



MONASH University
Accident Research Centre

EFFECT OF RIGHT TURN PHASES AT SIGNALISED INTERSECTIONS

PART 2 – MOBILITY PERFORMANCE

by

Michael A.P. Taylor
Department of Civil Engineering
Monash University

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ABSTRACT:

This study examined the mobility performance of partially and fully controlled right turn phases at signalised intersections. The objective of the study was to estimate the changes in delays, congestion and intersection performance resulting from changes in right turn control type. The evaluation of the safety performance of these right turn signals is covered in a separate report (Part 1).

The mobility study had three main parts: (1) the identification of intersections where different types of controls had been installed, (2) modelling of the mobility performance of 'typical' intersections under a range of traffic conditions, and (3) modelling the performance of a selection of case study intersections, drawn from the sites found in phase (1).

The major part of the study of mobility at signalised junctions was based on the analysis of typical or *stereotype* intersections, representing different design standards, geometrical and traffic features. Five stereotype intersections were considered: (1) a four-leg junction of a high design standard, (2) a four-leg junction of 'poor' design standard, (3) a high standard T-junction, (4) a 'poor' design standard T-junction and (5) a four-leg junction of medium design standard.

This study found that there are reductions in overall mobility when right turn controls are introduced, for most traffic conditions except some instances of peak period operations. Further, full control of right turns yields poorer intersection performance than partial control under virtually all conditions, although the differences in performance were slight, especially under off-peak conditions, and are most unlikely to negate the significant safety advantages reported in Part 1 of this study.

Under peak period conditions, right turn phases gave mobility benefits for unsaturated intersections. Introduction of turning controls leads to increased cycle times and more complex phasing arrangements, so that once saturation was reached the use of more stringent turn controls exacerbated the level of saturation. No advantage in mobility performance could then be found.

Under off-peak period conditions, the differences in mobility performance between alternative right turn control regimes are small, suggesting that the considerable safety benefits found for full control (see Part 1 of this study) should be of primary concern. At peak periods, partial control may offer mobility advantages, but at all other times the gains from partial control instead of full control are not significant.

Key Words:

Evaluation, capacity, congestion (traffic) intersection, right turn, traffic engineering, flow, traffic flow, traffic signal.

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EFFECT OF RIGHT TURN PHASES AT SIGNALISED INTERSECTIONS

PART 2 - MOBILITY PERFORMANCE

EXECUTIVE SUMMARY

This report presents the findings of a study which examines the mobility performance of partially and fully controlled right turn phases at signalised intersections. The evaluation of the safety performance of these right turn signals is covered in a separate report (Part 1).

During the 1980s the Victorian Roads Corporation (VIC ROADS) installed right turn control phases, either partial control or full control, at a large number of urban intersections where either right-turn-against accident rates or the physical characteristics of the intersection met the Corporation's guidelines. A number of intersections along tram routes in Melbourne also had right turn controlled phases installed as part of the Fairway Program aimed at reducing the delays caused to trams by other road users.

A partially controlled right turn phase allows vehicles to turn right in two stages, with signal control (green arrow) and without signal control (filtering). A fully controlled right turn phase allows vehicles to turn right only with signal control. Filtering is prohibited by the display of a red arrow.

The overall objective of the study was to quantify the impacts of alternative forms of right turn control, in terms of safety and mobility, to help signal designers and system operators make objective decisions about the choice of appropriate right turn controls.

In terms of mobility, the aim was to estimate the changes in delays, congestion and intersection performance resulting from changes in right turn control type. The following types of change were considered:

- (a) *Type 1*, the change from no control to partially controlled right turn phase;
- (b) *Type 2*, the change from no control to fully controlled right turn phase, and
- (c) *Type 3*, the change from partially controlled right turn phase to fully controlled right turn phase.

The quantitative assessment of mobility was made on the basis of:

- (1) the mean delay [d (s/veh)] for the intersection (and for individual turning movements, lanes and approaches), and
- (2) the SIDRA Performance Index (PI), defined as

$$T_u + w_1D + w_2KH + w_3N_m$$

where T_u (veh-h/h) is the total uninterrupted travel time, D (veh-h/h) is the total delay time, H (stops/h) is the number of stops, K is the stop weighting factor (default value 20), and N_m is the sum of the maximum back-of-queue values for all approach lanes. The w_i ($i = 1, 2, 3$) are weighting coefficients, usually set to 1.0.

PI is widely used in signals design and analysis as a useful overall measure of traffic performance and mobility.

The mobility study had three main parts: (1) the identification of metropolitan intersections where different types of controls had been installed, with particular interest in sites where control type had been varied in recent years, (2) modelling of the mobility performance of 'typical' intersections under a range of traffic conditions, and (3) modelling the performance of a selection of case study intersections, drawn from the sites found in phase (1). The case studies provided the opportunity to check the findings of the general analysis (phase (2)) in specific instances.

A consolidated list of intersections with various forms of right turn control and recent turning movement flows data was derived by combining the list of right turn control implementations (supplied by MUARC) with the list of intersection turning movement counts supplied by VIC ROADS. This yielded a total of 98 sites. Of these only five sites had existing turning movement counts before *and* after the implementation of new right turn controls.

A further 21 sites had turning movement counts available just prior to changes in right turn controls, and these were seen as candidate sites for the collection of new turning movement flows data. A limited program of traffic counting was then undertaken by VIC ROADS.

The intersections with before and after traffic counts were used for the selection of case study intersections.

The major part of the study of mobility at signalised junctions was based on the analysis of typical or *stereotype* intersections, representing different design standards, geometrical and traffic features. This analytical approach was adopted as the best means of investigating the influence of these factors on intersection performance. Five stereotype intersections were considered:

- (1) a four-leg junction of a high design standard, representing the junction of two major arterial roads;
- (2) a four-leg junction of 'poor' design standard, e.g. short lanes, confined right-of-way, incomplete channelisation and shared lanes;
- (3) a high standard T-junction similar to (1), and
- (4) a T-junction similar to (2).
- (5) a four-leg junction as a hybrid of (1) and (2), representing the intersection of a primary arterial road with a secondary arterial road (of lesser design standard).

The main findings of the mobility study were as follows.

There are reductions in overall mobility when right turn controls are introduced, for most traffic conditions except some instances of peak period operations. Further, full control of right turns yields poorer intersection performance than partial control under virtually all conditions. The differences in performance, particularly between partial and full control, were slight, especially under off-peak conditions, and are unlikely to negate the significant safety advantages reported

in Part 1 of this study.

Under peak period conditions, right turn phases gave mobility benefits for unsaturated intersections (i.e. those where the degree of saturation for no control was less than 0.9). Introduction of turning controls leads to increased cycle times and more complex phasing arrangements, so that once saturation was reached the use of more stringent turn controls exacerbated the level of saturation. No advantage in mobility performance could then be found. Thus there is a band of traffic demand levels for a given intersection that will give positive mobility benefits (perhaps this band is for degrees of saturation between 0.7 and 0.9 - the exact range needs further investigation).

Off-peak (i.e. degrees of saturation less than 0.5), the differences in mobility performance (as measured by the SIDRA Performance Index and average delays) between alternative right turn control regimes are small, suggesting that the considerable safety benefits found for full control (see Part 1 of this study) should be of primary concern. At peak periods, partial control may offer mobility advantages, but at all other times the gains from partial control instead of full control are not significant.

There is a need for further research to undertake economic analysis of the possible trade-off between the safety and mobility effects. The present study provides the basic data on which an economic analysis could be based. It generated a large database of intersection performance and design parameters (for individual turning movements, traffic lanes (by lane type), approach legs and whole junctions) under a variety of traffic conditions that could be used for further investigations.

The study concentrated on safety and mobility performance of isolated intersections, and was unable to consider network-wide effects. The traffic diversion effects of various turn controls at the network level are of interest in area-wide traffic control and in road demand management, and these effects should be the subject of further research. In particular, there is a compelling need for further research and development to draw together the safety and mobility findings from this study, so that the research results may be translated into practical design guidelines. In the interim period, comments should be sought from within VIC ROADS and from other road and traffic authorities so that maximum value can be extracted from the research completed to date.

The mobility report needs to be considered in conjunction with the report on Part 1 of the Safety-Mobility Study, which considers the safety performance of signalised intersections with right turn controls, and provides strong evidence of the significant safety benefits of fully controlled right turn phases.

EFFECT OF RIGHT TURN PHASES AT SIGNALISED INTERSECTION PART 2 - MOBILITY PERFORMANCE

1.0 INTRODUCTION

This report presents the findings of a study which examines the mobility performance of partially and fully controlled right turn phases at signalised intersections. The evaluation of the safety performance of these right turn signals is covered in a separate report (Part 1).

During the 1980s the Victorian Roads Corporation installed right turn control phases, either partial control or full control, at a large number of urban intersections where either right-turn-against accident rates or the physical characteristics of the intersection met the Corporations guidelines. A number of intersections along tram routes in Melbourne also had right turn controlled phases installed as part of the Fairway Program aimed at reducing the delays caused to trams by other road users.

A partially controlled right turn phase allows vehicles to turn right in two stages, with signal control (green arrow) and without signal control (filtering). A fully controlled right turn phase allows vehicles to turn right only with signal control. Filtering is prohibited by the display of a red arrow.

This study was undertaken in response to a recommendation by the Monash University Accident Research Centre (Corben and Foong, 1990), who suggested an investigation of the safety and mobility performance of alternative right turn control types. This would enable the pro-active technique for the identification and treatment of hazardous intersection approaches to be validated, and its capacity as a decision making aid could be assessed.

The study was commissioned and funded by the Victorian Roads Corporation (VIC ROADS) in January 1990.

2.0 STUDY OBJECTIVE

The overall objective of this study was to quantify the impacts of alternative forms of right turn control, in terms of safety and mobility. This would assist signal designers and system operators to make objective decisions on the choice of right turn control turn.

In terms of mobility, the aim was to estimate the changes in delays, congestion and intersection performance resulting from changes in right turn control type at signalised intersections. The following types of change were considered:

- * *Type 1*, the change from no control to partially controlled right turn phase
- * *Type 2*, the change from no control to fully controlled right turn phase
- * *Type 3*, the change from partially controlled right turn phase to fully controlled right turn phase.

3.0 STUDY METHODOLOGY

This part of the study considered the traffic performance and operations of signalised intersection approaches under different geometric configurations, traffic loads, signal settings and signal phasings. In particular, it examined the effects of alternative provisions for right turn phases (e.g. no control with right turns made in the face of opposing traffic, partially controlled phases and fully controlled phases) on delays, stops, fuel consumption and emissions for right turning traffic, other movements from the same approach leg, and movements on other legs at the intersection. The study used the SIDRA model (Akcelik, 1986) to provide realistic estimations of delays and other traffic performance measures and environmental impacts at isolated intersections. SIDRA is widely regarded as the best computer-based model for the analysis of signalised intersections.

The scope of the study prevented the study of broader network effects of alternative right turn controls, but suitable tools exist for these studies, such as MULATM (Taylor, 1989a) and SCATES (Sims, 1989).

