# TRIP GENERATION SURVEYS
# HIGH DENSITY RESIDENTIAL (CAR BASED)
# ANALYSIS REPORT
# BY BITZIOS CONSULTING

# FOR
# ROADS AND MARITIME SERVICES NSW

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# 1. INTRODUCTION

## 1.1 BACKGROUND

Roads and Maritime Services, NSW commissioned Bitzios Consulting to undertake a trip generation and parking demand survey and analysis of Car-Based High Density Residential buildings. The *Road's and Maritime Services Guide to Traffic Generating Developments – 2002* (hereafter referred to as the *Guide*), contains traffic generation and parking demand information based on surveys completed in 1993. This has recently been updated in a 2013 Technical Direction of the *Guide* based on a 2012 study.

Roads and Maritime Services recognised that previous studies have looked at sites generally close to high frequency - high capacity public transport. In recent years there has been a trend towards higher density residential developments along corridors not necessarily well serviced by public transport. Roads and Maritime Services identified that new data is required focusing on residential developments that are considered "Car-Based" due to potential differences in the trip generation and parking generation compared to developments in public transport orientated centres. Key considerations in identifying the need for this study include:

- awareness that previous (2012) surveys did not adequately reflect differences in regional areas;
- recognition that previous (2012) surveys did not adequately account for accessibility to public transport;
- changing demographics with an aging population and smaller average household sizes;
- housing affordability trends and the tendency for some younger people to stay living in the family home longer;
- higher residential densities;
- increases in car ownership;
- impacts of higher fuel costs;
- changing work and leisure patterns;
- increases in the average age for obtaining a drivers licence;
- increased awareness of child safety prompting more families driving children to school;
- generational change where driving distances reduce; and
- changing School-bound travel patterns.

## 1.2 SCOPE

The scope of this study included:

- identifying a suitable sample of high density residential developments that are not well served by public transport within greater Sydney and NSW regional areas, with a sufficient sample size and development variety to provide confidence in the results;
- collecting relevant background data for each site (e.g. number of units, ground floor developments, on-site parking availability);
- surveying each site to collect all-mode trip generation data;
- assembling information on all-mode trip generation and parking demand data;
- tabulating and analysing the collected data to establish key statistical relationships;
- comparing the data analysis findings with those in the *Guide* and in the 2012 study; and
- presenting the results and recommendations in a Data Report and Analysis Report.

This report refers to data collected from the survey sites and should be read in conjunction with its companion Data Report. This report presents the results of the analysis of the data and provides conclusions and recommendations for consideration determining appropriate trip, traffic and parking generation rates for sites across NSW.

## 1.3 DEFINITION OF KEY TERMS

Roads and Maritime Services – Roads and Maritime Services NSW

Trip Generation – Generation of trips undertaken by individuals, including pedestrian, cyclist, or persons.

Traffic Generation – Individual vehicle trips regardless of number of persons within the vehicle.

## 1.4 PROJECT CHALLENGES AND RESPONSES

Table 1.1 summarises challenges that occurred during the course of this project and the steps taken to address them.

Table 1.1: Addressing Project Challenges

| Challenges | Steps Taken |
|---|---|
| Identifying sites that meet Roads and Maritime Services criteria (i.e. distance from Public Transport), particularly within the Sydney Metropolitan Area. | Analysis of public transport routes and maps, discussions with Roads and Maritime Services and looking for sites in alternative locations. Over 80 sites were referred to Roads and Maritime Services for approval. |
| Contacting building or strata managers in order to gain permission to undertake surveys and receiving approval. | Site visits to all selected locations in conjunction with numerous phones calls and emails to various contacts connected to each site. |
| Ensuring a *typical* weekday and weekend was surveyed for each site. | Surveys were undertaken outside of School Holiday periods:<br>▪ Gold Coast sites – 20/04/17 to 31/06/17; and<br>▪ Sydney/NSW – 15/06/17 to 01/07/17. |
| Timing challenges impacting sub-contracted survey teams. | Due to challenges around survey timing and in contacting each site for permission an additional survey team was introduced. |
| Building or strata managers providing site information. Some sites required strata meetings to be held before data was provided, others preferred to only provide limited datasets. | Along with phone calls and emails to the relevant contacts, site visits and aerial imagery was utilised to source as much data on each site as possible. |
| The large number of survey sites increased the likelihood of data collection errors or corrupted datasets. | Where possible, additional surveys were undertaken to correct probably data errors. All other errors were noted within the Data Report and were taken into consideration throughout the data analysis. |

# 2. SITE SELECTION

## 2.1 CANDIDATE SITES

A total of 84 candidate sites were selected for initial consideration, comprising of 49 within Sydney metropolitan areas and 35 in regional areas. The key criteria used to determine candidate sites included:

- newer developments;
- limited accessibility to major public transport hubs and corridors;
- provides a reasonable geographic spread;
- either owner-occupied units or commercially tenanted;
- greater than six (6) storeys in height;
- range in size (minimum 20 units); and
- no significant traffic generators (e.g. shops) within the residential block.

## 2.2 SELECTION BASIS

A total of 28 sites were selected from the 84 candidate sites, comprising of 8 Sydney Metropolitan, 9 Sydney Sub-Metropolitan and 11 regional sites. The final selection of sites was based on a number of key factors to ensure that the surveys would provide a meaningful representation of 'car based' residential units, including:

- being at least 1km from rail stations and 500m from bus stops or ferry terminals;
- the availability of on-site parking provision and the relevant building information needed for the dataset;
- the site's proximity to sites in 2012 surveys to allow for some data comparison; and
- ensuring an appropriate level of geographical spread across metropolitan and regional areas.

Metropolitan sites have been defined as those located within built-up areas approximately 8 km from the Sydney CBD. Sites outside this area but within the defined Sydney metropolitan area have been defined as Sub-Metropolitan while the remaining sites across NSW and the Gold Coast have been defined as Regional.

Regional sites have been selected in Wollongong, Central Coast, Newcastle, Coffs Harbour and on the Gold Coast to provide geographical spread across regional areas. A total of four (4) sites were selected on the Gold Coast, QLD to provide alternative comparison data from a regional centre that is historically car based with very limited public transport availability.

A total of 15 sites were manually surveyed to provide a full set of information for analysis. A further 13 sites were surveyed automatically using survey cameras. The additional 13 automatic sites augmented traffic and pedestrian movement data to increase the sample sizes for these primary data sets.

Approximate site locations are shown in Figure 2.1.

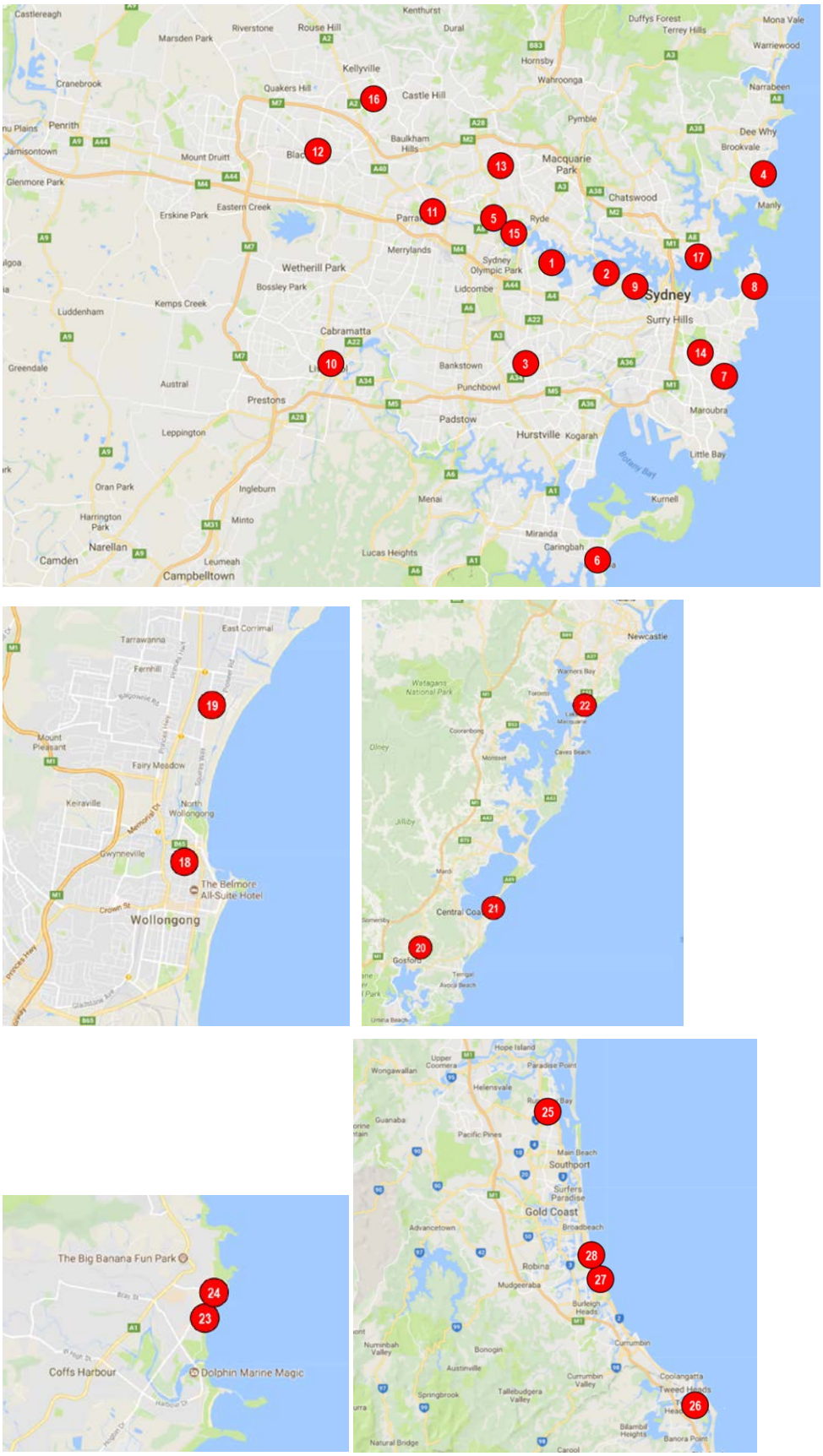



Figure 2.1: Site Locations

# 3. SURVEY DETAILS

## 3.1 SURVEY SCHEDULE

Surveys were completed for a single weekday and single weekend day at each of the 28 sites, resulting in a total of 56 full days of data. Weekday surveys occurred on a Tuesday and Thursday. Both Saturday and Sunday were used for the weekend surveys. All surveys were undertaken between 6:00am to 7:00pm.

Surveys within Sydney and surrounds were undertaken by Austraffic with survey summaries provided in Appendix B of the Data Report. Gold Coast surveys were undertaken by Traffic and Data Control (TDC) with survey summaries provided in Appendix C of the Data Report.

The survey program comprised a mix of manual and automatic counting, parking counts and intercept surveys. These include:

- 15 sites were manually surveyed to obtain parking occupancy and to interview residents regarding transport mode split and travel patterns (see Section 3.2);
- one site was manually surveyed for a full weekday and weekend day on the Gold Coast (6.00am – 7.00pm);
- 14 manual surveys were undertaken in the Sydney Metropolitan and Sub-Metropolitan areas. Due to various constraints, parking surveys involved an initial count in the morning and intercept surveys spanned a 2-hour period during the morning peak period (7.00am-9.00am). Full day (6.00am – 7.00pm) traffic and pedestrian movement surveys were conducted in conjunction with the manual surveys; and
- the remaining 13 sites were surveyed using cameras only to count pedestrian and traffic movements.

Traffic counts were also conducted on the nearest road (with reasonable traffic volumes) fronting each site, on a weekday and a weekend day. Site details are summarised in Table 3.1 and in Appendix A.

Table 3.1: Site Information Summary

| Site No. | Site Location | Address | Year Built | Units | Weekdays Survey Date | Weekends Survey Date |
|---|---|---|---|---|---|---|
| 1 | Metro | 25 Market Street, Breakfast Point | 2003 | 40 | 15/06/2017 & 27/06/2017^ | 17/06/2017 & 25/6/2017^ |
| 2 | Metro | 84 St Georges Crescent, Drummoyne | 1970 | 60 | 20/06/2017 & 27/06/2017^ | 18/06/2017 & 25/6/2017^ |
| 3* | Sub-Metro | 502-518 Canterbury Road, Campsie | 2016 | 95 | 22/06/2017 | 24/06/2017 |
| 4 | Sub-Metro | 20 Bonner Avenue, Manly | 1973 | 64 | 20/06/2017 & 27/06/2017^ | 18/06/2017 & 25/6/2017^ |
| 5 | Metro | 48-52 Bundarra Street, Ermington | 2016 | 329 | 15/06/2017 | 17/06/2017 |
| 6 | Sub-Metro | 13-17 Coast Ave Cronulla, New South Wales | 1969 | 23 | 20/06/2017 & 27/06/2017^ | 18/06/2017 & 25/6/2017^ |
| 7 | Sub-Metro | 178-180 Beach Street, Coogee | 1968 | 32 | 22/06/2017 | 24/06/2017 |
| 8 | Sub-Metro | 33 Kimberley St, Vaucluse | 1963 | 60 | 20/06/2017 & 27/06/2017^ | 18/06/2017 & 25/6/2017^ |
| 9* | Metro | 1 Buchanan Street, Balmain | 1990/2000 | 82 | 20/06/2017 & 27/06/2017^ | 18/06/2017 & 25/6/2017^ |
| 10 | Sub-Metro | 24 Lachlan St, Liverpool | 2014 | 104 | 15/06/2017 | 17/06/2017 |

| Site No. | Site Location | Address | Year Built | Units | Weekdays Survey Date | Weekends Survey Date |
|---|---|---|---|---|---|---|
| 11 | Metro | 3 Broughton Street, Parramatta | 2016 | 277 | 15/06/2017 | 17/06/2017 |
| 12 | Sub-Metro | 2 Bruce Street, Blacktown | 2009 | 32 | 22/06/2017 | 24/06/2017 |
| 13* | Sub-Metro | 27 Seven St, Epping Park | NA | 76 | 15/06/2017 | 17/06/2017 |
| 14* | Metro | 96 Alison Rd, Randwick | NA | 32 | 20/06/2017 | 18/06/2017 |
| 15* | Metro | 8 Marine Parade, Wentworth | 2012/2013 | 45 | 15/06/2017 | 17/06/2017 |
| 16 | Sub-Metro | 38 Solent Circuit, Baulkham | 2015/2016 | 93 | 20/06/2017 | 18/06/2017 |
| 17 | Metro | 17 Raglan Street, Mosman | 1969/1970 | 48 | 20/06/2017 & 27/06/2017^ | 18/06/2017 & 25/6/2017^ |
| 18 | Rural | 32-34 Church St, Wollongong NSW | 2015 | 34 | 22/06/2017 | 24/06/2017 |
| 19 | Rural | 1 Grand Court, Fairy Meadow, Wollongong NSW | 2013 | 44 | 22/06/2017 & 29/06/2017^ | 24/06/2017 & 01/07/2017^ |
| 20 | Rural | 80 John Whiteway Drive, Gosford, Central Coast NSW | 2004 | 188 | 22/06/2017 | 24/06/2017 |
| 21* | Rural | 65 Ocean Parade, The Entrance, Central Coast NSW | NA | 30 | 22/06/2017 | 24/06/2017 |
| 22 | Rural | 46 Brooks Parade, Belmont, Newcastle NSW | 1974 | 27 | 22/06/2017 | 24/06/2017 |
| 23 | Rural | 77-79 Ocean Parade, Coffs Harbour NSW | 1975 | 30 | 22/06/2017 | 24/06/2017 |
| 24 | Rural | 121 Ocean Parade, Coffs Harbour NSW | 1982 | 61 | 22/06/2017 | 24/06/2017 |
| 25 | Rural | Marina Shores, Harbourside Court, Biggera Waters QLD | 2015 | 192 | 20/04/2017 | 22/04/2017 |
| 26 | Rural | 22 Davey St, Tweed Heads NSW | Early 1980s | 71 | 27/04/2017 | 29/04/2017 |
| 27 | Rural | 194-198 The Esplanade, Burleigh Heads QLD | NA | 24 | 20/04/2017 | 22/04/2017 |
| 28* | Rural | 90 Marine Parade, Miami QLD | NA | 26 | 01/06/2017 | 03/06/2017 |

** Information for this site was not provided by building management and estimated using alternative methods.*

*^ Video Survey Error occurred and additional survey was undertaken.*

## 3.2 DATA COLLECTION

The following data was collected during the surveys:

- number of entering and exiting vehicles (cars/heavy vehicles) (in 15-minute periods);
- number of vehicle occupants (in 15-minute periods);
- number of pedestrians and cyclists (in 15-minute periods);
- the time that a vehicle enters the site;
- the time that a vehicle exits the site; and
- the number of vehicles passing the site (in 15-minute blocks).

In addition to the above data, 15 selected sites were manually surveyed for parking occupancy and to ask residents four questions aimed at determining trip mode and usage of on-street parking. The questions were:

1. "Are you catching public transport or did you use public transport?"
2. If Yes to Question 1 – "What mode of public transport? - Bus (B) / Train (T) / Taxi or Uber (U)"
3. "Do you have a car that you drive at other times?"
4. "If you have a car that you use at other times, do you park in the car park here or on the street?"

## 3.3 SITE INFORMATION

The following additional site information was collected for each building:

- year the building was constructed;
- on-site parking availability;
- parking allocation to residents, visitors, service vehicles, disabled and other;
- number of units by 1 bedroom, 2 bedrooms and 3+ bedroom sizes;
- building occupancy levels; and
- number of residents.

In addition to the above, each building's footprint area was estimated using NSW Globe Imagery data.

Local Council information and on-site observations were used where information was not available or not provided by building managers. Sites where information was sourced in this manner are noted in Table 3.1.

# 4. SUMMARY DATA AND GENERAL FINDINGS

Preliminary analysis was conducted on the data including determining site and network peak periods, vehicle trips per unit (traffic generation) and location-based differences.

## 4.1 COMPARISON WITH OTHER SURVEY DATA

### 4.1.1 Previous Roads and Maritime Services Surveys

The data has also been compared to equivalent site data from the previous 2012 study where possible, to check for consistencies and to identify any clear errors. Sites selected for comparison were based on being geographically close to the sites in the 2012 Study. Table 4.1 shows a comparison of traffic generation rates for previous studies.

Table 4.1 Site Specific Comparison of Traffic Generation with Previous Roads and Maritime Services Study

| Site Number | Peak Period Traffic Generation | 2012 Site Number | 2012 Study - Peak Period Traffic Generation |
|---|---|---|---|
| 6 | 23 units, 0.35 trips per unit (AM), 0.43 trips per unit (PM) | 3 | 28 units, 0.07 trips per unit (AM), 0.11 trips per unit (PM) |
| 9 | 82 units, 0.25 trips per unit (AM), 0.3 trips per unit (PM) | 10 | 131 units, 0.18 trips per unit (AM), 0.1 trips per unit (PM) |
| 11 | 277 units, 0.22 trips per unit (AM), 0.31 trips per unit (PM) | 5 | 83 units, 0.27 trips per unit (AM), 0.12 trips per unit (PM) |
| 15 | 154 units, 0.29 trips per unit (AM), 0.30 trips per unit (PM) | 6 | 64 units, 0.28 trips per unit (AM), 0.41 trips per unit (PM) |
| 18 | 34 units, 0.49 trips per unit (AM), 0.51 trips per unit (PM) | 9 | 9 units, 0.67 trips per unit (AM), 0.22 trips per unit (PM) |
| 22 | 27 units, 0.30 trips per unit (AM), 0.30 trips per unit (PM) | 8 | 108 units, 0.39 trips per unit (AM), 0.42 trips per unit (PM) |

*Note: Sites selected for comparison from this study are located in similar locations in the 2012 study.*

The comparison shows that, in general, traffic generation is lower for buildings located close to public transport (2012 study) than those further away (this study) for Metropolitan sites in Sydney.

The relationships between AM peak and PM peak rates, and the rates in general are far more consistent in the 2017 data compared to the 2012 data.

Table 4.2 compares 2017 traffic generation surveys resulting rates with previously published Roads and Maritime Services defined traffic generation rates from a *2013 Roads and Maritime Services Technical Direction* and the *Roads and Maritime Services Guide to Traffic Generating Developments - 2002*.

Table 4.2: Comparison with Previous Roads and Maritime Services Defined Traffic Generation Rates

| Weekday Trip Generation Rates | Bitzios 2017 Surveys Sydney Metropolitan Average | Bitzios 2017 Surveys Sub-Metropolitan Average | Bitzios 2017 Surveys Regional Average | Roads and Maritime Services Technical Direction – 2013 Sydney Average | Roads and Maritime Services Technical Direction - 2013 Regional Average | Roads and Maritime Services Guide – 2002 Peak Trips Metropolitan centres | Roads and Maritime Services Guide – 2002 Peak Trips Sub-Regional Centres |
|---|---|---|---|---|---|---|---|
| AM peak (1 hour) vehicle trips per unit | 0.26 | 0.28 | 0.31 | 0.19 | 0.53 | 0.24 trips per unit | 0.29 trips per unit |
| AM peak (1 hour) vehicle trips per car space | 0.19 | 0.21 | 0.21 | 0.15 | 0.35 | 0.24 trips per unit | 0.29 trips per unit |
| AM peak (1 hour) vehicle trips per bedroom | 0.10 | 0.11 | 0.16 | 0.09 | 0.21 | 0.24 trips per unit | 0.29 trips per unit |
| PM peak (1 hour) vehicle trips per unit | 0.29 | 0.34 | 0.32 | 0.15 | 0.32 | 0.24 trips per unit | 0.29 trips per unit |
| PM peak (1hour) vehicle trips per car space | 0.23 | 0.25 | 0.22 | 0.12 | 0.26 | 0.24 trips per unit | 0.29 trips per unit |
| PM peak (1 hour) vehicle trips per bedroom | 0.10 | 0.13 | 0.16 | 0.07 | 0.15 | 0.24 trips per unit | 0.29 trips per unit |
| Daily vehicle trips per unit | 1.97 | 2.15 | 2.37 | 1.52 | 4.58 | 0.24 trips per unit | 0.29 trips per unit |
| Daily vehicle trips per car space | 1.50 | 1.58 | 1.59 | 1.34 | 3.22 | 0.24 trips per unit | 0.29 trips per unit |
| Daily vehicle trips per bedroom | 0.74 | 0.80 | 1.30 | 0.72 | 1.93 | 0.24 trips per unit | 0.29 trips per unit |

As shown above, traffic generation rates found in the 2017 study are more consistent with the *Guide – 2002 Edition* than those within the 2013 Technical Direction. This is likely due to the focus of the 2017 study being on developments with limited access to public transport. Furthermore, historical trip rate and travel trends would typically be expected to remain similar at sites away from public transport than those that have been provided with improved public transport options over time.

### 4.1.2 Other Sources

In order to provide a detailed comparison, surveyed traffic generation and volumes were compared with a number of other traffic data sources, including *Institute of Transportation Engineers (ITE) Trip Generation Rates – 8th Edition* and *QLD government datasets (provided by online database)*.

Table 4.3 summarises the recommended ITE vehicle trip generation rates for High Rise Apartments and the resulting average traffic generation rates in this assessment (Bitzios 2017) for each geographical area.

Table 4.3: Traffic Generation Comparison with ITE Rates

| Period | 2017 Survey Rate - Sydney Metropolitan Average (per unit) | 2017 Survey Rate - Sub-Metropolitan Average (per unit) | 2017 Survey Rate - Regional Average (per unit) | ITE Rate - High Rise Apartments (per unit) |
|---|---|---|---|---|
| Weekday | 1.97 | 2.15 | 2.37 | 4.2 |
| AM | 0.26 | 0.28 | 0.31 | 0.3 |
| PM | 0.29 | 0.34 | 0.32 | 0.35 |

ITE rates recommend a significantly higher daily generation rate however peak period rates align with Sub-Metropolitan and Regional site averages.

QLD traffic data relating to high density residential apartments is available via an online database. Relevant high density residential building traffic volume data was found for surveys within Brisbane City suburbs, completed in March 2017. Each survey was 1 week in length. A comparison of Bitzios 2017 surveys in Sydney with QLD data surveys in Brisbane is provided Table 4.4, sites selected for comparison are those of a similar size (i.e. number of bedrooms).

Table 4.4: Surveyed Traffic Volumes Comparison with QLD Traffic Data

| | Site Number | Location | Total Bedrooms | Weekday Volume | Weekend Volume | Weekday Peak Volume | Weekend Peak Volume |
|---|---|---|---|---|---|---|---|
| 2017 Site Surveys | Site 17 | Mosman | 103 | 69 | 84 | 8 | 12 |
| 2017 Site Surveys | Site 8 | Vaucluse | 120 | 55 | 110 | 6 | 17 |
| 2017 Site Surveys | Site 2 | Drummoyne | 127 | 79 | 86 | 11 | 14 |
| 2017 Site Surveys | Site 4 | Manly | 190 | 142 | 101 | 19 | 16 |
| 2017 Site Surveys | Site 26 | Tweed Heads | 213 | 301 | 205 | 34 | 47 |
| QLD Data-2017 | NA | Woolloongabba | 107 | 350 | 286 | 31 | 27 |
| QLD Data-2017 | NA | Kangaroo Point | 118 | 194 | 205 | 18 | 20 |
| QLD Data-2017 | NA | Kangaroo Point | 148 | 146 | 149 | 20 | 20 |
| QLD Data-2017 | NA | Kangaroo Point | 200 | 325 | 320 | 32 | 32 |
| QLD Data-2017 | NA | Eagle Farm | 263 | 407 | 353 | 46 | 33 |

Brisbane sites typically have much higher daily traffic volumes on both weekdays and weekends than the selected Sydney sites of similar size. However, Site 26 in Tweed Heads, NSW appears to align more with the results from Brisbane sites.

