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COLLEGE OF ENGINEERING

CHARACTERISTICS OF PARALLEL ON-STREET PARKING IN QATAR

BY

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Masters of Science in Civil Engineering

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ABSTRACT

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Master of Science in Civil Engineering

Title: Characteristics of Parallel On-Street Parking in Qatar

Supervisor of Thesis: Dr. Khaled Salah. Shaaban.

One of the main reasons for traffic congestion is the existence of on-street parking on the side of the road. The purpose of this study is to identify the impact of parallel on-street parking on the traffic flow movement in Qatar using data collected at two locations with a different number of through lanes in the city of Doha. Several variables were measured including the required time to complete the entering and leaving parking maneuvers, the queues and delay that occur on the road due to the parking maneuvers, and the gap needed to join the traffic stream after leaving the parking space. The results of this study showed that the presence of parallel on-street parking causes a high delay for the through vehicles. This delay is mainly caused by the formed queue due to the in and out maneuvers of the on-street parking vehicles. The results also show that the maneuvering time increases as the parking occupancy level increases. Furthermore, the delay measured with higher for the four-lane divided road compared to the six-lane road.

Keywords: On-Street parking, parking maneuvering, gap acceptance, queue length, travel time, travel speed.

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Chapter 1 Introduction

Traffic congestion in urban areas has been increasing recently in a noticed way, which leads to categorizing this issue as a global situation. At the local scale, the city of Doha has been suffering recently from the traffic congestion due to the unexpected growth in population because of hosting World Cup 2022 in the State of Qatar. Many traffic elements can be studied and improved to reduce this congestion. The present of on-street parking in urban roads can be one of the factors in increasing the congestion and reducing the road capacity. Based on that, the impact of legal parallel on-street parking on traffic flow will be studied and focused on.

The required time to complete each parking maneuver (entering & leaving) should be measured and considered regarding the impact of on-street parking on traffic flow, where the required time in each parking maneuvering movement can't be the same all the time. This duration can vary between each parking maneuvers based on the parking occupancy level and maneuvering patterns. Therefore, the relationship between the parking maneuvering movement's duration and parking occupancy level will be investigated under different parking maneuvering patterns.

Parking maneuvering movement event was introduced as a short/long process. Such an event can cause an impact on driver's reaction and end up forming a temporary queue at some points. However, the formed queue can be a serious cause of unnecessary delay in moving vehicles. The queue length can vary from one pattern to another based on parking maneuver duration. Thus, the queue length will be measured in each parking maneuvering movement to derive a relationship between maneuvering duration and queue length.

Once maneuvering time and the queue length are measured, the unnecessary delay caused by on-street parking will be calculated. Such delay can be determined by knowing the actual travel time for through moving vehicles in the study area and comparing it with the ideal travel time. Measured delay value would vary between vehicles based on parking occupancy level. Knowing such value will give a clear indication of on-street parking impact on vehicles travel time.

The interaction between traffic flow and on-street parking is an important feature in road design. Thus, studying merging behavior from/to on-street parking will clearly affect in reducing the possibility of forming queues. However, a little obvious consideration has been given in studying the procedure of gap acceptance at on-street parking. So, rejected gap and gap acceptance will be measured in each leaving parking maneuvers, to determine a critical gap value that a driver would need to leave the parking lot to identify the behavior of the drivers. The study was done at two various locations in the city of Doha. Two different roads with a different number of lanes were used, to study the impact of the number of lanes on the traffic flow.

The objective of this research is to investigate the characteristics of parallel on-street parking in the city of Doha, Qatar. Different characteristics including the parking maneuvering movements and gap acceptance were studied. Furthermore, the impact of parallel on-street parking on average travel time, average travel speed, and average delay time on the adjacent movements was investigated.

Chapter 2 Literature Review

2.1. Maneuvering Movement Characteristics

In Sydney, Australia, a study has been done to provide an additional explanation of the traffic congestion that resulting from on-street parking and the related influences on the road capacity. A pilot a survey was done to measure the required time to complete parking maneuvers and the caused delay at Sydney road networks. Three different parking maneuvering patterns (Figure 1) were defined and measured during the survey in seconds. The statistical examination was done and relationship charts were derived measuring the influence of the parking maneuvers. A clear reduction in road capacity was noted when the time restriction of an on-street parking area is short. As a result, a reduction factor was suggested to be determined and use in road capacity estimations at the design stage, whenever on-street parking presented or required (Wijayaratna, 2015).

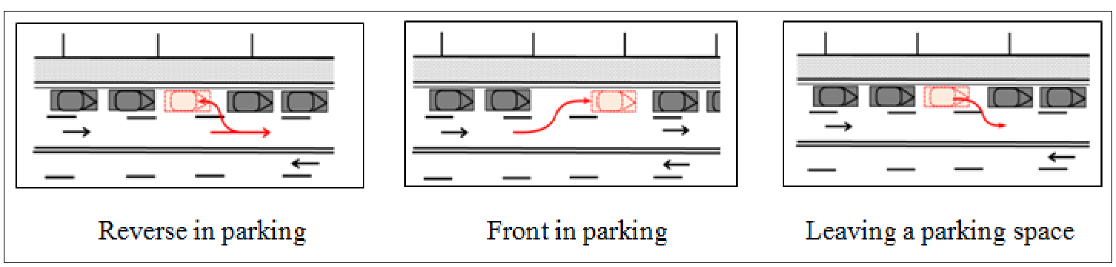


Figure 1, Parking Maneuvers Patterns (Wijayaratna, 2015)

In Manila, Philippine, most of the major streets are not properly designed to be having an on-street parking. A reduction in road capacity and an increase in traffic accidents were clearly noted. In this study, the authors try to understand the impacts of on-street parking to moving vehicles by integrating an equation measuring the impact of on-street parking on traffic flow. Characteristics of on-street parking maneuvers such as required time to maneuvers and number of maneuvered vehicles with parking patterns were studied. Parallel and angled 90-degree and 45-degree parking was studied at four different locations using10 hours of videotaping. The results showed that maneuvering movement duration varied between parallel, angled or perpendicular parking. In case of 45-degree parking, the maneuvering-out movement required 24.37 sec in average, while maneuvering-in movement required 21.94 sec, but the 90-degree parking required 18.04 sec in case of maneuvering-out movement and 25.2 sec in in case of maneuvering-in movement. For parallel on-street parking, maneuvering-in movement recorded 20.27 sec in average and 10.61 sec for maneuvering-out movement. Maneuvers movements that contain reverse movement requested more time than other movements (Lim, Hallare, & Briones, 2012).

In Cantabria, Spain in 2009, a study was published about doing a micro-simulation model in order to drive the relationship between the on-street parking maneuvers and the traffic flow. The study aimed to calculate the reduction in road capacity that caused by on-street parking maneuvers. Data such as maneuvering time, counts and velocity were collected from the technical department of Santander City Council in Spain and by using video cameras. The results showed that road capacity reduced by 6, 10 and 16% and the travel time increased by 15, 24 and 39% due the parking maneuvering movement (Portilla, Oreña, Berodia, & Díaz, 2009).

Different characteristics of entering and leaving parking maneuvering movement at on-street parking were studied and analyzed in Manchester, United Kingdom. The study focused on understands the reason for traffic congestion and to define the maneuver movement impact on the road network. Two different types of on-street parking performance (legal and illegal) were observed at two sites. Legal on-street parking included parallel and 90-degree parking including different patterns, where the illegal parking means that the vehicle is not parked in the designed space. A comparison was done to identify which type of maneuvering will be having the higher impact on the traffic capacity. The comparison was done by measuring the required time to complete each maneuvering movement. After seven hours of video recording, a detailed analysis was done back in the office such as parking types, patterns and times, where the time is usually impacted by the maneuvering patterns. The study ended up with the following: First, illegal parking maneuver required less time than the legal parking maneuver. Second, in case of reverse movement, angel on-street parking has more potential to cause delay for traffic than parallel on-street. Third, in case of entering parking maneuvers, parallel on-street parking has more potential to create delay than angled parking. Fourth, all maneuvers patterns which include reverse movement required a longer time than entering maneuvers. Therefore, maneuvers movement must be avoided by doing some changes to the on-street parking design. This can be done by replacing the angle parking and parallel space can be used instead (Yousif & Purnawan, 1999).

A study in Manchester, UK investigated the characteristics of vehicle on-street parking maneuvers. Data were collected by video recording from two sites with a different layout of on-street parking. Different patterns of maneuvering were categorized in entering and leaving parking space. The results point to that reverse parking required longer maneuvering times. Reversing movement is always required in case of angle parking to complete the maneuvering in and out movement. This is undesirable movement, especially while the road is operating at high levels of service. Recommendations were made for the design of on-street parking should be depending on traffic conditions and vehicle configuration (Yousif S. & Purnawan, 1999).

In 2004, a study was done in the United Kingdom, three sites were selected and studied in order to report findings based on observations of angle 45-degree and 90-degree and parallel parking layouts. Maneuvering movement length for entering and leaving vehicles was one of the main parameters that took into consideration. All vehicle movement was recorded by video cameras. Results displayed that on-street parking layouts design intensely affects drivers' maneuvering performance, where leaving movement requested higher time that entering movement for all cases. Such behaviors are unwanted, as they possibly will be an influential cause of delays in traffic flow and can be considered as dangerous behavior. Design of on-street parking stalls was recommended to be based on the local condition of the road and angle parking 45-degree and 90-degree was recommended to be avoided as much as possible regarding on-street parking (Yousif & Purnawan, 2004).

In a study was done by Purnawan in Indonesia, presenting the impact of on-street parking stall design on traffic performance because of the interactions with maneuvering vehicles. A microscopic simulation model has been developed to examine the study idea. The model showed that parallel on-street parking will create severe traffic interruption comparing with other kind parking stall designs. Observations at on-street parking areas presented that maneuvers parking and un-parking movement might create severe traffic interruptions and potential accidents if parking was not considered in the road design.

Driver maneuver pattern and time were also measured and categorized into two categories with and without reversing maneuvers. Parking maneuvering movements with reversing generally require a longer time to be completed than maneuvering without reversing. Generally, the result showed that as parking occupancy level increase, the average delay time may increase and it was concluded that parallel on-street parking has the worst impact on traffic flow (Purnawan, 2010).

A case study was done in Sydney in Australia in order to develop a mathematical model measuring the capacity adjustment factor which calculates the impact of on-street parking on road capacity. The study focused on the arterial roads of Sydney. The result aimed to improve the assessment of congestion in road networks. Six sites were selected and studied. Entering and leaving maneuvering movement's time and average turnover space were the main parameter in the equation. The case study presented a clear reduction in road capacity on arterial roads due to the existence of on-street parking. The application model can be useful in improving the traffic impact assessment for land use and congestion through road network (Wijayaratna, Sahan; Wijayaratna, Kasun P., 2015).

2.2. Queuing

In Zurich, a study was done to evaluate the impact of on-street parking on the traffic flow of nearby signalized intersection. The study focused on how forming a vehicles queue due to parking maneuvers can reduce the road capacity. The main idea of the study was to define the minimum distance between the parking lot and the intersection, so the parking maneuvers movements do not cause any unnecessary delay at the intersection. An analytical model was built to realize the effects of on-street parking maneuvers on the nearby intersections. Two indicators were selected to measure the effect of the on-street parking maneuver on the intersection: the capacity loss at the intersection, and traffic delay. The authors could end up with an equation showing the minimum length required for the on-street parking and the intersection. The results must apply worldwide to develop design guidelines for on-street parking areas with respect to the nearby signalized intersections. Furthermore, capacity loss and total delay in traffic flow caused by the parking maneuver should be measured (Cao, Menendez, & Vasileios, 2013).

Another study was done at Cantabria, Spain, measuring the effect of badly parked vehicles and on-street parking maneuvers on average journey times by applying an M/M/∞ (A model in which the arrivals and the departures have a Poisson's distribution, where every arrival experiences immediate services and does not wait) queuing model in entering and leaving process. The method has been confirmed using calibrated micro-simulation models. The delay analysis showed a good fit in M/M/∞ model where the error was lower than 5% compared to the micro-simulation models. This proves the effectiveness of the M/M/∞ model for studying the on-street parking maneuvers and badly parked vehicles impact on traffic flow. Several models were run for several times, which showed that road capacity reduced by 6, 10, and 16% and the travel time increased by 15, 24, and 29% as the frequencies (maneuvers/hour) increased 10, 20, and 30.The results showed that increase in average trip time for the head user effect on the rest of the following road users leading to queue forming causing an extra delay (Portilla, Oreña, Berodia, & Díaz, 2009).

2.3. Travel Time, Speed and Delay

In Washington, DC, a project was conducted to measure the efficiency of current rush hour parking restrictions and assess the effects of any improving measures. The project was implemented in two major corridors. The restriction times considered in the study were the morning peak and evening peak. Models were developed for four different scenarios (Table **1**) using Synchro simulation tool. The corridor level of service (LOS) was used to measure the mobility of the corridors. Few main outcomes were presented from the study. First, it indicated that the existing parking restrictions can improve the mobility on the road especially if the signal was optimized, but not necessarily represent the actual traffic condition. Secondly, establishing restrictions on traffic demand is an essential only if the mobility is measured; nevertheless, features like parking availability, parking demand, and land use should be considered. Third, traffic signal optimization can significantly improve the mobility issues (Elahi, Steverson, Dey, Dock, & Green, 2016).

Table 1, Used Scenarios-Washington DC Case Study (Elahi, Steverson, Dey, Dock, & Green, 2016

Scenario	Parking Condition	Signal Timing	Geometric
1	Allowed	As-is	As-is
2	Restricted	As-is	As-is
3	Allowed	Optimized	As-is
4	Restricted	Optimized	As-is

In Metropolitan Manila in Philippine, a study was done to evaluate the impact of the existence of on-street parking on traffic flow. Travel time for through moving vehicles was measured in three different parking types, parallel, perpendicular, and angled parking. The author here aimed to end up with an equation model that can assist in improving the traffic flow whenever on-street parking is allowed. The model estimates the average travel time in case of free flow and the expected delay due to the existence of on-street parking. Traffic flow speed results showed that the existence of on-street parking extends the travel time for through moving vehicles, whether it was parallel, angled or perpendicular parking, but in various percentage. It was found that each studied parking (angel, parallel and perpendicular) recorded an average travel consumed time to be 35, 20.5 and 15 sec respectively. Based on the results the impact of angled parking had the highest delaying value in traffic flow, where the perpendicular parking recorded the lowest which make such parking more recommended to be used than others (Lim, Hallare, & Briones, 2012).

A study was conducted in the US, aimed to evaluate the impact of relocating the on-street parking to off-street parking on the mobility. A traffic simulation model (VISSIM) software was used to evaluate the before and after cases. Traffic volumes were collected by using a video camera and manually. The results showed that the relocating of the parking will reduce the average travel time and delay by reducing the number vehicle searching for on front door parking. The average travel time reduced from 20.8 min. to be 19.7 min (Ryan Fries, 2010).

A study was done in New-Zealand to determine the impact of on-street parking existence on traffic flow by driving a relation between the travel speed and the parking demand level. Parking demand levels were calculated based on the availability of space at parking lots. As an example, parking level is 75% if three-quarter of the parking spaces are available. Ten roads of three different widths 8, 10 and 13 m were chosen. For data collection, speed gun and speed tube surveys were used to collect the data. The result showed average travel speed of traffic flow decrease as the parking level increase (Figure

2). The impact was increasing as the road width decrease. For any future research, the authors proposed to increase in the locations and execute a survey for more parking occupancy levels at the same sites (Praburam & Koorey, 2015).

