Australasian Transport Research Forum 2011 Proceedings
28 - 30 September 2011, Adelaide, Australia
Publication website: http://www.patrec.org/atrf.aspx

Exploring stop-line traffic flows at signalised intersections in the Adelaide CBD

Chansiri Suksri, Professor Michael A P Taylor and Dr Wen Long Yue

Barbara Hardy Institute, University of South Australia

sukcy001@mymail.unisa.edu.au

Abstract

Traffic flows are widely employed as a primary input in calculation of control variables including phase splits and cycle lengths for traffic signals. Flow characteristics normally vary in different locations and over time corresponding to different driver behaviours. The examination of traffic flows should provide better understanding of a study area and could move us towards an improved control model. This study analyses traffic flow data extracted from an existing adaptive control system (SCATS: Sydney Coordinated Adaptive Traffic System) in the Adelaide city centre in order to examine data characteristics and look for a suitable modelling approach and level of detail for the analysis. The system primarily measures traffic data using stop-line detectors and records the traffic flows in five-minute intervals. Morning peak period data at five intersections on King William Street were investigated using two analytical approaches: lane-by-lane analysis and approach-based analysis initially by sequential plots. The data shows the periodic nature of the flows. Being periodic, time series analysis has been introduced as an alternative analysis technique using spectral density function (SPF) and autocorrelation function (ACF) plots. The results show that this technique can differentiate batch traffic counts from different lane configurations by different shapes of the ACF and this could lead to an appropriate forecasting model for traffic flow. In addition, the different data characteristics indicated by this analysis technique between different lanes suggest that a flow model could be considered at the lane-by-lane level.

1. Introduction

Urban arterial networks face a challenge of accommodating traffic and facilitating local access. Signalised intersections are perhaps the most critical points in a traffic network. Traffic flows at the intersections are considered as a significant factor in measuring the effectiveness of traffic systems. The flows at intersections have been studied in various aspects including departure flows for capacity analysis and arrival flows which relate to traffic demands. As flows are dynamic there may therefore be variations in an intersection capacity apart from dynamical signal timing. Most automated traffic control systems operated in cities measure traffic data for a purpose of responsive or adaptive control. Those data including the flows are typically collected as historical traffic databases and the data may be made available for analysis upon request.

This paper presents a preliminary analysis of traffic flows at stop lines on King William Street in the Adelaide CBD. The traffic signals in this area are controlled by SCATS and the system records measured traffic count data (referred as SCATS VS) and signal operations data (referred as SCATS SM). The historical data are available via the NEXUS database held for DTEI (Department for Transport, Energy and Infrastructure) at the Barbara Hardy Institute, University of South Australia. SCATS VS data for five consecutive intersections on King William Street during morning peak period were initially extracted for a traffic flow study involving the micro analytical examination lane by lane, to investigate distinction of flow behaviour on different lane configurations. In addition, an approach-based flow analysis, corresponding to the approach groups in the SCATS control system, was also investigated. In this latter case the average lane flows were considered as approach flow. Considering SCATS VS as batch of traffic, time series analysis technique were applied to examine the

seasonality of data by sequential plots, Spectral Density Function (SPF) plots and Autocorrelation Function (ACF) plots. The sequential plots visually indicate the periodic natures of the stop-line traffic flows while the autocorrelation plots initially differentiate traffic flow behaviours between through and turning movements. Furthermore, there is evidence that a shape of the ACF could be used to indicate an appropriate model for a forecasting model of traffic flow evolution, and the model could also be adopted in estimating historical missing data.

2. Background

2.1 Traffic flows at a signalised intersection

Signalisation aims to reduce intersection conflicts by allocating discrete channels of time to crossing traffic (Boumediene et al., 2009). In addition, traffic signals are installed for increasing total throughput capacity, reducing delay and stabilising traffic flows. Performance of urban networks is greatly dominated by signalised intersection treatments. In service, operation of the intersections is considered as an important part aside from planning and design, as better operations lead to higher level of the performance and increase level of services. In a planning context, techniques for minimising degrees of saturation for favoured movements at signalised intersections could enhance network management performance by influencing route choice decisions (Ogden and Bennett, 1989). Most traffic control systems include traffic flow as an input variable, because of its significance and as flow rate is comparably straightforward and economical to measure automatically, compared to other variables such as speed and queue length. For traffic flows at intersections, both departure flows corresponding to intersection throughput and arrival flows representing traffic demand may be considered. Departure flows are measured at a reference point along a street (typically the stop line) while arrival flows are measured upstream in queuing areas (Akcelik et al., 1999). Even though the departure flows are equal to demand during under saturated conditions, detector locations play an important role during congested conditions when demand exceeds maximum departure flows.

Observation of individual vehicular traffic at stop lines can provide useful information including departure flows, queue discharge headway and actual saturation flows, which are important for traffic capacity analysis at intersections. However, this is difficult to do using standard traffic survey methods. With SCATS VS as a complementary data source, it is possible to obtain a batch of individual vehicular traffic within a five-minute interval. Exploring the utility of SCATS data at a micro analytical level to see what information could be obtained should assist traffic engineers to move towards a more economical approach that provides better understanding of traffic in a study area.

2.2 Time series applications in transport systems

Applications of Fourier series and Fourier transform have been widely used in time series analysis for modeling and forecasting cyclical data. Fourier series refers to a periodic function represented by sum of sines and cosines as expressed by Equation 1 (Gartner and Deshpande, 2009b).

Equation 1: $$f(x) = \frac{1}{2} \propto_0 + \sum_{n=1}^{\infty} \propto_n \cos(nx) + \sum_{n=1}^{\infty} b_n \sin(nx)$$

Where

$$\alpha_0 = \frac{1}{\pi} \int_{-\pi}^{\pi} \mathrm{f(x)dx}$$

$$\alpha_n = \frac{1}{\pi} \int_{-\pi}^{\pi} \mathrm{f(x)cos(nx)dx}$$

$$b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} \mathrm{f(x)sin(nx)dx}$$