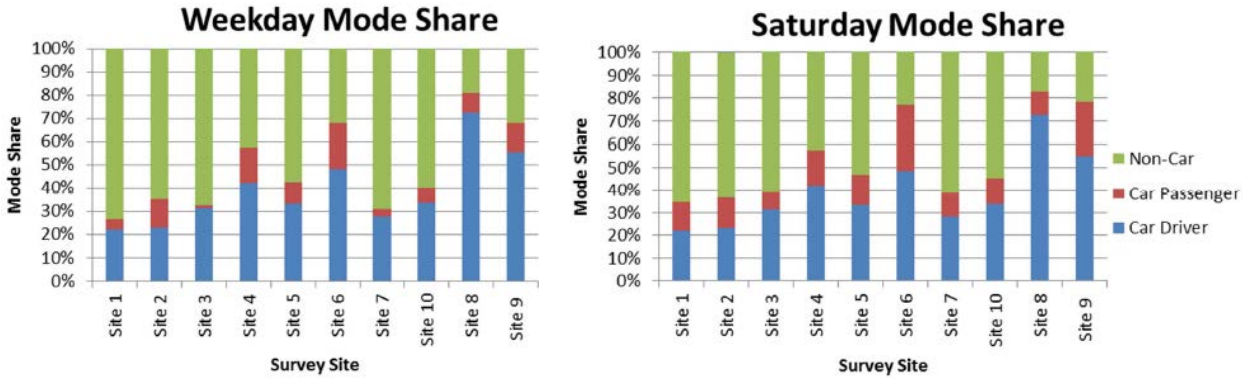
### 4.1.3 Surveyed Mode Share Comparison

A total of 21 of the sites surveyed provided sufficient data to approximate daily mode share for the following:

- Car Driver;
- Car Passenger; and
- Non-Car users (i.e. walk, cycle, public transport, etc).

It should be noted that a further breakdown of transport mode use for those sites that were manually surveyed with questionnaires in Sydney is available within Appendix A.

The 2012 traffic generation report for high density residential apartments summarised the following weekday and weekend mode shares for each site (Figure 9 from 2012 Report), shown in Table 4.1.




*Source: GHD Traffic Generation Analysis Report (2012)*

Figure 4.1: Previous 2012 Traffic Generation Report Mode Share Results

Weekday and weekend mode share at each site surveyed as part of this study are shown in Figure 4.2 and Figure 4.3 respectively. Comparatively with 2012 survey results the following differences were of note:

- less 'car passenger' mode share indicating a higher number of individual drivers;
- weekend and weekday mode share in the 2012 survey is relatively similar which aligns with regional sites in the 2017 surveys. However, metropolitan and sub- metropolitan sites showed a higher vehicle use on weekends, indicating people living within the city are more likely to travel on weekends as opposed to those in regional areas; and
- variability in mode share between sites is similar for all geographical locations, likely due to factors other than geographical location impact mode share (i.e. resident demographics).

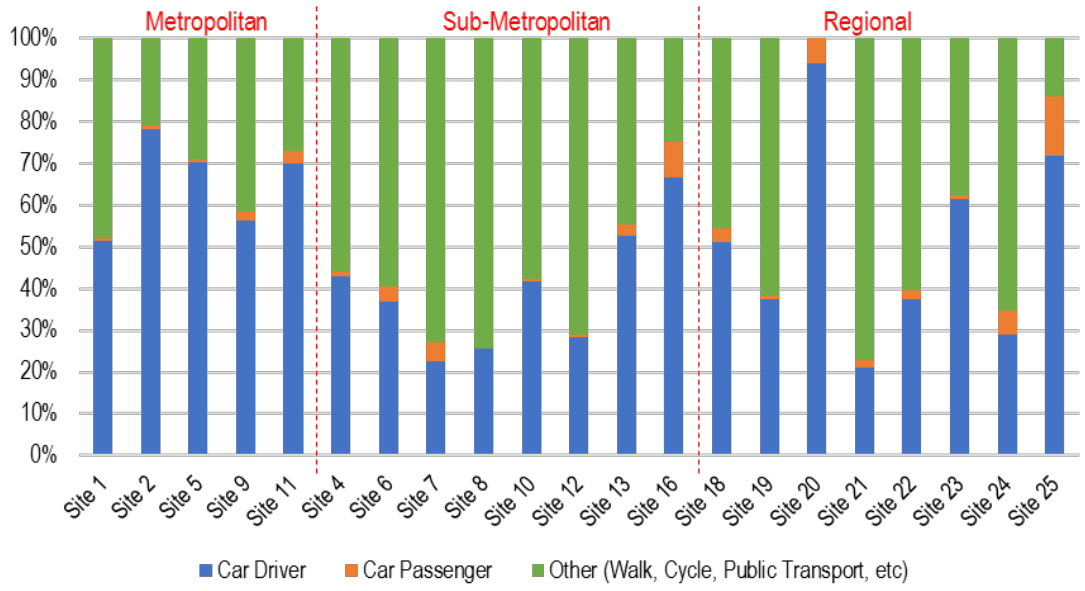



Figure 4.2: Weekday Mode Share – 2017 Survey Sites

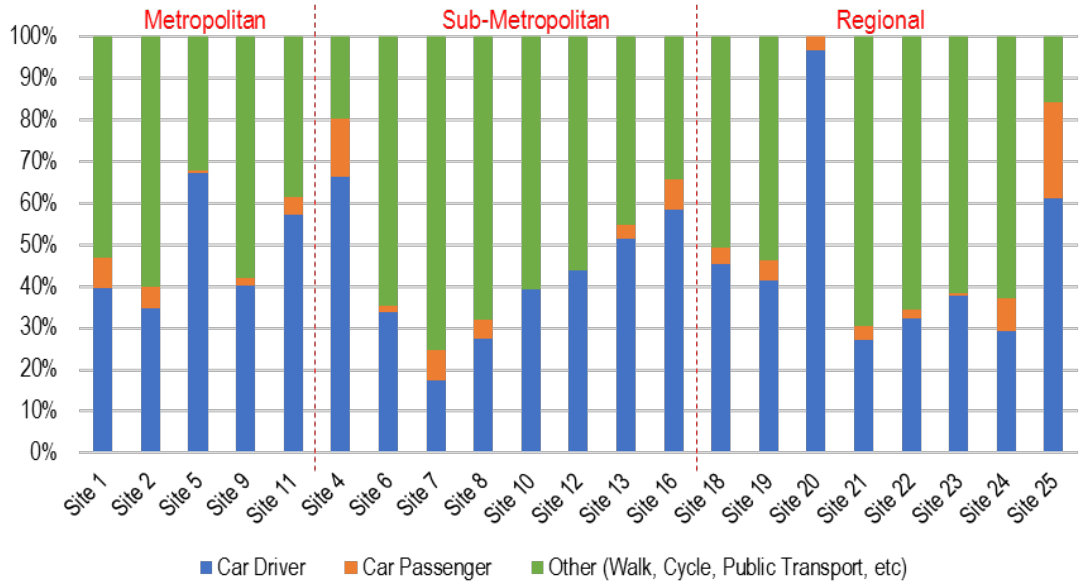



Figure 4.3: Weekend Mode Share – 2017 Survey Sites

Figure 4.4 shows the average mode share of 2017 survey sites by geographical location. Weekend mode share appears consistent across all geographical areas whilst during weekdays sub-metropolitan sites show the lowest average car mode share. It is interesting to note that metropolitan sites show the highest average car usage during weekdays.

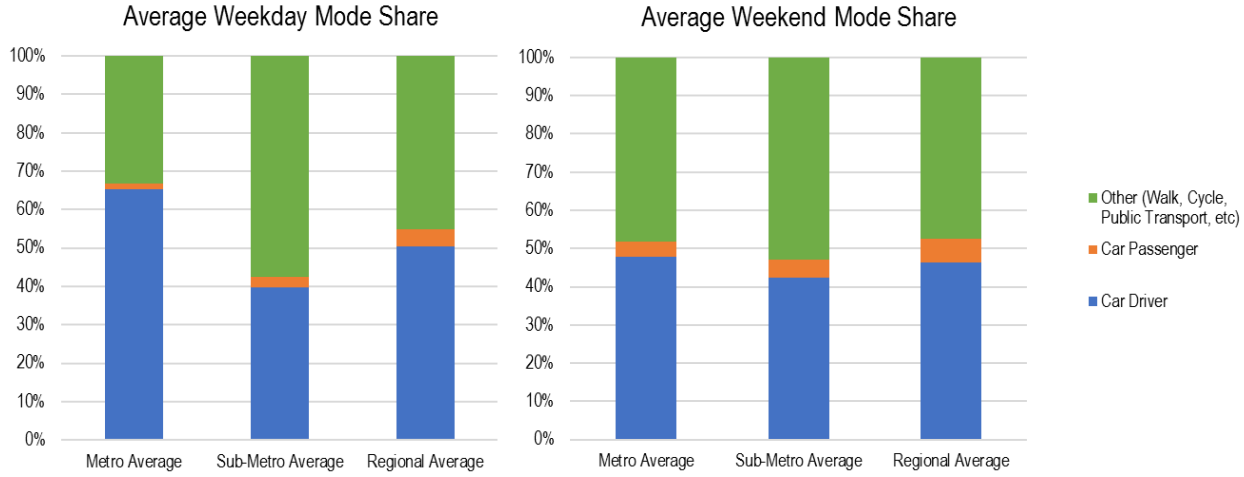



Figure 4.4: Average Mode Share by Geographical Location

It should be noted that car mode share and traffic generation rates were tested to determine any correlation. Analysis found no valid $R^2$ value for any scenario by location or time period between the two variables, as such this model would not provide confidence in use.

## 4.2 METROPOLITAN SITES DATA SUMMARY

### 4.2.1 Weekday Data

The key findings identified from weekday data at locations in the Sydney Metropolitan area were:

- the metropolitan sites showed similar trip generation rates during the AM peak period, but the PM peak shows a slightly greater variation in rates. Peak hours are typically between 7:00am - 8:00am and 5:15pm – 6:15pm;
- on average, the PM peak traffic generation at 0.32 vehicle trips per unit is the highest rate though it is not significantly different to the AM peak and Weekend peak rates;
- based on questionnaire response data, a large number of residents utilised on-street parking, particularly for larger developments where unrestricted on-street parking is available;

- Site 14 and Site 1 have the smallest number of units however their trip generation is relatively high indicating "scale" effects on trip generation rates for some developments;
- Site 5 has the largest number of units and is noted to have considerable unrestricted on-street parking in close proximity;
- average weekday vehicle occupancy for metropolitan sites is 1.05 persons per vehicle; and
- weekday daily trips were marginally lower than those on the weekend including when based on person trips, on vehicle trips and for pedestrian trips.

### 4.2.2 Weekend Data

The key findings were identified from weekend data at locations in the Sydney Metropolitan area were:

- the average weekend peak period occurs at lunch time;
- when compared to the frontage road peak, the site's peak periods were similar with variances up to one hour;
- there is no discernible variation when comparing Saturday and Sunday peak period times;
- average weekend vehicle occupancy for metropolitan sites is 1.11 persons per vehicle, slightly higher than weekdays as expected; and
- weekend peak trip generation rates are similar to those on weekends.

## 4.3 SUB-METROPOLITAN SITES DATA SUMMARY

### 4.3.1 Weekday Data

The key findings identified from weekday data at locations in Sub-Metropolitan areas were:

- when compared to the frontage road peak, the site's peak periods typically differed by up to an hour;
- the highest trip generation occurs during PM peak periods though the PM peak has slightly greater variation than the other peak times. The AM and PM peaks typically occurred between 8:00am - 10:00am and 3:00pm – 5:00pm;
- Sites 3, 7 and 8 show the greatest variation in average AM and PM peak trip generation. Site 7 has a "PM peak" that occurs in the early afternoon while Sites 3 and 8 both have earlier than average AM peak times;
- average weekday vehicle occupancy for sub-metropolitan sites is 1.07 persons per vehicle; and
- all sites consistently have a surprisingly large number of pedestrian trips generated, with counts at sites showing pedestrian volumes higher than the number of daily vehicle trips.

### 4.3.2 Weekend Data

The key findings identified from weekend data at locations in Sub-Metropolitan areas were:

- the weekend peak periods varied across the day between 11:00am and 6:00pm;
- when compared to the frontage road peak, all site peak periods differed considerably;
- there is no apparent pattern when comparing Saturday and Sunday peak periods, with peak periods occurring at varying times;
- sites typically revealed a larger number of vehicle trips than on a weekday;
- average weekend vehicle occupancy for sub-metropolitan sites is 1.14 persons per vehicle, slightly higher than weekdays as expected; and
- weekend peak trip generation rates per unit are relatively consistent across all sub-metropolitan sites.

## 4.4 REGIONAL SITES DATA SUMMARY

### 4.4.1 Weekday Data

The key findings identified from weekday data at locations in Regional areas were:

- AM and PM peaks typically occurred between 7:00am - 8:00am and 5:15pm – 6:15pm and when compared to the frontage road peak, typically differed by 15-30mins;

- AM peak period and PM peak period traffic generation rates at each site were consistent at approximately 0.3 trips per unit;
- sites 18, 25 and 26 have the highest traffic generation rates during the weekday peak periods. These sites are all located a significant distance from active transport attractors (i.e. shops, beach or park);
- the regional sites revealed a smaller number of pedestrian trips per unit than the metropolitan sites however those sites adjacent to the beach had a higher proportion of pedestrian trips;
- average weekday vehicle occupancy for regional sites is 1.07 persons per vehicle; and
- it was also noted that Site 23 (Coffs Harbour) and Site 19 (Wollongong) revealed midday peaks for weekday frontage traffic.

### 4.4.2 Weekend Data

The key findings identified from weekend data at locations in Regional areas were:

- trip generation for regional sites is higher during the weekend peak period than the weekday peak periods and the weekend peak trip rates also show more consistency than the weekday AM/PM peaks rates do;
- the average weekend peak occurs at approximately midday however peak times varied greatly with some site peaks occurring in the morning or in the late afternoon;
- when compared to the frontage road peak, the site peak periods typically differed by 15-30mins;
- there is no discernible variation when comparing Saturday and Sunday peak periods;
- average weekend vehicle occupancy for regional sites is 1.10 persons per vehicle, slightly higher than weekdays as expected; and
- sites typically have a higher number of weekend pedestrian trips generated compared to weekdays.

## 4.5 Peak Traffic Generation Periods

Analysis of survey data found peak traffic generation times for each site typically differed to the adjacent roads peak traffic times. The section below provides some examples of Metropolitan, Sub-Metropolitan and Regional sites development traffic and adjacent road traffic volume profiles throughout surveyed weekdays and weekends.

### 4.5.1 Weekday

Figure 4.5, Figure 4.6, and Figure 4.7 provide examples of surveyed Metropolitan, Sub Metropolitan and Regional site's weekday traffic volumes respectively. Each area's traffic generation profile is compared to the major adjacent roads traffic volumes across the same day.

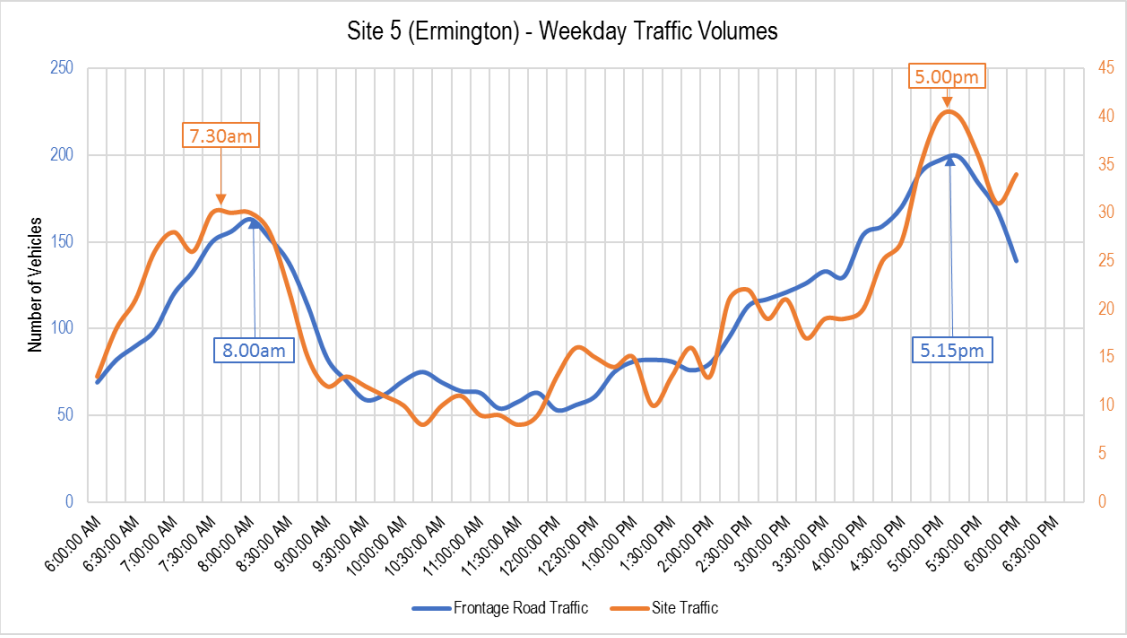



Figure 4.5: Weekday Peak Periods – Example Metropolitan Site

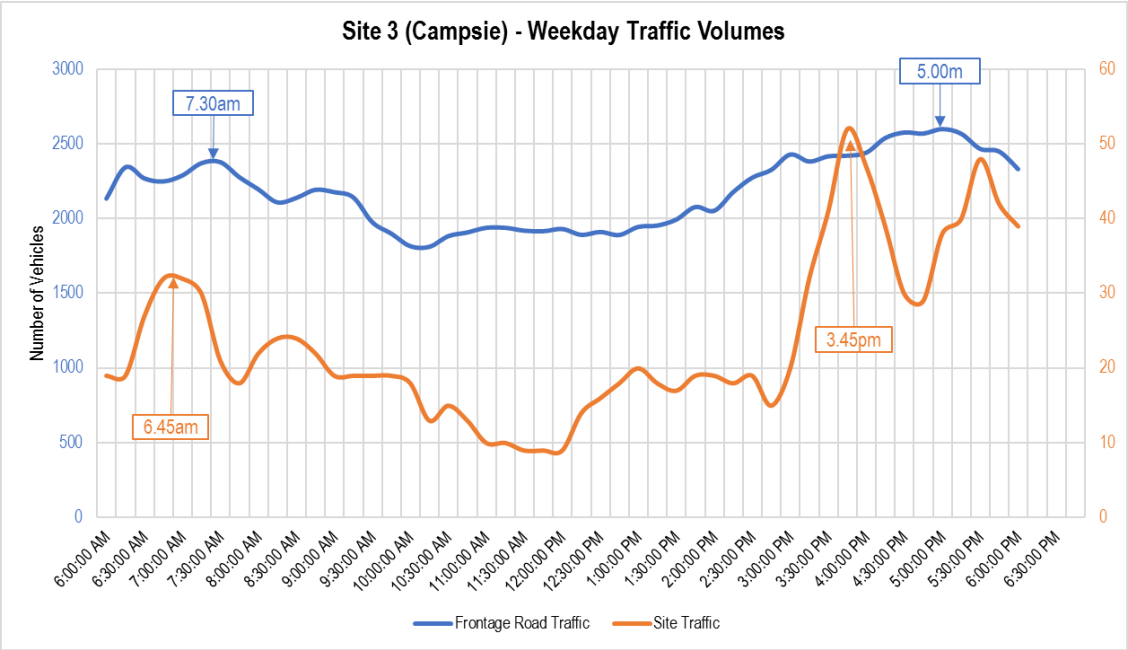



Figure 4.6: Weekday Peak Periods – Example Sub-Metropolitan Site

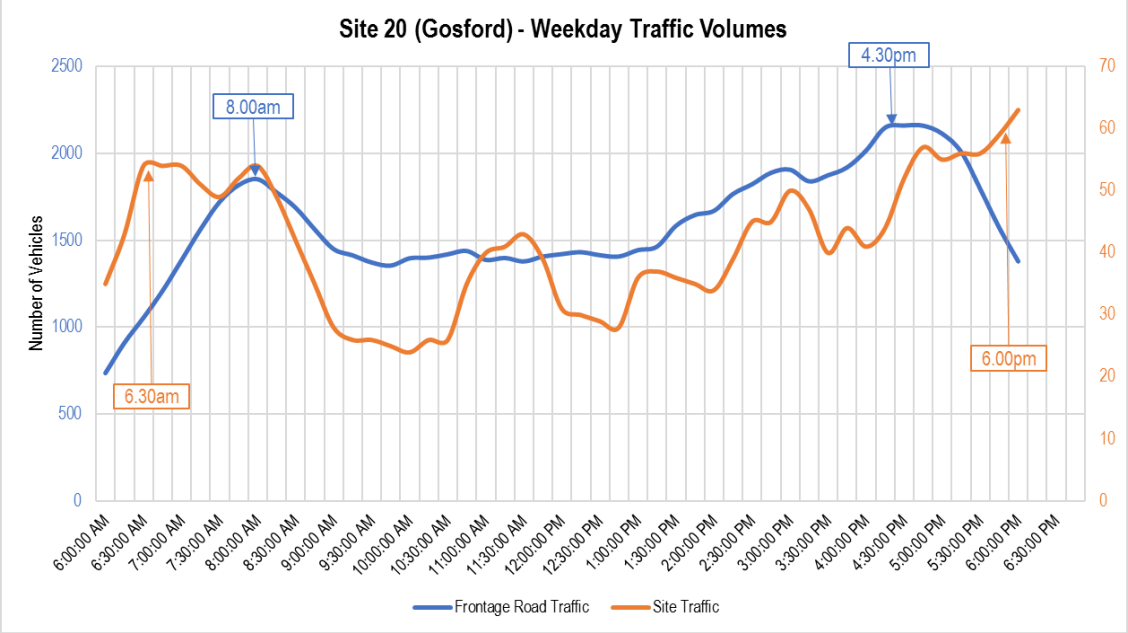



Figure 4.7: Weekday Peak Periods – Example Regional Site

As demonstrated above, each site's peak traffic volumes typically occurred just before or after the adjacent roads peak time. Factors that may influence this trend could include, but not be limited to, residents understanding of peak traffic times, distance from place of work, site demographics.

### 4.5.2 Weekend Peak Periods

Figure 4.8, Figure 4.9 and Figure 4.10 provide examples of a Metropolitan, Sub Metropolitan and Regional site's weekend traffic volumes respectively. Each is compared to the major adjacent roads traffic volumes across the same day.

