particular area instead of parking vehicle dimensions, parking type and the nature of land use merely.

2. METHODOLOGY

The flow chart of research methodology is indicated in Fig.1.

2.1 Parking and Traffic Flow Survey

The traffic flow survey was done in two conditions; namely parking and no-parking stated. The 18-hour field surveys of the through-traffic flow for both states use two video cameras which are set on a road segment along the Jatinegara Barat street, i.e. 28 meters and 230 meters toward the starting point of the on-street parking area. This

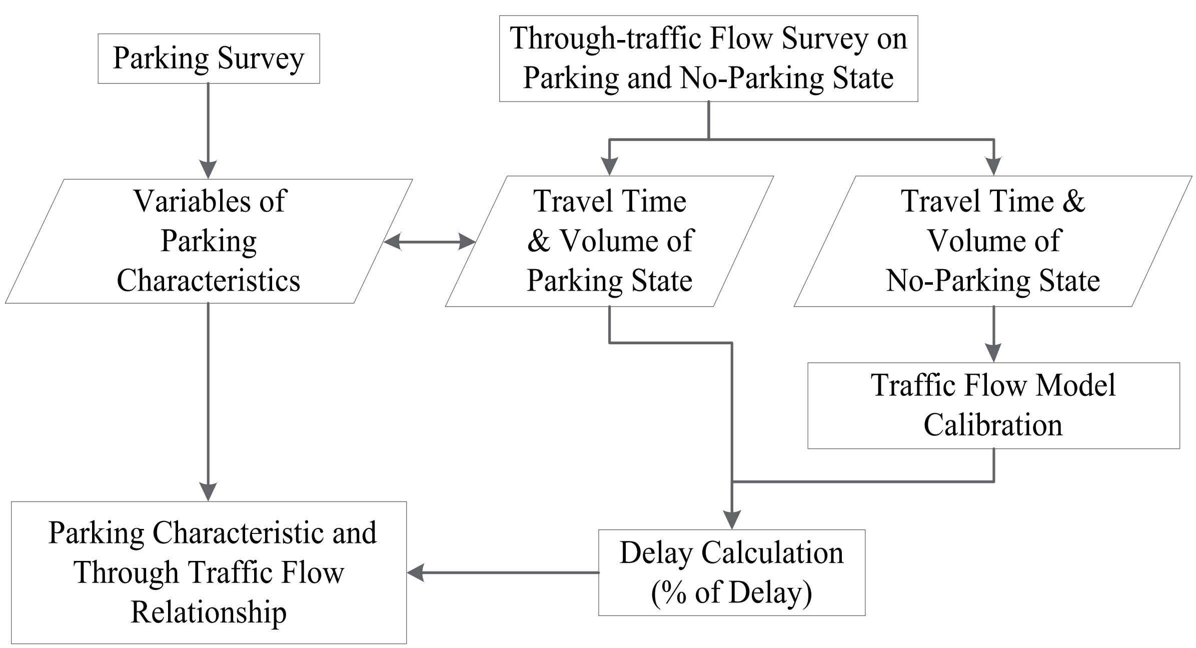

Fig. 1. Research Methodology

segment was located in a parking prohibited area but it was immediately affected by the parked vehicles maneuver on the parking area right after this segment. It was possible to find the traffic data for both states since the on-street parking policy was only performed on the weekend, while parking was prohibited on the weekdays. The 18 hours was divided into 15-minute time increment, so there were 72 data set of traffic flow. In further analysis, the traffic volume of each of 15 minutes' observation was transformed into hourly volume. The speed of each vehicle was calculated from data of travel time to pass the segment of observation. From the data of volume and speed, the traffic density was generated.