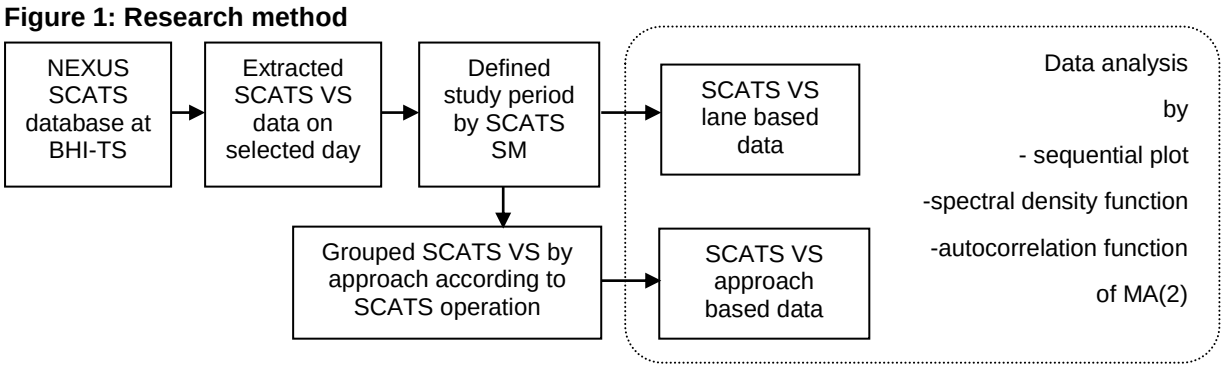
As traffic flow is also a time series, the Fourier application was introduced in traffic volume forecasting with the advent of the second generation of adaptive traffic control systems (Kreer, 1976). Fourier analysis is mainly adopted by considering both historical and recent past data (Kreer, 1976, Peeta and Anastassopoulos, 2002), and can be used in traffic prediction for both urban arterial roads and freeways. Williams et al. (1998) (cited in Peeta and Anastassopoulos, 2002) modeled traffic on urban freeway using seasonal exponential and ARIMA models, thus allowing for the periodic characteristics of traffic flows so the flows could be predicted more reasonably, especially for congested conditions. In addition, Peeta and Anastassopoulos (2002) suggested that employing Fourier as a unified method for calculation could help real-time operational system in terms of computation time.

In terms of traffic signal systems, Fourier application and analysis were considered by Gartner (2009b) in applying the harmonic analysis concept to model Link Performance Functions (LPFs) by considering a delay function as a function of offset [Delay = f(offset)]. This uses the concept that the periodic nature of the relationship is caused by a synchronous basis of the signal operation, such as the same cycle length (Deshpande, 2009, Deshpande et al., 2010, Gartner and Wagner, 2004, Gartner and Deshpande, 2009a, Gartner and Deshpande, 2009b, Gartner et al., 2010). Then the Fourier LPFs were also proposed in a dynamic programming procedure for signal optimisation at intersections.

3. Research method

The study aims at developing analysis techniques for micro analytical level (lane-by-lane) at signalised intersections by using SCATS VS data. The technique of time series analysis has been considered for the short-term batch data of traffic flows at stop lines. As a preliminary stage, SCATS VS data were limited to the first quarter in 2008. Morning peak traffic flows on a selected congestion day (based on maximum throughputs of the critical intersection in the study area which was 22 February 2008) at intersection stop lines on five intersections on King William Street were extracted from NEXUS for analysis. SCATS SM was also extracted to complement the flows data in identifying the morning peak period for the study, as peak conditions vary and this deviation may relate to area localisation (Drew, 1968). In this case, the peak period was specified by an operational perspective, as the data showed that cycle lengths slightly increased starting from early morning until reaching the maximum set value, then remained constant at that value (also corresponding to the constant phase splits for almost all intersections except the intersection on Victoria Square which only operated with the constant cycle time while the phase splits were dynamic) for a the period between 7.35 and 9.20 AM. The summary of research method is shown in Figure 1.

Figure 1: Research method



The SCATS VS data were analysed at two levels: lane based and approach based (according to SCATS system configuration). Lane-based analysis explores flow characteristics of each lane separately while approach-based analysis applies average flow per lane over all lanes within the approach as a characteristic of the traffic stream movement. The analysis reported in this paper only includes those approaches containing more than one

detector in the approach based analysis. Time series concepts were adopted as an analysis technique, in terms of short-term time series of batch data to assess the nature of SCATS VS data at the stop lines. Initially, sequential plots were obtained then spectral density of function was performed. As the spectral density function relates to autocorrelation by Fourier transforms, SCATS VS can be smoothed by a moving average at order 2: MA(2), after which the autocorrelation function will be calculated. This procedure applied for both lane-based and approach-based data for the selected intersections (which provided flow data for all legs of the intersection).

For spectral density function analysis, spectral composition of SCATS VS data is computed by Discrete Fourier Transform (Nuhertz, 2011) as explained by Equation 2

Equation 2: $$F(k) = (\frac{1}{N}) \sum_{n=0}^{N-1} T(n)\, W_N^{kn}$$

Where $$W_N = \exp(-J\frac{2\pi}{N})$$

F(k) is the complex frequency at frequency point k

T(n) is the time at time point n

N is the total number of time points, starting at point 0

and $J = \sqrt{-1}$

while the amplitude and phase angle from complex frequency can be calculated by Equation 3 and 4 respectively

Equation 3: $$A(k) = (\frac{1}{\sqrt{2}})\sqrt{F(k)r^2 + F(k)i^2}$$

Equation 4: $$\theta(k) = \left(\frac{180}{\pi}\right) ang(\frac{F(k)i}{F(k)r})$$

Where

A(k) is RMS amplitude of the frequency component at point k

$\theta(k)$ is phase angle in degrees of the frequency component at point k

F(k)r, F(k)i are the real and imaginary parts of the complex frequency at point k

ang ( ) is the 360 degrees $\tan^{-1}$ function.

The data was smoothed out using filter method by moving average process of order 2 which is typically use in traffic count data to aggregate the data measured. Then autocorrelation function can be estimated by Equation 5 with 95% confidence in Equation 6 by Barlett's approximation (Box and Jenkins, 1976). The first element of the autocorrelation function is unity as ACF (1) = 1 = lag 0 correlation.

