Impacts of On-street Parking on Road Capacity

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Abstract

Congestion within modern day urban transport networks has been a significant social, economic and environmental issue. A study by the Australian Bureau of Transport and Regional Economics estimated the total avoidable cost of congestion in 2005 for Australian cities was $9.4 billion. There are a number of factors which result in congestion including: lack of road capacity during peak periods, disruptions and road incidents occurring within the network and interruption of flow at intersections. Furthermore, a key factor which has not been studied quantitatively in great detail, that impacts road capacity and contributes to congestion, is the provision of on-street parking.

This study attempts to fill the gap in knowledge by providing a further understanding of the traffic congestion resulting from on-street parking and the associated impacts on road capacity. The study utilises field surveys to measure the time taken to complete parking manoeuvres and the resulting queues that occur on metropolitan roads in Sydney. Statistical analysis of these surveys was then conducted and a relationship was derived to measure the impact of these interruptions on road capacity.

The results of the study clearly indicate that the reduction in capacity of the lane adjacent to a parking lane is greater when the time restriction of an on-street parking zone is short. The study suggests possible reduction factors that can be used in road capacity estimations when on-street parking is allowed in an urban transport corridor. Once the adjustment factors developed in this study are refined and validated, they can be incorporated within transport guidelines and road infrastructure standards to appropriately account for the impacts of on-street parking on road capacity. This study has the potential to improve the assessment of traffic impacts from land use developments and take appropriate steps to alleviate congestion throughout the network.

Keywords: road capacity, on-street parking, congestion, land use, traffic impact assessment

1.   Introduction

Economic and population growth have led to the rapid urbanisation and development of Metropolitan Sydney. As a result of the rising level of development, the demand for local amenities such as on-street parking for developments adjacent to transport corridors has increased. However the process of the community utilising on-street parking can reduce road capacity as well as the achievable driving speeds for the roads adjacent to developments. Accordingly, traffic delays are a common experience in most of the urban transport corridors due to the complexity of the interaction between traffic flow and land use. To date, literature has not presented a comprehensive study quantifying the impact of on-street parking on traffic flow within the Sydney Metropolitan area and this study aims to fill this gap.

Traffic congestion within urban transport networks has been an issue for transport planners and traffic engineers during the past few decades. Currently, traffic congestion is a daily occurrence in Sydney's motorways and major arterial corridors during peak periods. Traffic congestion can be a result of a number of factors including the lack of capacity during peak periods, disruptions within a network such as traffic accidents, vehicle breakdowns, road works and traffic control measures (such as traffic signals and traffic calming devices). A city

based analysis shows that the cost of congestion in Sydney is $3 billion and will rise to about $6.1 billion in 2020 (BTRE 2007). The estimates do not take into account the cost of implementing appropriate measures to alleviate traffic congestion.

Traffic congestion can be managed by either controlling the travel demand or increasing the road capacity. Travel demand management is the use of policies and strategies to restrain trips, especially during peak traffic periods to alleviate traffic congestion. However, implementation of effective travel demand management measures are difficult, unpopular and politically sensitive (Gärling & Schuitema 2007). The conventional approach to address traffic congestion in urban areas is to construct new road infrastructure or expand the existing road transport corridors. This approach has become costly, time consuming and infeasible in most of the cities due to lack of space for road works and potential environmental factors. Furthermore, there have also been a number of studies which have suggested that an increase in the capacity of roadways can create a greater level of congestion (Mogridge 1997, Goodwin et al. 1998, Noland 2001, Cervero & Hansen 2002). Capacity expansion, by means of road widening, creates the phenemenon of induced travel demand for that particular corridor. The other alternative is to improve the capacity of the existing road infrastructure by application of congestion management strategies and policies. Implementation of congestion management strategies and policies are cheaper and faster, but often politically sensitive (Shiftan & Burd-Eden 2001, Marsden 2006, Hull 2008). Some of these policies require minimal effort and cost to implement; such as peak period parking restrictions, turning restrictions and imposing access restrictions for new traffic generating land use developments. The intention of this research study is to explore possible congestion management strategies and policies adjacent to traffic generating land use developments and provide quantification for the potential advantages and disadvantages of these policies. In particular, the study is focussed on understanding the impact of on-street parking on the capacity of adjacent arterial roads and developing a mathematical model to quantify these impacts.

2.   Background

On-street parking is a common feature in most of the metropolitan areas around the world. On-street parking assists to improve economic viability of commercial developments along transport corridors by providing easy and convenient access for customers, delivery vehicles and employees of such developments. However, the provision of on-street parking along transport corridors could adversely impact the capacity as well as the achievable driving speeds of the adjacent road. Road safety is another key factor which needs to be considered when considering the provision of on-street parking along a transport corridor. The debate regarding the merits and drawbacks of on-street parking stem from a lack of research surrounding the subject over the last two to three decades (Marshall, Garrick & Hansen 2008).

The utilisation of on-street parking is considered to be a more efficient use of land as it limits the need for off-street parking and access points to properties adjacent to major arterial roads (Litman 2013, Jakle & Sculle, 2004). This aspect of on-street parking also reduces costs for the businesses, maximises land utilisation and creates a pedestrian friendly environment for the community by delineating vehicles and land use. Extending from this concept it is believed to improve pedestrian safety by providing a barrier between the flowing traffic and the footpath as well as reducing the speed of vehicles travelling on the roadway (Byrd and Sisiopiku, 2006). Although there are a number of benefits in providing on-street parking, there are some adverse impacts, particularly on traffic flow.

