# Characterisation of Incidents on an Urban Arterial Road

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*The early warning of incidents on urban arterial roads in a congested city can reduce delay, accidents and pollutant emission. Freeway incident detection systems implemented in recent years may not be suitable for arterial incidents. Arterial incident detection is more difficult. The traffic flow on an arterial road is not conserved from the upstream end of a road link to the downstream end because urban traffic does turn in and out of side-streets, car-parks and local residences. Roadside friction such as kerbside parking and shopping traffic also tends to create apparent incidents which are in fact frequent and normal events. This paper develops a definition for an arterial incident and describes a case study on an arterial road in Melbourne, Australia. The study shows that detectors upstream of an incident are more useful for incident detection than downstream detectors. It also identifies occupancy and speed as the appropriate parameters to characterise and detect arterial incidents.*

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## INTRODUCTION

Road vehicle incidents such as car crashes, truck load spills, or simply vehicle breakdowns are common occurrences in large urban centres. These incidents often result in excessive travel delay, accidents and pollutant emission. It is vital that incidents be alerted to local traffic authorities as quickly as possible.

Automatic incident detection (AID) on freeways and the management of these incidents have received much attention in recent years in Australia (see, e.g. Luk and Sin, 1992; Snell et al. 1994; Dia and Rose, 1997) and other countries. Freeway AID systems together with driver information systems are now in operation in various cities. Most of these systems rely on inductive loop sensors installed at regular intervals along a freeway (or a tunnel) to detect abnormal changes in traffic parameters. A control centre receives a message or flag if the frequency and magnitude of these changes exceed certain threshold values. Freeway incident detection algorithms have also developed from rule-based techniques to pattern recognition using artificial neural networks.

While freeway incident management in general has reached a mature stage of development, the detection of incidents on arterial roads has received relatively less attention. A large proportion of vehicle travel in a city is on arterial roads rather than on freeways, especially in cities where urban freeway systems are still in a developing stage. There is also no obvious reason why incidents should occur less on arterials than on freeways. The degradation of network performance due to incidents is an important issue to road and traffic authorities. The lack of attention may be due to the complexity of the issues involved. This paper explores these issues and aims to:

- Identify the differences between freeway and arterial road incidents;
- Outline possible approaches to detect arterial incidents;

- Provide the results from a case study in Melbourne, Australia.

The case study in Melbourne aims to characterise some arterial incidents, i.e. study the impact of these incidents on the three basic traffic parameters: occupancy, speed and flow in an arterial road context. The characterisation of incidents is an important task preceding the development of detection algorithms.

## DIFFERENCES BETWEEN FREEWAY AND ARTERIAL INCIDENTS

It is common knowledge that roadside friction such as a parking manoeuvre on a busy arterial road causes disruptions to the smooth flow of traffic. Treating this disruption as an incident and informing a traffic control centre to take actions is difficult to justify. On the other hand, a vehicle breakdown on a freeway is definitely an incident worthy of automatically informing the control centre staff who then manage the incident. It is useful to identify the differences between the two incident types and, from these differences, develop a definition for an arterial incident. A proper definition should also ultimately lead to an appropriate detection framework.

The major differences between the two types of incidents are as follows:

(a) *Interrupted and uninterrupted flows* – Freeway traffic is a freely moving stream without the interruption of any traffic control facilities. Arterial flows are often interrupted by signalised and unsignalised intersections. They are often non-random flows because of the bunching effect of traffic signals along an arterial.

(b) *Conservation of flows* – Traffic entering a freeway segment must be equal to the traffic leaving that segment in the absence of on- or off-ramps. Flow conservation must still hold where a ramp exists in that segment if ramp traffic counts are considered. This principle facilitates incident detection on freeways. However, with traffic turning into or entering from side-streets, car-parks and other traffic sources and sinks on arterial roads, the flow conservation principle does not easily apply.

(c) *Lane blockage* – As already mentioned, a lane blocked on a freeway by any incident is a major event with a significant loss of road capacity. On the other hand, roadside friction is common on arterial roads. Alternative routes are available for traffic diversion in a surface street network. The blockage of a single lane on an arterial is an incident only if the impact is severe and lasts for more than, say, 30 minutes.

(d) *Incident duration* – The objective of a freeway incident algorithm is to detect incidents that last for a short duration of several minutes. The objective of arterial incident detection could be the screening out of 'minor' events to identify the more dramatic incidents that last over a longer time period.

(e) *Spatial impact* – The impact of an incident on a freeway is usually localised to a specific freeway route due to the difficulty for traffic to divert out of a freeway. Arterial incidents easily impact upon adjacent streets and even parallel arterial roads. This difference may imply that the detection of arterial incidents should cover a larger road network than detecting freeway incidents.

(f) *Discipline* – On arterial roads, the driver behaviour is expected to be less disciplined than that on freeway.

It is now possible to propose a definition for an arterial road incident. An arterial incident is an unexpected and non-recurrent event that significantly reduces link capacity and reduces travel speeds, and has a significantly longer term impact at specific locations than on freeways. An event that causes minor disruptions to traffic flow on arterial roads is therefore not to be treated as an incident. Some such examples are kerb lane parking in off-peak or inter-peak period and vehicle breakdowns near the entry end of a link.

New vehicle detection technologies in recent years have influenced the development of AID systems. In particular, area sensors using video imaging technology may replace the traditional inductive loops. Identifying a slow-moving or stationary object in a video image of a freeway segment as an incident event offers an attractive alternative to installing loop sensors. Video cameras are also invaluable tools in a traffic control centre to visually monitor a road network and can act as point sensors providing flow, speed and occupancy data. For the discussions below, it is assumed that point sensors and hence point processing remain a useful technique for incident detection.

## APPROACHES TO ARTERIAL INCIDENT DETECTION

An urban traffic control (UTC) or signal coordination system plays an important part in managing the progression of traffic through an arterial road. It can also play a useful role in detecting an incident. This section briefly describes the following three possible approaches to arterial incident detection:

- SCOOT-based method (Bowers and Bretherton, 1995),
- SCATS-based method (Luk, 1989 and 1992),
- Travel time data from floating-cars in real time (Bhandari et al., 1995; Sethi et al., 1995).