For parking survey, parking characteristic data was taken at the same time with the through-traffic data collected, and both types of data were matched for each time increment (i.e 15 minutes) during the observation period. The length of the parking area surveyed was 200 meters with parking capacity as 32 parking space unit (PSU). Primary data of parking activity included parking duration and flow-in and flow-out of the vehicle during a predetermined time of observation. Afterward, the data was processed to obtain a variable that represented the parking characteristics, i.e. parking turnover, parking activity index, parking index, flow-in, and flow-out.

2.2 Delay Calculation

The influence of parking characteristics on the traffic flow is represented by delay time. Delay measurements in this study are slightly different from other studies that generally define the delay through queuing theory or other measurements based on one condition only, namely parking state or using simulation methods [6]. Delay in this study is calculated by comparing the travel time of the through-traffic on a particular road segment right before the parking area under consideration to the travel time on the same segment at the time of no-parking state. Such delay is called absolute delay. Travel time of no-parking state is obtained at the time when the parking is prohibited, vice versa for parking-state. Comparison of travel time of the two states (surely taken at two different times) is allowable since both travel times are associated with the same traffic volume, and it is assumed that the side frictions (such as pedestrian activities and other obstacles) are the same for both states.

Travel time of parking-state and the respective traffic volume for each time of increment are directly found from the observation. Meanwhile, in order to find travel time of no-parking state at any condition of traffic volume, traffic flow model is generated, particularly the model that relates the volume of through-traffic and speed (and the respective travel time). From the calibrated model, the travel time to pass the segment of observation in any condition of traffic volume at the no-parking state could be determined.

Afterward, for each time increment of observation, a final parameter is applied, namely, relative delay. It is a percentage of delay that is expressed in the following equation:

$$\Delta TT = \frac{(TT_1 - TT_2)}{TT_2} x\ 100\% \tag{1}$$

where:

ΔTT = Percentage of delay (%)
TT_1 = Travel time of on-street parking state
TT_2 = Travel time of no on-street parking state

The parameter of a percentage of delay is intended to see the impact of parking to the through-traffic flow by excluding the internal delay within the traffic flow itself, for example, due to the high volume. By using the percentage of delay, local authorities can decide more judiciously the implementation of parking prohibition policy. For example, in the case of which the effect of on-street parking is not significant, the percentage of delay may be relatively small. It indicates that either the parking is prohibited or not the travel time is still high; accordingly, the travel time difference, as well as the percentage of delay, becomes small. Consequently, even if the travel time toward the parking area is high, parking prohibition is not always the best option to apply for traffic management.

2.3 Calibration Model of the Through Traffic Flow

The calibration model of the through-traffic flow is carried out using 72 data set of observation, namely volume, speed and density to model the relationship between the travel time (as the complement of speed) and volume of the road segment that represents the traffic flow under uninterrupted condition, i.e. no-parking state. It applies the traffic data at the time when the parking is prohibited. The Green Shields Model, Greenberg Model, and Underwood Model are applied, and one of them is finally chosen as the best model to represent such traffic flow.

2.4 Relationship between the Parking Characteristic and Through Traffic Flow

It is initialized by corresponding the travel time of no-parking state (TT_2) to the travel time of parking state (TT_1) on each time increment of parking state observation. The travel time of no-parking state (TT_2) can be found through the volume and speed relationship of the calibrated traffic flow model by applying the associated traffic volume of parking state to the model to find the speed. The travel time TT_2 comes after the length of observation divided by such speed.

Analysis of the relationship between variables of parking characteristics and through-traffic flow, which is represented by the percentage of delay, is carried out by performing a scatter diagram with the variable of parking characteristics on x-axis and percentage of delay on y-axis. Local authorities can take advantage of the model as a guideline in performing parking prohibition policy. Having the chart and the permitted percentage of delay, the local authority can decide when the parking prohibition should be performed. The decision considers the combination of parking characteristics and one of traffic flow rather than the parking characteristics as a single determinant. As the delay percentage is more than the permitted one, then the parking activity can be prohibited, and vice versa.