On-street parking can impact the road capacity in two ways. The reduction of the available lanes of a road to accommodate on-street parking is the primary factor that reduces road capacity. Additionally, on-street parking manoeuvres can cause extensive delays, especially on heavily trafficked roads. This creates stop-start traffic flow behaviour for the lanes adjacent to the parking lane, thus affecting the capacity of the road section.

Yousif & Purnawan (1999) had undertaken a detailed study to gain an understanding of the time taken to enter and leave on-street parking spaces. The study has explored ways to improve the design and provision of on-street parking facilities, to reduce the time required for parking manoeuvres. Furthermore, the study examined the time taken to park-in as well as to leave on-street parallel parking spaces and angle parking spaces. The findings indicated that the reverse parallel parking manoeuvre is the most time consuming and is positively correlated to the size of the vehicle. Further to these findings, O'Flaherty (1986) has suggested alternative designs for on-street parking spaces based on average sized vehicles in the UK as shown in Figure 1. The study presents designs which will minimise the need for the reverse parallel parking manoeuvre and thus reducing the delay incurred on the flow of traffic. Though both these studies provide evidence for the detrimental impact of on-street parking as well as potential solutions to minimise the impacts, neither study quantifies the impact of these delays on the capacity of the road.
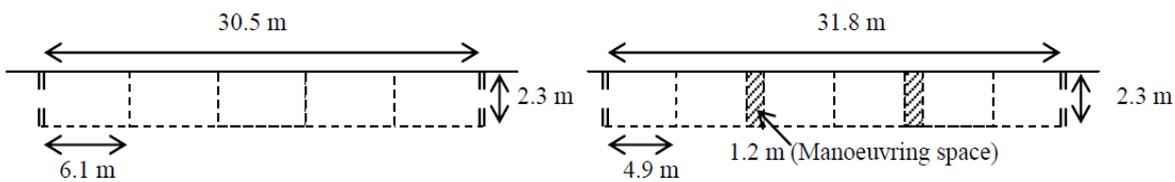
Figure 1 – Alternative designs for on-street parking spaces (O'Flaherty 1986)

There have also been a few studies in the past that have used data analysis techniques to assess the impact of on-street parking on road capacity. The American Association of State Highway and Transportation Officials (AASHTO 2011) claims that the road capacity of four to six lane arterial roads can be increased by 50% to 80% by removing kerb side on-street parking. Additionally, Weant & Levinson (1990) claim that the removal of on-street parking on a four-lane road doubles the capacity, while taking away on-street parking on a six-lane road achieves a 67% capacity gain. This result is the direct impact of on-street parking due to loss of traffic lanes when on-street parking is allowed. Accordingly the study has not considered the potential impact of on-street parking on the adjacent traffic lanes. However, a more recent study undertaken by Portilla et al. (2009) used micro-simulation modelling to show that the road capacity of the remaining lanes reduced significantly, by up to 16% due to 30 parking manoeuvres per hour. These studies provide great insight into the issues, however are case specific and do not offer a generalised approach to assessing the impacts of on-street parking.

Additionally a number of research studies have revealed that on-street parking contributes to traffic collisions and thereby affects the traffic flow. A study in the city of Hamilton in Ontario, Canada presented that non-intersection crash rates reduced by an average of 37% after on-street parking was removed along 6 major arterial road segments within the city centre (Desjardins 1977). A study undertaken by US Highway Research Board (1971) estimated that on-street parking affected 20% of all traffic collisions in urban areas. Furthermore, Weant & Levinson (1990) found that 15% of crashes within urban areas are caused by on-street parking and 5% of pedestrian mortalities involved people entering the roadway between parked vehicles. Interactions with on-street parked vehicles contributed to 6% of all crashes within London (London Research Centre 1995). These figures may be much higher as most minor traffic accidents where a parked vehicle is involved may not be recorded or may be recorded without acknowledging a parked vehicle as the main contributory factor of the accident. However, there have also been conflicting studies which suggest that the prohibition of on-street parking increased the number of crashes and the severity of the injuries. A study in Copenhagen on the provision of bicycle lanes as a substitute for on-street parking suggested that parking shifted to side streets, increased turning traffic movements which in turn increased the number of conflicts and accidents (Jensen et al. 2007).

It is evident from the review of literature that the impact of on-street parking has been researched. However, there have been no detailed studies quantifying the impacts on road capacity directly related to the driving manoeuvres involved in the act of parking a vehicle. This gap in knowledge is further investigated within this study. The value of the project lies in the application of this quantification within traffic management standards and guidelines. As such the following section discusses the current approaches in accounting for the impacts of on-street parking road capacity.