Equation 5: $$c_h = \frac{1}{N}\sum_{t=1}^{N-h}(Y_t - \bar{Y})(Y_{t+h} - \bar{Y})$$

Equation 6: $$B = \pm z_{1-\frac{\propto}{2}} SE(r_h)$$

Where r_h is the estimated autocorrelation at lag h and $SE(r_h) = \sqrt{\frac{1+2\sum_{i=1}^{h-1} r_i^2}{N}}$

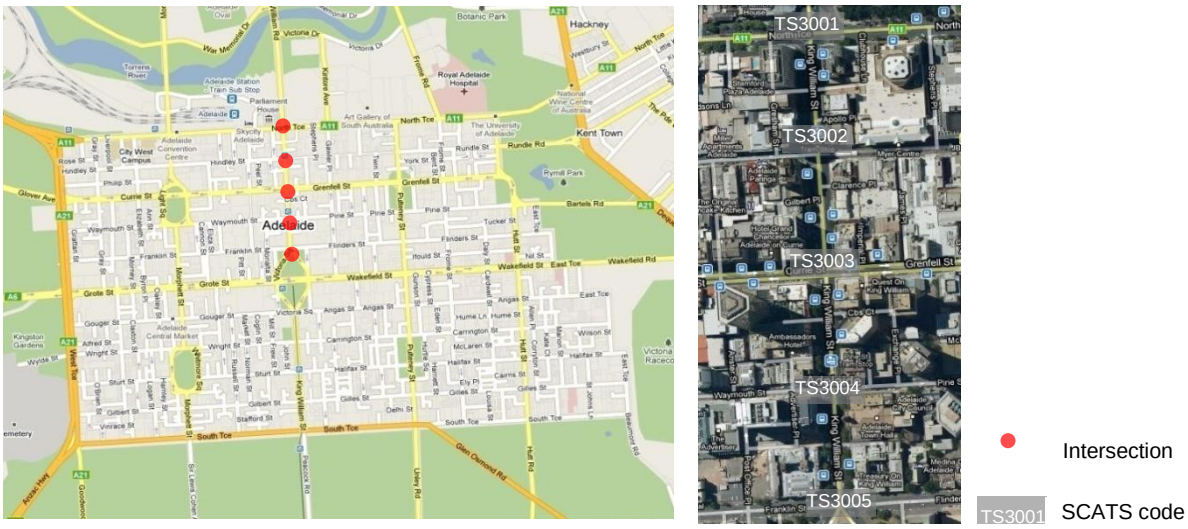
4. Data

This section provides a description of the geographical study area. It then provides a description of SCATS VS data used in the study.

4.1 Study area

The study area is located in the Adelaide CBD, as in the area map presented in Figure 2. Traffic diagrams indicating intersection code (TS), detector numbers (D), lane marking and approach numbers are shown in Appendix A. King William Street is one of the most congested arterial streets in the Adelaide CBD. According to SCATS SM data, the five consecutive signalised intersections selected as the study area represent the five busiest intersections in the CBD. Each intersection is represented by a code corresponding with the SCATS system as indicated in the map. They operate with a common cycle length during the morning peak period, with the maximum cycle length at 120 seconds. Phase splits of almost all intersections also operated with one split plan influenced fixed-time operation during the study period, except for TS3005. A tram line runs along the study area, in the median strip on King William Street from Victoria Square, then turning left at TS3001 (where there is a hook turn for buses only at the intersection). Right turns are permanently banned on King William Street while right turns from the cross street are banned during peak periods, except at TS3001 and TS3005.

Figure 2: Study area



Source: modified from the Google map (Europa Technologies and Tele Atlas, 2010)

4.2 SCATS VS data

SCATS VS collects traffic-count data by inductive loop detectors located at stop lines. Traffic passing over a detector is counted and recorded as the total number in a five-minute interval. SCATS VS data from the five intersections on King William Street for the period 7.35 to 9.20 AM on the 22 February 2008 were selected for an exploratory analysis of vehicular traffic in this study. All data of detectors related to trams, buses and bicycles were excluded. All data extracted from the database were primarily examined seasonality of data by sequential plots. However, there were two intersections within the study area that provided incomplete records. These were TS3002 (no records from detectors number 9 and 10 referred to Strategic Approach (SA) 190 on Hindley Street) and TS3004 (no records from detectors

number 5, 6, 7, 8, 9 and 10 referred to Strategic Input (SI) 229 and 317 on King William Street and Waymouth Street respectively). Therefore the analysis by spectral density and autocorrelation functions was only performed at the intersections with more comprehensive traffic data recorded for all legs.

According to the sequential plot analysis, cyclical patterns of data were revealed in both lane and approach based analysis. Considering approach flow rates by vehicles per lane of existing data, traffic patterns were dominated by the approach flows of Southbound traffic (SA189, 310, 112, 240) on King William Street for all most all intersections except TS3001 which was dominated by cross traffic (SA121) on North Terrace. Looking at the lane based traffic flows, similar patterns were found for Southbound directional traffic was presented. Through movements in the median lane mostly illustrated the highest flow rates (D7 at TS3002, D2 and 3 at TS3003, D3 at TS3004 and D3 at TS3005) excluding TS3001 which was dictated by right turning movement on D20 (as a far right detector) while most of turning or shared turning and through movements presented the lower flow rate.

5. Traffic analysis

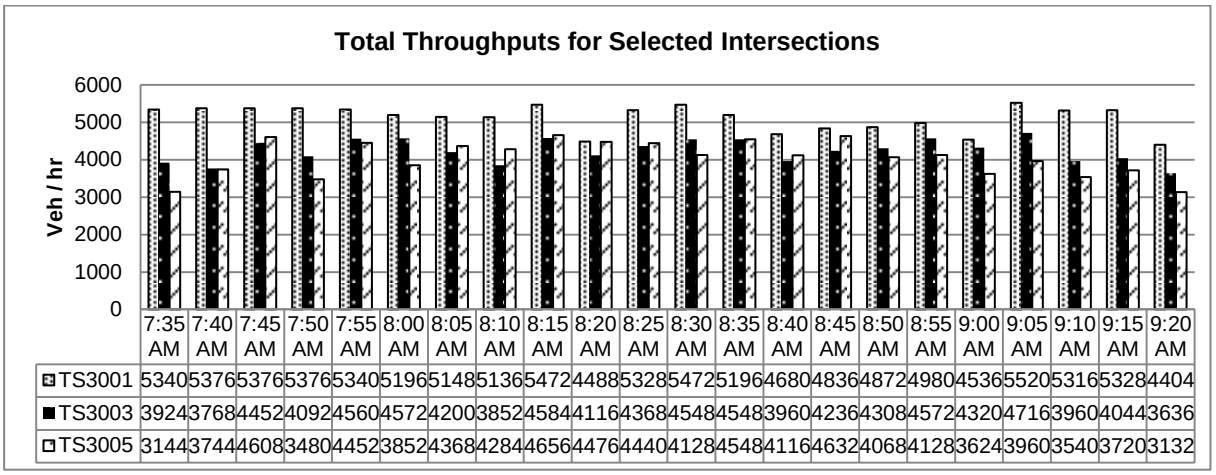
Apart from the sequential plots, to examine the SCATS VS data for all intersections as described in the previous section, this section analyses traffic data of the intersections with more comprehensive records including TS3001, TS3003 and TS3005 in terms of spatial distribution of traffic flows, and time series analysis by spectral density and autocorrelation function plots.