3. RESULTS AND DISCUSSION

3.1 Traffic Flow Model for No-Parking State

Based on the Goodness of Fit Test, it is found that the Underwood Model is the best model that represents the uninterrupted flow at the segment of observation with the coefficient of the determination as $R^2 = 0.901$. The relationship among the three variables of traffic flow is shown in Fig. 2 ~ Fig. 4. In our case, Fig. 4 becomes the most critical model since it relates the traffic volume and speed (and the associated travel time). From that figure, the travel time to pass the segment of observation in particular conditions of traffic volume at the no-parking state could be determined.

3.2 Relationships Between Parking Turnover and Delay

Tables 1 shows the result of the traffic flow survey in terms of three parameters, i.e volume, speed and density for parking state and no parking state during 18-hour observation. It can be seen that during period of observation the segment in no-parking state could perform better than the one of parking state by accommodating more vehicles per hour

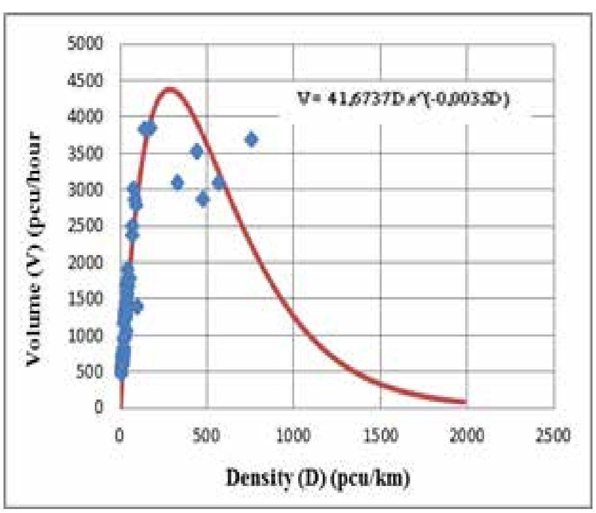

Fig. 2. Relationship of Vloume and Density

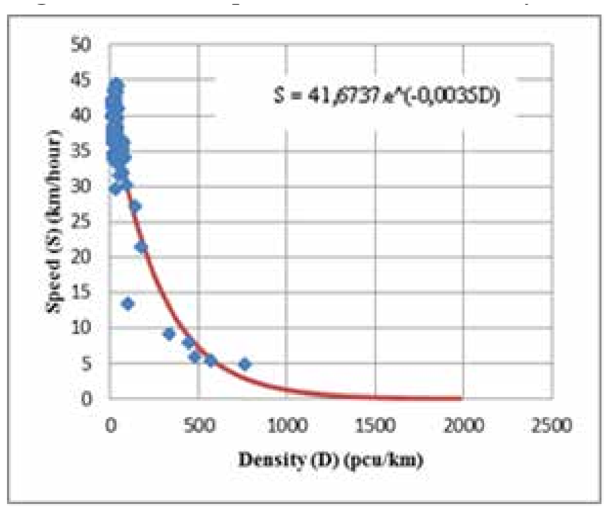

Fig. 3. Relationship of Speed and Density

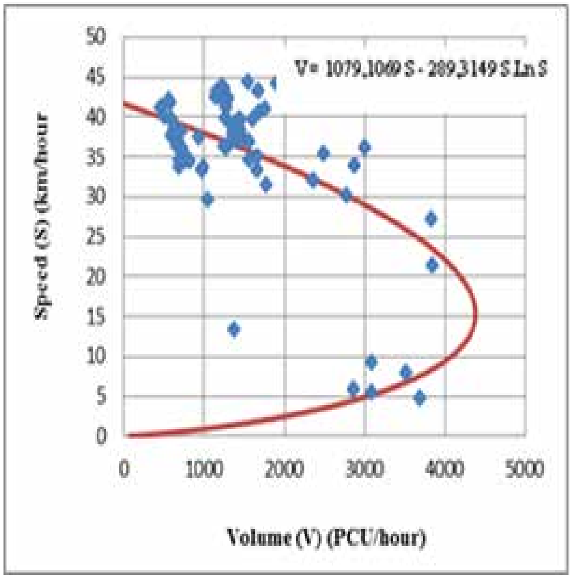

Fig. 4. Relationship of Speed and Volume

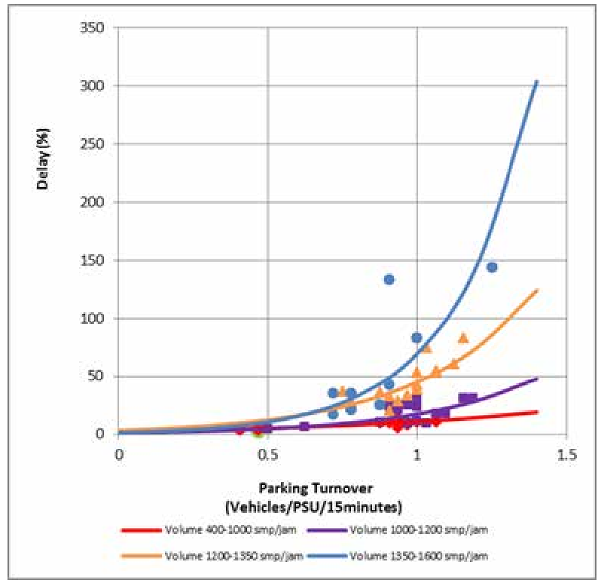

Fig. 5. Relationship between Parking Turnover and Percentage of Delay

(up to 150.78%) and more vehicles per km (up to 395.91%), as well as raising the higher maximum speed (up to 11.74%).

Table 2 shows the result of the parking survey during the 18-hour observation. It can be seen that during the period of observation, the parking system is still in good performance with the average 77.30% of total parking space is occupied, with the level of parking activity is 0.12. The parking turnover is quite low where only 0.36 vehicles occupy one parking space unit per hour. It is relevant to the characteristics of the land use of Jatinegara as a commercial shopping area.