The interaction between safety and traffic performance (e.g. delay) may be positive or negative, depending upon the particular circumstances of intersection design and traffic load. The interaction may take the form of a trade-off between accident cost reductions and increases in travel time (through increased delays), for example on installation of a fully controlled right turn phase that leads to increased delays over (say) a partially controlled phase. On the other hand, the installation of a right turn phase where none previously operated may decrease delays (to both through and right turn movements), with consequent savings in both accident cost and travel time. The strength and direction of these interactions was investigated using a comprehensive analysis of a number of stereotype intersections under a variety of traffic loads, and was confirmed by the analysis of a number of case studies.

The results of the study should be viewed from the perspective of an hierarchical consideration of intersection performance (Taylor, 1989b), which should include the following components:

- (a) the intersection in isolation, in which the unit of travel is the turning movement;
- (b) the intersection as a member of a 'cluster' network of adjoining intersections, so that the unit of travel is a trip segment (or 'microtrip'), and (ultimately)

- (c) the intersection as part of the wider network that represents the full trip being undertaken.

In cases (b) and (c) the delay at the intersection is a component of the travel cost. The hierarchical approach permits the inclusion of route diversion into the analysis. Changes to the phasing arrangement at an intersection may lead to differential changes in delay and travel cost for particular turning movements. Drivers may then seek to compensate for increases in delays by modifying their route choice behaviour, e.g. making a right turn at a neighbouring upstream or downstream junction in a grid network is one response to perceived increases in delay or travel cost associated with a particular turning movement. There are well-established theories and models for investigating the resulting equilibrium between travel demand (path choice) and intersection performance (Taylor, 1984, Fisk, 1990).

The consequence of route diversion for intersection performance analysis is that the balance of flows is disturbed. A proper account of the performance of an intersection under alternative right turn controls requires an examination of the likely diversion of traffic. It must therefore be stressed that the study reported in this document (case (a)), which relies solely on the investigation of the traffic performance of isolated intersections, is therefore of limited use in extrapolation to the performance of large-scale traffic networks. Proper account must be taken of the possible variations in traffic demand in network studies.

Case (a) was examined using the SIDRA software package for signalised intersection analysis, developed by ARRB (Akcelik, 1986). This package is recognised in Australia and elsewhere as perhaps the best analytical tool for studying the performance of signalised intersections and for the design of signal settings at an individual intersection. SIDRA provides detailed information on the performance of all lanes, turning movements and approach legs, as well as of the intersection *in toto*. It also provides information on fuel consumption and air pollution emissions.

Cases (b) and (c) require the use of traffic network models that considers the equilibrium between travel demand and system performance. There are several suitable models, including Monash University's MULATM package, the SCATES software developed by the NSW Roads and Traffic Authority, and the SATURN package from the University of Leeds. Such network investigations should be the subject of research in the near future, particularly given the current priorities attached to Travel Demand Management (TDM) in transport and traffic planning (Wigan, 1990).

The investigation of mobility performance was undertaken in two ways. Firstly, a general analysis of relative performance of right turn controls at 'standard' or 'stereotype' intersections (e.g. defined by numbers of lanes on approaches, provision of separate turning lanes, and signal phasing arrangements) was undertaken, to establish the relative changes in performance under traffic conditions representing peak hour, day time off-peak and night time periods. The stereotypes were based on the standard

library junctions provided with the SIDRA software. Secondly, the analysis techniques were applied to particular case study intersections. The case studies were selected from those signalised intersections in the Melbourne metropolitan area at which a change in right turn control had been made since 1985, and for which turning movement flows data were available for both the 'before' and 'after' situations.

The main parameters extracted from the SIDRA output for use in performance evaluation were:

- (a) the mean delay [d (s/veh)] for the intersection (and for individual turning movements, lanes and approaches);
- (b) the number of stops [H (stops/h)];
- (c) the overall fuel consumption [F (L/h)];
- (d) the mean travel speed [v (km/h)] through the intersection;
- (e) the optimum cycle time [c (s)], as computed by SIDRA;
- (f) the degree of saturation (x) of the intersection;
- (g) the capacity of the intersection [C (veh/h)], and
- (h) the SIDRA Performance Index (PI), defined as

$$T_u + w_1 D + w_2 K H + w_3 N_m$$

where T_u (veh-h/h) is the total uninterrupted travel time, D (veh-h/h) is the total delay time, K is the stop weighting factor (default value 20), and N_m is the sum of the maximum back-of-queue values for all approach lanes. The w_i ($i = 1, 2, 3$) are weighting coefficients, usually set to 1.0. This was the value used for the w_i in this study.

PI provides a useful, generalised measure of intersection performance.

These performance measures are functions of intersection geometry, signal phasing arrangements and traffic demand. The basic measure of traffic demand is the overall throughput [Q (veh/h)], i.e. the total number of vehicles using the intersection per unit time. This basic measure must also be split into its component turning movement flows, and the effects of different patterns of turning movements may be considered by simulating the changing patterns of turning flow movements at a junction over the hours of a day.

Total delay time D is given by $D = dQ$.

In this way both general trends in traffic performance and specific examples could be studied.

4.0 INTERSECTION IDENTIFICATION

A consolidated list of intersections with various forms of right turn control and recent turning movement flows data was derived by combining the list of right turn control implementations (supplied by MUARC) with the list of intersection turning movement counts supplied by VIC ROADS. This consolidated list is given as Appendix A of this report. It contains a total of 98 sites. Of these 98 only five sites had existing turning movement counts before *and* after the implementation of new right turn controls. These five sites are specified in Table 1.

Table 1
Intersections with Before and After Turning Movement Counts Covering Changes to Right Turn Controls

SCRAM No.	Melway Ref	Intersection Name	Date of Control Change	Turning Movement Counts	
				Before	After
117	048 F9	Maroondah Highway-Springvale Rd	24/06/86	02/05/85	14/09/89
121	048 K9	Maroondah Highway-Mitcham Road	02/08/88	30/05/85	20/07/89
281	093 E6	Springvale Rd-Wells Road	23/12/87	28/11/85	17/03/88
651	090 C8	Cheltenham Road-Hammond Rd	27/08/86	17/09/85	13/05/87
3198	079 C3	Centre Road-Clayton Road	30/01/86	11/06/85	24/03/88

A further 21 sites had turning movement counts available just prior to changes in right turn controls, and these could be seen as candidate sites for the collection of new turning movement flows data, which could then be used to complement the existing set of sites with before and after turning movement data (i.e. those sites listed in Table 1). These candidate sites are listed in Appendix B, which also provides a summary of the types of changes in right turn controls for three and four leg intersections. A limited program of traffic counting was undertaken by VIC ROADS, on the basis of the priority sites for new data collection defined in Appendix B.

The intersections with before and after traffic counts were used for the selection of case study intersections in the SIDRA analysis (see Section 6).

5.0 ANALYSIS OF STEREOTYPE INTERSECTIONS

This study of mobility at signalised junctions was based on the analysis of typical or *stereotype* intersections, representing different design standards, geometrical and traffic features. This analytical approach was adopted as the best means of investigating the influence of these factors on intersection performance. Five stereotype intersections were constructed from the SIDRA Library of Intersections provided with SIDRA 3.1. The basic SIDRA library intersections are:

- (1) L4B, a four-leg junction of a high design standard, representing the junction of two major arterial roads;
- (2) L4S, a four-leg junction of 'poor' design standard, e.g. short lanes, confined right-of-way, incomplete channelisation and shared lanes;
- (3) L3B, a high standard T-junction similar to L4B, and
- (4) L3S, a T-junction similar to L4S.

The fifth stereotype was a four-leg junction, constructed as a hybrid of L4B and L4S. It represented the intersection of a primary arterial road (of high design standard, e.g. dual carriageways with service roads) with a secondary arterial road (of lesser design standard, e.g. single carriageway, with short turning lanes at the intersection). This intersection may be classed as being of 'medium' standard, and was designated as intersection L4M.

5.1 HIGH STANDARD INTERSECTION (SIDRA LIBRARY L4B)

The layout of the SIDRA Library intersection L4B is shown in Figure 1. This intersection is of a high design standard, and represents the junction of two major arterial roads. Peak period traffic flows for the intersection are given in Figure 2 [these were taken from the SIDRA manual (Akcelik, 1986)]. An assumed temporal profile of travel demand is given in Figure 3, based on a generally acceptable distribution of traffic demand at an urban site over the hours of the day.

Typical turning movement flows covering each hour of the day were computed on the basis of Figures 2 and 3. These are in turn represented by the 12 time intervals shown in Figure 3.

Modelling of intersection performance was undertaken for each of the representative time periods, under four different phasing arrangements. These are shown in Figure 4, and represent the following alternatives:

