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Glossary

Call back - When a phase is run twice within a single cycle.

Cycle - One complete sequence of the signal phases

Double Diamond Overlap - A traffic signal phasing arrangement for a cross-roads intersection consisting of two right turn phases controlling the right turn movements off all approaches. Each right turn phase consists of both opposing right turn movements proceeding at the same time but also includes an overlap option. The overlap option occurs when one of the right turn movements has no more right turning traffic remaining. This right turn terminates through a yellow and red arrow display after which the opposing through movement is given a green. While this is occurring, the other right turn movement can continue to turn right. This right turn phase operation is repeated on the other two opposing approaches, hence the “Double”.

Exclusive Pedestrian Phase - When all vehicle lanterns are red and all pedestrian lanterns are green.

Flexilink - The local traffic signal controller uses predefined plans and time of day schedules for cycle time, phase splits, and offset from the fixed point. Each signal controller uses a software clock synchronised with the other intersections it coordinates with.

GEH - A formula derived by Geoffrey E Havers that is used to compare two independent sets of data while considering the size of values. The lower the GEH value, the closer the fit.

Incremental Split Selection - A routine used by SCATS to enable phase splits for up to four phases to be incrementally adjusted between +4% and -4% each cycle based on the degree of saturation of chosen stopline detectors. The alternative is that SCATS can only choose from predefined phase split plans.

Isolated - The local traffic signal controller operates in vehicle actuated mode with no coordination between sites. There is no defined cycle time. Each phase has a minimum and maximum green time. After the minimum green time has occurred, the controller will stay in the current phase until either the maximum green time is reached or the detector loops record no more vehicles using the phase green time. The phase then “gaps out” and the controller moves to the next demanded phase in a predefined phase sequence.

Master-isolated - Similar to Masterlink in that the cycle time and all phase lengths are calculated by the SCATS software. The only difference between Masterlink and Master-isolated is that there is no defined coordination point to be maintained for coordination purposes. This means that all phases can “gap” out.

Masterlink - The local traffic signal controller receives instructions from the SCATS regional computer. Cycle time, phase splits, and coordination are determined by the SCATS software. A requirement for Masterlink operation is that one of the operating phases must be permanently demanded never be allowed to terminate early and it must use up any time within the cycle not used by the other phases. This requirement ensures that coordination is maintained.

Phase - A group of movements that are setup with SCATS to run in conjunction with each other.

SCATS - Sydney Coordinated Adaptive Traffic System, the signal control system used in WA. It monitors traffic signals and reacts to vehicles detections by changing the signal cycle time, phase durations, and coordination between signals.

Single diamond overlap - A signal phase setup for a four leg intersection where the opposing right turn movements on the primary road run in conjunction with each other, followed then by the primary road through movements. The option exists to run only one right turn with the adjacent through movement if there are no right turn vehicles on one of the approaches.

Split Approach - When one approach runs its own phase, once finished the opposing approach runs its phase.

1. Introduction

1.1 Project purpose

Of all traffic management measures, the operation of traffic signals is often considered to have the most influence on the performance of metropolitan road networks. A well set up and maintained traffic signals system ensures that the maximum possible performance and capacity is achieved from existing network infrastructure. Likewise poorly performing intersections can unnecessarily constrain traffic flows, induce bottlenecks and can be unsafe.

RAC WA commissioned Aurecon to undertake an analytical and qualitative assessment of traffic signals operation and planning within the context of the Perth metropolitan road network. Main Roads WA was a key partner in the project. The aim of the analytical assessment is to highlight elements where signals are working well and similarly where traffic signals processes could be improved for the benefit of all road users. This included an assessment of the operational performance of selected demonstration sites, which included consideration of efficiency, road safety and the broader user experience.

1.2 Approach

The project was delivered in two phases. The first phase focused on the initial investigations of several sites, looking at the signal operation, surrounding land use, intersection geometry and facilities for other road users particularly relating to safety. The intent was to agree and confirm the sites most suitable for further investigation.

Phase two primarily involved analysis of the performance of the intersections and corridors, using micro-simulation modelling with integrated Sydney Coordinated Adaptive Traffic System (SCATS) signal control. This predicted how the sites were performing and was used as a tool to test a range of improvement options.

This document reports on the results of the alternate approach to refining signal phasing and timing and makes recommendations regarding signal operation and road geometry, giving due consideration to all road users and road safety outcomes.

2. Perth Context

2.1 Governance

The day to day operational maintenance of approximately 900 traffic signals is performed by Main Roads WA. The Main Roads WA Traffic Operations Centre (TOC) monitors traffic signal operation on all roads in WA using several systems including a network of approximately 200 CCTV cameras. TOC operators detect incidents on arterials, manage traffic generated by events and are also responsible for the implementation of all new signalised intersections.

Other state authorities and local councils work with Main Roads WA in the planning and design of signals relating to urban development, changing land use, public transport infrastructure, and other such schemes. However, only Main Roads WA is responsible for the performance of the road network once signals are operational.

2.2 Traffic signals system

All road traffic signals within Perth and Western Australia (WA) operate using the SCATS signal system.

SCATS monitors traffic volumes in real-time and coordinates traffic signals to ease traffic congestion and improve traffic flow. SCATS was originally developed by the New South Wales Roads and Maritime Services and is now used in all Australian States to some extent.

SCATS operates by adjusting the coordination and green time of signals depending on the traffic volumes detected on each approach. The coordination and green time is generally adjusted to favour arterial corridors whilst also balancing the delay across the remaining approaches.

SCATS operates on three levels:

- ***Traffic Signal Controller:*** metal cabinets are located on the road verge near traffic lights which contain electronics and hardware (the traffic signal controller) that operates traffic signals. Sensors or vehicle detector loops are installed in the traffic lanes and these register and relay information on traffic flow or ‘demand’ on each arm of an intersection to the traffic signal controller. Although the signal controller is controlled by SCATS, it does have the ability to make decisions that affect local on-street operations. For example, the signal controller can use the information from the detector loops to decide whether to extend a signal phase or terminate the phase early if no traffic remains. The signal controller also sends the detector information back to the SCATS regional computer for further analysis.

- ***SCATS Regional Computers:*** There are several regional computers, each controlling up to 250 separate signalised intersections. Each regional computer combines the on-road information with pre-programmed data, which results in traffic signal operation and coordination requirements for its signalised intersections.

- ***SCATS Central Monitoring Computer:*** The regional computers are networked to a central monitoring computer located at the TOC. This computer enables operators to monitor traffic conditions and make adjustments to traffic signals operation.

3. Methodology

Objectives, policies, and constraints are very important factors for signal refinement practices. Policies and guidelines describe the agency's approach and the strategies to be employed in signal adjustment relative to the prioritisation of objectives and resolving of conflicting objectives. This section sets out the methodology applied to test possible signal refinement options.

3.1 Stage One – Initial investigations

3.1.1 Agree and confirm methodology

A discussion was held with Main Roads WA to present and agree the project objectives and approach and to understand the TOC's systems including challenges and constraints as well as successes and opportunities.

3.1.2 Site selection

Several potential demonstration sites where further efficiencies could be gained were identified using the expertise and knowledge of the project team and site visits undertaken during the AM, midday, PM peaks to confirm if the demonstration sites were suitable for further investigation.

During the site visits, observations were made about signal operation, land use, intersection geometry, pedestrian demand, and the extent of signals coordination with adjacent intersections and the information presented in a Stage one report.

Following the site visits, the project team agreed on two sites to be carried forward into stage two. The sites that were not selected were deemed either not suitable for this study or were assessed as currently operating efficiently as occurred in several cases.

These were:

- **Site 1: Kelvin Road/ Tonkin Highway**
  This intersection is commonly raised as an issue in correspondence from RAC members.

- **Site 2: Orrong Road corridor**
  A busy corridor (comprising Francisco Street, Archer Street, Wright Street and Oats Street intersections) with multiple land uses each placing their own demands on the four sets of signals.

3.1.3 Data collection

Following confirmation of the two demonstration sites, the following data was collected:

- Count data: Austraffic was commissioned to collect full-day traffic count data including turning counts for each of the demonstration sites over two consecutive days (Tuesday and Wednesday) during normal flow conditions i.e. weeks that do not include a public holiday, school or university holidays.
- SCATS data: SCATS input and output files and traffic signal plans.
- Crash data: five year crash data was obtained from Main Roads WA.

3.1.4 Scan of other practice

A scan of signals operation and emerging technology was undertaken for other cities and captured in a paper. This was used to inform a feature article prepared for the RAC's Horizons Magazine on balancing the needs of various road users at signalised intersections.

3.2 Stage Two – SCATS options testing

3.2.1 Model build - existing situation

Using the traffic counts and on-street traffic observations, models were built and calibrated for each of the base year AM, PM, midday and off peak time periods using the VISSIM micro-simulation traffic analysis tool with integrated SCATS signal control. These models replicated the existing situation at each of the sites.

The model build methodology is key to the robustness of the model and its results. This modelling methodology used a range of data sources to form a solid foundation for the option testing. The steps were as follows:

1. Carry out site visits of the demonstration sites to observe traffic patterns and driver behaviour.
2. Build network using GIS aerial imagery with data such as signal setups coded in.
3. Check and balance turn count data to ensure anomalies between count sites were minimised and that latent demand was considered.
4. Distribute traffic on the corridor using the 'higher tier model cordon 2011 matrices' from the Main Roads WA Regional Operations Model (ROM).
5. Establish wider network demand by placing the ROM distribution through a Furness method to align it with the turn count data.

3.2.2 Model build - option testing

A workshop was held with Main Roads WA, RAC WA, and Aurecon to discuss and develop option testing plans for the demonstration sites. Options regarding improvements to the signal operations were identified for testing. These options consisted of technical changes to the signal operation and their 2013 model year performance was then compared to the existing on-street situation in terms of changes in delay and average speed. From this, the options that were performing closest to the optimum level could be identified.

3.2.3 Main Roads WA TOC signal adjustment process

A third workshop/meeting was held with Main Roads WA, RAC WA, and Aurecon to discuss the process of SCATS signal adjustment and resourcing within the Main Roads WA TOC. This meeting adopted a strengths, weaknesses, opportunities, and threats (SWOT) assessment approach and also considered what would ideally occur if there were fewer constraints and what occurs in some TOCs in other Australian States, looking at:

- Objectives in signal refinement
- Techniques used when refining signals
- Time intervals between signal audits
- Signal audit processes
- Constraints in signal refinement
- TOC resourcing.

4. Site Overviews

The following two sites were selected for this study due to their range of competing traffic movements, land uses, safety considerations, and for being commonly raised as an issue in correspondence from RAC members.

4.1 Tonkin Highway/ Kelvin Road

4.1.1 Location and geometry

The intersection of Tonkin Highway/ Kelvin Road is located in the suburb of Orange Grove, approximately 18 kilometres south east of the Perth CBD (refer to Figure 4-1 and Figure 4-2).

Figure 4-1: Tonkin Highway/ Kelvin Road site location map

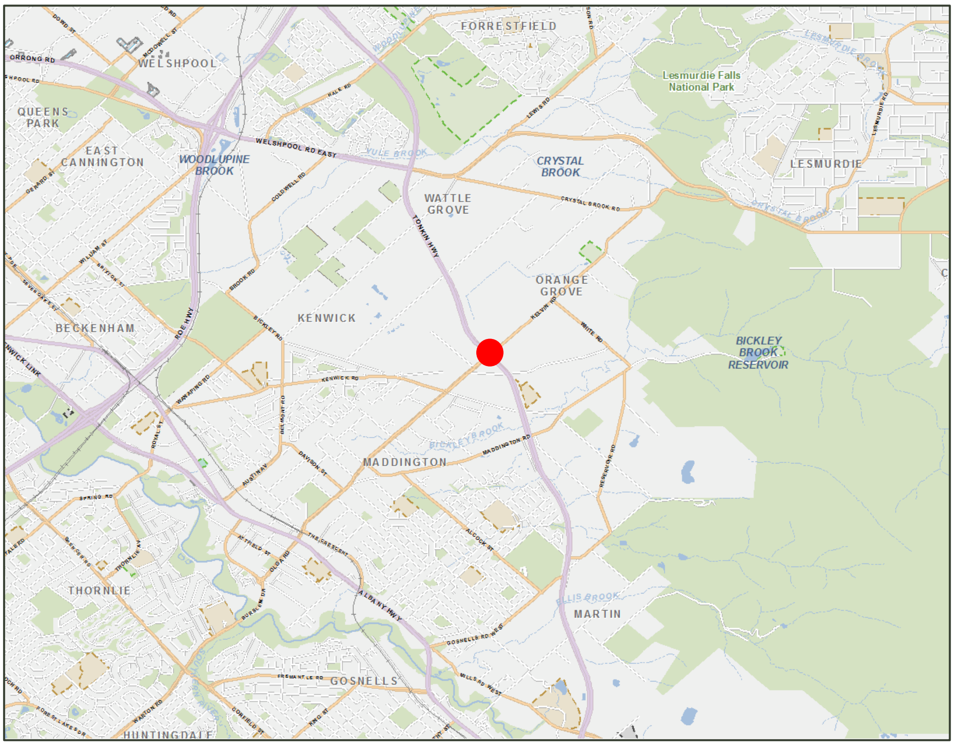


Figure 4-2: Tonkin Highway/ Kelvin Road site location map

The intersection of Tonkin Road and Kelvin Road is a signalised four arm intersection. The layout, as shown in Figure 4-3, consists of multiple lanes for each approach with signalised and non-signalised left turn slip lanes.

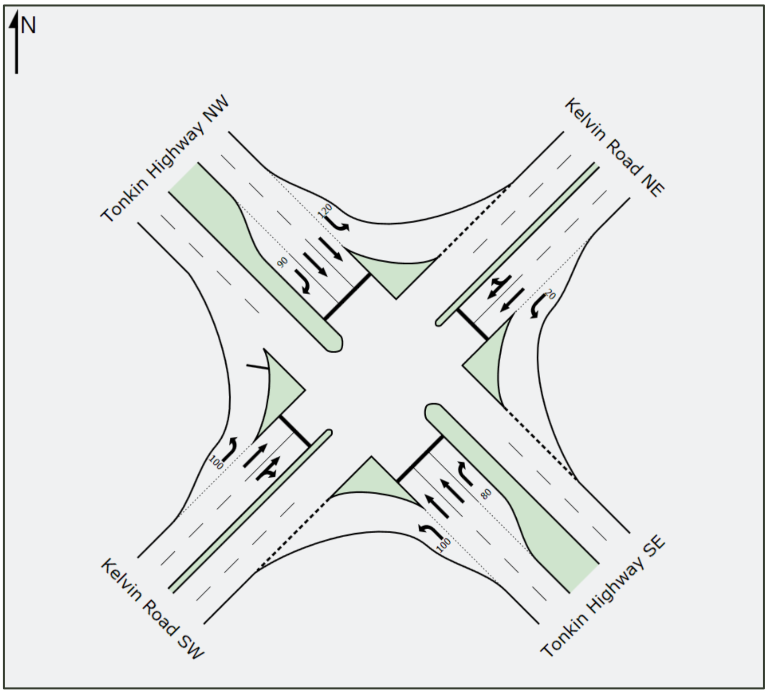


Figure 4-3: Tonkin Highway/ Kelvin Road intersection layout

The Main Roads WA classifications state that Tonkin Highway is a Primary Distributor with generally a 100 km/h speed limit, but this is reduced down to an 80 km/h speed limit at the Kelvin Road intersection.

Kelvin Road is a 'Distributor A' road on the south western approach and a 'Distributor B' road on the north eastern approach with a 70 km/h speed limit on both approaches.

4.1.2 Land use and subsequent traffic patterns

While the site is within the Perth metropolitan area, there is no proximate land use apparent apart from some light industrial land plots. Traffic patterns are therefore predominantly formed by vehicles passing through from the outer Perth metropolitan suburbs heading north in the morning period and south in the evening period. This flow is combined with heavy commercial vehicle movements.

4.1.3 Signal operation

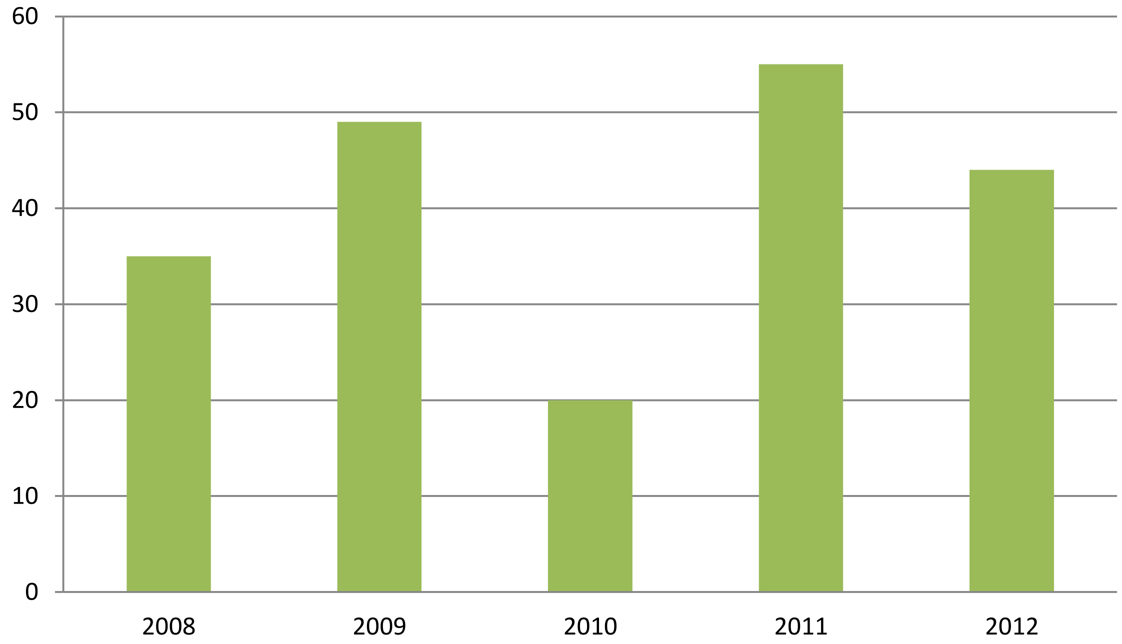
The signals at Tonkin Highway/ Kelvin Road operate in a single diamond, split approach arrangement, i.e. the Tonkin Highway right turn movements run first, followed by the through movements, and then each of the Kelvin Road approaches run individually. Due to heavy demand, the right turn from the Tonkin Highway northwest approach often gets a call back to run twice within a cycle. High cycle times exist in an attempt to minimise the number of stops for drivers.

4.1.4 Crash history

Crash data from Main Roads WA's Crash Analysis Reporting System (CARS) was analysed for the Tonkin Highway/ Kelvin Road intersection. Further crash data analysis is attached in Appendix A.

A total of 203 crashes, involving all modes of transport, occurred over the 2008 – 2012 period at the Tonkin Highway/ Kelvin Road intersection. Table 4-1 below shows that with the exception of a low number of crashes in 2010, the total crash numbers has been reasonably consistent between years.

Table 4-1: Total number of crashes 2008-2012



The crash data at the Tonkin Highway/ Kelvin Road intersection was also compared to other intersections within the City of Gosnells and the State. According to the Main Roads WA Intersection Crash Ranking Interactive Report, which covers all intersections which have had one or more reported road crashes over 5 years in the period ending 31 December 2012, the intersection was ranked as follows:

- State frequency rank **no. 123**, with 103 crashes within the given time period. The intersection of Eelup Rotary and Perth-Bunbury Highway is the worst ranked intersection in WA with 605 crashes.
- State cost rank **no. 40**, with a total crash cost of $6,670,493. The intersection of Tonkin Highway/ Horrie Miller Drive is the worst ranked intersection in WA with a crash cost of $19,035,513.
- Within the City of Gosnells, the intersection ranks at **no. 7** in terms of crash frequency. The intersection at Nicholson Road / Yale Road is the worst ranked intersection within the City of Gosnells with 305 crashes.
- Within the City of Gosnells, the intersection ranks at **no.3** in terms of crash cost. The intersection at Nicholson Road / Yale Road is the worst ranked intersection within the City of Gosnells with a crash cost of $8,100,303.