3.   Traffic Management Guidelines Approach to On-Street Parking

One of the most commonly used traffic management guidelines in Australia is the Austroads Guide to Traffic Management (2008). It provides a comprehensive guide to practitioners involved in traffic and transport engineering. This document is well regarded by professionals, road authorities and Local Government authorities. Part 3 of this guide discusses traffic analysis; specifically traffic surveys, data collection and analysis of traffic data for the purpose of managing existing transport infrastructure. Additionally, the Roads and Maritime Services has published a guideline known as Guide to Traffic Generating Developments (RMS 2002) to assist traffic engineers, council officers, town planners and others involved in the assessment of Development Applications. This guide provides information on potential traffic generations, parking requirements and impacts of various types of developments. Furthermore, US Highway Capacity Manual (TRB 2010) is used by traffic and transport engineers, especially when traffic studies are conducted in major projects. Relevant information found in these documents have been used throughout the study.

Austroads Guide to Traffic Management Part 3 (2008) states that lane capacity of an urban road under ideal conditions is 1800 vehicles per hour. However a number of factors such as roadway conditions, geometric design, traffic control measures and other physical elements could affect the capacity of a transport corridor. Austroads (2008) has identified the following factors that could influence the capacity of an urban road: traffic lane widths; shoulder widths and/or lateral clearances; design speed; terrain conditions (horizontal and vertical alignment of the road); traffic composition (percentage of heavy vehicles); driver behaviour; control conditions (traffic lights and other traffic management measures); pedestrian and bicycle facilities. To account for these factors Austroads (2008) has provided 'correction factors' or adjustment factors when estimating road capacity. Section 4.1.1 of the Austroads Guide states that capacity of a traffic lane, C, can be expressed as presented in Equation 1.

Equation 1 - Estimated capacity of a traffic lane (Austroads 2008)

$$C = 1800 . f_W . f_{HV}$$

Where

C = laneway capacity in veh/h under prevailing roadway conditions,

1800 = capacity of a traffic lane without overtaking capabilities

f_W = adjustment factor for narrow lanes and lateral clearances. Empirically derived factors are provided in Table 1

f_{HV} = adjustment factor for heavy vehicles, as shown in Equation 2.

Table 1 – Adjustment factor for lane and lateral clearance, f_W

Lateral clearances on each side (m)	Lane Width		
	3.7m	3.2m	2.7m
2	1.00	0.90	0.70
1	0.90	0.80	0.63
0	0.65	0.60	0.50

(Adapted from Austroads Guide to Traffic Management Part 3, 2008)

Equation 2 - Adjustment factor for heavy vehicles (Austroads 2008)

$$f_{HV} = 1 / [1 + P_{HV}(E_{HV} - 1)]$$

P_{HV} = the proportion of heavy vehicles expressed as a decimal

E_{HV} = the average passenger car equivalents for heavy vehicles as provided in Table 2.

Table 2 – Average passenger car equivalents for heavy vehicles, f_{HV}

Grade	Passenger car equivalents
Level	**2.0**
Moderate	**4.0**
Long sustained	**8.0**

(Adapted from Guide to Traffic Management Part 3, Austroads 2008)

Table 5.1 of Part 3 of the Austroads Guide has simplified the above expression and sets out typical mid-block capacities as presented in Table 3.

Table 3 – Typical mid-block capacities for urban roads with interrupted flow

Type of Lane	One-way mid-block capacity (veh/h)
Median or inner lane	
Divided road	1,000
Undivided road	900
Middle lane (of a 3 lane carriageway)	
Divided road	900
Undivided road	1,000
Kerb lane	
Adjacent to parking lane	900
Occasional parked vehicle	600
Clearway conditions	900

(Adapted from Table 5.1 – Guide to Traffic Management Part 3, Austroads 2008)

Austroads Guide (2008) states that the above volumes can be increased up to 1,400 vehicles per lane per hour if appropriate measures are implemented to reduce potential disruptions to upstream traffic flow. The measures suggested by Austroads (2008) include flaring at upstream intersections, wider carriageway widths, major road priority controls at intersections with minor roads, absence of on-street parking, banning right turns at difficult intersections and efficient coordination of traffic signals for upstream traffic flow. The Guide to Traffic Generating Developments (RMS 2002) advocates the use of mid-block capacities provided in Austroads Guide as presented in Table 3 for assessment of potential traffic impacts on the performance of urban road networks when new land-use developments are proposed.

According to the presented guidelines, there is no difference in the capacity of a kerb lane with clearway conditions and a lane 'adjacent to a parking lane', which is 900 vehicles per hour (RMS 2002). This assumes that the downstream traffic operation has no influence on lane capacity. Clearway restrictions minimise the potential for any interruptions to the mid block traffic flow and thus limiting any impact on the capacity of the adjacent lane. In contrast, the capacity of a lane 'adjacent to a parking lane' is affected on a regular basis during vehicle manoeuvres involved in vehicles parking in and pulling out of the parking lane. Thus the capacity of a kerb lane with 'clearway' conditions and a lane 'adjacent to a parking lane' should not be the same. As a result the road capacities provided in Traffic Impact Assessments may be overestimated and will not reflect the true capacity of a road network adjoining a development. Consequently, developments which may push existing roads over capacity may get mistakenly approved without the need for additional road upgrade works.

This research study attempts to develop a mathematical model to quantify the potential impacts on road capacity from on-street parking. Traffic engineers and council officers who assess Development Applications could use the findings of this study to better assess the impacts of future developments and implement appropriate traffic management measures to ensure that roads operate at satisfactory level of service.

