A Before-and-after Study of Traffic Signal Setting on an Arterial Road

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1 Introduction

Traffic signals are one of the ways to control traffic movement especially in high density urban areas. A suitable signal setting set can help to optimise the usage of traffic facilities, increase road capacity and reduce vehicle travel time. However inappropriate signal settings could cause unnecessary vehicle stops and traffic congestion. The evaluation of signal settings before these are implemented in the real world is an issue of concern to traffic engineers.

Some related comparisons in signal operation systems have been undertaken between the Sydney Coordinated Adaptive Traffic System (SCATS) and traditional control methods (Taylor & Wilshon 1998, Akcelik, Besley & Chung 1998). However a comparison over a range of traffic conditions in a given corridor and between SCATS Masterlink and Flexilink Modes is rare.

Based on the development of advanced computing power and techniques, the evaluation for transport planning purposes could be performed by computer simulations. Various simulation scenarios can be evaluated and their performance determined without influencing real environments. This research compares the two traffic signal operation modes based on a micro-simulation model of the research area.

The research detailed in this paper adopted the data from a probe vehicle, tube counters and SCATS to conduct travel time and traffic volume surveys. Based on these data sets, before and after data was collected on a real world road segment that has its traffic signal setting changed. An analysis of the data showed what the overall traffic system performance was for each case. A micro-simulation model was also developed, to evaluate the same section of road and traffic signal settings. The research can contribute to the process of traffic signal optimization of arterial roads and indicate the benefits or dis-benefits of changing signal settings from Flexilink Mode to Masterlink Mode in SCATS.

2 Background information

West Terrace is a 1.6 Km arterial road on the western edge of the Adelaide CBD. West Terrace contains 10 major intersections, of which 8 are controlled by SCATS. West Terrace carries around 35,000 vehicles per direction per day and its major movement is from South to North during AM peak. The large traffic volume causes congestion and several bottlenecks along West Terrace, especially in intersection 44 and 43 (see Figure 1). The figure shows the locations of the intersections along West Terrace.

The traffic signal system in West Terrace originally operated in Flexilink Mode, which then changed to Masterlink Mode in December 2005. Flexilink Mode is based on fixed time signal operation. The Flexilink Mode traffic signal system operates and changes based on a default schedule of signal setting (RTA 1996). The Masterlink Mode changes its signal setting in response to actual traffic conditions, using data collected by loop detectors. Figure 2 shows a typical Strategy Monitoring (SM) data set of Intersection 44 from SCATS. The information provided in the SM file includes Cycle Length, Link Plan and Split Plan and so on. In the Masterlink Mode, the Cycle Length of traffic signal starts from 102 seconds at 7:00 and then slowly increased to 152 seconds per cycle at 7:56:08 in order to satisfy real traffic demands. On the other hand, the Flexilink Mode has a fixed cycle length, 152 second, from 7:00 to

9:00. The two modes have the same cycle time during the busiest hour but different phase percentages.

Different signal operation modes can have significant influences on the traffic environment. It is difficult and time consuming to check all the changes along West Terrace on the basis of field data. It is also complicated to compare the efficiency of the two signal operation modes based on dynamic traffic conditions. However this information is helpful for refining the signal optimisation. Advanced transport micro-simulation software provides the opportunity for engineers and researchers to examine the impacts from traffic signals.

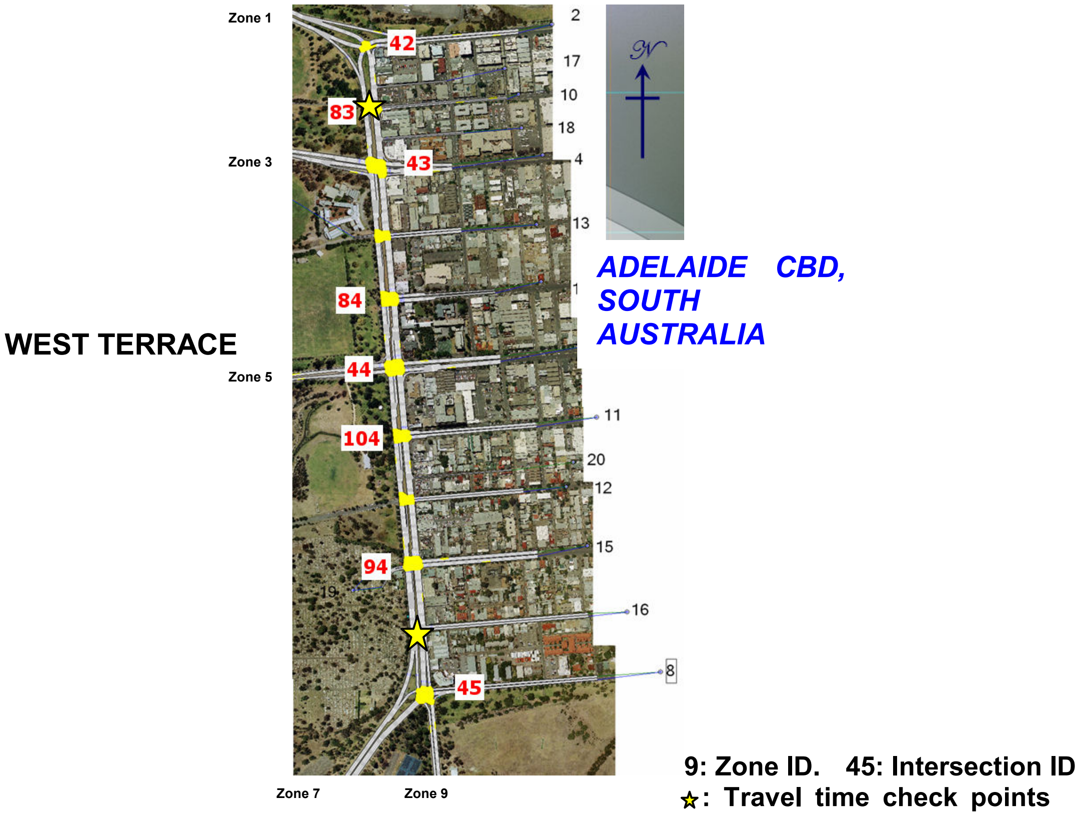

Figure 1: The experiment area, OD zone and intersection ID, West Terrace, Adelaide.

In solving this problem, the study has built a two-hour simulation model, 07:00~09:00 AM, as a test-bed for testing and comparing the two signal operation modes in West Terrace during AM peak hour. A series of comparisons between the two signal operation modes are discussed later in this paper.

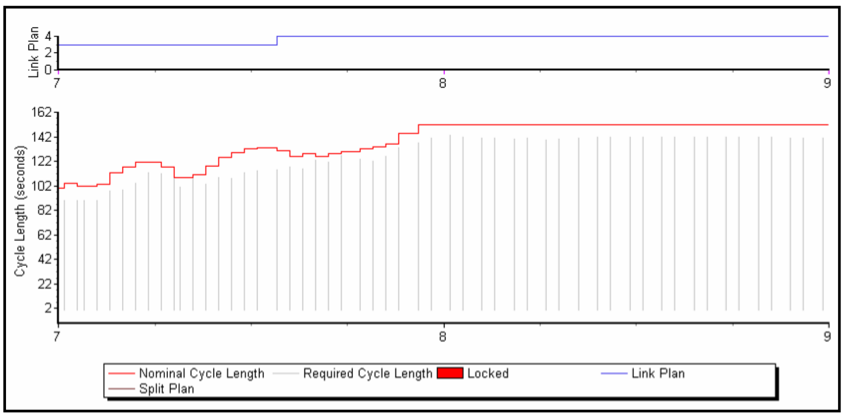

Figure 2: A typical Strategy Monitoring (SM) data from SCATS for Intersection 44.