While no specific aspects from the crash data was tested in the model option tests, any reductions in congestion, such as those achieved by refining the signal settings, often leads to a reduction in crashes due to less stop/start vehicle actions occurring.

4.1.5 Active transport demand

With no immediate residential or other land use activities nearby, active transport demand is low and is estimated to be less than one pedestrian or cyclist overall per cycle. The pedestrian facilities are missing line markings and drop down kerbs and some of the pedestrian lanterns do not have symbolic displays.

4.1.6 Key observations

The on-site observations of traffic patterns were as follows:

Morning Peak Period, 06:30 – 07:30

- Heavy queuing for the Tonkin Highway southeast approach through movement, beyond sightline of curve, approximately 800m.
- Tonkin Highway northwest approach right turn bay fills, sometimes blocks through lane to extend back towards 100 km/h area. This creates a safety issue with an increased risk of rear end crashes, especially considering the curvature of Tonkin Highway in that section of road.
- High left turn volume for the Kelvin Road southwest approach.

Midday Period, 12:00 – 13:00

- Tonkin Highway southeast approach through movement has a sizeable queue.
- Tonkin Highway northwest approach right turn bay intermittently filling.

Evening Peak Period, 16:00 – 17:00

- Tonkin Highway northwest approach through movement queuing goes beyond the corner intermittently, approximately 400m.
- Tonkin Highway northwest approach right turn bay is close to being full.
- Tonkin Highway southeast approach through movement and Kelvin Rd west approach queues are approximately 100m in length.

Off-Peak Period, 21:00 – 22:00

- Low volumes.

4.2 Orrong Road

4.2.1 Location and geometry

The Orrong Road study corridor is 2.2 kilometres long and located approximately 4.5 kilometres south east of the Perth CBD (refer to Figure 4-4 and Figure 4-5).

Figure 4-4: Orrong Road looking northwest to Oats Street

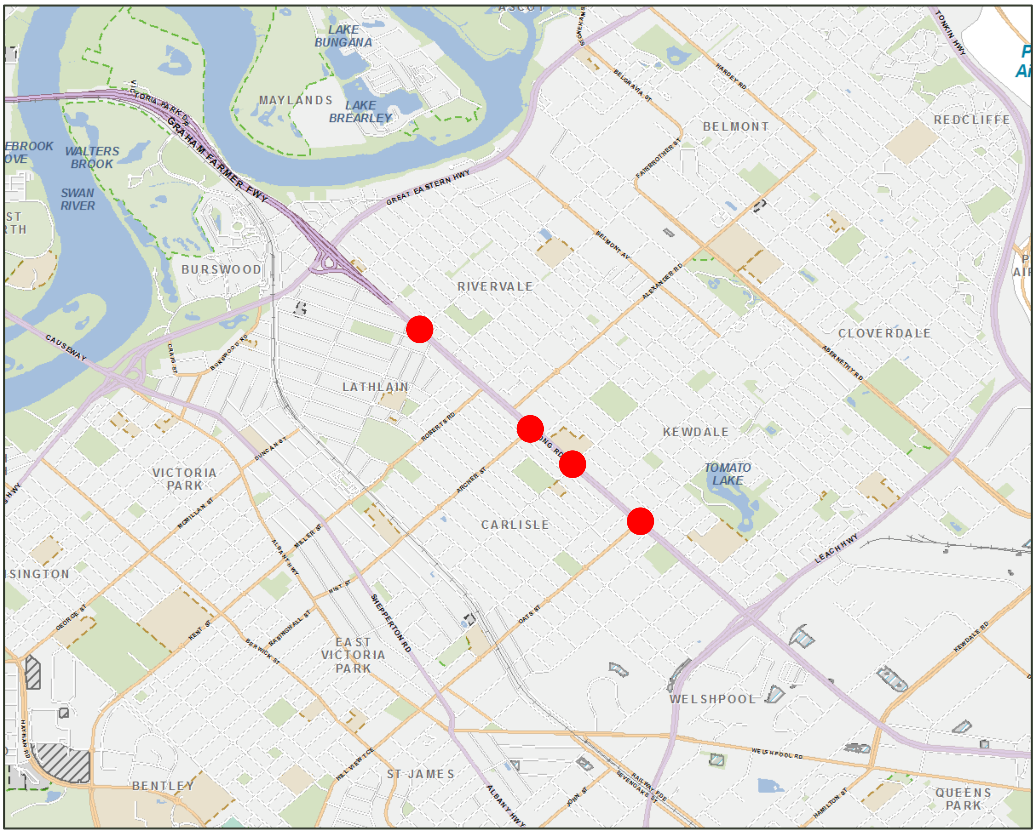


Figure 4-5: Orrong Road site location map

The section of the Orrong Road corridor assessed in this study includes four signalised intersections. The intersection layouts are shown in Figure 4-6 to Figure 4-9:

- Orrong Road/ Francisco Street

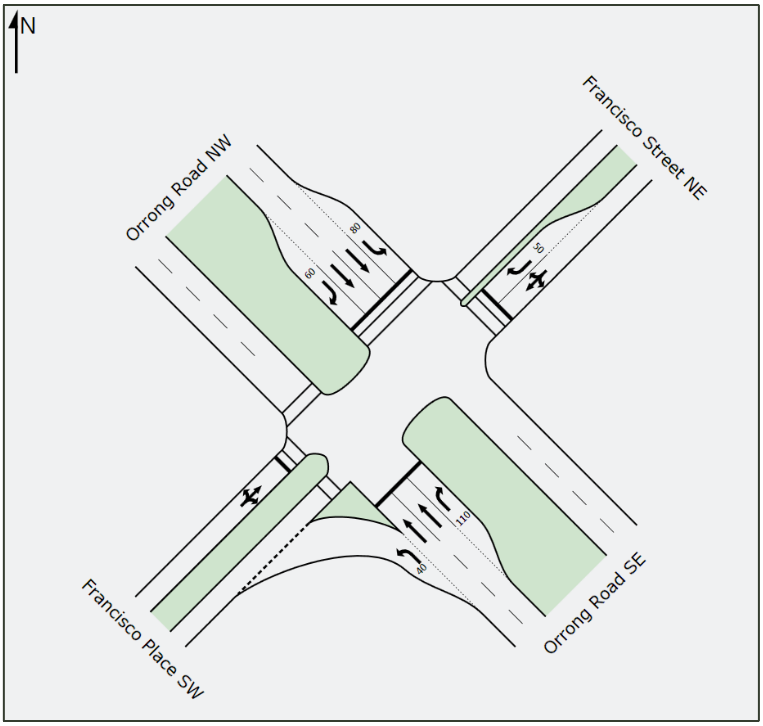


Figure 4-6: Orrong Road/ Francisco Street intersection layout

- Orrong Road/ Archer Street

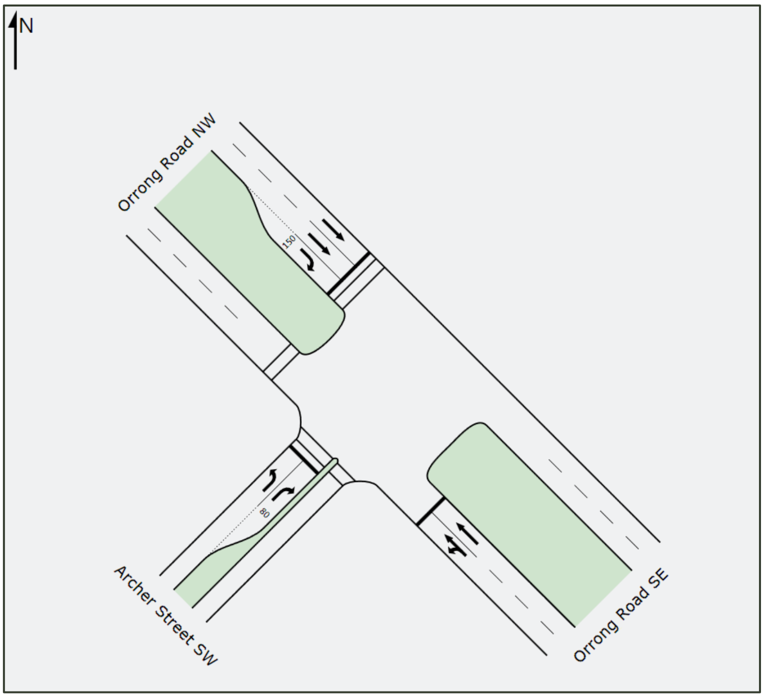


Figure 4-7: Orrong Road/ Archer Street intersection layout

- Orrong Road/ Wright Street

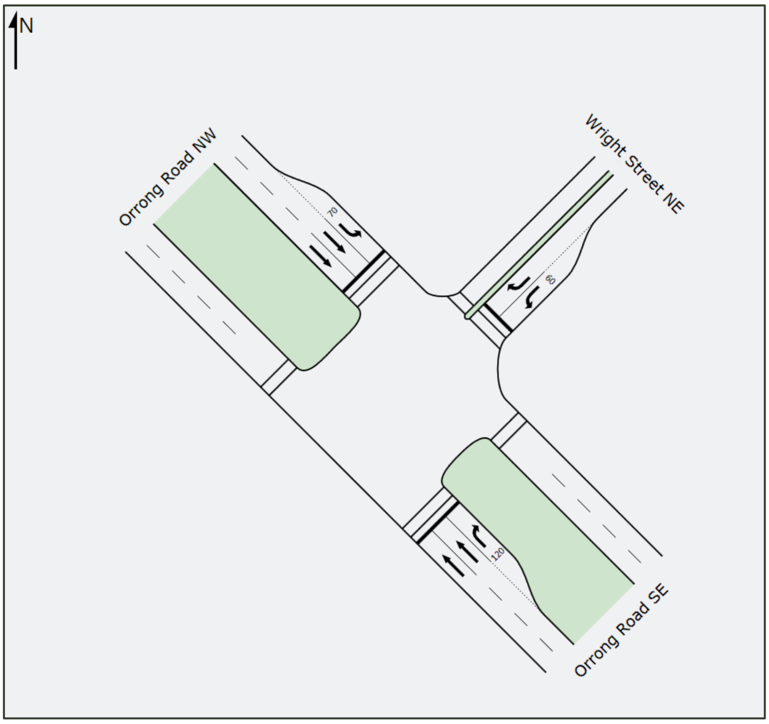


Figure 4-8: Orrong Road/ Wright Street intersection layout

- Orrong Road/ Oats Street

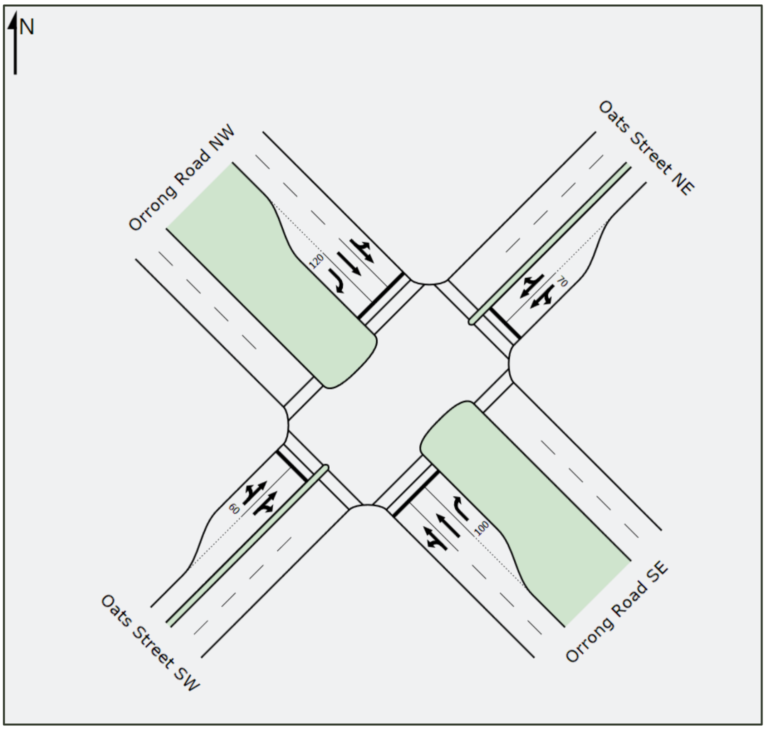


Figure 4-9: Orrong Road/ Oats Street intersection layout

The Main Roads WA classifications state that Orrong Road is a ‘Primary Distributor’ with a 70 km/h speed limit. The southwest approach of Oats Street is a ‘Distributor A’ road, Archer Street is a ‘Distributor B’ road, and Francisco Road, Wright Street, and the northeast approach of Oats Street are ‘Local Distributors’. All of these side roads have 50 km/h speed limits.

4.2.2 Land use and subsequent traffic patterns

The Orrong Road site is impacted by various land use types. The site is immediately surrounded by low density residential housing that has access to Orrong Road both directly and via the side roads. Orrong Road also provides one of the main links into the Perth Central Business District (CBD) from the east and as such has high eastbound and westbound traffic flows in the morning and evening peak periods respectively. A large industrial area exists to the east of the study corridor, resulting in high traffic flows in the counter direction. Carlisle Primary School is located at the corner of Orrong Road and Wright Street, increasing pedestrian demand at this location.

4.2.3 Signal operation

The four signalised intersections along the corridor are spaced over 2.2 km of road and they operate in a coordinated fashion however it is believed that this can be further improved. The two middle signalised intersections are T-intersections with the remaining two being four arm intersections. The levels of service at the signalised intersections seem to be unbalanced with the Orrong Road corridor not favoured enough compared to the side roads.

Intersection signal operations are as follows:

- Orrong Road/ Francisco Street: Single Diamond overlap with split side roads, i.e. the right turn movements from Orrong Road run first, followed by the Orrong road through movements and lastly the Francisco Street approaches running individually.
- Orrong Road/ Archer Street: Standard Three Phase Tee with a lead right turn into Archer Street, i.e. the Orrong Road west approach movements run first followed by the Orrong Road through movements, with the last movements being from Archer Street.
- Orrong Road/ Wright Street: Four Phase Repeat Right Turn with a pedestrian crossing on both sides of the stem of the Tee, i.e. the Orrong Road west approach movements runs first followed by the Orrong Road through movements, then Orrong Road west approach movements again, and lastly the Wright Street movements.
- Orrong Road/ Oats Street: Single Diamond Overlap plus a right turn phase off Oats Street southwest approach, i.e. the right turn movements from Orrong Road run first, followed by the Orrong Road through movements, then the Oats Street south approach movements, and lastly all Oats Street movements with the right turn movements giving way to opposing traffic.

4.2.4 Crash history

Crash data from CARS was analysed for the Orrong Road corridor between Francisco Street and Oats Street. Further crash data analysis is attached in Appendix A.

A total of 1,493 crashes, involving all modes of transport, occurred over the 2008 – 2012 period (refer to Figure 4-10).

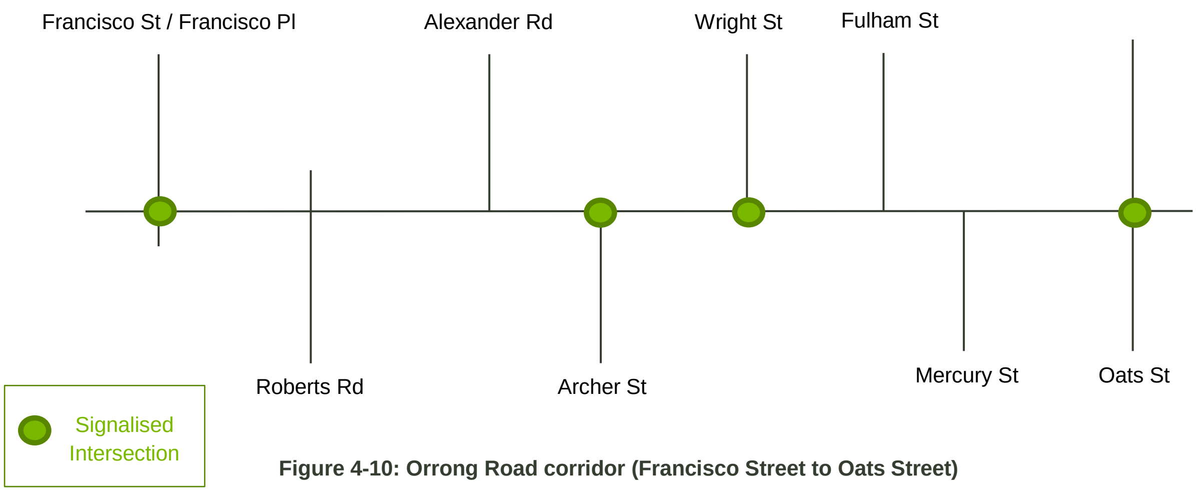


Figure 4-10: Orrong Road corridor (Francisco Street to Oats Street)

There are four signalised intersections along the corridor including Francisco Street, Archer Street, Wright Street and Oats Street.

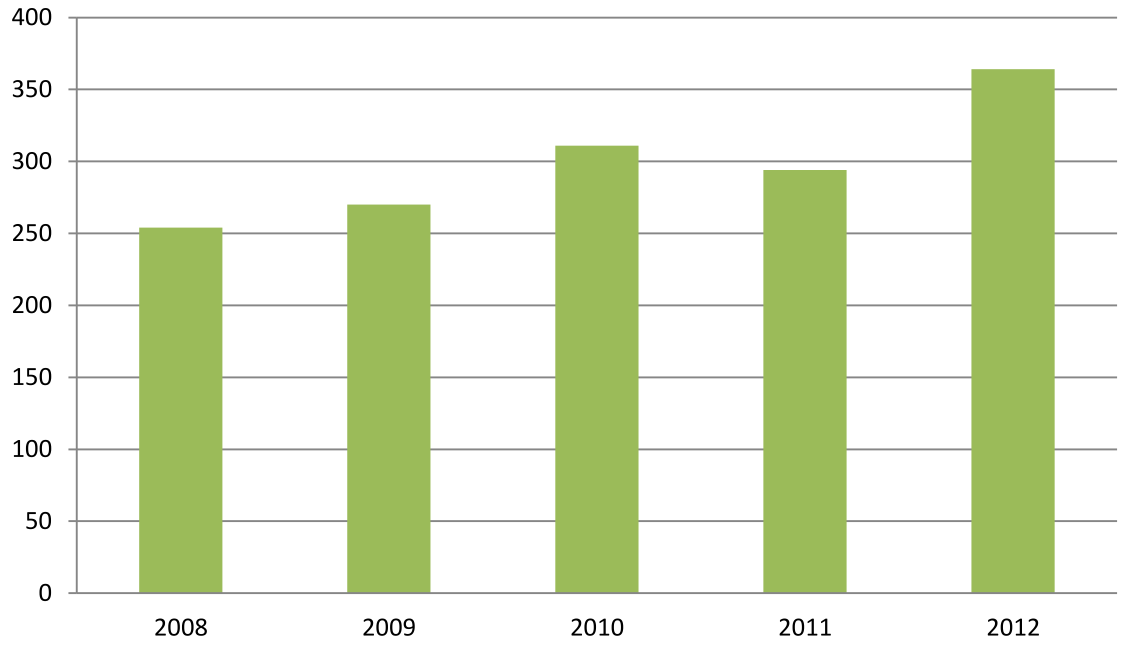
Not surprisingly, 77% of crashes along the corridor occurred at an intersection and nearly 70% of these crashes occurred at one of the four signalised intersections. The number of crashes at the signalised intersections is shown in Table 4-2. The highest number of crashes at a signalised intersection occurred at Orrong Road/ Oats Street and the worst midblock segment was between Archer Road and Wright Street.