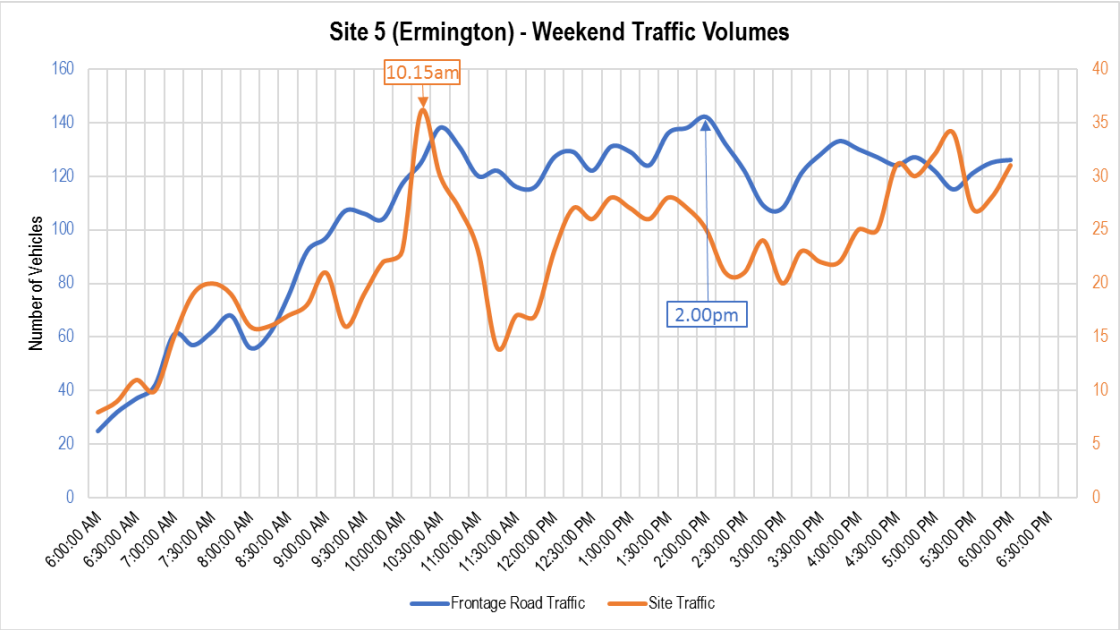



Figure 4.8: Weekend Peak Periods – Example Metropolitan Site

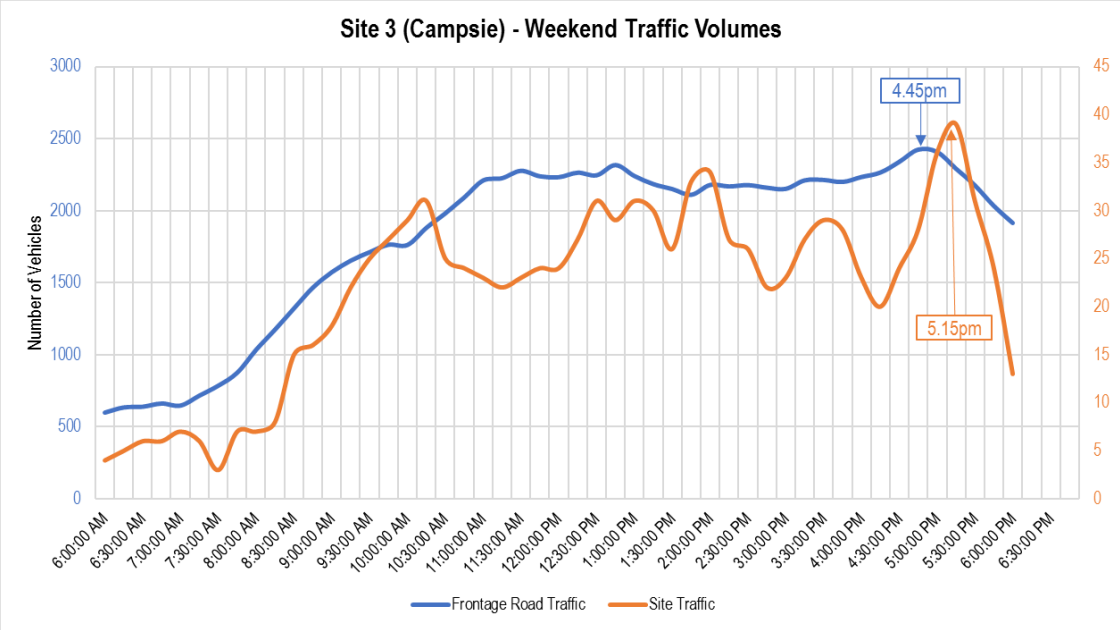



Figure 4.9: Weekend Peak Periods – Example Sub-Metropolitan Site

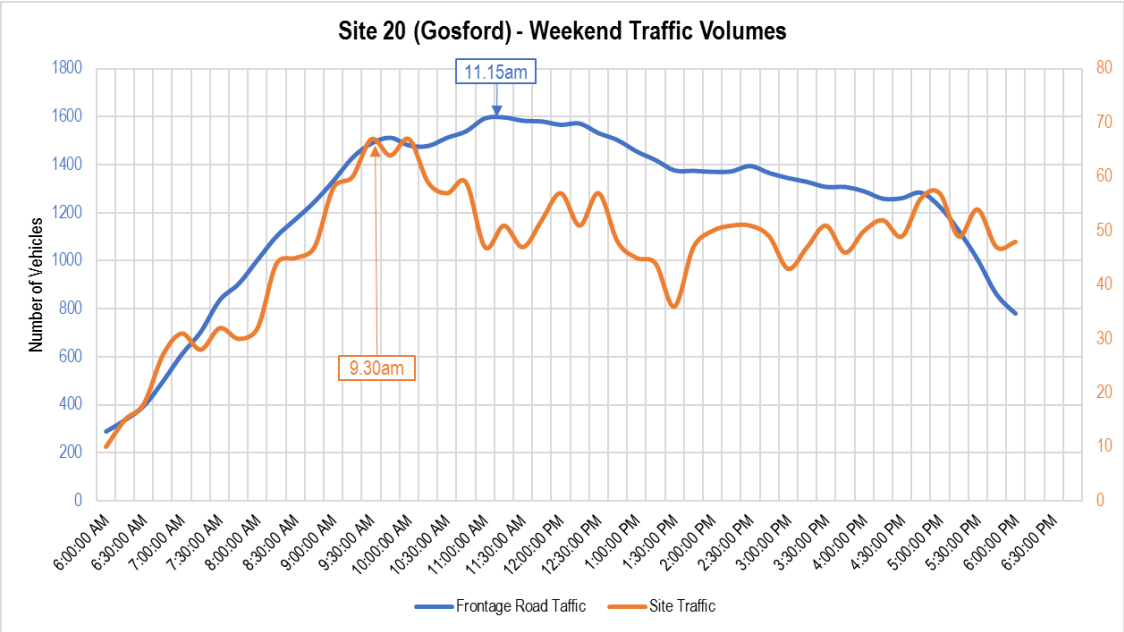



Figure 4.10: Weekend Peak Periods – Example Regional Site

As demonstrated above, weekend peak traffic volumes typically occur outside the adjacent roads peak time for all geographical locations. However, the peak times are less consistent and have a much greater variation than during weekdays. Factors that may influence this trend could include, but not be limited to, proximity to popular recreation locations or site demographics.

# 5. DATA ANALYSIS METHODOLOGY

Relationships between various independent variables were tested to determine the relationships between variables and the trip generation of the high density residential buildings surveyed. This analysis was considered for daily and peak periods and for both weekday and weekend data.

The method used for analysis was linear regression, of the following general form:

$Y = a_0 + a_1X_1 + a_2X_2 + \ldots + a_kX_k$

Where Y is the trip generate rate and $X_1$ to $X_k$ are the independent variables.

The following analysis processes were used:

- correlation matrix – matrices which indicate the level of relationship between independent variables, based on 'R';
- linear $R^2$ matrix - matrices which indicate the level of accuracy, or percentage of variation, in the dependant variable based on the independent variable used. Assists in determining appropriate sets of dependant and independent variables to model in Linear and Multiple Regression;
- linear regression – to determine the significance of relationships between one independent variable and trip generation rates based on $R^2$. Suitable independent variables were selected utilising the linear ($R^2$) and correlation (R) matrices in previous steps; and
- multiple linear regression – to determine the significance of relationship between multiple independent variables and trip generation rates based on $R^2$. Suitable independent variables were selected utilising the linear ($R^2$) and correlation (R) matrices in previous steps.

The correlation matrix gives an 'R' that compares the correlation of all dependent and independent variables. This matrix, when squared, will give the linear regression ($R^2$). The purpose of the correlation matrix is to identify independent variables which are correlated, as they should not be used together in subsequent multiple regression. For example, parking supply and number of units may be correlated for a level of significance that they should not be used together in a multiple linear regression equation.

The accuracy of the linear regression is given by the coefficient $R^2$, which represents the percentage of variation in the dependent variable and therefore how much of the variation is based on the independent variables. For example, a $R^2$ result of 1.0 indicates that 100% of variation in the dependent variable is associated with the independent variable, therefore as the $R^2$ value approaches 100% the more accurate the 'model' becomes. Typically values of $R^2$ less than 0.85 are not considered accurate enough to indicate a significant relationship between the dependent and independent variable. It should be noted that values approaching 0.85 are included for consideration.

Figure 5.1 shows an example of linear regression using Metropolitan Sites survey data to compare variables with 'good' and 'poor' correlation.

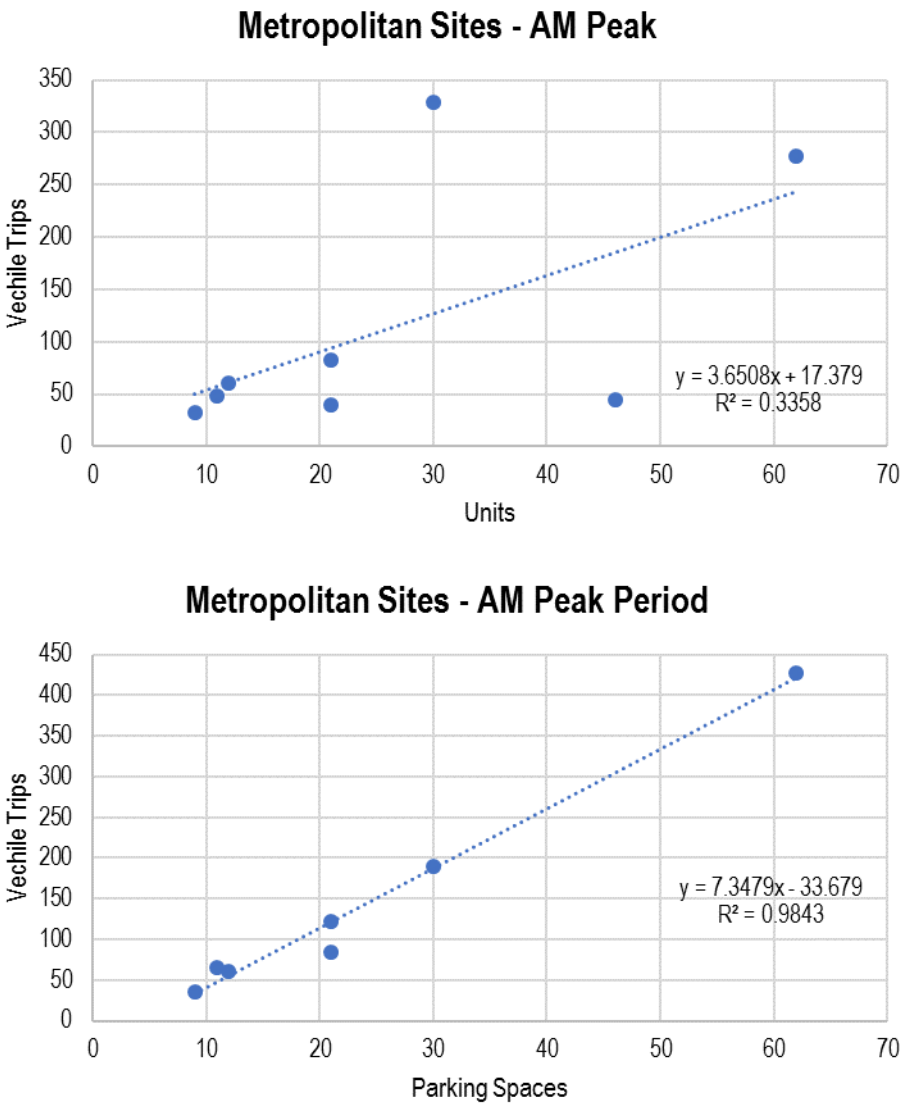



Figure 5.1: Example of Linear Regression with a Poor $R^2$ value

Both Linear and Multiple-Linear Regression analyses were conducted for all of the data to determine the significance of relationships. In addition, based on the findings of the preliminary data analysis sites, were grouped by geographic location (i.e. Metropolitan. Sub-Metropolitan and Region). The results of each step of the analysis process is provided in the following Chapter.

It is noted that once surveyed sites are separated geographically the number of data points included in the regression was reduced, and as some sites did not provide a complete data breakdown the available dataset was reduced further (e.g. only 6 regional sites have Bedroom breakdown data). Typically, such a small sample size is not considered appropriate for multiple regression. While undertaking Multiple Linear Regression with a limited sample size does not provide high confidence in results it does provide a comparison for correlation trends and indicators for any future analyses.

# 6. DATA ANALYSIS

## 6.1 OVERVIEW

Preliminary analysis of the data results detailed in the Data Report shows that an **influencing factor in trip generation rates is the site's geographical location (i.e. Metropolitan or Regional)**. This was expected and assists in providing area specific analysis and trip rates for various developments. Figure 6.1, Figure 6.2 and Figure 6.3 show a general trend of highest vehicle trip rates belonging to regional sites and lowest to metropolitan.

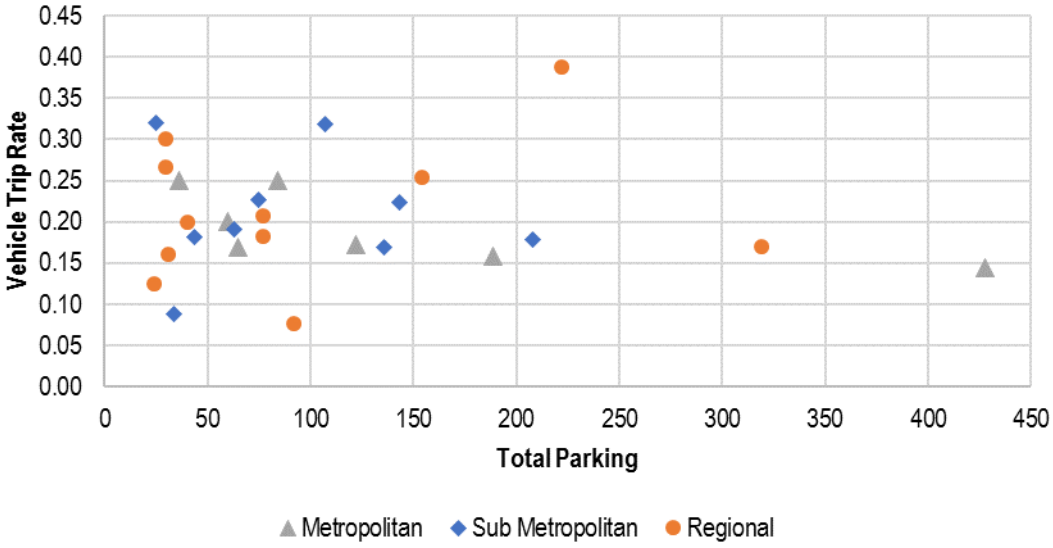



Figure 6.1: Vehicle Trips Per Parking Space (AM Peak Period)

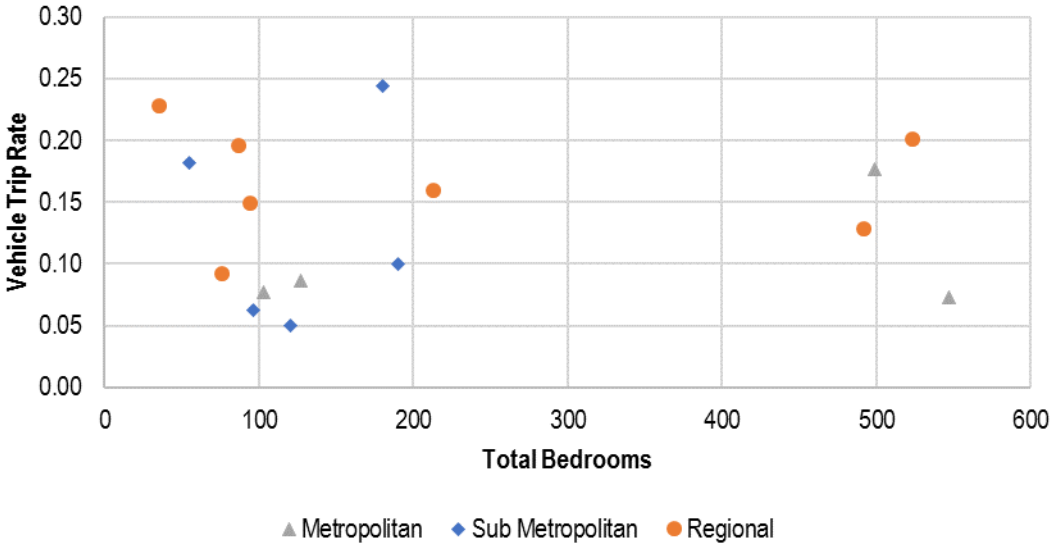



Figure 6.2: Vehicle Trips per Bedroom (PM Peak Period)

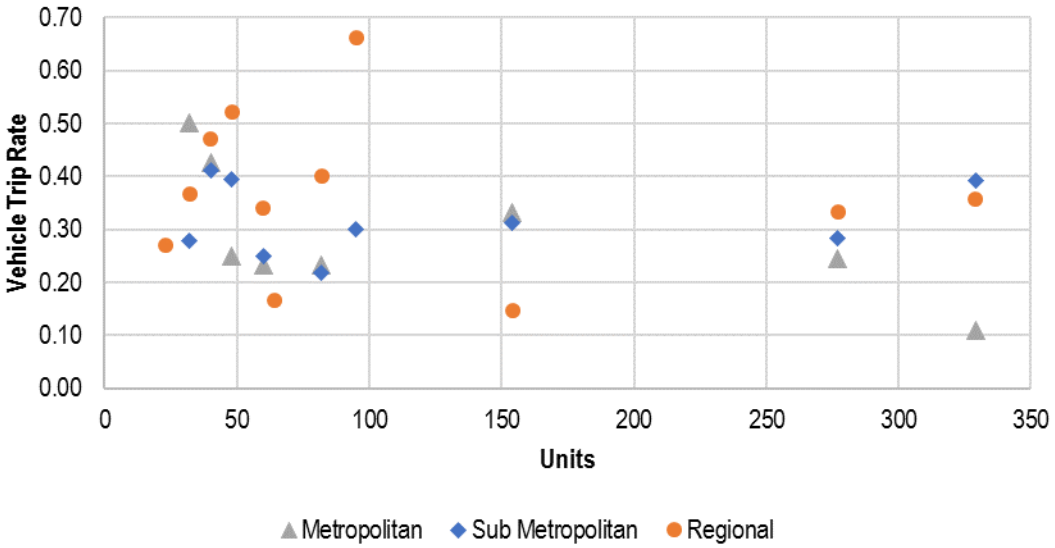



Figure 6.3: Vehicle Trips per Unit (Weekend Peak Period)

The following data analysis focusses on location-based analyses. Appendix A summarises the site-specific data. Preliminary analysis of data by geographical location shows that the sub-metropolitan sites appear to have a less consistent traffic generation than those in regional areas or central metropolitan areas. These differences in results seem to be based on:

- the site's proximity to a comprehensive public transport network – although all selected sites are located away from public transport, public transport was still reasonably well used via Ride Share or Taxi to access Public Transport routes or simply walking the additional distance;
- availability of on-street parking – parking restrictions surrounding the site appeared to have an impact on site vehicle traffic generation. Alternatively, if parking on-street was unrestricted the data shows that a proportion of residents would park on-street and drive thereby not being "counted" as site-based traffic generation; and
- demographics and locality of the site – the site's proximity to recreation, leisure and shopping areas appeared to influence the demographics of the building's residents, which then impact the number of trips generated.

As expected the critical period in relation to the impact of traffic generation on the road network for all sites is the weekday AM and PM peak hours. However, site peak periods typically differed slightly to the adjacent network peak times. This trend is more apparent at the Metropolitan sites and less apparent for Regional sites.

The site peak hours are typically very close to the network peak hours and accordingly the site peak hours have been used for determination of "design" trip generation rates.

To ensure a comprehensive analysis, testing was carried out based on data for all sites and separately for data by geographical location, using data occurring within the site's AM, PM and Weekend (lunch) peak hour as well as the daily data (Weekday and Weekend).

It should be noted that based on questionnaires undertaken at a number of sites the number of vehicle trips that involve walking to on-street parking was also estimated and analysed.

## 6.2 VARIABLES TESTED

The independent variables tested include:

- total number of on-site parking bays;
- total number of units;
- total number of bedrooms (noting this data was not available for all sites); and
- site/building footprint area ($m^2$).

The dependent variables that were used were:

- AM peak vehicle trips;
- AM peak person trips;
- PM Peak vehicle trips;
- PM Peak person trips;
- Daily Weekday vehicle trips;
- Daily Weekday Person Trips;
- Daily Weekday Vehicle Trips (including on-street parkers);
- Weekend Peak (lunch) Vehicle Trips;
- Weekend Peak (lunch) Person Trips;
- Daily Weekend Vehicle Trips;
- Daily Weekend Person Trips; and
- Daily Weekend Vehicle Trips (including on-street parkers).

The following sections present the outcomes of linear and multiple-linear regression analyses. A correlation and linear regression matrix is presented for each set of compared data with a summary of results and key relationships identified. Following this, the multiple regression analyses are prescribed combining the most likely independent variables to identify if there is any mathematical relationship with each dependent variable.

Please note:

- any regressions which have a negative R value or are not intuitive have been excluded from the analysis. While they might report a high $R^2$, since the negative is lost in the process of squaring; and
- regression analysis initially allows for a 'constant' in the regression equation. Once the most reasonable explanatory variables were identified using this process, the intercept value (the constant) was set to zero to determine which variables provides the more robust model without overcomplicating the equation. This testing determined whether it is:
  - better to have a zero constant (which is preferred for trip generation equations), or
  - better to maintain a constant and define an independent variable range for which the formula applies (e.g. for >20 units).

Essentially, where a resulting formula's constant makes up greater than 20% of the total trips generated by a site (when applying the chosen model's variable based equation) it has been considered inappropriate to apply the constant. An example of this process is provided in Table 6.1.

Table 6.1: Setting Constant to Zero Testing Example

| Model Scenario | Chosen Equation with Constant | Smallest Surveyed Variable | Percentage of Trips made up by constant | Recommendation |
|---|---|---|---|---|
| PM Peak – Metropolitan Sites | Vehicle Trips = 0.1985 x Parking Spaces + 1.3778 | 36 Parking Spaces | 16.2% | Apply preferred 'zero constant' to derive formula |
| AM Peak – Regional Sites | Vehicle Trips = 0.1377 x Bedrooms + 1.9214 | 24 Bedrooms | 36.8% | Maintain constant and define independent variable range (i.e. >56 Bedrooms) |

## 6.3 CORRELATION AND LINEAR REGRESSION ANALYSIS

### 6.3.1 All Surveyed Sites

A correlation of dependent and independent variables was undertaken to determine which variables were appropriate to consider for further modelling, as shown in Figure 6.4.

*Correlation Matrix*

| All Sites - Correlation Matrix (R Values) | | *Units* | *Parking Spaces* | *Total Bedrooms* | *Site Area (Building Footprint)* | *1 Bedroom* | *2 Bedrooms* | *3+ Bedrooms* |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.83 | 1.00 | | | | | |
| | Total Bedrooms | 0.97 | 0.82 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.66 | 0.78 | 0.67 | 1.00 | | | |
| | 1 Bedroom | 0.74 | 0.52 | 0.55 | 0.69 | 1.00 | | |
| | 2 Bedrooms | 0.93 | 0.73 | 0.81 | 0.76 | 0.89 | 1.00 | |
| | 3+ Bedrooms | 0.25 | 0.36 | 0.48 | -0.04 | -0.42 | -0.11 | 1.00 |
| Weekday 1-hr AM Peak | Vehicle Trips | 0.69 | 0.85 | 0.81 | 0.61 | 0.23 | 0.49 | 0.69 |
| | Person Trips | 0.63 | 0.78 | 0.74 | 0.70 | 0.36 | 0.55 | 0.47 |
| Weekday 1-hr PM Peak | Vehicle Trips | 0.74 | 0.87 | 0.84 | 0.65 | 0.32 | 0.57 | 0.61 |
| | Person Trips | 0.69 | 0.81 | 0.77 | 0.69 | 0.32 | 0.54 | 0.58 |
| Weekday (6am-7pm) | Vehicle Trips | 0.71 | 0.85 | 0.82 | 0.63 | 0.20 | 0.48 | 0.71 |
| | Vehicle Trips (inc on-street) | 0.78 | 0.97 | 0.82 | 0.77 | 0.49 | 0.69 | 0.36 |
| | Person Trips | 0.66 | 0.74 | 0.75 | 0.67 | 0.27 | 0.50 | 0.58 |
| Weekend 1-hr Peak | Vehicle Trips | 0.70 | 0.83 | 0.83 | 0.54 | 0.20 | 0.47 | 0.74 |
| | Person Trips | 0.65 | 0.74 | 0.73 | 0.71 | 0.24 | 0.46 | 0.64 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.75 | 0.89 | 0.87 | 0.59 | 0.29 | 0.57 | 0.67 |
| | Wkend Vehicle Trips (inc on-stre | 0.80 | 0.96 | 0.83 | 0.66 | 0.51 | 0.70 | 0.35 |
| | Person Trips | 0.72 | 0.83 | 0.78 | 0.73 | 0.37 | 0.56 | 0.57 |
| Selected for Regression | | | | | | | | |
| Some Correlation - intuitively expected | | | | | | | | |

Figure 6.4 All Sites Correlation Matrix

The above matrix for All Sites shows a reasonably good correlation between most variables, with the highest correlation being between Weekday Vehicle Trips (including on-street parkers) and Parking Spaces. These values assist in choosing the variables suitable for linear regression and for combining in multiple regression by eliminating correlated independent variable combinations.

The noted "high correlation" variables (above 0.85) for All-Sites include:

- Weekday Daily Vehicle Trips (including on-street parkers) – Parking Spaces;
- Weekday Daily Vehicle Trips – Parking Spaces;
- Weekend Daily Vehicle Trips (including on-street parkers) – Parking Spaces;
- Weekend Daily Vehicle Trips – Parking Spaces; and
- Weekend Daily Vehicle Trips – Bedrooms.

*Linear Regression*

Linear regression analysis presents $R^2$ results for each variable combination indicating the combination's correlation or ability to accurately estimate trip generation values. $R^2$ results are simply the correlation matrix R values squared, as shown in Figure 6.5.

| All Sites - Linear Regression ($R^2$) | | Units | Parking Spaces | Total Bedrooms | Site Area (Building Footprint) | 1 Bedroom | 2 Bedrooms | 3+ Bedrooms |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.69 | 1.00 | | | | | |
| | Total Bedrooms | 0.93 | 0.68 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.43 | 0.61 | 0.45 | 1.00 | | | |
| | 1 Bedroom | 0.54 | 0.27 | 0.30 | 0.48 | 1.00 | | |
| | 2 Bedrooms | 0.87 | 0.53 | 0.66 | 0.57 | 0.80 | 1.00 | |
| | 3+ Bedrooms | 0.06 | 0.13 | 0.23 | 0.00 | 0.18 | 0.01 | 1.00 |
| Weekday 1-hr AM Peak | Vehicle Trips | 0.47 | 0.73 | 0.66 | 0.37 | 0.05 | 0.24 | 0.47 |
| | Person Trips | 0.40 | 0.61 | 0.54 | 0.49 | 0.13 | 0.31 | 0.22 |
| Weekday 1-hr PM Peak | Vehicle Trips | 0.55 | 0.75 | 0.70 | 0.43 | 0.10 | 0.33 | 0.37 |
| | Person Trips | 0.48 | 0.65 | 0.59 | 0.47 | 0.10 | 0.29 | 0.33 |
| Weekday (6am-7pm) | Vehicle Trips | 0.51 | 0.72 | 0.67 | 0.40 | 0.04 | 0.23 | 0.51 |
| | Vehicle Trips (inc on-street) | 0.62 | 0.94 | 0.67 | 0.59 | 0.24 | 0.47 | 0.13 |
| | Person Trips | 0.43 | 0.55 | 0.56 | 0.44 | 0.07 | 0.25 | 0.33 |
| Weekend 1-hr Peak | Vehicle Trips | 0.49 | 0.69 | 0.69 | 0.29 | 0.04 | 0.22 | 0.55 |
| | Person Trips | 0.42 | 0.55 | 0.54 | 0.50 | 0.06 | 0.21 | 0.41 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.56 | 0.79 | 0.75 | 0.35 | 0.08 | 0.32 | 0.45 |
| | Wkend Vehicle Trips (inc on-stre | 0.64 | 0.93 | 0.68 | 0.44 | 0.26 | 0.48 | 0.12 |
| | Person Trips | 0.52 | 0.69 | 0.62 | 0.53 | 0.14 | 0.32 | 0.33 |

First Multiple Regression Value

Selected for multiple regression with Trip Gen

Figure 6.5 All Sites Linear Regression Matrix

Correlation and linear regression matrices were utilised to assist in determining suitable variables for testing in both linear and multiple regression models. Results for the best performing values in the All Sites comparison analysis are presented in Table 6.2.