3 Methodology and Limitation of the Research

The research adopts AIMSUN NG V5.0 as a simulation tool to build the experimental test-bed. For the comparison of different traffic signal settings, the research needs two sets of signal operation data from SCATS to represent the traffic conditions in the before-and-after cases. From the observed volume data, the signal operation data from 5th April 2005 and from 14th March 2006 are selected due to their similar traffic volume distributions during the AM peak hour. Table 2 shows the comparison of GEH values (see 4.2.1 for definition) the volume data for the two days are reasonable similar, i.e. GEH less than five.

Table 2: The comparison of GEH between two selected days in major intersections

S→N				
	Intersection 44		**Intersection 43**	
	7:00~8:00 AM	**8:00~9:00 AM**	**7:00~8:00 AM**	**8:00~9:00 AM**
5/04/2005	2691veh	3320veh	2253veh	2554veh
14/03/2006	2574veh	3119veh	2239veh	2513veh
GEH	2.28	3.54	0.30	0.81
N→S				
	Intersection 44		**Intersection 43**	
	7:00~8:00 AM	**8:00~9:00 AM**	**7:00~8:00 AM**	**8:00~9:00 AM**
5/04/2005	1726veh	2556veh	failure	failure
14/03/2006	1708veh	2380veh	1369veh	1899veh
GEH	0.43	3.54	-	-

Figure 3 shows the flow chart of the research project. The simulation model of Flexilink Mode is constructed based on the signal data set that was collected on 05 April 2005, followed by the calibration of the simulation model. After that the Masterlink Mode signal data, collected from 14 March 2006, will be input into the test-bed for further comparisons.

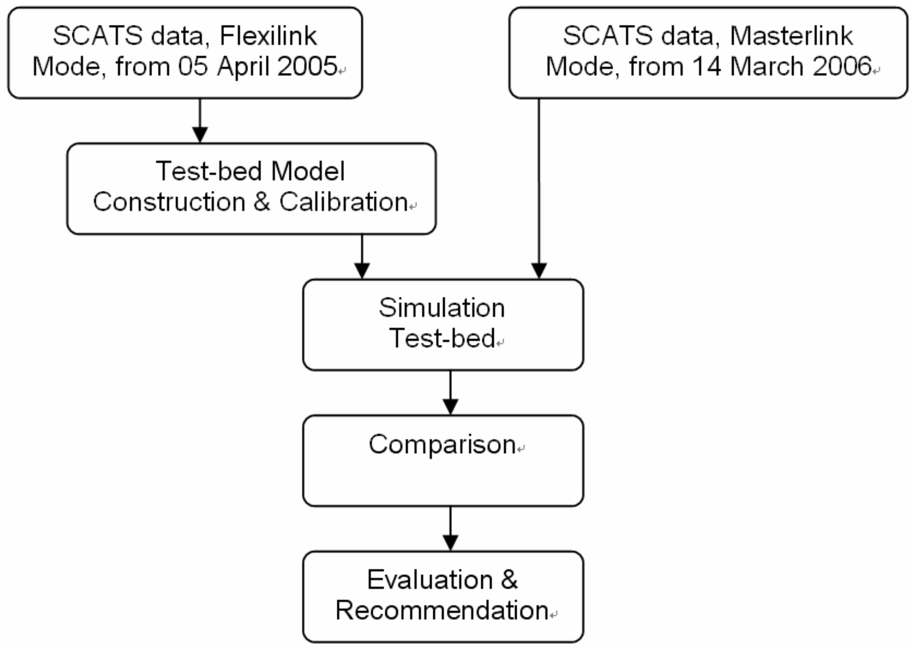

Figure 3: Flow-chart of the Experiment

The comparisons between the two signal operation modes were conducted based on three different levels: single movement level, intersection level and network level along West Terrace. The major indices adopted for the comparisons include approach delay and travel time for efficiency comparison and the amount of pollutants emitted for the environment concerns.

During the experiment, the research tried to reduce the inaccuracy of the simulation modelling process. The limitation of the study is that a Masterlink Mode signal setting is difficult to be simulated perfectly without a directly linking to SCATS or the adoption of a SCATS simulator (Millar, Tudge & Wilson 2004). However neither of these were available for this research. To overcome the problem, the research input signal settings phase by phase and cycle by cycle through the two-hour simulation period. The signal settings of the eight signalised intersections are based on first, the SM data for Masterlink Mode and second, a set of Flexilink Mode setting data from SCATS that was provided by Transport SA. The method has created a time-varying signal system, however some bias might still exist due to the difference of traffic volume distributions in particular time periods that could affect the signal settings of Masterlink in SCATS. On the other hand, the research provides same OD matrix for the two signal modes, so it provides a fixed demand comparison. The analysis of capacity improvement can only be estimated from the savings in travel time. Further investigation of capacity improvement would need a variable OD data set and a SCATS simulator (or its background algorithm).

4 Model Construction and Calibration

Model construction and calibration is a critical procedure that could influence the simulation results and research accuracy. This section introduces the data sources, procedure of test-bed construction and its calibration.

4.1 Data source

The major data for model construction and calibration includes traffic signal data, traffic flow data, road geometric data, travel time data and public transport data.

4.1.1 Signal setting data

The adopted data for the signal settings was collected from the SCATS SM data file. This file contains various traffic signal information including, signal cycle time, phase length, start time, intersection ID, active plan, vote plan, linking information and so on (RTA 2004). A basic understanding of the data format is necessary to read the data. Figure 4 shows a typical sample of SM data for Intersection 44.

```
Tuesday 14-March-2006 07:01 SS  44   PL 3.3  PV   0.2 CL  104 +0 RL  90' SA 139 DS 96
 Int    SA/LK   PH  PT!  DS  VO  VK!  DS  VO  VK!  DS  VO  VK!  DS  VO  VK! ADS
 3044 S 153       E  44!  12   3   3!   9   2   2!   0   0   0!   0   0   0!   10
 3044 S 154  '    E  44!  35   7   9!  17   3   4!  27   4   7!  10   2   2!   22
 3044 S 155  '    D  15!  45   3   3!  28   2   2!   -       -!   -       -!   34
 3044 S 156  '    F  15!  27   2   2!  51   3   4!   -       -!   -       -!   46
 3044 S 157  'ABG  32!  12   2   1!  93   7  10!  72   4   7!   -       -!   51
 3044 S 158    ACG  32!   0   0   0!   0   0   0!   0   0   0!   -       -!    0
 3044 S 159 *     7   0!   0   0   0!   -       -!   -       -!   -       -!    9
 3044 S 160 *     8  11!   0   0   0!   -       -!   -       -!   -       -!    0
 3044 L  40  '    E  44!   -       -!  17   3   4!  27   4   7!  10   2   2!  440
 3044 L  41  '    E  44!   -       -!   9   2   2!   0   0   0!   0   0   0!  100
A=20  B=1  C=1  D=14  E=<39>  F=13  G=#15
```

Figure 4: A sample of SM data from SCATS

4.1.2 Volume data

SCATS collects traffic flow data via numerous loop detectors along West Terrace. However for the estimation of Origin-Destination (OD) matrix, a number of locations still need to be covered by various tube traffic counts for traffic flow survey. The research installed eight MetroCount tube counters to helping in traffic volume collection for the OD matrix estimation and the model calibration.

4.1.3 Geometric data

The geometric layout of West Terrace and its intersection was determined from aerial photography and intersection drawings. In addition, numerous field surveys were undertaken to confirm the road geometry and traffic signal design.