Table 4-2: Crash locations at signalised intersections

Location of Crash	Number of Crashes
Orrong Rd / Francisco St intersection	202
Orrong Rd / Archer St intersection	185
Orrong Rd / Wright St intersection	132
Orrong Rd / Oats St intersection	274

Table 4-3 shows that the number of crashes across the entire corridor has a pattern of slowly increasing, likely to be partly due to increasing traffic volumes.

Table 4-3: Total number of crashes from 2008-2012



The crash statistics presented in Appendix A show the nature of the crash event for the particular vehicle movement. From this, it was identified that the prevailing crash movement is in the east-west and west-east direction, (i.e. on Orrong Road) with the highest proportion of these being rear end crashes.

The crash data for the intersections in the Orrong Road corridor was also compared to other intersections within the Town of Victoria Park and the State. According to the Main Roads WA Intersection Crash Ranking Interactive Report, which covers all intersections which have had one or more reported road crashes over 5 years in the period ending 31 December 2012, the following was summarised:

Table 4-4: Crash ranking comparison for Orrong Road corridor

Intersection	State Frequency Rank	State Cost Rank	Frequency Rank within Town of Victoria Park	Cost Rank within Town of Victoria Park
Orrong Road / Francisco Street	123	160	3	4
Orrong Road / Archer Street	153	157	4	3
Orrong Road / Wright Street	287	500	11	15
Orrong Road / Oats Street	61	126	1	2

As with the Tonkin Highway/ Kelvin Road demonstration site, no specific aspects from the crash data were tested in the model option tests.

4.2.5 Active transport demand

With the surrounding residential land use, active transport demand is at a moderate level, with the Carlisle Primary School at the corner of Orrong Road and Wright Street contributing to this active transport demand. Pedestrian facilities are well marked and well provided however there are no dedicated cyclist facilities. The high cycle times result in long wait times for pedestrians.

4.2.6 Key observations

The on-site observations of traffic patterns were as follows with journey times collected on Orrong Road from Leach Highway to the Great Eastern Highway overpass.

Morning Peak Period, 07:00 - 08:00

- Large levels of congestion for the westbound through movement, coordination can be improved but would not be done through increasing cycle times.
- Westbound queue extends back from Oats Road to nearly the Leach Highway Interchange.
- Eastbound travel time between 5 to 6 minutes, westbound travel time between 5 to 12 minutes.

Midday Period, 12:00 - 13:00

- Steady traffic flows with short queues.

Evening Peak Period, 16:30 - 17:30

- Large levels of congestion for both the eastbound and westbound directions of travel.
- Eastbound queue extending back from Francisco Street to the Great Eastern Highway bridge.
- Westbound queue extending back from Oats Road to nearly the Leach Highway Interchange.
- Eastbound travel time between 5 to 8 minutes, westbound travel time between 6 to 8 minutes.

Off-Peak Period, 21:00 - 22:00

- Low volumes.

5. Model Build and Calibration: Existing Situation

5.1 Overview

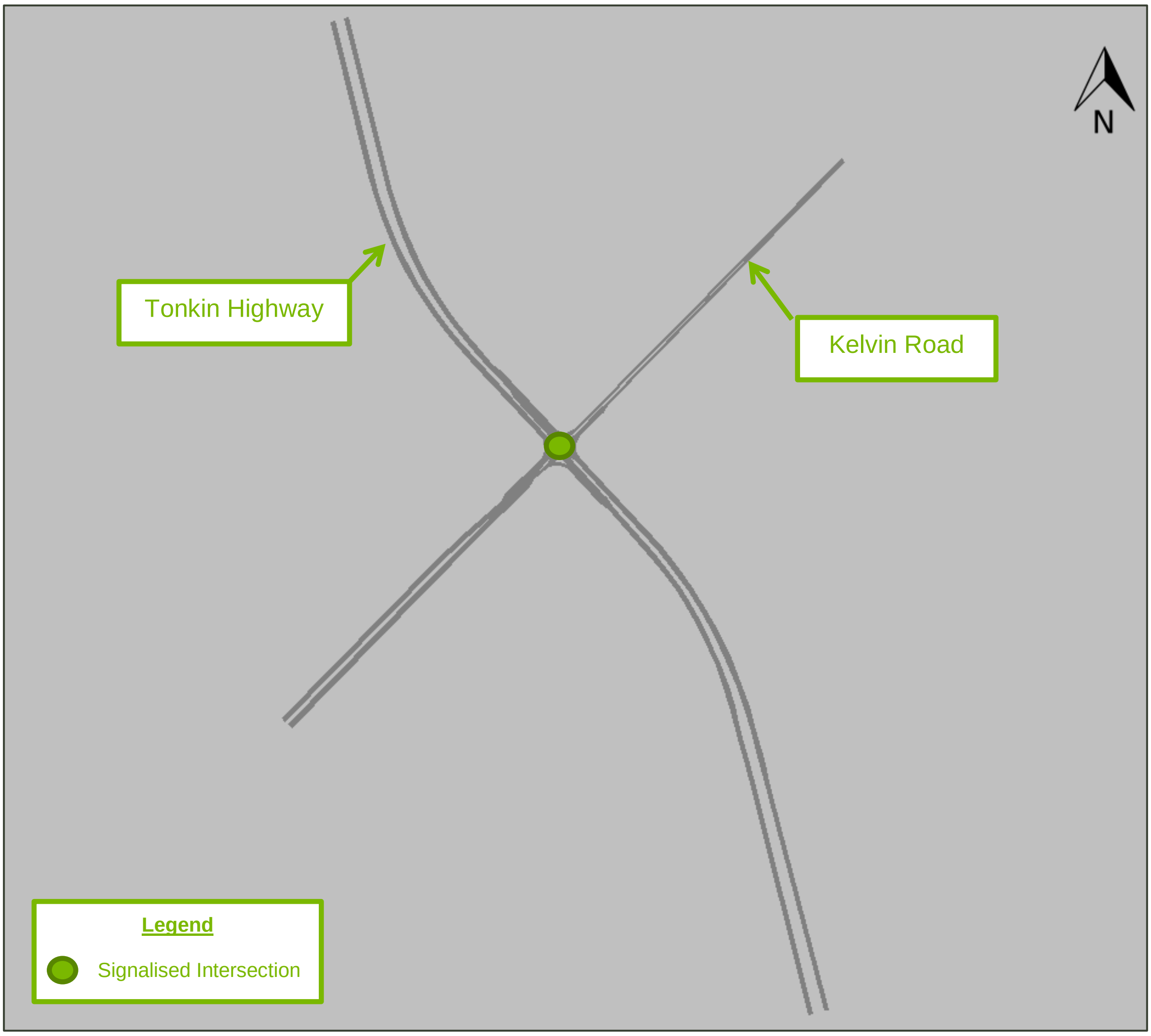
The modelling phase of the project involved the analysis of the performance of the sites using micro-simulation modelling with integrated SCATS signal control. The model provides a base to which the impact of tested options could be quantitatively compared.

The first stage of model build was the development of calibrated and validated base VISSIM models, which reflected existing traffic conditions at each intersection. These base models were then adjusted to create new models to test each proposed option. By minimising uncertainty around impacts, these assessments provide valuable information that can be used to aid decision making regarding the future operation of the demonstration sites.

5.1.1 Tonkin Highway/ Kelvin Road model area

The micro-simulation model was developed for the Tonkin Highway/ Kelvin Road intersection and its respective approaches, as shown in Figure 5-1.

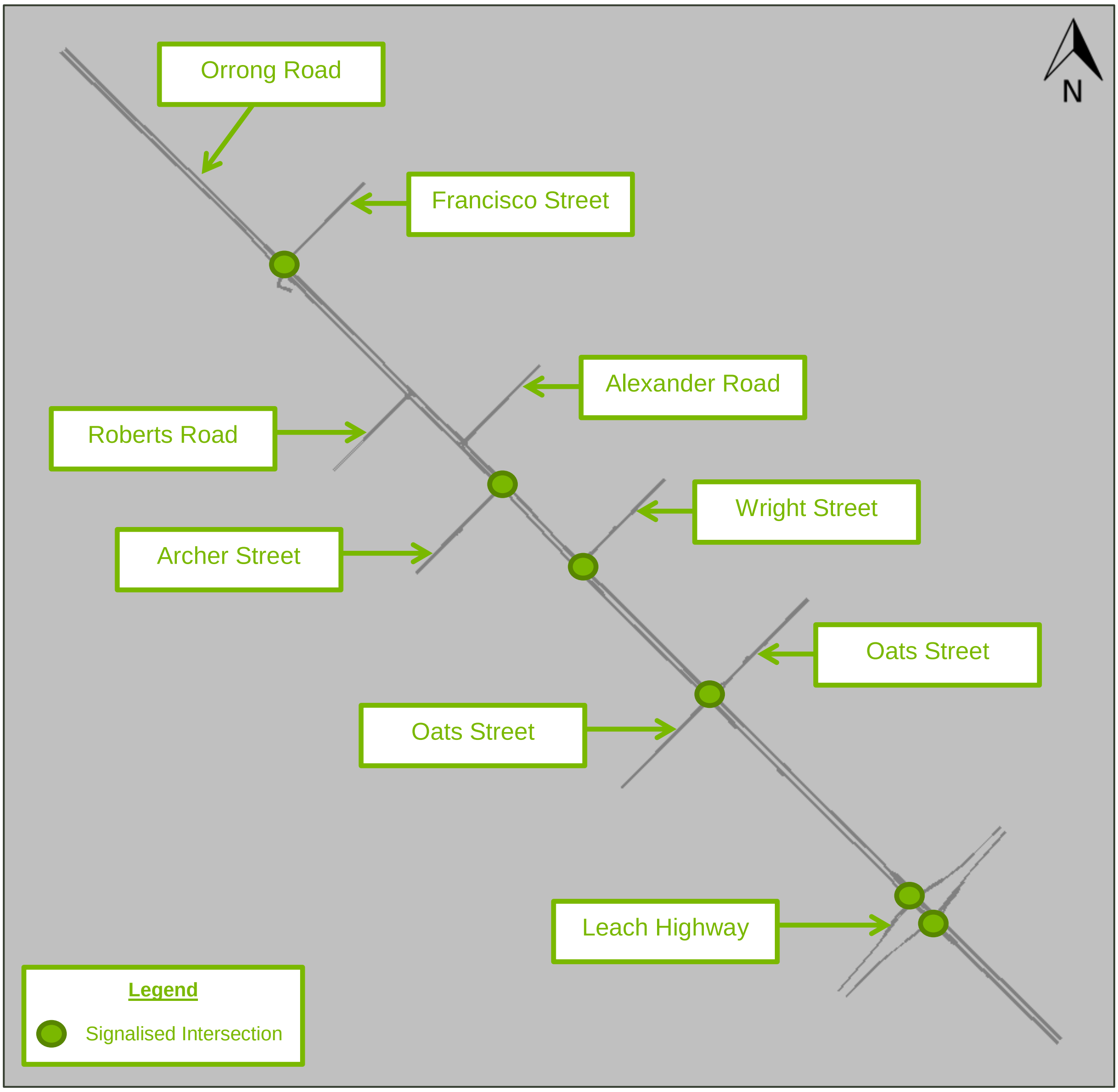
Figure 5-1: Model area for Tonkin Highway/Kelvin Road



5.1.2 Orrong Road corridor model area

The Orrong Road corridor model covers an area from north-west of Francisco Street to south-east of Leach Highway and major intersections in between. While the model build covers several intersections, the model calibration (Section 5.4) was only focussed on the four key signalised intersections, as described in Section 4.2. The Leach Highway/ Orrong Road Interchange was included in the model area so that its links with the SCATS signal corridor could be considered and to incorporate the platooning traffic patterns along the Orrong Road corridor that the interchange creates whereby traffic moves along the corridor in a cluster. The model area is shown in Figure 5-2 below.

Figure 5-2: Model area for the Orrong Road corridor



5.2 Data sources

Calibration of models to existing traffic conditions is only as effective as the quality of data used to build and calibrate the model. For this project several sets of data were collected and therefore a robust amount of data has been used. This data is detailed below.

Gathered data:

- Classified turning counts (by Austraffic) for each of the sites collected on Tuesday the 9th and Wednesday the 10th of April 2013, from 06:00 to 22:00
  - Used to ascertain the traffic demands and calibrate the model to.
- On-site journey time data collection
  - Used for the validation of the model
- RAC WA journey time data, 2011
  - Used as a check for intersection to intersection travel times
- Site aerial imagery from GIS
  - Used to code the modelled network links to
- SCATS input files including the LX, ram, TC, sft, and central manager database files
  - Used for the SCATS signal control within the model.
- SCATS output files including the VS, SM, and IDM files
  - Used to review the on-street signal performance and to provide realistic pedestrian demands at each signalised intersection.
- Signal plans for each selected intersection
  - Used to check the signal phasing and setup.
- ROM cordon matrices
  - Used to establish the distribution of traffic within the network.

5.3 Assumptions

A model is essentially formed by developing a set of assumptions, some regarding the model inputs and operations, and others which are prebuilt into the modelling software. Some of the key assumptions that apply to this study are:

- Only signalised intersections and major side roads have been included in the models.
- The survey data used to build the traffic demands replicates an average day.
- SCATS input files and associated signal settings from the provided files are the same as those used on site.
- The ROM model distribution has been adjusted in line with the traffic counts during the calibration process.
- Vehicle spacing and average vehicle lengths have been adjusted to better replicate current WA conditions. Vehicle spacing is 2.3m and vehicle lengths upper range is up to 5.17m.
- No changes in traffic volumes occurred between the current base and option models.

5.3.1 Tonkin Highway/ Kelvin Road peak hour periods

A range of data was collected and in most instances three hour models were developed with the primary peak hour being calibrated, validated, and analysed for. The Tonkin Highway/ Kelvin Road peak hours were established from the turn count data and were as follows:

- AM peak period: 0645 to 0745
- Midday peak period: 1145 to 1245
- PM peak period: 1600 to 1700
- Off-peak period: 2100 to 2200

5.3.2 Orrong Road peak hour periods

The Orrong Road corridor peak hours were found to be as follows:

- AM peak period: 0715 to 0815
- Midday peak period: 1130 to 1230
- PM peak period: 1615 to 1715
- Off-peak period: 2100 to 2200

5.4 Model calibration and validation

Model calibration and validation is necessary to ensure that a model accurately represents an existing traffic situation and can be used with confidence to test alternatives. Model calibration is the process of comparing observed data to the model output data to check that the model reflects on-street conditions. Calibration of the model has been based on the following:

- Vehicle Behaviour: Undertaking a visual check to confirm the observed vehicle behaviour in the model is consistent with that observed on-street.
- Turn Counts: Comparing observed and modelled turning movements for general traffic over the modelled peak hour periods.
- Link Counts: Comparing observed and modelled link counts for general traffic over the modelled peak hour periods.
- Queue Lengths: Undertaking a visual check to confirm the modelled queue operation is consistent with those observed on site.
- Signal timings: Undertaking a check to confirm that the observed signal timings in the model are relatively consistent with those collected on-street.

After the model is calibrated, validation is undertaken. Validation is the process of comparing the model outputs against independently measured data, which was not used in the calibration process, to confirm the model replicates existing network conditions. For the purposes of this study, validation is based on comparisons of observed and modelled journey travel times for general traffic over the modelled peak hour periods.

While Roberts Road, Alexander Road, and Leach Highway are included in the model, their volumes are only indicative and have not been calibrated. No analysis has been conducted at these intersections.

5.4.1 Tonkin Highway/ Kelvin Road turn and link count calibration

A Traffic Modelling Guidelines document is made available by the New South Wales Roads and Maritime Services (NSW RMS). As a summary the network wide calibration criteria from this document have been used for this study as well as the more useable criteria issued through the New Zealand Economic Evaluation Manual (NZTA EEM). These guidelines are used in the absence of any similar WA documents currently available.

As shown below, all of the turn and link count calibration criteria have been met as would be expected with a single intersection model and therefore the model is deemed calibrated. Further details regarding the calibration are contained in Appendix B.

Table 5-1: NSW RMS Criteria for Turn Counts at Tonkin Highway/ Kelvin Road

Criteria	AM	Midday	PM	Off-peak
GEH < 5 Minimum 85 per cent	100%	100%	100%	100%
Counts with GEH > 10 require explanation	0	0	0	0
R^2 to be > 0.9	0.9967	0.9998	0.9990	0.9997

Table 5-2: NZTA EEM Criteria at Tonkin Highway/ Kelvin Road

Criteria and Measures	Range	AM	Midday	PM	Off-peak
Calibration Acceptance Targets - Within 30% of Observed	< 99 vph	83%	100%	100%	90%
	100 -199 vph	100%	-	100%	-
	200 - 499 vph	100%	100%	100%	100%
	500 - 999 vph	100%	100%	100%	-
	> 1,000 vph	100%	-	100%	-
	> 100 vph	100%	100%	100%	100%
Turn Criteria and Measures	**Criteria**				
GEH statistic < 5.0 for individual turn volumes	>60% of cases	100%	100%	100%	100%
GEH statistic < 10.0 for individual turn volumes	>95% of cases	100%	100%	100%	100%
GEH statistic < 12.0 for individual turn volumes	100% of cases	100%	100%	100%	100%
Link Count R^2 Measure	**Criteria**				
R^2 value for modelled versus observed volumes for all individual Links	**> 0.85**	0.9958	0.9997	0.9988	0.9999
Links Criteria and Measures	**Criteria**				
GEH statistic < 5.0 for individual Links volumes	>60% of cases	100%	100%	100%	100%
GEH statistic < 10.0 for individual Links volumes	>95% of cases	100%	100%	100%	100%
GEH statistic < 12.0 for individual Links volumes	100% of cases	100%	100%	100%	100%
Criteria and Measures	**Criteria**				
Percentage RMSE Turns	<30%	13%	3%	7%	4%

5.4.2 Tonkin Highway/ Kelvin Road queue length calibration

Queuing is an inherently unstable phenomenon which can vary greatly from day to day. Queue measurements can be very subjective as the definition of what vehicles count as "queued" can differ between observers and between modelling packages.

Notwithstanding the issues relating to queue variability, queue comparisons are still valuable and have been made between observed and modelled queue length data to ensure queue patterns are appropriately represented in the model.

In the AM period substantial queuing exists northbound on Tonkin Highway and stretches several hundred metres. Conversely there is queuing on the Tonkin Highway southbound right turn that often exceeds its turn bay length as well as on the Kelvin Road western approach for the left turn movement. In the PM period queuing is not as pronounced but is still present on Tonkin Highway in the northbound and southbound directions.

These observed queues have been replicated in the model.

5.4.3 Orrong Road turn and link count calibration

Calibration results across the four selected signalised intersections on the Orrong Road corridor are shown in Table 5-3 and Table 5-4. All of the turn and link count calibration criteria has been met and the model can therefore be deemed calibrated.