Table 6.2: Linear Regression Results Table – All Sites

| Time | Scenario | Dependent Value (Y) | Independent Value (X) | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|
| Weekday | 1[1] | Daily Vehicle Trips (including on-street parkers) | Number of Parking Spaces | 0.94 | Yes |
| Weekday | 2 | Daily Vehicle Trips | Number of Parking Spaces | 0.72 | No |
| Weekend | 1[1] | Daily Vehicle Trips (including on-street parkers) | Number of Parking Spaces | 0.93 | Yes |
| Weekend | 2 | Daily Vehicle Trips | Number of Parking Spaces | 0.79 | No |

[1] *Scenario considered to provide the most accurate results*

Variables selected for multiple regression analysis (Section 6.4) are based on Linear Regression results. Independent variables selected for multiple regression testing include all those outlined in the table above.

Those sites selected as the "most accurate", as indicated in Table 6.2, are presented for further analysis in Figure 6.6. All Linear Regression scenarios that showed a high $R^2$ and were selected for testing are shown in Appendix B.

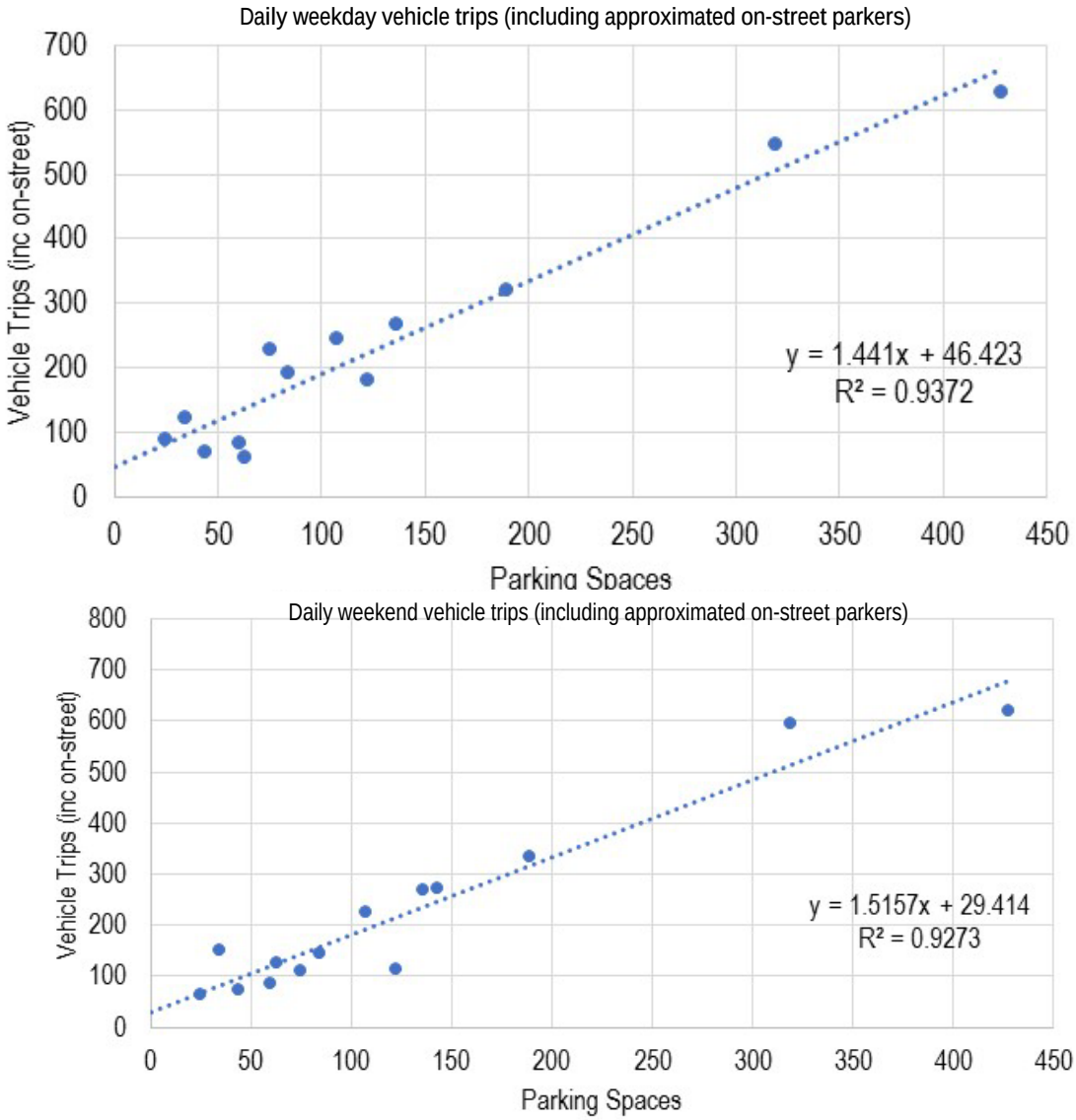



Figure 6.6: Most Accurate Linear Regression Outputs – All Sites

Whilst a high correlation ($R^{2)}$ value is shown, it should be noted the data for "on-street parkers" has been estimated based on manual surveys of a proportion of residents limiting the accuracy of the results. No other variables apparent from "Parking Spaces" reveal an appropriate level of correlation. Considering this, and that no other trip generation periods (AM, PM or weekend peak) show a correlation that meet the criterion for appropriate models for predicting trip generation, it is considered that no appropriate general Linear model is available in these scenarios to predict trips generated.

A more disaggregated analysis has therefore been undertaken, as shown in the following section.

### 6.3.2 Metropolitan Sites

A correlation of dependent and independent variables was undertaken to determine which survey elements were appropriate to consider for analysis, as shown in Figure 6.7.

*Correlation Matrix*

| Metropolitan Sites - Correlation Matrix (R Values) | | Units | Parking Spaces | Bedrooms | Site Area (Building Footprint) | 1 Bedroom | 2 Bedrooms | 3+ Bedrooms |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.77 | 1.00 | | | | | |
| | Bedrooms | 1.00 | 0.69 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.59 | 0.84 | 0.57 | 1.00 | | | |
| | 1 Bedroom | 0.98 | 0.84 | 0.97 | 0.75 | 1.00 | | |
| | 2 Bedrooms | 1.00 | 0.78 | 0.99 | 0.67 | 0.99 | 1.00 | |
| | 3+ Bedrooms | -0.82 | -0.81 | -0.80 | -0.74 | -0.84 | -0.86 | 1.00 |
| Weekday 1-hr AM Peak | AM Vehicle Trips | 0.58 | 0.99 | 0.70 | 0.59 | 0.85 | 0.79 | -0.81 |
| | AM Person Trips | 0.55 | 0.97 | 0.62 | 0.71 | 0.79 | 0.72 | -0.77 |
| Weekday 1-hr PM Peak | PM Vehicle Trips | 0.69 | 0.97 | 0.72 | 0.70 | 0.86 | 0.80 | -0.81 |
| | PM Person Trips | 0.70 | 0.98 | 0.72 | 0.74 | 0.86 | 0.80 | -0.81 |
| Weekday (6am-7pm) | Wkday Vehicle Trips | 0.65 | 0.99 | 0.69 | 0.67 | 0.84 | 0.78 | -0.80 |
| | Wkday Vehicle Trips (inc on-street) | 0.75 | 0.99 | 0.65 | 0.84 | 0.85 | 0.77 | -0.90 |
| | Wkday Person Trips | 0.66 | 0.98 | 0.71 | 0.75 | 0.85 | 0.79 | -0.80 |
| Weekend 1-hr Peak | Wkend Peak Vehicle Trips | 0.62 | 0.98 | 0.74 | 0.54 | 0.88 | 0.82 | -0.82 |
| | Wkend Peak Person Trips | 0.62 | 0.98 | 0.62 | 0.73 | 0.79 | 0.71 | -0.74 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.64 | 0.99 | 0.73 | 0.56 | 0.87 | 0.82 | -0.83 |
| | Wkend Vehicle Trips (inc on-street) | 0.82 | 0.98 | 0.67 | 0.79 | 0.86 | 0.79 | -0.92 |
| | Wkend Person Trips | 0.67 | 0.98 | 0.65 | 0.76 | 0.82 | 0.74 | -0.71 |

Selected for Regression

Some Correlation - intuitively expected

Figure 6.7 Metropolitan Sites Correlation Matrix

The above matrix for Metropolitan sites shows a very good correlation between most variables and the number of Parking Spaces. These values assist in choosing the variables suitable for linear regression and for combining in multiple linear regression.

The variables considered to have a "high correlation" are those with a result above 0.85.

*Linear Regression*

Linear regression analysis presents $R^2$ results for each variable combination indicating the combinations correlation or ability to accurately estimate values. $R^2$ results are simply the correlation matrix R values squared, as shown in Figure 6.8.

| Metropoliton Sites - Linear Regression ($R^2$) | | Units | Parking Spaces | Bedrooms | Site Area (Building Footprint) | 1 Bedroom | 2 Bedrooms | 3+ Bedrooms |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.59 | 1.00 | | | | | |
| | Bedrooms | 1.00 | 0.47 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.35 | 0.71 | 0.33 | 1.00 | | | |
| | 1 Bedroom | 0.97 | 0.70 | 0.94 | 0.56 | 1.00 | | |
| | 2 Bedrooms | 0.99 | 0.60 | 0.98 | 0.46 | 0.98 | 1.00 | |
| | 3+ Bedrooms | 0.68 | 0.66 | 0.65 | 0.55 | 0.70 | 0.74 | 1.00 |
| Weekday 1-hr AM Peak | AM Vehicle Trips | 0.34 | 0.98 | 0.49 | 0.35 | 0.72 | 0.62 | 0.65 |
| | AM Person Trips | 0.30 | 0.94 | 0.39 | 0.50 | 0.62 | 0.51 | 0.59 |
| Weekday 1-hr PM Peak | PM Vehicle Trips | 0.47 | 0.94 | 0.52 | 0.49 | 0.74 | 0.64 | 0.65 |
| | PM Person Trips | 0.49 | 0.95 | 0.51 | 0.55 | 0.74 | 0.64 | 0.65 |
| Weekday (6am-7pm) | Wkday Vehicle Trips | 0.42 | 0.97 | 0.48 | 0.45 | 0.71 | 0.61 | 0.64 |
| | Wkday Vehicle Trips (inc on-street) | 0.57 | 0.98 | 0.42 | 0.71 | 0.72 | 0.59 | 0.82 |
| | Wkday Person Trips | 0.43 | 0.96 | 0.50 | 0.56 | 0.73 | 0.63 | 0.64 |
| Weekend 1-hr Peak | Wkend Peak Vehicle Trips | 0.38 | 0.96 | 0.55 | 0.29 | 0.77 | 0.67 | 0.67 |
| | Wkend Peak Person Trips | 0.39 | 0.95 | 0.38 | 0.54 | 0.62 | 0.51 | 0.55 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.41 | 0.97 | 0.54 | 0.31 | 0.76 | 0.67 | 0.69 |
| | Wkend Vehicle Trips (inc on-street) | 0.67 | 0.96 | 0.45 | 0.63 | 0.74 | 0.62 | 0.84 |
| | Wkend Person Trips | 0.45 | 0.96 | 0.43 | 0.57 | 0.67 | 0.55 | 0.50 |

First Multiple Regression Value

Selected for multiple regression with Trip Gen

Figure 6.8 Metropolitan Sites Linear Regression

Correlation and linear regression matrices were utilised to assist in determining suitable variables for testing in both linear and multiple regression models. Results for the best performing values in the Metropolitan sites comparison analysis are presented in Table 6.3.

Table 6.3: Linear Regression Results Table – Metropolitan Sites

| Time | Scenario | Dependent Value (Y) | Independent Value (X) | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|
| AM Peak Period | 1[1] | Vehicle Trips | Number of Parking Spaces | 0.98 | Yes |
| AM Peak Period | 2 | Person Trips | Number of Parking Spaces | 0.94 | Yes |
| PM Peak Period | 1[1] | Vehicle Trips | Number of Parking Spaces | 0.94 | Yes |
| PM Peak Period | 2 | Person Trips | Number of Parking Spaces | 0.95 | Yes |
| Weekday | 1[1] | Daily Vehicle Trips | Number of Parking Spaces | 0.97 | Yes |
| Weekend Peak Period | 1[1] | Vehicle Trips | Number of Parking Spaces | 0.96 | Yes |
| Weekend Peak Period | 2 | Person Trips | Number of Parking Spaces | 0.95 | Yes |
| Weekend | 1[1] | Daily Vehicle Trips | Number of Parking Spaces | 0.97 | Yes |

*[1] Scenario considered to provide the most accurate results*

Variables selected for multiple regression analysis (Section 6.4) are based on the Linear Regression results. Independent variables selected for multiple regression testing include all those outlined in the table above.

Those sites selected as the "most accurate", as indicated in Table 6.3, are presented for further analysis in Figure 6.9 and Figure 6.10. All Linear Regression scenarios that showed a high $R^2$ and were selected for testing are shown in Appendix B.

The best result for predicting the number of vehicle trips was found in the AM peak period.

It should be noted that within the resulting model formulae, the daily vehicle trips multiplier of 1.34 is 10 times the AM peak multiplier of 0.134 which aligns with "rules of thumb" that daily traffic is 10 times peak hour traffic.

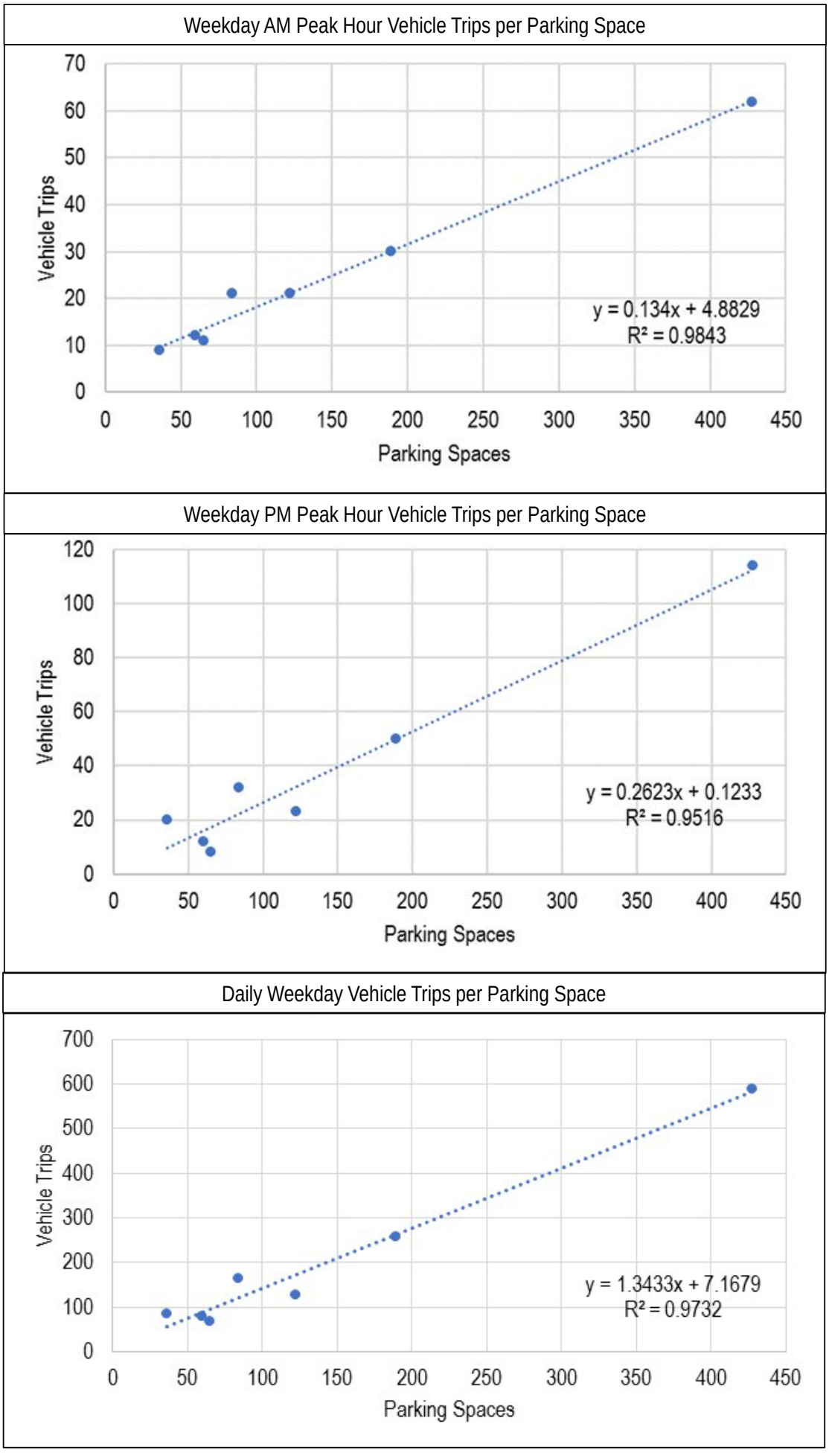



Figure 6.9: Most Accurate Linear Regression Outputs – Metropolitan Sites (Weekday)

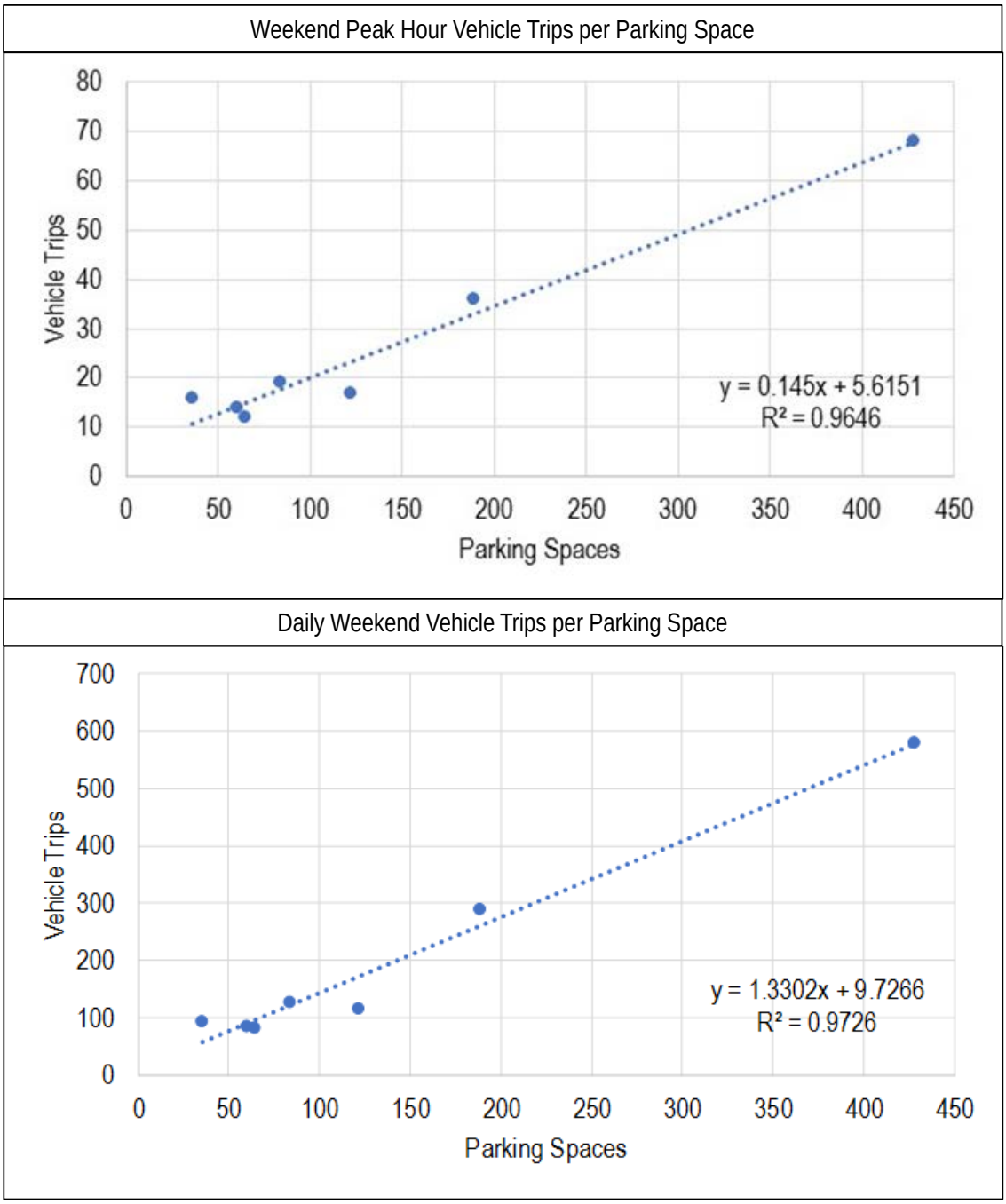



Figure 6.10: Most Accurate Linear Regression Outputs – Metropolitan Sites (Weekend)

Analysis shows an excellent correlation between Vehicle Trips and the Number of Parking Spaces for all periods. However, during the PM peak period the number of Person trips shows a better correlation with Parking Spaces than Vehicle Trips for the same period.

### 6.3.3 Sub-Metropolitan Sites

*Correlation Matrix*

A correlation of dependent and independent variables was undertaken to determine which survey elements were appropriate to consider for analysis, as shown in Figure 6.11.

| Sub-Metropolitan Sites - Correlation Matrix (R Values) | | Units | Parking Spaces | Bedrooms | Site Area (Building Footprint) | 1 Bedroom | 2 Bedrooms | 3+ Bedrooms |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.90 | 1.00 | | | | | |
| | Bedrooms | 0.88 | 0.71 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.62 | 0.68 | 0.69 | 1.00 | | | |
| | 1 Bedroom | 0.69 | 0.62 | 0.32 | 0.57 | 1.00 | | |
| | 2 Bedrooms | 0.75 | 0.91 | 0.38 | 0.91 | 0.73 | 1.00 | |
| | 3+ Bedrooms | 0.07 | -0.19 | 0.53 | -0.20 | -0.46 | -0.58 | 1.00 |
| Weekday 1-hr AM Peak | AM Vehicle Trips | 0.85 | 0.91 | 0.73 | 0.62 | 0.59 | 0.89 | -0.15 |
| | AM Person Trips | 0.69 | 0.70 | 0.81 | 0.71 | 0.55 | 0.81 | -0.01 |
| Weekday 1-hr PM Peak | PM Vehicle Trips | 0.79 | 0.88 | 0.68 | 0.36 | 0.40 | 0.85 | -0.14 |
| | PM Person Trips | 0.88 | 0.90 | 0.70 | 0.48 | 0.39 | 0.83 | -0.10 |
| Weekday (6am-7pm) | Wkday Vehicle Trips | 0.90 | 0.91 | 0.77 | 0.50 | 0.43 | 0.82 | -0.04 |
| | Wkday Vehicle Trips (inc on-street) | 0.80 | 0.84 | 0.77 | 0.82 | -0.59 | -0.76 | 0.94 |
| | Wkday Person Trips | 0.94 | 0.82 | 0.91 | 0.47 | 0.46 | 0.69 | 0.18 |
| Weekend 1-hr Peak | Wkend Peak Vehicle Trips | 0.92 | 0.83 | 0.75 | 0.44 | 0.75 | 0.87 | -0.15 |
| | Wkend Peak Person Trips | 0.88 | 0.70 | 0.68 | 0.64 | 0.90 | 0.82 | -0.19 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.92 | 0.87 | 0.73 | 0.52 | 0.74 | 0.90 | -0.18 |
| | Wkend Vehicle Trips (inc on-street) | 0.89 | 0.92 | 0.34 | 0.48 | 0.26 | -0.38 | 0.35 |
| | Wkend Person Trips | 0.87 | 0.71 | 0.37 | 0.55 | 1.00 | 0.72 | -0.40 |

Selected for Regression
Some Correlation - intuitively expected

Figure 6.11 Sub-Metropolitan Sites Correlation Matrix

The above matrix for Sub-Metropolitan sites shows a very good correlation between most variables and the number of Units and Parking Spaces. These values assist in choosing the variables suitable for linear regression and for combining in multiple regression.

The variables considered to have a "high correlation" are those with a result above 0.85.