### Incident Detection in SCOOT

SCOOT is an adaptive UTC system developed by the then Transport and Road Research Laboratory in UK. It employs detectors located at the upstream end of a road link to capture traffic profiles, which are then assumed to progress down the link with a dispersion model.

Delay and other performance indicators are calculated from the predicted arrival profile and current signal timings. The detector at the upstream end of a road link can also identify a large occupancy time – an indication of the blocking of a road link possibly due to an incident.

Using SCOOT data in flow and occupancy, Bell and Thancanamootoo (1988) reported some findings on arterial incident detection research. Their method is to calculate the expected upper and lower bounds of the cyclic occupancy for a particular site at a particular level of congestion. The algorithm considers the smoothed occupancy from adjacent pairs of sensors, one upstream and one downstream. Between a pair of sensors, an incident has occurred. If the upper bound of the upstream occupancy is exceeded, an incident is expected downstream of the upstream detector. If the downstream occupancy lower bound is infringed at the same time, then an incident is confirmed. The upper and lower bounds are adaptive thresholds that vary with prevailing traffic conditions. Some tests were carried out using simulated data but no significant empirical results have been reported.

Bowers and Bretherton (1995) reported the integration of incident and congestion management in SCOOT. A database (called ASTRID) containing normal traffic flow data retrieved from SCOOT was prepared for Southampton. A separate real-time incident detection system (called INGRID) was tested using the ASTRID database. An evaluation suggested that 'severe' incidents can be detected after 4 min with a 100 per cent detection rate and with confidence. The detection algorithm consists of two parts. The first part examines current traffic data for sudden changes in flow and occupancy. The second part uses the reference data from ASTRID. It compares the current traffic situation with the reference data, making use of standard deviations and mean values to determine a confidence level. `

## Incident Detection in SCATS

SCATS is a traffic adaptive UTC system developed in Australia. It normally employs 24 loop sensors located near the stopline of an intersection for timing optimisation. The absence of a sensor at the upstream end of a road link does not allow a direct indication of link blocking due to an incident, although the stopline sensors of an adjacent upstream intersection can indicate conditions of very low throughput.

Luk (1989) proposed a scheme to introduce queue estimation in SCATS at the end of each signal cycle as an on-line performance indicator. The queue estimates are not predictive as in SCOOT and therefore can be quite accurate, and can be an optional feedback for timing optimisation. He found that on-line queue estimation was also useful in identifying those signal cycles with excessively long queues. In other words, it could be useful for arterial incident detection.

On-line queue estimation was implemented in the TRACS signal system in Queensland, Australia and the accuracy was in the range of 10 – 30 % (Luk, 1992). More investment in communication hardware and software is required to improve this level of accuracy, but the concept of estimating queue lengths on-line for performance monitoring and incident detection with the deterministic queuing theory is fundamentally sound.

### Travel Time and Speed Data in Real Time

In recent years, automatic vehicle identification or vehicle tagging is promoted as useful for many traffic management applications, including incident detection. It can implement measures such as electronic road pricing, public transport priority, freight vehicle monitoring and dynamic traffic management in general. Real-time travel times or speeds in an urban network are now easily available using automatic vehicle identification technologies. They can indicate the level of congestion and other information if enough tagged or tracked vehicles are ‘floating’ in the traffic streams.

Using floating or probe cars to monitor travel time and delay is an established method. What is new is the potential of obtaining a large number of travel time or speed samples efficiently throughout the day. An accurate picture of delays in various parts of a city could be possible.

An example of using real-time travel time data for arterial road management is the ADVANCE project in Chicago (Bhandari et al., 1995; Sethi et al., 1995). The approach is a combination or fusion of data sources from:

- fixed detectors in a road network,
- floating vehicles with tags,
- other sources, e.g. emergency service centres.

In the ADVANCE project, the fixed detector method monitors flow with detectors at about 110 m from a stopline. The method of incident detection is to calculate the deviation of the prevailing traffic parameters (occupancy and volume/occupancy ratio) from historical data. When floating car data are available, the ratio of historical, non-incident affected travel times and speeds to current travel times and speeds are also calculated. An incident alarm is triggered if various deviations from the norm exceed threshold values. The information from an emergency centre can add further data to confirm whether an incident has indeed occurred in a specific link.

An alternative to vehicle tagging is the Global Positioning System (GPS) making use of several satellites to locate a vehicle at a particular time. GPS could form the basis of an island-wide system for electronic road pricing in Singapore (Ong and Do, 1998). Most taxis in Singapore are now equipped with GPS units for routine despatching. Some 7000 of these units were recently modified to also provide speed data for real-time display in the TrafficScan system in Singapore (see Internet site: www.trafficscan.lta.gov.sg).

The concept of using tagged vehicles as a source of travel time information works well if there are enough travel time or speed samples. In peak hours, this requirement is viable but is certainly difficult to achieve during periods with few tagged vehicles moving in a network. A long travel time sample is also not necessarily an indication of an incident because the driver of a tagged or tracked vehicle may slow down or stop by the roadside for a range of reasons. The filtering of outlying samples is a critical process to turn floating car data into meaningful information. It is argued that the characterisation of an arterial incident is a fundamental issue that goes beyond monitoring and processing travel times or speeds.

## A CASE STUDY ON CHARACTERISING ARTERIAL INCIDENTS

This study attempted to characterise arterial incidents and explored an appropriate platform for their detection. The test site was on a road link in the eastbound direction on Princes Highway East (PHE) in Melbourne. Apart from the usual set of SCATS detectors at the stopline, two extra sets of loop sensors were installed as shown in Figure 1. Three sets of loops were available to collect traffic parameters.

**INSERT** Figure 1 – Study site along Princes Highway East (PHE), Melbourne

It has always been difficult to capture incidents, which are random events in a road network. Dia and Rose (1997) reported the use of time-lapse video recording to capture freeway incidents over time. The absence of strategically located cameras at the study site precluded the chance of video taping arterial incidents for this study. Roadwork events along Princes Highway East were the only available incidents.