4.   Survey Methodology

A comprehensive methodology was developed to gain an understanding of the influence of on-street parking on the capacity of urban transport corridors. Adjoining land uses to transport corridors generate the need for on-street parking which in turn impacts the traffic flow, ultimately affecting the capacity of the road network. In order to investigate the impacts of on-street parking on capacity, the following tasks were undertaken:

- Conduct field surveys to obtain adequate data to quantify the impact of on-street parking on traffic flow.
- Conduct statistical analysis and develop mathematical models to establish the relationship between on-street parking and road capacity.

A survey was necessary to initially understand the impact of on-street parking zones on driving behaviour within a section of a road. Furthermore the survey provided an opportunity to collect data which had been identified as necessary to observe qualitative impacts and develop mathematical models to quantify impacts. Based on a detailed review of related literature, no survey methodology has been used or developed to achieve the above objectives. As a result, a novel observational survey methodology was devised for this study.

4.1   Pilot Survey

Initially, an observational pilot field survey was conducted on Wednesday, 23 July 2014 to establish the most practical, viable and safe method of undertaking a field survey necessary to collect data. The pilot survey was conducted by two personnel during the morning peak period at a location in Kingsgrove Road between Shaw Street and Morgan Street, Kingsgrove (a suburb within the Sydney Metropolitan Area). The site provides an on-street period parking zone (half an hour) on the eastern side of Kingsgrove Road adjoining the Kingsgrove Shopping Strip. The purpose of the pilot survey was to observe and document the data necessary to be collected to conduct the research and develop the final survey methodology.

4.1.1   Key observations

The observations and findings of the pilot survey which assisted in the development of the survey methodology have been discussed in this section. The parking zones and major land uses present were initially documented prior to undertaking the survey, to ensure all movements related to parking were accounted.

The pilot survey revealed that the area which could be monitored by two personnel was limited to a maximum of 150 meters, in order to capture all the movements into and out of parking spaces. A greater area was deemed difficult to monitor due to a lack of sight and the potential to monitor a large number of movements. Arterial roads, of urban areas, tend to have intersections within every 200 metres meaning that the flow of traffic along the road will be managed by a controlled intersection. Thus, this limitation of the observational survey methodology was deemed not to have a major impact on the data collected.

The nature of the parking zone was documented during the Pilot Survey. Time restrictions associated with a parking zone affected the turnover rate and consequently the number of manoeuvres into and out of the parking zones. Thus, the time restriction applied to a parking zone could be considered as a factor which affects the impact on traffic flow and road capacity. As a result, the time restrictions associated with the zone was documented for the

survey period. Time taken for parking manoeuvres when parking at an on-street parking space and the disruption to traffic flow during each parking manoeuvre varied across the observed users'. The differences lay in the final stages of the parking manoeuvres that were completed within the parking lane. As the objective of this study is to establish potential impact on road capacity as a result of parking manoeuvres, it was decided to measure the disruption to traffic flow during each parking manoeuvre in seconds.

As demonstrated below, three parking manoeuvres were identified during the pilot survey:

- Reverse parking when there is only one parking space available (Figure 2),
- Front in parking when there are more than one consecutive parking spaces available - disruptions to through traffic flow in this instance was comparatively low (Figure 3),
- Leaving an on-street parking space - disruptions to through traffic flow in this instance was comparatively low as vehicles usually wait for a gap within the traffic flow. However, it was noted that occasionally, drivers who were looking for a parking space give-way to vehicles leaving parking bays. In such instances the total disruption to the through traffic flow is very high (Figure 4).
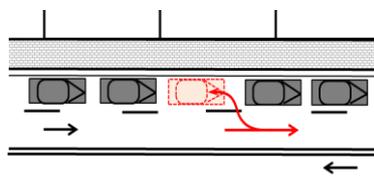
Figure 3 – Reverse Parking   **Figure 2 – Front-in-parking**   **Figure 4 – Leaving a parking space**
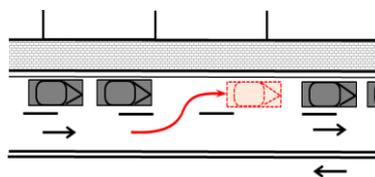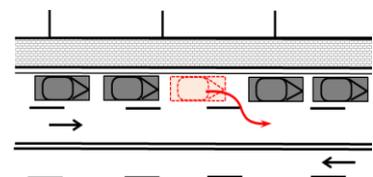
Queue lengths, waiting times and formation of queues were considered important to observe and document within the final survey methodology. These traffic flow characteristics define the impact of the disruption created by the parking manoeuvres completed by the vehicles.

It was considered important to collect additional information such as weather and traffic conditions (congestion level). For an example, during periods of congestion, traffic moves at a very low speed or is stationary. Thus, the presence of on-street parking may have a negligible impact, as heavy traffic volumes already result in queueing. However, it must be noted that even a minor delay could affect the operation of traffic lights. This is the case as, the current traffic signal system in Sydney (SCATS) operates based on demand at each approach at an intersection and upstream delays will have affect the arrival demand profiles.

The knowledge obtained from the pilot survey was used to develop the final survey methodology and is presented in the following section.