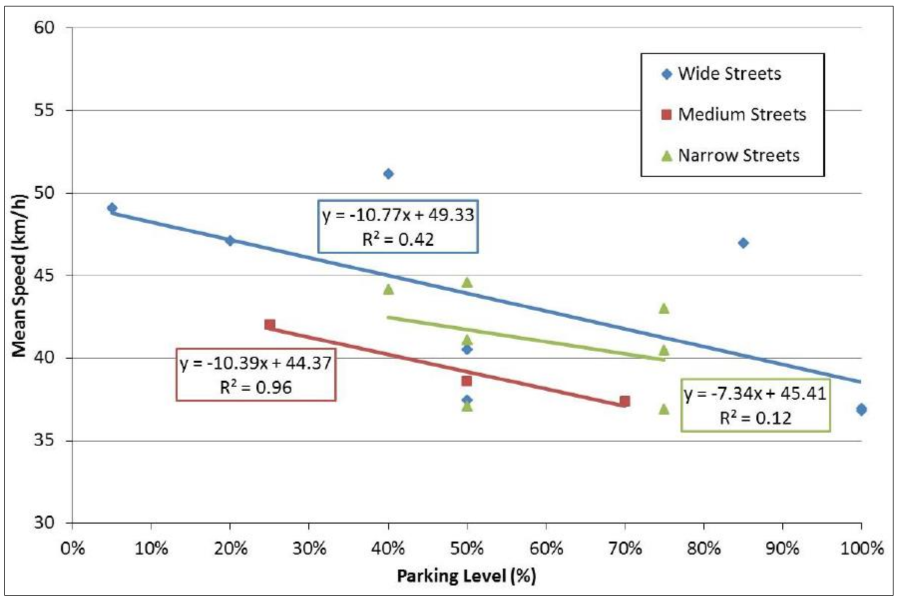


Figure 2, Variation of Mean Speeds Across Different Parking Levels (Praburam & Koorey, 2015)

A study in England was conducted to develop a better explanation to on-street parking by measuring average vehicle speeds and levels of crash severity. On-street parking should be only used at locations where the road is part of the destination and the intent is to slow down the drivers. The impact of on-street parking on average vehicle speed was studied at over 250 roadway segments. On-street parking was measured at three various levels of parking occupancy: 50 - 100%, 30 - 50% and less than 30%. The results showed that 50 - 100% & 30 - 50% levels have a numerical difference at free-flow speeds, while values under 30% occupancy of on-street parking found to be not significantly affecting the free flow speeds (Marshall, Garrick, & Hansen, 2008).

In China, a study investigated the effect of on-street parking occupancy level on the performance of traffic and safety. The author here tried to give a numerical analysis of this kind of effect. All travel time data were collected by two observers manually from seven segments on four streets. All segments were having the same width and length. The results displayed that the lane width, number of parking maneuvers and on-street parking occupancy level have a major influence on the travel time. For any future work, an investigation with more datasets is mandatory and it is required to derive the relation between delay and the influence of on-street parking (Guo, Gao, Yang, Zhao, & Wang, 2012).

In Australia, a driving simulator was used to examine the impact of on-street parking on driver performance. This study included three parking levels (none bays, empty bays, and full bays). The driver's behaviors were studied in the three levels whither were no action, slowing down or shifting their side position to roadway center away from the on-street parking. Twenty-nine members drove a simulated urban and arterial route. Four scenarios were covered: arterial with no parking, urban with no parking, urban with empty parking and urban with full parking. As per Figure 3, the results showed a significant difference in traveling speed between the arterial road with no parking and urban road with full parking, where the travel speed was decreasing as parking level increase. The other two conditions (urban with no parking and empty bays) were not significantly different from each other (Edquist, Rudin-Brown, & Lenné, 2012).

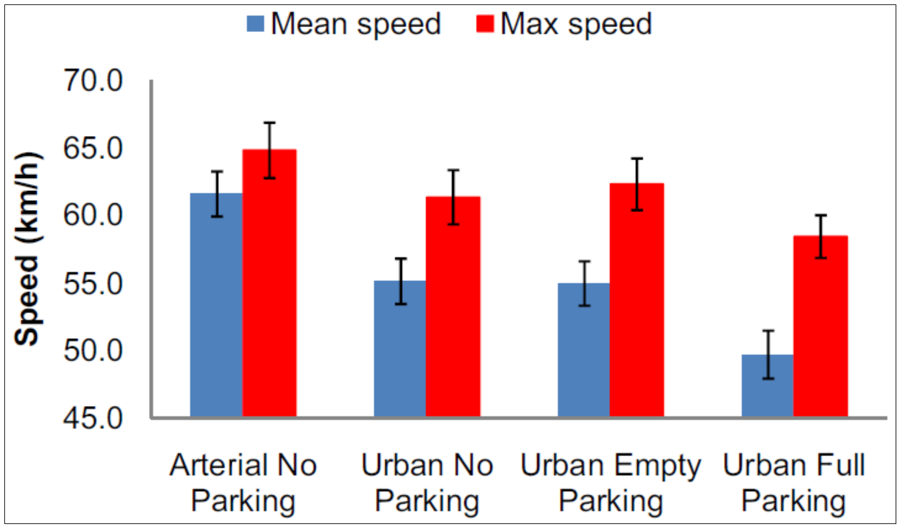
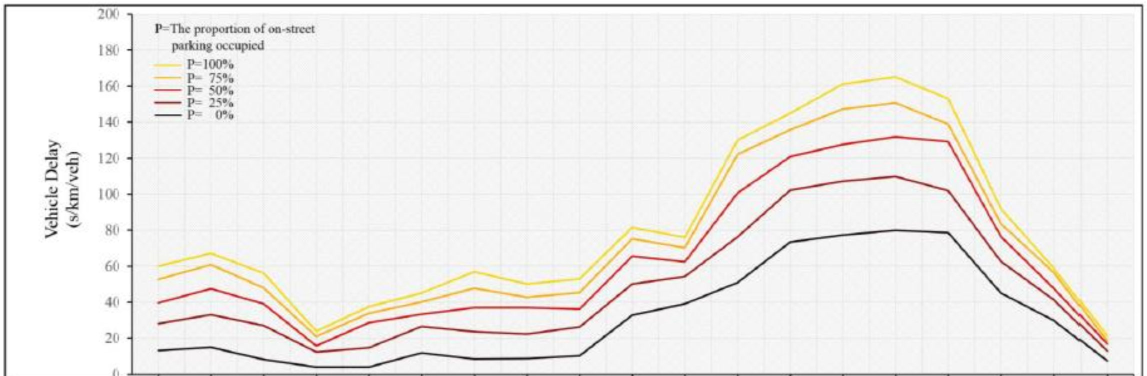


Figure 3, Mean and Maximum Speed by Road Environment and Parking Condition .
(Edquist, Rudin-Brown, & Lenné, 2012)

In a study was done in Cantabria-Spain, the impact of on-street parking maneuvering movement on the average travel time was measured. M/M/α queuing model was used (A model in which the arrivals and the departures have a Poisson's distribution, where every arrival experiences immediate services and does not wait.). Average travel time values were used to finalize the evaluation process. The results showed that an increase in the average travel time varies between 15, 24 and 39% from the ideal travel time for the head user, which effect on the following drivers leading to queue forming and causing an extra delay (Portilla, Oreña, Berodia, & Díaz, 2009).

In 2015 a study was done evaluating the impact of on-street parking on vehicle delay on urban roads. The data were collected from six different locations in Nanjing in China. Data was collected by video recording at peak and non-peak periods to obtain various traffic situations. The influence of on-street parking on moving traffic was clear, where the vehicles had to reduce the traveling speed to avoid any potential conflicts, resulting in an increasing in travel time and extreme travel delay for traffic flow (Figure 4). It was recommended to design the on-street parking based on its location and the surrounding land use. Plus, the city planner should always consider both on/off street parking in the area (Chen, Li, Jiang, Zhu, Wang, & Chen, 2015).



Time	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30
Vehicle Volume (veh/h)	393	363	335	217	177	261	354	343	253	269	482	587	652	714	698	683	484	304	224
Bicycle Volume (bic/h)	623	693	508	414	462	854	508	600	647	969	763	887	1237	1546	1670	1237	928	722	485

Figure 4, Case study of Vehicle Delays in Respect of Parking Occupancy Level (Chen, Li, Jiang, Zhu, Wang, & Chen, 2015)

The impact of on-street parking on traffic congestion was examined in Lokoja City in Nigeria. A field survey was to collect the required data from the study location. Improper management of parking spaces forced the driver to park along the road such as public transport operators for uploading or offloading goods and passengers (illegal parking). This act has created the problem of road congestion in the study area as the majority of the drivers exposed that delay. This delay was measured by measuring the travel time of moving vehicles, where it was found that such parking could cause an average traffic delay varies between 10 to 30 min. Several recommendations were stated such as; first, traffic rules and regulations should be instituted to provide a proper parking management. Second, minimize the number of on-street parking at narrow roads (Oluwaseyi, Adebola, Edwin, Eno, & Stephen, 2014).

An application of microscopic simulation model has been developed to report the impact of on-street parking on the performance of the traffic flow due to the existence of on-street parking in Indonesia. Four parking types were used (parallel parking with marking stalls, parallel parking with no marking stalls, angle parking stall of 45° and angle parking stall of 90°). The parameter of average speed, average delay, and parking occupancy level were measured and used in generating the model. It was showed that an increase in traffic flow leads to increase in parking occupancy level (Figure 5), decreasing in the average spot (Figure 6). Such increase in speed leads to create an unnecessary delay at certain times (Figure 7) (Purnawan, 2010).

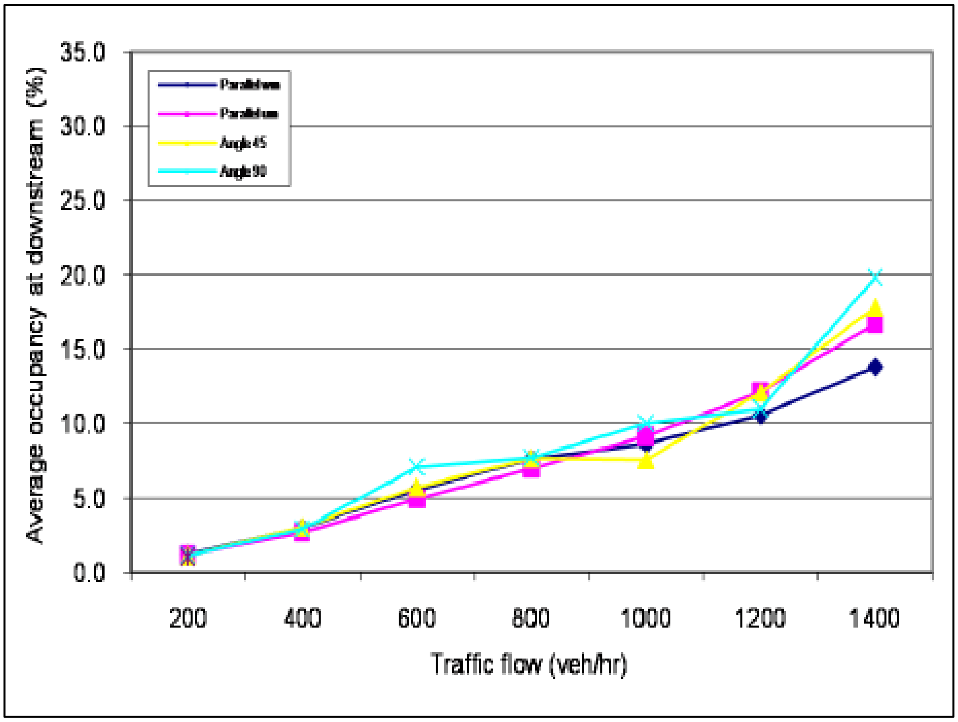


Figure 5, the Average Occupancy at Downstream Parking Areas for Different Parking Stall Designs (Purnawan, 2010)

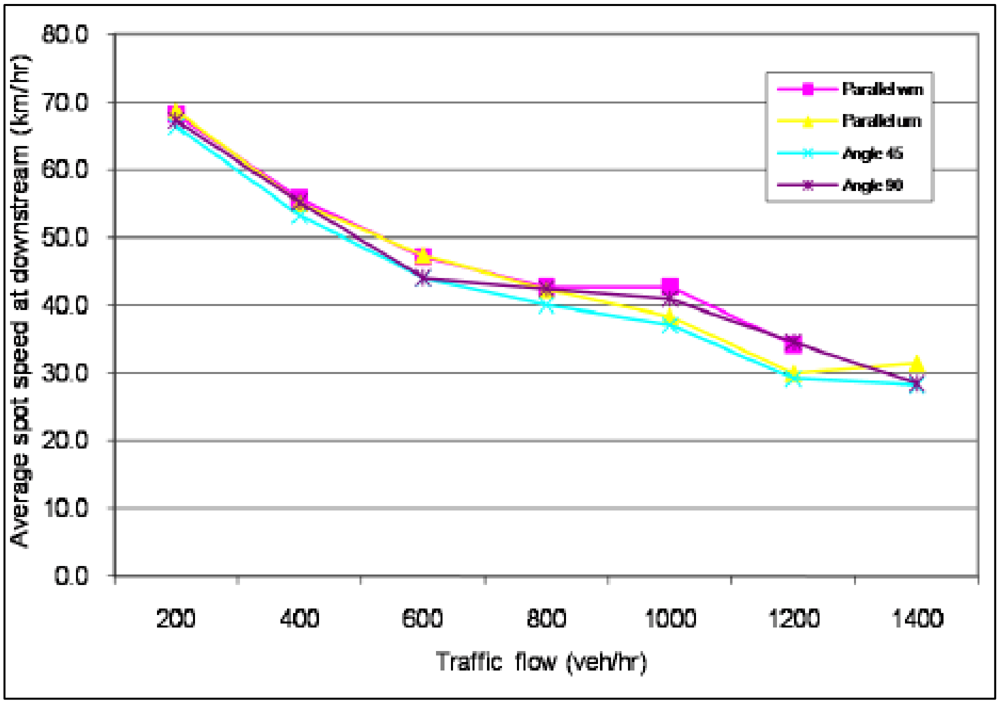


Figure 6, the Average Spot Speed at Downstream Parking Areas for Different Parking Stall Designs (Purnawan, 2010)

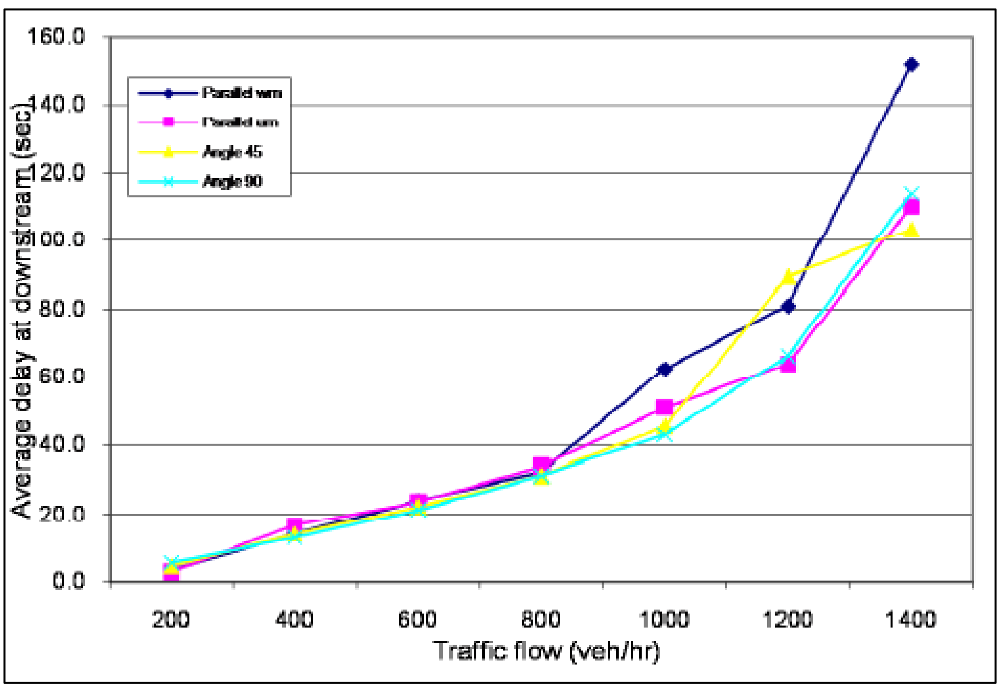


Figure 7, the Average Delay at Downstream Parking Areas for Different Parking Stall Designs (Purnawan, 2010)

Naseri worked in estimating the average delay time that caused due to the presence of on-street parking in Tehran-Iran. Different parameters were included in the study such as speed, delay, flow rate and capacity. Four general groups of roadways were studied: highways, residential arterials, business arterials and local streets. The study was done at four various levels of parking level 25, 50, 75 and 100, where all data were collected by video cameras. The observation of the study showed that increase in the parking occupancy percentage leads to increasing in the delay time as *Figure **8*** and decreasing in the flow rate as shown in *Figure **9*** which will cause a reduction in the capacity of the road (Naseri, 2013).