Table 5-3: NSW RMS Criteria for Turn Counts for the Orrong Road Corridor

Criteria	AM	Midday	PM	Offpeak
GEH < 5 Minimum 85 per cent	94%	100%	97%	97%
Counts with GEH > 10 require explanation	0	0	0	0
R^2 to be > 0.9	0.9901	0.9966	0.9964	0.9937

Table 5-4: NZTA EEM Criteria for the Orrong Road Corridor

Criteria and Measures	Range	AM	Midday	PM	Offpeak
Calibration Acceptance Targets - Within 30% of Observed	< 99 vph	60%	92%	78%	80%
	100 -199 vph	100%	100%	100%	100%
	200 - 499 vph	86%	100%	89%	100%
	500 - 999 vph	100%	-	-	100%
	> 1,000 vph	100%	100%	100%	-
	> 100 vph	95%	100%	96%	100%
Turn Criteria and Measures	**Criteria**				
GEH statistic < 5.0 for individual turn volumes	>60% of cases	94%	100%	97%	97%
GEH statistic < 10.0 for individual turn volumes	>95% of cases	100%	100%	100%	100%
GEH statistic < 12.0 for individual turn volumes	100% of cases	100%	100%	100%	100%
Link Count R^2 Measure	**Criteria**				
R^2 value for modelled versus observed volumes for all individual Links	**> 0.85**	0.9814	0.9929	0.9913	0.9872
Links Criteria and Measures	**Criteria**				
GEH statistic < 5.0 for individual Links volumes	>60% of cases	89%	100%	93%	96%
GEH statistic < 10.0 for individual Links volumes	>95% of cases	100%	100%	100%	100%
GEH statistic < 12.0 for individual Links volumes	100% of cases	100%	100%	100%	100%
Criteria and Measures	**Criteria**				
Percentage RMSE Turns	<30%	14%	8%	9%	8%

5.4.4 Orrong Road queue length calibration

In the AM period the predominant queues are westbound, primarily at Oats Street but also eastbound at Archer Street. The PM period again has some queuing westbound on Orrong Road but the primary queue is late in the PM period where traffic heading eastbound from the Graham Farmer Freeway arrives at the Orrong Road corridor and more specifically the Francisco Street intersection. These observed queues have been replicated in the model.

5.4.5 Orrong Road journey time validation

Journey time data was collected during the peak AM and PM hours by Aurecon using a floating car method on a day of the Austraffic surveys. The journey time data was recorded for both the eastbound and westbound directions from after the Orrong Road/ Leach Highway Interchange to the Great Eastern Highway over pass.

As well as this set of data, the RAC WA provided a further 2011 journey time data collected between individual intersections. Due the collection of the RAC WA data preceding the study a direct comparison could not be made, rather the data has been referred to. These journey times have also been recorded over a different distance to those used in the RAC WA surveys and those used in the option model comparisons further in the report.

The NSW RMS Modelling Guidelines suggest modelled journey times should be within 15% or 1 minute of the observed value, whichever is greater.

The eastbound and westbound journey time comparisons are shown below. All of the journey time routes match the set criteria with the exception of the AM period eastbound route, which is 1:11 over the observed value. However, only two observed runs form the basis of this comparison, and referring to the RAC WA data for a shorter route, journey times vary from 4:52 minutes to 7:11 minutes for a similar time period. On this basis, the modelled journey time has been deemed acceptable.

Table 5-5: Westbound Journey time comparison for the Orrong Road corridor

Journey Time Source	AM	PM
Average Observed Journey Time	9:32	6:35
Average Modelled Journey Time	8:15	6:06
Difference (min:secs)	1:17	0:29
% Difference	-13.5%	-7.3%

Table 5-6: Eastbound Journey time comparison for the Orrong Road corridor

Journey Time Source	AM	PM
Average Observed Journey Time	5:37	5:42
Average Modelled Journey Time	6:48	6:05
Difference (min:secs)	1:11	0:23
% Difference	21.1%	6.7%

6. Option Testing: Tonkin Highway/ Kelvin Road

6.1 Option plan

A workshop was held in order to present a series of options that were proposed for testing to Main Roads WA. These options were agreed by RAC WA and Main Roads WA and the following option test plan was developed.

Option	Option Details
Option 1	Adjust SCATS signal settings including Master-isolated operation (maximum green times for each phase are determined by SCATS based on the approach degree of saturation) and optimal cycle time, no infrastructure costs.
Option 2	Test under a Double diamond overlap phasing, minor infrastructure costs in the order of $1,000's.
Option 3	Double right turn on Tonkin Highway north approach and localised additional lane flaring on the Tonkin Highway south approach, medium infrastructure in the order of $100,000's.
Option 4	Ultimate test, adjustment of the SCATS signal settings including Master-isolated operation, optimal cycle time, and test under a Double diamond overlap phasing, minor infrastructure costs in the order of $1,000's.

6.2 Option testing results

All of the result tables are presented with shades of green or red to represent the relative positive or negative impacts of the option tests. Focus has been given to delay and level of service as this best evaluates changes in performance of an intersection. The total columns take into account the cumulative effect of the traffic volumes over all of the periods.

6.2.1 Delay

The tables below present the total delay of all the vehicles in the network recorded for the base model and the subsequent option models for all four of the modelled time periods. These tables show that as a total Option 3 achieves up to a 36% reduction in delay over the base model for all of the model periods. Options 1, 2, and 4 also show a reduction in delay and even though these reductions are to a lesser extent, these options require less infrastructure works than Option 3.

Using the following formula the annual delay cost was calculated based on 260 travel days (workdays) per year and an average hourly rate of AUD$35 and vehicle occupancy of 1.2.

Calculation:

Daily Hours of Reduction in Vehicle Delay x Vehicle Occupancy = Daily Person Hour Delay

Then:

Daily Person Hours Delay x 260 Days (work week) x Cost per Hour = Annual Delay Savings

Equating this to annual delay cost to occupants, Option 4 would save approximately $802,000 per year in lost time cost.

Table 6-1: Tonkin Highway/ Kelvin Road total vehicle delay (hours)

	AM	Midday	PM	Off-Peak	Total
Base	139.8	23.9	106.3	4.3	**274.3**
Option 1	132.3	18.6	112.3	4.1	**267.4**
Option 2	124.6	19.9	100.1	3.3	**248.0**
Option 3	58.8	21.5	92.5	4.3	**177.0**
Option 4	91.9	16.6	89.1	3.2	**200.8**

Table 6-2: Tonkin Highway/ Kelvin Road total vehicle delay (percentage change from base)

	AM	Midday	PM	Off-Peak	Total
Option 1	-5.4%	-22.2%	5.7%	-4.1%	**-2.5%**
Option 2	-10.8%	-16.9%	-5.8%	-22.9%	**-9.6%**
Option 3	-57.9%	-10.1%	-13.0%	-0.5%	**-35.5%**
Option 4	-34.3%	-30.5%	-16.2%	-24.3%	**-26.8%**

A breakdown of the delay for each movement and the associated levels of service are attached in Appendix C.

6.2.2 Average speeds

An average speed comparison across the base and four option model networks was undertaken and is displayed in Table 6-3. The weighted total average speed values were calculated by multiplying the network volumes in each period by the average speeds in each period. These values were summed for all periods and divided by the total of all volumes to get the weighted total average speed for each option.

Calculation:

(AM volume x AM speeds) + (Midday volume x Midday speeds) + (PM volume x PM speeds) + (Offpeak volume x Offpeak speeds) = Total volume speed value

Then:

Total volume speed value / (AM volume + Midday volume + PM volume + Offpeak volume) = Weighted total average speed

By referring to the average speeds across all the models, Option 3 and Option 4 show a substantial increase in average speeds across all model periods with the exception of a reduction in the average speed for the off-peak period of Option 3.

Table 6-3: Tonkin Highway/Kelvin Road average speed (km/h)

	AM	Midday	PM	Off-Peak	Total
Base	29.3	57.8	39.3	72.3	**42.9**
Option 1	30.0	62.3	37.1	72.6	**43.4**
Option 2	30.2	62.2	38.5	75.7	**44.2**
Option 3	45.6	58.2	40.8	71.6	**48.7**
Option 4	37.6	64.4	42.7	76.0	**48.7**

6.2.3 Carbon emissions

The total estimated carbon emissions for all movements in the models were calculated within the VISSIM micro-simulation software and are displayed in Table 7-5 in the unit of grams. Option 3 has a significant reduction in carbon emissions across all model periods. It is understood that different vehicle operations in the model with the lower cycle times is the reason for higher carbon emissions for many of the options, despite having a reduction in the vehicle delays.

Table 6-4: Tonkin Highway/Kelvin Road carbon emissions (grams)

	AM	Midday	PM	Off-Peak	Total
Base	6,986	4,597	8,949	1,397	**21,927**
Option 1	7,638	4,570	9,793	1,362	**23,362**
Option 2	7,644	4,593	9,752	1,270	**23,259**
Option 3	6,559	4,229	8,552	1,321	**20,662**
Option 4	7,796	4,290	8,653	1,264	22,003

6.3 Summary results

By reviewing the total delays, average speeds, carbon emissions, and likely scale of cost for the civil works, Option 4 has been identified as the best performing option compared to the base model, most highlighted by its 26.8% reduction in delay over all the periods. The right turn from Tonkin Highway north into Kelvin Road westbound does have an increase in delay for Option 1 and Option 4 but a decrease in delay for Options 2 and 3. This increase in delay for the Option 1 and Option 4 north approach right turn is due to no call back running. It is anticipated that a civil works capacity upgrade for the north approach right turn bay is required regardless of the signal operation due to its impact on road safety.

Option 3 performs well but it has high cost civil works associated with it. Option 1 and Option 2 have overall positive increases in delay.

The increases in performance of the Tonkin Highway/ Kelvin Road intersection are achieved by implementing the following:

- A double diamond overlap phasing arrangement.
- Master-isolated operation instead of flexi-link but this dependent on the treatment of the Tonkin Highway North approach right turn bay.
- Lowering the current 250 second peak period cycle time.

7. Option Testing: Orrong Road

7.1 Option plan

A workshop was held in order to present a series of options that were proposed for testing to Main Roads WA. Several of these options were agreed by RAC WA and Main Roads WA and the following option test plan was agreed.

Table 7-1: Option test plan

Option	Option Details
Option 1	Determine the optimal cycle time and refine SCATS data which will include operating incremental split selection, no infrastructure costs.
Option 2	Stagger the pedestrian crossing on Wright and Oat Streets, minor infrastructure costs in the order of $1,000s.
Option 3	On south approach of the San Francisco Place implement a left turn only with a u-turn bay, on Archer Street and Wright Street implement a lag right turn. SCATS data refined. Minor infrastructure costs in the order of $10,000s.
Option 4	Testing of Oats Street under a double diamond operation, minor infrastructure costs in the order of $10,000s.
Option 5	Ultimate test, as per Option 1 with further refinement to SCATS data and coordination, no infrastructure costs.

7.2 Option testing results

7.2.1 Delay

The tables below present the total vehicle delay (hours) for the base model and the subsequent option models for all four of the modelled time periods. No single option offers a reduction in delay over all of the model periods, however Option 5 shows the greatest overall reduction in delay.

Equating this to annual delay cost to occupants, Option 5 would save approximately $760,000 per year in lost time cost.

Table 7-2: Orrong Road Corridor total vehicle delay (hours)

	AM	Midday	PM	Off-Peak	Total
Base	337.9	106.7	238.0	17.0	**699.6**
Option 1	278.3	134.2	243.2	15.8	**671.6**
Option 2	329.7	107.0	219.4	17.4	**673.4**
Option 3	284.2	109.2	258.3	15.7	**667.4**
Option 4	390.2	115.3	317.3	16.6	**839.4**
Option 5	281.2	126.3	206.6	15.9	**629.9**

Table 7-3: Orrong Road Corridor total vehicle delay (percentage change from base)

	AM	Midday	PM	Off-Peak	Total
Option 1	-17.6%	25.8%	2.2%	-7.0%	**-4.0%**
Option 2	-2.4%	0.3%	-7.8%	2.1%	**-3.7%**
Option 3	-15.9%	2.4%	8.5%	-7.8%	**-4.6%**
Option 4	15.5%	8.0%	33.3%	-2.5%	**20.0%**
Option 5	-16.8%	18.4%	-13.2%	-6.7%	**-10.0%**

A breakdown of the delay for each movement and the levels of service are attached in Appendix C. Note: there was some isolated queuing that at times extended beyond the model bounds but sensitivity tests showed that the effect of this on delay was minimal.

7.2.2 Average speeds

An average speed comparison across all the links of the models was undertaken and is displayed in Table 7-4. The weighted total average speed values were calculated by multiplying the network volumes in each period by the average speeds in each period. These values were summed for all periods and divided by the total of all volumes to get the weighted total average speed for each option.

There is little overall change in average speeds compared to the base model however Option 2 and Option 5 are the best performing.

Table 7-4: Orrong Road average speeds (km/h)

	AM	Midday	PM	Off-Peak	Total
Base	26.9	38.3	31.9	49.4	**33.9**
Option 1	29.1	36.9	30.2	50.0	**33.8**
Option 2	27.3	38.8	32.9	49.3	**34.5**
Option 3	28.4	39.4	29.8	49.9	**34.1**
Option 4	22.6	38.1	28.1	49.6	**31.3**
Option 5	28.7	37.9	33.2	49.8	**34.8**

7.2.3 Carbon emissions

The total estimated carbon emissions for all movements in the models are displayed in Table 7-5 in the unit of grams. No model has a reduction in emissions over all the periods however Option 2 and Option 5 has a total reduction in carbon emissions.

Table 7-5: Orrong Road Corridor carbon emissions (grams)

	AM	Midday	PM	Off-Peak	Total
Base	28,866	20,013	26,590	6,418	**81,886**
Option 1	26,786	20,953	27,641	6,038	**81,419**
Option 2	28,943	19,913	26,501	6,418	**81,775**
Option 3	27,273	19,776	28,161	6,044	**81,255**
Option 4	32,101	20,153	28,086	6,375	**86,716**
Option 5	27,546	20,484	26,614	6,092	**80,736**

7.2.4 Journey time comparison graphs

Journey time comparisons, focusing on the Orrong Road corridor movements, are displayed below. They show that some marginal improvement is achieved with most options however some options perform poorly. In the AM period Options 2 and 3 show improvement in the journey times and in the

PM period Options 2 and 5 perform better than the base case. The largest improvement is experienced in the AM period eastbound by Options 1 and 5, with an average saving of over 2 minutes.

Figure 7-1: Eastbound Journey Times for the Orrong Road corridor in the AM peak hour period

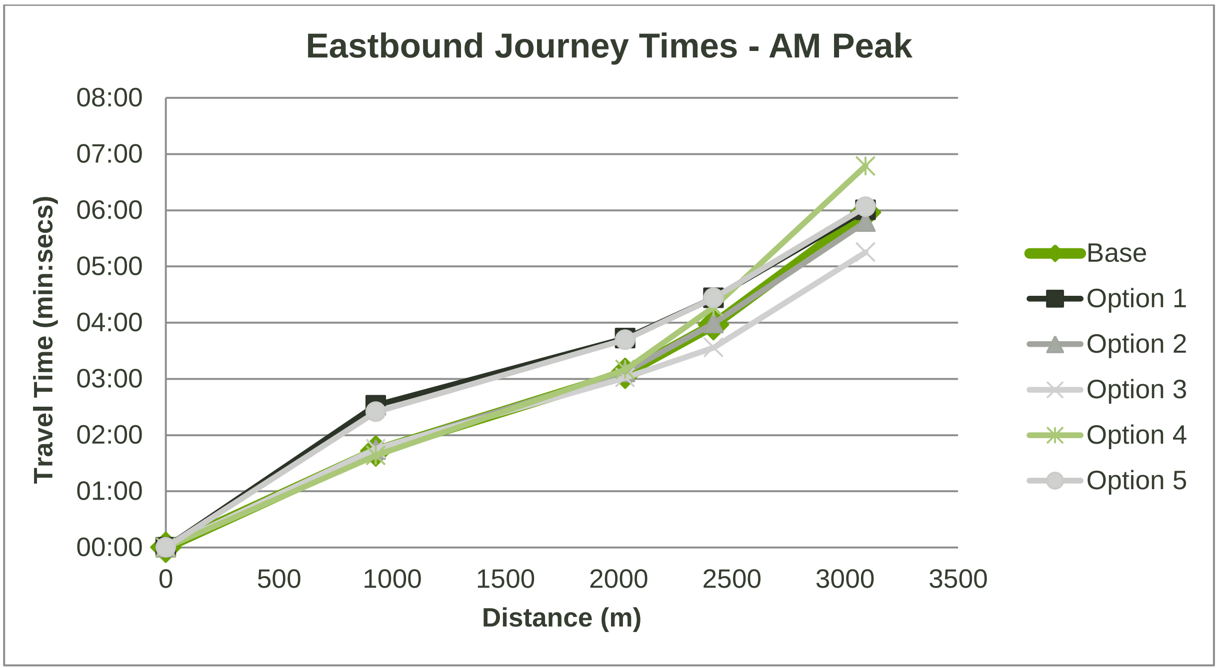


Figure 7-2: Westbound Journey Times for the Orrong Road corridor in the AM peak hour period

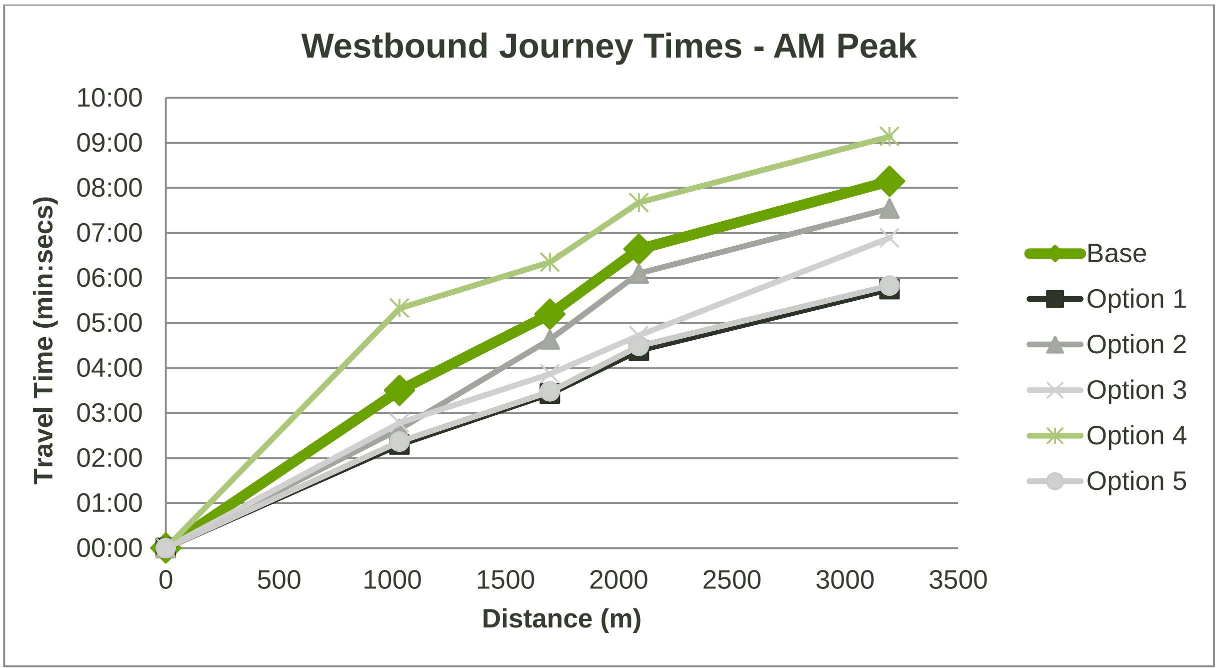


Figure 7-3: Eastbound Journey Times for the Orrong Road corridor in the PM peak hour period