4.2   Data Acquisition and Site Selection

The main impact on through traffic flow from on-street parking is caused from manoeuvring of vehicles into and out of on-street parking spaces. Six sites within Sydney metropolitan were selected to undertake the surveys to measure disruption to traffic flow as a result of on-street parking manoeuvres. The sites were selected based on time-restrictions at the parking zone to compare the rate of turnover of parking spaces with different time restrictions. The six sites selected to measure disruptions to through traffic flow as a result of parking manoeuvres at on-street parking areas on:

1. Forest Road between Pearl Street and Gloucester Road, Hurstville, (**unrestricted**)
2. Botany Road between King Street and High Street, Mascot. (**½P**)
3. Botany Road between Hayes Road and Harcourt Parade, Rosebery. (**1P**)
4. Anzac Parade between Gardeners Road and Borrodale Road, Kingsford. (**½P**)
5. Anzac Parade between Borrodale Road and Strachan Street, Kingsford. (**1P**)
6. Anzac Parade south of Gardeners Road at Kingsford Commercial Centre. (**2P**)

As shown above, two selected sites have half-an-hour parking (**½P**) zones, two have one-hour parking (**1P**) zones, one has a two-hour parking (**2P**) zone and one has an unrestricted parking zone.

Each site was surveyed on two weekday peak periods. On each occasion surveys were conducted for a period of one-hour to acquire sufficient data to develop a mathematical model to establish the relationship between on-street parking and road capacity.

The following information and data were collected at each site:
- Existing parking and traffic situation – parking restrictions, parking occupancy rate, lane widths, number of traffic lanes available;
- Day, date and weather;
- Start & end times of each survey;
- Existing traffic condition (free flow vs already congested);
- Other observations– driver behaviour/dangerous manoeuvres;
- Number of vehicles parked/hour (number of disruptions to traffic flow) – turnover rate;
- Start & end times of disruption to the traffic flow (time) during each parking manoeuvre;

Disruption to traffic flow (time taken) during each parking manoeuvre was recorded using a digital watch. Two personnel were used at each site to ensure road safety and accuracy of measurements.

5. Results and Analysis

5.1 Data validation

The objective of field surveys was to use the collected data to develop mathematical models to forecast potential reductions in road capacity of transport corridors as a result of on-street parking. Accordingly, it is important to validate the collected data to ensure that the collected data is consistent, homogenous and fits a theoretical distribution to calculate descriptive statistics such as sample man and standard deviation (Devore & Farnum 2005).

Figure 5 presents the process used to validate collected data prior to incorporating the descriptive statistics into the model.
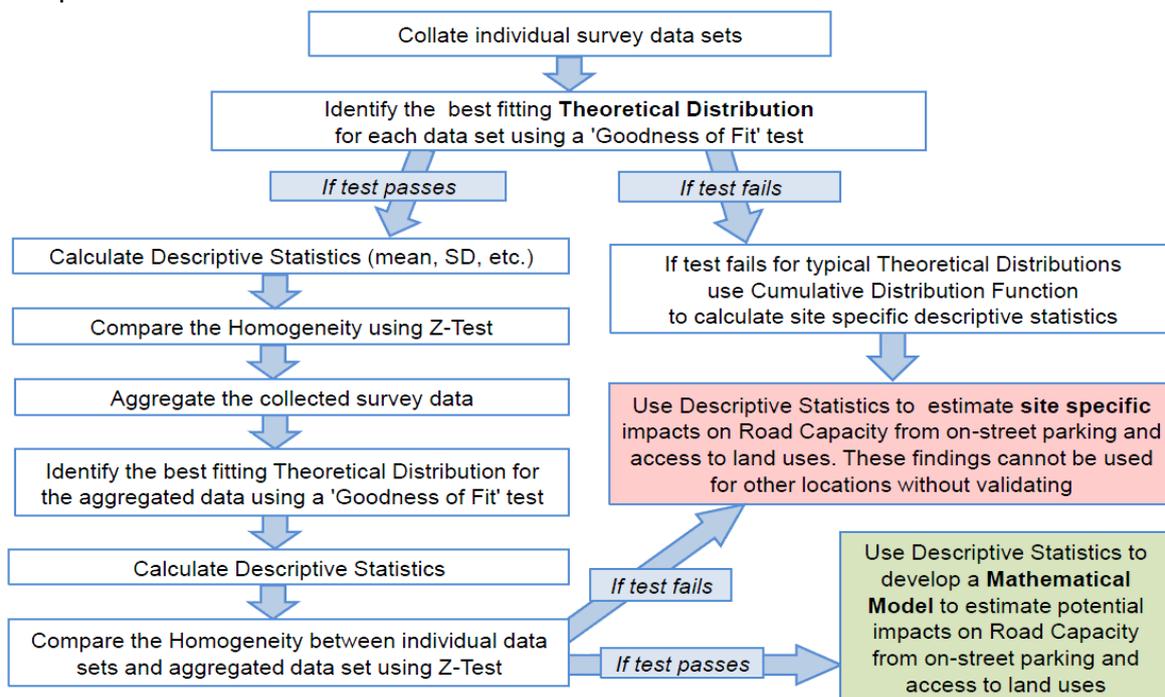
Figure 5 – Flow chart of Data Validation Process for Survey Data

The Anderson-Darling Goodness of Fit test was used to identify the best fitting theoretical probability distribution for each data set. It was concluded 11 out of 12 parking manoeuvre data sets fit a normal distribution with a 95% confidence level. Data set P12 could not be statistically verified due to a small sample size. Consequently, descriptive statistics such as maximum value, minimum value, sample means and standard deviations were calculated con sidering the above distribution, as shown in Table 5.