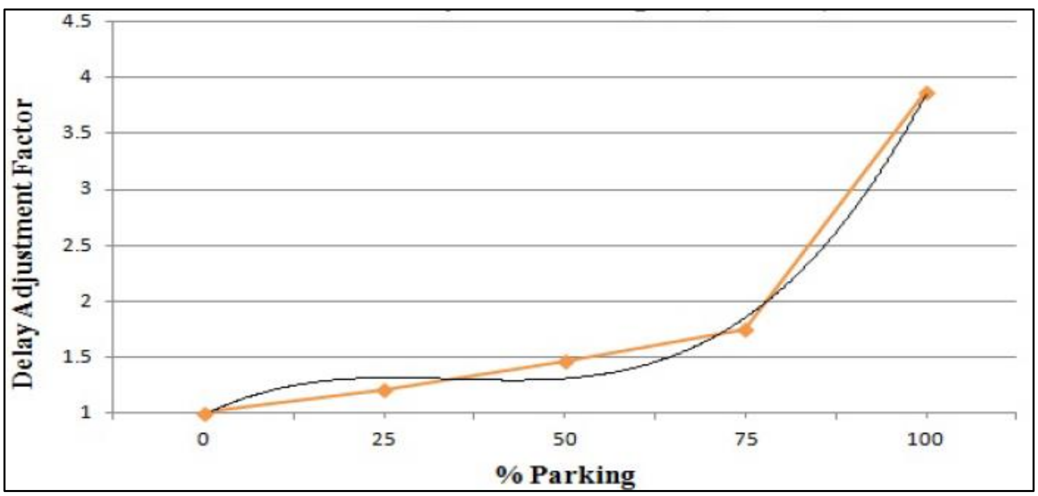


Figure 8, Influence Coefficient of On-Street Parking on Average Flow Delay in Business Arterial (Naseri, 2013)

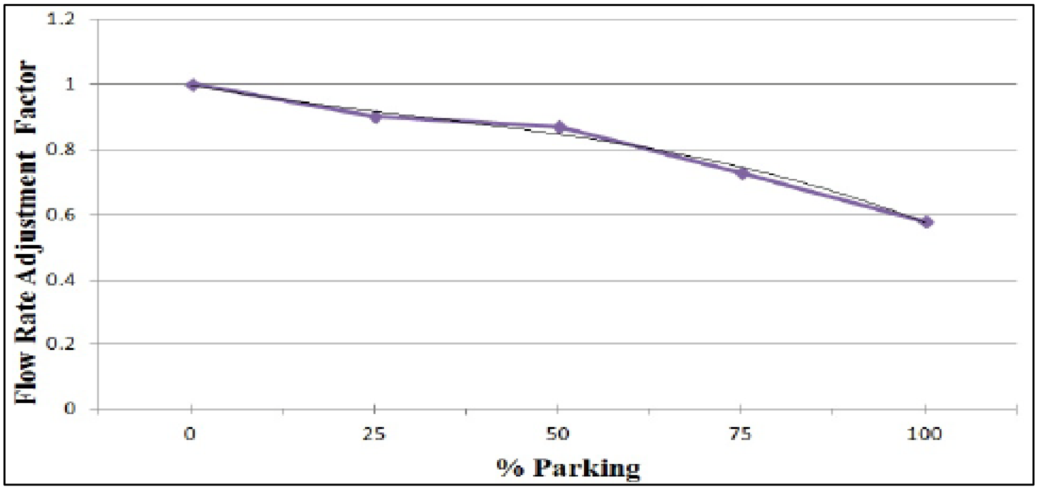


Figure 9, Influence Coefficient of On-Street Parking, Maximum Flow Density on Business Arterial (Naseri, 2013)

2.4. Gap Acceptance

Merging procedure from (parallel/angle) on-street parking stall was investigated at two sites in Manchester-UK. The driver's accepted sufficient gap for joining the traffic flow was measured. The gap acceptance values are intensely affected by the design of the on-street parking space. Increasing in the parking stall angle will lead to increase in gap values. Over the gap choice procedure, the driver will associate the calculated driver accepted gap with traffic lag. If a driver decides to accept a gap less than the critical gap, the critical gap value then is used as the driver accepted gap. The result showed that angle on-street parking has quite higher accepted gaps than that of parallel on-street parking. The value of average accepted gap was 10.1 sec in case of parallel parking and 11.1 sec for angle parking. By knowing the accepted and rejected gap values, the critical gap values were identified as 7.4 sec for the parallel case and 9.2 sec for the angled case. It was proven that the accepted gaps are not subjective by the vehicle approaching speeds by the cumulative frequency of traffic flow. Finally, there is a possibility of generating traffic congestion caused by forced merging from on-street parking especially at high traffic flow (Purnawan, 2000).

In another study in the UK, four different parking types were selected (parallel, angle 45 and angle) to be studied at three selected sites. Observations from a selection sites display different distributions of mean gap acceptance depending mainly on the design layout of parking space the studies have been done by using videotaping systems where each site was recorded almost for 6 hours; a total of 30 hours of recording was obtainable for analysis. The accepted gaps were measured once the vehicle starts moving to merge with traffic stream. In the study, the recorded average gap values were 8.3, 13.2 and 12.3 sec respectively for parallel, angle 45, and angle parking. The results showed that the mean accepted gaps in angle parking are higher than that in case of parallel parking (Purnawan; Yousif, 2000).

In a study in Indonesia, leaving and entering maneuvers and gap acceptance were investigated to develop a microscopic simulation model. Two types of gap acceptance have been included. First, gap acceptance for the un-parking process was conducted. Second, gap acceptance when crossing adjacent lane when maneuvering in and out processes were preceded. The model was established generally to simulate the intersection between entering and leaving maneuvers and traffic flow (Purnawan, 2010).

Several studies have investigated the characteristics of on-street parallel parking. However, there have been no studies conducted in the Arabian Gulf region. This study aims to understand the behavior of the drivers and characteristics of the parking maneuvers in this region.

Chapter 3 Data Collection

3.1. Studied Locations

In this study, data have been collected from two various locations in Doha-Qatar. Figure 10 is showing an aerial photo of the selected study locations, where Figure 11 and Figure 12 are representing the camera locations for both sites. Figure 13 and Figure 14 show the cross sections of the study locations. Both locations were chosen in busy areas, where both roads serving restaurants and retail with 80km/hr. posted speed. Figure 15 and Figure 16 show the ADT for both locations. The studied segment length was 100 m for both locations. The studied parking areas were undivided, so the assumed dimension of each parking was 6 m in length and 2.5 m in width as per (Qatar Highway Design Manual-QHDM) (MOTC, 2015) to end up with almost 16 parallel on-street parking. The nearest intersection or driveway was almost 200 m away from the studied segments to make sure all vehicles are entering the segment at the road speed. Table **2** summarized all information's about both sites.

Table 2, Characteristics of the Study Locations

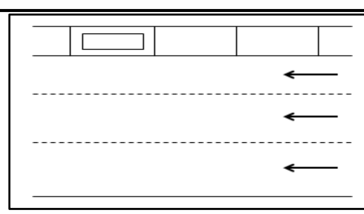
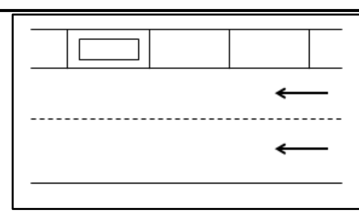
Parameters	First location	Second location
Layout location		
Road/Street	Al-Corniche St.	Ras Abu-Aboud St.
Number of through lanes	Three-lanes	Two-lanes
Direction of travel	One-way traffic	One-way traffic