Three roadwork events ($W_1$, $W_2$ and $W_3$ in Figure 1) on lane 4 were available for this study. $W_1$ involved the temporary closure of a short segment of about 40 m in the median lane (lane 4). The segment was at 150 m from either the upstream or downstream detector sets. This event occurred at 3:15 p.m. and lasted for 30 min.

Events $W_2$ and $W_3$ occurred on a different day from $W_1$. $W_2$ occurred in the same location as $W_1$ at 2:15 p.m. and lasted for 45 min. The roadwork returned at 3:30 p.m. after a break and shifted 250 m downstream in the same median lane. This third event $W_3$ lasted for 30 min. It was about 100 m upstream of the stopline of the Hawthorn Road intersection. Table 1 provides the detail of these three events.

**INSERT** Table 1 – Three roadwork events on Princes Highway East, Melbourne

Occupancy, flow and speed data were recorded on-site with portable data loggers. SCATS also logged the degree of saturation (DS), green time, space time and volume each cycle, from which occupancy values were derived.

The method of developing a detection scheme is similar to those proposed in Bell and Thancanamootoo (1988) and Bowers and Bretherton (1995). A historical database of incident-free data was first established for each loop sensor. Initially, six days of data on weekdays were collected at the study site. Of these six days, two were on Thursdays. When news that the roadwork events were to be held on Thursdays, data were collected on two more Thursdays of the weeks preceding the roadwork events. Hence, a total of eight days were available for data analysis, with four on the same weekday when the incidents occurred.

These data consisted of occupancy, flow and speed values at a time resolution of 1 min. Data smoothing was further introduced to maintain a reasonably representative set of incident-free data. The average value and the ± 1 standard deviation (s.d.) for all the incident-free data were calculated and smoothed using the method of double exponential smoothing (Makridakis et al., 1983) as follows:

$$\begin{aligned}
\hat{X}_{t+1} &= 2S'_t - S''_t + \left(\frac{\alpha}{1-\alpha}\right)(S'_t - S''_t) \\
S'_t &= \alpha X_t + (1-\alpha)S'_{t-1} \\
S''_t &= \alpha S'_t + (1-\alpha)S''_{t-1}
\end{aligned}$$

where $\hat{X}_{t+1}$ = smoothed occupancy at time t+1,

$S'_t$ = single exponential smoothed value at t,

$S''_t$ = double exponential smoothed value at t,

$\alpha$ = smoothing coefficient, $0 < \alpha < 1$.

The exponential smoothing method has the benefit of requiring very little information to be stored and is particularly suitable for real-time applications. Double exponential smoothing is also more suitable for non-stationary data than single exponential smoothing. A value of $\alpha$ = 0.03 was found to be satisfactory for this study.

The prevailing traffic data were exponentially smoothed and superimposed onto the normal or incident-free data. An incident is defined in the following discussions as an event when the smoothed prevailing traffic parameter exceeds the ± 1 s.d. envelope. This definition was adopted to investigate a conservative approach to arterial incident detection. A ± 2 s.d. envelope would require more substantial changes in the traffic flow parameters before being registered as an incident. The experience from freeway incident detection suggests that a narrower envelope coupled with a perseverance test is an appropriate approach. The results described below seem to suggest that a ± 1 s.d. envelope is reasonable, although more studies would be required to refine the detection threshold values.

In the following analysis, the three incidents are categorised into two cases. Case 1 represents incidents $W_1$ and Case 2 includes both incidents $W_2$ and $W_3$.

**Case 1 - Incident $W_1$**

This event took place between 3:15 to 4:00 p.m. in lane 4. It was at mid-way between the upstream and downstream detector sets. Figures 2, 3 and 4 illustrate the time series variation of the parameters: occupancy, speed and flow respectively. In each diagram, the time series for the upstream and downstream detectors, and for lanes 3 and 4, show the variations before, during and after the incident $W_1$. The impact on lanes 1 and 2 nearer to the kerb-side was small and the corresponding time series are not shown.

In lane 4, the occupancy at the upstream detector set (Figure 2) decreased as a result of roadwork but was still within the ± 1 s.d. envelope. On the other hand, occupancy went up in lane 3 due to the traffic diverted from lane 4. The increase exceeded the ± 1 s.d. envelope thus registering a potential incident. It is interesting to note the differences between the upstream and downstream detector sets. The downstream detector set did not register much deviation from the average incident-free time series.

The speed data in Figure 3 showed values falling below the lower bound of the ± 1 s.d. envelope in both lanes 3 and 4 upstream of the incident. The downstream detectors again showed little impact during the incident.

An interesting result was the lack of significant fluctuations in the flow parameter during the incident (Figure 4). The upstream detectors in both lanes did not register significant changes in flow during the incident. The lane 4 detector recorded a drop in flow during $W_1$ (but within the ± 1 s.d. envelope) and the lane 3 detector recorded a corresponding increase in flow but was well within the envelope. The downstream detectors register even less impact.

Due to logistical problems, the on-line system monitoring facility in SCATS did not record traffic data when incident $W_1$ occurred. The facility was available during incidents $W_2$ and $W_3$.

**INSERT** Figure 2 – Occupancy at upstream and downstream detector sets (Case 1)

**INSERT** Figure 3 – Speed at upstream and downstream detector sets (Case 1)

**INSERT** Figure 4 – Flow at upstream and downstream detector sets (Case 1)

### Case 2 - Incidents $W_2$ and $W_3$

These two incidents occurred in the same afternoon. The roadwork first started at location $W_2$ and, after a break of 30 minutes, moved to location $W_3$ (see Figure 1 and Table 1).

Figure 5 shows the variation of occupancy values from the SCATS stopline detectors in lanes 3 and 4. The lane 3 occupancy values were within the ± 1 s.d. envelope throughout the two incidents. The lane 4 detector did show a decline due to the diversion of traffic away from this lane. The change was small, even though incident $W_3$ was only 100 m upstream of the detector. The cycle length and DS values in SCATS also did not show significant changes due to these two incidents and will not be presented.