Table 5 – Results of the Goodness of Fit Tests and Descriptive Statistics

Data Set ID	Tested Theoretical Distribution	Anderson-Darling GoF Result	Sample size (N)	Max value	Min value	Sample mean	Standard deviation
P1	Normal Distribution	**Pass**	42	38	15	25.98	3.88
P2	Normal Distribution	**Pass**	41	32	18	26.05	3.28
P3	Normal Distribution	**Pass**	35	33	11	26.09	4.04
P4	Normal Distribution	**Pass**	33	40	16	26.24	4.42
P5	Normal Distribution	**Pass**	22	30	21	25.95	2.21
P6	Normal Distribution	**Pass**	23	31	21	25.96	2.57
P7	Normal Distribution	**Pass**	24	31	10	25.83	3.90
P8	Normal Distribution	**Pass**	24	32	22	25.96	3.40
P9	Normal Distribution	**Pass**	6	29	24	26.17	1.72
P10	Normal Distribution	**Pass**	7	30	19	25.86	2.41
P11	Normal Distribution	**Pass**	5	32	22	26.40	3.65
P12	Normal Distribution	**N/A**	4	30	23	26.25	3.30
Aggreg	**Normal Distribution**	**Pass**	**265**	**40**	**10**	**26.03**	**3.43**

Table 5 shows that irrespective of the sample size or survey location of the data set 'sample mean' of each data set is approximately equal. Nevertheless, it is necessary to test homogeneity of data sets before the above results can be generalised. If successful, the data can be used to develop an expression for the factor that represents the potential loss of road capacity as a result of on-street parking.

Homogeneity was tested across the data sets to determine whether the collected sample data can be used to represent on-street parking manoeuvres (or in the case of access to properties, access manoeuvres) across urban areas. Homogeneity of data was tested using Z-test by comparing the descriptive statistics of each data set. Z-test was conducted for each pair of data using a Microsoft Excel spreadsheet. The results of the Z-test demonstrate that 65 of the 66 pairs of data sets were homogeneous. Since more than 98% of the pairs of data sets passed the test, the collected data was treated as homogeneous and used in the development of the mathematical model. The aggregated data set was also tested with the Anderson-Darling GoF test and the aggregated on-street parking manoeuvre time data formed a 'normal distribution' similar to that of individual sets of data.

5.2   Development of the Model

Disruptions to traffic flow as a result of vehicles manoeuvring in and out of parking spaces can be considered analogous to the disruptions resulting at signalised intersections or midblock traffic signals used for pedestrian crossings. At traffic signals, traffic flow slows down when the signal changes to amber and stops when it turns red. Similarly, when a vehicle on the lane adjacent to a parking lane indicates to turn left to notify the vehicles behind its intention to park in a parking space, traffic flow slows down and then stops once the subject vehicle starts to manoeuvre into a vacant parking space. Equation 3 presents the expression used to estimate road capacity at traffic signals.

Equation 3 – Road capacity at traffic signals (Austroads 2008)

$$C = \frac{S\,g}{c}$$

Where

C = the capacity in vehicles per hour

S = the saturation traffic flow or the maximum rate of traffic flow in vehicles per hour, if the traffic signals are not in place.

g = the effective green time per cycle in seconds, and

c = the cycle time in seconds

Hence the capacity adjustment (reduction) factor at traffic signals is g/c.

5.2.1 *Formulation of road capacity adjustment factor for on-street parking*

The above basic theory and analysis process described in Austroads Guide (2008) was used to derive an adjustment (reduction) factor to represent the disruptions to traffic flow on the lane adjacent to a parking lane caused by vehicles manoeuvring in and out of on-street parking spaces.

In this instance the cycle time is considered as one hour (3600 seconds). Accordingly, if the cumulative stoppage time (disruption) caused by vehicle manoeuvring in and out of an on-street parking zone into traffic flow on the lane adjacent to a parking lane is $\mathbf{T_P}$

> The effective green time   = (3600 – $\mathbf{T_P}$) seconds

> Thus the adjustment factor, f_P = Effective green time/Cycle Time   = (3600 – $\mathbf{T_P}$)/3600

During the pilot survey it was noted that in most instances parked vehicles wait for a gap in traffic flow on the adjacent lane before pulling out of a parking space.

Occasionally, through vehicles travelling on the adjacent traffic lane slow down and give-way for vehicles pulling out of an on-street parking space. However, the impact on the traffic flow due to the slowing down traffic is difficult to measure without comprehensive speed surveys of comparable sites with and without on-street parking. This type of survey was not possible due to resource and time constraints involved with this particular study. It was also noted that, vehicles searching for a parking space stop and give-way for vehicles pulling out of an on-street parking space holding the traffic flow on traffic lane.

As detailed above, in a majority of the occasions, vehicles pulling out of parking spaces do not disrupt traffic flow. Thus, the impact on road capacity resulting from vehicles pulling out of an on-street parking space is a fraction of the time taken for the parking in manoeuvre. This fraction is considered as k.

Thus, $\mathbf{T_P}$ = $\sum$ (Time taken for **park-in** manoeuvre + k x time taken for **pull-out** manoeuvre)

Considering the above interpretation of the delays incurred by parking manoeuvres, f_P can be expressed by the relationship shown in Equation 4.