4.1.4 Travel time data

Travel time survey was performed by a probe vehicle during the AM peak in West Terrace. The data can be compared with simulation results for calibration. Meanwhile a set of vehicle emission data from the probe vehicle is available to help to improve the estimation of pollutants from the simulation model in the future.

4.1.5 Public transport data

Public transport buses have a major influence on the performance of West Terrace. The research built 30 bus lines into the simulation test-bed based on public transport timetables. The influence of public transport on West Terrace could also be observed from the test-bed.

4.2 Construction and calibration

The research focuses on comparing the difference between Masterlink Mode and Flexilink Mode signal settings during AM peak period, i.e. 07:00 - 09:00. The construction of the full test-bed model will be conducted based on this aim. Aimsun NG V5.0 has been adopted in the model construction due to its capacity to include a large number of signal control plans to mimic Masterlink Mode operation. The major procedure of the model construction includes OD matrix estimation, road geometry and traffic signal settings.

4.2.1 OD matrix estimation and calibration

Twenty zones have been used to represent the traffic-flow distribution during the two simulated hours in West Terrace, shown in Figure 1. The hourly OD matrix was developed by Paramics Estimator first and then a manual adjustment was made to divide it into a 5-minute interval OD matrix based on the volume proportions calculated from real traffic volume data. The work has thus produced a more detailed traffic distribution OD than the hourly OD.

The final OD matrix has been calibration using GEH, invented by Geoffrey E. Havers in 1970s, as Formula 1. GEH is a modified χ^2 (Chi-squared) statistic that incorporates both relative and absolute difference (Speirs 2006). The traffic volume can be considered as a "good fit", if the value of GEH< 5.0. Meanwhile if the GEH value is between 5 and 10 then the flow may require further investigation. An important prerequisite for using GEH is that the calibration of volume must base on hourly volume.

$$GEH = \sqrt{\frac{(simulated - observed)^2}{0.5 \times (simulated + observed)}} \qquad (1)$$

GEH < 5.0 → Flows can be considered a "good fit"
5 < GEH < 10 → Flows may require further investigation
GEH >10 → Flows cannot be considered a "good fit"

The calibration of volume is conducted based on hourly volume, 7:00 - 8:00 and 8:00 - 9:00. Table 2 displays the outcome of the calibration along West Terrace. The average of GEH value for the first hour is 1.21 while 1.34 is the outcome for the second hour. Overall the result, the test-bed model has a "good fit" GEH value that is far less than the critical value "5".

Table 2: GEH values for the experiment test-bed

	Intersection														Average GEH
	42	Rose	83	Philip	43	Waymouth	84	44	104	Alfred	Wright	94	Gilbert	45	(OD)
7:00~8:00	0.69	1.18	1.67	1.06	1.95	0.93	0.73	1.21	1.26	2.00	1.28	1.59	0.75	0.62	1.21
8:00~9:00	0.78	1.03	1.83	1.15	1.16	0.72	1.39	1.68	1.93	2.22	1.21	1.11	1.16	1.36	1.34
Average GEH (Intersections)	0.73	1.10	1.75	1.11	1.55	0.82	1.06	1.45	1.59	2.11	1.25	1.35	0.95	0.99	1.27

4.3 Road geometric setting

As shown in Figure 1, aerial-photography provides extensive information for model geometric construction. For more detailed information, intersection drawings and field survey helped to solve some ambiguities that could not be clarified from the aero-images.

4.4 Signal settings

Signal setting is a major challenge for the Masterlink Mode model building in this research. In Masterlink Mode the signal settings could vary cycle by cycle. It is almost impossible to mimic the dynamic behaviors of SCATS properly without a direct linkage to SCATS, or by adopting a SCATS simulator. The research input the signal settings phase by phase and cycle by cycle for the Masterlink Mode model during the simulation period. There are 54 signal control plans included in the Masterlink Mode model and each of them contains eight signal settings for individual signalized intersections. The method could represent a similar operation pattern for a dynamic traffic system that based on similar traffic volume condition. In additional the signal linking has also been put into account during the modeling procedure.

For the Flexilink Mode model, a much simpler signal setting process is required for representing the fixed time signal setting through the two simulation hours. The comparison between the two models will be introduced in the next section.

5 Traffic Index Comparison

In order to determine the difference in the before-and-after study, this research compared several traffic indices that include intersection approach delay, travel time and pollution and emission from the simulation outputs. This is a fixed demand comparison, based on same OD matrix. Thus the comparison of traffic indices does not include degree of saturation because they have same OD and similar degree of saturation between the two signal operation modes.

Intersection approach delay could help to understand the impacts of traffic signal change on individual movements within the network. On the other hand, travel time comparison could indicate the difference between the two signal modes in a larger network scale. The procedure of travel time comparison can also help to evaluate the efficiency of signal linkage between the two modes. A suitable signal linkage could contribute to travel time reduction, eg a ‘green wave’. The final index that been considered is pollutant emissions. The index provides a network level examination to point out the impacts of signal change on environmental viewpoint. The application also draws the outline of the potential of micro-simulation in benefiting the development of sustainable transportation.

5.1 Intersection approach delay

Intersection approach delay is an important index to evaluate the efficiency of individual movements for intersections. Appendix A provides a comparison of the delay for individual movements in signalised intersection along West Terrace for the before-and-after study. Appendix A displays the result of delay proportions which are the difference of approach delay time between Masterlink mode and Flexilink mode (DM-DF) divided to the approach delay time of Flexilink Mode (DF). The formulation is represented as below:

$$\text{Delay Time Proportion} = \frac{(DM - DF)}{DF} \times 100\% \qquad (2)$$

The results help us to understand the difference after the change in the signal operation mode from Flexilink Mode to Masterlink Mode is made. For related locations and traffic movements please refer to Figure 1. The paper provides a more detailed comparison and analysis for two major intersections, 43 and 44, as follows. Further analysis could be conducted based on Appendix A for other intersections.

Appendix A provides a general idea of the changed approach delay in percentage. For considering the actual amount of time difference between the two signal operation modes, the research also provides the other results that combine the difference of approach delay and traffic volume as shown in Appendix B. The result provides a different viewpoint for the comparison.

5.1.1 Intersection West Terrace/ Currie Street (Intersection 43)

Intersection 43 is a very busy and important intersection in West Terrace. During the AM peak hour it is always full of vehicles and pedestrians. The major movement of vehicles in this intersection is from South to North during AM peak. Table 3 provides a summary of the delay change in Intersection 43 after change to Masterlink Mode. Overall the AM peak hour, Masterlink Mode provides a reduction of a 13.9 per cent approach delay for the intersection and contributed a 48.7 per cent less approach delay for the major movement, South to North.

For hourly analysis, the first hour average delay of the intersection has reduced by 29.8 per cent that includes a significant 57.8 per cent improvement in the major movement, South to North. Surprisedly, all the other movements have reduced their approach delay from three per cent to 50 per cent. Besides, even though the improvement of the second hour approach delay is not as outstanding as the first hour, it still offers a 39.6 per cent improvement in the approach delay for the major movement during the second hour.

The different level of approach delay improvement between the first and second hours might be due to the fact that Masterlink and Flexilink Modes have different signal cycle times in the first hour but the same cycle time during the second hour. The result shows a dynamic signal cycle time could benefit more in traffic efficiency than fixed cycle length.

Generally, the result shows clearly that the Masterlink Mode has greatly improved approach delay at intersection 43, especially for its major movement. However some increases of approach delay also happened for its minor traffic movements, such as W>E and N>S, during the second hour. Appendix B shows the result of total approach delay according to the passing volume. Intersection 43 has saved 41423 seconds approach delay during the AM peak.