Figure 10, Aerial Photo of the Selected Study Locations

Figure 11, Two-lane Location

Figure 12, Three-lane Location

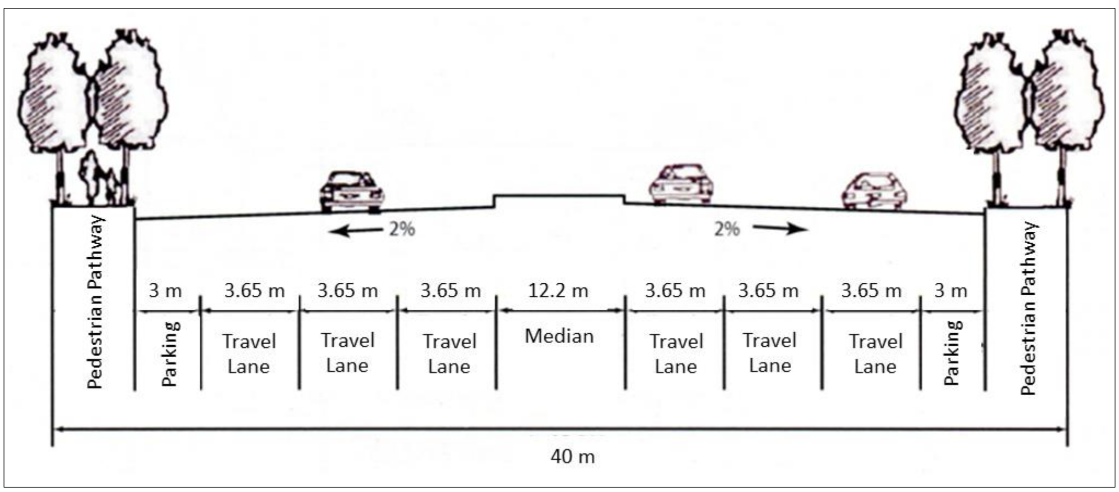


Figure 13, Three-lane Location Cross Section

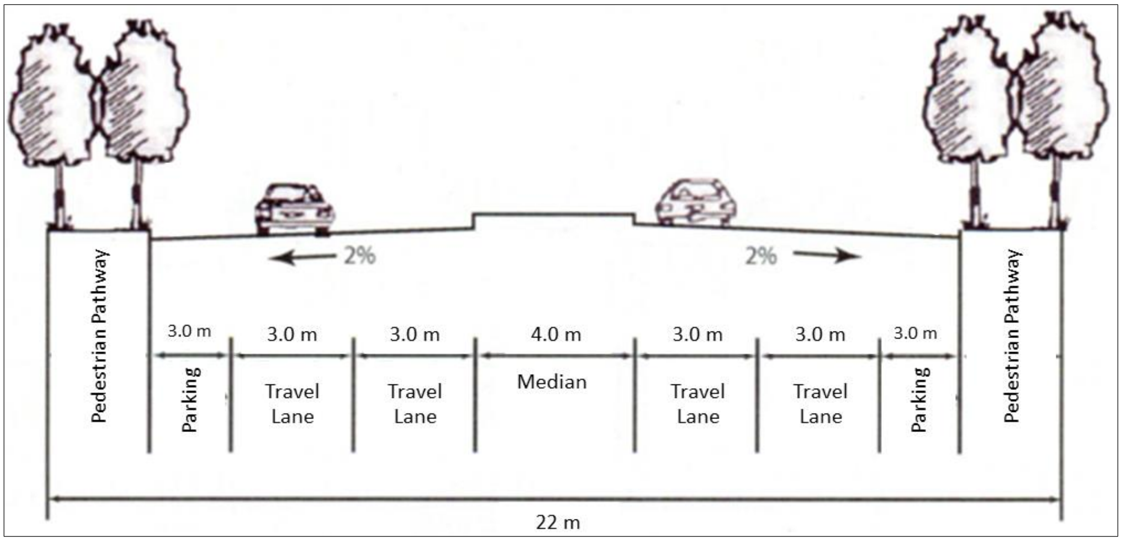


Figure 14, Two-lane Location Cross Section

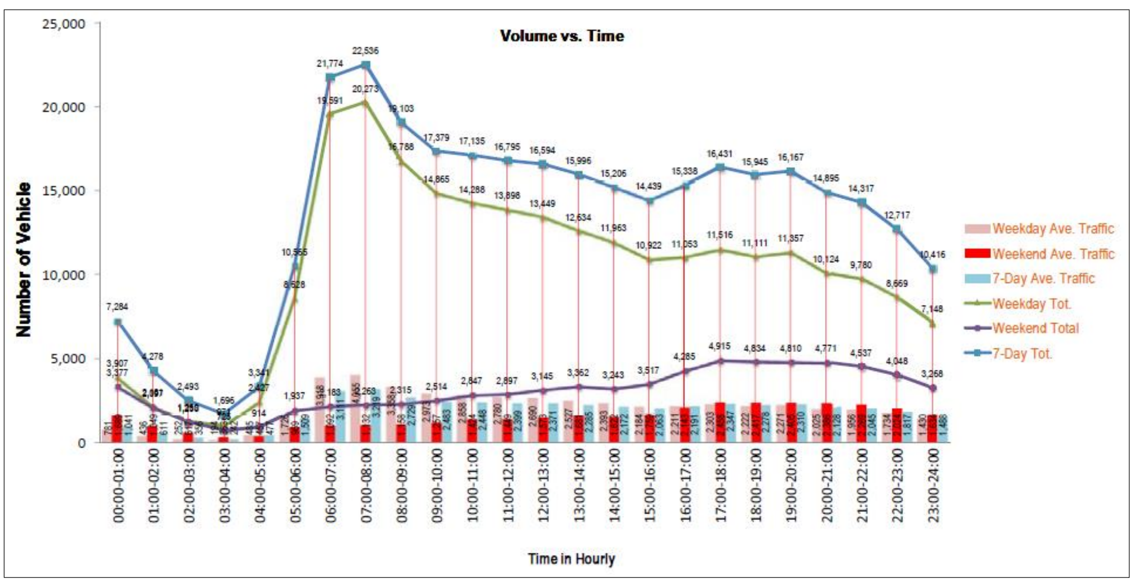


Figure 15, ADT for Three-lane Location

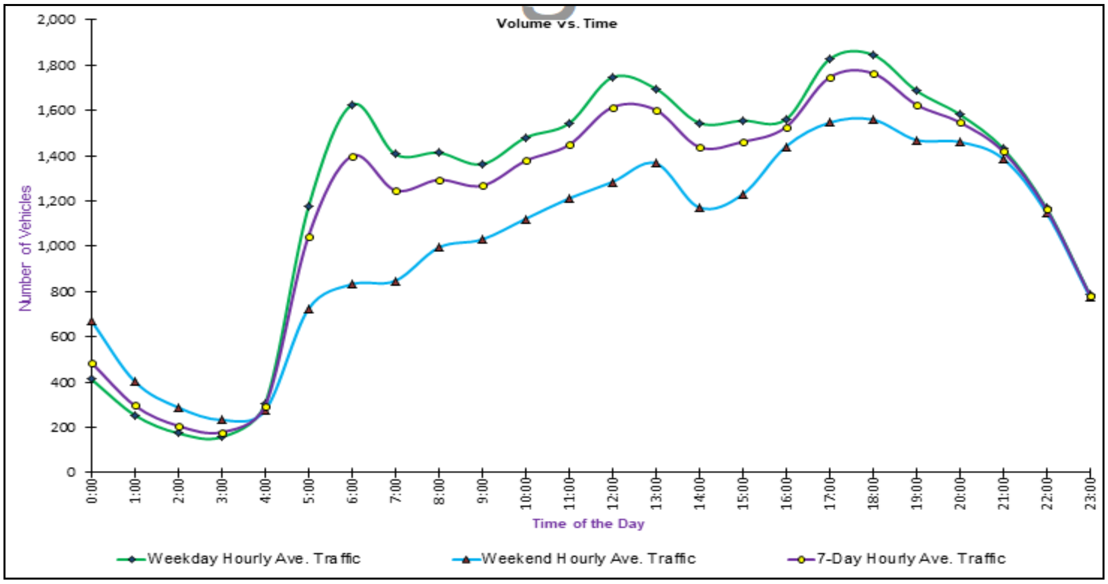


Figure 16, ADT for Two-lane Location

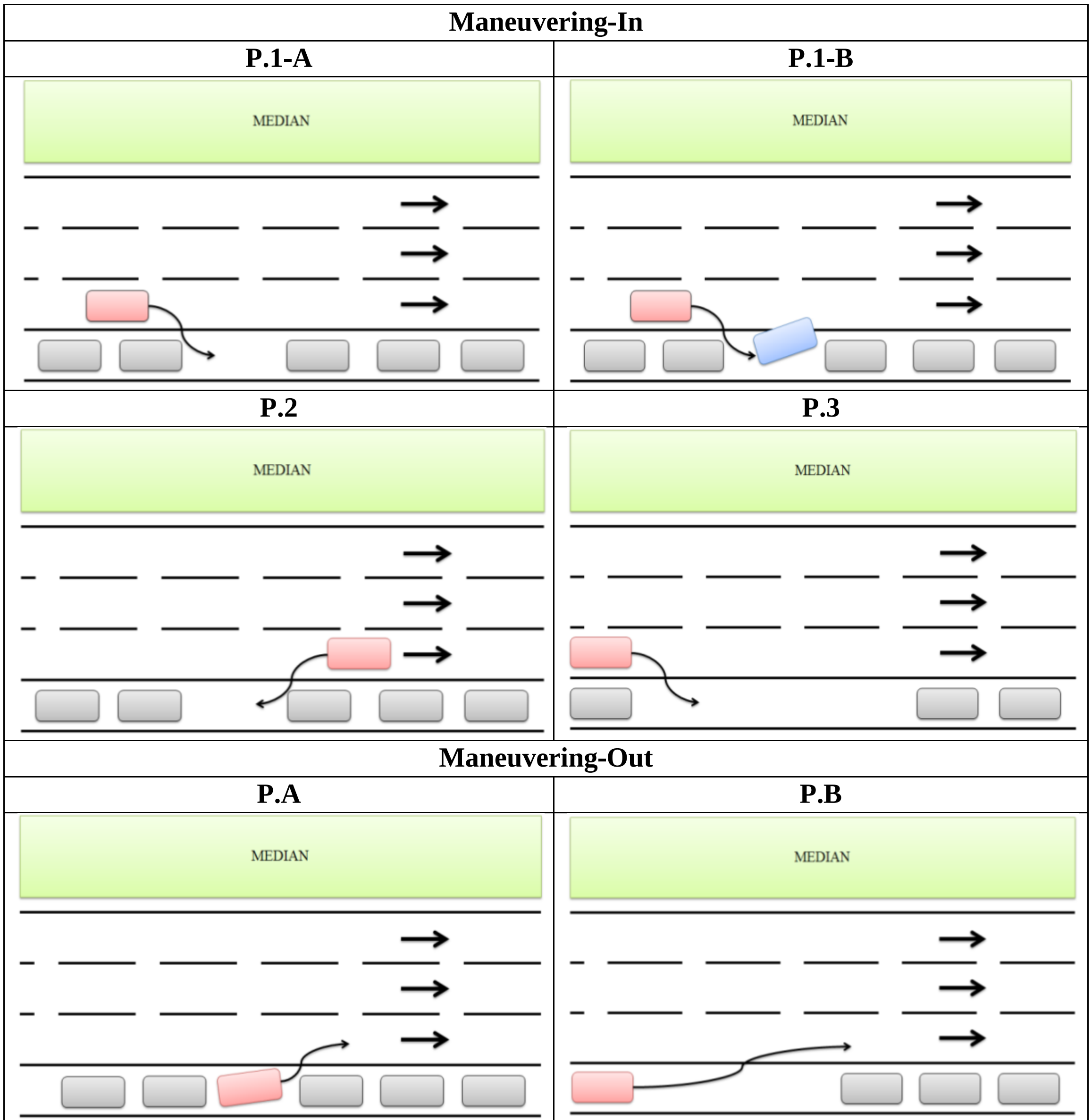
3.2. Collection Techniques

Several video cameras were installed in the study locations to capture the traffic and the maneuverability from different angles to provide a full vision of the trap length. The installed cameras were used to record the behavior of the passing and maneuvering vehicles at the studied segments. Table 3 shows the sites details and conditions regarding the recoding process for both locations. All kind of vehicles were counted and recorded in case of through movement except motorcycles in order to simplify the analysis process. In case of maneuvering movement, vehicles were counted and recorded as the following (Sedan, SUV, VAN, Pickup, Mini-truck, Medium-bus and Big-bus). The vehicles categorization aimed to identify the impact of vehicles type (size) on the traffic flow during the maneuvering movement.

Table 3, Studied Sites and Recording Process

Site Category	St. Name	Day	Timing	Studied Hours	Weather	No. of Cameras	Land Use
Three-Lane Site	Al-Corniche St.	Wed.	6 am - 12 am	18 hrs.	Clear	4	Park, commercial, and residential
Two-Lane Site	Ras Abu-Abbud St.	Wed.	6 am - 12 am	18 hrs.	Clear	3	Commercial and residential

Each entering and leaving maneuvering movement was categorized into different patterns as shown in Figure 17. Each pattern movement occurred at a certain percentage of parking occupancy level. Each Pattern movement required certain time to complete the parking maneuvering movement. Patterns classification provides the necessary assistance in classifying the impact degree of each pattern on traffic flow movement.



P.1-A : Front parking into an empty space between two parked vehicles.

P.1-B : In case of a parked vehicle is leaving and the maneuvering vehicle is waiting to park.

P.2 : Reverse parking to an empty space between to parked vehicles.

P.3 : Front parking into a parking space that almost empty with enough space to decelerate.

P.A : Leaving the parking lots from narrow space.

P.B : Leaving the parking lots with enough space to accelerate.

Note. Drivers may have two patterns if they fail to park using one pattern then they try another pattern. Such pattern is described as a combination (Ex., P.1-A failed then P.2 was completed).

Figure 17, Maneuvering Patterns

3.3. Definitions

Maneuvering-In Time: Measuring the time begins once the driver starts parking the vehicle or stopped totally and starts waiting a parked vehicle to leave the parking lots. This maneuvering movement finishes once the vehicle is totally in the parking space.

Maneuvering-Out Time: Maneuvering-out timing is the sum of three different timings (preparation time, waiting time, and joining time)

> **Preparation Time:** It is the time the driver spends in preparing the vehicle to leave the parking lot since he starts moving the vehicle or just rotate the tire until the vehicle is stopped at the parking space limit waiting for the right gap to leave.
>
> **Waiting Time:** It is the time the driver spends in waiting for the right gap to leave the parking space and join the traffic flow. It is measured once the driver stops the front tire on the parking line until he starts moving the vehicle to join the flow.
>
> **Joining Time:** Measuring this time starts once the driver starts moving the vehicle to join the traffic flow until the vehicle is totally on the road.

Parking occupancy Level: Parking occupancy level is measured as a percentage of vehicles occupying the parking lots in the studied segment. (Equation 1) (Guo, Gao, Yang, Zhao, & Wang, 2012)

$$\boldsymbol{Occupancy}\,\% = \frac{\boldsymbol{Occupied\ Parkings}}{\boldsymbol{Total\ Spaces}} \times \mathbf{100}\ldots$$ *Equation 1 : Parking Occupancy Level (%)*

Queue Length: The length of the stopped vehicles that formed as a result of parking maneuver movement.

Average Travel Time: The time a vehicle spend to travel through the trap length starting when the vehicle back bumper enter the trap length until this vehicle is totally out (*Figure **18*** 18). This time was measured for traveling vehicles in each lane.

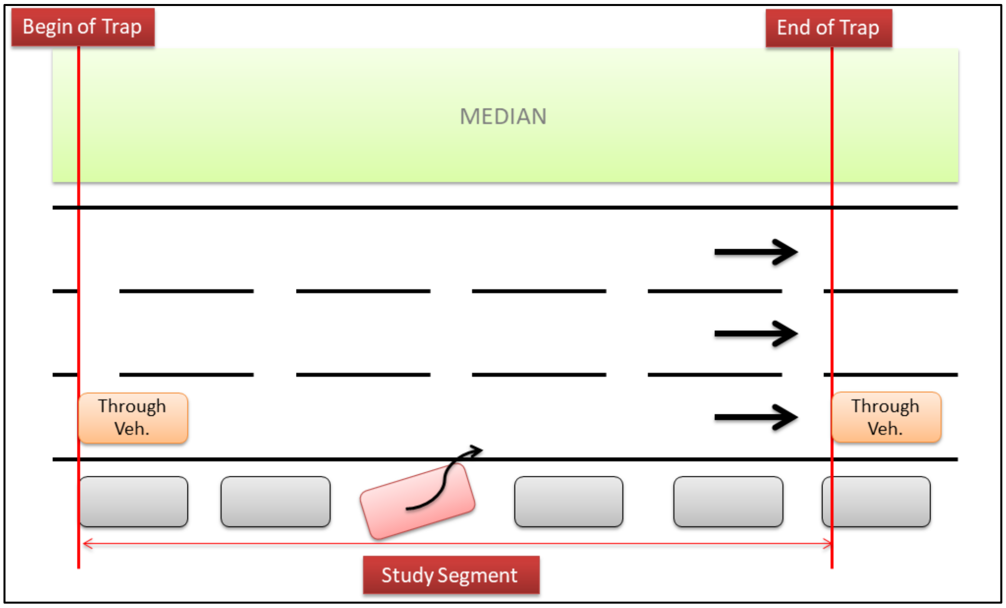


Figure 18, Travel Time Calculation

Average Speed: The Average speed of a vehicle traveling through the trap length.

Average Speed = Segment Length/Average Travel Time… *Equation 2 : Average Speed*

Average Delay Time: Subtract the vehicle travel time from the ideal time, where the ideal time equals 4.5 sec (Ideal Time is the required time to go through a distance of 100 m at 80km/hr.)

Average Delay Time =Ideal Time – Average Travel Time… *Equation 3 : Average Delay Time*

Gap Acceptance: Was measured as the time between two successive traveling vehicles in the traffic stream, when the parked vehicle starts leaving the parking space to merge into moving vehicles path as explained in Figure 19 (Yousif & Purnawan, 2004).

Rejected Gap: It was measured as the time between two successive traveling vehicles in the traffic stream when the parked vehicle rejects to leave the parking space and merge with the traffic stream as presented in Figure 20.

Critical Gap: is a parameter for capacity calculation of un-signalized intersections. Such parameter cannot be measured straight away from the field. Rejected gaps and accepted gaps of each though vehicle in the stream should be measured.

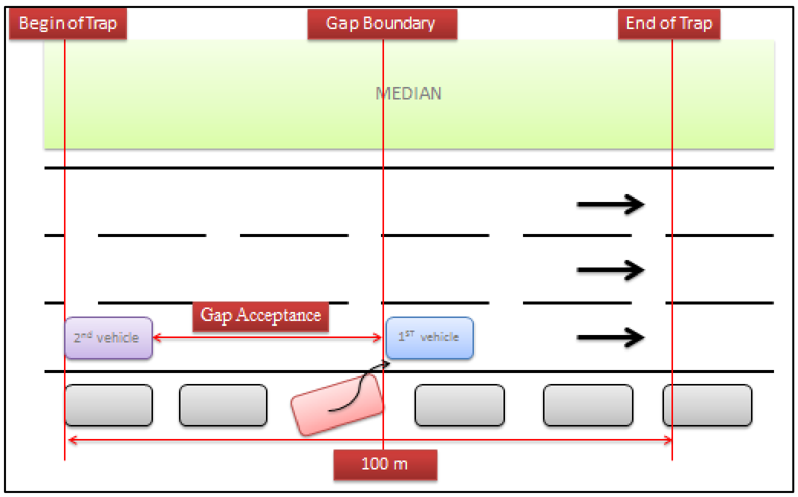


Figure 19, Gap Acceptance

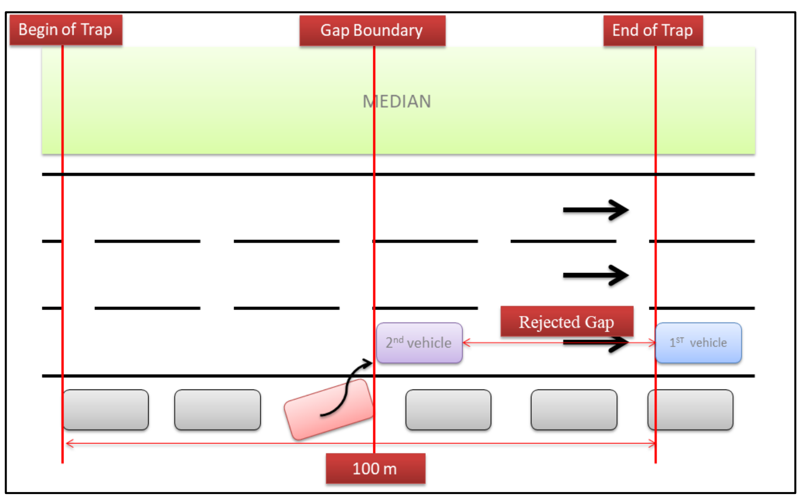


Figure 20, Rejected Gap

Chapter 4 Maneuvering Movement Characteristics

4.1. Background

The availability of on-street parking may well have an impact on the traffic flow at any road and end up causing congestion by parking maneuvering movement (Entering or Leaving). Such maneuvering movements are usually passed over by transportation engineers at the design stage of roads, which may lead to reducing the road capacity. Through understanding the impact of maneuvering movement on the moving vehicles, better measurement of the road capacity can be provided. In addition, it gives an indication of which area that parallel on-street parking should be allowable. Vehicle maneuvering movement in case of entering or leaving on-street parking can be a responsible cause of traffic congestion. In case of design a new road network or improvements of an existing network, such maneuvering movement must be considered to reduce its impact on traffic flow. In this chapter, the required time to complete each parking maneuvering movement (entering or leaving) has been measured and categorized by different patterns. The measurements were done at the different level of parking occupancy. The main idea of this chapter is to investigate the impact of parking occupancy level and vehicles type (size) on parking maneuvering movement length.