**INSERT** Figure 5 –SCATS occupancy at Hawthorn Road intersection (Case 2)

The earlier results from Case 1 suggest that occupancy and speed are the more sensitive parameters to characterise an arterial incident. Figures 6 and 7 illustrate their variations in response to incidents $W_2$ and $W_3$.

In Figure 6, the impact on the occupancy of the upstream detector in lane 3 due to $W_2$ was large as expected because of traffic diversion from lane 4 to lane 3. The impact in both lanes and in both detector sets became large when the incident moved to location $W_3$. Note that both the upstream and downstream detector sets became upstream detectors when the incident moved to $W_3$ (i.e. $W_3$ was at 400 m away from the upstream set and 100 m from the downstream set). The relative increase in impact due to $W_3$ was most likely due to the increase in traffic volumes as the p.m. peak period began at around 4:00 p.m. at the test site.

The speed values in Figure 7 showed similar results. Incident $W_3$, in a congested flow situation, was able to influence a detector up to 400 m upstream.

**INSERT** Figure 6 – Occupancy at upstream and downstream detector sets (Case 2)

**INSERT** Figure 7 – Speed at upstream and downstream detector sets (Case 2)

### Summary of Findings

The three roadwork events in this case study are not minor events according to the definition previously developed. They took place on a median lane and lasted sufficiently long to allow some understanding of the way traffic reacted to these incidents. The key findings from this case study are as follows:

(a) Of the three traffic parameters: occupancy, speed and flow, the flow parameter appears to be the least sensitive indicator of changes due to an incident on an arterial road. Speed is likely to be the most sensitive. If cameras are available along an arterial road, it would be quite practical to monitor speed accurately lane-by-lane across a carriageway using image processing technologies.

(b) In incidents $W_1$ and $W_2$, a detector 150 m downstream of an incident did not register significant changes in occupancy, speed or flow. This observation is likely due to traffic diverting out of lane 4 and returning to the same lane downstream of these incidents. Note that the stopline detectors in SCATS also failed to register changes in occupancy and DS values at 100 m downstream of incident $W_3$.

(c) The sphere of influence from these results would appear to be within 150 m upstream of an incident in moderate flows of about 600 veh/h per lane, and possibly beyond 400 m in a congested flow of 800 veh/h per lane and above. A reasonable detector spacing is probably about 300 m. This spacing allows an incident at a distance up to 300 m downstream of the detector to produce significant impact on the upstream detector in near-congested conditions, i.e. resulting from a major incident. It is assumed that traffic data downstream of an incident are not particularly useful for identifying an incident.

(d) The results also suggest that an appropriate incident detection algorithm for arterial roads should make use of lane-by-lane data, rather than carriage-wide data.

(e) The 1 min resolution for data collection and processing seems appropriate. The need for a fast response time on a freeway with a time resolution of, say, 20 s (Luk and Sin, 1992) is perhaps less critical on an arterial road. There are usually alternative routes in a surface street system.

(f) The use of an envelope of ± 1 s.d. has screened out traffic flow as an incident indicator in this study (Figure 4). Judging from the results in Figures 2 to 7, this envelope is reasonably wide to reduce erroneous false alarms, and narrow enough to allow both occupancy and speed to be useful incident indicators.

A viable platform for arterial incident detection therefore consists of the following system requirements:

- 1 min resolution for data collection and processing,
- detector spacing of about 300 m,
- detectors capable of measuring either occupancy or speed (preferably both), and
- lane-by-lane provision of vehicle detection.

More incident data are necessary for refining the detection thresholds as already mentioned, and also the related issue of an appropriate perseverance time period. The likelihood of an incident occurring increases with the duration that the incident continuously exceeds the threshold. In Figures 3 and 7, using the speed values from the upstream detectors, the perseverance time needs only be of a short duration, although Bowers and Bretherton (1995) found that a range of 4 to 6.5 min would be needed to indicate an incident with increasing confidence. More data from real-world incidents would clarify these issues. It would appear that video cameras are more appropriate for further studies on arterial road incidents. ‘Virtual loops’ can be easily prepared on an image of an arterial carriageway segment. Such a set-up allows incident and incident-free data to be collected effectively to study a wide range of arterial incidents.

## CONCLUDING REMARKS

This paper has analysed the characteristics of three roadwork incidents on an arterial road. From this characterisation, a viable automatic incident detection framework was proposed. The framework consists of collecting and processing traffic parameters at a time resolution of 1 min, and a detector spacing of about 300 m. Data collection and analysis on a lane-by-lane basis also appear more appropriate than carriageway-wide analysis. More empirical incident data are necessary to investigate this issue and the refinement of threshold levels and the perseverance test period.

It is worth emphasising that an urban traffic control system should incorporate incident detection as part of its daily function. The large number of detectors in, say, a SCATS-controlled network could provide a useful source of data for characterising arterial incidents. Further, as driver information systems become common especially on freeways, they may spread the impact of freeway incidents by diverting traffic onto surface streets. A truly intelligent UTC system should transcend spatial boundaries and manage arterial and freeway incidents in an integrated manner.

## ACKNOWLEDGEMENTS:

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# LIST OF TABLE AND FIGURES

**Table 1 - Three roadwork events on Princes Highway East, Melbourne**

| Event | Time of occurrence | Location |
|---|---|---|
| $W_1$ (day 1) | 3:15 – 3:45 p.m. | 150 m from both the downstream and upstream detectors sets |
| $W_2$ (day 2) | 2:15 – 3:00 p.m. | same as $W_1$ |
| $W_3$ (day 2) | 3:30 – 4:00 p.m. | 100 m from the intersection stopline |