In order to see the relationships between the parking characteristic and percentage of delay, the entire variables of parking characteristics are

Table 1. Traffic Flow Characteristics

No	Traffic Flow Characteristics	Parking State	No-Parking State	% of difference (to parking state)
1	The Lowest Volume	205,60 pcu/hour	458,80 pcu/hour	123.15%
2	The Highest Volume	1533,60 pcu/hour	3846 pcu/hour	150.78%
3	The Lowest Speed	9,98 km/hour	4,84 km/hour	-51.50%
4	The Highest Speed	39,71 km/hour	44,37 km/hour	11.74%
5	The Lowest Density	5,39 pcu/km	11,40 pcu/km	111.50%
6	The Highest Density	153,72 pcu/km	762,31 pcu/km	395.91%

Table 2. Parking Characteristics

No	Parking Characteristics	Value
1	Flow-In Parking Volume	195 vehicles
2	Flow-Out Parking Volume	182 vehicles
3	Average Parking Index	77,30%
4	Parking Turnover	0,36 vehicle/PSU/hour
5	Parking Activity Index	0,12

analyzed (i.e. parking turnover, parking activity index, parking index, flow-in, flow out). It is carried out by conducting Regression Analysis with the percentage of delay as the dependent variable and each of parking variables as the independent variables. The results show that only parking turnover that has good correlation with the percentage of delay. It is relevant to the study done by Borovskoy, A. and Yakovleva, E. [9] that the increase in the turnover leads to an increase in delays in traffic flows. Meanwhile study of Gao and Ozbay [10] on double parking violations of commercial vehicles show that the location, frequency, and duration of the double parking event and overall traffic demand have a certain impact on the average travel time.