4.2. Methodology

The chapter focuses on measuring the actual time that vehicles need to complete parking maneuver wither was entering or leaving movement at parallel on-street parking. All maneuvering movements were categorized into different patterns based on the required time that the movement needs to be completed and based on the percentage of parking occupancy level. Drivers decide which pattern to use based on the availability of parking space. Consequently, the on-street parking occupancy level is studied to derive a relationship between parking occupancy and the maneuvering duration. Maneuvering vehicles were categorized in this chapter based on type in order to determine their impact on the maneuvering duration.

4.3. Results and Analysis

4.3.1. Entering Maneuver Movement

In the case of entering maneuver (Table 4), 171 maneuvering movement were recorded at the three-lane location and 107 movements at the two-lane location. Five different patterns were categorized as shown in (Figure 4). In the case of three-lane location, patterns P.1-B, P.2 and Combination have recorded the highest maneuvering time 22.5, 26.1 and 38.8 sec respectively, and 32.33, 17.47, and 36.67 sec respectively in case of the two-lane location. This can be explained as that, such patterns are occurring at high-level of parking occupancy, where the parking maneuvers are slightly hard and require more than one movement to be completed. On the other hand, patterns P.1-A and P.3 recorded less time to complete the maneuvers, 5.27 and 2.35 sec were recorded respectively in case of the three-lane location and 5.98 and 2.67 sec respectively in case of the two-lane location. Where such patterns occurred at the low or medium level of parking occupancy, so parking space is enough to complete the maneuver for the first time.

Table 4, Maneuvering-In Time Summary In Respect of Pattern Classification

Pattern Code	**Counts**	**Average Parking Occupancy %**	**Average Maneuvering-In Time (sec)**
		Three-lane Location	
P.1-A	45	74	5.27
P.1-B	6	86	22.50
P.2	17	79	26.10
P.3	93	40	2.35
Combinations	10	81	38.80
		Two-lane Location	
P.1-A	48	77	5.98
P.1-B	9	86	32.33
P.2	17	79	17.47
P.3	27	63	2.67
Combinations	6	80	36.67

Table 5 represents the occurred increasing in entering maneuvers duration as parking occupancy level increased regarding all patterns.

Table 5, Maneuvering-In Time In Respect of Parking Level

Parking Occupancy (%)	**Average Maneuvering-In Time (sec)**			
	Three-Lane Location	**Counts**	**Two-Lane Location**	**Counts**
0	2.00	2	*N/A*	0
6	2.20	5	*N/A*	0
12	2.17	6	*N/A*	0
18	2.14	14	*N/A*	0
24	2.60	5	*N/A*	0
30	2.00	6	*N/A*	0
36	2.33	9	*N/A*	0
42	2.17	6	2.00	2
48	3.20	10	2.60	5
54	5.50	6	3.43	7
60	3.56	16	4.00	7
66	3.62	13	8.00	8
72	9.05	19	10.55	11
78	13.50	24	9.23	35
84	23.81	16	13.92	12
90	21.06	11	18.17	18
96	13.00	2	46.50	2

Figure 21 represents the relation between the required time to complete the entering maneuver and the parking occupancy level regarding all patterns, where required time increases as the parking occupancy level increase at both locations. The impact of lanes number can be shown in the figure below, where the impact of parking level increase as the number of lane decreases.

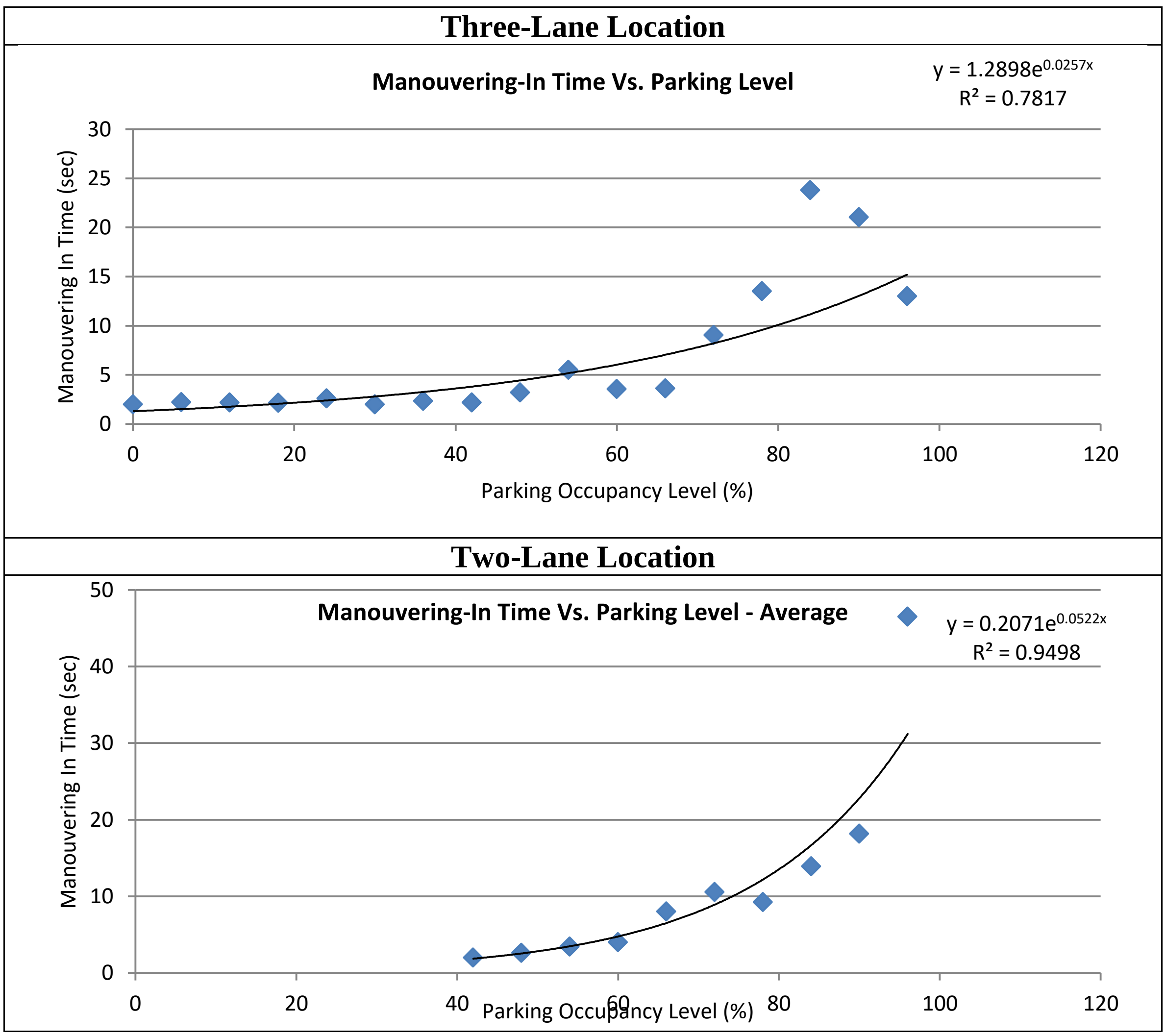


Figure 21, Maneuvering-In Time vs. Parking Occupancy Percentage

The average of the required time for entering maneuvers for both locations were listed in respect of maneuvered vehicles type (size) in Table 6. As per table 6, it is clear the vehicle type (size) has no impact on the maneuvering movement in both locations regarding all patterns.

Table 6, Maneuvering-In Time In Respect of Vehicle Type

Vehicle Type	**Three-Lane Location**		**Two-Lane Location**	
	Counts	**Average Maneuvering-In Time(sec)**	**Counts**	**Average Maneuvering-In Time(sec)**
Sedan	103	10.30	54	8.63
SUV	42	6.83	34	13.06
VAN	2	2.00	5	22.00
Pick-up	14	2.79	13	10.15
Mini-truck	1	8.00	1	7.00
Medium-bus	6	2.67	0	*N/A*
Big-bus	1	3.00	0	*N/A*

4.3.2. Leaving Maneuver Movement

In case of leaving maneuvers (Table **7**), 170 maneuvers were recorded at the three-lane location and 93 maneuvers at the two-lane location. Two different patterns were recorded as in (Figure 4).

Each leaving maneuvering movement were divided into three different timing (preparation time, waiting time and joining time), where each timing was measured and recorded. Pattern P.A has recorded the highest leaving maneuvering time, 15.45 sec at the three-lane location and 14.6 sec at the two-lane location. That can be referred to the high-level of parking occupancy, where preparation time and waiting time requires more time to be done. On the other hand, pattern P.B has recorded 7.06 sec in case of three-lane location and 5.50 sec in case of two-lane location, where preparation time and waiting time required lower time. Table 8 representing the occurred increasing in leaving maneuvers duration due to the increase in parking occupancy level. At Table 9 the average of the required time for leaving maneuvers for both locations were listed in respect of maneuvered vehicles type (size). It is clear that the vehicle type (size) has no impact on the maneuvering movement for both locations.

Table 7, Maneuvering-Out Time Summary In Respect of Pattern Classification

Maneuvering-Out						
			Three-Lane Location			
Pattern Code	**Counts**	**Parking Occupancy %**	**Avg. Preparing Time(sec)**	**Avg. Waiting Time(sec)**	**Avg. Joining Time(sec)**	**Avg. Maneuvering-Out Time(sec)**
P.A	118	71	6.25	6.49	2.70	15.45
P.B	52	38	3.92	1.04	2.10	7.06
			Two-Lane Location			
P.A	91	81	6.56	4.58	3.46	14.60
P.B	2	60	2.50	1.00	2.00	5.50

Table 8, Maneuvering-Out Time Details In Respect of Parking Level

Parking Occupancy (%)	**Avg. Preparing Time (sec)**	**Avg. Waiting Time (sec)**	**Avg. Joining Time (sec)**	**Avg. Maneuvering-Out Time (sec)**	**Avg. Preparing Time (sec)**	**Avg. Waiting Time (sec)**	**Avg. Joining Time (sec)**	**Avg. Maneuvering-Out Time (sec)**
	Three-Lane Location				**Two-Lane Location**			
12	4.33	2.83	2.00	9.17	*N/A*	*N/A*	*N/A*	*N/A*
18	3.67	4.50	2.33	10.50	*N/A*	*N/A*	*N/A*	*N/A*
24	4.27	3.40	1.93	9.60	*N/A*	*N/A*	*N/A*	*N/A*
30	2.56	1.67	2.00	6.22	*N/A*	*N/A*	*N/A*	*N/A*
36	4.22	2.56	2.44	9.22	*N/A*	*N/A*	*N/A*	*N/A*
42	4.62	1.50	2.25	8.37	*N/A*	*N/A*	*N/A*	*N/A*
48	3.14	4.86	2.43	10.43	2.50	0.50	2.50	5.50
54	1.60	5.40	4.20	11.20	3.75	1.50	3.00	8.25
60	5.00	12.17	2.83	20.00	2.17	1.50	3.00	6.67
66	7.46	1.69	2.23	11.38	5.17	6.83	2.83	14.83
72	3.44	6.28	2.61	12.33	7.62	3.63	4.38	15.63
78	7.15	6.15	3.15	16.46	8.22	7.00	3.44	18.67
84	7.35	6.61	2.78	16.74	5.12	4.15	3.27	12.54
90	8.00	6.63	3.11	17.74	6.54	4.77	3.38	14.69
96	7.20	3.40	2.40	13.00	10.69	4.50	3.50	18.69

Figure 22 shows that the maneuvering duration increases as the parking occupancy level increase in both locations. The impact in case of two-lane location was clearly higher than the three-lane location.

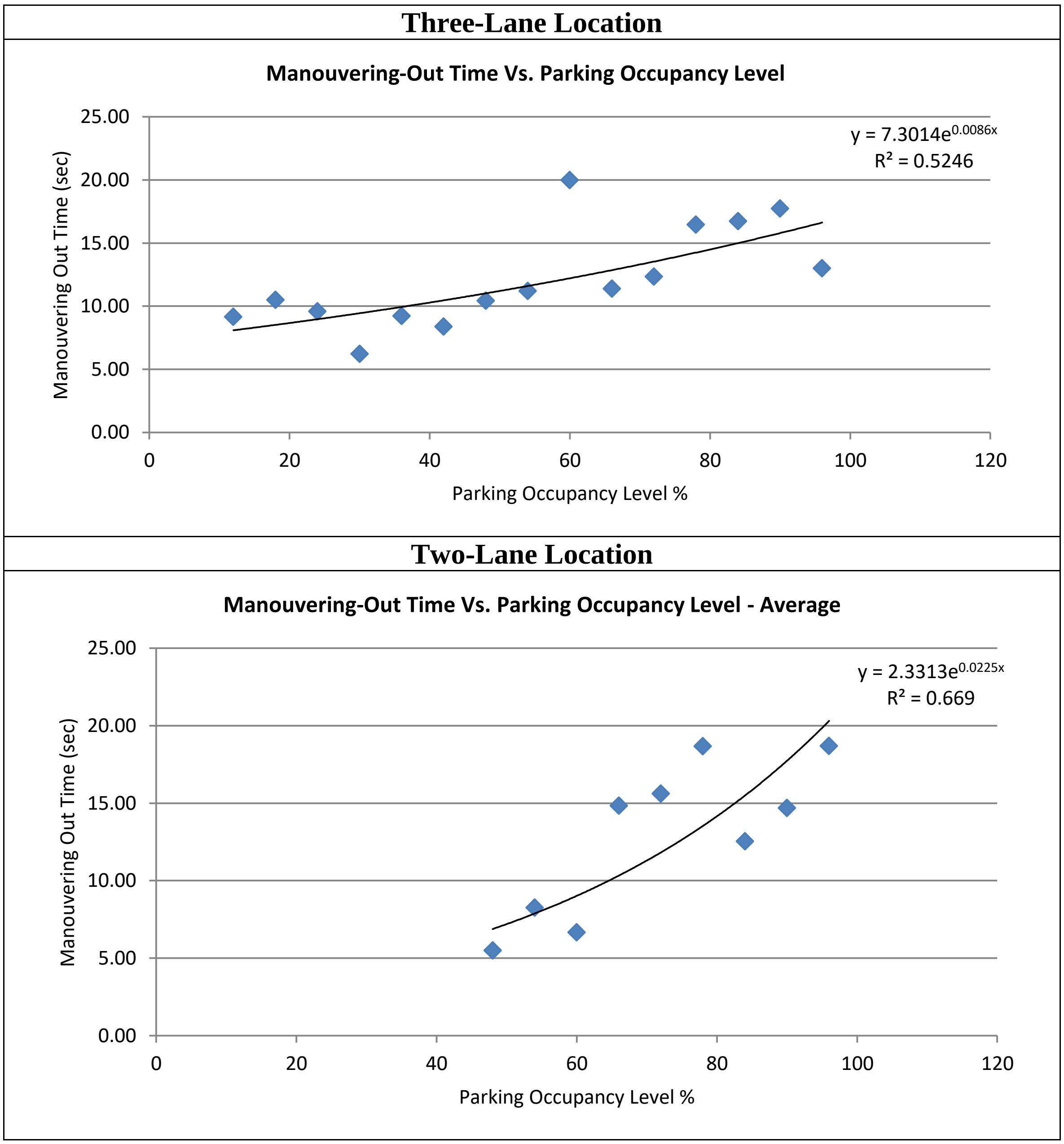


Figure 22, Maneuvering-Out Time vs. Parking Occupancy Percentage

Table 9, Maneuvering-Out Time in Respect of Vehicle Type

Vehicle Type	**Three-Lane Location**		**Two-Lane Location**	
	Counts	**Average Maneuvering-Out Time(sec)**	**Counts**	**Average Maneuvering-Out Time(sec)**
Sedan	99	14.01	47	11.89
SUV	42	11.95	28	14.86
VAN	3	6.67	1	29.00
Pick-up	13	13.54	14	19.93
Mini-truck	1	5.00	1	10.00
Medium-bus	10	6.40	0	*N/A*
Big-bus	1	7.00	0	*N/A*