Figure 1
Layout of Stereotype Intersection L4B

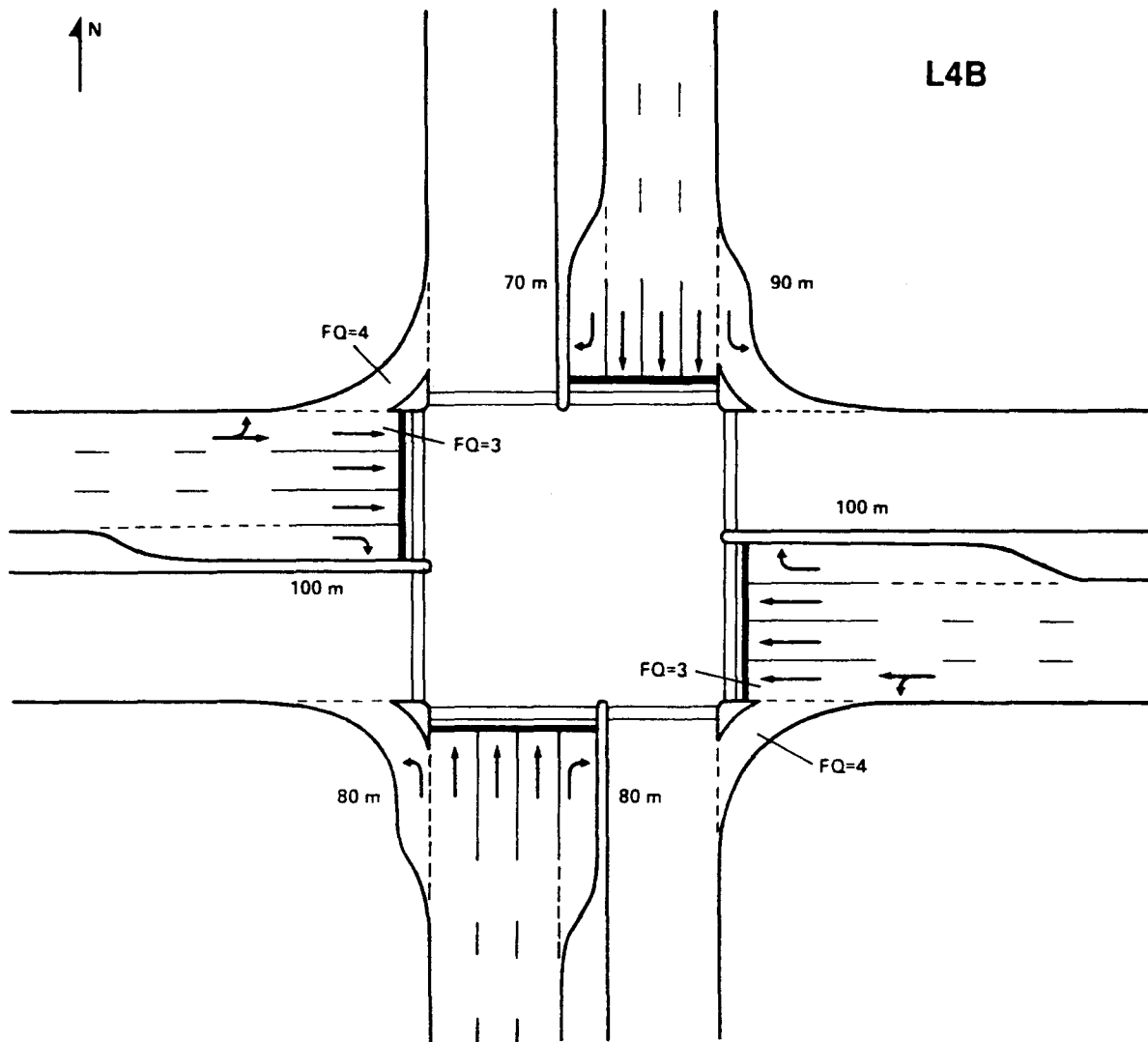


Figure 2
Assumed Peak Period Flows at Stereotype Intersection L4B

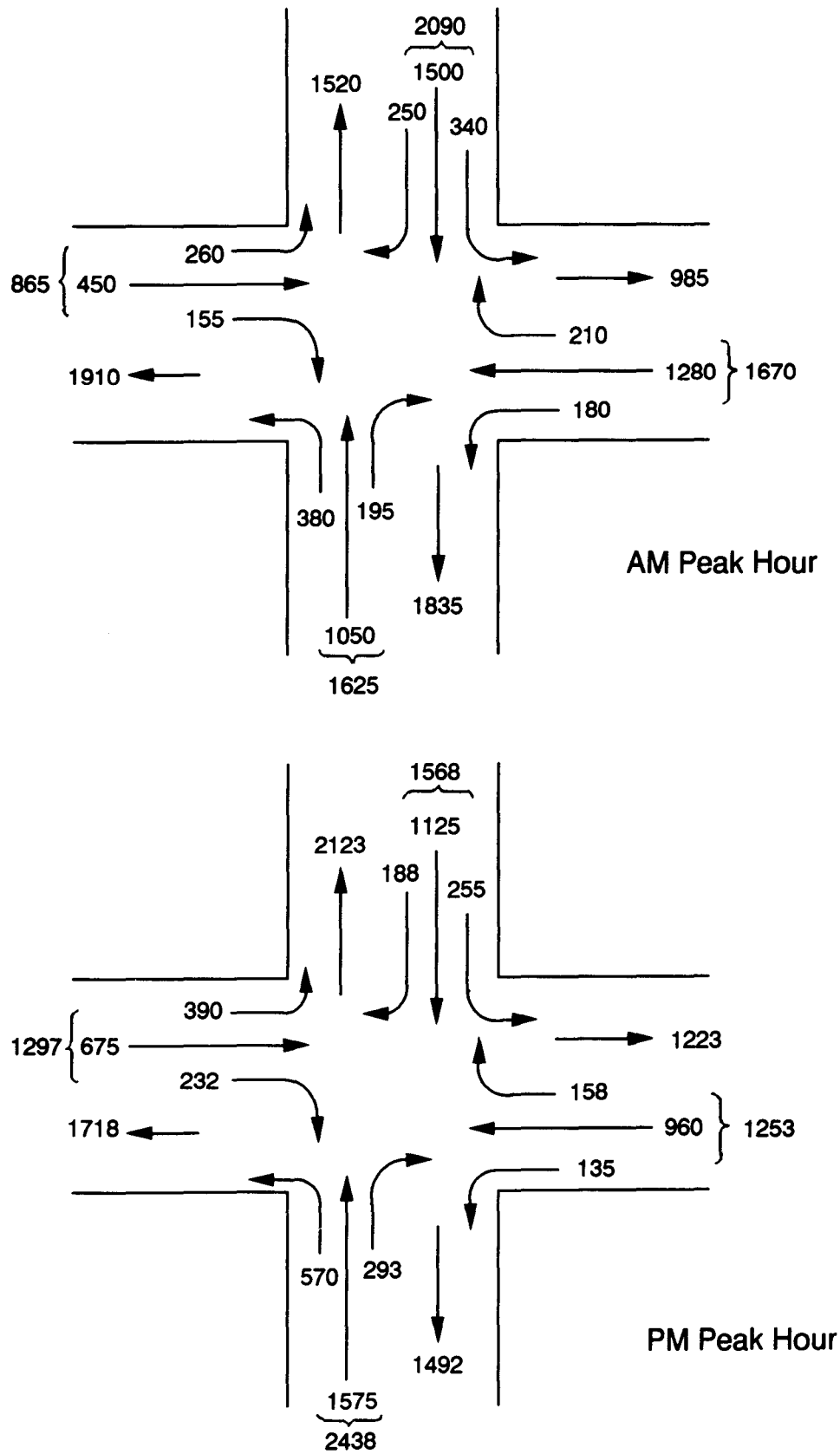


Figure 3
Assumed Temporal Profile of Travel Demand for a Stereotype Urban Intersection

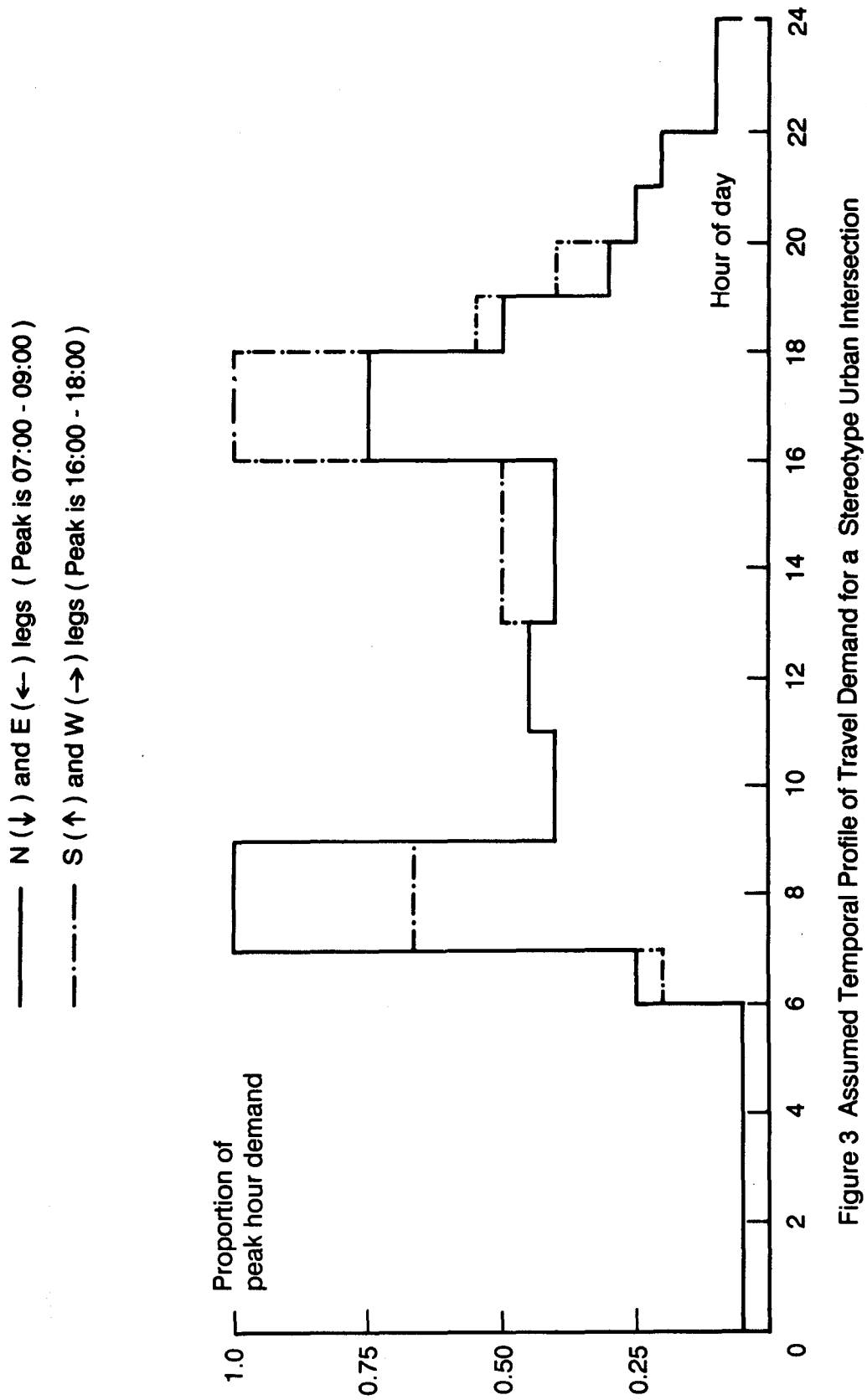
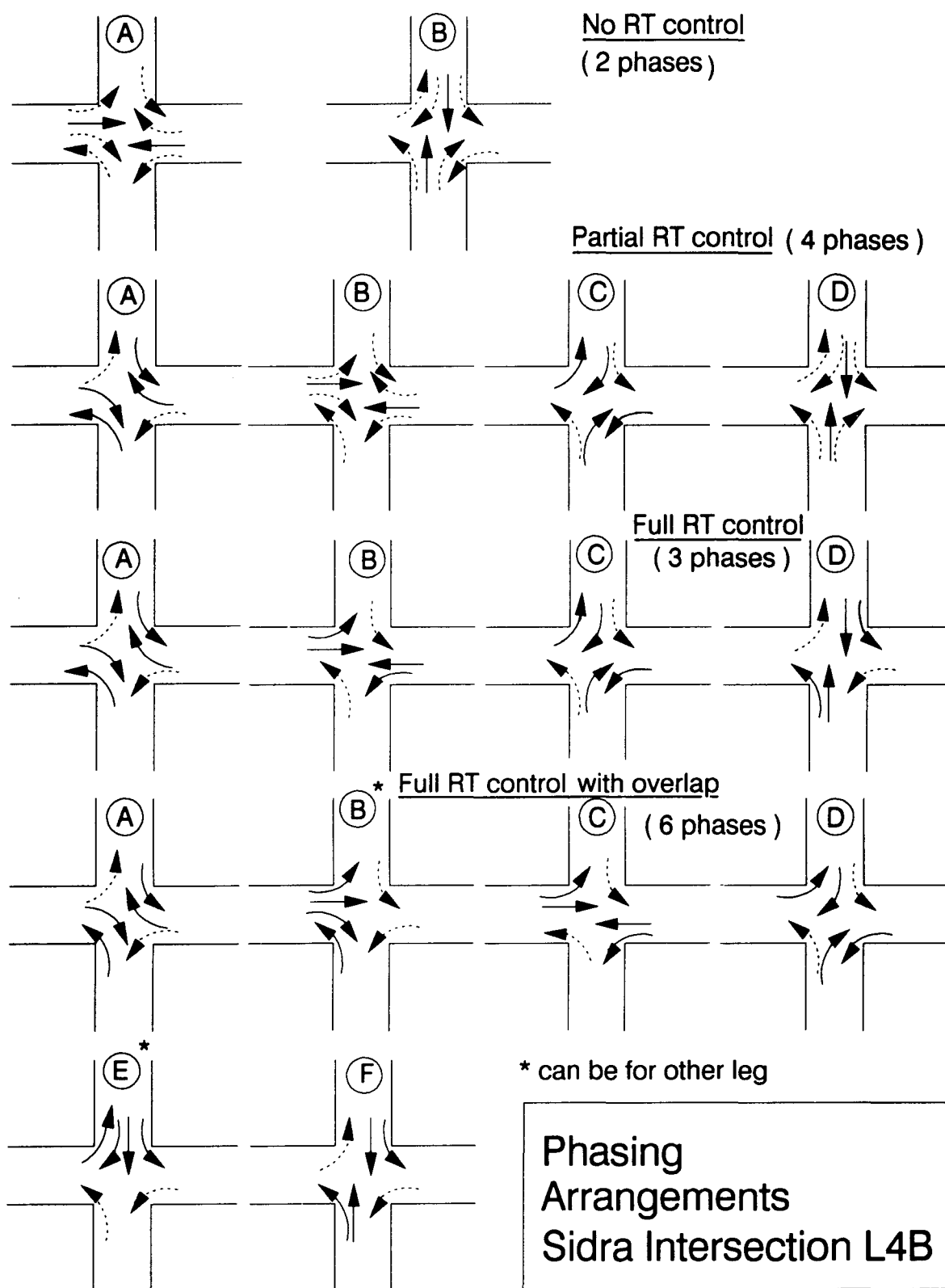