*Linear Regression*

Linear regression analysis presents $R^2$ results for each variable combination indicating the combinations correlation or ability to accurately estimate values. $R^2$ results are simply the correlation matrix R values squared, as shown in Figure 6.12.

| Sub-Metropoliton Sites - Linear Regression ($R^2$) | | Units | Parking Spaces | Bedrooms | Site Area (Building Footprint) | 1 Bedroom | 2 Bedrooms | 3+ Bedrooms |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.80 | 1.00 | | | | | |
| | Bedrooms | 0.77 | 0.51 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.39 | 0.47 | 0.47 | 1.00 | | | |
| | 1 Bedroom | 0.48 | 0.39 | 0.10 | 0.33 | 1.00 | | |
| | 2 Bedrooms | 0.56 | 0.82 | 0.14 | 0.82 | 0.54 | 1.00 | |
| | 3+ Bedrooms | 0.01 | 0.04 | 0.28 | 0.04 | 0.21 | 0.33 | 1.00 |
| Weekday 1-hr AM Peak | AM Vehicle Trips | 0.73 | 0.82 | 0.54 | 0.38 | 0.34 | 0.79 | 0.02 |
| | AM Person Trips | 0.48 | 0.49 | 0.66 | 0.51 | 0.30 | 0.65 | 0.00 |
| Weekday 1-hr PM Peak | PM Vehicle Trips | 0.63 | 0.77 | 0.46 | 0.13 | 0.16 | 0.72 | 0.02 |
| | PM Person Trips | 0.77 | 0.81 | 0.49 | 0.23 | 0.15 | 0.69 | 0.01 |
| Weekday (6am-7pm) | Wkday Vehicle Trips | 0.81 | 0.83 | 0.59 | 0.25 | 0.19 | 0.67 | 0.00 |
| | Wkday Vehicle Trips (inc on-street) | 0.64 | 0.70 | 0.60 | 0.67 | 0.34 | 0.57 | 0.88 |
| | Wkday Person Trips | 0.89 | 0.67 | 0.82 | 0.22 | 0.22 | 0.47 | 0.03 |
| Weekend 1-hr Peak | Wkend Peak Vehicle Trips | 0.84 | 0.69 | 0.57 | 0.19 | 0.56 | 0.76 | 0.02 |
| | Wkend Peak Person Trips | 0.78 | 0.48 | 0.46 | 0.41 | 0.81 | 0.67 | 0.04 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.85 | 0.76 | 0.54 | 0.28 | 0.55 | 0.80 | 0.03 |
| | Wkend Vehicle Trips (inc on-street) | 0.80 | 0.85 | 0.11 | 0.23 | 0.07 | 0.15 | 0.12 |
| | Wkend Person Trips | 0.76 | 0.51 | 0.14 | 0.30 | 0.99 | 0.52 | 0.16 |

First Multiple Regression Value
Selected for multiple regression with Trip Gen

Figure 6.12 Sub-Metropolitan Sites Linear Regression

Correlation and linear regression matrices were utilised to assist in determining suitable variables for testing in both linear and multiple regression models. Results for the best performing values in the Metropolitan comparison analysis are presented in Table 6.4.

Table 6.4: Linear Regression Results Table – Sub-Metropolitan Sites

| Time | Scenario | Dependent Value (Y) | Independent Value (X) | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|
| AM Peak Period | 1[2] | Vehicle Trips | Number of Parking Spaces | 0.82 | No |
| PM Peak Period | 1[2] | Vehicle Trips | Number of Parking Spaces | 0.81 | No |
| Weekday | 1[2] | Daily Vehicle Trips | Number of Units | 0.81 | No |
| Weekday | 2 | Daily Vehicle Trips | Number of Parking Spaces | 0.83 | No |
| Weekday | 3[1] | Daily Person Trips | Number of Units | 0.89 | Yes |
| Weekday | 4[2] | Daily Person Trips | Number of Bedrooms | 0.82 | No |
| Weekend Peak Period | 1[1] | Vehicle Trips | Number Units | 0.84 | Yes |
| Weekend | 1 | Daily Vehicle Trips | Number of Parking Spaces | 0.75 | No |
| Weekend | 2[1] | Daily Vehicle Trips | Number of Units | 0.85 | Yes |
| Weekend | 3 | Daily Vehicle Trips (Including on-street parkers) | Number of Parking Spaces | 0.85 | Yes |
| Weekend | 4[2] | Daily Vehicle Trips (Including on-street parkers) | Number of Units | 0.80 | No |

*[1] Scenario considered to provide the most accurate results*

*[2] Acceptable $R^2$ are those approaching or greater than 0.85.*

Variables selected for multiple regression analysis (Section 6.4) are based on Linear Regression results. Independent variables selected for multiple regression testing include all those outlined in the table above.

Those sites selected as the "most accurate", as indicated in Table 6.4, are presented for further analysis in Figure 6.13. All Linear Regression scenarios that showed a high $R^2$ and were selected for testing are shown in Appendix B.

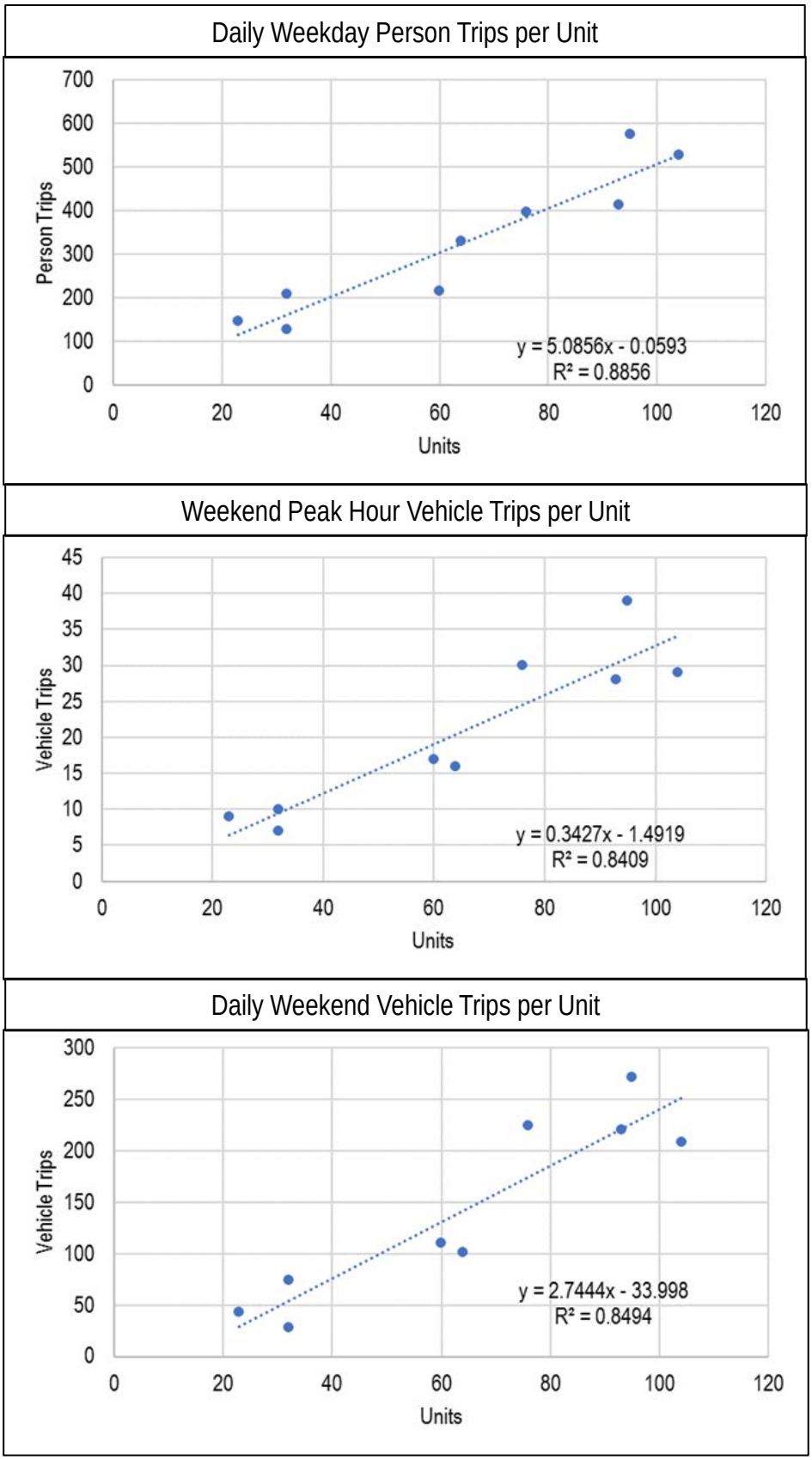



Figure 6.13: Most Accurate Linear Regression Outputs – Sub-Metropolitan Sites

The analysis shows a reasonably good correlation between independent variables and the number of units in each site (on face value) however there are issues with these models. The constant in the "Daily Weekend" model is too high and overwhelms the multiplier's importance, leading to an insensitive model for changes in the number of units. The weekday person trips and weekend peak vehicle trips models are more reasonable however due to the variability of site data within the Sub-Metropolitan geographical area these sites were also tested against both Metropolitan and Regional models to determine if either were suitable.

### 6.3.4 Regional Sites

A correlation of dependent and independent variables was undertaken to determine which survey elements were appropriate to consider for analysis, as shown in Figure 6.14.

*Correlation Matrix*

| Regional Sites - Correlation Matrix (R Values) | | *Units* | *Parking Spaces* | *Bedrooms* | *Site Area (Building Footprint)* | *1 Bedroom* | *2 Bedrooms* | *3+ Bedrooms* |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.95 | 1.00 | | | | | |
| | Bedrooms | 1.00 | 0.95 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.79 | 0.81 | 0.76 | 1.00 | | | |
| | 1 Bedroom | -0.44 | -0.51 | -0.50 | -0.35 | 1.00 | | |
| | 2 Bedrooms | 0.90 | 0.86 | 0.88 | 0.84 | -0.37 | 1.00 | |
| | 3+ Bedrooms | 0.97 | 0.92 | 0.99 | 0.63 | -0.55 | 0.78 | 1.00 |
| Weekday 1-hr AM Peak | AM Vehicle Trips | 0.93 | 0.86 | 0.96 | 0.71 | -0.48 | 0.72 | 0.98 |
| | AM Person Trips | 0.88 | 0.75 | 0.86 | 0.90 | -0.23 | 0.86 | 0.79 |
| Weekday 1-hr PM Peak | PM Vehicle Trips | 0.94 | 0.84 | 0.96 | 0.77 | -0.44 | 0.76 | 0.96 |
| | PM Person Trips | 0.85 | 0.71 | 0.86 | 0.97 | -0.40 | 0.70 | 0.89 |
| Weekday (6am-7pm) | Wkday Vehicle Trips | 0.95 | 0.86 | 0.97 | 0.76 | -0.48 | 0.77 | 0.97 |
| | Wkday Vehicle Trips (inc on-street) | - | - | - | - | - | - | - |
| | Wkday Person Trips | 0.85 | 0.67 | 0.83 | 0.93 | -0.30 | 0.78 | 0.80 |
| Weekend 1-hr Peak | Wkend Peak Vehicle Trips | 0.94 | 0.87 | 0.97 | 0.69 | -0.49 | 0.73 | 0.99 |
| | Wkend Peak Person Trips | 0.84 | 0.66 | 0.85 | 0.71 | -0.45 | 0.68 | 0.89 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.98 | 0.91 | 0.99 | 0.80 | -0.46 | 0.88 | 0.97 |
| | Wkend Vehicle Trips (inc on-street) | - | - | - | - | - | - | - |
| | Wkend Person Trips | 0.91 | 0.77 | 0.92 | 0.86 | -0.46 | 0.77 | 0.94 |

Selected for Regression

Some Correlation - intuitively expected

Figure 6.14: Regional Sites Correlation Matrix

The above matrix for Regional sites shows excellent correlation between all independent and dependent variables, excluding the Building Footprint. These values assist in choosing the variables suitable for linear regression and for combining in multiple regression.

The variables considered to have a "high correlation" are those with a result above 0.85.

*Linear Regression*

Linear regression analysis presents $R^2$ results for each variable combination indicating the combinations correlation or ability to accurately estimate values. $R^2$ results are simply the correlation matrix R values squared, as shown in Figure 6.15.

| Regional Sites - Linear Regression ($R^2$) | | *Units* | *Parking Spaces* | *Bedrooms* | *Site Area (Building Footprint)* | *1 Bedroom* | *2 Bedrooms* | *3+ Bedrooms* |
|---|---|---|---|---|---|---|---|---|
| | Units | 1.00 | | | | | | |
| | Parking Spaces | 0.90 | 1.00 | | | | | |
| | Bedrooms | 0.99 | 0.90 | 1.00 | | | | |
| | Site Area (Building Footprint) | 0.62 | 0.66 | 0.58 | 1.00 | | | |
| | 1 Bedroom | 0.19 | 0.26 | 0.25 | 0.12 | 1.00 | | |
| | 2 Bedrooms | 0.82 | 0.74 | 0.77 | 0.71 | 0.14 | 1.00 | |
| | 3+ Bedrooms | 0.94 | 0.85 | 0.97 | 0.40 | 0.31 | 0.61 | 1.00 |
| Weekday 1-hr AM Peak | AM Vehicle Trips | 0.87 | 0.74 | 0.92 | 0.51 | 0.23 | 0.52 | 0.95 |
| | AM Person Trips | 0.78 | 0.56 | 0.74 | 0.81 | 0.05 | 0.74 | 0.62 |
| Weekday 1-hr PM Peak | PM Vehicle Trips | 0.88 | 0.70 | 0.92 | 0.59 | 0.20 | 0.58 | 0.92 |
| | PM Person Trips | 0.72 | 0.50 | 0.74 | 0.94 | 0.16 | 0.48 | 0.79 |
| Weekday (6am-7pm) | Wkday Vehicle Trips | 0.90 | 0.75 | 0.94 | 0.58 | 0.23 | 0.60 | 0.95 |
| | Wkday Vehicle Trips (inc on-street) | - | - | - | - | - | - | - |
| | Wkday Person Trips | 0.72 | 0.45 | 0.70 | 0.87 | 0.09 | 0.61 | 0.64 |
| Weekend 1-hr Peak | Wkend Peak Vehicle Trips | 0.89 | 0.76 | 0.94 | 0.48 | 0.24 | 0.54 | 0.97 |
| | Wkend Peak Person Trips | 0.70 | 0.44 | 0.73 | 0.51 | 0.20 | 0.47 | 0.80 |
| Weekend (6am-7pm) | Wkend Vehicle Trips | 0.96 | 0.83 | 0.99 | 0.64 | 0.21 | 0.78 | 0.95 |
| | Wkend Vehicle Trips (inc on-street) | - | - | - | - | - | - | - |
| | Wkend Person Trips | 0.82 | 0.59 | 0.84 | 0.74 | 0.21 | 0.60 | 0.89 |

First Multiple Regression Value

Selected for multiple regression with Trip Gen

Figure 6.15: Regional Sites Linear Regression

Correlation and linear regression matrices were utilised to assist in determining suitable variables for testing in both linear and multiple regression models. Results for the best performing values in the Metropolitan comparison analysis are presented in Table 6.5.

Table 6.5: Linear Regression Results – Regional Sites

| Time | Scenario | Dependent Value (Y) | Independent Value (X) | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|
| AM Peak Period | 1[1] | Vehicle Trips | Number of Bedrooms | 0.92 | Yes |
| AM Peak Period | 2 | Vehicle Trips | Number of Units | 0.87 | Yes |
| PM Peak Period | 1[1] | Vehicle Trips | Number of Bedrooms | 0.92 | Yes |
| PM Peak Period | 2 | Vehicle Trips | Number of Units | 0.88 | Yes |
| Weekday | 1[1] | Daily Vehicle Trips | Number of Bedrooms | 0.94 | Yes |
| Weekday | 2 | Daily Vehicle Trips | Number of Units | 0.90 | Yes |
| Weekend Peak Period | 1[1] | Vehicle Trips | Number of Bedrooms | 0.94 | Yes |
| Weekend Peak Period | 2 | Vehicle Trips | Number of Units | 0.89 | Yes |
| Weekend | 1[2] | Daily Vehicle Trips | Number of Parking Spaces | 0.83 | No |
| Weekend | 2[1] | Daily Vehicle Trips | Number of Bedrooms | 0.99 | Yes |
| Weekend | 3[1] | Daily Vehicle Trips | Number of Units | 0.96 | Yes |
| Weekend | 1 | Daily Vehicle Trips (including on-street parkers) | Number of Bedrooms | 0.84 | Yes |
| Weekend | 2[2] | Daily Vehicle Trips (including on-street parkers) | Number of Units | 0.82 | No |

*[1] Scenario considered to provide the most accurate results*

*[2] Acceptable $R^2$ are those approaching or greater than 0.85*

Variables selected for multiple regression analysis (Section 6.4) are based on Linear Regression results. Independent variables selected for multiple regression testing include all those outlined in the table above.

Those sites selected as the "most accurate", as indicated in Table 6.5, are presented for further analysis in Figure 6.16 and Figure 6.17. All Linear Regression scenarios that showed a high $R^2$ and were selected for testing are shown in Appendix B.

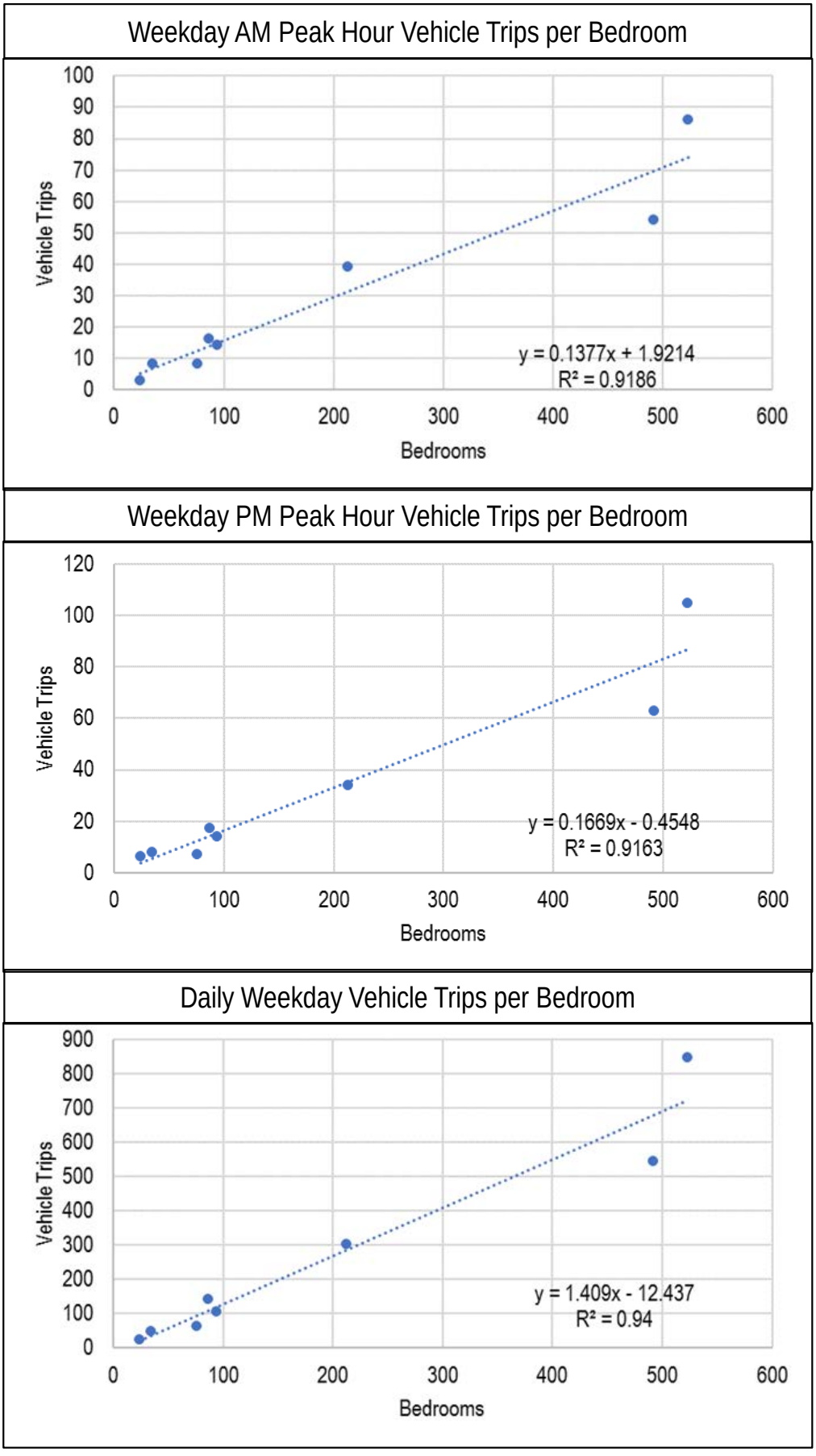



Figure 6.16: Most Accurate Linear Regression Outputs – Regional Sites (Weekday)

The weekday multipliers are 8-12 times the size of the peak multipliers, which is reasonable, and the constants are relatively small in all models.

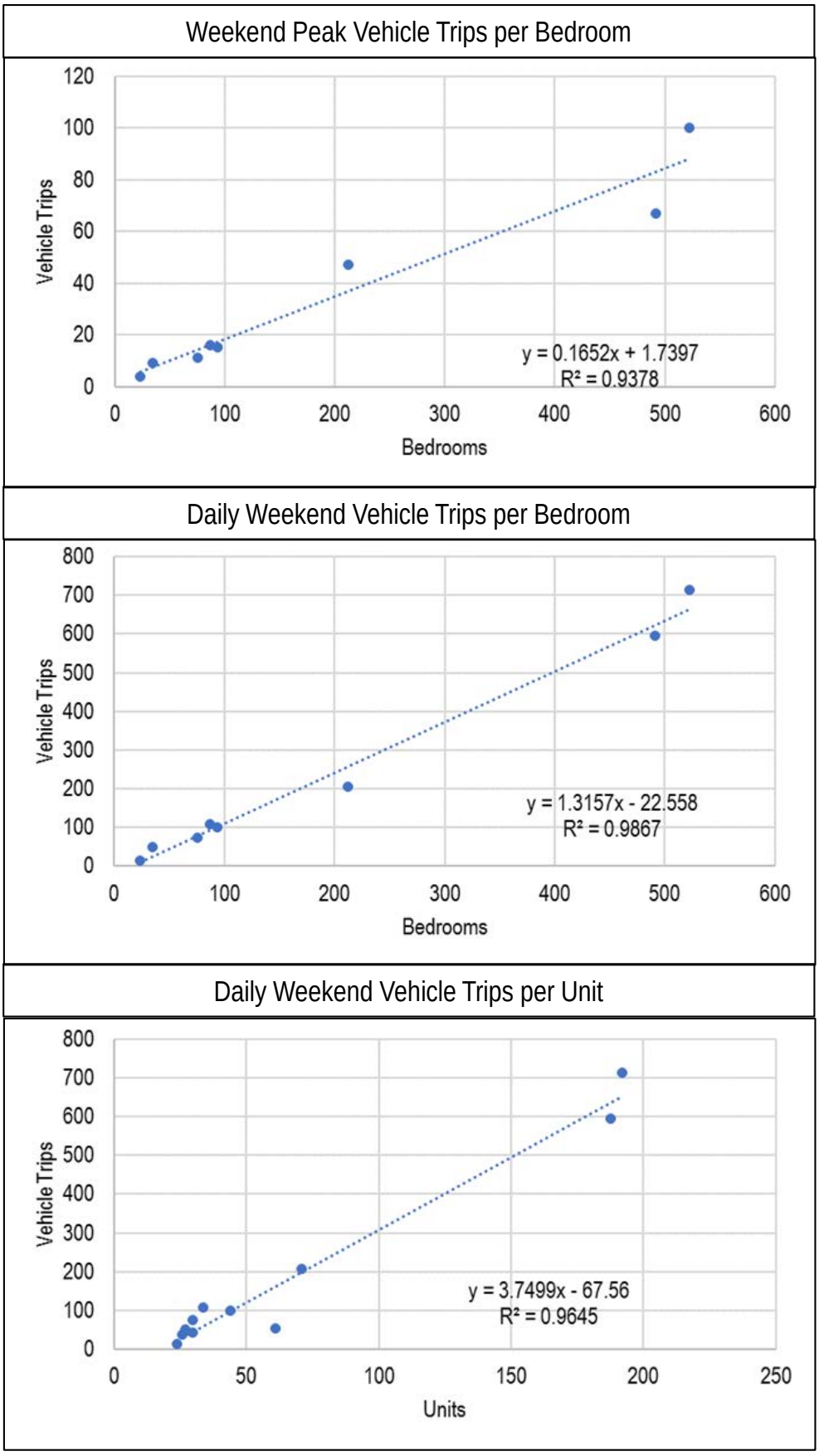



Figure 6.17: Most Accurate Linear Regression Outputs – Regional Sites (Weekend)

The analysis shows a reasonable correlation between Vehicle Trips and the Number of Bedrooms or Number of Units for all periods. However, the constants for both daily models (particularly the 'units based' model) is very high and would make the models insensitive for smaller developments.

## 6.4 MULTIPLE LINEAR REGRESSION

Scenarios selected for analysis multiple regression testing have been based on the Linear Regression results outlined in Section 6.3. The dependent variables of Number of Bedrooms and Number of Units were not included in the same multiple regression analysis for any scenario due to their high correlation. Furthermore, where correlation (R) or level of accuracy ($R^2$) between all variables was determined to be very low it was excluded from multiple linear regression analysis. Refer Section 5 for further information.

### 6.4.1 All Sites

The selected independent variables were grouped to see if together they can better describe the dependent variable. When comparing All Sites, the dependent variables tested were Number of Vehicle Trips with and without "on-street parkers". Each was tested against a combination of two variables and the results of all tested scenarios are shown in Table 6.6. All Multiple Regression scenarios that displayed a high $R^2$ and were selected for testing are shown in Appendix C.