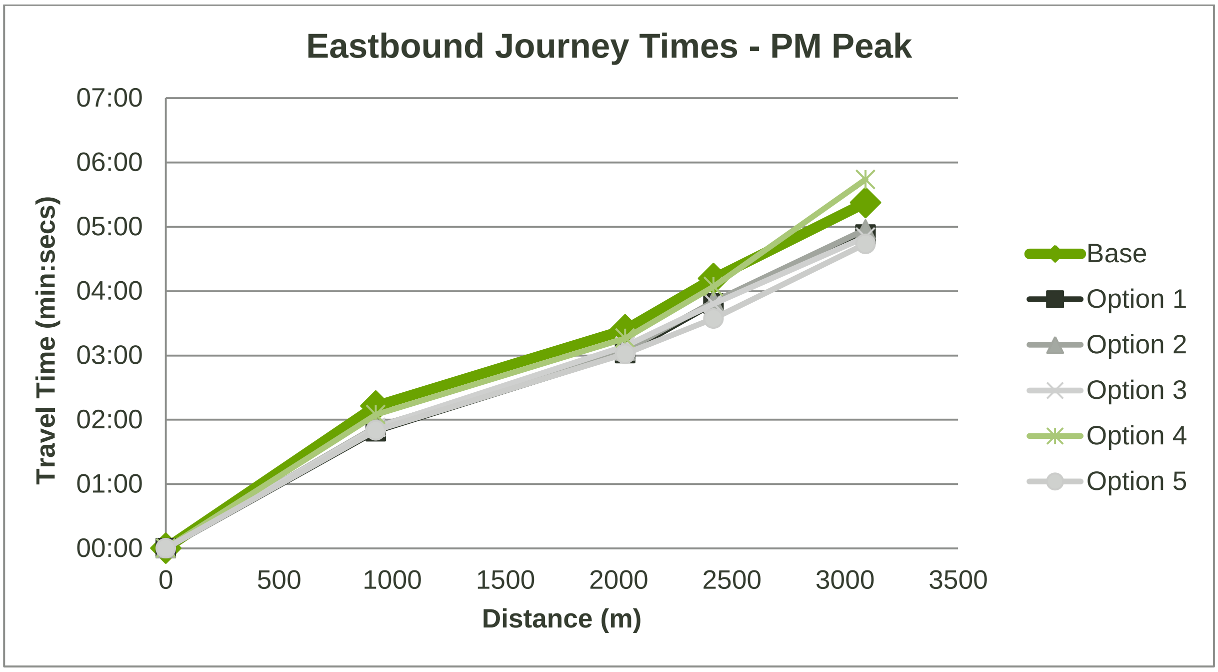
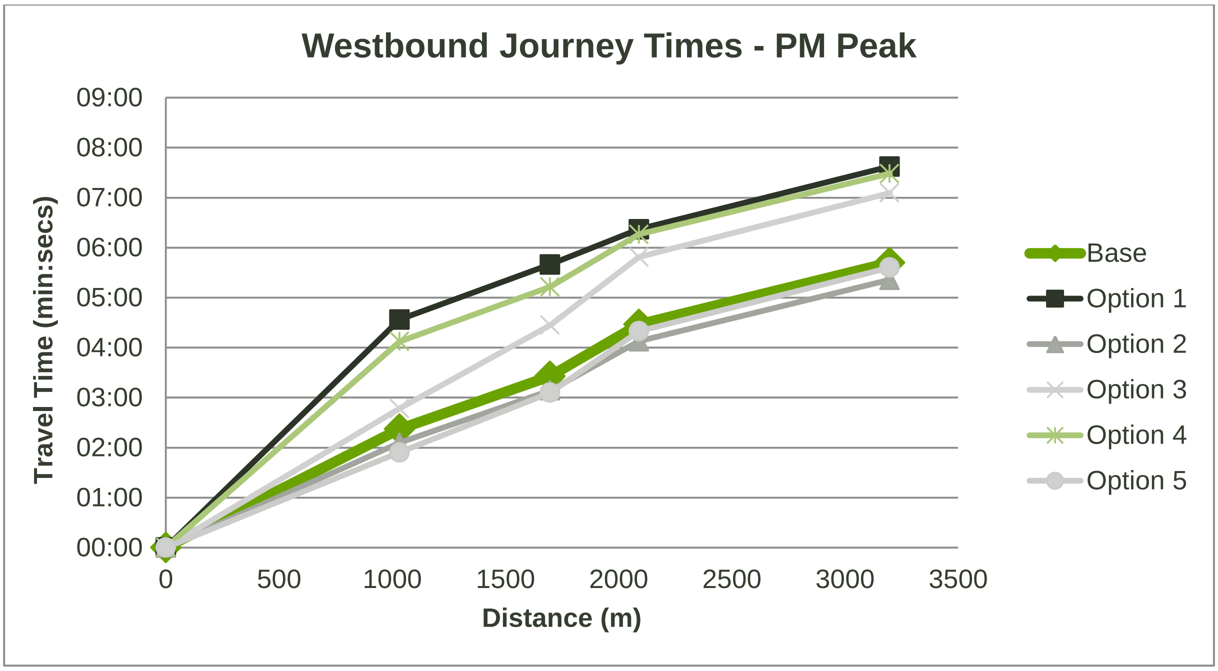


Figure 7-4: Westbound Journey Times for the Orrong Road corridor in the PM peak hour period



7.3 Summary results

From this analysis Option 5 has been put forward as the recommended option due to its overall improvement over the base case scenario in terms of reducing delay by 10% and some improvement in the average speeds, carbon emissions, and Orrong Road journey times. There is also no civil work costs required for Option 5.

Option 5 achieved these improvements by implementing the following:

- A switch to incremental split selection.
- Lowering the cycle time from the current range of 160-180 seconds.
- Refinement of the corridor coordination.

The alternative options only showed a marginal overall improvement in delay with the exception of the Oats Street double diamond overlap Option 4 which performs very poorly.

8. Key Findings and Conclusions

8.1.1 SCATS settings

From this study of the SCATS signal operations and settings, several noteworthy aspects have emerged. Firstly, Main Roads WA currently has many of the demonstration sites in this particular study operating close to their optimal level. It is obtaining the final 5-10% of capacity where the difficulty lies, as shown with the Orrong Road option testing, and while some tested options improved the network performance, equally some of the other options had a detrimental effect on the network operation. By using micro-simulation modelling, this final level of optimisation can be attempted without the risk of a poorly performing option being tested on-street. This is especially important considering that most of the proposed measures should only be implemented on a site by site basis rather than broadly across the network.

The option testing highlighted that the following changes to the way SCATS is used would have a positive impact on the selected sites.

Cycle times

A key finding is that reducing cycle times reduces the delay to road users. The Tonkin Highway/ Kelvin Road option testing found that lowering the cycle times in the peak periods from 250 seconds to 190 seconds, or preferably further to 145 seconds, reduced vehicle delay as well as the delay for any pedestrians waiting to cross at the signalised intersection. This final cycle time is dependent on the signal phasing that is in operation and the traffic conditions at different times throughout the day. It is known in Perth that the public express that they like to have longer green times rather than short phases but shorter phases means that on average people will experience less delay and thus communication around any change to cycle times will be key.

The maximum cycle times on the Orrong Road corridor are again dependent on the time of day but in the AM and PM periods a maximum cycle time up to 155 seconds is advised.

Incremental Split Selection

Secondly, switching to incremental split selection, a function within SCATS, allows the signals to be more adaptive to the detected traffic volumes which generally improves the signal performance compared to using fixed signal plans. For this reason average phase splits have not been provided from the modelling analysis. From the Orrong Road Option 5 analysis, incremental split selection reduced delay, particularly in the peak periods.

Master-isolated operation

Specifically relating to the Tonkin Highway/ Kelvin Road intersection, a change from Flexi-link to Master-isolated (both of which are SCATS operation settings) shows improvements, particularly if it is carried out in conjunction with double diamond overlap phasing. This does have an impact on the Tonkin Highway north approach right turn movement which is currently a safety issue on-street and the length of this turn bay is a factor in the success of this SCATS setting at this demonstration site.

SCATS signal settings guidance

There is little useful guidance or tools within the industry that communicate the range of SCATS settings that may be employed by operators, and the time periods for which they are appropriate. As a result, when traffic engineers at the TOC make changes to the operation of a set of signals they use techniques developed from their signals experience and these techniques include reviewing traffic patterns at the signalised intersection as each site has its own unique characteristics and behaviours.

8.1.2 Main Roads WA TOC procedure

Signal auditing

As is common in all TOC's, operators observe the network to identify sites where congestion can be reduced by balancing the delay on intersection approaches. This leads to adjustment of the SCATS signal settings to the point where the on-street performance is deemed to be optimal.

It is evident from the workshops with Main Roads WA that the TOC is very responsive to comments from both the public and from other road authorities. To some extent complaints made to Main Roads WA drive which signalised intersections or corridors will be reviewed. This aligns with Main Roads WA philosophy of valuing and prioritising the experience of road network users.

A secondary driver for undertaking signal reviews is changes in land use, particularly new developments that result in changes to the road network. These will generally change traffic patterns and trigger a need to audit nearby SCATS signals that may have been impacted by the change. Audits relating to these types of changes are generally planned in advance.

This approach is however reactive and the more proactive, and more resource intensive, approach of auditing of signals currently occurs approximately once every three years.

Figure 8-1 shows the process that the TOC currently apply to audit and adjust SCATS signal settings.

Figure 8-1: Main Roads WA signal adjustment process

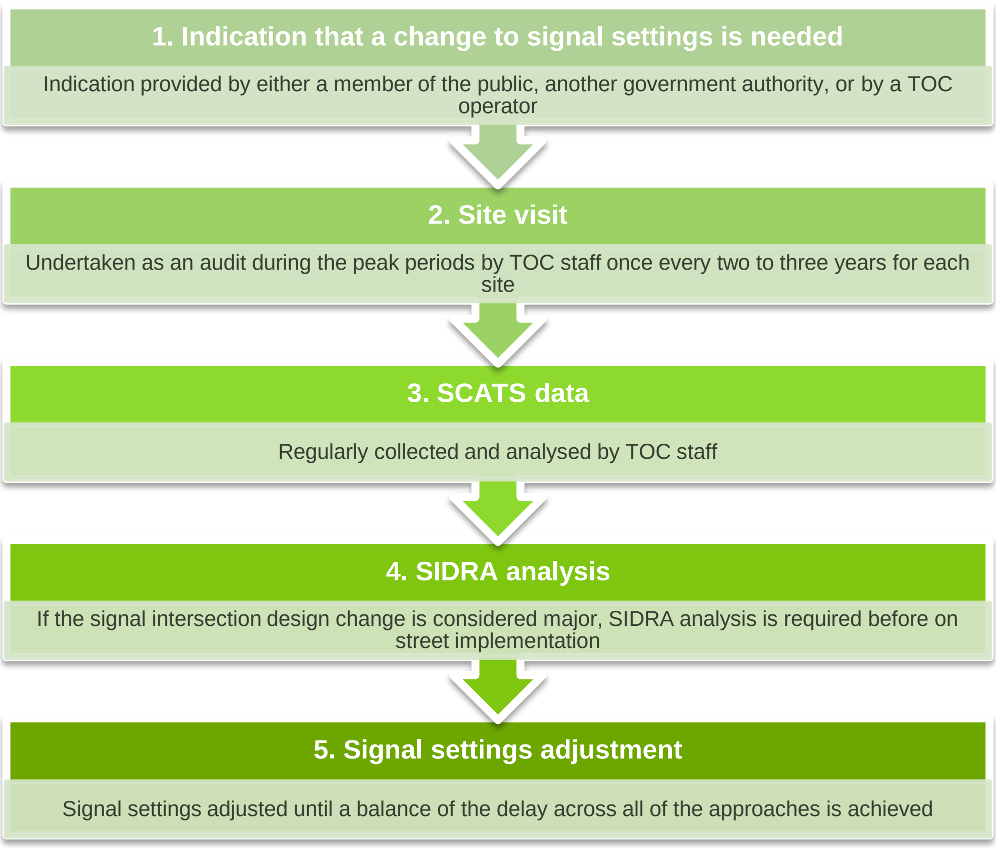
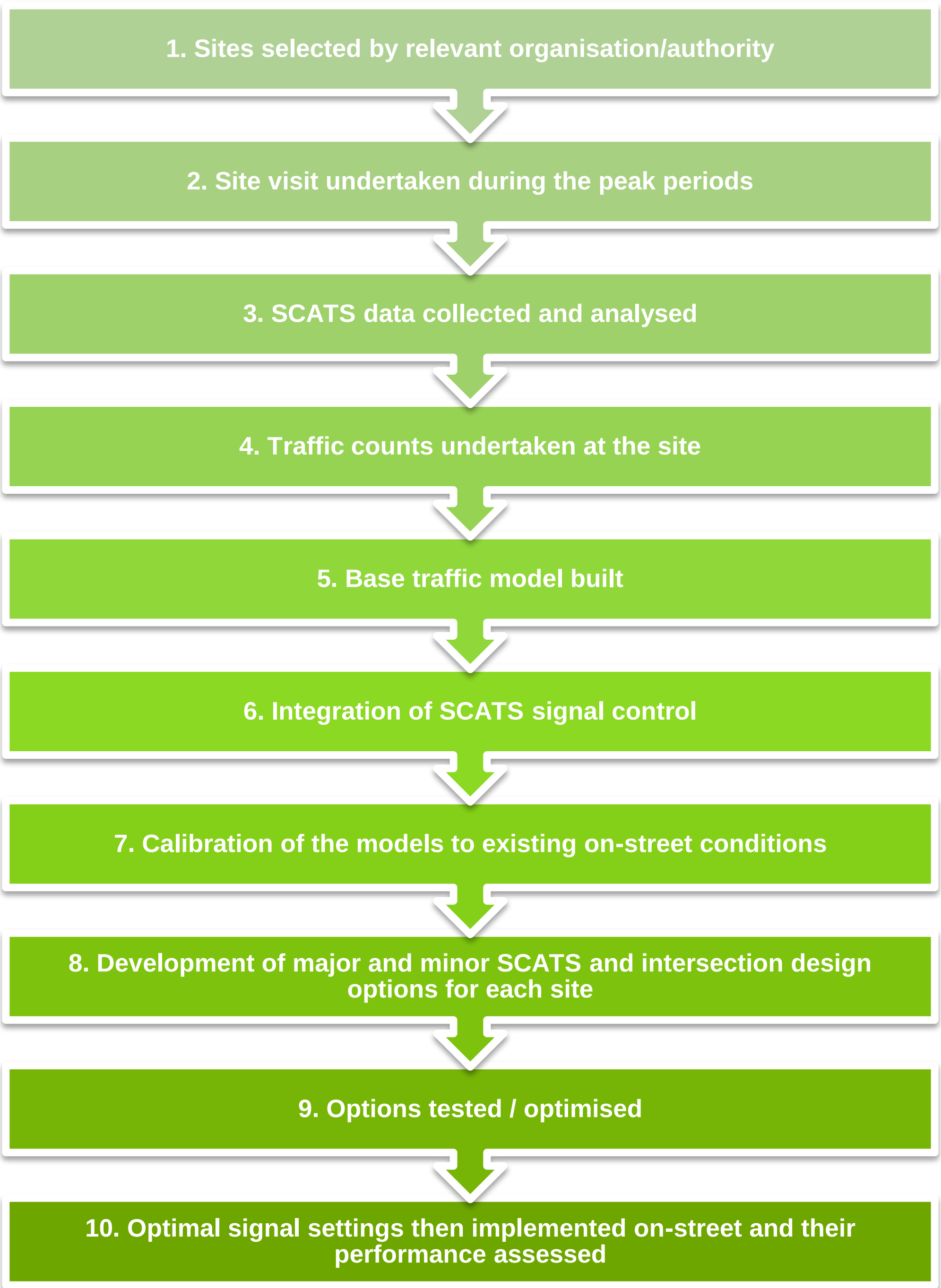


Figure 8-2 shows the process applied to audit and adjust SCATS signal settings, as used in this study. The primary differences between the two methodologies are the additional steps of collecting on-site traffic count data and the development of an operational micro-simulation model to look at both individual intersections and corridors.

Figure 8-2: Signal adjustment process used for this study



Austroads Guide to Traffic Management Part 9 identifies five different audit levels with Level 3, Strategic Data Audit, and Level 4, Minor Network Control, most applicable to this study. They generally advise site visits and analysis of scats data to identify which of the wide range of SCATS settings should be adjusted.

8.1.3 Testing of possible refinement options before implementation

The implementation of a wider range of adjustments such as the new phasing arrangements along the Orrong Road corridor, not only has the potential to improve signal operation but equally the potential to have a detrimental impact on the road network. Additionally, because permanent civil works are sometimes required, confidence is needed that the adjustments will result in improvements.

This is where the benefit of using intersection and network analysis software programs to predict the impact of signal and design changes is demonstrated. For most new installations, Main Roads WA currently uses SIDRA to assist in the selection of the phasing. However, this uses fixed formulas for the analysis rather than an operational model such as micro-simulation, which replicates observed on-street driver behaviour.

A further benefit of an operational model is that quantitative analysis can be carried out later, beyond the time when signals are installed, to take account of continuing changes in land use and traffic flow. Micro-simulation, as used in this study, is the next step forward as it allows SCATS signal control to be used within the virtual environment and it models individual vehicles in an operational format to provide a high level of confidence about what the outcomes will be. However, micro-simulation models take more time to build, require more data, and often require modelling personnel.

As shown in this study, analysis of some options may show that the existing on-street signal setup operates better than some alternate options that are proposed and that the infrastructure is performing close to its optimal performance level.

Conversely analysis showed that positive improvements can potentially be achieved without civil works. Regardless of how slight some of these improvements may be they are nonetheless justified by extending the life of the existing infrastructure and thus the additional investment in micro-simulation analysis is recouped.

There is an opportunity for Main Roads WA to use analysis techniques to assist in getting the most out of the existing infrastructure. Many road agencies around the world invest in modelling or analysis teams to work alongside the TOC to ensure the optimal signal setup is used not only at the time of signal installation, but also at regular intervals during the signals lifetime.

Real-time incident modelling

The next generation of using modelling to simulate real life network operation is real-time incident modelling. This works by inputting the incident as a road network ‘blockage’ into a prebuilt model. The model then quickly runs several network scenarios producing outputs which advise TOC operator’s how best to manage traffic so the impact of the incident on the network can be minimised.

8.1.4 Resourcing

TOC staff numbers

The Main Roads WA TOC currently has 6 staff each covering approximately 150 intersections. More staff with high skill sets would allow signals and corridors to be audited in accordance with Austroads guidelines at more frequent intervals. This would ultimately result in a network that is operating closer to its optimum level. In the NSW RMS, TOC operators cover between 250 and 300 sites each, however these sites are located in a more condensed pattern than in Perth, making it easier for staff to reach sites for on-street monitoring and auditing.

The ‘Traffic Signal Operations and Maintenance Staffing Guidelines’, made available by the US Department of Transportation Federal Highway Administration (FHWA), states that 75 to 100 signals per operator/ traffic engineer are recommended to achieve desired efficiency targets. However the use of fixed time signal is more prevalent in the US, as opposed to the SCATS adaptive system, and these fixed time signals generally require more operator involvement thus more operators are required.

Industry constraints

Attracting and retaining TOC staff with the appropriate skill set is no easy task. In today’s environment, SCATS operators must not only be highly competent in SCATS signal setup, monitoring, and maintenance but must also have a good understanding of traffic engineering and the related concepts. This is to ensure that staff take into consideration the impact of their signal decision on the rest of the road network as well as other road users.

Traditionally many SCATS operators have come from an electrical engineering background and have been trained ‘on the job’. Today there are various courses available for new staff to gain knowledge in this field. However with SCATS operation being so specialised, it is believed that some staff fear being pigeon-holed as a SCATS specialist.

The FWHA guidelines state that, as a minimum, new technicians should have High School Qualifications, knowledge of electrical aspects, and initial certification from a traffic signals course. At the other end of the scale, the traffic system engineering team leader should be professional registered as an engineer, preferably with a traffic operations engineer certification of some sort.

9. Recommendations

The study examined two demonstration sites and Main Roads WA signal processes to determine the following:

- What signalised intersection treatments are currently utilised.
- What signal improvements can be achieved.
- General considerations and requirements for refining SCATS signal settings.
- Signal refinement methodologies.
- Performance measures and evaluation of signal timing performance.
- Barriers to refining signal settings.
- Main Roads WA signal refinement policy, management, planning, and resources.

From this study the following items are recommended for implementation at demonstration sites and for further investigation for the wider Main Roads WA network. These items would allow the SCATS signal system to be used to its full potential.