Figure 3 Assumed Temporal Profile of Travel Demand for a Stereotype Urban Intersection

Figure 4
Phasing Systems at Stereotype Intersection L4B



- (1) no control on right turns;
- (2) partial right turn control;
- (3) full right turn control, and
- (4) full right turn control with overlap phases (that provide an extended green time for the leg with the higher volume of right turning traffic).

SIDRA calculated optimal cycle times and green times for each phasing arrangement in each representative time period. The calculations were based on the imposition of minimum green times to accommodate pedestrian movements. Thus the modelling should provide signal settings much like those used in practice.

Table 2 provides a detailed indication of the traffic performance of L4B during the morning and evening peak periods.

Figure 5 summarises the results for total traffic at the intersection, over the assumed 24 hour period. It shows the SIDRA Performance Index (PI) for each phasing system. PI is a weighted sum of delay times, number of stops, and queuing (see Section 3.0 for a precise definition). Note that an increasing value of PI means that intersection performance is deteriorating i.e. the smaller the PI, the better the quality of the intersection performance for a given intersection and level of traffic demand. The variations in PI over time of day mirror the distribution of traffic demand at the junction, as seen in Figure 6 which shows the vehicle throughput of the intersection over time of day.

An interpretation of Figure 5 suggests that, for intersection L4B, the following hold true:

- (a) at low demand periods the intersection functions well with no control on right turns, but this situation changes rapidly in the peaks when the junction becomes heavily congested. The degrees of saturation for the peak periods with all right turns made in the face of opposing traffic were 1.106 (am peak) and 1.103 (pm peak), which are unsatisfactory (see also Figure 7, for an indication of the significant delays to right turning traffic in these periods);
- (b) under partial right turn control, intersection performance off-peak is marginally worse than under no right turn control. The difference is due to the longer cycle time needed (83 seconds as opposed to 61 seconds) to accommodate the extra turn phases. However, the partially controlled intersection copes most adequately with the peak period flows. Indeed, this control is superior to all of the other control systems examined;
- (c) full control of right turns leads to a diminished level of performance compared to partial control, under all traffic conditions. The differences are most pronounced in the peak periods (e.g. PI values of 380.3 (am peak) and 405.4 (pm peak) compared to the corresponding values of 293.9 and 315.3 for partial right turn

Table 2

Detailed Performance of Stereotype Intersection L4B during the Morning and Evening Peak Periods (SIDRA output)

	AM Peak			PM Peak		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	46.3	24.2	41.6	39.7	25.7	41.1
Number of stops (stops/h)	4070	4983	5777	4659	5193	5851
SIDRA Performance Index	466.57	293.94	380.28	423.31	315.25	405.41
Fuel used (L/h)	635.46	605.98	649.59	646.04	638.99	680.11
Throughput (veh/h)	6250	6250	6250	6556	6556	6556
Junction Capacity (veh/h)	12597	10134	9758	12384	10240	9486
Degree of saturation	1.106	0.851	0.908	1.103	0.882	0.907
Cycle time (s)	220	83	104	161	87	115

Figure 5
Performance of Stereotype Intersection I4B by Time of Day,
as represented by the SIDRA Performance Index (PI)

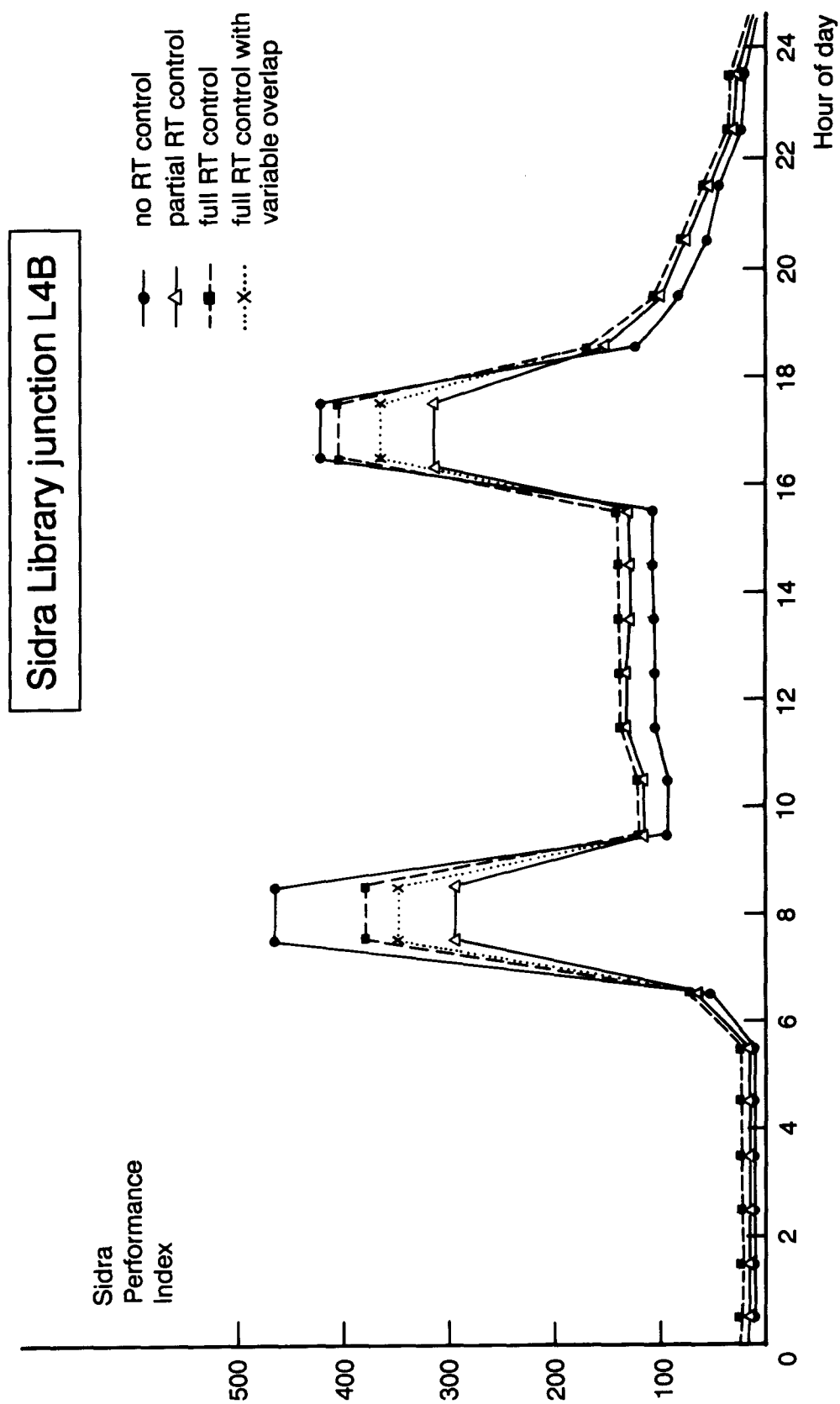


Figure 6
Total Hourly Traffic Volumes at Stereotype Intersection L4B, by Time of Day