Table 6.6: Multiple Regression Tested Scenarios – All Sites

| Time | Primary Aspect | Scenario | Aspect 1 | Aspect 2 | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| Weekday | Daily Vehicle Trips (Including On-street Parkers) | 1 | Parking Spaces | Number of Bedrooms | 0.597 | No |
| Weekday | Daily Vehicle Trips (Including On-street Parkers) | 2 | Parking Spaces | Number of Units | 0.615 | No |
| Weekday | Daily Vehicle Trips | 3[1] | Parking Spaces | Number of Bedrooms | 0.766 | No |
| Weekday | Daily Vehicle Trips | 4 | Parking Spaces | Number of Units | 0.728 | No |
| Weekday | Daily Vehicle Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.549 | No |
| Weekday | Daily Vehicle Trips | 6 | 1+2 Bedrooms | 3+ Bedroom | 0.544 | No |
| Weekday | AM Peak Vehicle Trips | 7 | Parking Spaces | Number of Bedrooms | 0.607 | No |
| Weekday | AM Peak Vehicle Trips | 8 | 1 Bedroom and 2 Bedroom | 3+ Bedroom | 0.549 | No |
| Weekday | PM Peak Vehicle Trips | 9 | Parking Spaces | Number of Bedrooms | 0.664 | No |
| Weekday | PM Peak Vehicle Trips | 10 | 1 Bedroom and 2 Bedroom | 3+ Bedroom | 0.559 | No |
| Weekend | Daily Vehicle Trips (Including On-street Parkers) | 1 | Parking Spaces | Number of Bedrooms | 0.609 | No |
| Weekend | Daily Vehicle Trips (Including On-street Parkers) | 2 | Parking Spaces | Number of Units | 0.628 | No |
| Weekend | Daily Vehicle Trips | 3[1] | Parking Spaces | Number of Bedrooms | 0.846 | Yes |
| Weekend | Daily Vehicle Trips | 4[2] | Parking Spaces | Number of Units | 0.797 | No |
| Weekend | Daily Vehicle Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.549 | No |
| Weekend | Daily Vehicle Trips | 6 | 1+2 Bedrooms | 3+ Bedroom | 0.538 | No |
| Weekend | Peak Vehicle Trips | 7 | Parking Spaces | Number of Bedrooms | 0.602 | No |

*[1] Scenario considered to provide the most accurate results*

*[2] Acceptable $R^2$ are those approaching or greater than 0.85*

As shown, a single $R^2$ result was established near of greater than 0.85 for Weekend Daily Vehicle trip generation was identified. No other scenario presented a sufficiently accurate model for approximating vehicle trip generation. Detailed results of the "best case" Weekday scenario and the single appropriate Weekend scenario are presented in Figure 6.18 and Figure 6.19 respectively.

However, neither result shows an improvement over the 'best case' Linear Regression analysis. As such, it is considered that no appropriate model is available in these scenarios to predict trips generated.

A more disaggregated analysis has therefore been undertaken, as shown in the following section.

Weekday - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.875 |
| R Square | 0.766 |
| Adjusted R Square | 0.733 |
| Standard Error | 12.211 |
| Observations | 17.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 6841.985 | 3420.993 | 22.943 | 0.000 |
| Residual | 14.000 | 2087.544 | 149.110 | | |
| Total | 16.000 | 8929.529 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 1.769 | 4.505 | 0.393 | 0.701 | -7.894 | 11.432 | -7.894 | 11.432 |
| Parking Spaces | 0.116 | 0.047 | 2.493 | 0.026 | 0.016 | 0.216 | 0.016 | 0.216 |
| Bedrooms | 0.042 | 0.027 | 1.519 | 0.151 | -0.017 | 0.100 | -0.017 | 0.100 |

Figure 6.18 Weekday Multiple Regression – Daily Vehicle Trips, Parking and Bedrooms

$R^2$ equals 0.766 is not sufficient to draw conclusions with an acceptable level of significance and the models show standard errors which are too high to be robust. There are no other variables of sufficient significance to be worthy of analysis in the multiple regression tests. This was expected considering the initial correlation values and the clear differences based on geographical location.

Weekend - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.920 |
| R Square | 0.846 |
| Adjusted R Square | 0.824 |
| Standard Error | 91.663 |
| Observations | 17.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 645811.476 | 322905.738 | 38.432 | 0.000 |
| Residual | 14.000 | 117628.406 | 8402.029 | | |
| Total | 16.000 | 763439.882 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -23.654 | 33.820 | -0.699 | 0.496 | -96.190 | 48.882 | -96.190 | 48.882 |
| Parking Spaces | 1.019 | 0.349 | 2.917 | 0.011 | 0.270 | 1.768 | 0.270 | 1.768 |
| Bedrooms | 0.469 | 0.205 | 2.286 | 0.038 | 0.029 | 0.910 | 0.029 | 0.910 |

Figure 6.19 Weekend Multiple Regression – Vehicle Trips, Parking and Bedrooms

An $R^2$ value of 0.846 shows some evidence that the combination of Parking Space and Number of Bedrooms variables are linked. However, since Parking Spaces by itself had an $R^2$ of 0.79, there is negligible difference in the regression while unnecessary complexity is added to the model. Also, the standard error on the intercept coefficient is very high, reducing the confidence of this model.

### 6.4.2 Metropolitan Sites

The selected independent variables were grouped to see if together they can better describe the dependent variable. When comparing Metropolitan Sites, the dependent variables tested were Number of Vehicle Trips and Number of Person Trips. Each was tested against a combination of two (2) variables and the results of all tested scenarios are shown in Table 6.7.

All Multiple Regression scenarios that displayed a high $R^2$ and were selected for testing are shown in Appendix C.

Table 6.7: Multiple Regression Tested Scenarios – Metropolitan Sites

| Time | Primary Aspect | Scenario | Aspects in Model | Aspects in Model | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| AM Peak Period | Peak Vehicle Trips | 1 | Parking Spaces | Number of Bedrooms | 0.469 | No |
| AM Peak Period | Peak Vehicle Trips | 2 | Parking Spaces | Number of Units | 0.473 | No |
| AM Peak Period | Peak Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.675 | No |
| AM Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+Bedroom | 0.469 | No |
| AM Peak Period | Peak Person Trips | 5 | Parking Spaces | Number of Bedrooms | 0.593 | No |
| AM Peak Period | Peak Person Trips | 6 | Parking Spaces | Number of Units | 0.567 | No |
| PM Peak Period | Peak Vehicle Trips | 1 | Parking Spaces | Number of Bedrooms | 0.469 | No |
| PM Peak Period | Peak Vehicle Trips | 2 | Parking Spaces | Number of Units | 0.473 | No |
| PM Peak Period | Peak Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.841 | Yes |
| PM Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+Bedroom | 0.625 | No |
| PM Peak Period | Peak Person Trips | 5 | Parking Spaces | Number of Bedrooms | 0.593 | No |
| PM Peak Period | Peak Person Trips | 6 | Parking Spaces | Number of Units | 0.566 | No |
| Weekday | Daily Vehicle Trips | 1 | Parking Spaces | Number of Bedrooms | 0.590 | No |
| Weekday | Daily Vehicle Trips | 2 | Parking Spaces | Number of Units | 0.596 | No |
| Weekday | Daily Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 bedroom and 3+ Bedroom | 0.782 | No |
| Weekday | Daily Vehicle Trips | 4 | 1+2 Bedrooms | 3+Bedroom | 0.568 | No |
| Weekend Peak Period | Peak Vehicle Trips | 1 | Parking Spaces | Number of Bedrooms | 0.453 | No |
| Weekend Peak Period | Peak Vehicle Trips | 2 | Parking Spaces | Number of Units | 0.470 | No |
| Weekend Peak Period | Peak Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.691 | No |
| Weekend Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+Bedroom | 0.528 | No |
| Weekend Peak Period | Peak Person Trips | 4 | Parking Spaces | Number of Bedrooms | 0.662 | No |
| Weekend Peak Period | Peak Person Trips | 5 | Parking Spaces | Number of Units | 0.655 | No |

| Time | Primary Aspect | Scenario | Aspects in Model | Aspects in Model | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| Weekend | Daily Vehicle Trips | 1 | Parking Spaces | Number of Bedrooms | 0.492 | No |
| Weekend | Daily Vehicle Trips | 2 | Parking Spaces | Number of Units | 0.508 | No |
| Weekend | Daily Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.699 | No |
| Weekend | Daily Vehicle Trips | 4 | 1+2 Bedroom | 3+ Bedroom | 0.544 | No |

[1] *Scenario considered to provide the most accurate results*

As shown above, only a single $R^2$ result approaching 0.85 was identified. No other scenario presented a sufficiently accurate model for approximating vehicle trip generation. Detailed results of the scenarios identified as providing the most accurate results are presented in Figure 6.20, Figure 6.21 and Figure 6.23.

Weekday AM - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.822 |
| R Square | 0.675 |
| Adjusted R Square | 0.431 |
| Standard Error | 14.164 |
| Observations | 8.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 1667.472 | 555.824 | 2.770 | 0.175 |
| Residual | 4.000 | 802.528 | 200.632 | | |
| Total | 7.000 | 2470.000 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 24.825 | 7.020 | 3.536 | 0.024 | 5.334 | 44.316 | 5.334 | 44.316 |
| 1 Bedroom | 3.165 | 2.023 | 1.564 | 0.193 | -2.452 | 8.782 | -2.452 | 8.782 |
| 2 Bedrooms | -0.736 | 0.558 | -1.319 | 0.258 | -2.284 | 0.813 | -2.284 | 0.813 |
| 3+ Bedrooms | -1.350 | 0.792 | -1.706 | 0.163 | -3.548 | 0.848 | -3.548 | 0.848 |

Figure 6.20 Metropolitan Sites Multiple Regression – Weekday AM Peak Period Vehicle Trip Generation with Bedroom Breakdowns

A multiple regression output of $R^2$ equals 0.675 is not sufficient for a significant model. As such, the AM peak period trip generation for metropolitan sites is recommended to use the Linear Regression model (see Section 6.3.2).

Weekday PM - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.917 |
| R Square | 0.841 |
| Adjusted R Square | 0.721 |
| Standard Error | 14.069 |
| Observations | 8.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 4182.224 | 1394.075 | 7.043 | 0.045 |
| Residual | 4.000 | 791.776 | 197.944 | | |
| Total | 7.000 | 4974.000 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 27.098 | 6.973 | 3.886 | 0.018 | 7.738 | 46.458 | 7.738 | 46.458 |
| 1 Bedroom | 4.847 | 2.009 | 2.412 | 0.073 | -0.732 | 10.426 | -0.732 | 10.426 |
| 2 Bedrooms | -1.112 | 0.554 | -2.007 | 0.115 | -2.650 | 0.426 | -2.650 | 0.426 |
| 3+ Bedrooms | -1.915 | 0.786 | -2.436 | 0.072 | -4.098 | 0.268 | -4.098 | 0.268 |

Figure 6.21 Metropolitan Sites Multiple Regression – Weekday PM Peak Period Vehicle Trip Generation with Bedroom Breakdowns

While a multiple regression output of $R^2$ equals 0.841 indicates a valid result, further analysis of the model finds that 2 of the 3 coefficients are negative and the model presents a large constant value. Furthermore,

the improvement in $R^2$ over the best performing single Linear regression model is very minor. As such, the PM peak period trip generation for metropolitan sites is recommended to use the Linear Regression model (see Section 6.3.2). It is noted that the AM and PM outputs do show consistency in results, further affirming the grouping of sites by geographical location.

Weekday - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.884 |
| R Square | 0.782 |
| Adjusted R Square | 0.619 |
| Standard Error | 111.165 |
| Observations | 8.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 177523.959 | 59174.653 | 4.788 | 0.082 |
| Residual | 4.000 | 49430.916 | 12357.729 | | |
| Total | 7.000 | 226954.875 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 187.170 | 55.096 | 3.397 | 0.027 | 34.199 | 340.141 | 34.199 | 340.141 |
| 1 Bedroom | 32.601 | 15.877 | 2.053 | 0.109 | -11.481 | 76.683 | -11.481 | 76.683 |
| 2 Bedrooms | -7.543 | 4.377 | -1.723 | 0.160 | -19.696 | 4.611 | -19.696 | 4.611 |
| 3+ Bedrooms | -12.528 | 6.212 | -2.017 | 0.114 | -29.777 | 4.721 | -29.777 | 4.721 |

Figure 6.22 Metropolitan Sites Multiple Regression – Weekday Daily Vehicle Trip Generation with Bedroom Breakdowns

Weekend Peak - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.831 |
| R Square | 0.691 |
| Adjusted R Square | 0.459 |
| Standard Error | 15.177 |
| Observations | 8.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 2059.558 | 686.519 | 2.981 | 0.159 |
| Residual | 4.000 | 921.317 | 230.329 | | |
| Total | 7.000 | 2980.875 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 26.289 | 7.522 | 3.495 | 0.025 | 5.405 | 47.173 | 5.405 | 47.173 |
| 1 Bedroom | 3.267 | 2.168 | 1.507 | 0.206 | -2.751 | 9.286 | -2.751 | 9.286 |
| 2 Bedrooms | -0.742 | 0.598 | -1.242 | 0.282 | -2.401 | 0.917 | -2.401 | 0.917 |
| 3+ Bedrooms | -1.390 | 0.848 | -1.638 | 0.177 | -3.744 | 0.965 | -3.744 | 0.965 |

Figure 6.23 Metropolitan Sites Multiple Regression - Weekend Peak Period Vehicle Trip Generation with Bedroom Breakdowns

A multiple regression output of $R^2$ equals 0.691 is not sufficient for a significant model. As such, the Weekend peak period trip generation for metropolitan sites is recommended to use the Linear Regression model (see Section 6.3.26.3.2).

Weekend - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.836 |
| R Square | 0.699 |
| Adjusted R Square | 0.473 |
| Standard Error | 134.670 |
| Observations | 8.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 168519.660 | 56173.220 | 3.097 | 0.152 |
| Residual | 4.000 | 72543.840 | 18135.960 | | |
| Total | 7.000 | 241063.500 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 191.299 | 66.745 | 2.866 | 0.046 | 5.985 | 376.614 | 5.985 | 376.614 |
| 1 Bedroom | 28.772 | 19.234 | 1.496 | 0.209 | -24.630 | 82.174 | -24.630 | 82.174 |
| 2 Bedrooms | -6.471 | 5.303 | -1.220 | 0.289 | -21.194 | 8.252 | -21.194 | 8.252 |
| 3+ Bedrooms | -11.811 | 7.526 | -1.569 | 0.192 | -32.707 | 9.084 | -32.707 | 9.084 |

Figure 6.24 Metropolitan Sites Multiple Regression - Weekend Daily Vehicle Trip Generation with Bedroom Breakdowns

### 6.4.3 Sub-Metropolitan Sites

The selected independent variables were grouped to see if together they can better describe the dependent variable. When comparing Sub-Metropolitan Sites, the dependent variables tested were Number of Vehicle Trips and Number of Person Trips. Each was tested against a combination of variables, the results of all tested scenarios are shown in Table 6.8.

All Multiple Regression scenarios that displayed a high $R^2$ and were selected for testing are shown in Appendix C.

Table 6.8: Multiple Regression Tested Scenarios – Sub-Metropolitan Sites

| Time | Primary Aspect | Scenario | Aspects Tested in Regression | Aspects Tested in Regression | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| AM Peak Period | Peak Vehicle Trips | 1 | Parking Spaces | Number of Units | 0.830 | Yes |
| AM Peak Period | Peak Vehicle Trips | 2 | Parking Spaces | Number of Bedrooms | 0.844 | Yes |
| AM Peak Period | Peak Vehicle Trips | 3 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.270 | No |
| AM Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.228 | No |
| PM Peak Period | Peak Person Trips | 1 | Parking Spaces | Number of Units | 0.832 | Yes |
| PM Peak Period | Peak Person Trips | 2[1] | Parking Spaces | Number of Bedrooms | 0.894 | Yes |
| PM Peak Period | Peak Person Trips | 3 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.277 | No |
| PM Peak Period | Peak Person Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.175 | No |
| PM Peak Period | Peak Vehicle Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.291 | No |
| PM Peak Period | Peak Vehicle Trips | 6 | 1+2 Bedrooms | 3+ Bedroom | 0.176 | No |
| Weekday | Daily Vehicle Trips | 1 | Units | Parking Spaces | 0.868 | Yes |
| Weekday | Daily Vehicle Trips | 2 | Parking Spaces | Number of Bedrooms | 0.882 | Yes |
| Weekday | Daily Vehicle Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.220 | No |
| Weekday | Daily Person Trips | 3[1] | Units | Parking Spaces | 0.888 | Yes |
| Weekday | Daily Person Trips | 4 | Number of Bedrooms | Parking Spaces | 0.797 | No |
| Weekday | Daily Person Trips | 7 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.119 | No |
| Weekend Peak Period | Peak Vehicle Trips | 1[1] | Units | Parking Spaces | 0.842 | Yes |
| Weekend Peak Period | Peak Vehicle Trips | 2[2] | Parking Spaces | Number of Bedrooms | 0.827 | No |
| Weekend Peak Period | Peak Vehicle Trips | 3 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.195 | No |

| Time | Primary Aspect | Scenario | Aspects Tested in Regression | Aspects Tested in Regression | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| Weekend Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.195 | No |
| Weekend Peak Period | Peak Person Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.256 | No |
| Weekend | Daily Vehicle Trips | 1 | Units | Parking Spaces | 0.861 | Yes |
| Weekend | Daily Vehicle Trips | 2[1] | Parking Spaces | Number of Bedrooms | 0.887 | Yes |
| Weekend | Daily Person Trips | 3 | Parking Spaces | Number of Units | 0.712 | No |
| Weekend | Daily Person Trips | 4 | Parking Spaces | Number of Bedrooms | 0.444 | No |
| Weekend | Daily Person Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.415 | No |

*[1] Scenario considered to provide the most accurate results*

*[2] Acceptable $R^2$ are those approaching or greater than 0.85*

Sub-metropolitan sites show a number of sufficiently accurate results (i.e. R square over 0.85) indicating multiple options for an appropriate method of approximating vehicle trip generation. Appropriate scenarios were established for:

- PM Peak Person Trip generation
- Weekday Daily Person and Vehicle Trip generation; and
- Weekend Daily Vehicle Trip generation.

Most results show a minor improvement over the Linear Regression analysis and detailed results of the three "best case" scenarios are presented in Figure 6.25 to Figure 6.27. It is noted that no multiple regression model was considered appropriate for the AM or Weekend peak periods for the Sub-Metropolitan sites though all scenarios show an improvement from the Linear Regression results.

Weekday - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.942 |
| R Square | 0.888 |
| Adjusted R Square | 0.851 |
| Standard Error | 62.988 |
| Observations | 9.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 189095.800 | 94547.900 | 23.831 | 0.001 |
| Residual | 6.000 | 23805.089 | 3967.515 | | |
| Total | 8.000 | 212900.889 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -7.214 | 55.306 | -0.130 | 0.900 | -142.544 | 128.115 | -142.544 | 128.115 |
| Units | 5.642 | 1.660 | 3.398 | 0.015 | 1.579 | 9.705 | 1.579 | 9.705 |
| Parking Spaces | -0.309 | 0.825 | -0.374 | 0.721 | -2.329 | 1.711 | -2.329 | 1.711 |

Figure 6.25: Sub-Metropolitan Sites Multiple Regression – Weekday Daily Person Trip Generation with Units and Parking

The $R^2$ equals 0.888 when combining the number of units and parking spaces to generate a model for daily person trip generation. The combination of these variables has resulted in a reasonable model for Daily Person Trips generated. However, the parking spaces coefficient has a negative sign, is relatively small and is therefore considered redundant.

Weekday PM - MULTIPLE REGRESSION 2
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.945 |
| R Square | 0.894 |
| Adjusted R Square | 0.858 |
| Standard Error | 8.814 |
| Observations | 9.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 3925.449 | 1962.725 | 25.265 | 0.001 |
| Residual | 6.000 | 466.107 | 77.684 | | |
| Total | 8.000 | 4391.556 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 8.751 | 6.044 | 1.448 | 0.198 | -6.038 | 23.540 | -6.038 | 23.540 |
| Parking Spaces | 0.360 | 0.052 | 6.962 | 0.000 | 0.233 | 0.486 | 0.233 | 0.486 |
| Bedrooms | -0.089 | 0.040 | -2.232 | 0.067 | -0.187 | 0.009 | -0.187 | 0.009 |

Figure 6.26 Sub-Metropolitan Sites Multiple Regression – Weekday PM Peak Person Trip Generation with Number of Parking and Bedrooms

The $R^2$ equals 0.894 when combining the number of parking spaces and units to generate a model for PM Peak Period person trip generation. The combination of variables has resulted in a reasonable model for PM Peak Person Trips generated. However, the intercept is relatively large and the 'bedrooms' coefficient is negative meaning it is counterintuitive.

Weekend - MULTIPLE REGRESSION 2
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.942 |
| R Square | 0.887 |
| Adjusted R Square | 0.849 |
| Standard Error | 34.901 |
| Observations | 9.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 57333.667 | 28666.834 | 23.534 | 0.001 |
| Residual | 6.000 | 7308.555 | 1218.093 | | |
| Total | 8.000 | 64642.222 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 45.998 | 23.932 | 1.922 | 0.103 | -12.563 | 104.558 | -12.563 | 104.558 |
| Parking Spaces | 1.353 | 0.205 | 6.614 | 0.001 | 0.852 | 1.854 | 0.852 | 1.854 |
| Bedrooms | -0.407 | 0.158 | -2.576 | 0.042 | -0.793 | -0.020 | -0.793 | -0.020 |

Figure 6.27 Sub-Metropolitan Sites Multiple Regression – Weekend Daily Traffic with Parking Spaces and Bedrooms

The $R^2$ equals 0.887 when combining the number of parking spaces and bedrooms to generate a model for daily vehicle trip generation. The combination of these variables has resulted in a reasonable model for Weekend Daily Traffic generated. However, the bedrooms coefficient is negative and the intercept values very high significantly reducing the confidence in the model.

### 6.4.4 Regional Sites

The selected independent variables were grouped to see if together they can better describe the dependent variable. When comparing Regional Sites, the dependent variables tested were Number of Vehicle Trips and Number of Person Trips. Each was tested against a combination of two (2) variables and the results of all tested scenarios are shown in Table 6.9.

All Multiple Regression scenarios that displayed a high $R^2$ and were selected for testing are shown in Appendix C.

Table 6.9: Multiple Regression Tested Scenarios – Regional Sites

| Time | Primary Aspect | Scenario | Aspect 1 | Aspect 2 | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| AM Peak Period | Peak Vehicle Trips | 1 | Number of Bedrooms | Parking Spaces | 0.935 | Yes |
| AM Peak Period | Peak Vehicle Trips | 2 | Number of Units | Parking Spaces | 0.874 | Yes |
| AM Peak Period | Peak Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.968 | Yes |
| AM Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.963 | Yes |
| PM Peak Period | Peak Vehicle Trips | 1[1] | Number of Bedrooms | Parking Spaces | 0.945 | Yes |
| PM Peak Period | Peak Vehicle Trips | 2 | Number of Units | Parking Spaces | 0.908 | Yes |
| PM Peak Period | Peak Vehicle Trips | 3 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.937 | Yes |
| PM Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.935 | Yes |
| Weekday | Daily Vehicle Trips | 1 | Number of Bedrooms | Parking Spaces | 0.958 | Yes |
| Weekday | Daily Vehicle Trips | 2 | Number of Units | Parking Spaces | 0.908 | Yes |
| Weekday | Daily Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.961 | Yes |
| Weekday | Daily Vehicle Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.960 | Yes |
| Weekend Peak Period | Peak Vehicle Trips | 1 | Number of Bedrooms | Parking Spaces | 0.942 | Yes |
| Weekend Peak Period | Peak Vehicle Trips | 2 | Number of Units | Parking Spaces | 0.893 | Yes |
| Weekend Peak Period | Peak Vehicle Trips | 3[1] | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.977 | Yes |
| Weekend Peak Period | Peak Vehicle Trips | 4 | 1+2 Bedrooms | 3+ Bedroom | 0.961 | Yes |
| Weekend | Daily Vehicle Trips | 1[1] | Number of Bedrooms | Parking Spaces | 0.976 | Yes |
| Weekend | Daily Vehicle Trips | 2 | Number of Units | Parking Spaces | 0.968 | Yes |
| Weekend | Daily Vehicle Trips | 5 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.977 | Yes |
| Weekend | Daily Vehicle Trips | 7 | 1+2 Bedrooms | 3+ Bedroom | 0.974 | Yes |
| Weekend | Daily Person Trips | 3 | Number of Bedrooms | Parking Spaces | 0.786 | No |
| Weekend | Daily Person Trips | 4 | Number of Units | Parking Spaces | 0.903 | Yes |

| Time | Primary Aspect | Scenario | Aspect 1 | Aspect 2 | $R^2$ Value | Valid Analysis[2] |
|---|---|---|---|---|---|---|
| Weekend | Daily Person Trips | 6 | 1 Bedroom and 2 Bedroom | 2 Bedroom and 3+ Bedroom | 0.755 | No |
| Weekend | Daily Person Trips | 8 | 1+2 Bedrooms | 3+ Bedroom | 0.736 | No |

*[1] Scenario considered to provide the most accurate results*

*[2] Acceptable $R^2$ are those approaching or greater than 0.85*

Regional sites show a large number of sufficiently accurate results (i.e. R2 over 0.85) indicating multiple potential options for an appropriate model for approximating vehicle trip generation. Testing scenarios were established for:

- AM Peak Vehicle Trip generation;
- PM Peak Vehicle Trip generation;
- Weekday Daily Vehicle Trip generation;
- Weekend Peak Vehicle Trip generation; and
- Weekend Daily Vehicle and Person Trip generation.

Detailed results of the five "best case" tests are presented in Figure 6.28 to Figure 6.32.

Multiple Regression results show only a marginal difference to the Linear Regression analysis results. Furthermore, the 'parking spaces' coefficient is negative and much smaller than the 'bedrooms' coefficient, which is intuitively unreasonable and suggests that the variable is not providing benefit to the models. As such it is recommended that the Linear Regression models be used in trip generation for simplicity. The high correlation between the number of vehicle trips and number of bedrooms is consistent between both Linear and Multiple Regression analysis methods.