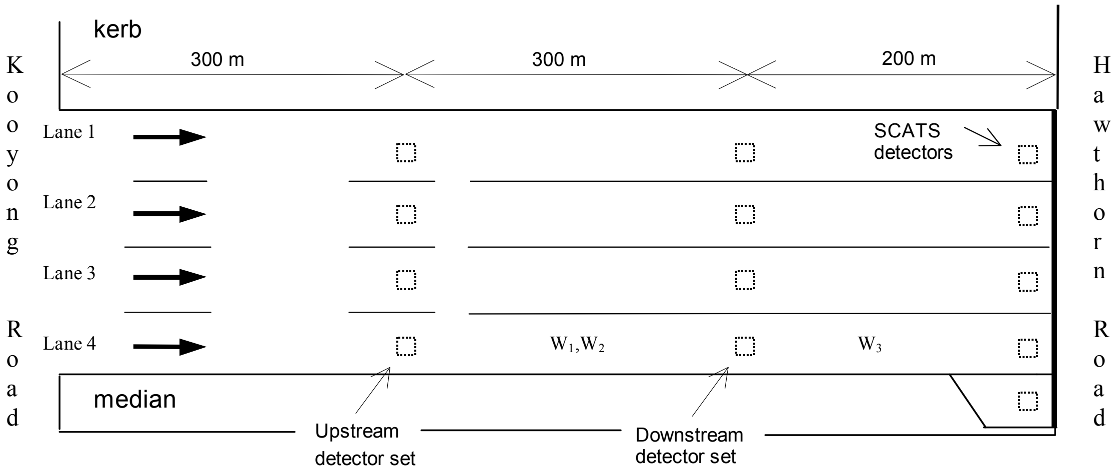

**Figure 1 - Study site along Princes Highway East (PHE), Melbourne**

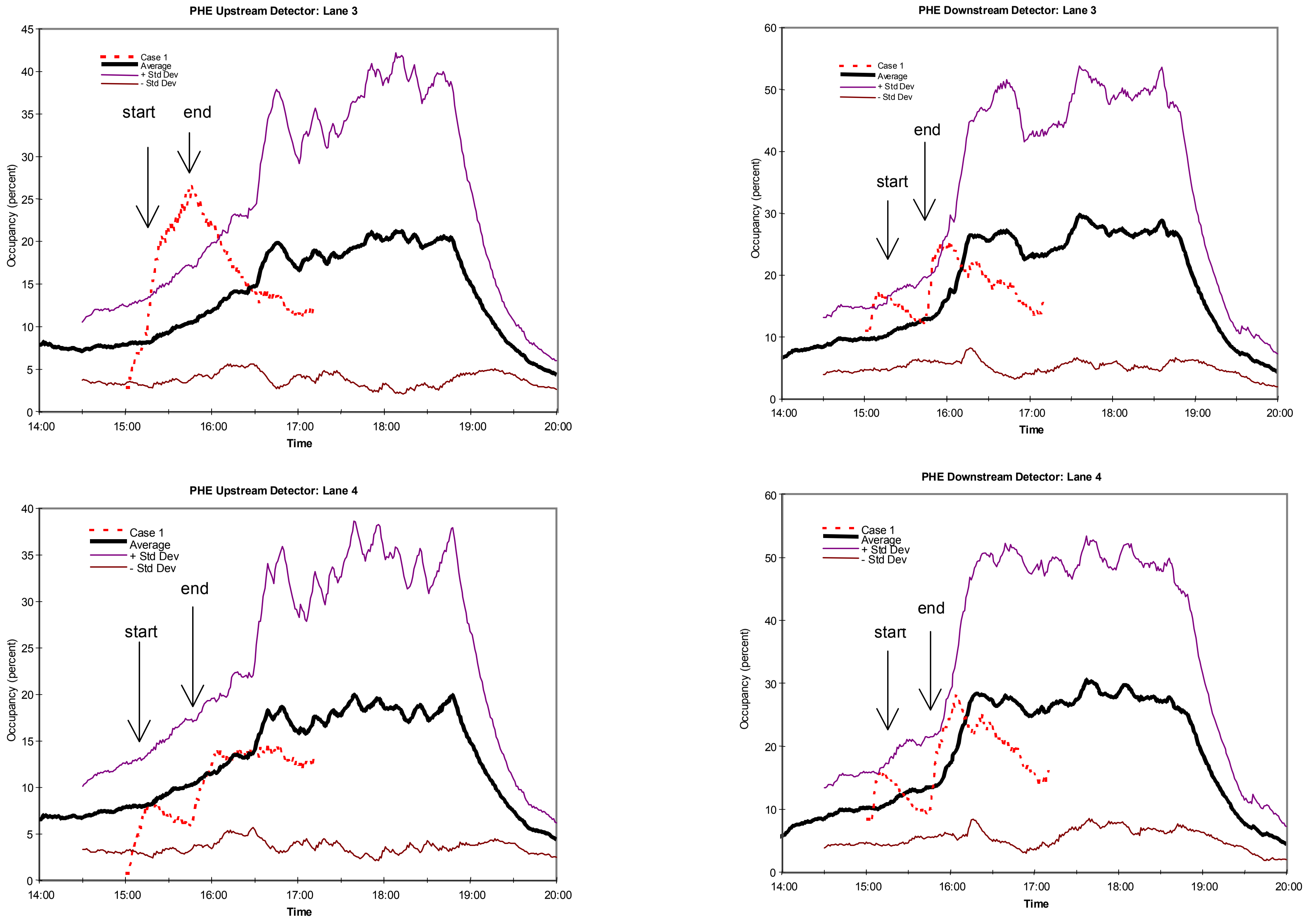

Figure 2 - Occupancy at upstream and downstream detector sets  (Case 1)