Table 3: The change of approach delay percentage for Intersection 43

	Intersection 43						
Movements	S>N	N>S	W>E	E>W	S>E	E>N	Average
7:00~8:00	-57.8	-14.1	-3.2	-24.1	-50.5	-29.2	-29.8
8:00~9:00	-39.6	35.1	86.0	-4.5	-60.2	-4.4	2
Am peak Average	-48.7	10.5	41.4	-14.3	-55.4	-16.8	-13.9

5.1.2 West Terrace/ Grote Street (Intersection 44)

Intersection 44 is the Master intersection along West Terrace, which means the traffic signal linkage within West Terrace are based on this intersection. Intersection 44 is located in the middle of West Terrace. It is an important intersection for both traffic movements, South-North and East-West. Table 4 provides a summary of the delay variation in Intersection 44 after change to Masterlink Mode. Overall the AM peak period, Masterlink Mode increases approach delay by 3.6 per cent for Intersection 44 compared to Flexilink Mode. During the first hour, most approach delays for different movements are reduced by different levels, except for the S>N and N>S movements. During the second hour, except for N>S and S>E, the other movements have improved approach delays.

Table 4: The change of approach delay percentage for Intersection 44

	Intersection 44								
Movements	S>N	N>S	E>W	W>E	S>E	N>W	E>N	W>S	Average
7:00~8:00	8.5	117.4	-16.2	-7.4	-8.0	-25.0	-37.5	-16.8	1.9
8:00~9:00	-16.2	139.3	-11.5	-6.0	5.6	-14.1	-55.4	0.2	5.2
Am peak Average	-3.9	128.4	-13.8	-6.7	-1.2	-19.6	-46.5	-8.3	3.6

Overall the result displays that Masterlink Mode has improved the approach delay in most movements, except for N>S. That means Masterlink Mode reduced the Level Of Service (LOS) of the traffic movements N>S but increased the LOS for the other movements. A possible reason for this result is that the priority movement in Intersection 44 is the South-North direction in Flexilink Mode. However the Masterlink Mode adjusted its signal setting based on real traffic demands. That changed the distribution of signal splits to provide a better LOS to the major movements and produced the results shown in Table 4. Appendix B is the result of weighted method using Appendix A and traffic volume. It shows that Intersection 44 saved 22502 seconds of approach delay. A further adjustment and optimisation of signal system could be considered based on this analysis.

5.2 Travel time

Travel time is an important index to evaluate the traffic efficiency in a larger scale. The research used this index to test the difference in travel time between Masterlink and Flexilink Modes in South-North direction in West Terrace. The area of the travel time test is between two check points that include six signalised intersections, see Figure 1. Figure 5 shows the result of travel time survey in South to North bound direction in West Terrace. A light blue triangle represents travel time for a single vehicle during the data collection in Masterlink Mode while a golden circle represents a travel time result for Flexilink Mode.

A pair of polynomial lines is provided to indicate the trend of travel time change for the two signal operation modes. Flexilink Mode displays a more stable polynomial line than Masterlink Mode. That is because travel time in Flexilink Mode is mainly affected by the change of traffic volume.

According to the similar traffic factors and background between the two modes, such as same OD matrix and vehicle type, the difference of travel time between the two modes should cause by the different traffic signal settings. The result also highlights the importance of signal settings in travel time studies. Overall the results, travel time in Masterlink Mode is shorter than that in Flexilink Mode in the direction South to North. This result is expected because the direction is the major traffic movement during the AM peak in West Terrace.

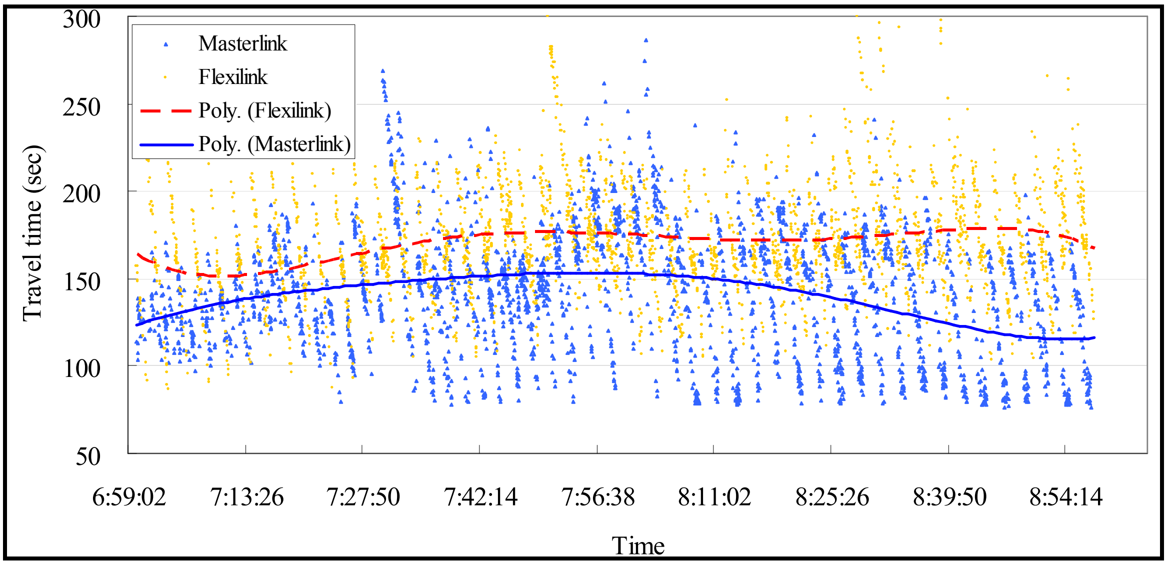

Figure 5: Travel time distribution S>N under Masterlink and Flexilink Modes

Figure 6 shows the result for the travel time survey in the reverse direction, North to South. The travel time results from Masterlink Mode are much higher than those for Flexilink Mode.

Table 5 shows the summation results of the travel time survey for each direction. For the direction of South to North, a total 95453 seconds travel time is saved by adopting Masterlink Mode with 2654 travel time records. Meanwhile the other direction, North to South, has a total increase in travel time of 38101 seconds. From the viewpoint of the whole corridor with the collected data, a total of 57352 seconds travel time is saved. Masterlink Mode demonstrates its advantage significantly via the comparison. According to the traffic volume data, the result is reasonable as it provides a better capacity for the major movement.

Table 5: The difference of summarised ravel time between two signal operation modes

	Travel Time Summation S>N			Travel Time Summation N>S		
	Masterlink	Flexilink	Δ	Masterlink	Flexilink	Δ
7:00~9:00	370615 sec	466068 sec	-95453 sec	118942 sec	80841 sec	38101 sec
No. of Data	2654			740		

The comparison of Figure 5 indicates an important result. Based on similar through volumes between Masterlink and Flexilink Modes, the shorter travel time in Masterlink Mode also represents a higher capacity than that in Flexilink Mode in the direction of South to North during a unit time period. The same, Figure 6 shows the increase in travel time and the reduction of capacity in North to South direction after using Masterlink Mode. During the observation of the test bed, an unnecessary stop point in Intersection 94 from the North bound was found from Masterlink Mode. A further improvement of signal linkage based on the finding could benefit reducing travel time in the direction from North to South on West Terrace. Micro-simulation also demonstrates the capability to assist in optimizing signal settings.