5.1 Spatial distribution of traffic flows

As closely-separated intersections on an urban arterial street, most of vehicles could be assumed to be through traffic travelling in platoons between intersections. Total intersection volume could be applied as an analysis of spatial distribution characteristics of traffic flows on the link (Fu et al., 2009). Total throughputs of intersections and average of total flows per lane were observed to indicate the spatial distribution across the link. Figure 3 presents the total throughputs of three intersections while Figure 4 presents the average total flow rates per lane during the morning peak period.

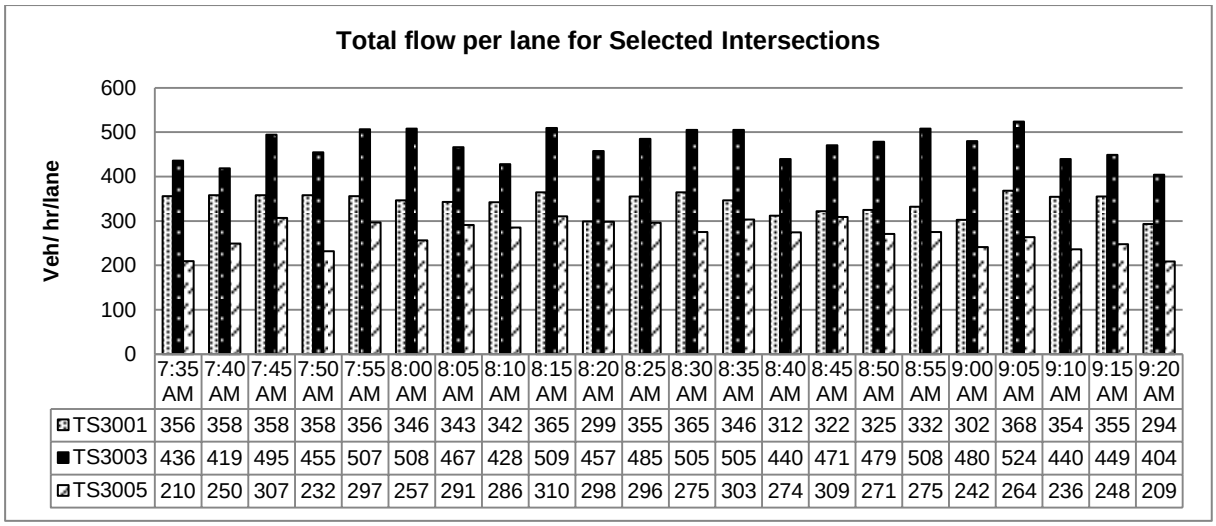
The total throughput graph in Figure 3 shows that TS3001 had the highest throughputs compared with other intersections in the study area, while when considering lane based flow TS3003 became the dominant intersection. The result of the highest total throughput may be influenced by the physical geometry of TS3001 which accommodates higher numbers of traffic lanes for the crossing street (two-way total 9 lanes on North Terrace) compared with other intersections (6 lanes at TS3002 and 8 lanes at TS3005). On lane-base flow data in Figure 4, TS3003 presented the highest avarage flows per lane during the peak period. This may result from TS3001 accommodating some underutilised lanes, such as a general effect of lower traffic flows on turning-movement lanes, while TS3003 mainly has through movement resulted from turning bans during the study period. For TS3005, total throughputs were generally equal to TS3003 while the average flows per lane presented the lowest rate in the group. This may indicate that TS3005 accommodated less traffic compared with TS3001 and TS3003.

Figure 3: Intersection throughputs



	7:35 AM	7:40 AM	7:45 AM	7:50 AM	7:55 AM	8:00 AM	8:05 AM	8:10 AM	8:15 AM	8:20 AM	8:25 AM	8:30 AM	8:35 AM	8:40 AM	8:45 AM	8:50 AM	8:55 AM	9:00 AM	9:05 AM	9:10 AM	9:15 AM	9:20 AM
TS3001	5340	5376	5376	5376	5340	5196	5148	5136	5472	4488	5328	5472	5196	4680	4836	4872	4980	4536	5520	5316	5328	4404
TS3003	3924	3768	4452	4092	4560	4572	4200	3852	4584	4116	4368	4548	4548	3960	4236	4308	4572	4320	4716	3960	4044	3636
TS3005	3144	3744	4608	3480	4452	3852	4368	4284	4656	4476	4440	4128	4548	4116	4632	4068	4128	3624	3960	3540	3720	3132

Figure 4: Average flow rate per lane



	7:35 AM	7:40 AM	7:45 AM	7:50 AM	7:55 AM	8:00 AM	8:05 AM	8:10 AM	8:15 AM	8:20 AM	8:25 AM	8:30 AM	8:35 AM	8:40 AM	8:45 AM	8:50 AM	8:55 AM	9:00 AM	9:05 AM	9:10 AM	9:15 AM	9:20 AM
TS3001	356	358	358	358	356	346	343	342	365	299	355	365	346	312	322	325	332	302	368	354	355	294
TS3003	436	419	495	455	507	508	467	428	509	457	485	505	505	440	471	479	508	480	524	440	449	404
TS3005	210	250	307	232	297	257	291	286	310	298	296	275	303	274	309	271	275	242	264	236	248	209

5.2 Time series analysis

Using time series to analyse short-term batch of traffic flow data, spectral density functions of the data were plotted to examine traffic characteristics. The autocorrelation function of smoothed data by moving average was plotted for both lane-by-lane and group by approach. Time series analysis of data may extract periodic fluctuations, and the significant of fluctuation is useful for incorporation in forecasting models (Bonsall, 1997).

The autocorrelation function describes a theoretical stochastic process and the function discloses how the correlation between two values in time series changes as their separation changes (Box and Jenkins, 1976). The autocorrelation function (ACF) plot can differentiate cyclical data from random patterns, and could be used to investigate the stationarity of the data as well. The ACF plot of extremely randomness may be represented by all zero or close to zero. The stationarity of data is represented by the plot decaying to zero.