1. To reduce delay, lower cycle times should be implemented at the demonstration sites. No single ideal cycle time number exists as it depends on the signal phasing at the site and the traffic conditions which change throughout the day. Research to further develop an understanding of the driver behaviour that leads to this relationship would be useful.
2. The use of incremental split selection is recommended. Incremental split selection is a SCATS setting that allows a more dynamic selection of split plans and thus more dynamic signal operation to further assist the balancing approaches and reducing delay.
3. A change to master-isolated settings should be investigated at Flexilink sites. Master-isolated signals allow maximum green times for each phase to be determined by SCATS based on the approach degree of saturation. Flexi-link operates differently using predefined plans and time of day schedules.
4. Some of the signal refinement options identified as having efficiency benefits should be trialled on-street. Data would need to be collected before and during the trials across a number of days during the critical time periods with final adjustments also made once in operation on-street. Post-implementation data such as travel time data can be collected once the new signal settings are fully operational. The SCATS settings adjusted in the Orrong Road corridor Option 5 test, particularly the use of incremental split selection, would be the best to trial first on-street due to no civil works required.
5. More detailed operational analysis using micro-simulation modelling within the TOC methodology would allow for a more diverse range of options to be tested in order to achieve the best possible level of performance from the existing road network. Improvements can be tested for the most conventional of signalised intersections to the very complex.
6. Since resource constraints are the most significant factor contributing to sub-optimal signal retiming it is recommended that there is a reduction in the average number of signals monitored per TOC operator.
7. Investigation into new signal refinement approaches and tools such as real-time incident modelling should be continued.
8. It is advised that if one approach works at a selected intersection, it should not be automatically applied to others. Staff at the TOC should follow a robust methodology to assess what changes may be required on a site by site basis, as each site has their own characteristics and reacts accordingly. This important point was displayed in this study with some of the tested options worsening the performance of the respective demonstration sites.

9. There is little useful national guidance or tools that communicate the range of SCATS settings that may be employed by operators, and the time periods for which they are appropriate. As a result, traffic engineers at the TOC use techniques based on experience and by reviewing traffic patterns as each site has its own unique characteristics and behaviours. Research is also needed to develop guidance based on intersection performance measures.
10. Data is a crucial factor in being able to assess if signals are currently performing satisfactorily and if refinements are having the desired outcomes. To provide a basis for improved signal refinement, collection and calculation of the following data is recommended:
    - Total volume throughput
    - Degree of saturation
    - Average corridor speeds
    - Spillback of queues through turn bays or to nearby intersections
    - Delay caused to other movements by these queues spilling back
11. The Main Roads WA TOC delivers a wide range of network management services, and obtaining and retaining sufficient numbers of skilled staff within budget constraints is a difficult task. It is recommended that Main Roads WA compare their signal operations with NSW RMS and other Australian States. This will assist Main Roads WA in ensuring that their team of staff maintain the highest skill set possible. This is particularly relevant with the wide range of new Intelligent Transport Systems technologies that are soon to be trialled in Perth which will further stretch Main Roads WA TOC resources.

Appendix A
Further Crash Data

A. Tonkin Highway / Kelvin Road

A total of 203 crashes, involving all modes of transport, occurred over the 2008 – 2012 period at the Kelvin Road - Tonkin Highway intersection.

A.1 Crash Severity

The number of crashes and severity per year is shown in Table 4-1. In summary:

- A total of 203 crashes occurred on the intersection
- 4.5% resulted in hospital treatment
- 16% resulted in medical treatment
- 53% resulted in major property damage only (PDO Major)
- 26.5% resulted in minor property damage only (PDO Minor)

It is observed that more than 20% of the crashes resulted in either medical or hospital treatment.

A.2 Time of Crash

For detailed time analysis of the data, only the Monday to Friday data was used, however, Saturday and Sunday statistics are also included. Nearly 50% of the total number of crashes occurred during the morning (6am – 10am) and afternoon (2pm – 5pm) peaks. This suggests that congestion of the intersection plays an important factor in the time during which a crash occurred.

Detailed summary of the time of crash occurrences

Time of Crash	Number of Crashes	Number of Crashes as a percentage
Morning 6 am – 10 am	57	28%
Midday 10 am – 2 pm	26	13%
Afternoon 2 pm – 5pm	42	21%
Early Evening 5 pm – 7 pm	22	11%
Other 7 pm – 6 am	21	10%
Saturday and Sunday	35	17%

A.3 Vehicle Type and Crash Movement Summary

The tables below summaries the type of vehicle involved in the crash and the crash movement. Nearly 90% of vehicles involved in a crash were those that involved a car. The majority of the crashes occurred when the vehicle was either fully stopped or travelling straight (not out of control).

Type of vehicle involved in crashes

Vehicle Type	Number of Crashes	Number of Crashes as a total Percentage
Motorcycle	5	2.5%
Cars	178	88%
Bus	1	0.5%
Truck	6	3%
Unclassified	13	6%

Crash movement summary

Description of Crash Movement	Number of Crashes at Intersection
Out of control	7
Overtaking	7
Reversing or Rolling Back	1
Stopped	72
Turning	8
Swing Wide	1
Straight ahead – not out of control	107
TOTAL	**203**

A.4 Nature of Crash Event

The crash statistics data represented in the table below shows the nature of the event for the particular vehicle movement. From this we identify the Tonkin Highway North – South and South – North movements as the prevailing crash movements with the highest proportion of these being rear endings.

Nature of crash at Tonkin Highway / Kelvin Road

	Nature of Event					TOTAL
Movement	**Rear End**	**Right Angle**	**Right Turn Through**	**Sideswipe Same Direction**	**Undefined**	
E-S	2					**2**
E-W	1					**1**
N-W	7		4	1		**12**
N-S	21	2	2	3	1	**29**
N-E				1		**1**
N-undefined	1					**1**
W-N	5					**5**
W-E	2	2				**4**
S-E	9			1		**10**
S-N	22	1				**23**
S-W	3					**3**
S-undefined	1					**1**
Undefined-Undefined	6	1			1	**8**
TOTAL	**80**	**6**	**6**	**6**	**2**	**100**

B. Orrong Road

B.1 Crash Severity

The number of crashes and severity per year is shown in Table 4-3. In summary:

- A total of 1493 crashes occurred along the corridor
- 0.15% resulted in a fatality
- 4% resulted in hospital treatment
- 15.85% resulted in medical treatment
- 50% resulted in major property damage only (PDO Major)
- 30% resulted in minor property damage only (PDO Minor)

It is observed that 20% of the crashes resulted in either medical or hospital treatment. Alarmingly, a clear upward trend, in terms of the number of crashes, can be identified from the data. The reason for the trend is not clear but an increase in the number of vehicles on our roads is a likely contributing factor. More than 50% of the crashes resulted in major property damage only.

B.2 Time of Crash

For detailed time analysis of the data, only the Monday to Friday data was used, however, Saturday and Sunday statistics are also included. 46% of the total number of crashes occurred during the morning and afternoon peaks. This suggests that congestion along the corridor plays an important factor in the time during which a crash occurred.

Detailed summary of the time of crash occurrence

Time of Crash	Number of Crashes	Number of Crashes as a percentage
Morning 6 am – 10 am	331	22.17 %
Midday 10 am – 2 pm	193	12.93 %
Afternoon 2 pm – 5pm	356	23.84 %
Early Evening 5 pm – 7 pm	211	14.13 %
Other 7 pm – 6 am	134	8.97 %
Saturday and Sunday	268	17.96 %

B.3 Vehicle Type and Crash Movement Summary

The tables below summaries the type of vehicle involved in the crash and the crash movement. Nearly 90% of vehicles involved in a crash were those that involved a car. For both crashes that occurred at an intersection and for those that occurred midblock of two intersections, the majority of the crashes happened when the vehicle was either fully stopped or travelling straight (not out of control).

Type of vehicle involved in the crash

Vehicle Type	Number of Crashes	Number of Crashes as a total Percentage
Pedestrians	2	0.13 %
Bicycle	8	0.54 %
Motorcycle	19	1.27 %
Cars	1314	88.01 %
Bus	7	0.47 %
Truck	38	2.55 %
Unclassified	105	7.03 %

Crash movement summary

Description of Crash Movement	Number of Crashes at Intersection	Number of Crashes Midblock
Out of control	19	10
Overtaking	18	22
Reversing or Rolling Back	12	1
Stopped	346	86
Turning	165	14
Swing Wide	5	1
Swerving	3	2
Straight ahead – not out of control	575	214
TOTAL	**1143**	**350**

B.4 Nature of Crash Event

This is the data collected for the direction of the target vehicle only. The colliding vehicle direction was ignored within this summary. Note that Rivervale Wattle Grove Link is referred to as Orrong Road on the surveyed data.

B.4.1 Francisco Street / Francisco Place / Orrong Road

The table below represents the nature of the crash event and the respective given movement at the Francisco Street, Francisco Place and Orrong Road intersection. From this we identify rear end crashes as the dominant type of crash with the West – East and East – West movements as the prevailing crash movements.

Nature of crash at Francisco Street / Francisco Place / Orrong Road

	Nature of Event					TOTAL
Movement	**Rear End**	**Right Angle**	**Right Turn Through**	**Sideswipe Same Direction**	**Undefined**	
W-E	33		2		1	**36**
W-N	2					**2**
W-S			6			**6**
E-W	25	1	2			**28**
E-N	2		11	1		**14**
N-undefined	2					**2**
N-W	2					**2**
N-E	3				1	**4**
Undefined	3	2				**5**
TOTAL	**72**	**3**	**21**	**1**	**2**	**99**

B.4.2 Archer Street / Orrong Road

The table below represents the nature of crashes and the respective given movement at Archer Street and Orrong Road. The most number of crashes occurred on the East – West direction, where the majority of crashes were rear end. Right turn through crashes was dominant in the West – South direction.

Nature of crash at Archer Street / Orrong Road

	Nature of Event					TOTAL
Movement	**Rear End**	**Right Angle**	**Right Turn Through**	**Sideswipe Same Direction**	**Undefined**	
W-E	8					**8**
W-S		1	18		2	**19**
E-W	28	1	9	1		**39**
E-S	6					**6**
S-E	2	3				**5**
S-W	4	1			1	**6**
S-undefined	2	1				**3**
Undefined	4					**4**
TOTAL	**54**	**7**	**27**	**1**	**3**	**92**

B.4.3 Wright Street / Orrong Road

The table below represents the nature of crashes and the respective given movement at Wright Street and Orrong Road. Rear end crashes were the most dominant in both the West – East and East – West directions.

Nature of crashes at Wright Street / Orrong Road

	Nature of Event					TOTAL
Movement	**Rear End**	**Right Angle**	**Right Turn Through**	**Sideswipe Same Direction**	**Undefined**	
W-E	21		1	1		**23**
W-N	1			1		**2**
W-undefined	1					**1**
E-W	19	1				**20**
E-N	4	1				**5**
N-E	1			1		**2**
N-W	3	2	1		1	**7**
N-undefined	1			1	2	**4**
Undefined	1					**1**
TOTAL	**52**	**4**	**2**	**4**	**3**	**65**

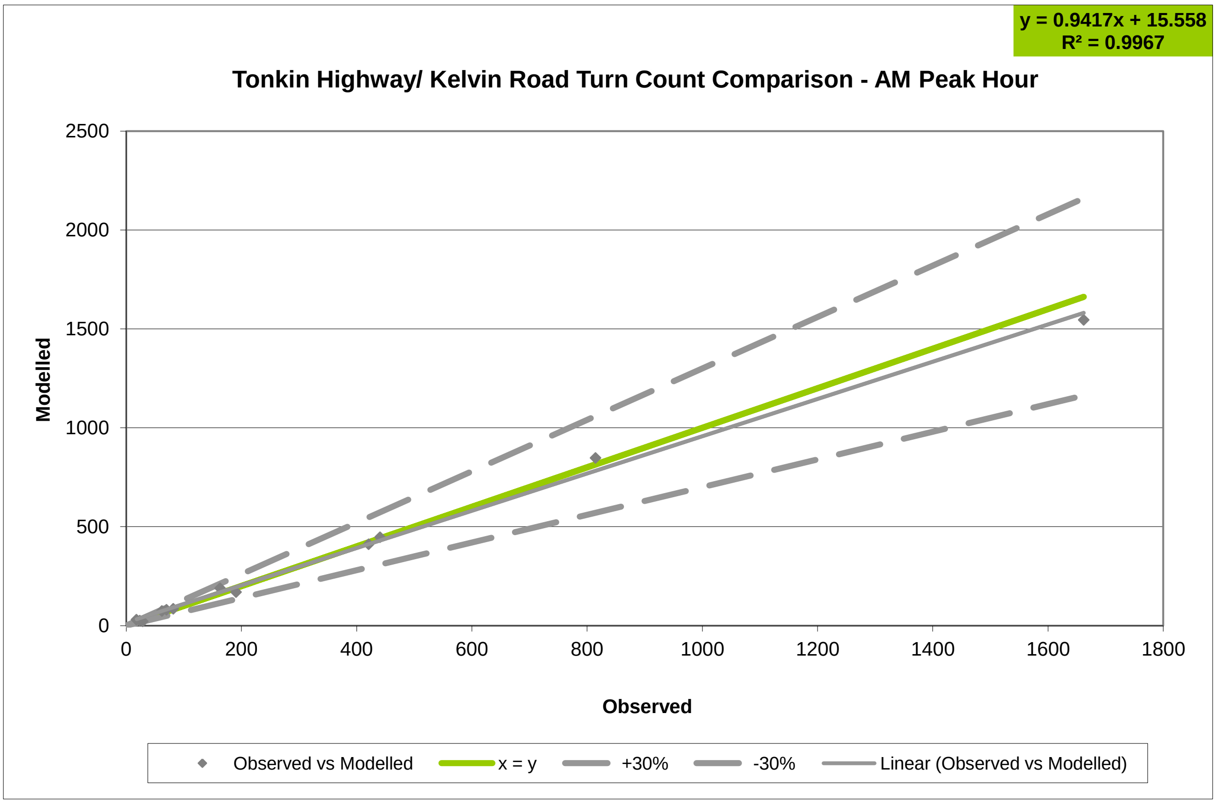
B.4.4 Oats Street / Orrong Road

The table below represents the nature of crashes and the respective given movement at Oats Street and Orrong Road. Rear end crashes were the most dominant in both the West – East and East – West directions.

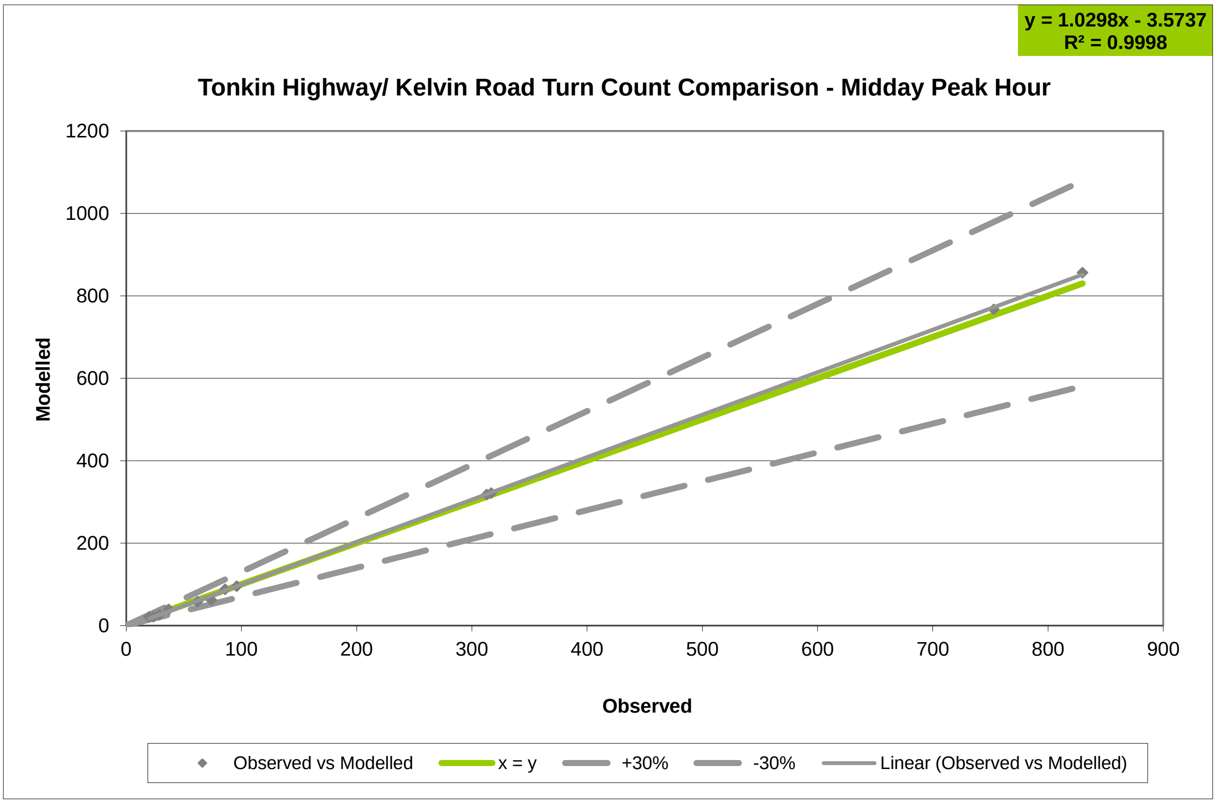
Nature of crashes at Oats Street / Orrong Road

	Nature of Event					TOTAL
Movement	**Rear End**	**Right Angle**	**Right Turn Through**	**Sideswipe Same Direction**	**Undefined**	
W-E	40			3		**43**
W-S	2			1		**3**
E-W	51			1		**52**
E-S	1					**1**
E-N	1		1			**2**
E-undefined	2					**2**
N-S	3	1	1			**5**
N-W			5	1		**6**
N-E	1					**1**
S-N	4	1	3	2		**10**
S-W	1					**1**
S-E	1					**1**
S-undefined	2					**2**
Undefined	4			2		**6**
TOTAL	**113**	**2**	**10**	**10**		**135**