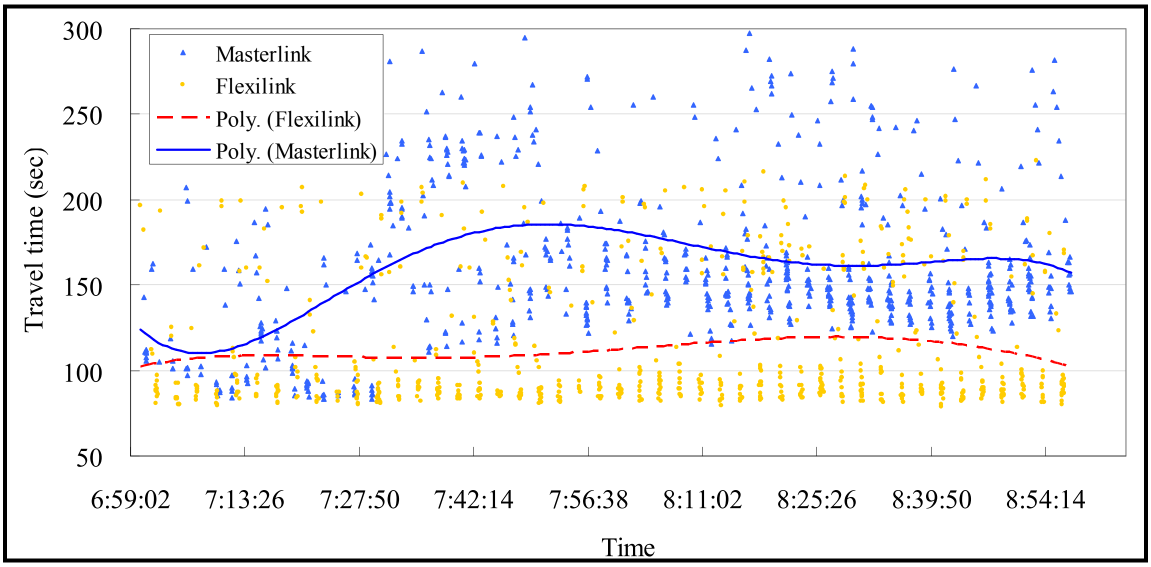

Figure 6: Travel time distribution N>S under Masterlink and Flexilink Modes

5.3 Pollution & emission

This paper attempts to look into the difference of environment impact between the two signal modes from the simulation models. The research firstly defines the default value of emission and fuel consumption factors for a single vehicle in this simulation model, as shown in Figure 7 (TSS 2005). Those emission factors are provided from the Aimsun Simulator User's Manual. A briefly comparison between those factors and the output from a real probe vehicle has been conducted and indicated their variation. The difference might cause by the differences in vehicle and road characteristics between Europe and Australia. However the research can only use the emission factors from Aimsun to estimate pollution and emission due to the emission results of the probe vehicle are still under discovery now. Australian vehicle emission factors will be considered in future research.

Emission rates for cars (g/s)	CO	NOx	HC
Idling emission rate (g/s)	0.060	0.0008	0.0067
Accelerating emission rate (g/s)	0.377	0.0100	0.0200
Decelerating emission rate (g/s)	0.072	0.0005	0.0067
Cruising emission rate (g/s)			
10 km/h	0.060	0.0006	0.0063
20 km/h	0.091	0.0006	0.0078
30 km/h	0.130	0.0017	0.0083
40 km/h	0.129	0.0022	0.0128
50 km/h	0.090	0.0042	0.0097
60 km/h	0.110	0.0050	0.0117
70 km/h	0.177	0.0058	0.0136

Figure 7: The default value of vehicle emission rate in the simulation model.

Figure 8 shows the change in emissions of three different pollutants, CO, HC and NOx, in percentages after running Masterlink Mode at the 'whole network' scale. The three pollutants show similar change trends during AM peak. Generally, Masterlink Mode has a little higher emission of pollutants, around four per cent, than that Flexilink Mode. The result suggests that signal settings and linkages cannot only improve travel time and approach delay but also have the potential to benefit our environment through improvements in emissions performance from the transport sector.

According to Figure 8, two probable reasons might affect the result of pollutant from the simulation test bed. Firstly, this is a fixed demand comparison. The experiment shows the improvement of travel time from Masterlink Mode in the direction of South to North and this can be regarded as an improvement of road capacity. However the increased capacity cannot be used in the estimation of pollutant benefits as this is a fixed demand comparison. An increased volume might change the signal settings in Masterlink Mode. A higher volume condition might change the result of the pollutant comparison. Secondly, according to a brief comparison between Aimsun emission factors and a data set from an instrument vehicle, the emission factors from Aimsun appear to be different from the real conditions experienced in Australia. This could lead to different pollution comparison results.

Summarising the comparison, Masterlink Mode provides a better LOS for the major movements, more users, in West Terrace but increases delays in the other minor movements. Masterlink Mode demonstrates its advantage to satisfy more road users than just provide a "fair" delay time for all movements. From the comparison of approach delays at Intersections 43 and 44, Masterlink Mode has a better performance in the first hour than the second hour. A further adjustment or cooperation of Masterlink Mode signal setting according to Flexilink Mode signal setting might help to optimise the signal system for the time period 8:00 to 9:00. The study shows signal setting control could influence traffic efficiency and have the potential to help with the development of sustainable transport and to benefit the environment.

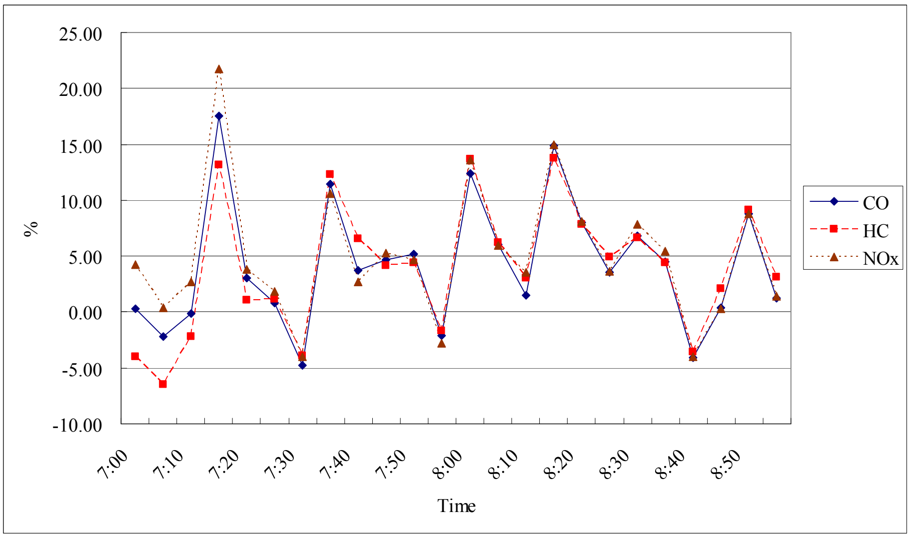

Figure 8: The change of pollutants in a whole network level after change to Masterlink Mode.

6 Further Research

The study has provided a basic comparison for the before-and-after situation of signal operations change. The test-bed will be applied on various further applications and studies in subsequent research. On the other hand, some further field surveys in West Terrace could help with the comparison between field and the test-bed. The further study could focus on firstly, the optimisation of signal settings in West Terrace via the help from micro-simulation. Secondly, there is the potential for the development of sustainability transport from a viewpoint of traffic signal design and traffic management. Thirdly, a SCATS cooperated travel time prediction model could be developed based on the test-bed for arterial roads. Finally cooperation with SCATS or SCATS simulator could help to evaluate the benefits of adopting Masterlink Mode in a full version.

7 Conclusions

SCATS is one of the most popular adaptive signal control systems that have been installed around the world. West Terrace in Adelaide is a major arterial road that controlled by SCATS, and West Terrace changed its signal operation mode from Flexilink Mode to Masterlink Mode in December 2005. For evaluating the difference in the before-and-after case, the research has built a micro-simulation model for testing the two signal operation modes. The major difference between the two operation modes is that the Flexilink Mode operates as kind of fixed time signal operation while the Masterlink Mode changes its cycle length and phase proportions based on field traffic data all the time.