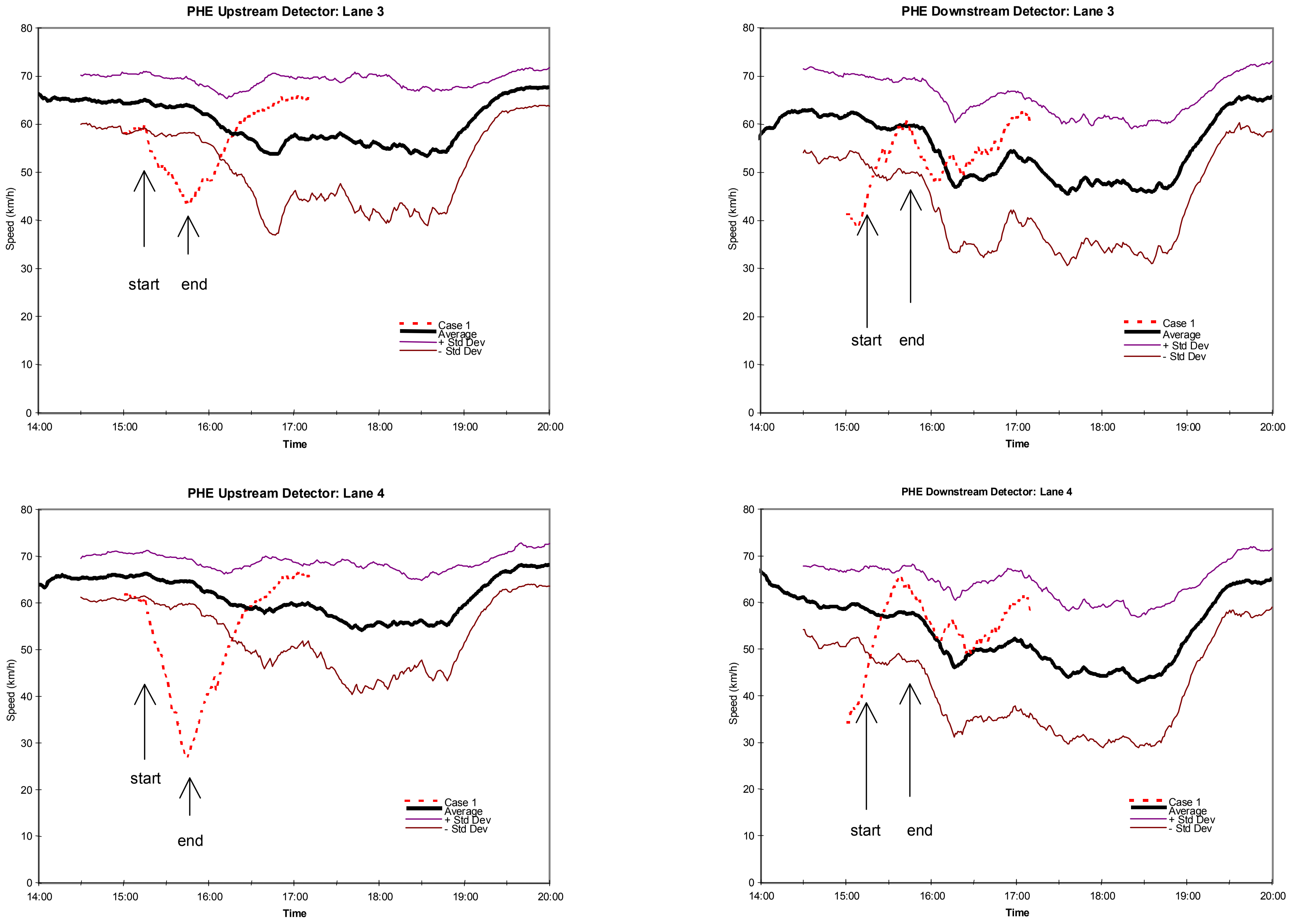

Figure 3 - Speed at upstream and downstream detector sets (Case 1)