4.4. Discussion

Generally the results concluded an agreement with Purnawan and Samaher Yousif in (Traffic operations at on-street parking facilities, On-street parking: effects on traffic congestion and On-street parking maneuvers and their effects on design) (Yousif & Purnawan, 2004) (Yousif & Purnawan, 1999) (Yousif S. & Purnawan, 1999), where each parking pattern required different maneuvering time in order to be completed. For both entering and leaving movements the maneuvering time increases as the parking occupancy level increases. The impact of the reduction in lanes number was noted where the maneuvering movements (entering and leaving) increased as the number of lanes decrease. The impact of vehicle type was not clear at both entering and leaving maneuvers. This can conclude that the pattern type which is usually selected by the drivers based on the parking occupancy level and lanes number are the main factors that impacting on the maneuvering movement's duration. Results showed that the case of entering maneuver required more time than leaving maneuver to be done and this as was mentioned by Marc Alvin Lim, Eriko Luis Hallare and Jesus Gerard Briones in Modeling the Impact of On-street Parking on Vehicular Traffic (Lim, Hallare, & Briones, 2012). For leaving maneuvering the movement was divided into three parts preparing time, waiting time and joining time, where preparing time and waiting time can be considered as the controlling factors on leaving maneuver moment. Preparing time and waiting time clearly increases as the parking occupancy level increase and the joining time had a minimum impact at both locations.

Chapter 5 Queuing

5.1. Background

The duration of the parking maneuver at the on-street parking varies from one pattern to another, as introduced earlier in Chapter.3, which may affect the following driver's reaction as well as affecting the traffic flow movement. For example, a driver may decide to change lanes to avoid any extra delay or decide to stay in the lane until the maneuver movement is completed forming a queue. Such behavior may cause a temporary bottleneck leaving the following vehicle suffering an unnecessary delay. In addition, the reaction of the following vehicle may affect the vehicle movement of the nearby intersection leading to an excessive delay and impact the overall intersection movement. The length of the formed queues of the following vehicles might vary from one pattern to another based on the time required to complete the maneuvering movement.

In this chapter, the relationship between the queue length and parking maneuvering time, as well as the relationship between queue length and parking occupancy level were investigated. The formed queue length was measured and categorized for each maneuvering pattern. This kind of measurement can be helpful to identify the capacity reduction caused by the existence of on-street parking.

5.2. Methodology

The formed vehicles queue length due to parking maneuvers at on-street parking was measured. Each queue length was measured and categorized by maneuvering patterns and parking occupancy level. Measured parking maneuvering time and occupancy level were used to present a relationship with the measured queue length. The relationship presents the impact of on-street parking maneuver and parking occupancy level on through vehicles movement and formed a queue. The reaction of passing vehicles due the maneuvering movement varies from one driver to another in this study. The reaction was categorized and tabulated into four different categories to have an indication of the common behavior of the drivers in the country and the reasons behind queue forming. Driver's reactions were categorized as Table 10.

Table 10, Driver's Reactions and definitions

Driver Reaction	Definition
Stop and wait	Drivers chose to wait in a queue until the parking maneuver is done
Slow down then change lane	Driver chose to change his/her lane before joining the queue to avoid any kind of delay
Stop then change lane	Driver slow down at the beginning and join the queue, but after a while, the driver chose to leave the queue and change the lane

5.3. Results and Analysis

5.3.1. Queuing at Entering Maneuver Movement

As shown in Table 11, the average queue length was tabulated and categorized by the defined parking maneuvering patterns as shown earlier in along with parking entering maneuvering time and parking occupancy level for both locations. In case of three-lane location, pattern P.3, no queue was recorded since the required maneuvering time remains low as such pattern occurred at low percentage of parking level, while pattern P.1-A required more time in maneuvering movement and occurred at average parking occupancy level which relatively higher than P.3, and may lead to a low average queue length 9 m on average. Patterns P.1-B, P.2, and Combination have caused relatively higher queue length 12, 17 and 18 m respectively since they required high maneuvering movement time. At the two-lane location, the pattern P.3 resulted in no queue same as the previous location. Similarly, to the three-lane location Pattern P.1-A also caused 8 m queue in average. Patterns P.1-B, P.2, and Combination caused the higher queue length in average 22, 14 and 11 m respectively since they required high maneuvering movement time. From Table 11, it was clear that the queue length increase as the maneuvering duration of the pattern increase. At, the average queue length was represented in respect of maneuvering-in time and parking occupancy level for both locations.

Table 11, Queue Length in respect of Pattern Classifications

Maneuvering-In Case						
	Pattern	**P.3**	**P.1-A**	**P.1-B**	**P.2**	**Combination**
Three-Lane Location	Counts	93	45	6	17	10
	No. of Cases Resulting a Queue	0	9	4	9	8
	Average Maneuvering-In Time (sec)	2.35	5.27	22.50	26.10	38.80
	Average Parking Occupancy Level (%)	40	74	86	79	81
	Min. Queue Length (m)	*N/A*	6	6	6	6
	Max. Queue Length (m)	*N/A*	18	24	24	36
	Average Queue Length (m)	*N/A*	9	12	17	18
	Pattern	**P.3**	**P.1-A**	**P.1-B**	**P.2**	**Combination**
Two-Lane Location	Counts	27	48	9	17	6
	No. of Cases Resulting a Queue	0	16	3	10	4
	Average Maneuvering-In Time (sec)	2.67	5.98	31.44	17.47	36.67
	Average Parking Occupancy Level (%)	63	77	86	79	80
	Min. Queue Length (m)	*N/A*	6	12	6	6
	Max. Queue Length (m)	*N/A*	24	36	24	12
	Average Queue Length(m)	*N/A*	8	22	14	11

Table 12, Queue Length in respect of Parking Occupancy Level

Parking Occupancy (%)	Three-Lane Location				Two-Lane Location			
	Counts	No. of Cases Resulting a Queue	Avg. Maneuvering-In Time (sec)	Avg. Queue Length (m)	Counts	No. of Cases Resulting a Queue	Avg. Maneuvering-In Time (sec)	Avg. Queue Length (m)
0	2	0	2.00	*N/A*	0	*N/A*	*N/A*	*N/A*
6	5	0	2.20	*N/A*	0	*N/A*	*N/A*	*N/A*
12	6	0	2.17	*N/A*	0	*N/A*	*N/A*	*N/A*
18	14	0	2.14	*N/A*	0	*N/A*	*N/A*	*N/A*
24	5	0	2.60	*N/A*	0	*N/A*	*N/A*	*N/A*
30	6	0	2.00	*N/A*	0	*N/A*	*N/A*	*N/A*
36	9	0	2.33	*N/A*	0	*N/A*	*N/A*	*N/A*
42	7	0	2.14	*N/A*	2	0	2.00	*N/A*
48	10	0	3.20	*N/A*	5	0	2.60	*N/A*
54	6	2	5.50	6	7	2	3.43	6
60	16	0	3.56	*N/A*	7	1	4.00	12
66	13	1	3.62	6	8	2	8.00	12
72	19	5	9.05	10	11	5	10.55	13
78	24	7	13.50	14	35	8	9.23	8
84	16	11	23.81	13	12	3	13.92	14
90	11	5	21.06	14	18	9	18.17	13
96	2	0	13.00	*N/A*	2	2	46.50	12

5.3.2. Queuing at Leaving Maneuver Movement

At Table 13 the average queue length data in case of leaving maneuvering movement was represented, consistently with maneuvering patterns. In case of the pattern P.B no queue was recorded for both locations due to the low value of maneuvering-out duration, where such pattern occurring and a low percentage of parking level which providing a smooth maneuvering for drivers. Queue lengths were recorded in case of P.A for both locations where such pattern required more time for maneuvering-out the parking space. Similar values were recorded for both locations, 14 m in case of three-lane location and 11 m in case of two-lane location. Table 14 shows the recorded average queue length in respect of parking occupancy level in both locations. It noticeable that mostly the vehicles queue start forming once the percentage of parking level reaches 60% and above for both location.

Table 13, Maneuvering-Out Time and Queue Length in Respect of Pattern Classifications

Maneuvering-Out Case			
Three-Lane Location	**Pattern**	**P.A**	**P.B**
	Count	118	52
	No. of Cases Resulting a Queue	8	0
	Average Maneuvering-Out Time (sec)	15.45	7.06
	Average Parking Occupancy Level (%)	71	38
	Min. Queue Length (m)	6	*N/A*
	Max. Queue Length (m)	30	*N/A*
	Average Queue Length (m)	14	*N/A*
Two-Lane Location	**Pattern**	**P.A**	**P.B**
	Count	91	2
	No. of Cases Resulting a Queue	13	0
	Average Maneuvering-Out Time (sec)	14.60	5.50
	Average Parking Occupancy Level (%)	81	60
	Min. Queue Length (m)	6	*N/A*
	Max. Queue Length (m)	36	*N/A*
	Average Queue Length (m)	11	*N/A*

Table 14, Maneuvering-Out Time and Queue Length in respect of Parking Occupancy Level

Parking Occupancy (%)	Three-Lane Location				Two-Lane Location			
	Counts	**No. of Cases Resulting a Queue**	**Avg. Maneuvering-Out Time (sec)**	**Avg. Queue Length (m)**	**Counts**	**No. of Cases Resulting a Queue**	**Avg. Maneuvering-Out Time (sec)**	**Avg. Queue Length (m)**
12	6	0	9.17	*N/A*	0	*N/A*	*N/A*	*N/A*
18	6	0	10.50	*N/A*	0	*N/A*	*N/A*	*N/A*
24	15	0	9.60	*N/A*	0	*N/A*	*N/A*	*N/A*
30	10	0	6.40	*N/A*	0	*N/A*	*N/A*	*N/A*
36	9	0	9.22	*N/A*	0	*N/A*	*N/A*	*N/A*
42	8	0	8.37	*N/A*	0	*N/A*	*N/A*	*N/A*
48	7	0	10.43	*N/A*	2	0	5.50	*N/A*
54	5	0	11.20	*N/A*	4	0	8.25	*N/A*
60	8	0	17.63	*N/A*	6	1	6.67	12
66	13	0	11.38	*N/A*	6	1	14.83	6
72	18	0	12.33	*N/A*	8	1	15.63	6
78	13	2	16.46	18	11	11	19.09	3
84	23	2	16.74	15	27	3	12.67	6
90	19	1	17.74	12	13	2	14.69	6
96	10	1	13.00	12	16	4	18.69	14

5.3.3. Driver's Reaction

Based on Table 15 and Table 16, the reactions of passing vehicles due to the maneuvering movement were recorded. For both entering and leaving maneuvers at both locations, it was clear that the number of drivers who decided to stop and wait in the queue was always higher than those decided to change to another lane. This behavior can explain the reason for queue forming. A probable cause is that most drivers prefer the safety way than changing the lane and end up with a rear-end crash or side-swipe. It was noticed that most prefer able reaction was to change the lane while the vehicle still in motion.

Table 15, Driver's Reaction in Respect of Maneuvering-In

	Location	Three-Lane Location	Two-Lane Location
	Maneuvering-In Counts	171	107
	Cases Caused Driver's Reaction	46	42
Driver Reactions Counts	**Stop and Wait**	58	52
	Stop then Change Lane	22 (with an average waiting time 6.5 sec and median 4.5 sec)	8 (with an average waiting time 8.5 sec and median 6.0 sec)
	Slow Down then Change Lane	67	67

Table 16, Driver's Reaction in Respect of Maneuvering-Out

	Location	Three-Lane Location	Two-Lane Location
	Maneuvering-Out Counts	170	93
	Cases Caused Driver's Reaction	13	12
Driver Reactions Counts	**Stop and Wait**	8	15
	Stop then Change Lane	0	0
	Slow Down then Change Lane	12	24

5.4. Discussion

In this chapter, the relationship between the leaving and entering maneuvers, parking occupancy level and the queue length was investigated. This increase in the duration of the maneuvering process forces some through vehicles to yield and change the lane or to totally stop to avoid any rear-end crash, causing a bottleneck at some point as mentioned by Jin Cao, Nikias Vasileios and Monica Menendez in on-street parking near intersections: effects on traffic (Cao, Menendez, & Vasileios, 2013). It was noted that the impact of entering maneuvers was higher than leaving maneuvers in queue forming. On the other hand, the number of lanes had no clear impact in queue value, where no sufficient difference was recorded in the queue length between both locations and they almost recorded similar values for both entering and leaving maneuvers. This can be explained that most drivers prefer to change the lane while the vehicle still in motion.

Driver's reaction was studied in this chapter to identify the behavior of drivers. Three reactions were recorded for the drivers during the maneuvering movement (stop and wait, stop then change lane and slow down then change lane). In both cases, at the two locations, it was noted that most drivers prefer to stop and wait then take the risk to change the lane. It was noted that drivers rather prefer to slow down to change the lane before merging with the queue more than changing the lane after the merging. Such behavior can be explained that a driver prefers to change the lane as long he is still moving and accelerating than starting from a stop. It was noted also that in case of stop and wait reaction, the two-lane location recorded a higher number of reactions than the three-lane location and that can be referred to the reduction in the number of lanes and narrowing the roads which make change the lane dangerous situation and may cause to rear-end or sideswipe crashes. It was noted in case of stop then change lane for both locations that the drivers are not able to wait for more than 7.5 sec in waiting once he/she decide to change the lane, which may have an impact in causing road accidents.