The comparison indicates that when considering individual movements, Masterlink Mode improves the approach delay, travel time and road capacity for the major movements but may worsen the value of those indexes for some other minor movements. In other words, Masterlink provides a better LOS for more road users than Flexilink Mode does, but some individuals may be made worse off. When looking at the results in an intersection level, most intersections have an increased average approach delay, after changing to Masterlink Mode based on the traffic performance of Intersection 43. However the result could be different when considering the number of road users in each movement, as suggested in Appendix B.

From the viewpoint of travel time comparison, Masterlink Mode improved the travel time of major movement, South to North, and increased travel time in the reverse direction, North to South. According to the Aimsun emission factors and based on a fixed demand condition, the comparison of pollutant emissions at the 'whole network' level indicates that Masterlink Mode produced a slight increase in pollution compared to Flexilink. The study demonstrates the capability of micro-simulation in estimation environmental impacts from transport sector. However further research is needed to improve the estimated accuracy of pollution estimation. This would include the development of Australian emission factors instead of the current European emission factors from Aimsun, and the development of a methodology to evaluate the benefits of equal road capacity compared to travel time savings.

Micro-simulation plays a key role in the research. It displays the full view of the experiment area and that is unavailable before. An appropriate application of the tool can help to accelerate the development of advanced transport control and management methodology.

8 Acknowledgement

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Appendix A- The Difference of Approach Delay Proportion after Change to Masterlink Mode along West Terrace.

*Delay Time Proportion (%) = (DM-DF)/DF*100% DM = Delay of Masterlink Mode DF = Delay of Flexlink Mode

	Intersection 42			Intersection 83				Intersection 43						Intersection 84			
Time	S>N	N>S	E>W	S>N	N>S	S>E	E>N&S	S>N	N>S	W>E	E>W	S>E	E>N	S>N	N>S	S>E	E>S&N
07:05	12.8	-13.0	-39.7	332.0	-49.9	-16.3	45.5	-74.3	-29.8	-26.6	-68.9	-80.8	-58.7	64.4	3.6	-54.2	-4.5
07:10	-6.0	-18.6	-12.1	139.2	-57.3	-14.0	55.5	-87.1	-27.8	-14.1	-56.6	-51.9	-36.9	53.0	10.6	-39.0	-31.4
07:15	66.3	-17.1	-5.1	179.4	-74.2	10.3	78.9	-92.6	-29.3	13.6	-25.8	-68.2	-15.5	129.8	-47.2	-55.3	-31.8
07:20	58.1	-22.3	63.1	338.5	-51.3	80.1	118.4	-39.8	-19.3	-15.6	-28.0	-42.6	-49.4	13.3	-33.1	-32.9	44.3
07:25	26.9	-29.9	-19.5	127.2	-90.3	61.4	66.1	-67.7	-26.7	-28.7	-40.8	-29.0	-27.8	-15.7	-54.9	-25.5	2.0
07:30	14.9	13.5	-29.5	23.6	-66.9	-18.0	27.8	-56.3	46.2	8.2	-15.6	-69.6	-33.7	-34.5	-42.9	40.8	118.8
07:35	-55.0	23.9	1.8	-79.6	-59.5	-4.6	6.8	-55.6	23.9	18.9	-3.6	-35.3	-13.0	339.8	-15.7	-3.8	-26.6
07:40	-13.9	-27.9	-29.2	0.2	-60.1	220.0	108.4	-75.4	-32.5	11.4	-14.2	-39.9	10.5	-54.7	-57.5	248.9	-37.2
07:45	101.1	9.0	18.5	70.8	-55.0	193.8	34.3	-61.6	-34.4	-18.0	1.6	-74.5	-46.7	-69.6	-44.6	35.8	2.7
07:50	37.3	-24.5	-22.3	-0.1	-48.0	281.5	31.9	-46.3	-18.6	21.4	-27.7	-75.9	-29.1	-41.4	-42.7	6.4	-30.9
07:55	42.1	1.3	-16.1	83.4	-6.6	215.1	28.9	-53.3	-19.5	-14.7	-4.9	-11.1	-27.2	-44.8	-35.1	104.1	-11.7
08:00	-28.9	-8.9	5.9	-45.2	-67.8	78.8	65.7	15.8	-1.1	6.4	-4.5	-27.4	-23.3	36.1	-13.0	67.7	-30.0
08:05	1.6	-1.8	-5.6	14.4	-34.1	58.5	206.5	21.0	11.8	12.0	4.1	-27.9	11.3	-9.3	-43.6	102.1	-41.7
08:10	30.0	-6.4	29.1	390.9	-38.6	8.6	75.3	-8.7	9.7	-1.7	24.2	-12.8	31.5	7.2	-52.3	44.0	14.1
08:15	-1.0	5.1	16.0	67.3	-24.5	45.2	134.3	-48.8	56.3	31.6	-18.2	-65.8	-40.2	61.9	-12.1	37.9	14.6
08:20	-16.1	-19.2	13.8	16.3	-36.0	78.8	136.8	-38.3	32.4	20.9	-5.9	-65.2	-46.2	21.1	-20.1	29.5	24.8
08:25	-10.9	-6.5	-25.5	43.0	-58.7	33.0	177.7	-21.5	90.5	47.1	-24.4	-65.4	34.5	115.3	-40.2	108.2	-37.8
08:30	39.4	19.0	32.2	-7.0	-62.0	61.3	36.9	-29.8	28.6	120.9	-10.9	-66.2	17.1	30.2	-8.6	136.5	-22.7
08:35	0.4	-6.6	10.6	26.4	-43.9	39.0	46.5	-14.9	-3.1	46.0	-29.2	-67.3	-10.1	59.4	-47.4	73.6	-1.4
08:40	-41.6	29.8	-22.2	21.9	-47.8	75.0	71.0	-60.5	68.5	15.6	-1.9	-55.2	28.4	8.8	-16.6	72.0	-20.0
08:45	-21.5	10.7	-11.3	5.7	-37.4	97.2	106.1	-73.5	8.6	48.4	1.2	-72.6	-1.6	2.8	-48.6	52.0	-0.9
08:50	-32.7	-1.0	16.6	28.0	-61.5	69.2	24.7	-67.6	20.7	207.6	-8.4	-73.1	-38.8	-31.2	-18.2	60.2	9.6
08:55	-22.7	-5.4	25.6	78.8	-20.3	98.2	119.3	-62.3	15.5	245.7	4.5	-72.7	-20.9	8.8	-43.8	16.0	-46.3
09:00	8.2	20.0	4.1	8.5	-17.9	44.7	50.8	-70.4	81.2	237.8	11.0	-78.8	-17.9	1.8	-26.0	165.8	-2.6
Average 7-8:00	21.3	-9.6	-7.0	97.4	-57.2	90.7	55.7	-57.8	-14.1	-3.2	-24.1	-50.5	-29.2	31.3	-31.0	24.4	-3.0
Average 8-9:00	-5.6	3.1	6.9	57.9	-40.2	59.1	98.8	-39.6	35.1	86.0	-4.5	-60.2	-4.4	23.1	-31.5	74.8	-9.2
Sum-Average		1.5			45.3					-13.9						9.9	