Weekday AM - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.984 |
| R Square | 0.968 |
| Adjusted R Square | 0.954 |
| Standard Error | 5.628 |
| Observations | 11.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 6718.796 | 2239.599 | 70.698 | 0.000 |
| Residual | 7.000 | 221.750 | 31.679 | | |
| Total | 10.000 | 6940.545 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 4.700 | 2.358 | 1.993 | 0.086 | -0.875 | 10.274 | -0.875 | 10.274 |
| 1 Bedroom | 0.204 | 0.291 | 0.701 | 0.506 | -0.484 | 0.891 | -0.484 | 0.891 |
| 2 Bedrooms | -0.157 | 0.140 | -1.125 | 0.298 | -0.489 | 0.174 | -0.489 | 0.174 |
| 3+ Bedrooms | 0.580 | 0.069 | 8.414 | 0.000 | 0.417 | 0.743 | 0.417 | 0.743 |

Figure 6.28 Regional Sites Multiple Regression – Weekday AM Peak Period Vehicle Trip Generation by Bedroom Breakdown

Weekday PM - MULTIPLE REGRESSION 1
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.972 |
| R Square | 0.945 |
| Adjusted R Square | 0.931 |
| Standard Error | 8.383 |
| Observations | 11.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 9611.994 | 4805.997 | 68.390 | 0.000 |
| Residual | 8.000 | 562.188 | 70.274 | | |
| Total | 10.000 | 10174.182 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 7.349 | 4.160 | 1.767 | 0.115 | -2.242 | 16.941 | -2.242 | 16.941 |
| Bedrooms | 0.227 | 0.038 | 5.901 | 0.000 | 0.138 | 0.315 | 0.138 | 0.315 |
| Parking Spaces | -0.145 | 0.077 | -1.872 | 0.098 | -0.323 | 0.034 | -0.323 | 0.034 |

Figure 6.29 Regional Sites Multiple Regression – Weekday PM Peak Period Vehicle Trip Generation with Bedrooms and Parking

Weekday - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.980 |
| R Square | 0.961 |
| Adjusted R Square | 0.944 |
| Standard Error | 63.183 |
| Observations | 11.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 688876.604 | 229625.535 | 57.521 | 0.000 |
| Residual | 7.000 | 27944.305 | 3992.044 | | |
| Total | 10.000 | 716820.909 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 15.381 | 26.465 | 0.581 | 0.579 | -47.199 | 77.962 | -47.199 | 77.962 |
| 1 Bedroom | 1.242 | 3.263 | 0.381 | 0.715 | -6.473 | 8.958 | -6.473 | 8.958 |
| 2 Bedrooms | 0.038 | 1.572 | 0.024 | 0.981 | -3.678 | 3.754 | -3.678 | 3.754 |
| 3+ Bedrooms | 5.200 | 0.774 | 6.721 | 0.000 | 3.371 | 7.030 | 3.371 | 7.030 |

Figure 6.30 Regional Sites Multiple Regression – Weekday Daily Vehicle Trip Generation by Bedroom Breakdown

Weekend Peak - MULTIPLE REGRESSION 3
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.989 |
| R Square | 0.977 |
| Adjusted R Square | 0.968 |
| Standard Error | 5.597 |
| Observations | 11.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3.000 | 9432.677 | 3144.226 | 100.352 | 0.000 |
| Residual | 7.000 | 219.323 | 31.332 | | |
| Total | 10.000 | 9652.000 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 6.009 | 2.345 | 2.563 | 0.037 | 0.465 | 11.553 | 0.465 | 11.553 |
| 1 Bedroom | 0.155 | 0.289 | 0.535 | 0.609 | -0.529 | 0.838 | -0.529 | 0.838 |
| 2 Bedrooms | -0.164 | 0.139 | -1.181 | 0.276 | -0.494 | 0.165 | -0.494 | 0.165 |
| 3+ Bedrooms | 0.676 | 0.069 | 9.861 | 0.000 | 0.514 | 0.838 | 0.514 | 0.838 |

Figure 6.31 Regional Sites Multiple Regression – Weekend Peak Period Vehicle Trip Generation by Bedroom Breakdown

Weekend - MULTIPLE REGRESSION 1
SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.988 |
| R Square | 0.976 |
| Adjusted R Square | 0.970 |
| Standard Error | 41.860 |
| Observations | 11.000 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2.000 | 566155.928 | 283077.964 | 161.548 | 0.000 |
| Residual | 8.000 | 14018.254 | 1752.282 | | |
| Total | 10.000 | 580174.182 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 12.174 | 20.771 | 0.586 | 0.574 | -35.723 | 60.071 | -35.723 | 60.071 |
| Bedrooms | 1.319 | 0.192 | 6.878 | 0.000 | 0.876 | 1.761 | 0.876 | 1.761 |
| Parking Spaces | -0.170 | 0.386 | -0.442 | 0.671 | -1.061 | 0.720 | -1.061 | 0.720 |

Figure 6.32: Regional Sites Multiple Regression – Weekend Daily Vehicle Trip Generation with Bedrooms and Parking

## 6.5 PARKING ACCUMULATION ANALYSIS

A total of 13 sites were manually surveyed to determine the building's on-site parking occupancy at the beginning of each survey (approximately 7pm). Vehicle arrival and departure data was then used to determine the car park occupancy throughout the day. This occupancy does not take into account any residents parking on-street or near the development.

The average daily parking occupancy for Metropolitan, Sub-Metropolitan and Regional sites is shown in Figure 6.33 and Figure 6.34 for Weekday and Weekend results respectively.

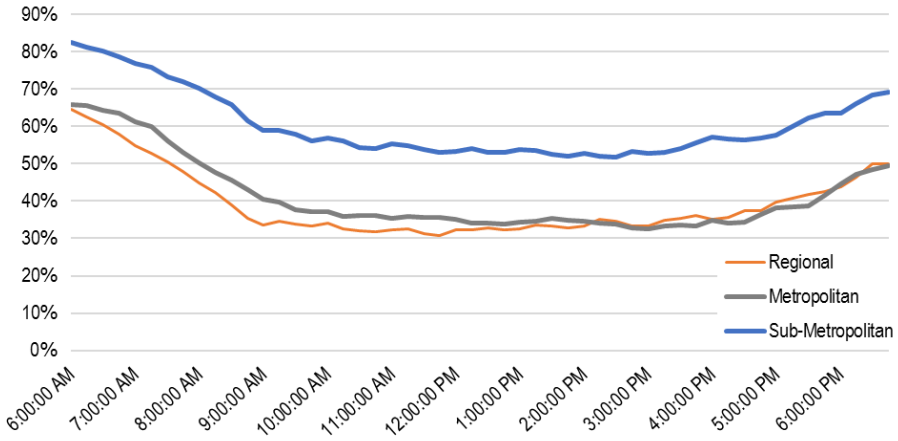



Figure 6.33: Weekday Average Parking Occupancy (%)

The weekday daily trend for arrival and departure of vehicles remains consistent across all surveyed sites. However, weekday data shows a significant difference in the total occupancy between sub-metropolitan sites and metropolitan or regional sites. This result may be due to any number of demographical or geographical reasons including the availability of unrestricted parking in proximity to the site or age demographic of the developments (i.e. seaside apartments).

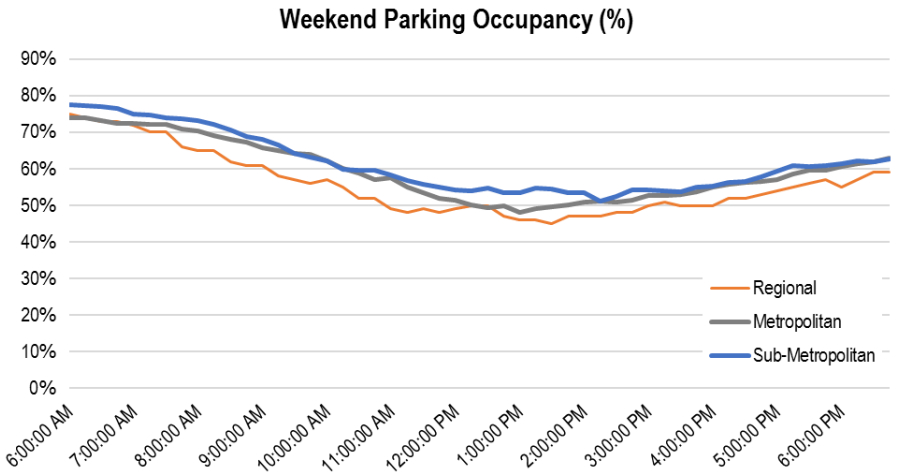



Figure 6.34: Weekend Average Parking Occupancy (%)

Weekend parking accumulation shows a higher percentage of occupancy throughout the day for all sites with a more gradual decline in parking numbers across the morning than weekdays.

As expected, peak parking occupancy for all high density residential sites occurs at 6.00am or 'overnight' and lowest parking occupancy times occurred across the middle of the day for both weekday and weekend surveys.

*On-Street Parking*

Based on manual questionnaire surveys it was found that at some sites a number of residents were parking on-street near their building. While this occurred at all sites where on-street parking was unrestricted and easily accessible regardless of geographical location, most were sub-metropolitan sites.

# 7. RESULTS INTERPRETATION

## 7.1 DRAFT MODELS

Comparison of both Linear and Multiple regression models found that the most appropriate robust models were derived using single-variable Linear Regression. Each of the best performing linear and multiple regression models, of all variable combination scenarios that were selected for analysis, are presented in Table 7.1. Assessment of the multiple linear regression results identified that **no equation created using multiple linear regression provided significant improvements to single-variable regression results**. Some multiple regression formulas that appeared more acceptable in a mathematical sense did not hold up to logical interrogation of the model.

Only those relationships which had an $R^2$ value greater than or close to 0.85 are included for recommendation. Where no reliable relationship was able to be established, practitioners should select representative site(s) from the survey list and prepare site-specific trip rate data based on selected sites.

Table 7.1: Best Performing Models for Trip Generation

| Site Location | Method of Regression | Period | Model* | $R^2$ Value |
|---|---|---|---|---|
| Metropolitan Sites | Linear Regression | AM Peak | Vehicle Trips = 0.134 x Parking Spaces + 4.883<br>Person Trips = 0.204 x Parking Spaces + 4.668 | 0.98<br>0.94 |
| Metropolitan Sites | Linear Regression | PM Peak | Vehicle Trips = 0.199 x Parking Spaces + 1.378<br>Person Trips = 0.262 x Parking Spaces + 0.123 | 0.94<br>0.95 |
| Metropolitan Sites | Linear Regression | Daily (Weekday) | Vehicle Trips = 1.343 x Parking Spaces + 7.717 | 0.97 |
| Metropolitan Sites | Linear Regression | Weekend Peak | Vehicle Trips = 0.145 x Parking Spaces + 5.615<br>Person Trips = 0.262 x Parking Spaces + 2.360 | 0.96<br>0.95 |
| Metropolitan Sites | Linear Regression | Daily (Weekend) | Vehicle Trips = 1.330 x Parking Spaces + 9.727 | 0.97 |
| Metropolitan Sites | Multiple Regression | PM Peak | Vehicle Trips = 4.8 x (1 Bed) – 1.1 x (2 Bed) – 1.9 x (3+ Bed) + 27.01 | 0.84 |
| Sub-Metropolitan Sites | Linear Regression | AM Peak | Vehicle Trips = 0.189 x Parking Spaces + 1.785 | 0.82 |
| Sub-Metropolitan Sites | Linear Regression | PM Peak | Person Trips = 0.346 x Parking Spaces + 3.646 | 0.81 |
| Sub-Metropolitan Sites | Linear Regression | Daily (Weekday) | Vehicle Trips = 1.608 x Parking Spaces + 1.445<br>Person Trips = 5.086 x Units - 0.059 | 0.83<br>0.89 |
| Sub-Metropolitan Sites | Linear Regression | Weekend Peak | Vehicle Trips = 0.343 x Units - 1.4919 | 0.84 |
| Sub-Metropolitan Sites | Linear Regression | Daily (Weekend) | Vehicle Trips = 2.744 Units - 33.998 | 0.85 |
| Sub-Metropolitan Sites | Multiple Regression | AM Peak | Vehicle Trips = 0.15 x (Parking Spaces) + 0.08 x (Units) - 0.17<br>Vehicle Trips = 0.19 x (Parking Spaces) - 0.02 x (Bedrooms) + 3.16 | 0.83<br>0.84 |
| Sub-Metropolitan Sites | Multiple Regression | PM Peak | Person Trips = 0.22 x (Parking Spaces) + 0.28 x (Units) – 2.94<br>Person Trips = 0.36 x (Parking Spaces) + 0.09 x (Bedrooms) + 8.75 | 0.83<br>0.89 |
| Sub-Metropolitan Sites | Multiple Regression | Daily (Weekday) | Vehicle Trips = 1.65 x (Parking Spaces) -0.30 x (Bedrooms) + 18.880<br>Person Trips = 5.642 x (Units) - 0.309 x (Parking Spaces) - 7.214 | 0.88<br>0.89 |
| Sub-Metropolitan Sites | Multiple Regression | Weekend Peak | Vehicle Trips = 0.32 x (Units) + 00.01 x (Parking Spaces) – 1.24 | 0.84 |

| Site Location | Method of Regression | Period | Model* | $R^2$ Value |
|---|---|---|---|---|
| Sub-Metropolitan Sites | Multiple Regression | Daily (Weekend) | Vehicle Trips = 2.106 x (Units) + 0.354 x (Parking Spaces) - 25.794 | 0.86 |
| | | | Vehicle Trips = 1.353 x (Parking Spaces) - 0.407 x (Bedrooms) + 45.998 | 0.89 |
| Regional Sites | Linear Regression | AM Peak | Vehicle Trips = 0.138 x Bedrooms + 1.921 | 0.92 |
| | | | Vehicle Trips = 0.389 x Units – 3.065 | 0.87 |
| Regional Sites | Linear Regression | PM Peak | Vehicle Trips = 0.167 x Bedrooms – 0.455 | 0.92 |
| | | | Vehicle Trips = 0.475 x Units – 6.660 | 0.88 |
| Regional Sites | Linear Regression | Daily (Weekday) | Vehicle Trips = 1.409 x Bedrooms – 12.437 | 0.94 |
| | | | Vehicle Trips = 4.017 x Units – 67.429 | 0.90 |
| Regional Sites | Linear Regression | Weekend Peak | Vehicle Trips = 0.165 x Bedrooms + 1.740 | 0.94 |
| | | | Vehicle Trips = 0.464 x Units – 3.671 | 0.89 |
| Regional Sites | Linear Regression | Daily (Weekend) | Vehicle Trips = 1.316 x Bedrooms – 22.558 | 0.99 |
| | | | Vehicle Trips = 3.750 x Units – 67.560 | 0.96 |
| Regional Sites | Multiple Regression | AM Peak | Vehicle Trips = 0.171 x (Bedrooms) - 0.083 x (Parking Spaces) + 7.0 | 0.94 |
| | | | Vehicle Trips = 0.2 x (1 Bed) – 0.15 x (2 Bed) + 0.58 x (3+ Bed) + 4.7 | 0.97 |
| Regional Sites | Multiple Regression | PM Peak | Vehicle Trips = 0.23 x (Bedrooms) - 0.14 x (Parking Spaces) + 7.35 | 0.95 |
| | | | Vehicle Trips = 0.2 x (1 Bed) – 0.01 x (2 Bed) + 0.62 x (3+ Bed) + 3.07 | 0.94 |
| Regional Sites | Multiple Regression | Daily (Weekday) | Vehicle Trips = 1.79 x (Bedrooms) - 0.94 x (Parking Spaces) + 40.28 | 0.96 |
| | | | Vehicle Trips = 1.24 x (1 Bed) + 0.04 x (2 Bed) + 5.2 x (3+ Bed) + 15.38 | 0.96 |
| Regional Sites | Multiple Regression | Weekend Peak | Vehicle Trips = 0.19 x (Bedrooms) - 0.075 x (Parking Spaces) + 7.63 | 0.98 |
| | | | Vehicle Trips = 0.16 x (1 Bed) – 0.16 x (2 Bed) + 0.68 x (3+ Bed) + 6.0 | 0.96 |
| Regional Sites | Multiple Regression | Daily (Weekend) | Vehicle Trips = 1.32 x (Bedrooms) - 0.17 x (Parking Spaces) + 12.17 | 0.97 |
| | | | Vehicle Trips = 0.09 x (1 Bed) + 2.9 x (2 Bed) + 3.46 x (3+ Bed) + 13.95 | 0.98 |
| | | | Person Trips = 10.816 x (Units) - 4.230 x (Parking Spaces) – 27.026 | 0.90 |

**only 'best case' models showing a good $R^2$.*

When considering the above 'best performing' models it is important to note:

- negative constants or coefficients are not intuitively appropriate for trip generation (i.e. as dependent value (X) approaches '0' the trip generation becomes negative);
- large constant values indicate a lower dependence on the variable in the equation and would make the models insensitive for smaller developments;
- the closer a constant is to '0' the more sensitive the equation is considered to be when describing trip generation; and
- model produced equation credibility is reduced when coefficients do not appear logical. For example, *Regional Sites – Weekend Daily Vehicle Trips*, where there is a large difference in coefficients for smaller units vs the larger units. Based on this 3+ bedroom units would produce almost 10 times the number of trips of 1 and 2 Bedrooms combined, which is not logical.

It should also be noted that the available dataset for multiple regression analysis is considered to be a small sample size and not large enough to provide confidence in this type of regression modelling.

For example, combining the 1 and 2 bedroom units as a single variable (i.e. variables in model were 1+2 Bedroom and 3+ Bedroom units) was investigated and found that while, in some cases, the models are mathematically better, a closer look at the equation outputs finds their credibility is reduced due the large difference in multipliers/coefficients for the smaller units vs the larger. One formula showed:

*Daily Vehicle Trips = 0.6*(1+2Bedroom Units) + 5.2*(3+Bedroom Units)*

In this formula 3 + bedroom units are producing 10 times the number of trips of 1 and 2 Bedrooms combined, which is not logical.

## 7.2 REFINED MODELS

Each of the best performing models have been refined with consideration to the impact of the equation's constant value. Methods used to refine the trip generation models include:

- a model that results in the constant value being less than 20% of the total trip generation (for the smallest variable values used) has been considered sensitive enough to apply 'No Intercept' (i.e. a constant of '0');
- a model that results in the constant value greater than 20% of the total trip generation has had a condition set on the single-variable dataset range that is appropriate for its application; and
- those models with a very large constant that are found to exclude the majority of surveyed sites when determining an appropriate 'range' are considered inappropriate for use.

The refined models considering the above adjustments are shown in Table 7.2, while final recommendations are presented in Section 9 of this report.

Table 7.2: Refined Models for Trip Generation

| Site Location | Period | Model | Notes |
|---|---|---|---|
| Metropolitan Sites | AM Peak | Vehicle Trips = 0.134 x Parking Spaces + 4.883<br>Person Trips = 0.2036 x Parking Spaces + 4.6676 | Most appropriate for sites with greater than 147 parking spaces.<br>Most appropriate for sites with greater than 92 parking spaces. |
| Metropolitan Sites | PM Peak | Vehicle Trips = 0.204 x Parking Spaces<br>Person Trips = 0.263 x Parking Spaces | Simplified to exclude constant value. |
| Metropolitan Sites | Daily (Weekday) | Vehicle Trips = 1.3715 x Parking Spaces | Simplified to exclude constant value. |
| Metropolitan Sites | Weekend Peak | Vehicle Trips = 0.145 x Parking Spaces + 5.615<br>Person Trips = 0.2617 x Parking Spaces + 2.36 | Most appropriate for sites with greater than 156 parking spaces.<br>Most appropriate for sites with greater than 36 parking spaces. |
| Metropolitan Sites | Daily (Weekend) | Vehicle Trips = 1.3685 x Parking Spaces | Simplified to exclude constant value. |
| Sub-Metropolitan Sites | AM Peak | Vehicle Trips = 0.189 x Parking Spaces + 1.785 | Most appropriate for sites with greater than 38 parking spaces. |
| Sub-Metropolitan Sites | PM Peak | Person Trips = 0.3463 x Parking Spaces + 3.646 | Most appropriate for sites with greater than 43 parking spaces. |
| Sub-Metropolitan Sites | Daily (Weekday) | Vehicle Trips = 1.6197 x Parking Spaces<br>Person Trips = 5.0848 x Units | Simplified to exclude constant value. |
| Sub-Metropolitan Sites | Weekend Peak | Vehicle Trips = 0.3427 x Units - 1.4919 | Most appropriate for sites with greater than 27 units. |

| Site Location | Period | Model | Notes |
|---|---|---|---|
| Sub-Metropolitan Sites | Daily (Weekend) | Vehicle Trips = 2.744 Units - 33.998 | Most appropriate for sites with greater than 74 units. |
| Regional Sites | AM Peak | Vehicle Trips = 0.1377 x Bedrooms + 1.9214<br>Vehicle Trips = 0.3889 x Units – 3.0649 | Most appropriate for sites with greater than 55 bedrooms.<br>Most appropriate for sites with greater than 47 units. |
| Regional Sites | PM Peak | Vehicle Trips = 0.1657 x Bedrooms<br>Vehicle Trips = 0.475 x Units – 6.660 | Simplified to exclude constant value.<br>Most appropriate for sites with greater than 85 units. |
| Regional Sites | Daily (Weekday) | Vehicle Trips = 1.409 x Bedrooms – 12.437<br>Vehicle Trips = 4.017 x Units – 67.429 | Most appropriate for sites with greater than 53 bedrooms.<br>Most appropriate for sites with greater than 101 units. |
| Regional Sites | Weekend Peak | Vehicle Trips = 0.1652 x Bedrooms + 1.7397<br>Vehicle Trips = 0.4641 x Units – 3.6714 | Most appropriate for sites with greater than 42 bedrooms.<br>Most appropriate for sites with greater than 47 units |
| Regional Sites | Daily (Weekend) | Vehicle Trips = 1.3157 x Bedrooms – 22.558<br>Vehicle Trips = 3.750 x Units – 67.560 | Most appropriate for sites with greater than 104 bedrooms.<br>Most appropriate for sites with greater than 109 units. |

It should be noted that Sub-Metropolitan Site trip generation was the most difficult to predict. This is most likely due to the great variability of site characteristics, location and development demographics.

## 7.3 FINAL MODEL RESULTS

Recommended models were tested to ensure the equations accuracy by comparing its predicted trips against the actual survey data. For example, based on Linear Regression we may have a resulting model equation of "Vehicle Trips = 0.3 x Parking Spaces". In order to check the accuracy of this model, the number of parking spaces was input for each site into the formula and the resulting number of vehicle trips compared with the actual surveyed vehicle trips for each corresponding site. The figures below demonstrate the level of fit between model and actual trip generation.