Chapter 6 Travel Time, Speed, and Delay

6.1. Background

The main concept of roadways is to provide mobility and accessibility to allow road users arrive at their destinations in proper timing and without unnecessary delay. Nevertheless, most people prefer short ways (on-street parking) which leads directly to their destinations. Thus, the main challenge in busy cities and towns is to provide a balance between mobility and parking accessibility. Average Traffic flow speed and traveling time are a developing concern in transportation and safety engineering. The existence of on-street parking would have a clear impact on travel time and flow speed. Formed queues resulting from parking maneuver movements would reflect on traffic flow performance by reducing the traffic flow speed and increasing vehicle travel time. In this study, the main idea was to evaluate the impact of such parking on the traffic flow movement by driving a relationship representing parking occupancy level with average travel speed, travel time and delay.

6.2. Methodology

This study evaluated the impact of parallel on-street parking occupancy level on the traveling vehicles. As mentioned previously increasing in parking occupancy level means that the maneuvering movement duration increases which lead to form a queue for some cases. The evaluation was conducted by measuring the following parameters; the average speed, traveling time and delay (as defined in Chapter.2) through the studied segments. The comparison could be done between the ideal travel time (as defined in Chapter.2) and the average travel time to obtain the actual delay value. The study aimed to investigate the parking occupancy level impact on the three mentioned parameters. The impact was studied in each lane of the road to identify the impact percentage on each lane. The three mentioned parameters were measured at each parking occupancy level. Similar numbers of vehicles were counted in each lane in order to avoid the impact of the sample size. In order to capture the impact of parking occupancy on the through vehicles, vehicles before and after any conducted maneuvering movement were counted as presented in Figure 23. All counting process was done at the off-peak period to avoid any kind of other impacts other than on-street parking.

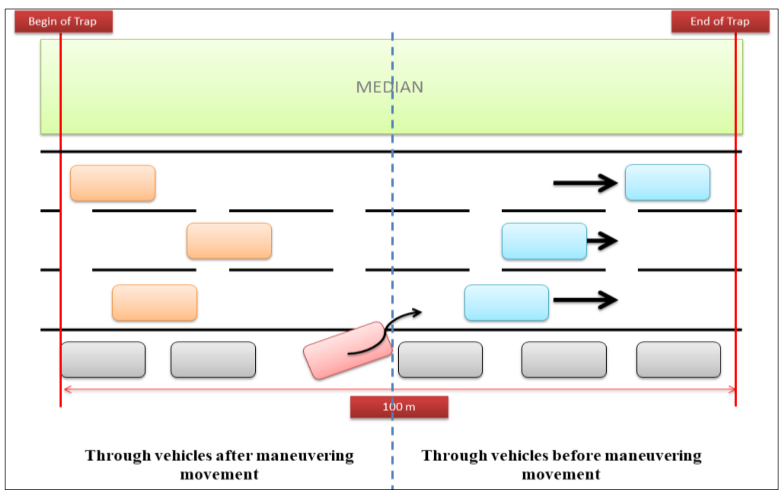


Figure 23, Process of Counting Through Vehicles

6.3. Results and Analysis

As the represented data on Figure 17, 5961 vehicles were recorded in the three-lane location and 2980 vehicles at the two-lane location. In both locations the impact on travel time, speed and delay reached the highest value on the inner lane and the lowest value on the outer lane. Another observation was observed that as the number of lanes decrease in the road as the impact of the on-street parking increase. To explain the small number of counts in case of two-lane, please refer to the limitations section in Chapter 8.

Figure 24 shows the relation between the parking occupancy level and the average travel time for the passing vehicle due to the entering and leaving maneuvers at parallel on-street parking. For both locations, the impact varied between the different numbers of lanes. The highest impact can be noted in the inner lane while the lowest value can be shown in the outer lane. An important note that in case of three-lane location, all cases of parking level 0% to 100% were measured, but in case of two-lane, measured parking occupancy level range was 42% to 100%.

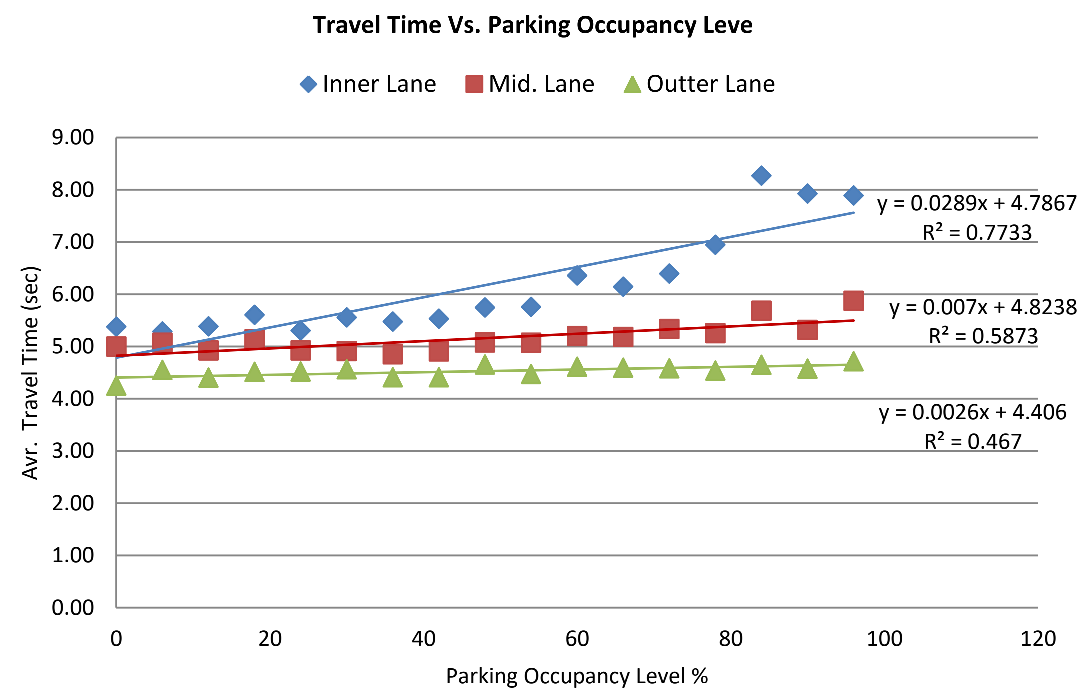
Figure 25 shows the relation between the parking occupancy level and the average travel speed for the passing vehicle due to the entering and leaving maneuvers at parallel on-street parking for both locations. The highest speed reduction occurred in the inner lane, and the reduction value keeps decreasing as the lane goes farther from the parking lots.

Figure 26 representing the relation between the parking occupancy level and the occurred delay for the passing vehicle due to the entering and leaving maneuvers at parallel on-street parking. In case of three-lane location, the delay has increased by an average 1.98 sec from the ideal travel time 4.5 sec at the inner lane and almost by 0.79 sec at mid-lane, while 0.32 sec in delay were recorded on the outer lane. In case of two-lane location, the delay may reach up to 4.41 sec from the ideal time at the inner lane and almost 2.31 sec at the outer lane.

Table 17, Travel Time, Speed, and Delay for the Through Vehicles

	Lane Location	Inner Lane	Mid Lane	Outer Lane		Lane Location	Inner Lane	Outer Lane
Three-lane Location	**Counts**	1987	1987	1987	**Two-lane Location**	**Counts**	1490	1490
	Average Travel Time (sec)	6.46	5.20	4.55		**Average Travel Time (sec)**	8.91	4.81
	Min. Travel Time (sec)	4.00	3.00	2.00		**Min. Travel Time (sec)**	6.00	4.00
	Max. Travel Time (sec)	42.00	10.00	7.00		**Max. Travel Time (sec)**	42.00	14.00
	Average Travel Speed (Km/hr.)	61.0	71.1	80.9		**Average Travel Speed (Km/hr.)**	42.6	43.9
	Min. Travel Speed (Km/hr.)	8.6	36.0	51.4		**Min. Travel Speed (Km/hr.)**	8.6	25.7
	Max. Travel Speed (Km/hr.)	90.0	120.0	180.0		**Max. Travel Speed (Km/hr.)**	60.0	90.0
	Average Delay Time (sec)	1.98	0.79	0.32		**Average Delay Time (sec)**	4.41	2.31
	Min. Delay Time (sec)	0.00	0.00	0.00		**Min. Delay Time (sec)**	1.50	0.00
	Max. Delay Time (sec)	37.50	5.50	2.50		**Max. Delay Time (sec)**	37.50	9.50
	Total number of vehicle = 5961					**Total number of vehicle = 2980**		

Three-lane Location



Two-lane Location

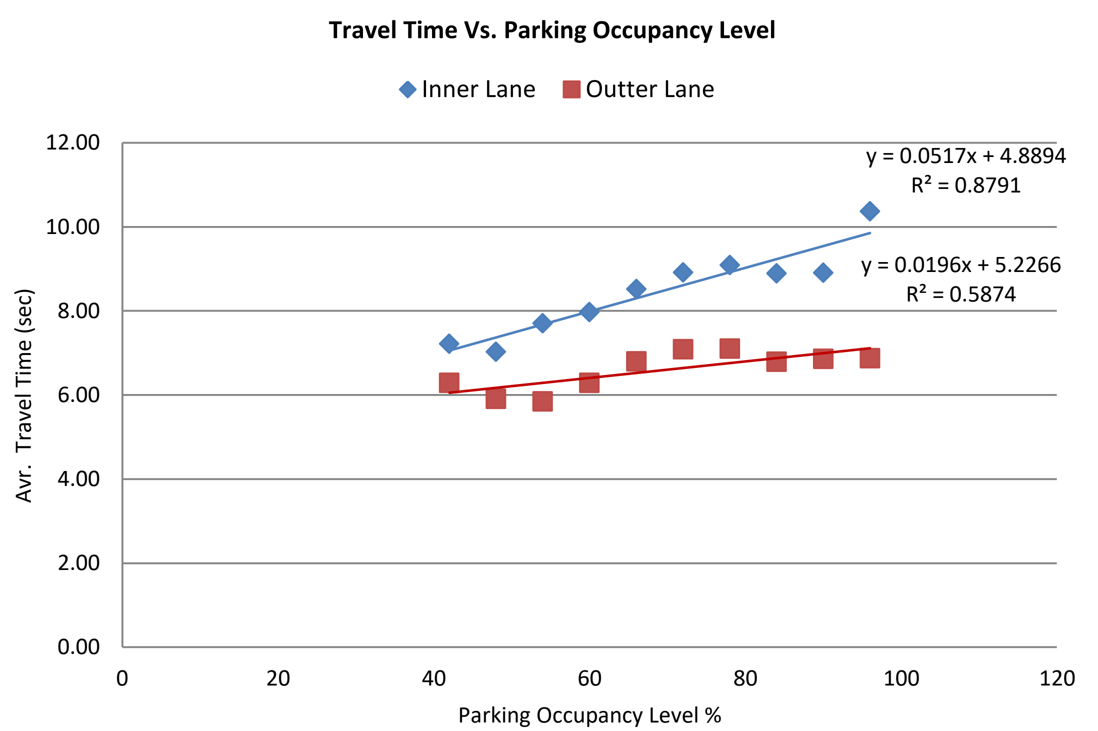
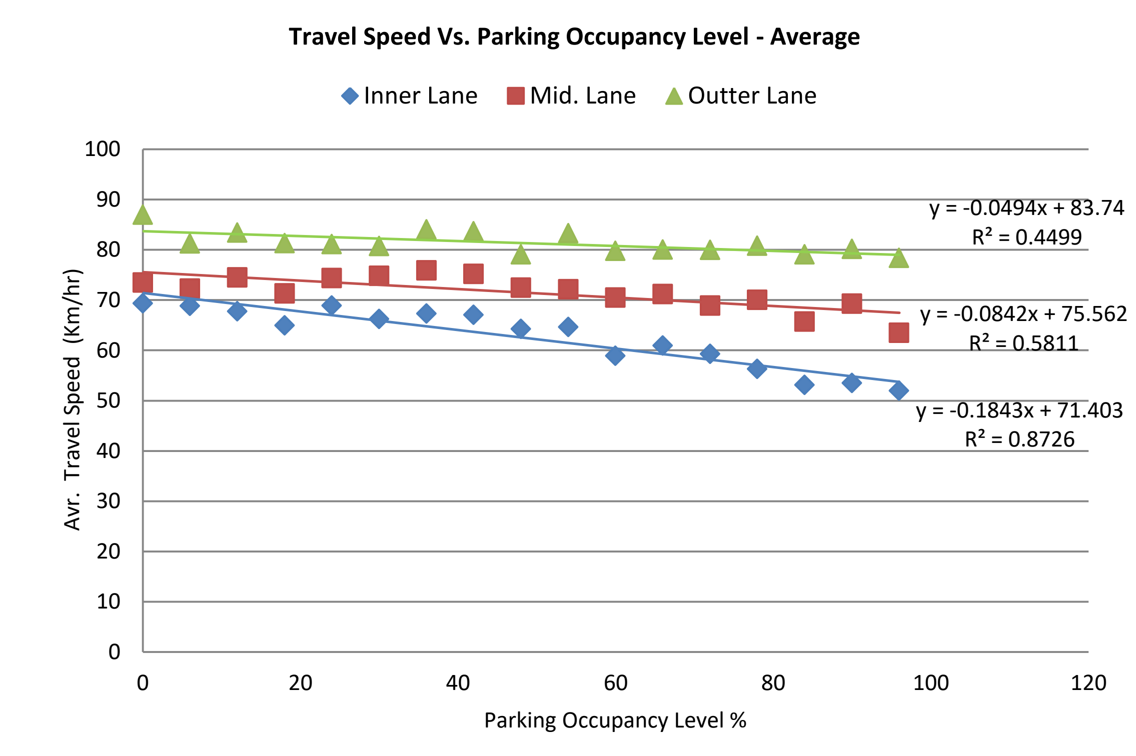