	Intersection 44								Intersection 104				Intersection 94			
Time	S>N	N>S	E>W	W>E	S>E	N>W	E>N	W>S	S>N	N>S	S>E	E>N&S	S>N	N>S	S>E	E>S&N
07:05	-4.0	33.7	-32.4	-24.4	-59.9	-7.5	-88.0	-54.4	214.2	1.9	-30.8	-63.0	6.4	495.1	-50.5	51.9
07:10	-26.0	40.4	-36.3	-23.3	-14.7	-13.2	-73.0	-94.8	337.5	28.0	26.7	-26.9	35.7	1704.3	-49.1	19.9
07:15	27.1	-78.2	5.4	-31.3	-19.0	-24.6	-47.7	9.4	138.2	-66.8	-23.4	6.9	75.2	401.7	-26.9	-31.0
07:20	15.3	93.4	-19.5	-2.8	-33.3	-14.0	-38.7	-51.0	32.1	4.8	-10.1	65.3	27.4	617.9	-22.5	-59.3
07:25	15.4	78.6	-19.2	30.7	-30.3	-47.7	-47.4	-75.8	100.3	-30.1	-82.6	-10.5	-30.5	462.4	7.3	-45.9
07:30	51.9	33.8	-34.8	0.0	-15.6	-48.9	-21.0	55.4	296.7	-23.8	-3.0	-25.3	-57.7	491.3	-60.7	-51.3
07:35	48.4	1006.4	-20.8	-20.8	-25.2	-49.4	-46.0	-37.0	1096.5	-54.5	0.7	13.1	-45.2	1164.0	-42.8	-42.8
07:40	9.7	9.9	28.5	17.3	81.1	60.8	-25.0	13.4	41.0	48.3	15.2	-41.9	-64.0	1538.3	-72.4	-53.2
07:45	32.5	-37.6	-2.1	-6.1	11.1	-68.9	-10.2	-0.4	75.2	140.4	29.1	-16.2	-66.5	3575.8	-78.2	-40.1
07:50	-12.9	48.8	-8.8	-24.6	20.2	-20.9	-49.7	1.9	84.8	113.7	26.5	-52.4	-60.2	2676.8	-69.8	-1.9
07:55	-17.8	9.2	-26.4	4.6	5.7	-38.0	-31.9	43.8	82.4	37.5	17.1	-38.7	-50.6	2710.3	-51.5	-28.6
08:00	-37.9	171.1	-28.0	-7.7	-16.4	-27.7	28.6	-12.3	11.7	124.1	21.2	-24.4	-36.8	3604.0	-41.4	1.7
08:05	-29.9	124.1	-13.4	-24.7	12.5	-33.8	-54.5	16.2	448.6	-7.7	322.2	-42.6	-23.7	6337.3	-40.3	-12.2
08:10	-15.6	103.5	-37.2	-18.9	-22.8	-18.1	-14.0	-28.6	161.6	-16.5	260.9	-22.5	-28.0	1685.7	52.8	-11.8
08:15	-13.5	144.1	-16.2	12.8	26.7	-37.5	-66.4	-19.1	180.9	-0.1	353.2	-69.6	-30.9	2171.2	41.8	-15.1
08:20	16.9	224.3	17.5	-2.4	34.0	-15.6	-78.6	-43.4	271.0	-14.4	357.5	-83.5	-19.1	3342.0	-20.9	5.4
08:25	-4.0	221.8	-18.3	-3.6	48.5	-4.8	-67.3	-34.3	96.0	-47.4	176.8	-86.9	-27.0	2790.3	-40.2	-23.4
08:30	-42.4	88.9	-23.5	-31.3	2.4	-24.4	-82.1	-11.2	99.3	1.0	153.7	-90.8	-35.4	3477.0	26.7	27.4
08:35	-17.6	169.9	-19.2	2.8	-1.1	-27.2	-35.9	70.5	66.5	10.4	215.8	-88.8	-27.8	2924.4	-15.0	-7.7
08:40	-9.8	118.5	-27.1	-0.9	-22.5	11.4	-66.1	-20.5	157.8	-4.1	158.6	-90.0	-22.3	3728.6	-65.9	-31.7
08:45	-21.5	214.4	-19.5	3.7	-9.4	-17.0	-38.2	75.6	110.6	0.1	258.8	-92.7	-28.7	3013.9	-6.7	-30.1
08:50	-7.6	94.1	8.3	0.5	-5.6	6.4	-54.5	23.5	303.3	-42.4	425.4	-93.9	-34.3	4248.9	28.9	-42.0
08:55	-24.3	86.4	-5.5	3.9	8.3	2.9	-51.5	-13.6	174.8	-24.8	108.1	-93.0	-40.4	4516.3	37.9	-24.4
09:00	-25.7	81.3	16.6	-14.1	-3.2	-12.0	-56.0	-12.3	272.9	-53.4	60.3	-94.0	-17.9	2047.2	-41.0	-24.2
Average 7-8:00	8.5	117.4	-16.2	-7.4	-8.0	-25.0	-37.5	-16.8	209.2	27.0	-1.1	-17.8	-22.2	1620.2	-46.5	-23.4
Average 8-9:00	-16.2	139.3	-11.5	-6.0	5.6	-14.1	-55.4	0.2	195.3	-16.6	237.6	-79.0	-28.0	3356.9	-3.5	-15.8
Sum-Average				3.6							69.3			604.7		

	Intersection 45				
Time	S>N	N>S	N>W	E>W&N	W>E
07:05	-7.8	-41.2	46.4	15.1	-20.5
07:10	-2.9	-74.4	-93.0	120.8	30.5
07:15	4.5	-9.4	-115.9	144.5	46.2
07:20	-33.4	-34.4	-7.4	72.0	-1.5
07:25	15.1	-51.7	-17.4	106.9	48.2
07:30	20.8	23.4	62.3	39.1	77.2
07:35	-43.9	-18.3	40.4	164.3	73.8
07:40	-34.9	57.2	73.5	96.1	66.8
07:45	3.4	62.6	56.2	-0.1	-21.3
07:50	-32.9	65.1	66.2	53.6	-53.6
07:55	-6.9	119.1	64.4	51.9	-15.6
08:00	-13.7	193.3	67.9	35.1	9.3
08:05	-14.1	38.8	54.9	15.7	29.2
08:10	-16.3	62.9	48.3	-25.1	40.7
08:15	11.8	57.7	58.3	73.3	37.9
08:20	-6.0	133.4	53.8	35.6	13.1
08:25	-6.4	40.3	31.0	103.7	19.6
08:30	7.7	9.2	44.5	23.7	9.2
08:35	3.6	51.3	27.2	45.8	9.3
08:40	-20.7	101.5	44.9	55.1	10.5
08:45	16.8	203.0	72.1	6.5	71.9
08:50	-12.1	95.5	75.3	25.5	77.6
08:55	-0.7	89.2	57.6	115.6	52.1
09:00	-7.4	71.7	47.1	186.3	73.9
Average 7-8:00	-11.0	24.3	20.3	74.9	20.0
Average 8-9:00	-3.6	79.5	51.2	55.1	37.1
Sum-Average		34.8			

Appendix B- The Difference of Approach Delay when Considering Volume Data after Change to Masterlink Mode along West Terrace.