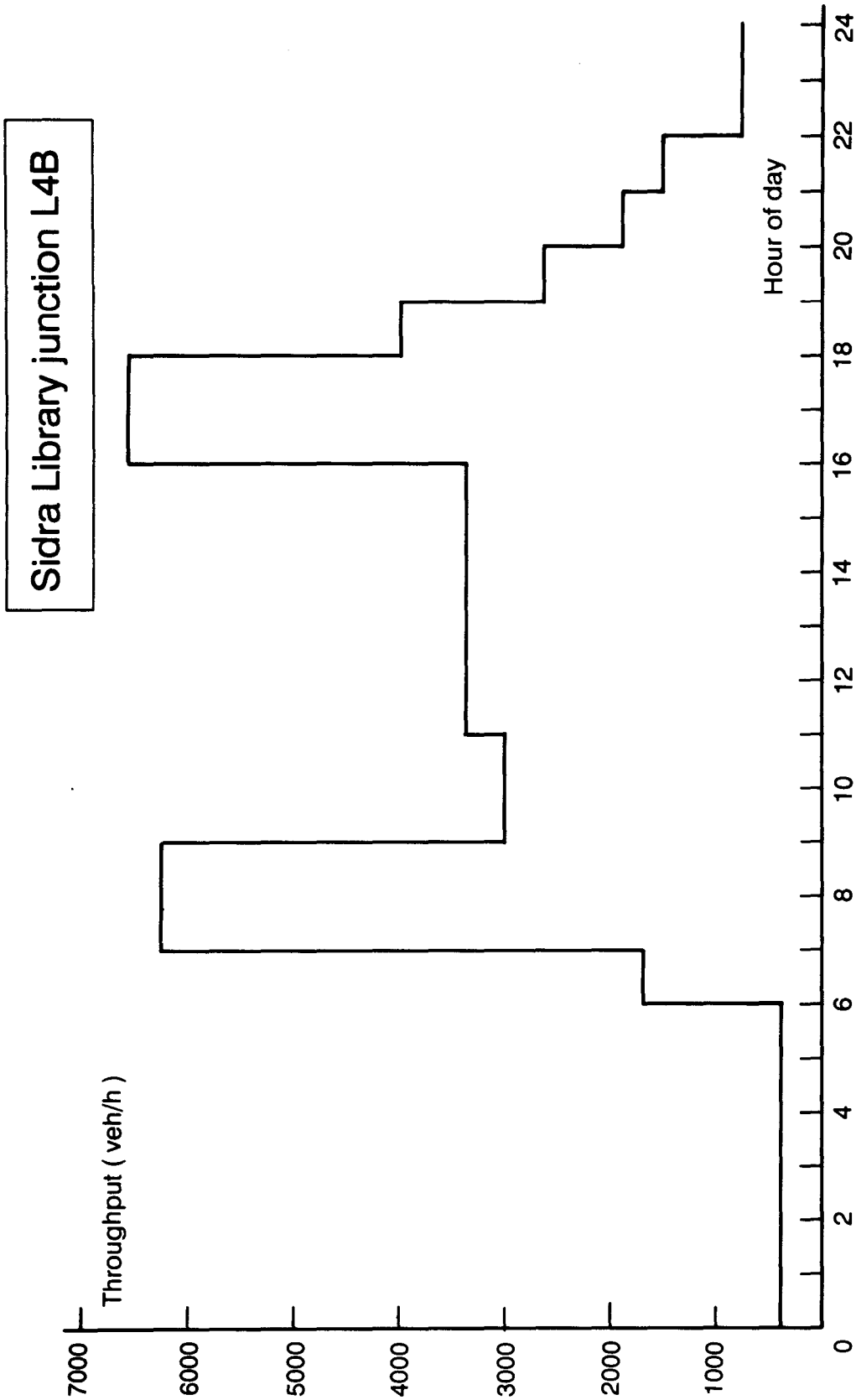
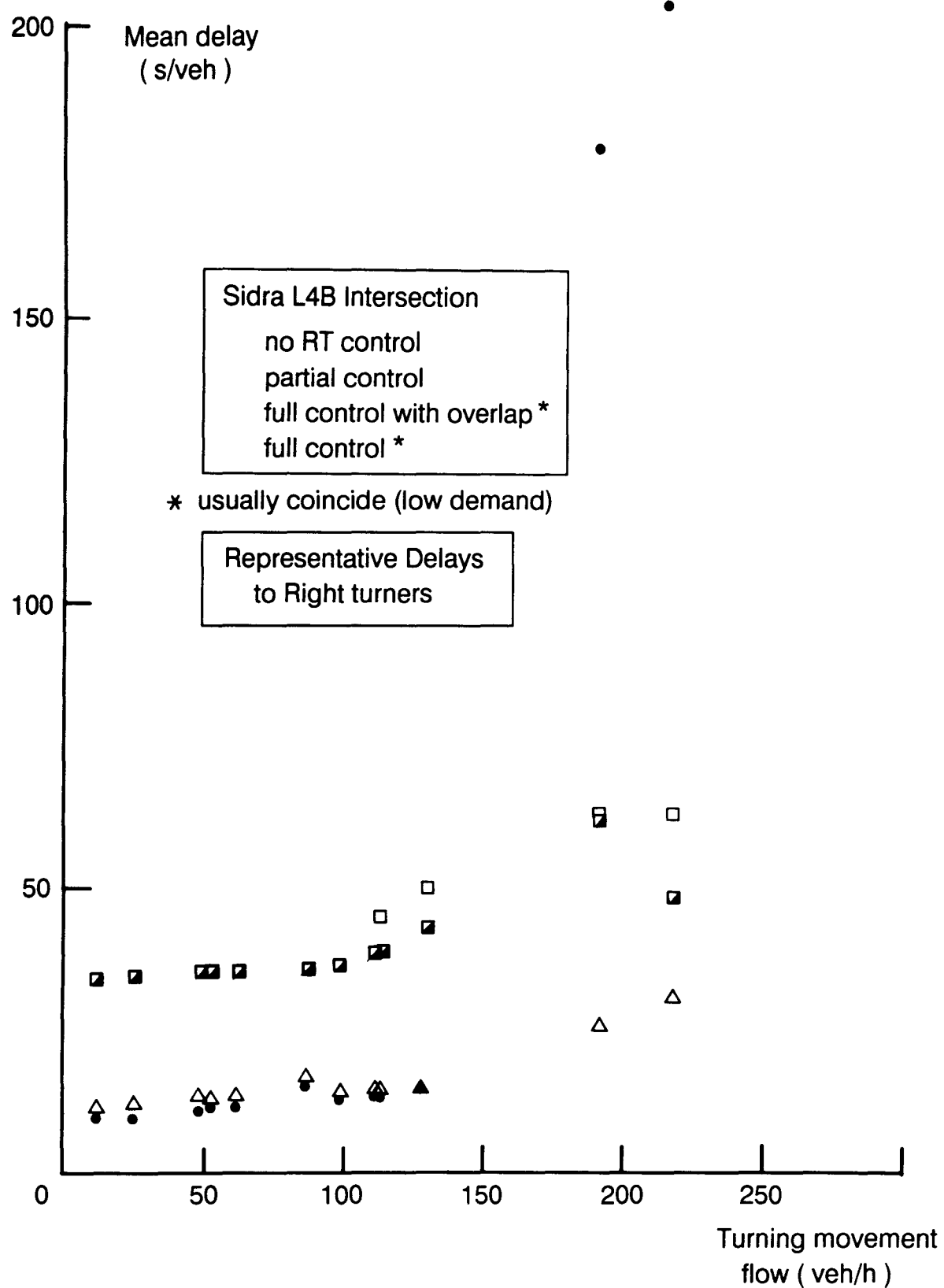


Figure 6 Total Hourly Traffic Volumes at Stereotype Intersection L4B , by Time of Day

Figure 7
Representative Delays to Right Turners at Stereotype Intersection L4B



control). This finding supports the supposition behind the project that full control of right turning movements for increased safety entails a delay time trade-off, and

- (d) full control of right turns with overlap phasing to accommodate tidal flow movements (e.g. see Figure 4) improves intersection performance marginally over rigid full control, but is still inferior (in delay and queuing terms) to partial control.

Full control with or without overlap leads to similar cycle times to partial control for low demand periods, but peak period cycle times are increased compared to those for partial control. For example, the pm peak had cycle times of 87 seconds for partial control, 115 seconds for full control, and 89 seconds for full control with overlap. These were the longest cycle times calculated for the intersection with some form of right turn control in place.

These results apply to all traffic using the intersection. Figure 7 provides an indication of mean delays to right turners, which again shows the same pattern of relative performance. Mean delays under partial control are perhaps one second greater than for no control, during off-peak periods. At peak periods, delays for right turns without turning phases escalate to severe levels (about 190-200 seconds)! Peak period delays under partial control are the least of all the phasing systems. In all cases the delays under full control are about twice those experienced under partial control.

These results rightly apply to the one stereotype intersection only. This intersection, however, is of significance because it represents what would be regarded as the highest level of intersection design, and would represent an important intersection of two major metropolitan arterial roads with high traffic volumes.

5.2 LOW STANDARD INTERSECTION (SIDRA LIBRARY L4S)

The second intersection is the SIDRA Library intersection L4S, shown in Figure 8. This junction represents a restricted geometric design, featuring shared lanes, short turning lanes, parking close to the intersection, and narrow carriageways. It could be taken as representative of an inner-area intersection of secondary arterial roads and/or collector roads, possibly in a strip shopping centre. There are many such intersections in the metropolitan area! Assumed peak hour turning movement flows are shown in Figure 9, and an hourly demand profile was synthesised using the same method applied previously (to intersection L4B).

Modelling of intersection performance was undertaken for each of the representative time periods under the four different phasing arrangements shown in Figure 10, i.e.

- (1) no control on right turns;
- (2) partial right turn control on the east-west road;
- (3) full right turn control on the east-west road, and