Equation 4 – Adjustment factor for on-street parking

$$f_P = [3600 - N_P N_T (t_{PI} + k t_{PO})]/3600$$

Where:

f_P = adjustment factor for estimating road capacity when traffic flow is interrupted by a vehicle manoeuvring in and out of a parking space

N_P = number of parking spaces in the on-street parking zone within the mid-block area under investigation

        = length of the on-street parking zone / average length of a parking space = $L_P/6$

L_P = length of the on-street parking zone

N_T = number of turnovers per parking space per hour

t_{PI} = average time taken for park-in manoeuvre

t_{PO} = average time taken to pull-out from a parking space

k = reduction factor for t_{PO}

The following assumptions underlie the relationship developed to express the adjustment factor for estimating road capacity when traffic flow is interrupted by a vehicle manoeuvring in and out of a parking space:

- Disruptions to traffic flow as a result of vehicles manoeuvring in and out of a parking space is analogous to the disruptions caused at traffic signals when the 'red' phase is in operation.
- Disruption to the traffic flow on the lane adjacent to an on-street parking facility is equal to $(t_{P1} + kt_{P0})$, where t_{p1} is the average time taken for park-in manoeuvre and t_{p0} is average time taken to pull-out from a parking space and k reduction factor for t_{p0}.
- The length of an on-street parking space is 6 metres. This assumption was based on current traffic engineering practices and RMS guidelines (2002).

Based on the findings from the surveys, the disruptions to traffic flow from vehicles pulling out of on-street parking spaces were significantly low. Thus, the reduction factor for t_{PO}, k, was assumed to be zero.

Therefore, t_{PI} = average time taken for park-in manoeuvre = 26 seconds
t_{PO} = average time taken to pull-out from a parking space = 14.6
k = reduction factor for t_{PO} = 0 (as detailed above)
N_P = $L_P/6$

Accordingly, the expression for road capacity adjustment factor, f_P, for on-street parking can be simplified based on the survey data to form a mathematical model as presented in Equation 5.

$$f_P = \frac{(3600 - 26\,L_P N_T)}{3600 \times 6}$$

Equation 5 – Adjustment factor for on-street parking

$$f_P = 1 - 0.0012\,L_P N_T$$

L_P = length of the on-street parking zone
N_T = number of turnovers per parking space per hour. N_T for commonly used period parking zones derived from the survey data (Refer to Section 5.2.2).

5.2.2   Determination of average turnover of vehicles per parking space

As detailed in the methodology, the average turnover of parking spaces is the ratio between the number of vehicles parked-in within a specific time period and the total available parking spaces within the parking zone. Detailed calculations of average turnover of parking spaces at each survey site during the survey periods were undertaken. The summary of the analysis is depicted below as Table 6.

Table 6 – Average turnover of parking spaces at each survey site

Survey Site Location	Existing Period Parking Restriction			
	½ P	1 P	2 P	Unrestricted
Botany Rd @ Mascot shops	2.63	-	-	-
	2.56	-	-	-
Botany Rd, Rosebery	-	1.28	-	-
	-	1.33	-	-
Forest Rd, Hurstville	-	-	-	0.25
	-	-	-	0.20
Anzac Pde, Kingsford	2.69	1.22	0.75	-
	2.54	1.28	0.88	-
Average turnover, veh/pkg sp./hr	**2.60**	**1.28**	**0.81**	**0.23**

Accordingly, N_T values for the expression derived for road capacity adjustment factor, f_P for on-street parking was taken as the average turnover of vehicles per parking space per hour which is presented in Table 7.

Table 7 – N_T for commonly used period parking zones

On-street parking time restriction	½ P	1 P	2 P	Unrestricted
N_T Average turnover of vehicles per parking space per hour	2.60	1.28	0.81	0.23

5.2.3 Estimation of road capacity when on-street parking is permitted

An expression for capacity was derived, incorporating the adjustment factor developed in this study to account for on-street parking, f_P, to the relationship provided by the Austroads Guide (2008) in Equation 1. This modified relationship has been presented in Equation 6.

Equation 6 – Estimated capacity of a traffic lane incorporating the proposed on-street parking adjustment factor

$$C = 1800.f_W \cdot f_{HV} \cdot f_P$$

Where:

C = laneway capacity in veh/h under prevailing roadway conditions

1800 = capacity of a traffic lane without overtaking capabilities

f_W = adjustment factor for narrow lanes and lateral clearances as provided in Table 1.

f_{HV} = adjustment factor for heavy vehicles

= $1/[1 + P_{HV}(E_{HV} - 1)]$

P_{HV} = the proportion of heavy vehicles expressed in decimal

E_{HV} = the average passenger car equivalents for heavy vehicles as provided in Table 2.

f_P = the adjustment factor for on-street parking as derived in Equation 5.

5.3 Application of Model for Road Capacity Estimation

Table 8 provides a comparison of estimated road capacities with and without taking into account potential impacts from on-street parking. In other words, the table provides a comparison of the two methods that have been considered throughout the study.

It is evident from the results that short term parking has a greater impact on the road capacity compared to long term parking. Accounting for the half hour parking zones reduces the estimated capacity by up to 13% (Botany Road @ Mascot Shops). However this impact reduces as the time restriction increases and the turnover of parking spaces reduce. It is noted that for the two hour parking zone, the percentage reduction in capacity caused by on-street parking is less than 2.5%.