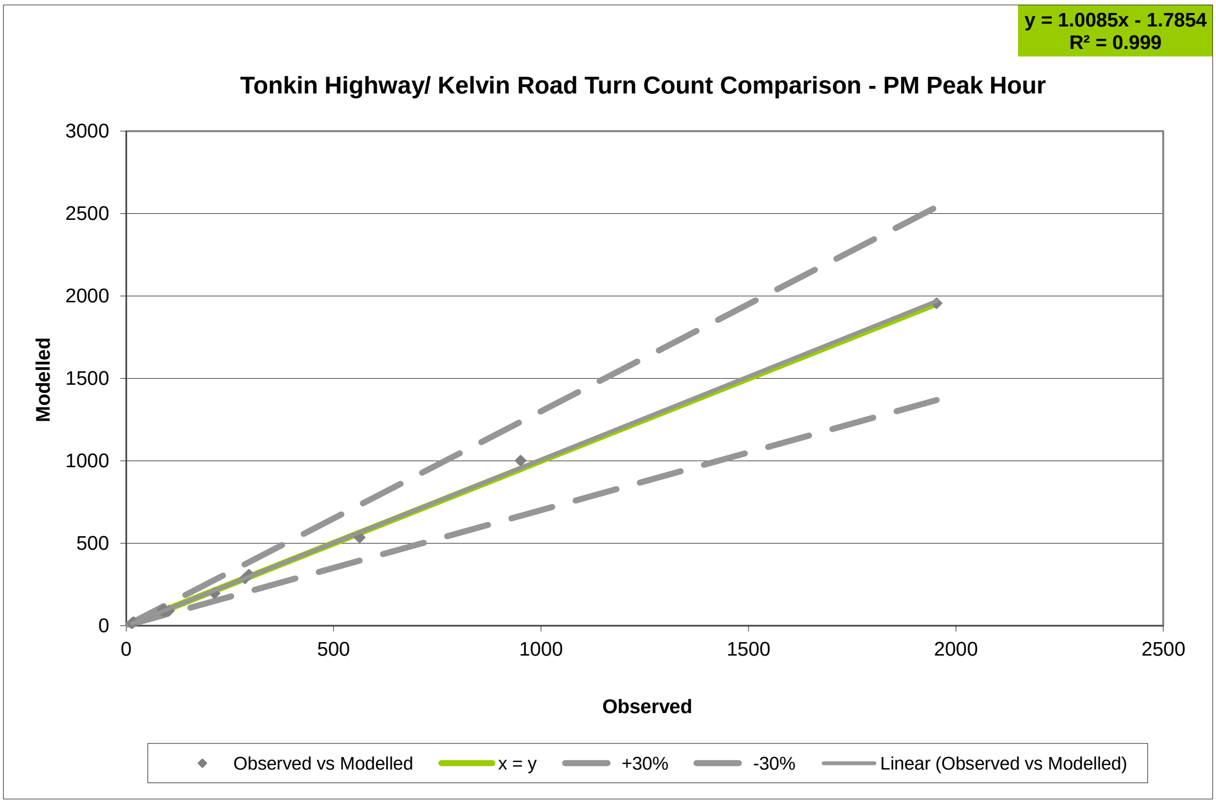
Appendix B
Calibration Details

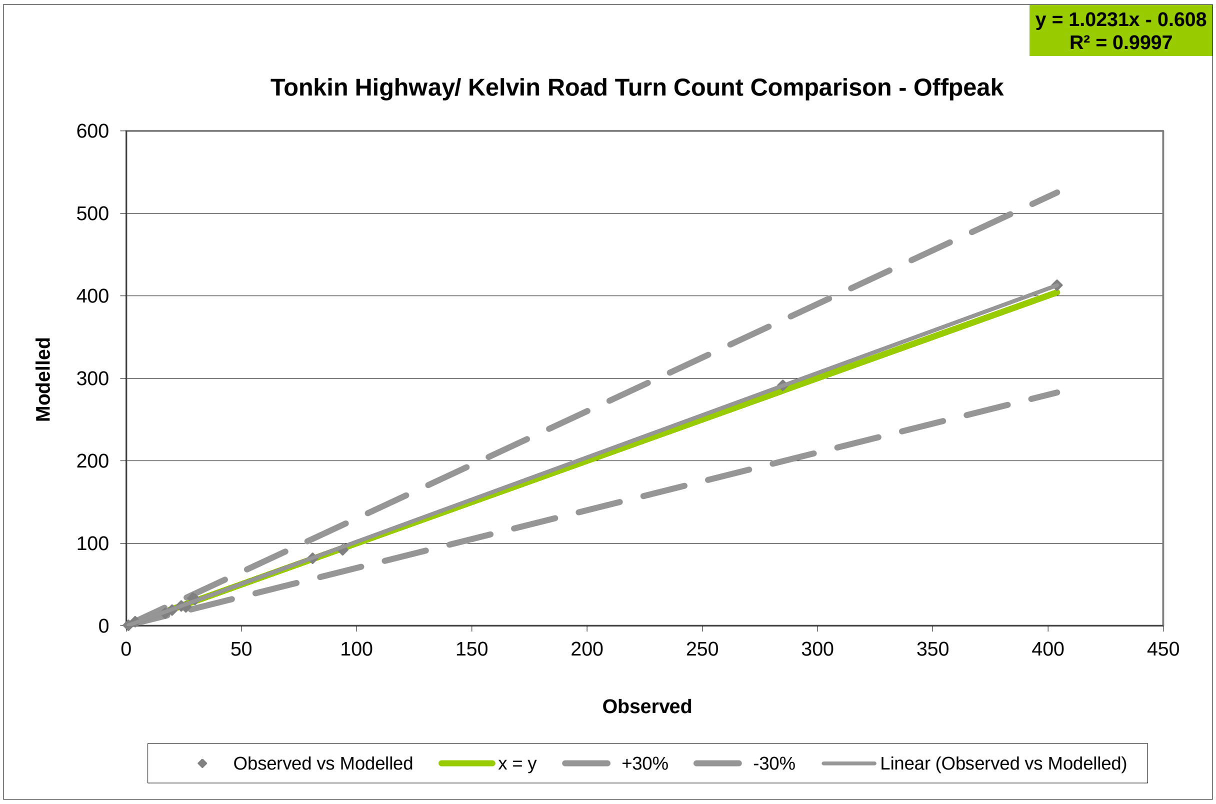


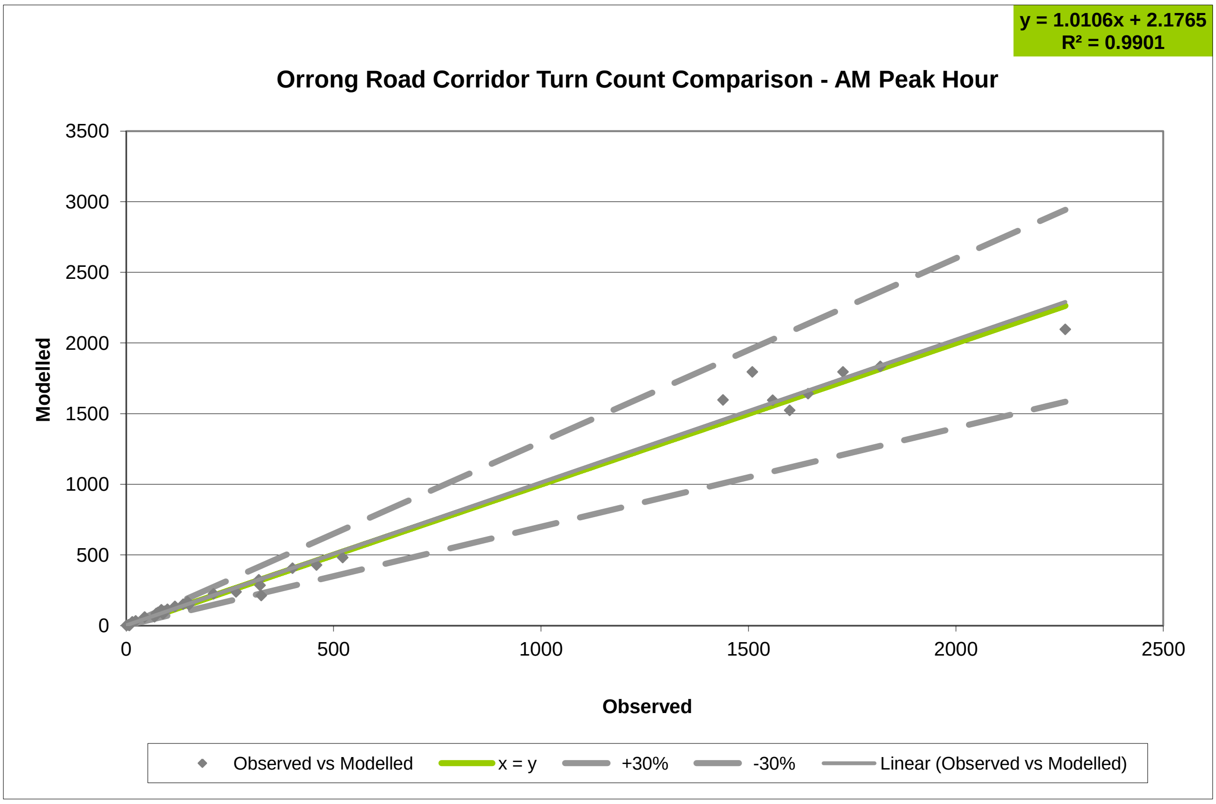
y = 0.9417x + 15.558
R² = 0.9967
Tonkin Highway/ Kelvin Road Turn Count Comparison - AM Peak Hour
Modelled
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
1600
1800
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)

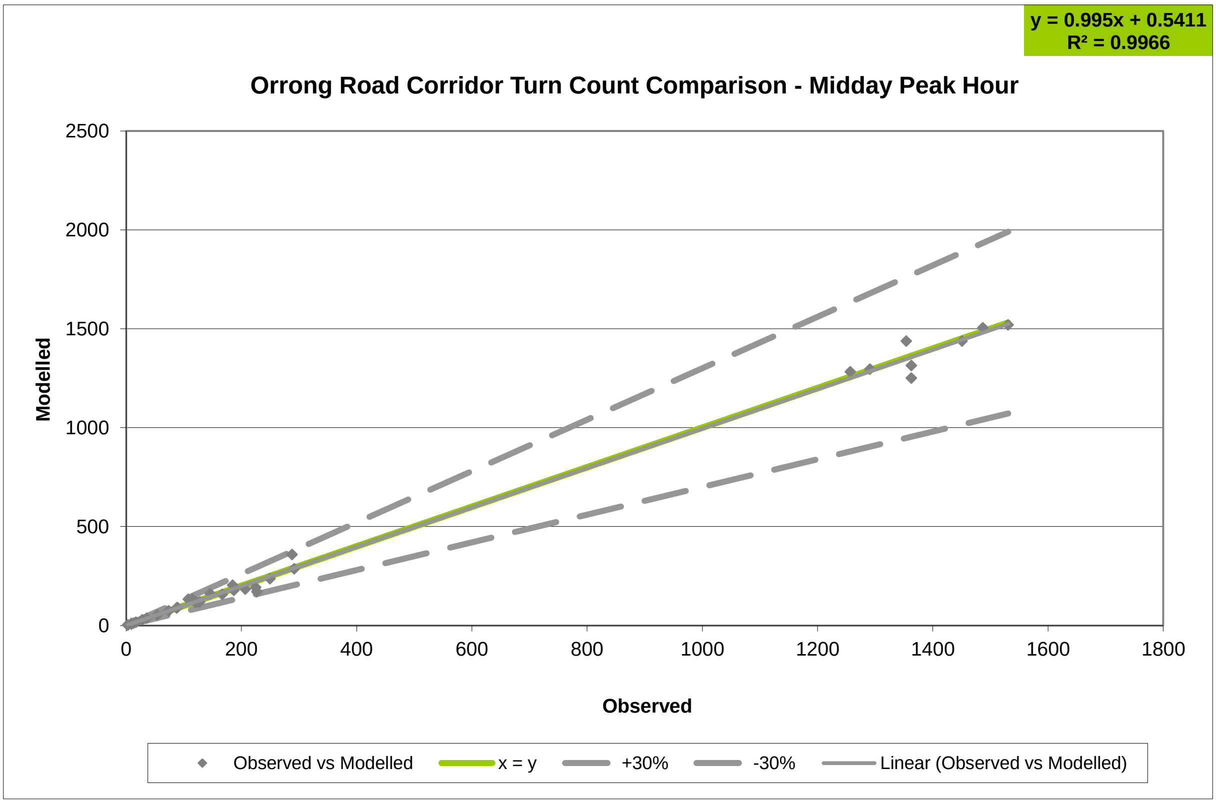


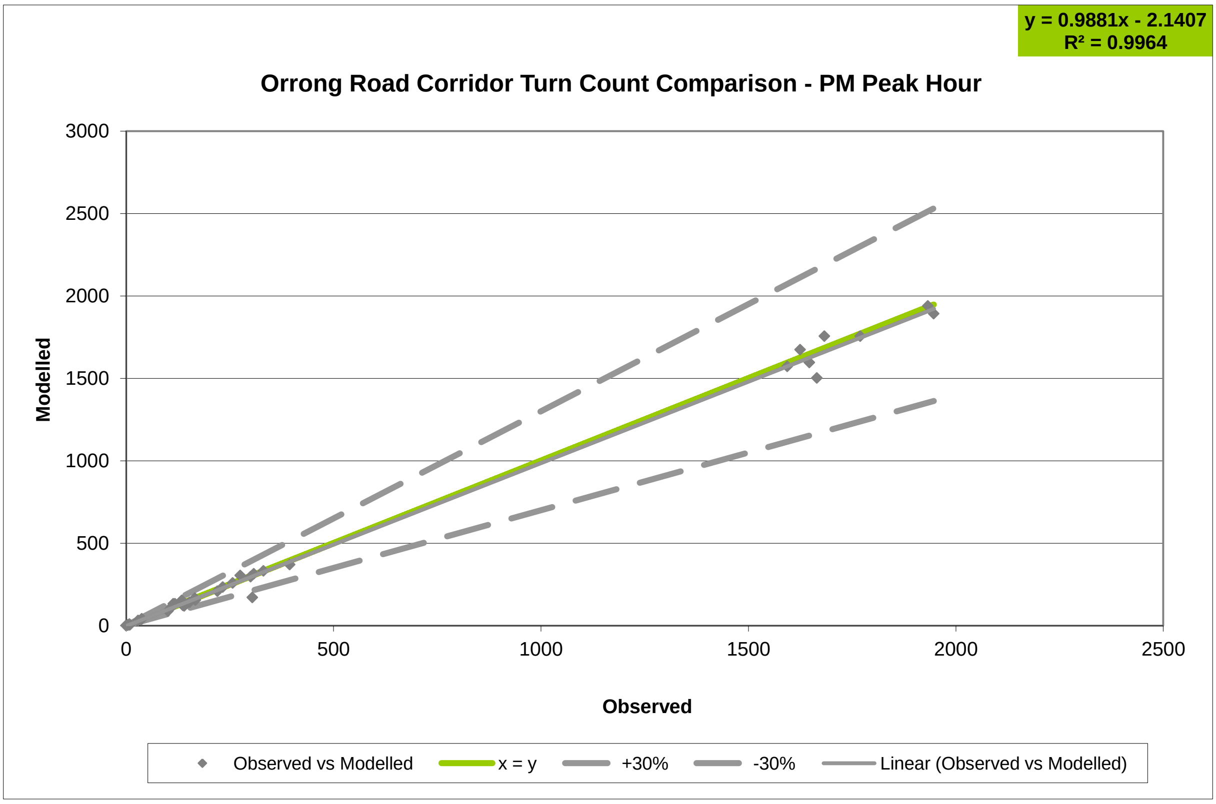
y = 1.0298x - 3.5737
R² = 0.9998
Tonkin Highway/ Kelvin Road Turn Count Comparison - Midday Peak Hour
Modelled
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)


y = 1.0085x - 1.7854
R² = 0.999
Tonkin Highway/ Kelvin Road Turn Count Comparison - PM Peak Hour
3000
2500
2000
1500
1000
500
0
Modelled
0
500
1000
1500
2000
2500
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)

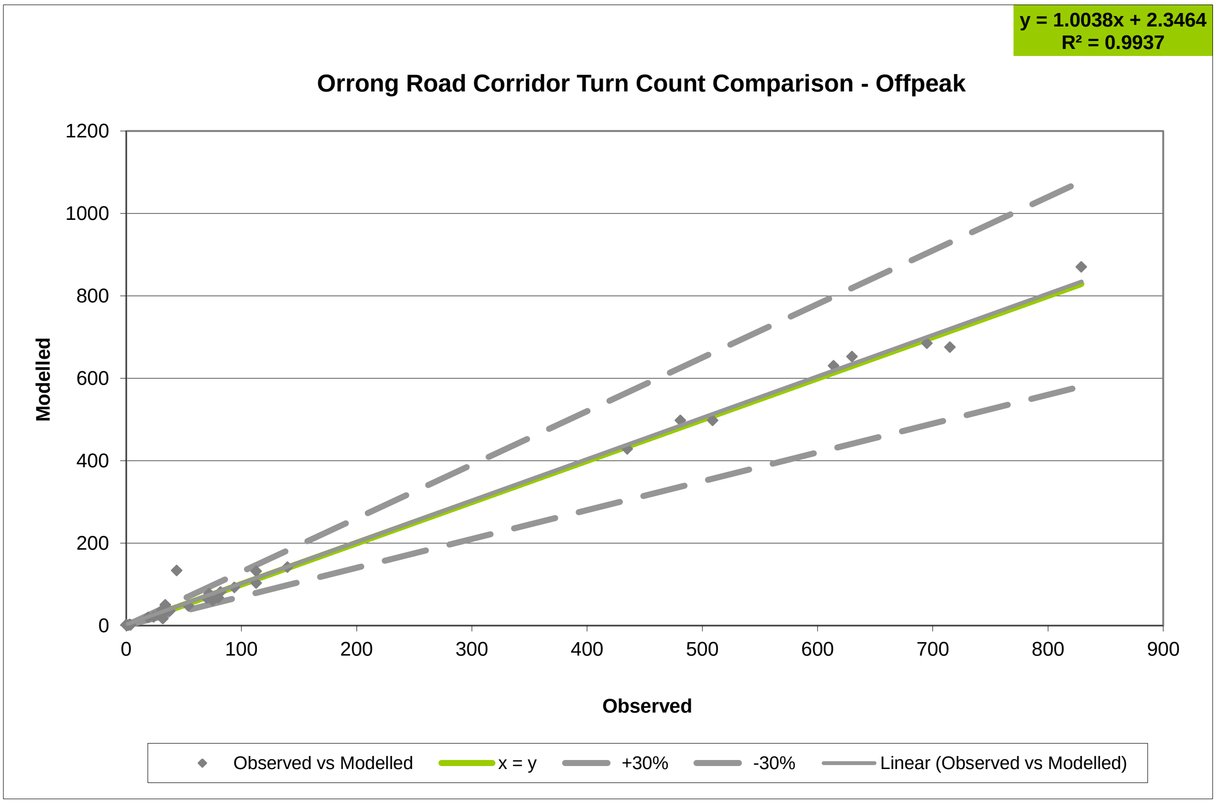

y = 1.0231x - 0.608
R² = 0.9997
Tonkin Highway/ Kelvin Road Turn Count Comparison - Offpeak
600
500
400
300
200
100
0
Modelled
0
50
100
150
200
250
300
350
400
450
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)


y = 1.0106x + 2.1765
R² = 0.9901
Orrong Road Corridor Turn Count Comparison - AM Peak Hour
3500
3000
2500
2000
1500
1000
500
0
Modelled
0
500
1000
1500
2000
2500
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)


y = 0.995x + 0.5411
R² = 0.9966
Orrong Road Corridor Turn Count Comparison - Midday Peak Hour
2500
2000
1500
1000
500
0
Modelled
0
200
400
600
800
1000
1200
1400
1600
1800
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)



y = 0.9881x - 2.1407
R² = 0.9964
Orrong Road Corridor Turn Count Comparison - PM Peak Hour
3000
2500
2000
1500
1000
500
0
Modelled
0
500
1000
1500
2000
2500
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)



y = 1.0038x + 2.3464
R² = 0.9937
Orrong Road Corridor Turn Count Comparison - Offpeak
1200
1000
800
600
400
200
0
Modelled
0
100
200
300
400
500
600
700
800
900
Observed
Observed vs Modelled
x = y
+30%
-30%
Linear (Observed vs Modelled)

Appendix C
Modelling Delay Outputs

Level of Service Legend (seconds/vehicle)

LOS	From	To
A	0	10
B	10	20
C	20	35
D	35	55
E	55	80
F	80	<

Tonkin Highway/ Kelvin Road Base Model Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume		AM Delay	MD Delay	PM Delay	OP Delay
Tonkin/ Kelvin	Tonkin N	L	22	21	22	5		12	13	69	8
		T	849	856	1956	413		17	15	80	8
		R	447	318	310	92		59	28	96	27
	Kelvin E	L	81	40	89	23		87	18	72	10
		T	170	62	91	33		157	74	104	41
		R	25	22	14	1		160	79	119	37
	Tonkin S	L	189	96	97	15		197	7	27	0
		T	1546	767	1001	292		221	49	67	13
		R	31	27	87	19		311	87	152	44
	Kelvin W	L	412	322	536	82		45	21	70	19
		T	85	58	197	32		106	70	118	34
		R	75	88	288	24		105	67	116	32