Figure 8
Layout of Stereotype Intersection L4S

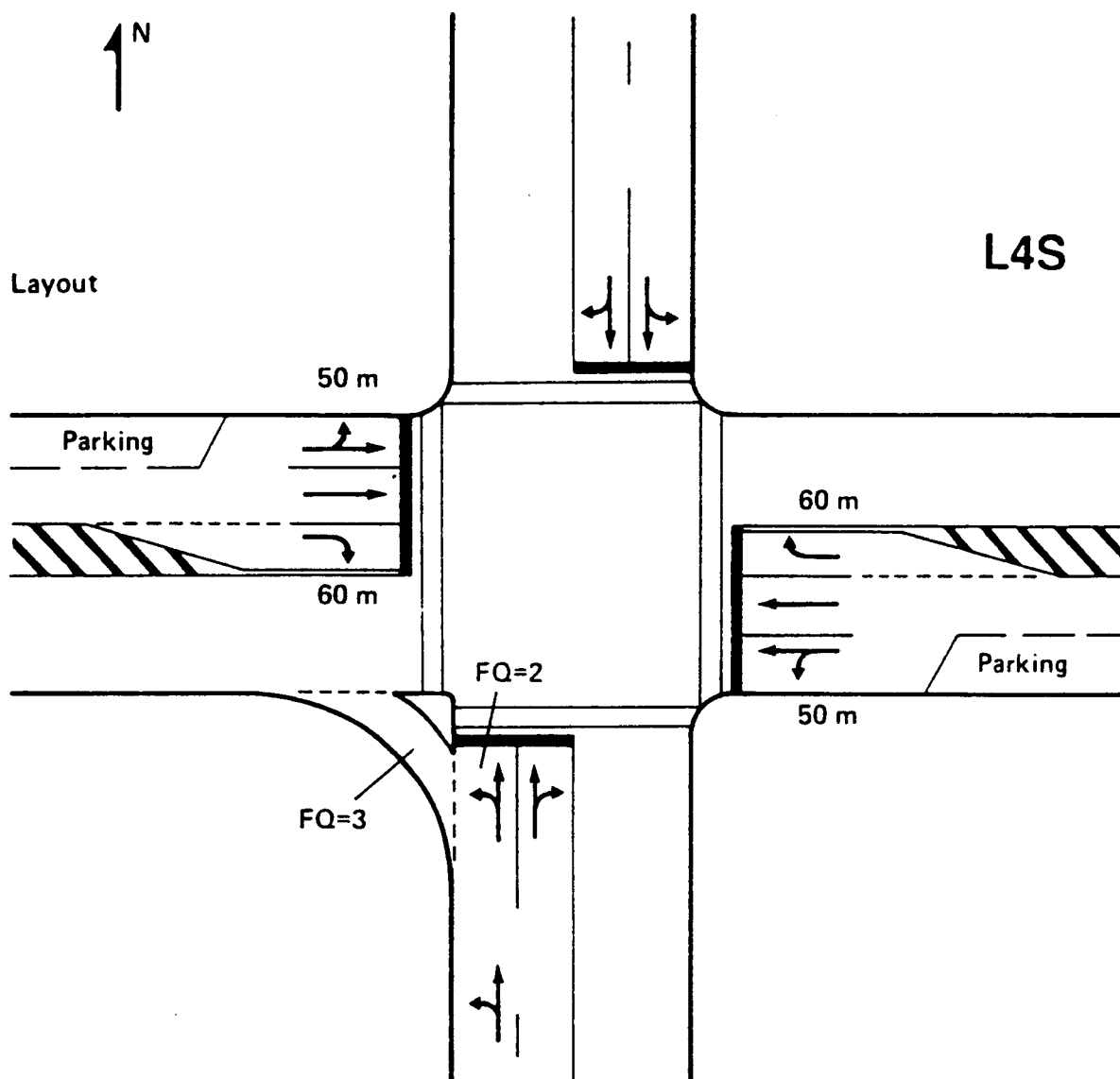


Figure 9
Assumed Peak Period Flows at Stereotype Intersection L4S

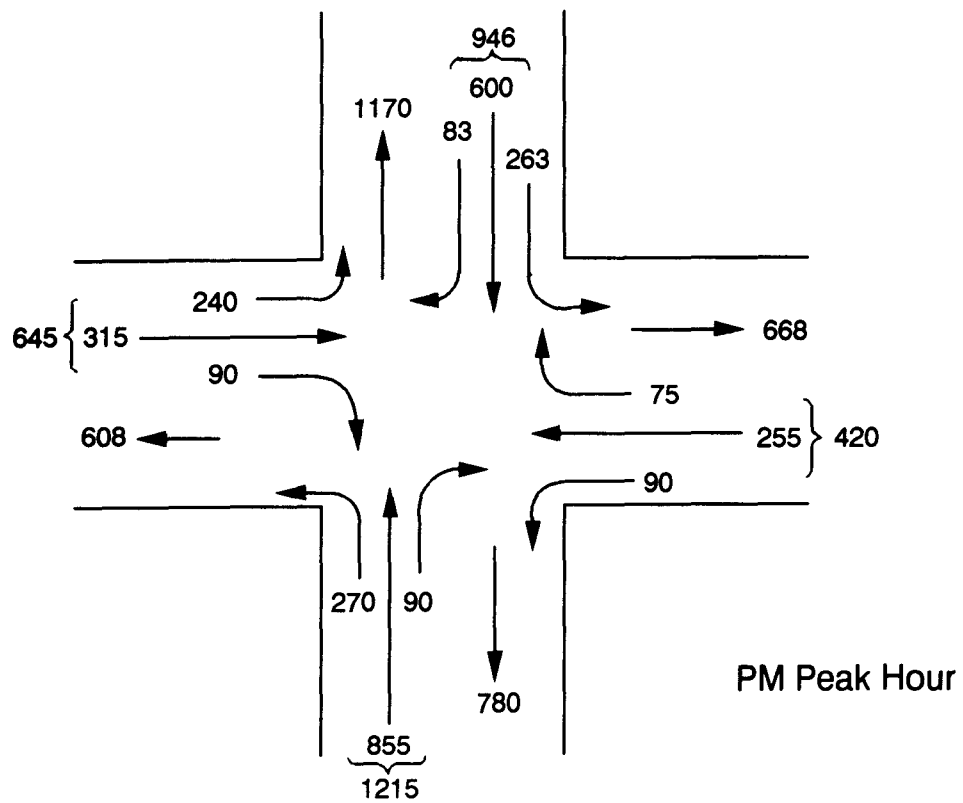
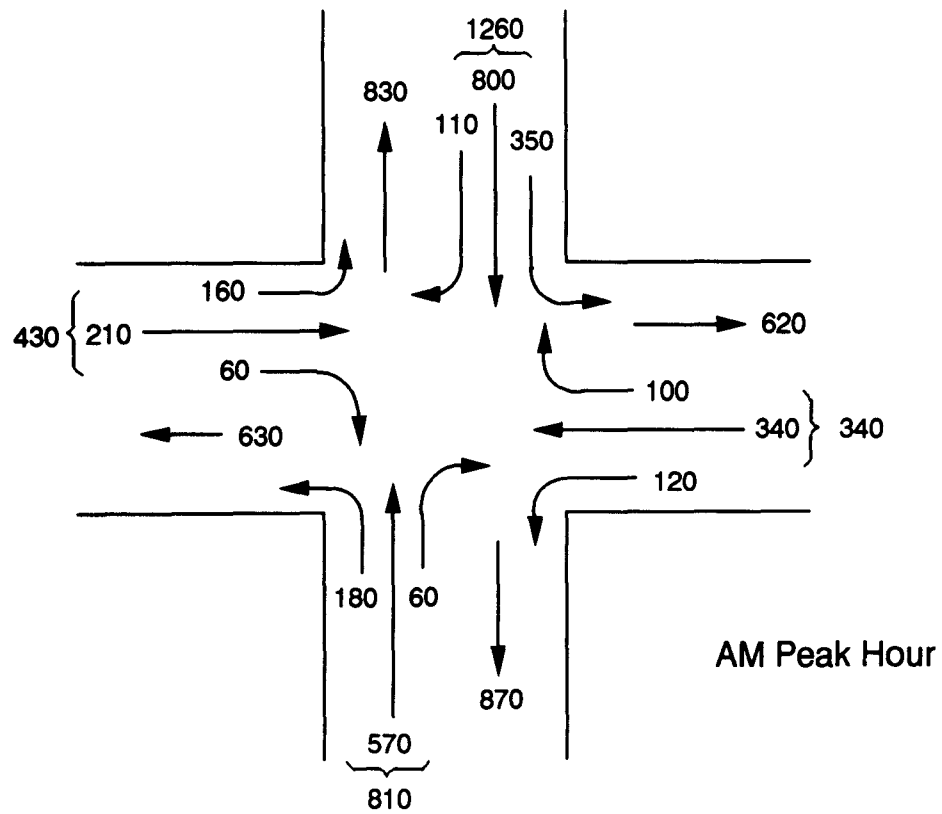
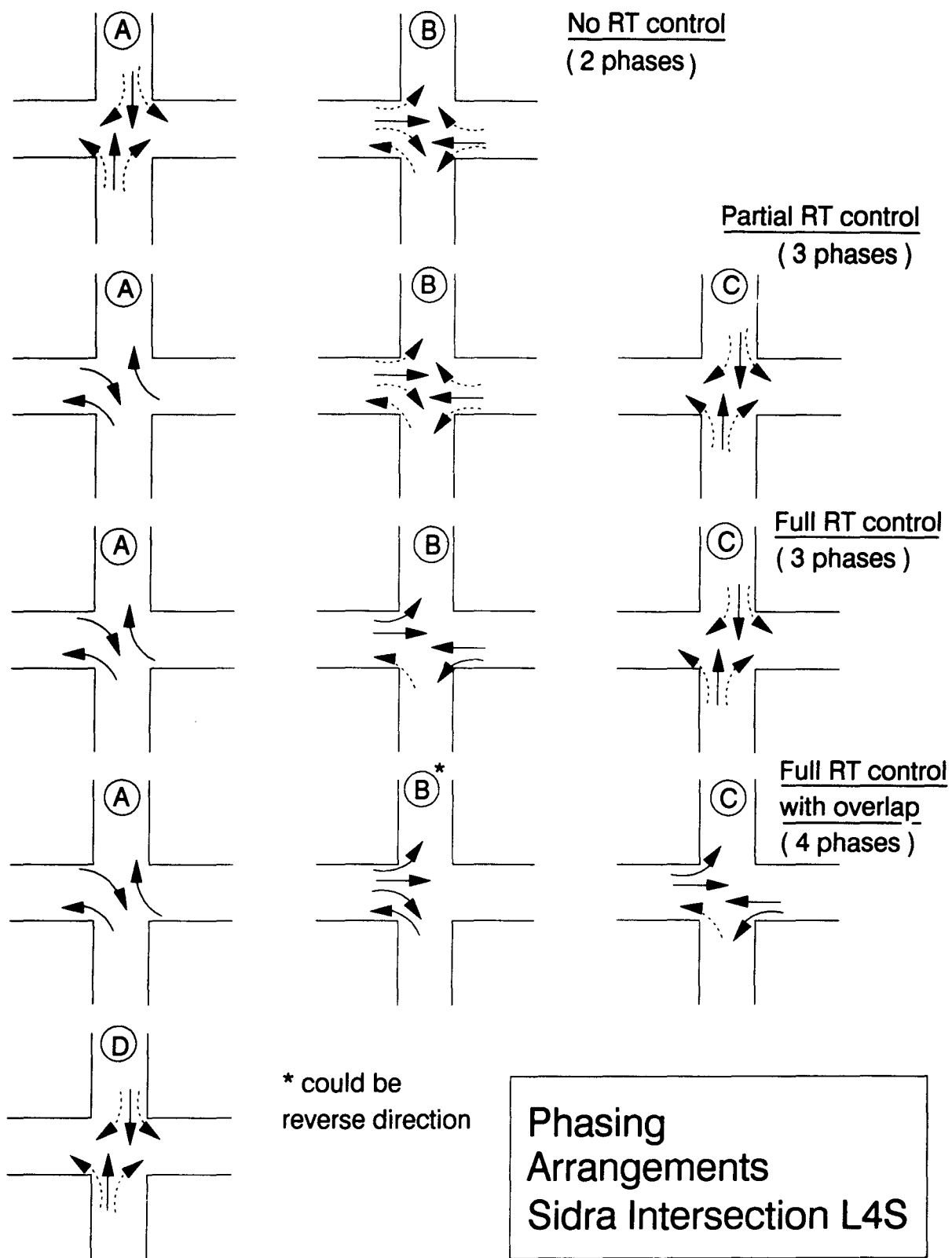


Figure 10
Phasing Systems at Stereotype Intersection L4S



- (4) full right turn control with overlap phases (that provide an extended green time for the leg with the higher volume of right turning traffic) on the east-west road.

The north-south road at L4S cannot be subject to any right turn control because of the shared lanes and the inability to separate the through and turning traffic. The only possibility would be to stagger the phases so that south-bound and north-bound traffic flowed separately. One simulation of this was attempted, but the results were so poor compared to all other simulations that this option was not considered further.

Figure 11 shows the vehicle throughput of the intersection over time of day.

SIDRA calculated optimal cycle times and green times for each phasing arrangement in each representative time period. The calculations were based on the imposition of minimum green times to accommodate pedestrian movements. Thus the modelling should provide signal settings much like those used in practice.

Table 3 provides a detailed indication of the traffic performance of L4B during the morning and evening peak periods.

Figure 12 summarises the results for total traffic at the intersection over the assumed 24 hour period, showing the SIDRA Performance Index (PI) for each phasing system. The results are similar to those found earlier for intersection L4B (see Section 5.1). The only difference is that the phasing system with no right turn control yields less delay under all traffic conditions tested at this intersection (see Figure 12). This could be attributed to the short lane lengths for the right turning lanes, and the consequent possibility of blocking the through lanes.

Performance of the fully controlled right turn cycle was always inferior to that for the partially controlled cycle, although the difference are very small off-peak and only become significant during periods of peak demand. For example, in the evening peak, the PI value for the fully controlled cycle was 201.6 compared to 163.3 for the partially controlled cycle and 123.7 for the simple two-phase cycle.

There was little variation in cycle times between the various phasing systems. Cycle time for the simple two-phase system (no right turn control) was about 48 seconds, while cycle time under the other phasing systems was in the range 57 – 60 seconds.