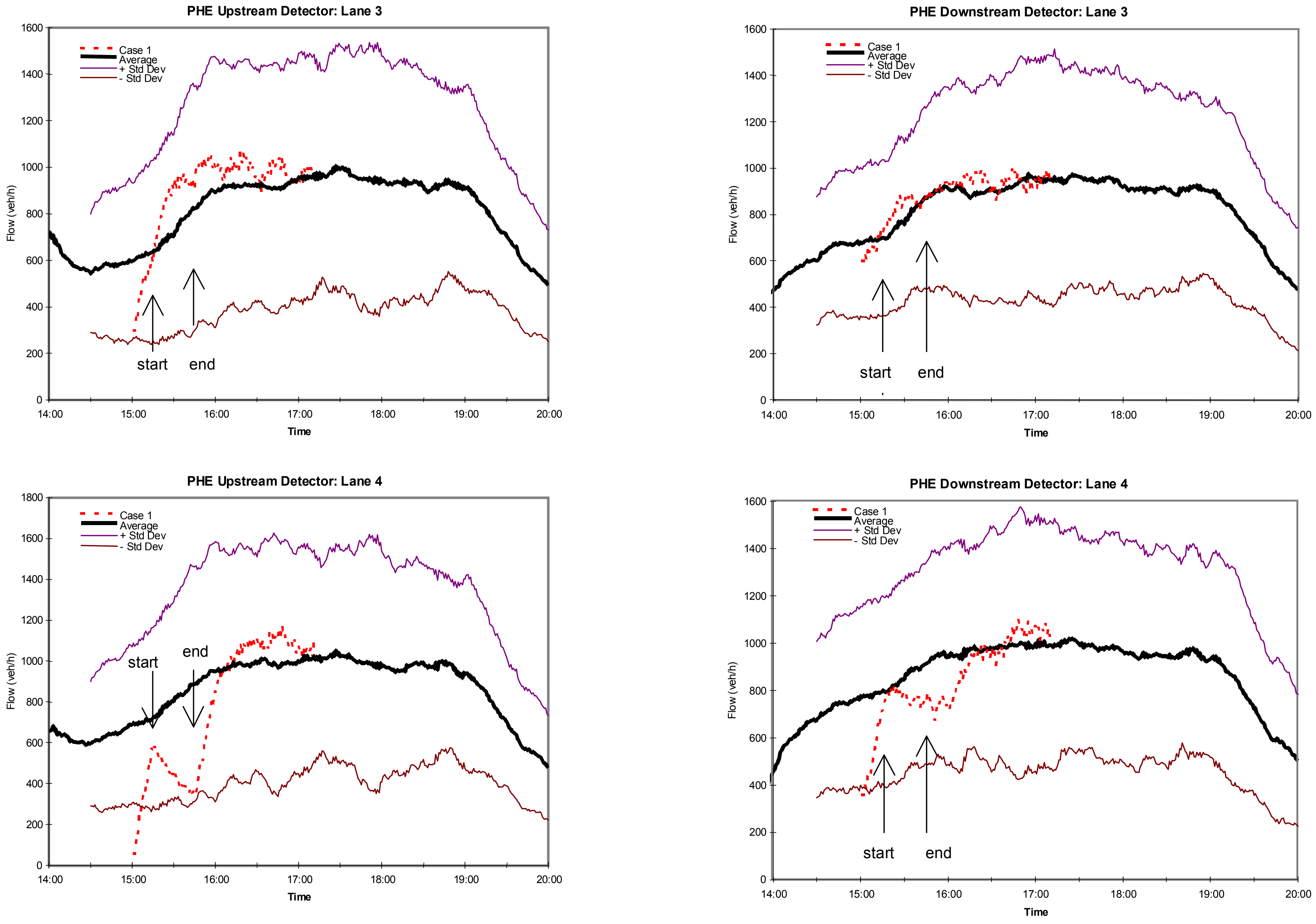

**Figure 4 - Flow at upstream and downstream detector sets (Case 1)**

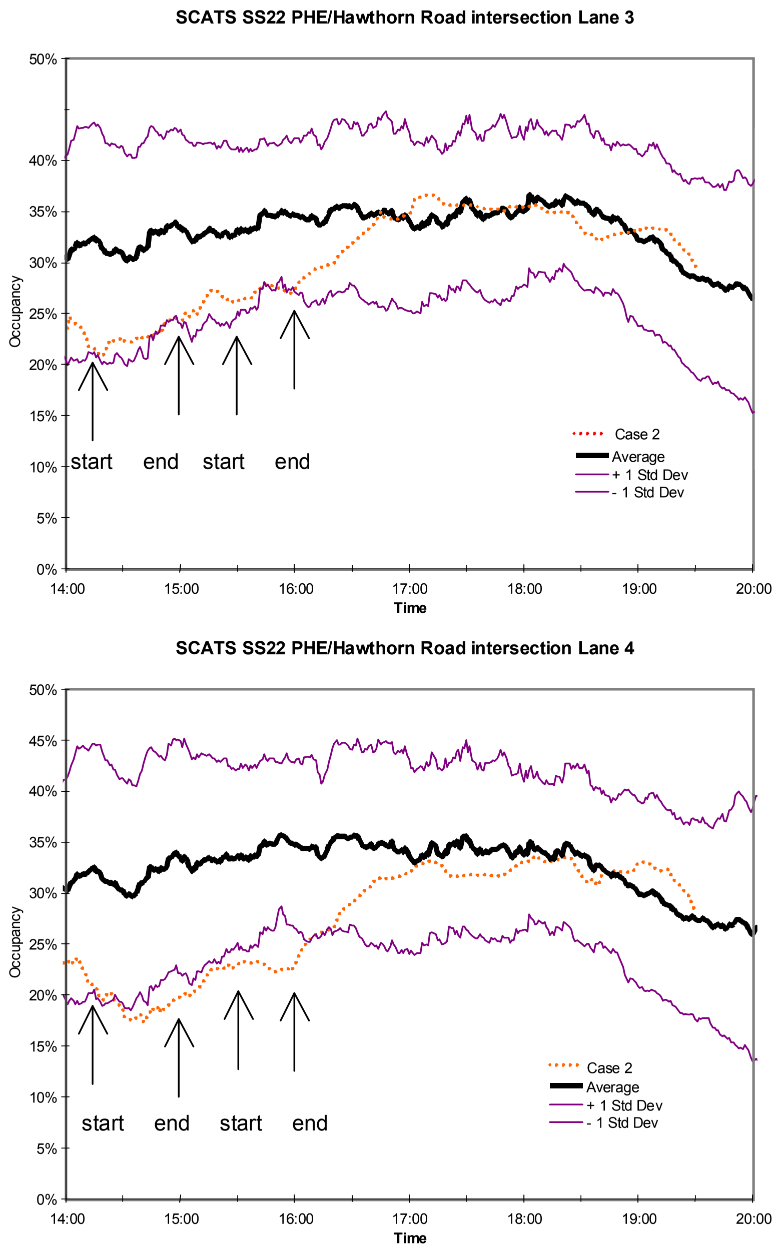

**Figure 5 - SCATS occupancy at Hawthorn Road intersection (Case 2)**