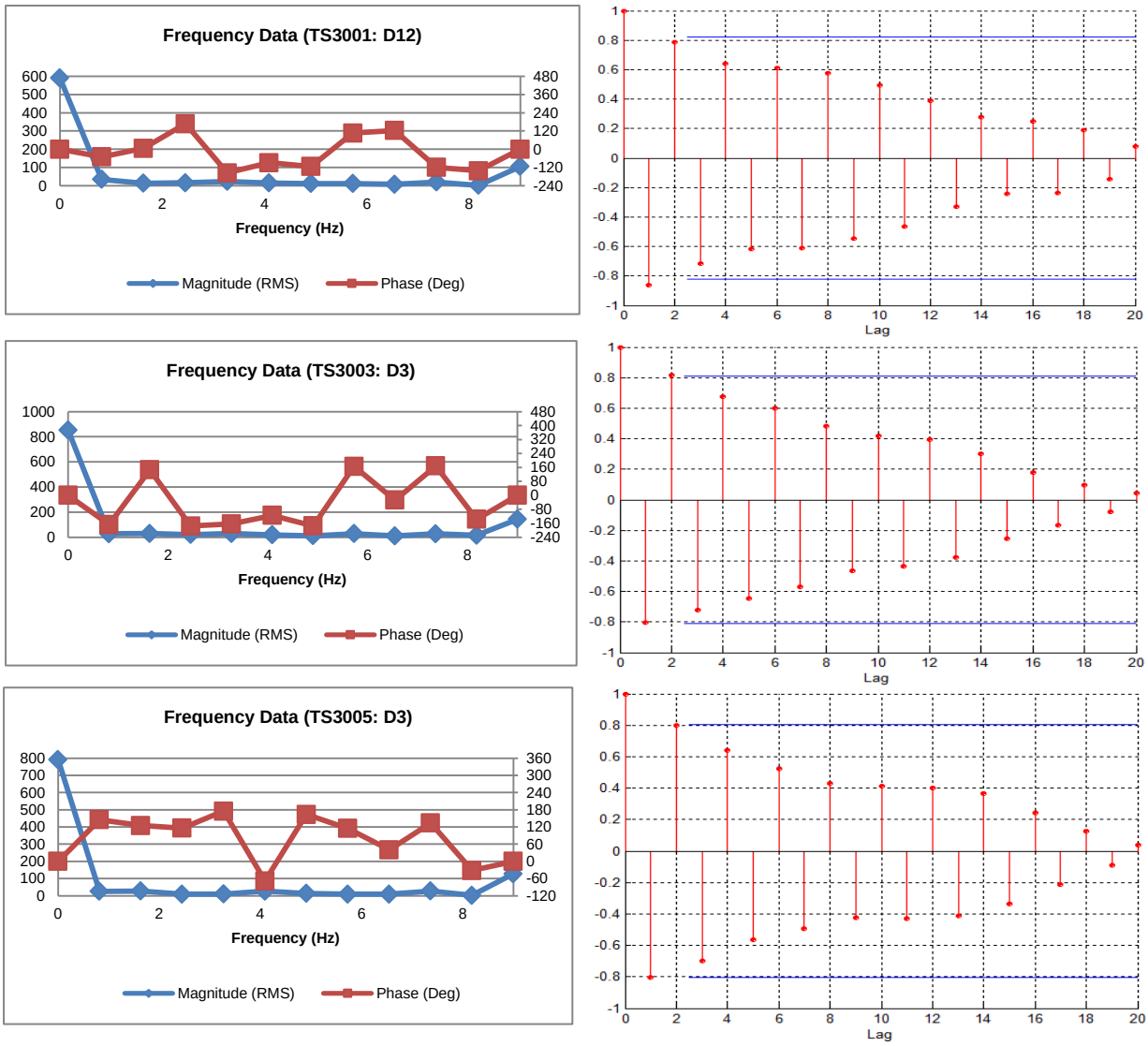
As SCATS stop-line traffic data may be considered as periodic stationary data, the use of time series analysis technique should be able to differentiate the traffic characteristics and identifying the suitable model to represent the data.

5.2.1 Lane-by-lane spectral density and autocorrelation functions analysis

All lane-based data was analysed by spectral density and auto correlation functions. The results show that this technique could distinguish different traffic patterns in different lane configurations, as may be seen in some selected sample plots. The through movement plots in Figure 5 display similar shapes, while the sample through movement plot on North Terrace, as an exception, is shown in Figure 6.

The ACF plots of through movements for all intersections in Figure 5 present similar shapes which direct the pattern of alternating positive and negative differences while decaying to zero. This plot shape indicates an autoregressive model and confirms the stationary of the data series. On other hand, a sample plot of through movement on North Terrace (Figure 6) shows a different pattern which looks like a sinusoidal model decaying to zero, and for which the spectral density function and the last frequency are also different from the sample of most general shapes. This may be the result of the adjacent turning movement lane.

Figure 5: Spectral density and autocorrelation functions of through movement



The sample plots of turning movements are show in Figure 7. Figure 8 shows a similar plot for the shared movements.

Figure 6: Spectral density and autocorrelation functions of through movement on North Tce