Figure 11
Total Hourly Traffic Volumes at Stereotype Intersection L4S, by Time of Day

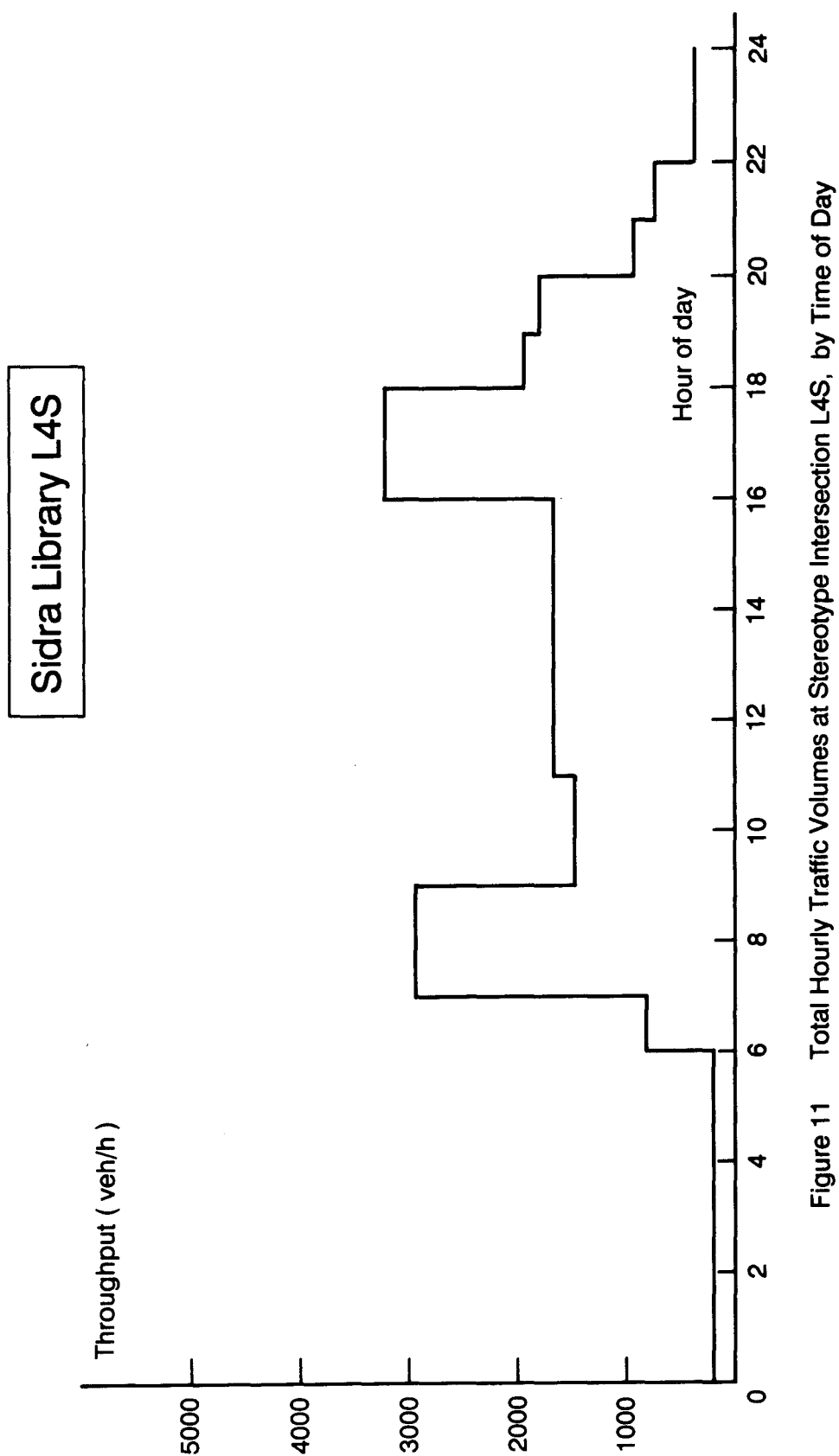
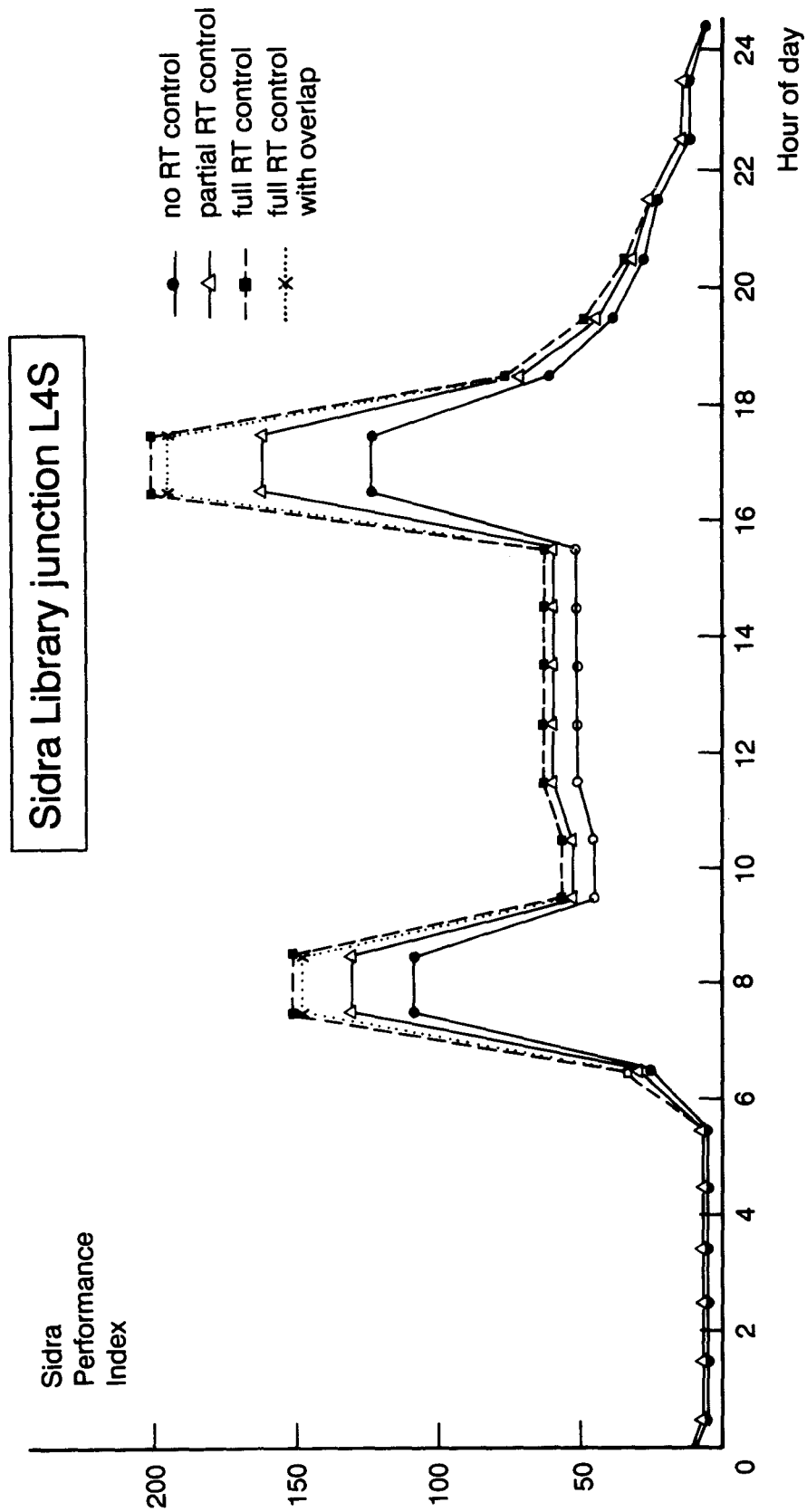


Table 3
Detailed Performance of Stereotype Intersection L4S during the Morning and Evening Peak Periods (SIDRA output)

	AM Peak			PM Peak		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	15.0	17.9	30.5	14.6	24.6	39.6
Number of stops (stops/h)	2269	2349	2616	2736	2725	2920
SIDRA Performance Index	109.15	131.31	151.07	123.72	163.13	201.63
Fuel used (L/h)	274.41	282.69	293.17	303.63	317.77	335.80
Throughput (veh/h)	2941	2941	2941	3226	3226	3226
Junction Capacity (veh/h)	5472	4838	4332	5330	4768	4268
Degree of saturation	0.827	0.852	0.903	0.793	0.853	0.894
Cycle time (s)	53	73	79	51	86	108

Figure 12

Performance of Stereotype Intersection L4S by Time of Day,
as represented by the SIDRA Performance Index (PI)



5.3 MEDIUM STANDARD FOUR-LEG JUNCTION (L4M)

This junction was a hybrid of the L4B and L4S junctions available in the SIDRA library, and its configuration is shown by Figure 13. The north-south road is a high-standard dual carriageway arterial road, while the east-west road may be taken as a single carriageway secondary arterial. Right turn controls were only considered for the north-south road. The three control options of no control, partial control and full control were applied (see Figure 14 for phasing details) for the simulated pattern of traffic demands based on the assumed am and pm peak hour traffic flows shown in Figure 15. Off-peak flows were generated using the same method as applied previously to L4B and L4S.

SIDRA was used to calculate optimal cycle times and signal settings for each representative time period over a day.

Table 4 provides a detailed indication of the traffic performance of L4B during the morning and evening peak periods.

Figure 16 summarises the results of the analysis over each time period, in terms of the SIDRA Performance Index (PI) for each phasing system. The results concur with those found for L4B and L4S. The simple two-phase system provides the best overall level of service, and maximum delays always occurred under the fully-controlled regime. Performance indices for full control were never more than 12 per cent above those for no control, with those for partial control always less than those for full control. Modelled cycle times varied from 61 to 82 seconds. There were some proportionally larger variations in delay times, the maximum absolute difference between full control and no control was 5.3 seconds (37 per cent, in the pm peak), while that for partial control was 3.4 seconds (28 per cent, in the time period 18:00-19:00).

Thus the analysis of the stereotype four-leg junctions indicate that the no control option yielded the best *overall* intersection performance under nearly all traffic conditions, while the full control option always yielded the worst case performance, although the differences never exceeded 20 per cent.