All day parking has minimal impact on the capacity of the lane adjacent to parking lane. This is evident with the Forest Road site, with capacities ranging between 890 and 917, across the three methods. The comparison clearly demonstrates that it is important to incorporate the presence of on-street parking in the estimation of road capacity. Application of the mathematical expressions developed in this study indicates that the presence of short term parking, between ½ hour and 1 hour, has a significant impact on road capacity measurement.

Table 8 – Comparison of Austroads and Study Road Capacity Estimates

Surveyed Site Location	Austroads road capacity estimate (veh/h) "A"	Proposed empirical model estimate including adjustment factor for parking, f_P (veh/h) "B"	Difference, (veh/h) "A - B"	Percentage reduction (veh/h) "((A - B)/A)%"
Botany Rd @ Mascot shops at 1/2 P zone	1,906	1,650	256	13%
Botany Rd, Rosebery @ 1P zone	1,014	841	173	17%
Anzac Pde, Kingsford @ 1/2P zone	1,851	1,649	202	11%
Anzac Pde, Kingsford @ 1P zone	1,920	1,774	146	8%
Anzac Pde, Kingsford @ 2P zone	2,057	2,007	50	2%
Forest Rd, Hurstville @ unrestricted zone	917	890	27	3%

6. Discussion

6.1 Value of this project to key stakeholders

The findings of this research study clearly demonstrate that on-street parking significantly impacts the capacity of the adjacent traffic lane. At present these factors are not considered when assessing impacts of new land use developments on the adjoining road network. As a result operational capacities of roads are overestimated. If the impacts of on-street parking are taken into account, some of the complying land use developments may not be feasible without major road infrastructure upgrades.

Consequently, the findings of this research study will be of interest to Traffic Engineers, Transport Planners, Town Planners and Local Government Authorities in preparing traffic impact assessments for new developments, assessing planning proposals and development applications to accurately predict potential impacts of existing and proposed developments on the adjoining road network.

Additionally, the findings and recommendations of the study can also be used for further studies and planning of future land use developments adjacent to transport corridors. It is also anticipated that the findings of this research project would motivate other researchers to further investigate the impacts of on-street parking and access to adjoining land uses on road capacity. Consequently, this research project will be of interest to transport research institutions, Universities, Local Government Authorities, the Roads and Maritime Services (RMS), Transport for NSW, Department of Planning & Environment and consultants.

6.2 Recommendations to alleviate impacts of land uses on road capacity

Road authorities and other planning authorities use a number of traffic control measures and travel demand management strategies to reduce traffic congestion by either improving road capacity or restraining private vehicular trips, especially during peak traffic periods. Some of the measures that are in use to reduce potential impacts of on-street parking include introducing peak period parking restrictions such as clear-ways to improve road capacity in peak periods (TfNSW 2013). Additionally, it is recommended that a review was conducted on the existing on-street parking facilities along major transport corridors, to explore the possibility of removing them or relocating them to adjacent local streets. Traffic congestion can also be managed by introducing travel demand management strategies to restrain trips, especially during peak traffic periods to alleviate traffic congestion.

Suggested alternative measures to reduce potential impacts of on-street parking include the provision of better designed marked on street parking bays to reduce the impact of parking manoeuvers. As detailed in Section 2, O'Flaherty (1986) suggested alternative designs for

on-street parking spaces based on average sized vehicles in the UK. The study revealed that providing a 1.2 metre manoeuvring area as presented in Figure 1 will allow cars to enter the parking spaces in a front direction without the need for reversing. This will reduce the potential interruptions to the traffic flow on the adjoining traffic lane.

7.   Conclusion

Traffic congestion within modern day urban transport networks has been a significant social, economic and environmental issue. At present, impacts on traffic flow from adjoining land use activities such as on-street parking is not taken into account when assessing road capacities (Austroads Guide to Traffic Management, 2008).

This study has focused on investigating and quantifying the indirect impacts on road capacity as a result of vehicle manoeuvres associated with on-street parking facilities. A tailored survey methodology was developed, to assess and collect the necessary data. The findings of this research study clearly demonstrate that on-street parking markedly impact the capacity of roads, with ½ P zones resulting in a 17% reduction in theoretical capacity as compared to the current Austroads assessment. Additionally, the results indicate that the reduction in capacity of the lane adjacent to a parking lane is greater when the time restriction of an on-street parking zone is short. The study suggests possible reduction factors that can be used in road capacity estimations when on-street parking is allowed in an urban transport corridor.

Conversely, due to the scale and scope of this research study, the collected data may not be representative of all transport corridors throughout Sydney. Consequently, it would be beneficial to extend this study by undertaking a larger sample of field surveys to cover a wider range of roads in Sydney Metropolitan area to refine the adjustment factors recommended in this study.

Once the adjustment factors developed in this study are refined and validated, they can be incorporated within transport guidelines and road infrastructure standards to appropriately account for the impacts of on street parking and access points on road capacity. If the impacts of on-street parking are taken into account, some of the complying land use developments may not be feasible without major road infrastructure upgrades. Accordingly, the findings of this study have the potential to improve traffic flow and to take appropriate steps to alleviate congestion throughout the network.

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