*Metropolitan Sites*

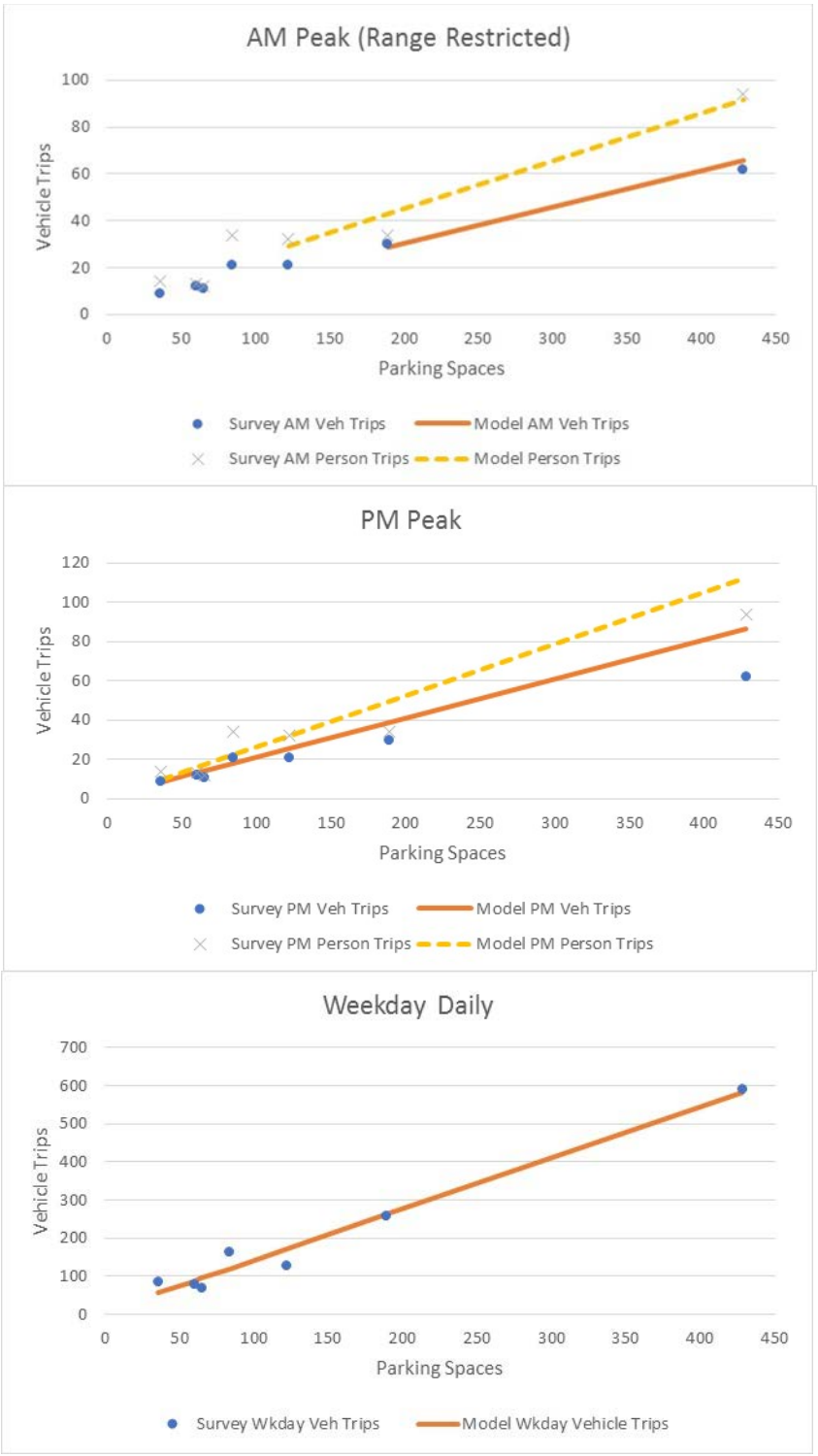



Figure 7.1: Model Test Examples – Weekday Metropolitan Scenarios

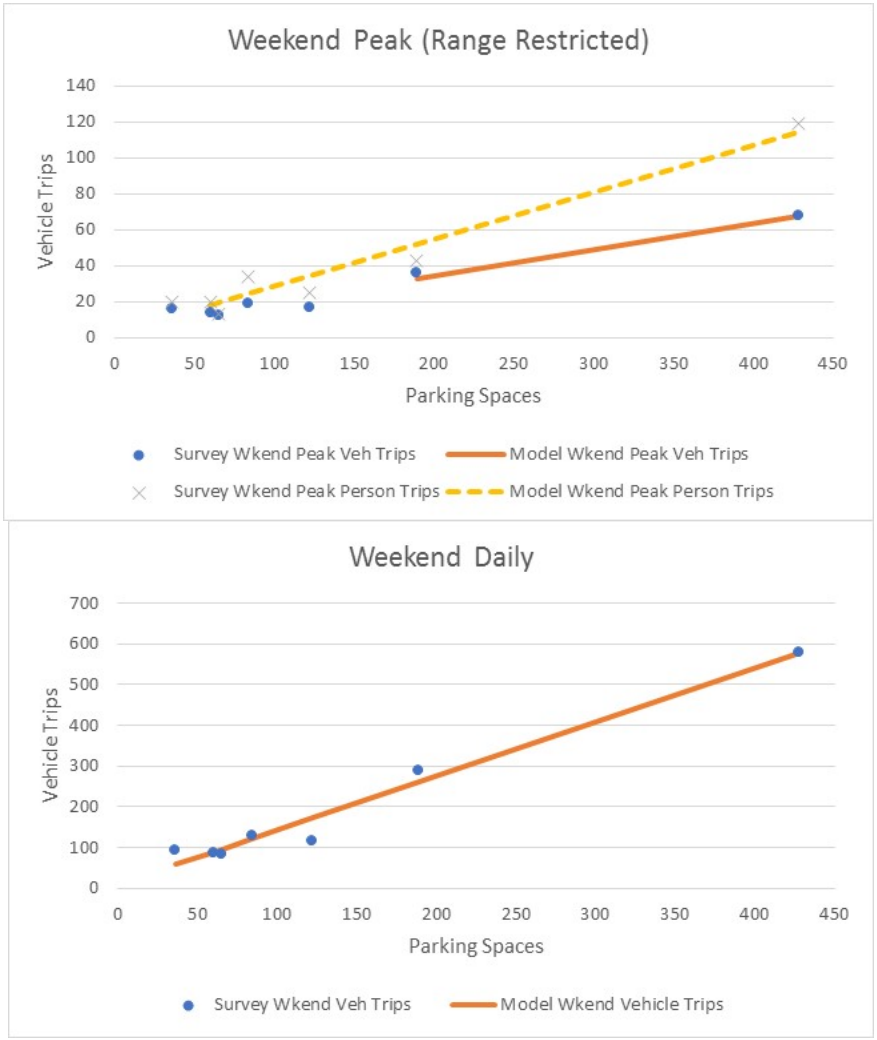



Figure 7.2: Model Test Examples – Weekend Metropolitan Scenarios

*Sub-Metropolitan Sites*

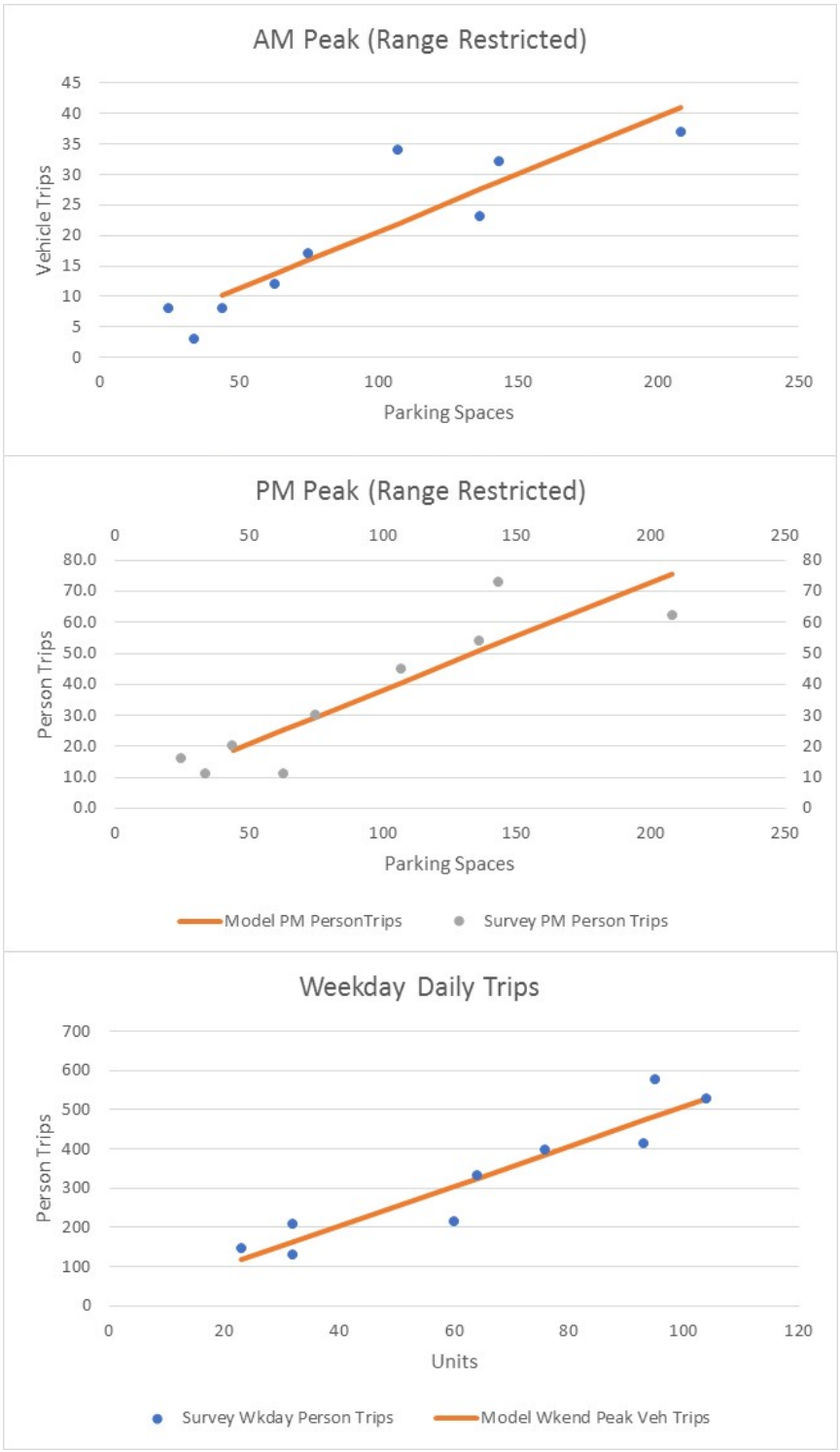



Figure 7.3: Model Test Examples – Weekday Sub-Metropolitan Scenarios

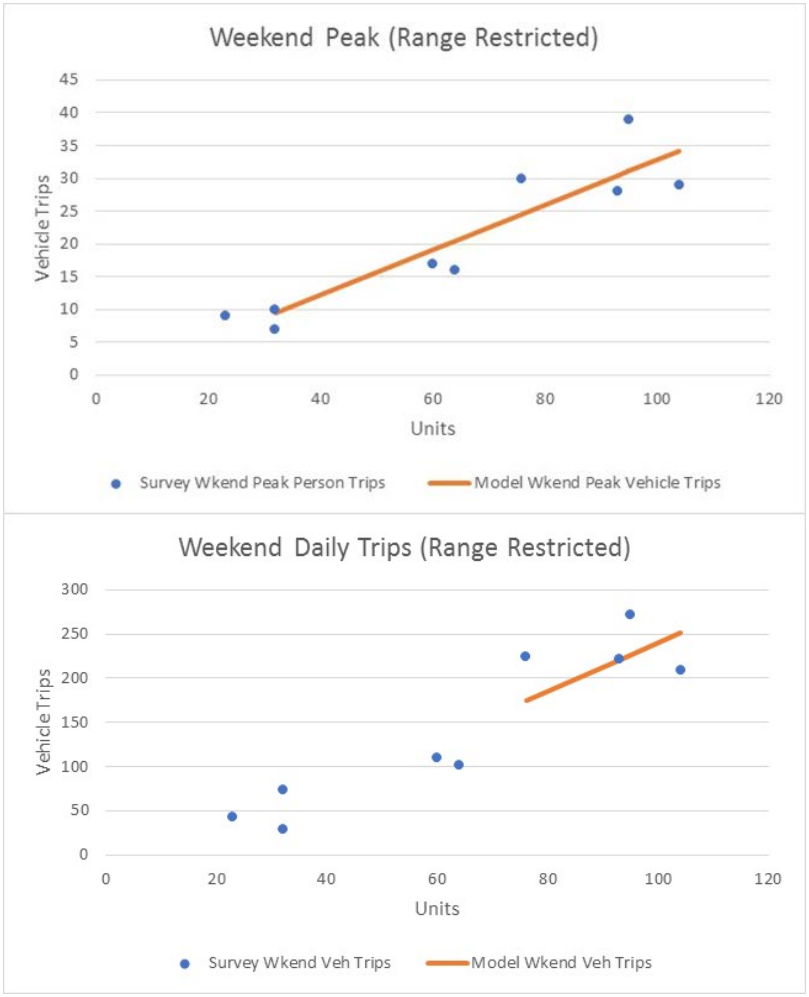



Figure 7.4: Model Test Examples – Weekend Sub-Metropolitan Scenarios

*Regional Sites*

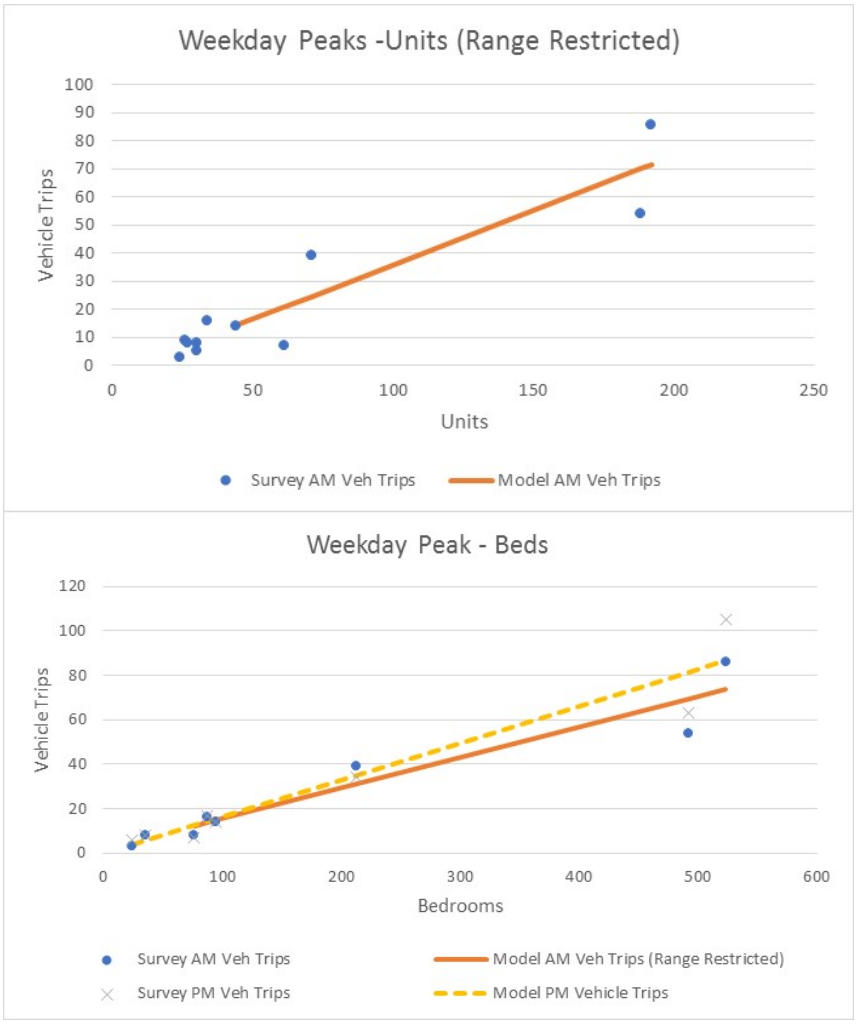



Figure 7.5: Model Test Examples – Weekday Regional Scenarios

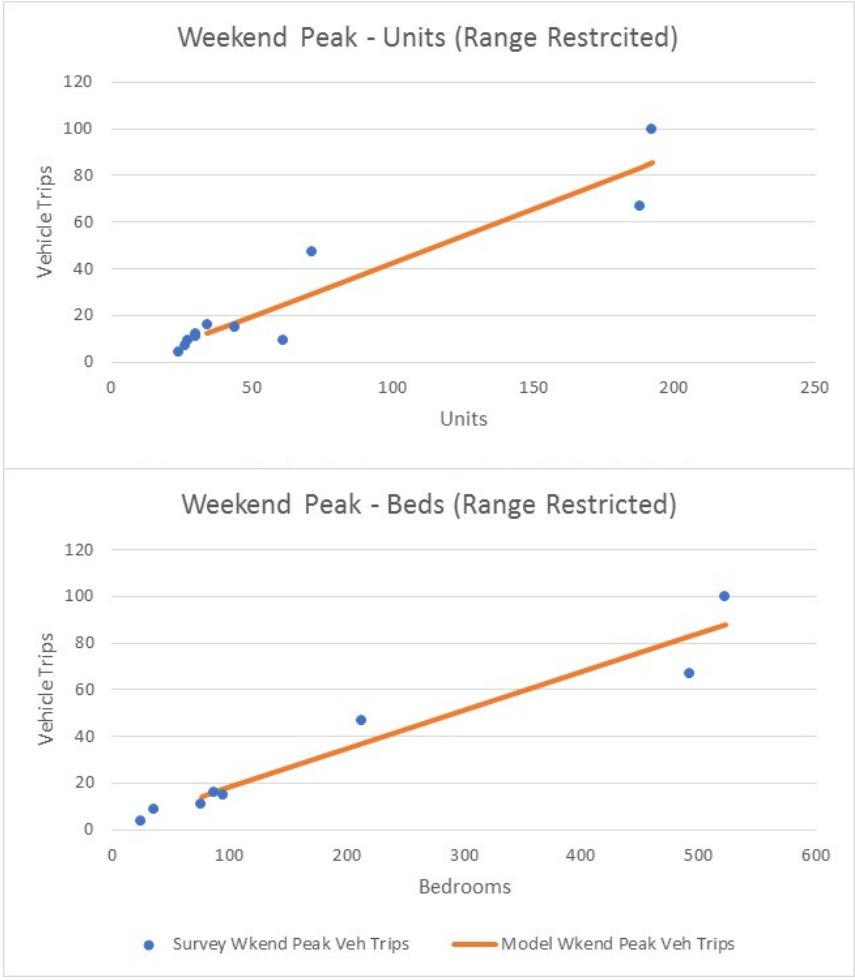



Figure 7.6: Model Test Examples – Weekend Regional Scenarios

# 8. CONCLUSIONS

The conclusions drawn from the assessment of the analysis of trip generation data using single-variable linear regression and multiple-variable regression models is presented below.

*All Sites*

When comparing all development sites, the only linear model resulting in a satisfactory correlation was between the number of parking spaces and traffic generation which included vehicle trips generated by residents parking 'on-street'. However, as the data for the number of vehicle trips generated by people parking 'on-street' has been estimated based on a percentage of resident questionnaires, the resulting model cannot be relied upon and has been excluded from recommendations.

Comparing "All Sites" shows inconsistent results in the relationship between traffic generation and parking spaces, although this relationship is strongest for Metropolitan and Sub-Metropolitan sites.

The linear regression and multiple regression analysis showed no statistically significant relationships that described trip generation when considering all of the NSW data together. Preliminary data analysis suggested that geographical location in NSW affected traffic generation. Sites were subsequently categorised by geographical location for further analysis. Site geographical categories included:

- Metropolitan – Sydney sites near the city CBD that are located a distance away from public transport with mostly restricted on-street parking surrounding the site;
- Sub-Metropolitan – Sydney sites located away from the city CBD and from public transport with a variation of restricted and unrestricted on-street parking surrounding the site; and
- Regional – all surveyed sites outside of the Sydney area located a distance away from public transport routes, including Central Coast and Gold Coast sites.

*Metropolitan Sites*

The Metropolitan sites showed the best correlation between trip generation and the number of available parking spaces. In particular, where surrounding on-street parking is restricted, the trip generation was shown to be focused around the availability of off-street parking.

The linear regression models showed good relationships between all Trip Generation and Number of Parking Spaces for the following periods:

- development AM Peak Period;
- development PM Peak Period;
- development Weekday (daily trips);
- development Weekend Peak Period; and
- development Weekend (daily trips).

Multiple linear regression models for the Metropolitan Sites showed no statistically significant relationships. It was noted that including the number of units or bedrooms in the formulation appears to have limited benefit on better understanding the number of trips generated compared to just including the available on-site parking as a single variable, particularly for those sites surrounded by short-term parking restrictions.

It is important to apply caution in the application of trip generation rates that are founded on parking spaces as the key variable, as the collected data and the subsequent formulae are only based on those vehicular trips which enter/exit the site.

Surveys of residents found that a number of sites involved a reasonably large proportion of their traffic generation not even entering the site, but rather parking in surrounding on-street areas. Whilst the sample was limited, this varied from about 10% at metropolitan sites to 20% at sub-metropolitan sites and was somewhat related to the availability of on street parking and overnight parking regulations. The proportion of 'off-site' traffic generation would not be considered as part of the assessment of turning volumes into and out of the development's accesses but would be prudent to include for a local network assessment of the development's impacts on both traffic operations and parking.

In essence, relying on site-based traffic generation formulae only is likely to underestimate the level of traffic introduced by a development into areas that have available overnight on-street parking and should therefore be considered as a lower bound of a development's vehicular traffic generation.

*Sub-Metropolitan Sites*

Sub-Metropolitan sites showed that the correlation between trip generation and number of parking spaces, units or bedrooms, varied across each site. This may be due to the availability of on-street parking or the specific location. The linear regression model results showed a reasonable number of $R^2$. Those variables that produced relationships that were considered appropriate included:

- Weekday Daily Person Trips and the Number of Units;
- Weekend Daily Vehicle Trips and the Number of Units; and
- Weekend Daily Vehicle Trips (including on-street parkers) and the Number of Parking Spaces.

Though multiple linear regression models showed an improvement in $R^2$ compared to single-variable Linear regression models, further analysis found that equations produced either constant values that were too large or variables with negative coefficients. Whilst negative coefficients can be used in regression formulae, when they are relatively small and of a counter-intuitive sign, it is often better to remove these parameters to strengthen the 'integrity' of the model. The is particularly the case when used with input ranges where the variable being multiplied by the negative coefficient could be large compared to the variable with the positive coefficient.

As such, all sub-metropolitan multiple regression model formulae are only valid over the size ranges of the sites in the survey sample. Accordingly, a robust Linear Regression model is preferred over multiple linear regression models.

Furthermore, due to the variability of site data within the Sub-Metropolitan geographical area these sites were tested against both Metropolitan and Regional models to determine if either were suitable as a proxy model. It was determined that neither Metropolitan nor Regional modelling accurately predicted trip generation for Sub-Metropolitan sites.

*Regional Sites*

The traffic generation for regional sites was higher than for metropolitan sites. Correlation between the number of trips generated and dependent variables was best for the 'Number of Units' and 'Number of Bedrooms' variables, which is in contrast to the Metropolitan Sites where parking spaces were determined as the best dependent variable. Linear regression models showed excellent relationships between Trip Generation and either the Number of Units or Number of Bedrooms for the following periods:

- development AM Peak Period (Number of Bedrooms);
- development PM Peak Period (Number of Bedrooms and Number of Units);
- development Weekday Daily (Number of Bedrooms and Number of Units);
- development Weekend Peak Period (Number of Bedrooms and Number of Units); and
- development Weekend Daily (Number of Bedrooms and Number of Units).

Multiple linear regression models showed no combination of available variables which significantly improved the $R^2$ results and to avoid overcomplicating formulas robust linear regression models have been recommended for use.

# 9. RECOMMENDATIONS

Recommended Person and Vehicle trip generation rates derived from the analysis of survey data are summarised in Table 9.1.

Table 9.1: Trip Generation Recommendations

| Site Location | Period | Recommended Model* | Application Restrictions |
|---|---|---|---|
| Metropolitan Sites | AM Peak | Vehicle Trips = 0.134P + 4.9 | For sites > 147 parking spaces. For sites < 147 parking spaces use Site Specific Method. |
| Metropolitan Sites | AM Peak | Person Trips = 0.20P + 4.67 | For sites > 92 parking spaces. For sites < 92 parking spaces use Site Specific Method. |
| Metropolitan Sites | PM Peak | Vehicle Trips = 0.20P | No restrictions. |
| Metropolitan Sites | PM Peak | Person Trips = 0.26P | No restrictions |
| Metropolitan Sites | Daily (Weekday) | Vehicle Trips = 1.37P | No restrictions. |
| Metropolitan Sites | Daily (Weekday) | Person Trips = N/A | Site Specific Method. |
| Metropolitan Sites | Weekend Peak | Vehicle Trips = 0.145P + 5.6 | For sites > 156 parking spaces. For sites < 156 parking spaces use Site Specific Method. |
| Metropolitan Sites | Weekend Peak | Person Trips = 0.26P+ 2.36 | For sites > 36 parking spaces. For sites < 36 parking spaces use Site Specific Method. |
| Metropolitan Sites | Daily (Weekend) | Vehicle Trips = 1.37P | No restrictions. |
| Metropolitan Sites | Daily (Weekend) | Person Trips = N/A | Site Specific Method. |
| Sub-Metropolitan Sites | AM Peak | Vehicle Trips = 0.19P + 1.79 | For sites > 38 parking spaces. For sites < 38 parking spaces use Site Specific Method. |
| Sub-Metropolitan Sites | AM Peak | Person Trips = N/A | Site Specific Method. |
| Sub-Metropolitan Sites | PM Peak | Vehicle Trips = N/A | Site Specific Method. |
| Sub-Metropolitan Sites | PM Peak | Person Trips = 0.35P + 3.65 | For sites > 43 parking spaces. For sites < 43 parking spaces use Site Specific Method. |
| Sub-Metropolitan Sites | PM Peak | Person Trips = 0.35P + 3.65 | For sites > 43 parking spaces. For sites < 43 parking spaces use Site Specific Method. |
| Sub-Metropolitan Sites | Daily (Weekday) | Vehicle Trips = 1.62P | No restrictions. |
| Sub-Metropolitan Sites | Daily (Weekday) | Person Trips = 5.09U | No restrictions. |
| Sub-Metropolitan Sites | Weekend Peak | Vehicle Trips = 0.34U - 1.49 | For sites > 27 units. For sites < 27 units use Site Specific Method. |
| Sub-Metropolitan Sites | Weekend Peak | Person Trips = N/A | Site Specific Method. |
| Sub-Metropolitan Sites | Daily (Weekend) | Vehicle Trips = 2.74U - 34 | For sites > 74 units. For sites < 74 units use Site Specific Method. |
| Sub-Metropolitan Sites | Daily (Weekend) | Person Trips = N/A | Site Specific Method. |
| Regional Sites | AM Peak | Vehicle Trips = 0.14B + 1.92<br>Vehicle Trips = 0.39U – 3.06 | For sites > 55 bedrooms or > 47 units. For sites < 55 bedrooms or <47 units use Site Specific Method. |
| Regional Sites | AM Peak | Person Trips = N/A | Site Specific Method. |
| Regional Sites | PM Peak | Vehicle Trips = 0.17B<br>Vehicle Trips = 0.475U – 6.66 | No restrictions.<br>For sites > 85 units. For sites < 85 units use Site Specific Method. |
| Regional Sites | PM Peak | Person Trips = N/A | Site Specific Method. |
| Regional Sites | Daily (Weekday) | Vehicle Trips = 1.41B – 12.44 | For sites > 53 bedrooms. For sites < 53 bedrooms use Site Specific Method. |

| Site Location | Period | Recommended Model* | Application Restrictions |
|---|---|---|---|
| Regional Sites | Daily (Weekday) | Person Trips = N/A | Site Specific Method. |
| Regional Sites | Weekend Peak | Vehicle Trips = 0.17B + 1.74<br>Vehicle Trips = 0.46U – 3.67 | For sites > 42 bedrooms or > 47 units. For sites < 42 bedrooms or <47 units use Site Specific Method. |
| Regional Sites | Weekend Peak | Person Trips = N/A | Site Specific Method. |
| Regional Sites | Daily (Weekend) | Vehicle Trips = 1.32B – 22.56 | For sites > 104 bedrooms. For sites < 104 bedrooms use Site Specific Method. |
| Regional Sites | Daily (Weekend) | Person Trips = N/A | Site Specific Method. |

**Model estimates of total vehicle trips produced by a development may increase by approximately 10% at Metropolitan sites and 20% at Sub-Metropolitan sites considering the sites proximity and availability of long term/overnight on-street parking.*

*P = Number of Off-street Parking Spaces*

*U = Number of Units*

*B = Number of Bedrooms*

*N/A = Not available, no reasonable model.*

*'Site Specific Method' = Select the most representative site(s) from the detailed data and use its trip generation rate(s).*

# APPENDIX A

# DATA SUMMARY SHEET

# APPENDIX B

# LINEAR REGRESSION SCENARIOS

# APPENDIX C

# MULTIPLE LINEAR REGRESSION SCENARIOS