Figure 24, Parking Occupancy Level vs. Average Travel Time

Three-lane Location



Two-lane Location

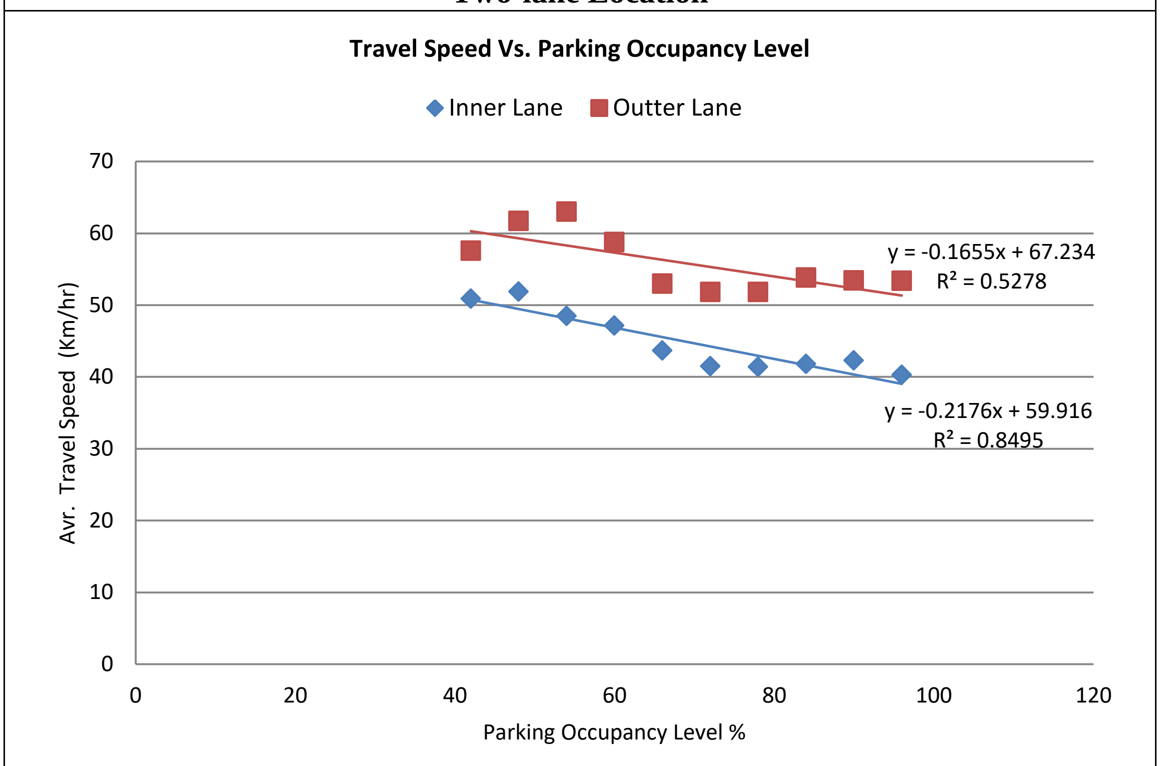
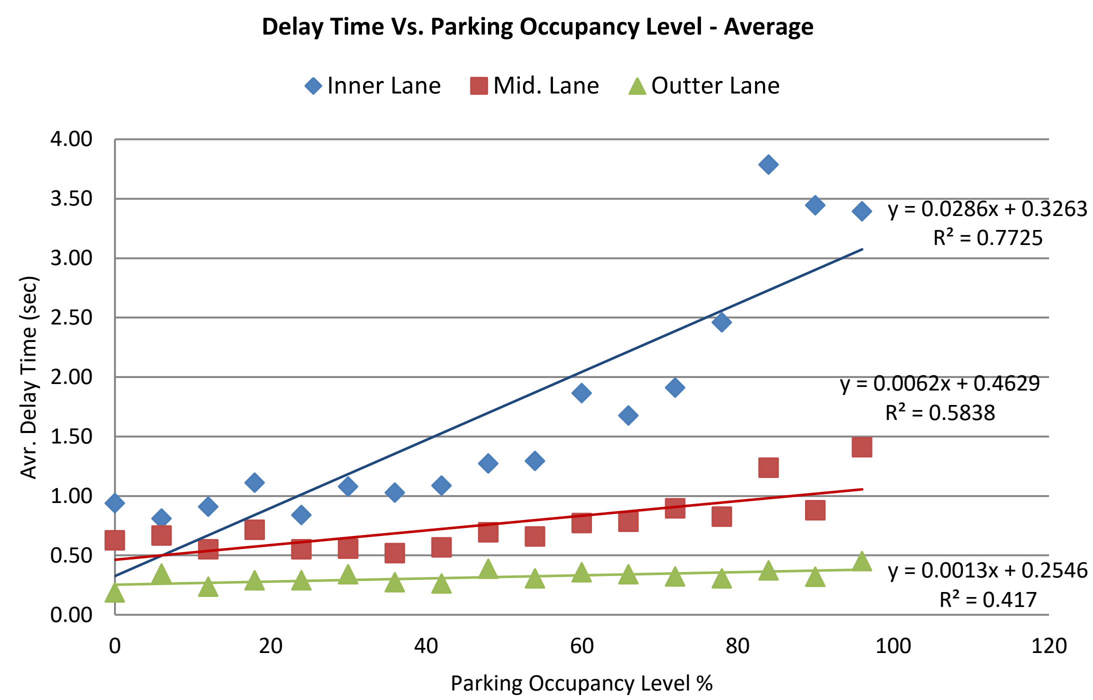


Figure 25, Parking Occupancy Level vs. Average Travel Speed

Three-lane Location



Two-lane Location

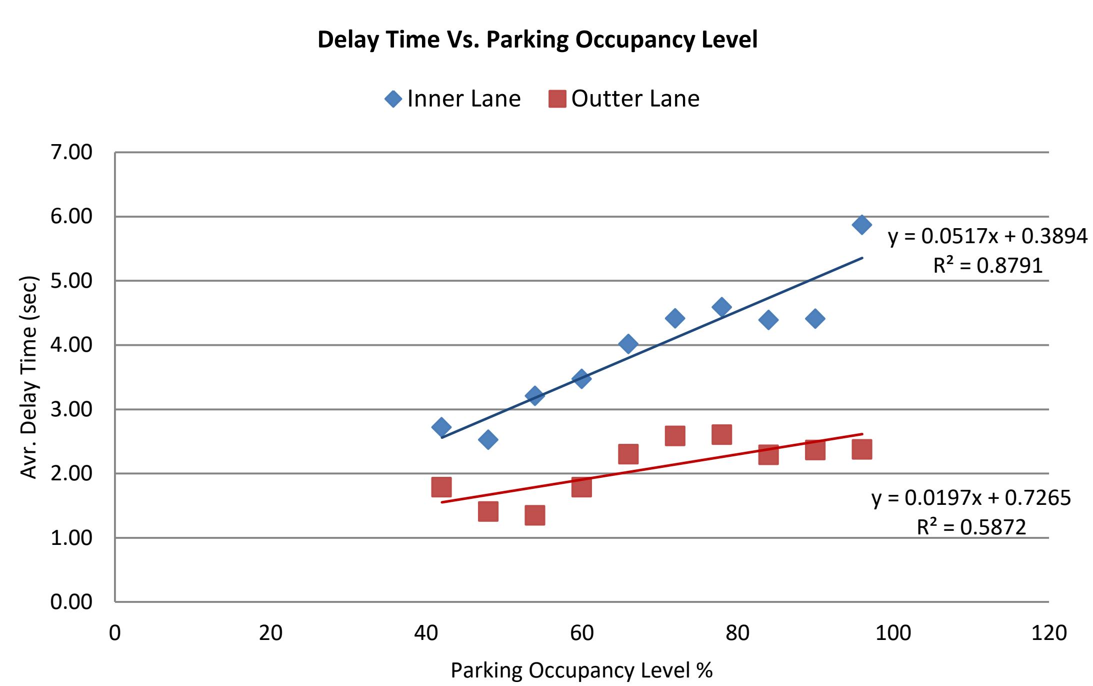


Figure 26, Parking Occupancy Level vs. Average Delay Time

6.4. Discussion

This chapter showed that the existence of parallel on-street parking on the side of the road can clearly impact the traveling time of traveling vehicles and end up causing unnecessary delay, as was mentioned by Marc Alvin Lim, Eriko Luis Hallare and Jesus Gerard Briones in modeling the impact of on-street parking on vehicular traffic (Lim, Hallare, & Briones, 2012), Naseri Alireza in a method for estimating average delay time due on-street parking (Naseri, 2013), Koorey, Gautham Praburam and Glen in effect of on-street parking on traffic speeds (Praburam & Koorey, 2015), Portilla, Angel Ibeas; Oreña, Borja Alonso; Berodia, José Luis Moura; Díaz, and Francisco José Ruisánchez in using M/M queuing model in on-street parking maneuvers (Portilla, Oreña, Berodia, & Díaz, 2009) and Purnawan in study effect on-street parking stall design using microscopic simulation (Purnawan, 2010) . This kind of impact was a result of parking maneuvering movement and the formed queue as mentioned in Chapter 3 Chapters 4. The percentage of impact varied from one lane to another based on its location from the on-street parking. In general, the peak point of delay occurred in the adjacent lane to the on-street parking and the impact start decreasing on the farther lanes. The number of lanes was also a main factor in the study. The traveling vehicles increase as the number of lane decrease, where the average delay for the inner lane increased from 1.98 sec in case of three-lane to 4.41 sec in case of two-lane. The results showed that the increase in the parking level can increase the impact of the on-street parking, as mentioned by (Chen, Li, Jiang, Zhu, Wang, & Chen, 2015).

Chapter 7 Gap Acceptance

7.1. Background

Most of the researchers focused on the merging behavior from/to on-street parking and traffic flow by studying the parking maneuvering movement and its impact. However, little obvious consideration has been given in studying the procedure of gap acceptance that occurs at on-street parking, which occurs when the leaving vehicle maneuvering-out trying to leave the parking space and join the traffic stream. The cases of the maneuvering-out process can be explained as the method of leaving the parking space and joining the traffic flow, where the driver should be able to select an acceptable gap to join the flow. The gap acceptance was defined as the time between two successive vehicles in the traveling lane when the parked vehicle starts leaving the parking space joining the traveling vehicles. (Yousif & Purnawan, 2004). In the procedure of merging maneuver, drivers keep waiting until an acceptable gap is available and during that period several gaps may be rejected from the driver due the inadequate time to leave the parking lots and join the moving flow. It is similar in merging process at uncontrolled junctions where the operation is ruled by the availability of enough gaps in the main traffic stream. (D.E & G.H, 1979) . However, when a driver decides not to spend more time in waiting for a sufficient gap and leave the parking space, this may force the following vehicle to suddenly break or change the lane to avoid a potential crash. This chapter provides a better understanding of the impact of the parallel on-street parking operations on the traffic flow due studying the rejected and accepted gap values.

7.2.Methodology

The gap time needed by the driver to leave the parking space from the parallel on-street parking to join the traffic stream was measured. The rejected gap values were measured beside the gap acceptance values to be able to end up with average values for both for such cases. The rejected and accepted gap values were measured as defined earlier in Chapter 2. Some maneuvering-out vehicles were excluded due to the existence of illegally parked vehicle blocking the traveling lane. Another observation, that gap acceptance counts were higher than rejected values for both locations, where some driver accepts the first available gap to join the traffic flow. The impact of road width on gap acceptance values was studied by implanting the study at two different locations with a different number of lanes (road width).

7.3. Results and Analysis

The average values for the recorded rejected and accepted a gap in both locations was calculated. In case of rejected gap value, both locations scored similar average value of 3.04 sec in case of three-lane location and 3.06 sec in case of two-lane location. For gap acceptance case, three-lane location recorded 10.20 sec which was higher from the two-lane location 8.79 sec

7.4. Discussion

In this chapter, the average values of the rejected gap and the accepted gap in case of parallel on-street parking were recorded. The results showed that gap acceptance value increased as the number of road lanes decrease. The study recorded almost similar value in case of the rejected gap 3.04 sec in case of three-lane location and 3.06 sec in case of two-lane location, the small increment in case of two-lane can refer due to the reduction of the number of lanes. The recorded average gap acceptance in case of three-lane was 10.20 sec, while 8.79 sec was recorded in case of the two-lane road. The small difference in values could be a result of the difference in counts between both sites. The average of gap acceptance values were almost close to what was mentioned by Purnawan (Purnawan, 2000), who recorded 10.1 sec in average gap acceptance for parallel on-street parking and Yousif and Purnawan (Purnawan; Yousif, 2000), who recorded 8.3 sec for similar parking case. The critical gap values for both locations were almost similar (4 sec), which was lower than what was mentioned by Purnawan (Purnawan, 2000) , who recorded 7.4 sec in case of parallel parking.

In case of any reduction in gap acceptance value should be investigated, while ignoring the reduction may force the following vehicles either to sudden break or sudden lane change which may create a chance of crash. The obtained values from this study could be helpful in any further studies in order to identify the critical gap value for such parking case in Qatar.

Chapter 8 Conclusion

8.1. General Discussion

Traffic congestion has been increasing rapidly in the last few years in Qatar. Placing an on-street parking randomly on the road would have a benefit in providing extra parking spaces for road users, but on the other hand, it may impact traffic flow movement. In this study, the characteristics of on-street parking and its impact on traffic flow movement were investigated. The study was done at two locations in Doha-Qatar with a different number of lanes.

In this study, the duration of the entering/leaving maneuvers duration was recorded and categorized into different patterns. The parking occupancy levels were also recorded for each case of maneuvering movement. The impact of parking occupancy level on the maneuvering movement was clear. In both entering /leaving maneuvering movements, the duration increases as the parking level increases. In addition, decreasing the number of lanes leads to extra impact in the increasing of the maneuvering movement duration. Increasing the maneuvering movement duration means changing the maneuvering pattern from a smooth pattern to difficult one. The impact of vehicle type was also investigated, and it was found that the vehicle type did not have an impact on the maneuvering movement duration for both cases entering and leaving at both locations.

As a result of maneuvering movement, vehicles' queues were formed. The length of the formed queue was linked with maneuvering movement time, parking occupancy level, and the number of lanes. Any increase in the maneuvering movement duration or parking occupancy level would lead to an increase in the queue length. Furthermore, any reduction in the number of lanes would lead to extra increase the queue length. The impact of formed queues would increase as its length increase. The impact on the through vehicles during the maneuvering movement would vary to be either stop and wait in the queue, slow down then change the lane before joining the queue or stop in the queue for 6 to 8 sec in average then changing the lane. It was found out that most of the drivers prefer to slow down and change the lane before merging with a formed queue to avoid any kind of delay. And in case the drivers merged with the queue, they prefer to wait rather than take the risk and change the lane.

The caused delay was measured for each passing vehicle in each lane. The values were measured by measuring the actual travel time for through vehicles before and after the maneuvering movement in each lane and comparing it with the ideal travel time for such a case. The measuring was done before and after the maneuvering movement in order to capture the impact of parking occupancy level as mentioned earlier in Chapter 3, the maneuvering movement increase as the parking occupancy increase. Relationships were derived between parking occupancy level and the following parameters (average travel time, average travel speed and average delay). It was clear that as the parking occupancy level increases the average traveling speed decrease which leads to an increase in the travel time and delay. The impact of a number of lanes was clear, where the delay and travel time value increase as the number of lanes decreases. The location of traveling lane was found to have a significant impact on through traffic flow with the max impact taking place at the adjacent lane to the curb parking and the impact decrease as the lane location gets farther away from the parking.

Rejected and accepted gap values were studied and determined for both locations. It was noticed that the rejected gap increased as the number of lanes decreased. Obtained gap acceptance values were close to values obtained in previous studies. By knowing the rejected and accepted gap values can lead to determine the critical gap value for such case, where it was similar for both locations. Gap value, it would give an indication of road user's mentality and the expected delay.

8.2. Study Limitations

Several limitations were recorded and noted throughout the study period time. First, the study was limited to what cameras could only capture and to what was available in the videotaping. Second, the vehicles counting had to be stopped at some periods, due to the impact of other factors than the maneuvering movement such as peak hour's congestion and illegal parking. Third, on the second location (two-lane) the percentages of 0% to 40% in parking occupancy level were not possible to cover due to the high movement in the parking lots. Fourth, in some cases, it was not possible to measure the entire length where the queue length may reach beyond the segment length. Fifth, for some gap acceptance cases, it was not possible to measure the gap due to illegally parked vehicles blocking the adjacent traveling lane to the on-street parking. Sixth, the study was done only during the off-peak hours to avoid any impact other than on-street parking.

8.3. Recommendations and Future Work

More sites are needed to verify the results of this research. A longer segment length should be investigated by increasing number of cameras and the trap length to be able to collect a higher number of vehicles. Angle parking (90 and 45 degrees) should also be investigated and compared against the results from the study. Maneuvering movement time, queue length, expected delay, gap values and travel lanes should be considered during the design stage or in the case of adding on-street parking to existing roads.

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