Total Delay Time Change (second)= (DM-DF) Number of Vehicles DM = Delay of Masterlink Mode DF = Delay of Flexlink Mode

	Intersection 42			Intersection 83				Intersection 43						Intersection 84			
Time	S>N	N>S	E>W	S>N	N>S	S>E	E>N&S	S>N	N>S	W>E	E>W	S>E	E>N	S>N	N>S	S>E	E>S&N
07:05	98	-310	-324	749	-391	-106	262	-2860	-509	-734	-282	-660	-214	204	53	-56	-14
07:10	-54	-453	-118	339	-309	-96	207	-3960	-208	-250	-688	-901	-294	71	86	-83	-87
07:15	690	-420	-30	397	-1280	53	406	-4249	-660	276	-265	-671	-72	151	-677	-190	-83
07:20	617	-805	446	1026	-644	434	501	-1543	-393	-467	-480	-433	-241	20	-446	-74	172
07:25	239	-897	-207	535	-1070	371	367	-3336	-414	-979	-369	-368	-207	-34	-815	-122	9
07:30	191	288	-398	57	-860	-120	214	-2516	496	230	-226	-1017	-161	-97	-773	152	181
07:35	-517	516	21	-427	-770	-25	88	-2964	442	573	-56	-314	-71	787	-211	-12	-87
07:40	-205	-827	-468	1	-844	1268	1042	-5520	-623	352	-189	-1028	63	-235	-1111	435	-326
07:45	865	279	183	579	-772	1384	370	-3427	-699	-1023	29	-1357	-465	-310	-804	267	18
07:50	505	-739	-367	-1	-963	1180	331	-2947	-519	907	-464	-972	-244	-215	-1098	49	-195
07:55	792	31	-273	473	-115	1114	347	-3983	-426	-634	-43	-212	-346	-171	-770	419	-110
08:00	-397	-249	93	-556	-1159	472	1241	1182	-26	269	-52	-269	-204	122	-280	238	-174
08:05	39	-60	-91	168	-571	321	1460	1530	351	657	37	-711	97	-53	-1411	498	-459
08:10	686	-174	276	2476	-776	78	1006	-529	219	-146	489	-441	243	29	-1463	260	201
08:15	-16	145	205	337	-539	270	2166	-2019	1476	3315	-369	-2203	-487	183	-339	281	158
08:20	-352	-472	186	132	-702	486	1028	-1970	864	2223	-101	-3243	-344	67	-593	119	309
08:25	-243	-176	-465	280	-1683	218	1427	-1032	1669	5085	-616	-3077	266	307	-1145	824	-753
08:30	643	575	282	-74	-1263	374	598	-1611	707	9588	-144	-3391	116	158	-240	840	-394
08:35	8	-257	160	163	-1221	291	915	-827	-124	5140	-674	-4179	-87	205	-1630	717	-26
08:40	-716	759	-334	198	-1325	396	746	-2934	1045	2303	-32	-4192	162	31	-552	555	-204
08:45	-494	300	-165	78	-708	791	1155	-3872	225	6201	11	-4279	-7	12	-1361	344	-12
08:50	-696	-27	246	221	-1356	299	325	-3640	471	11828	-167	-4835	-227	-125	-455	300	154
08:55	-423	-152	301	435	-323	482	1097	-3189	338	12832	76	-4356	-132	37	-1242	115	-606
09:00	96	590	58	54	-315	195	484	-4257	1463	11367	174	-4487	-172	9	-640	517	-30
Summary 7-8:00	2826	-3587	-1442	3170	-9178	5929	5376	-36123	-3540	-1480	-3084	-8202	-2456	294	-6846	1022	-696
Summary 8-9:00	-1468	1050	660	4467	-10781	4201	12409	-24351	8705	70393	-1316	-39395	-573	861	-11071	5373	-1661
Summary		-1960			15594					-41423					-12726		

	Intersection 44								Intersection 104				Intersection 94			
Time	S>N	N>S	E>W	W>E	S>E	N>W	E>N	W>S	S>N	N>S	S>E	E>N&S	S>N	N>S	S>E	E>S&N
07:05	-94	152	-292	-199	-664	-42	-430	-225	391	14	-72	-137	99	1417	-135	721
07:10	-467	89	-411	-362	-96	-83	-263	-120	573	172	30	-106	574	976	-231	62
07:15	842	-399	60	-470	-229	-167	-191	14	311	-1049	-40	13	1093	951	-228	-271
07:20	619	427	-234	-36	-343	-89	-76	-240	122	52	-31	380	588	1304	-63	-1002
07:25	418	240	-324	243	-202	-473	-237	-202	263	-374	-387	-34	-513	724	24	-657
07:30	2527	96	-524	1	-106	-290	-102	146	1213	-287	-8	-221	-1097	1271	-217	-765
07:35	2027	3359	-332	-461	-277	-251	-615	-153	2935	-978	2	62	-1000	2417	-246	-462
07:40	436	59	558	495	541	788	-237	73	214	1362	79	-401	-1650	3756	-526	-1094
07:45	1628	-164	-47	-128	186	-454	-79	-2	472	2318	100	-139	-1743	10045	-371	-721
07:50	-979	250	-113	-763	278	-189	-398	9	425	3030	65	-491	-1747	7065	-207	-31
07:55	-1060	50	-564	97	80	-325	-208	202	517	952	51	-406	-1424	8105	-444	-432
08:00	-2316	678	-569	-271	-201	-263	234	-49	73	2432	91	-213	-1202	6327	-182	20
08:05	-2143	952	-285	-892	169	-431	-404	84	1967	-189	767	-641	-820	10321	-149	-200
08:10	-809	1215	-1420	-953	-452	-197	-140	-181	940	-439	836	-354	-826	9090	321	-231
08:15	-779	1286	-453	340	480	-630	-1131	-105	905	-3	778	-2205	-1100	8256	148	-288
08:20	933	2386	496	-90	552	-240	-3483	-350	1838	-449	676	-4557	-655	10842	-159	81
08:25	-239	1326	-470	-128	594	-75	-2221	-237	686	-1817	816	-5441	-1016	10267	-338	-455
08:30	-2741	1181	-743	-1782	44	-370	-2005	-65	993	29	569	-7610	-1326	10179	173	295
08:35	-1055	1509	-522	170	-28	-446	-526	207	580	386	685	-8074	-1060	11929	-172	-109
08:40	-515	1275	-694	-35	-360	130	-1400	-200	856	-111	558	-10009	-522	10647	-795	-581
08:45	-1059	1469	-528	116	-104	-232	-364	314	366	2	516	-11805	-774	9181	-40	-521
08:50	-388	855	157	23	-87	68	-656	91	945	-1414	1038	-16126	-1097	10099	161	-907
08:55	-1231	811	-134	159	131	25	-574	-65	966	-553	269	-17722	-1249	10003	232	-406
09:00	-1379	986	271	-674	-46	-169	-905	-39	1138	-1631	186	-18196	-545	10721	-487	-537
Summary 7-8:00	3584	4837	-2795	-1854	-1032	-1839	-2602	-545	7509	7644	-120	-1694	-8024	44357	-2826	-4632
Summary 8-9:00	-11406	15248	-4325	-3746	893	-2566	-13809	-546	12179	-6188	7694	-102738	-10989	121535	-1107	-3859
Summary					-22502					-75714				134455		

	Intersection 45				
Time	S>N	N>S	N>W	E>W&N	W>E
07:05	-135	-212	292	74	-189
07:10	-47	-371	-379	627	135
07:15	87	-36	-235	517	266
07:20	-566	-493	-51	362	-17
07:25	213	-380	-184	531	324
07:30	317	165	807	204	747
07:35	-829	-194	551	1026	873
07:40	-672	861	2203	464	826
07:45	59	1058	2300	-2	-354
07:50	-723	1065	2264	288	-1279
07:55	-104	2316	4245	384	-229
08:00	-232	2145	2353	245	142
08:05	-288	793	2214	219	445
08:10	-306	1080	2067	-367	1037
08:15	174	1007	2405	703	843
08:20	-96	2103	2275	252	281
08:25	-118	1113	1244	784	517
08:30	102	293	1800	332	176
08:35	59	1207	1185	429	240
08:40	-343	1784	2486	290	257
08:45	225	2863	3277	51	1195
08:50	-215	2211	4221	352	1527
08:55	-9	2037	2748	848	1155
09:00	-121	1689	1987	2252	1498
Summary 7-8:00	-2634	5925	14165	4720	1245
Summary 8-9:00	-936	18182	27910	6147	9172
Summary			83895		