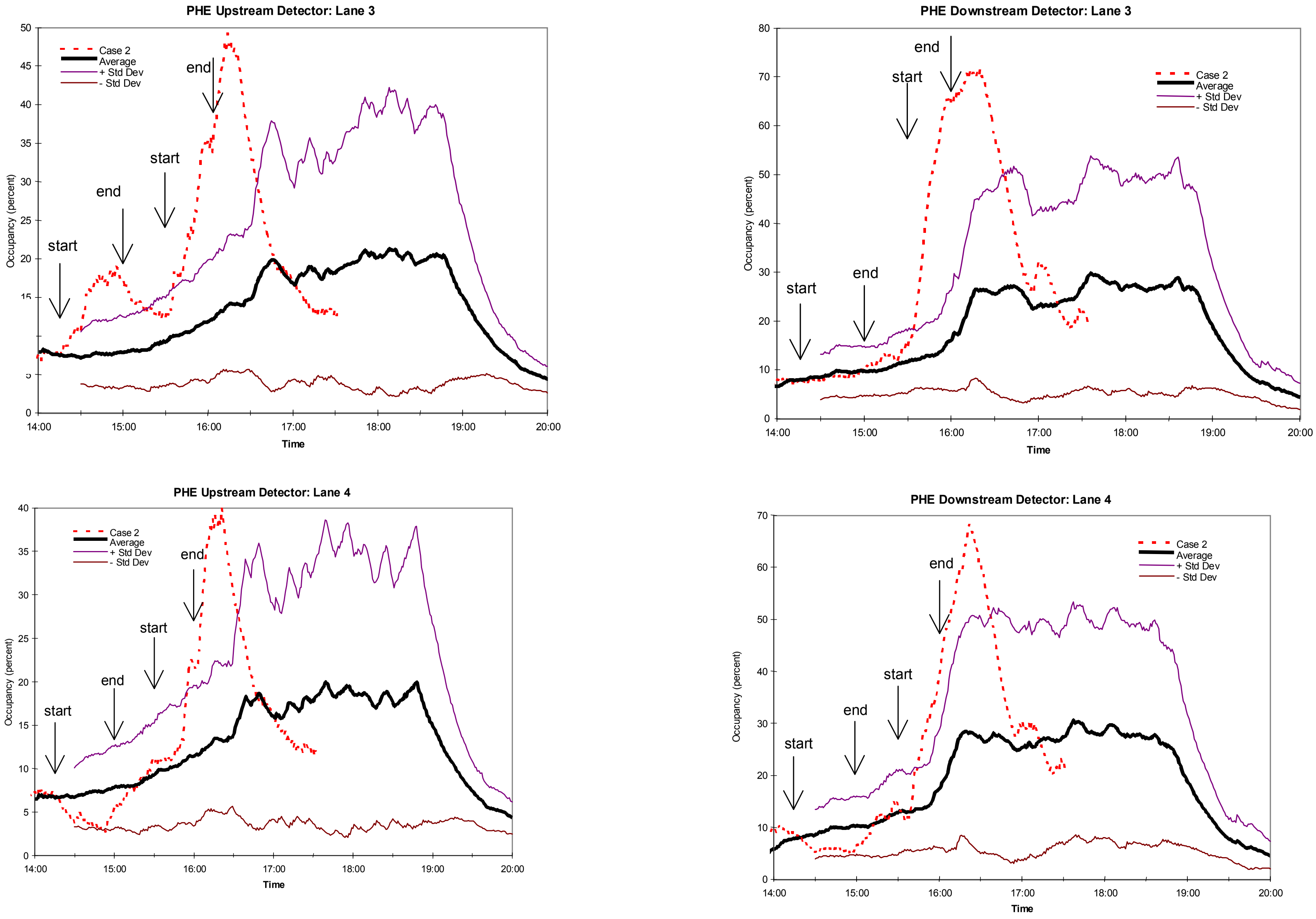

**Figure 6 – Occupancy at upstream and downstream detector sets (Case 2)**

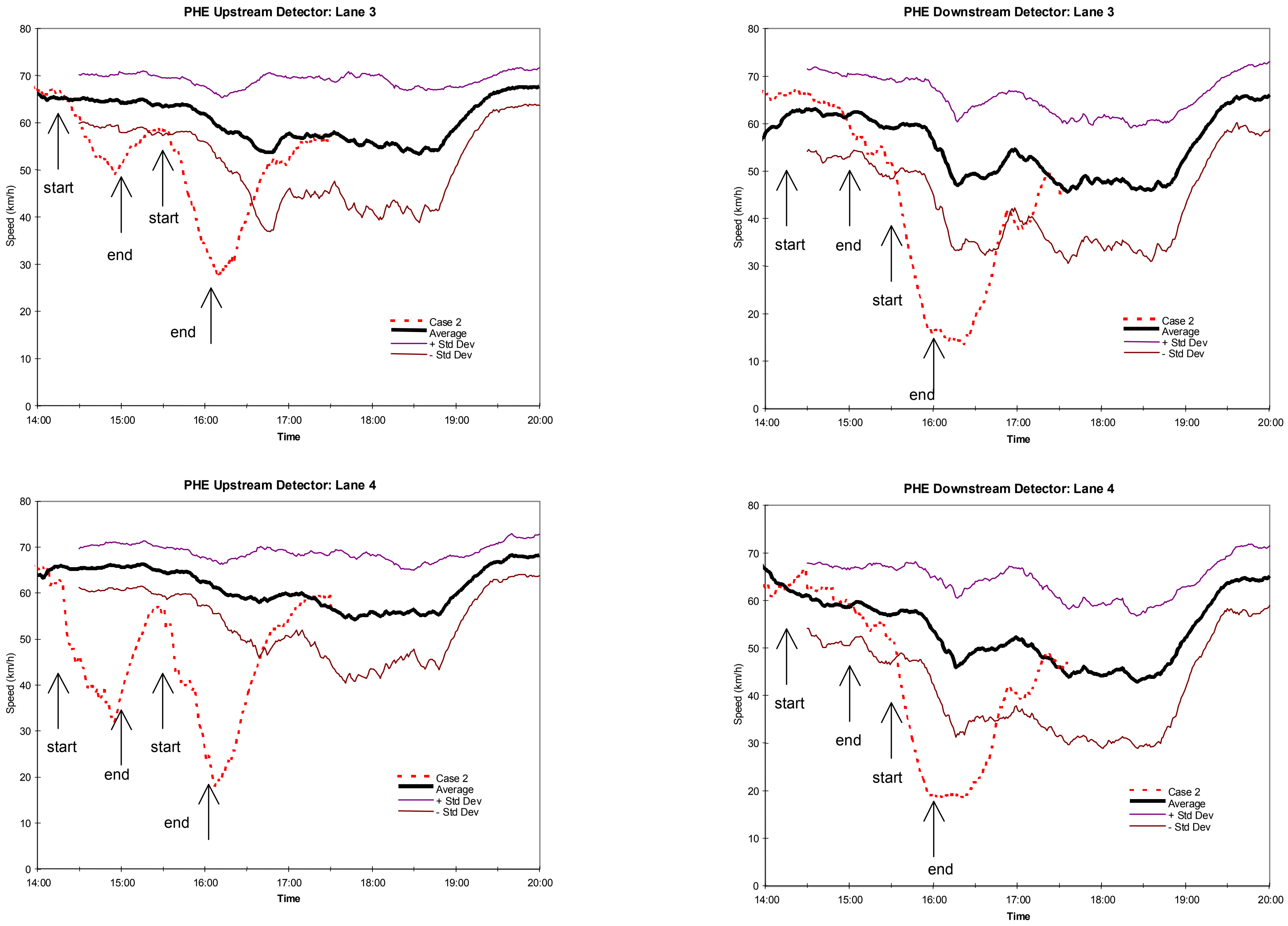

Figure 7 - Speed at upstream and downstream detector sets (Case 2)