Tonkin Highway/ Kelvin Road Option 1 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Tonkin/ Kelvin	Tonkin N	L	22	21	21	5	15	14	125	8
		T	849	854	1803	413	17	14	140	7
		R	449	317	286	93	84	27	144	20
	Kelvin E	L	83	40	89	23	44	15	38	10
		T	176	68	98	32	96	50	65	45
		R	23	22	14	1	106	50	66	37
	Tonkin S	L	183	96	97	15	191	4	8	1
		T	1514	774	1007	293	218	35	39	14
		R	30	26	90	19	249	54	66	42
	Kelvin W	L	410	320	542	81	38	17	32	16
		T	86	59	205	32	84	43	68	39
		R	75	89	296	24	79	42	67	35

Tonkin Highway/ Kelvin Road Option 2 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Tonkin/ Kelvin	Tonkin N	L	22	21	22	5	12	14	37	8
		T	845	860	1958	414	13	14	45	5
		R	447	318	309	94	49	23	50	23
	Kelvin E	L	69	39	94	23	416	20	88	10
		T	141	71	115	34	460	56	114	29
		R	22	22	15	1	404	72	110	37
	Tonkin S	L	194	96	97	15	135	5	14	0
		T	1573	775	994	294	159	40	50	10
		R	32	27	88	19	217	69	88	35
	Kelvin W	L	413	320	482	81	37	16	106	13
		T	87	59	182	32	83	47	162	24
		R	75	87	219	24	95	58	422	35

Tonkin Highway/ Kelvin Road Option 3 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Tonkin/ Kelvin	Tonkin N	L	22	21	22	5	12	13	71	8
		T	849	857	1919	413	16	15	85	8
		R	444	317	306	92	43	23	88	27
	Kelvin E	L	82	40	90	23	59	15	54	10
		T	172	72	109	34	125	67	93	41
		R	24	22	14	1	124	67	88	37
	Tonkin S	L	198	96	96	15	31	3	8	0
		T	1630	779	993	293	65	43	58	13
		R	32	26	90	19	150	81	102	43
	Kelvin W	L	408	319	547	82	45	19	33	20
		T	83	58	205	32	95	56	82	32
		R	74	87	295	24	92	55	79	32

Tonkin Highway/ Kelvin Road Option 4 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Tonkin/ Kelvin	Tonkin N	L	22	21	21	5	21	13	101	8
		T	838	858	1868	413	26	12	113	5
		R	443	317	299	94	118	36	132	23
	Kelvin E	L	80	40	90	23	103	15	36	10
		T	169	71	110	34	143	35	51	31
		R	22	22	14	1	131	50	70	37
	Tonkin S	L	189	96	97	15	92	4	6	0
		T	1533	778	998	294	115	28	28	9
		R	31	26	90	19	133	50	50	32
	Kelvin W	L	412	321	546	82	31	15	28	14
		T	89	59	207	32	54	32	50	25
		R	74	87	296	24	78	41	1	34

Orrong Road Corridor Base Model Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume		AM Delay	MD Delay	PM Delay	OP Delay
Francisco/Orrong	Francisco N	L	60	134	134	134		18	22	2	1
		T	2	0	1	1		224	0	0	0
		R	473	359	333	93		214	57	120	21
	Orrong E	L	2	7	7	3		18	22	2	1
		T	2086	1521	1893	631		22	21	10	6
		R	154	158	167	67		49	29	24	5
	Francisco S	L	6	11	6	2		86	72	81	36
		T	5	3	3	2		72	56	87	25
		R	7	12	6	2		58	66	84	22
	Orrong W	L	325	288	316	142		35	15	68	1
		T	1837	1505	1941	870		48	31	80	7
		R	7	17	10	1		53	26	68	2
Archer/Orrong	Orrong E	L	95	120	133	17		61	30	41	8
		T	1790	1438	1757	498		62	30	40	6
	Archer S	L	426	184	298	132		65	55	54	16
		R	229	204	210	61		76	46	69	26
	Orrong W	T	1534	1251	1503	676		16	9	5	4
		R	211	172	172	103		56	38	56	4
Wright/Orrong	Wright N	L	119	119	121	37		56	38	82	22
		R	283	237	260	77		73	61	124	34
	Orrong E	T	1646	1318	1620	438		58	2	22	3
		R	115	134	155	51		101	52	75	38
	Orrong W	L	169	194	234	67		14	3	18	2
		T	1648	1314	1597	685		30	12	24	8
Oats/Orrong	Oats N	L	84	89	123	29		227	43	77	27
		T	400	162	305	37		230	57	91	32
		R	63	54	37	20		222	57	89	33
	Orrong E	L	34	38	43	21		151	30	82	16
		T	1622	1297	1675	429		145	28	80	13
		R	87	118	155	36		194	72	149	42
	Oats S	L	97	92	89	36		66	33	153	18
		T	238	178	371	81		81	43	159	20
		R	148	75	142	48		123	52	196	24
	Orrong W	L	30	29	32	30		80	42	34	18
		T	1608	1284	1573	653		79	43	31	17
		R	142	119	114	36		136	73	89	42

Orrong Road Corridor Option 1 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume		AM Delay	MD Delay	PM Delay	OP Delay
Francisco/Orrong	Francisco N	L	66	134	134	134		6	8	13	0
		T	2	0	1	1		98	0	0	0
		R	508	359	336	93		98	49	61	30
	Orrong E	L	3	9	7	3		6	8	13	0
		T	2039	1498	1863	632		19	13	10	4
		R	144	158	169	67		35	22	34	4
	Francisco S	L	6	11	6	2		78	66	80	49
		T	5	3	3	2		96	61	79	51
		R	7	12	6	2		81	53	62	34
	Orrong W	L	323	288	316	142		87	13	42	1
		T	1827	1505	1939	870		104	29	55	6
		R	7	17	10	1		106	27	42	3
Archer/Orrong	Orrong E	L	97	119	132	17		33	49	22	4
		T	1811	1436	1738	499		35	52	19	3
	Archer S	L	426	184	298	132		73	71	56	33
		R	229	204	210	61		84	39	66	41
	Orrong W	T	1503	1256	1503	674		5	35	6	4
		R	213	171	174	103		74	68	46	3
Wright/Orrong	Wright N	L	119	119	121	37		53	40	40	21
		R	283	237	260	77		87	92	68	37
	Orrong E	T	1675	1314	1614	438		26	11	24	2
		R	114	134	153	50		80	44	67	36
	Orrong W	L	165	195	233	67		17	44	21	3
		T	1660	1304	1609	686		21	54	24	5
Oats/Orrong	Oats N	L	83	89	123	29		250	36	55	30
		T	398	162	305	37		256	50	67	37
		R	64	54	37	20		252	51	62	38
	Orrong E	L	34	37	44	22		73	32	212	18
		T	1641	1303	1646	429		75	27	204	13
		R	88	121	152	36		124	59	258	44
	Oats S	L	97	92	91	36		62	31	63	22
		T	239	178	375	81		77	38	70	23
		R	149	75	146	48		123	45	102	21
	Orrong W	L	28	29	32	30		54	25	29	15
		T	1600	1263	1569	652		53	25	24	13
		R	144	119	115	36		144	61	74	50

Orrong Road Corridor Option 2 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Francisco/Orrong	Francisco N	L	60	134	134	134	23	20	2	0
		T	2	0	1	1	264	0	0	0
		R	468	359	332	93	247	59	120	20
	Orrong E	L	2	8	6	3	23	20	2	0
		T	2079	1520	1872	630	19	20	9	7
		R	152	157	167	67	50	30	26	5
	Francisco S	L	6	11	6	2	71	58	85	33
		T	5	3	3	2	89	67	99	32
		R	7	12	6	2	74	66	74	27
	Orrong W	L	325	288	317	142	38	16	46	1
		T	1837	1505	1941	870	49	33	59	7
		R	7	17	10	1	46	30	44	2
Archer/Orrong	Orrong E	L	96	120	135	17	62	28	39	6
		T	1764	1439	1731	496	63	29	37	7
	Archer S	L	426	184	298	132	60	55	60	16
		R	229	204	210	61	73	48	70	27
	Orrong W	T	1538	1250	1505	675	16	9	5	4
		R	210	171	174	104	59	38	51	4
Wright/Orrong	Wright N	L	119	119	120	37	62	38	110	24
		R	283	237	258	77	91	61	157	34
	Orrong E	T	1641	1314	1605	439	76	2	21	3
		R	111	135	155	51	111	52	77	37
	Orrong W	L	167	193	235	67	15	4	17	3
		T	1654	1313	1594	684	30	12	22	7
Oats/Orrong	Oats N	L	77	89	123	29	297	47	116	28
		T	376	162	305	37	294	59	131	36
		R	58	54	37	20	294	57	119	30
	Orrong E	L	34	37	43	22	94	28	62	16
		T	1637	1301	1680	429	94	27	63	14
		R	88	121	155	36	140	70	132	42
	Oats S	L	96	92	89	36	83	36	155	19
		T	237	178	366	81	103	48	163	23
		R	148	75	141	48	137	50	196	23
	Orrong W	L	30	30	33	30	67	43	29	18
		T	1610	1284	1570	653	67	42	27	17
		R	144	118	116	35	119	79	91	46

Orrong Road Corridor Option 3 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Francisco/Orrong	Francisco N	L	66	134	134	134	19	4	14	0
		T	2	0	3	1	102	0	0	0
		R	508	359	195	93	111	47	73	32
	Orrong E	L	2	9	5	3	19	4	14	0
		T	2002	1503	1871	631	49	14	13	4
		R	138	157	163	67	63	17	28	5
	Francisco S	L	17	25	15	6	75	57	77	50
		T	0	0	0	0	0	0	0	0
		R	0	0	0	0	0	0	0	0
	Orrong W	L	325	288	316	142	36	10	45	1
		T	1837	1505	1942	870	50	23	59	6
		R	7	17	10	1	50	18	50	0
Archer/Orrong	Orrong E	L	96	119	134	17	29	50	58	3
		T	1787	1434	1755	499	29	50	57	3
	Archer S	L	411	184	298	132	135	74	53	33
		R	221	204	210	61	124	36	74	40
	Orrong W	T	1535	1254	1536	675	10	20	9	4
		R	215	171	259	103	68	53	72	4
Wright/Orrong	Wright N	L	117	119	121	37	107	48	84	24
		R	280	237	260	77	110	68	86	42
	Orrong E	T	1633	1322	1645	437	24	7	57	2
		R	114	135	157	51	85	47	99	40
	Orrong W	L	162	195	236	67	3	8	12	1
		T	1625	1315	1595	683	8	15	16	3
Oats/Orrong	Oats N	L	83	89	123	29	252	40	85	30
		T	393	162	305	37	258	50	96	40
		R	62	54	37	20	255	52	93	32
	Orrong E	L	34	38	44	21	99	29	105	14
		T	1604	1303	1686	430	101	28	104	13
		R	86	120	154	36	147	57	190	44
	Oats S	L	97	92	88	36	69	27	172	22
		T	239	178	367	81	82	37	180	23
		R	149	75	142	48	130	41	226	25
	Orrong W	L	29	30	32	30	62	32	24	13
		T	1567	1283	1563	651	61	32	22	12
		R	141	119	114	36	143	66	84	49

Orrong Road Corridor Option 4 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Francisco/Orrong	Francisco N	L	60	134	134	134	14	19	3	1
		T	2	0	1	1	254	0	0	0
		R	469	359	333	93	243	57	109	21
	Orrong E	L	2	8	7	3	14	19	3	1
		T	2070	1510	1876	631	20	21	9	7
		R	156	157	168	67	51	28	26	6
	Francisco S	L	6	11	6	2	76	69	86	26
		T	5	3	3	2	92	57	80	46
		R	7	12	6	2	68	58	77	32
	Orrong W	L	325	288	316	142	32	17	58	1
		T	1836	1505	1943	870	43	33	71	7
		R	7	17	10	1	39	29	64	3
Archer/Orrong	Orrong E	L	95	119	134	17	54	36	41	6
		T	1758	1431	1724	497	55	36	40	7
	Archer S	L	426	184	298	132	63	56	57	16
		R	229	204	210	61	81	47	71	28
	Orrong W	T	1537	1255	1506	676	24	9	5	4
		R	210	172	174	103	60	38	50	5
Wright/Orrong	Wright N	L	119	119	121	37	68	37	80	21
		R	283	237	260	77	92	59	118	33
	Orrong E	T	1602	1325	1599	438	20	2	24	3
		R	112	132	149	51	70	51	78	37
	Orrong W	L	167	194	233	67	24	3	19	2
		T	1650	1316	1609	686	43	11	24	7
Oats/Orrong	Oats N	L	73	88	116	29	287	49	208	25
		T	351	160	288	37	287	60	215	36
		R	57	54	37	20	266	41	190	20
	Orrong E	L	32	38	43	21	249	35	183	12
		T	1584	1297	1665	431	246	34	180	12
		R	85	120	151	36	295	77	251	41
	Oats S	L	96	90	81	36	78	52	218	26
		T	234	176	330	81	97	66	227	31
		R	149	75	136	48	124	53	232	23
	Orrong W	L	29	29	31	30	107	50	60	14
		T	1569	1278	1572	654	108	48	59	13
		R	142	120	115	35	158	75	104	47

Orrong Road Corridor Option 5 Delay (seconds/vehicle)

Name	Approach	Movement	AM Volume	MD Volume	PM Volume	OP Volume	AM Delay	MD Delay	PM Delay	OP Delay
Francisco/Orrong	Francisco N	L	66	134	134	134	10	1	1	1
		T	2	0	1	1	105	0	0	0
		R	508	359	336	93	90	48	67	29
	Orrong E	L	3	9	8	3	10	1	1	1
		T	2052	1485	1898	630	17	13	12	4
		R	142	156	169	67	43	21	35	5
	Francisco S	L	6	11	6	2	71	56	67	47
		T	5	3	3	2	67	62	66	38
		R	7	12	6	2	74	54	68	34
	Orrong W	L	325	288	316	142	77	15	44	1
		T	1836	1505	1937	870	93	31	56	7
		R	7	17	10	1	102	29	43	4
Archer/Orrong	Orrong E	L	99	117	136	17	37	61	50	3
		T	1834	1411	1763	497	38	60	50	3
	Archer S	L	426	184	298	132	81	61	57	32
		R	229	204	210	61	83	36	66	42
	Orrong W	T	1517	1255	1502	674	10	23	5	4
		R	213	171	174	103	110	64	70	4
Wright/Orrong	Wright N	L	119	119	121	37	57	38	57	27
		R	283	237	260	77	89	77	82	38
	Orrong E	T	1682	1318	1638	438	25	18	29	1
		R	115	134	155	51	83	59	86	40
	Orrong W	L	166	196	236	67	20	17	8	2
		T	1665	1318	1614	686	22	23	11	4
Oats/Orrong	Oats N	L	83	89	123	29	250	38	78	30
		T	396	162	305	37	255	53	94	37
		R	63	54	37	20	255	54	87	36
	Orrong E	L	34	38	44	22	80	32	53	17
		T	1642	1301	1682	431	78	29	52	13
		R	88	120	154	36	123	65	151	43
	Oats S	L	97	92	88	36	68	28	162	20
		T	240	178	366	81	79	37	166	24
		R	149	75	141	48	126	43	205	24
	Orrong W	L	29	29	32	30	56	32	27	11
		T	1598	1273	1587	654	57	33	29	12
		R	144	119	114	36	147	68	100	44

Appendix D
SCATS Counts Comparison

The Austraffic traffic counts and SCATS detector counts were compared for both the Tonkin Highway / Kelvin Road intersection, and the Orrong Road corridor and are shown below for the AM peak, Midday peak, PM peak and Off peak periods. These results show that the SCATS counts are within 10% of traffic surveys and can then be considered relatively accurate. However SCATS counts do not capture individual movements in shared lanes.

Traffic count and signal data comparison for Tonkin Highway / Kelvin Road intersection

AM PEAK 6:45 - 7:45 AM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Tonkin Highway / Kelvin Road	North	1285	1245	3.11%
	West	565	530	6.19%
	South	1843	1665	9.66%
	East*	215	188	12.56%
	Total	**3908**	**3628**	**7.16%**
MIDDAY PEAK 11.45 AM - 12:45 PM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Tonkin Highway / Kelvin Road	North	1163	1129	2.92%
	West	465	423	9.03%
	South	878	769	12.41%
	East*	98	94	4.08%
	Total	**2604**	**2415**	**7.26%**
PM PEAK 4:00 - 5:00 PM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Tonkin Highway / Kelvin Road	North	2268	2225	1.90%
	West	1063	1007	5.27%
	South	1129	1037	8.15%
	East*	117	111	5.13%
	Total	**4577**	**4380**	**4.30%**
OFFPEAK 9:00 - 10:00 PM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Tonkin Highway / Kelvin Road	North	502	485	3.39%
	West	135	130	3.70%
	South	322	308	4.35%
	East*	30	28	6.67%
	Total	**989**	**951**	**3.84%**

*Note that this approach does not include the left turn movement out of Kelvin Road

Traffic count and signal data comparison for the Orrong Road corridor

AM PEAK 7:15 - 8:15 AM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Orrong Road / Oats Street	West	1692	1660	1.89%
	South	506	581	-14.82%
	East	1535	1499	2.35%
	North	559	522	6.62%
Orrong Road / Wright Street	West	1792	1809	-0.95%
	East	1595	1550	2.82%
	North	423	414	2.13%
Orrong Road / Archer Street	West	1926	1838	4.57%
	South	670	674	-0.60%
	East	1805	1805	0.00%
Orrong Road / Francisco Street	West	2145	1822	15.06%
	South	18	14	22.22%
	East	2410	2345	2.70%
	North	568	-	N/A
	Total	**17076**	**16533**	**3.18%**

MIDDAY PEAK 11.30 AM - 12:30 PM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Orrong Road / Oats Street	West	1408	1420	-0.85%
	South	350	426	-21.71%
	East	1447	1428	1.31%
	North	288	288	0.00%
Orrong Road / Wright Street	West	1588	1559	1.83%
	East	1469	1465	0.27%
	North	371	346	6.74%
Orrong Road / Archer Street	West	1590	1587	0.19%
	South	392	375	4.34%
	East	1579	1560	1.20%
Orrong Road / Francisco Street	West	1796	1489	17.09%
	South	25	21	16.00%
	East	1707	1673	1.99%
	North	399	-	N/A
	Total	**14010**	**13637**	**2.66%**

PM PEAK 4:15 - 5:15 PM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Orrong Road / Oats Street	West	1733	1694	2.25%
	South	648	761	-17.44%
	East	1797	1762	1.95%
	North	448	433	3.35%
Orrong Road / Wright Street	West	1880	1853	1.44%
	East	1850	1784	3.57%
	North	397	343	13.60%
Orrong Road / Archer Street	West	1969	1901	3.45%
	South	520	461	11.35%
	East	1888	1891	-0.16%
Orrong Road / Francisco Street	West	2249	1861	17.25%
	South	16	15	6.25%
	East	2122	2058	3.02%
	North	445	-	N/A
	Total	**17517**	**16817**	**4.00%**

OFFPEAK 9:00 - 10:00 PM				
Intersection	**Approach**	**Austraffic Count**	**SCATS count**	**% Difference**
Orrong Road / Oats Street	West	695	682	1.87%
	South	169	238	-40.83%
	East	497	499	-0.40%
	North	79	76	3.80%
Orrong Road / Wright Street	West	775	773	0.26%
	East	515	503	2.33%
	North	106	96	9.43%
Orrong Road / Archer Street	West	828	817	1.33%
	South	188	180	4.26%
	East	541	524	3.14%
Orrong Road / Francisco Street	West	971	828	14.73%
	South	7	4	42.86%
	East	687	670	2.47%
	North	139	-	N/A
	Total	**6058**	**5890**	**2.77%**

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