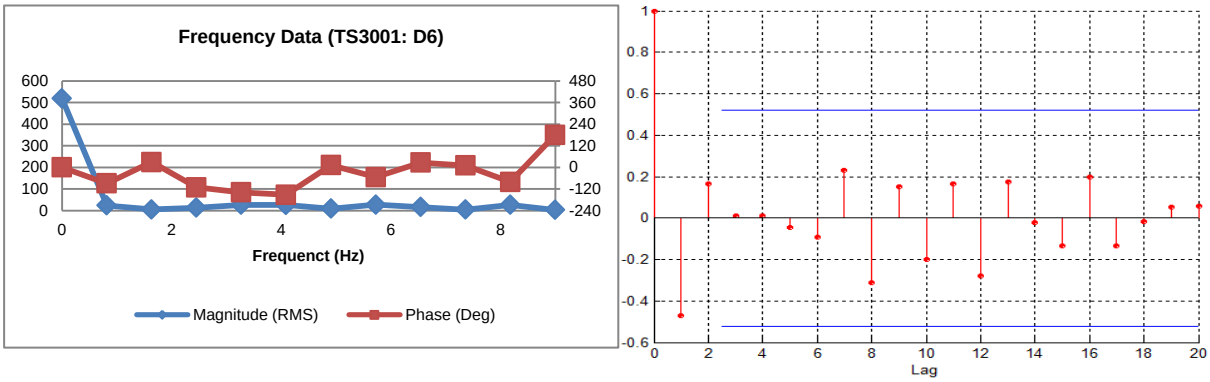
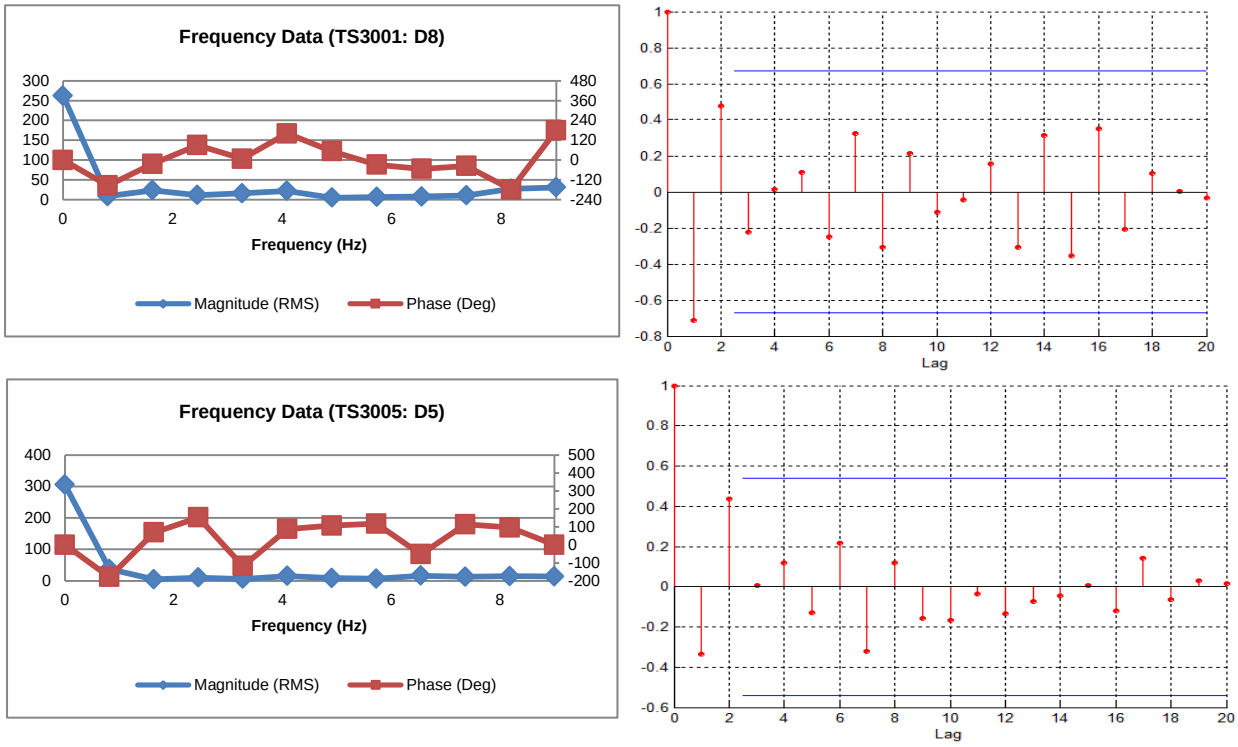
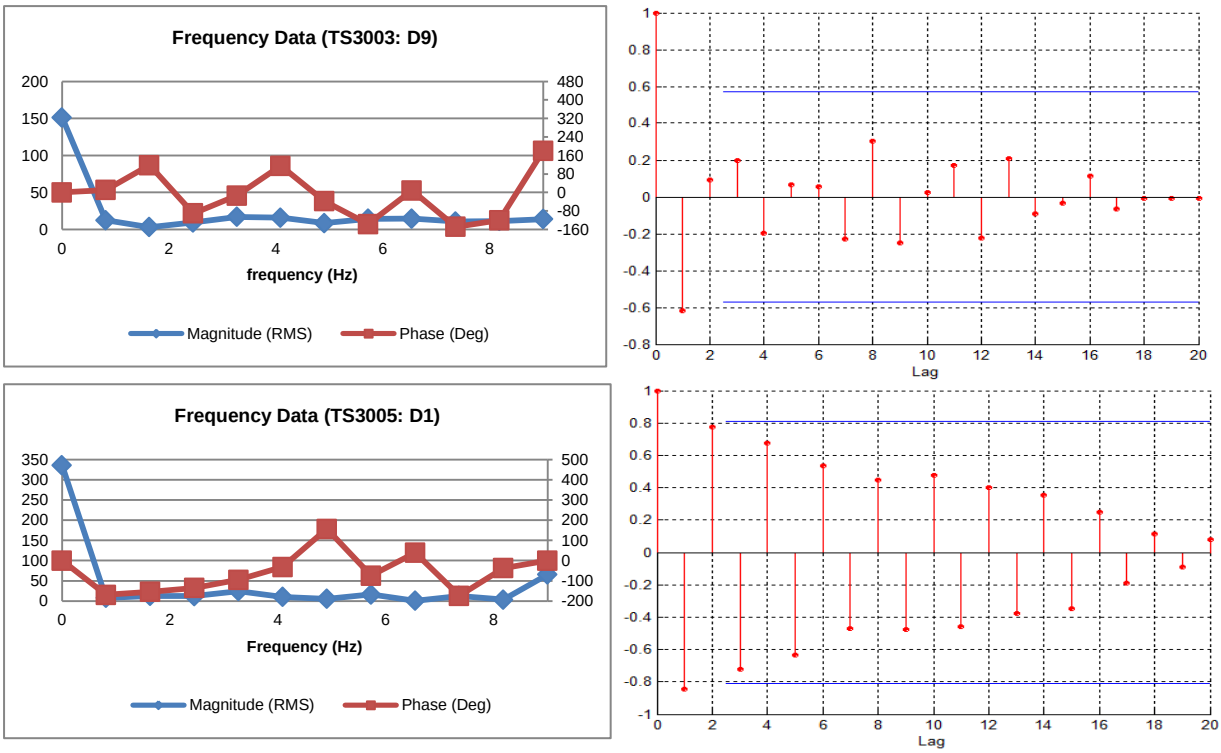


Figure 7: Spectral density and autocorrelation functions of dedicated turning movement



The ACF plots of turning movement lanes in Figure 7 are similar for left and right turning movements. They represent a sinusoidal model decaying to zero as well as the spectral density function and the last frequency are near zero, which is different from the typical plots of through movements.