Furthermore, since the range of traffic volume is quite big, then the volume is classified into five groups; hence further analysis of the relationship between Parking Turnover and Percentage of Delay becomes more suitable. The classification is as follows:

- Group 1: 0-400 pcu/hour
- Group 2: 400-1000 pcu/hour
- Group 3: 1000-1200 pcu/hour
- Group 4: 1200-1350 pcu/hour
- Group 5: 1350-1600 pcu/hour

Using such classification, the relationship between the parking turnover and percentage of delay is determined and indicated in Fig. 5. From the chart in Fig. 5 it can be explained that:

The relationships between parking turnover (x) and percentage of delay (y) is as follows:

- Group 2 (400-1000 pcu/hour):
  y = 2,802e1,381x, R^2 = 0,660
- Group 3 (1000-1200 pcu/hour):
  y = 1,497e2,476x, R^2 = 0,476
- Group 4 (1200-1350 pcu/hour):
  y = 3,646e2,519x, R^2 = 0,559
- Group 5 (1350-1600 pcu/hour):
  y = 1,760e3,680x,R^2 = 0,629

From the R^2 values, it can be concluded that for the entire group of volume, parking turnover has a strong influence on vehicle delay. The higher the parking turnover, the higher the additional travel time of the vehicles approaching the parking area. At low volume, this condition is not quite sensitive, but as the volume increased the contribution of parking activity to increase the travel time becomes more significant. The delay change indicates it as the parking turnover changed from 0 to 1:

- For group 2: delay changed at 8.35%
- For Group 3: delay changed at 16.31%
- For Group 4: delay changed at 41.62%
- For Group 5: delay changed at 68.02%

For all groups of volume, as the parking turnover is zero, i.e. a condition in which there are no flow-in and flow-out vehicles at the parking area (where the parking volume is not always zero), the delay of through-traffic still occurs. It may occur since when a driver sees the road segment in front of him is occupied by parking vehicles, he may tend to move away from his lane and shift to the next lane while approaching the bottleneck (the initial point of parking area). Hence, such movement may mess up the traffic and affects the travel time of other vehicles.

The model shown in Fig. 5 could be used to see the borderline at which the authority is allowed to prohibit the parking operation. It can be done simply by defining the maximum allowable percentage of delay. Then by using the observed maximum volume of the segment, we can find the maximum parking turnover allowed. This number could be used to justify the parking prohibition policy. Using this number, the effect or contribution of parking to the traffic jam could be justified more accurately.

As the local authority only takes into account the land use type or vehicle dimension without considering the parking characteristics before the application of parking prohibition, the regulation may not be successful in practice. For example, one wholesale business district has a low parking turn over, while the other is a retail business district whose parking turnover is quite high. Both districts have similar characteristics of traffic flow. When the parking regulation only considers their types of land use (as a business district) and the traffic flow, regardless of their parking turn over, both districts may be treated as on-street parking prohibition areas. In contrast, as their parking turnover is different, they may result in different disturbances on through-traffic indeed.

4. CONCLUSIONS

For the area under consideration, e.g. 2 lanes one direction road with parallel on-street parking in the business district, there is a reasonably strong relationship between parking turnover and the delay of through traffic flow that move toward to the parking location, and the volume of the through-traffic also affects such relationship. The higher the volume and the parking turnover, the higher the delay will be. At low volumes, the relationship is less sensitive, while as the traffic volume increased the impact of parking to the delay becomes greater.

Local authority can take advantage of the model that relates the parking turn over and the delay as a guideline in performing parking prohibition policy. Having the relationship, the local authority can decide when the parking prohibition should be performed. In this case, the decision considers the combination of characteristics of both parking and through-traffic flow rather than the parking characteristics as a single determinant. Due to the limited space for movement and parking, especially in the downtown area, all road users compete for the space. Hence, the local authority needs rigorous exercise before the implementation of parking regulation.

As a preliminary study, the proposed model still needs further improvement on model calibration by using more data, as well as its validation.

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