Figure 8: Spectral density and autocorrelation functions of shared movement



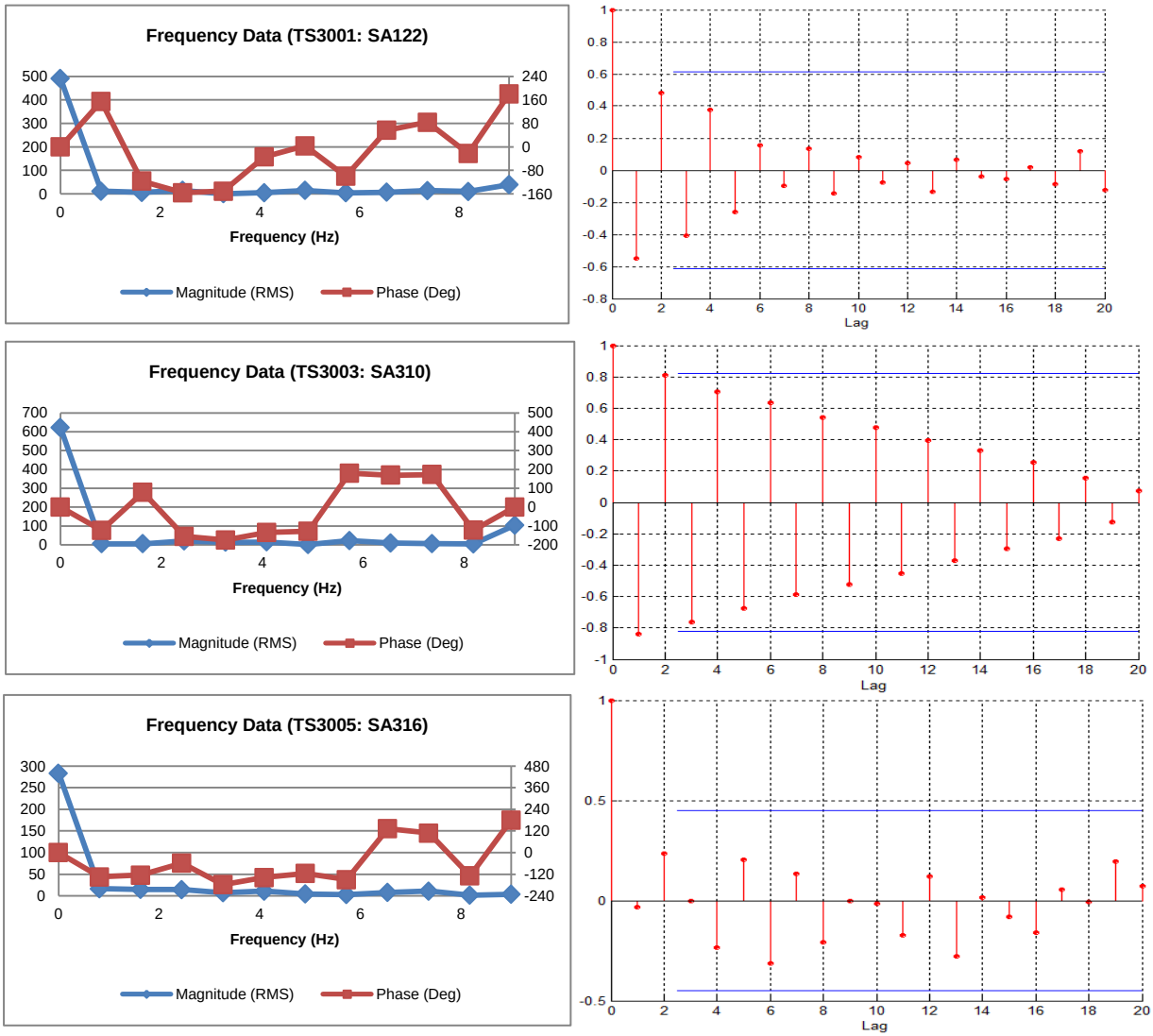
In the case of the shared movements in Figure 8, the sample plots suggest different shapes. The shared lane at TS3003 shows the pattern of turning movement plot while the shared lane at TS3005 shows the pattern of through movement plot. This may indicate that the one representing the turning movement pattern may have a higher degree of turning traffic than the other. However, as the SCATS VS data cannot provide the turning movement percentage in the shared lane, this aspect requires further investigation.

In summary, the initial study indicates that traffic flow data generally display different characteristics with regard to lane configuration (through movements versus turning movements). The proposed time series technique using autocorrelation plots could be used in identifying and modelling SCATS VS data. As indicated by the different shapes of the ACF plots, lane by lane basis of model should be considered to maximise reliability in forecasting models. In addition, the assumptions for shared-lane patterns require further investigation, including direct observations of shared lane traffic movements and perhaps the use of simulation models.

5.2.2 Approach-based spectral density and autocorrelation functions analysis

ACF plots of approaches as calculated from average traffic flows per lane presents different shapes as illustrated for the data sample shown in Figure 9. The sample from different intersections shows diverse shapes, with the plot for TS3001 combining left and through movement (thus representing a partial through movement pattern) rapidly decays to zero, while the plot at TS3003 combining left and through movement represents a through movement pattern and the plot at TS3005 combining left, right and through movement represent the turning movement pattern. This may also be the result from the weighted values from different lane flows of the approach which are based more on through or turning traffic in the average process or may be the result from the turning movement percentage of combined lane within the approach. However, further investigation is also required for this aspect by investigating the dominant of the average approach flow values and a turning movement percentage investigation similar to the proposed further study indicated for the ACF plot of turning movement pattern.

Figure 9: Spectral density and autocorrelation functions of approach



6. Conclusion and further study

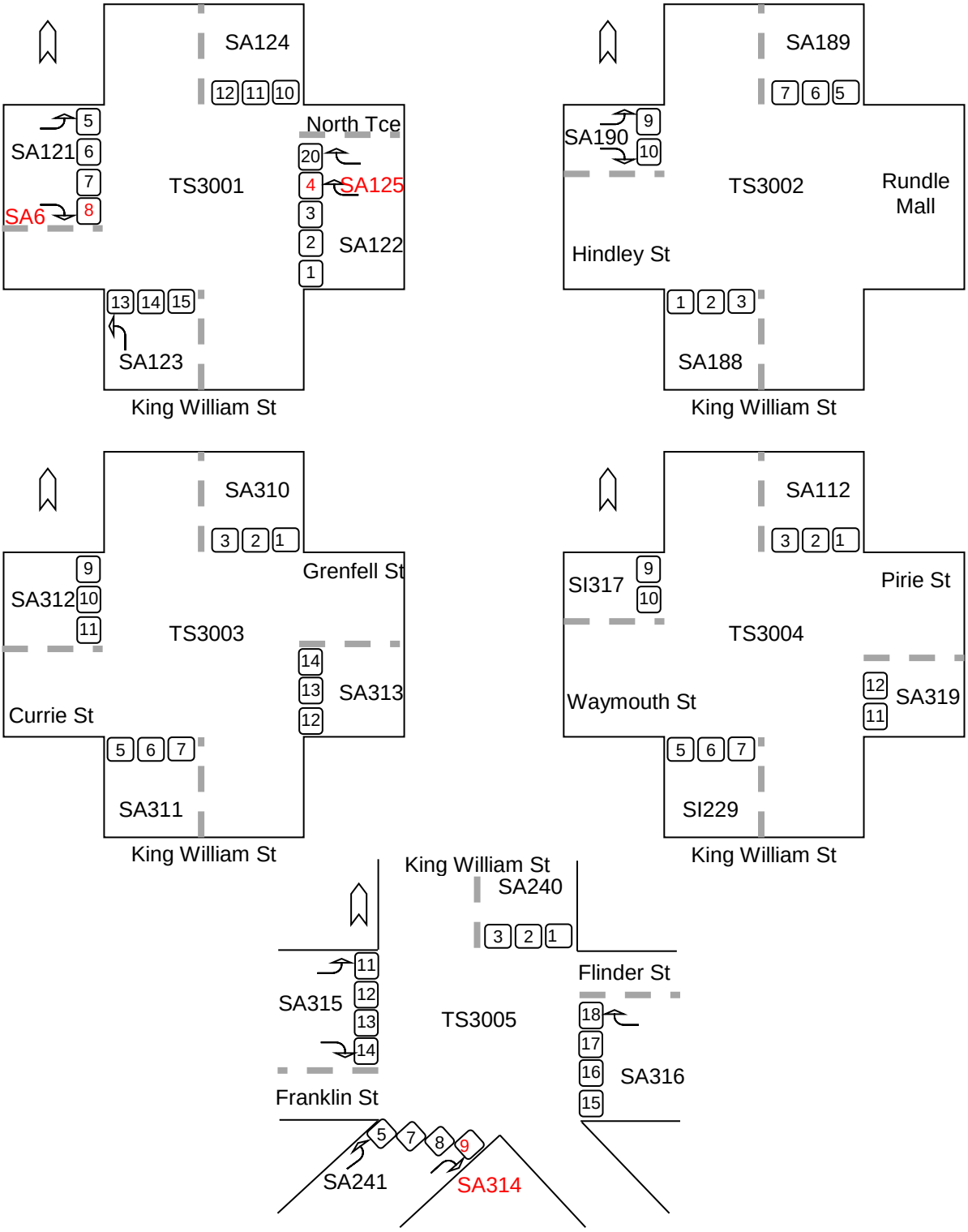
This study applied time series analysis techniques in a preliminary examination of stop-line flows at signalised intersections, as recorded by the traffic control system (SCATS). The sequential plots directed to the periodic nature of data and the spectral density and autocorrelation function plot could indicate the traffic characteristics on different lane configurations by differentiating the through movement pattern from the turning movement pattern. The plot also suggested that the data could be modelled by autoregressive methods, and different models for different lanes should be considered. This model might be useful in terms of short-term traffic prediction for the control system as well as for estimating missing data in the database. To validate the proposed technique, supplementary data sets for different locations and conditions are required. Within the existing database used in the research, turning movement percentages could not be obtained for any shared lanes, therefore conclusions related to shared lane traffic required further investigation by using more comprehensive data. The simulation approach may be helpful in generating the data needed for further study.

Acknowledgements

The authors would like to thank Dr Nikolaos Vogiatzis for the help in extracting data from NEXUS database and Mr Branko Stazic for the insights in SCATS systems and recorded data.

Appendices

A: Intersection layouts



References

Akcelik R, Besley M & Roper R (1999). *Fundamental relationships for traffic flows at signalised intersections,* Vermont South, Vic., Australian Road Research Board

Bonsall P W (1997). Principles of transport analysis and forecasting. *In:* O'FLAHERTY, C A (ed.) *Transport planning and traffic engineering.* London, New York: Arnold ; Wiley

Boumediene A, Brahimi K, Belguesmia N & Bouakkaz K (2009). Saturation flow versus green time at two-stage signal controlled intersections. *Transport,* (24)**,** 288-295

Box G E P & Jenkins G M (1976). *Time series analysis : Forecasting and control,* San Francisco, Holden-Day

Deshpande R. (2009). *Investigation of policies for arterial street operations.* Ph.D. 3388366, University of Massachusetts Lowell

Deshpande R, Gartner N & Zarrillo M (2010). Urban street performance. *Transportation Research Record: Journal of the Transportation Research Board,* (2173)**,** 57-63

Drew D R (1968). *Traffic flow theory and control,* New York, McGraw-Hill

Europa Technologies & Tele Atlas. (2010). *Google map*.

Fu W, Jie L, Yonghui S & Qiuping W. (2009) Published. Traffic flow characteristics analysis at intersection in wuhan city. Management and Service Science, MASS '09. International Conference on, 20-22 Sept. 2009. 1-4

Gartner N & Wagner P (2004). Analysis of traffic flow characteristics on signalized arterials. *Transportation Research Record: Journal of the Transportation Research Board,* (1883)**,** 94-100

Gartner N & Deshpande R (2009a). Assessing quality of progression with cyclic coordination functions. *Transportation Research Record: Journal of the Transportation Research Board,* (2130)**,** 66-74

Gartner N H & Deshpande R (2009b). Harmonic analysis and optimization of traffic signal systems. *In:* LAM, W H K, WONG, S C & LO, H K (eds.) *Transportation and traffic theory 2009: Golden jubilee.* Springer US

Gartner N H, Deshpande R M & Stamatiadis C. (2010) Published. Performance potential of signalized arterials and intersections. 12th WCTR, July 11-15 2010 Lisbon, Portugal.

Kreer J B (1976). Factors affecting the relative performance of traffic responsive and time-of-day traffic signal control. *Transportation Research,* (10)**,** 75-81

Nuhertz (2011). Spectra. 1.13 ed.: Nuhertz Technologies, L.L.C.,

Ogden K W & Bennett D W (1989). *Traffic engineering practice,* Clayton, Vic., Dept. of Civil Engineering Monash University

Peeta S & Anastassopoulos I (2002). Automatic real-time detection and correction of erroneous detector data with fourier transforms for online traffic control architectures. *Transportation Research Record: Journal of the Transportation Research Board,* (1811)**,** 1-11