Figure 13
Layout of Stereotype Intersection L4M

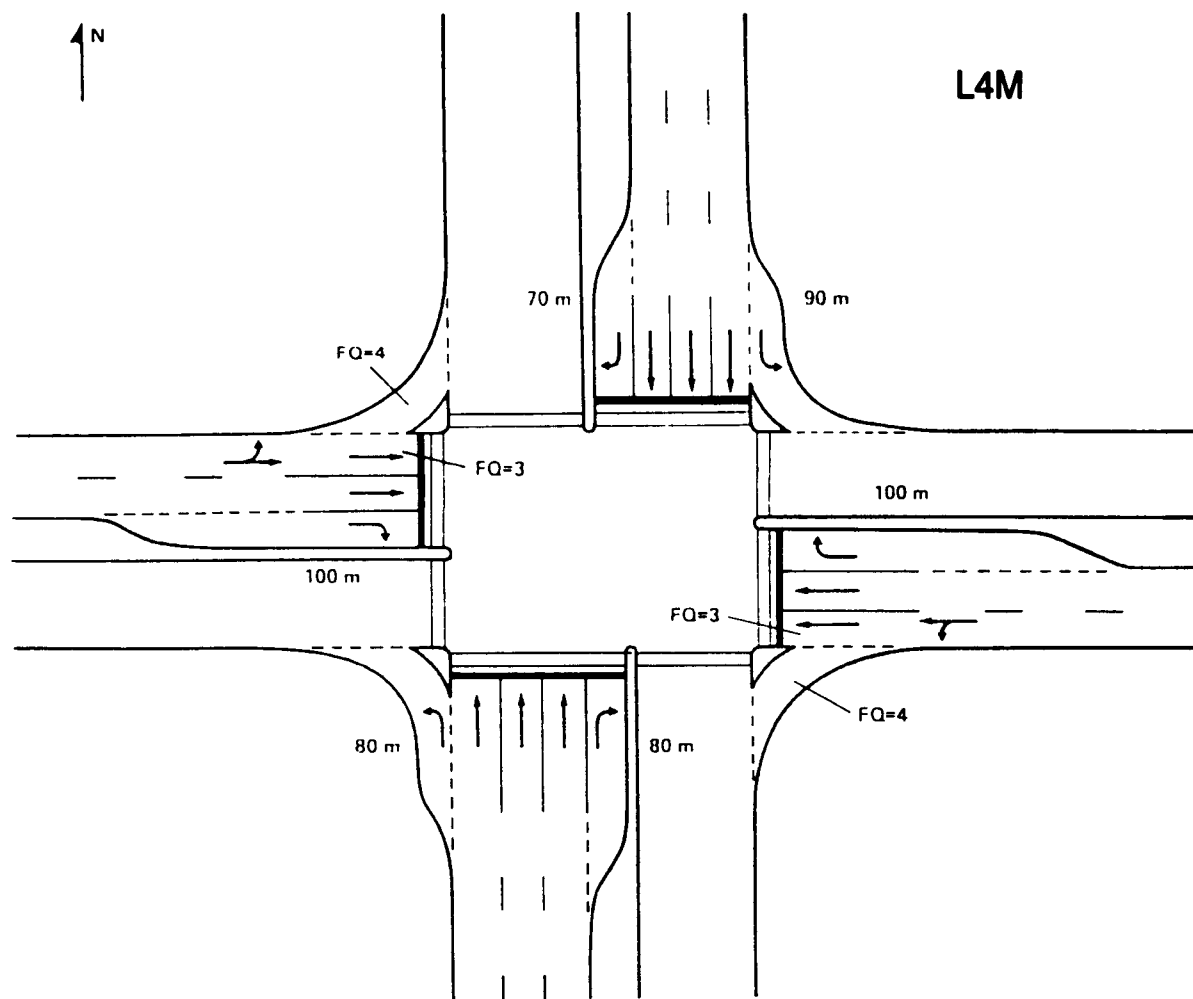


Figure 14
Phasing Systems at Stereotype Intersection L4M

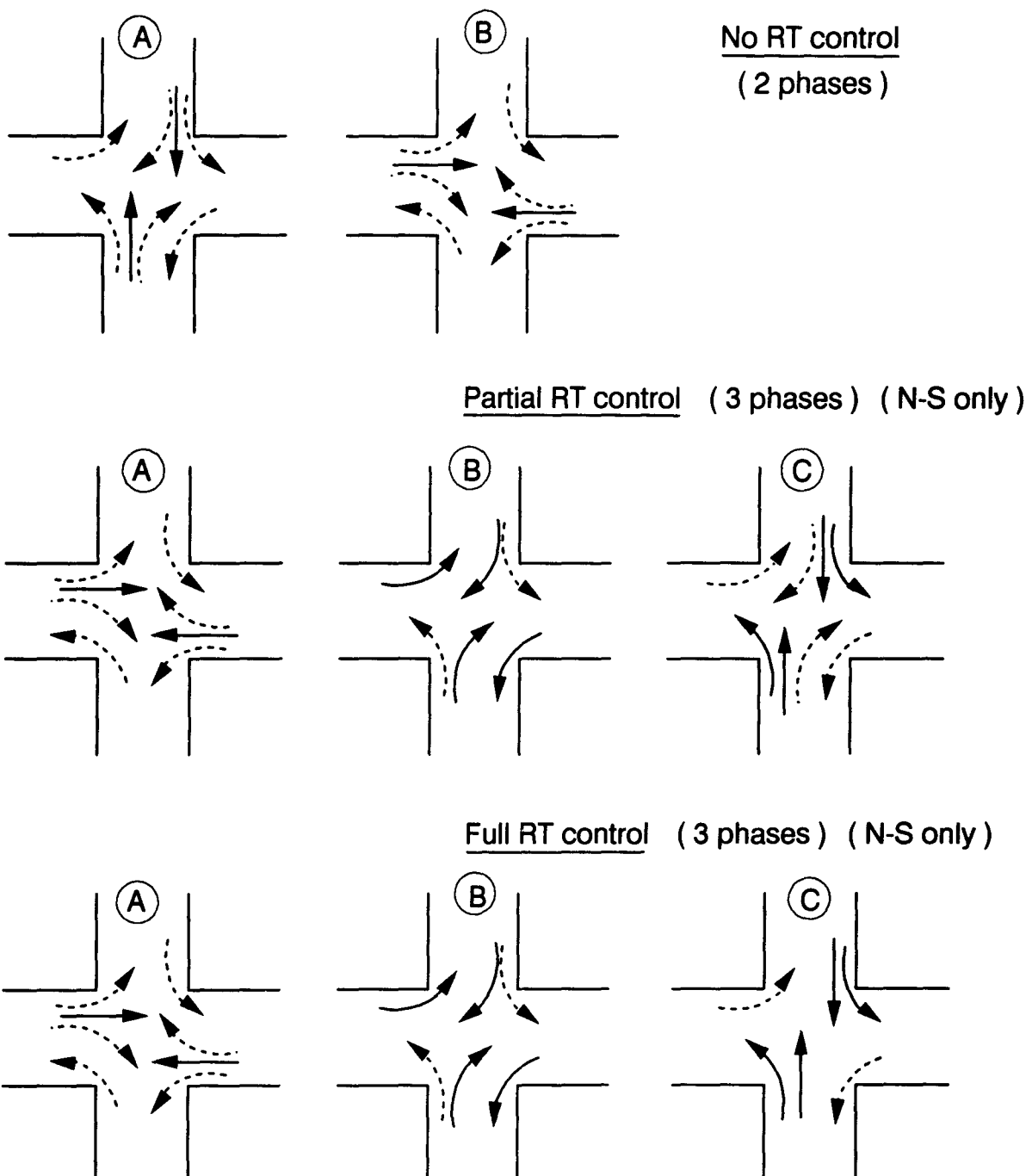


Figure 15
Assumed Peak Period Flows at Stereotype Intersection L4M

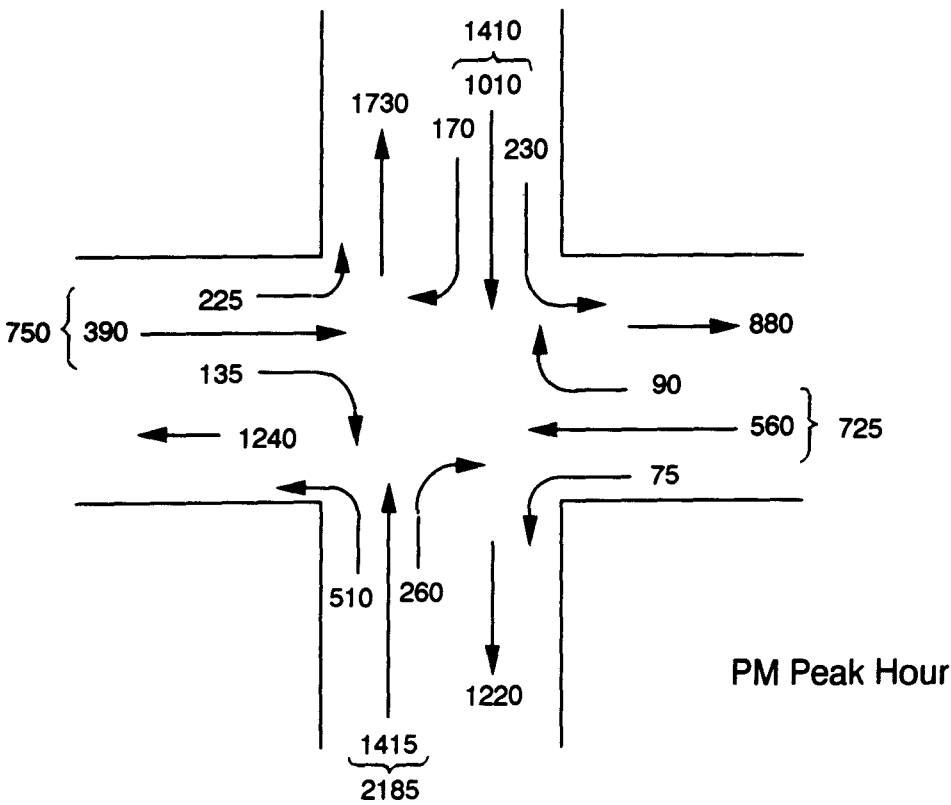
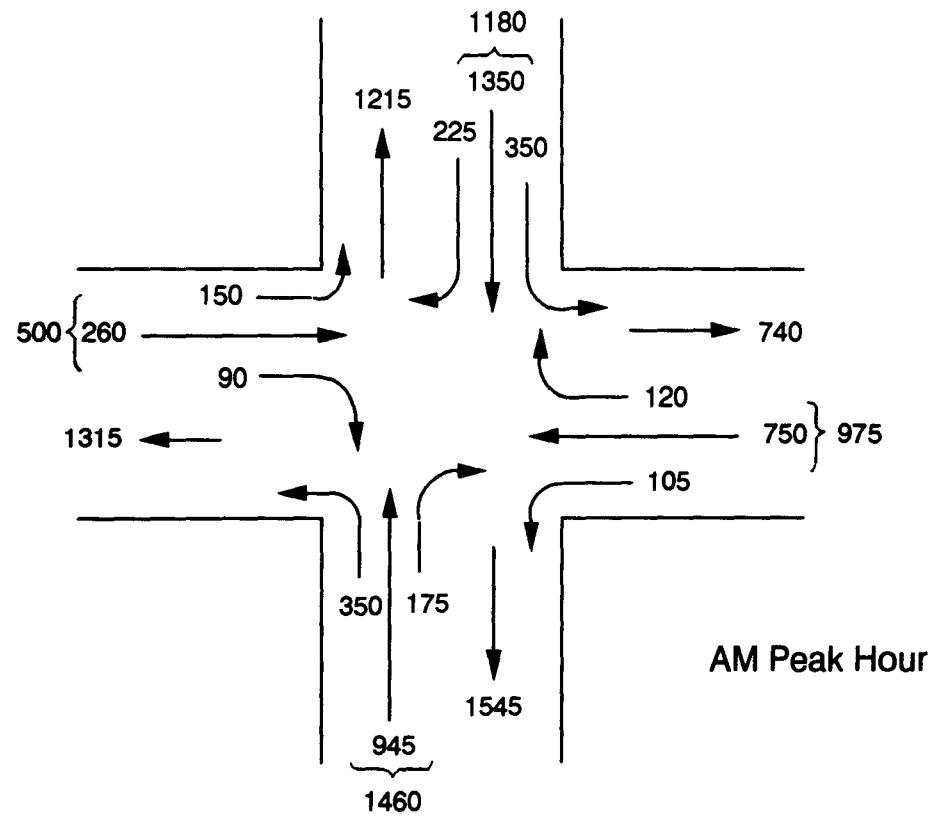
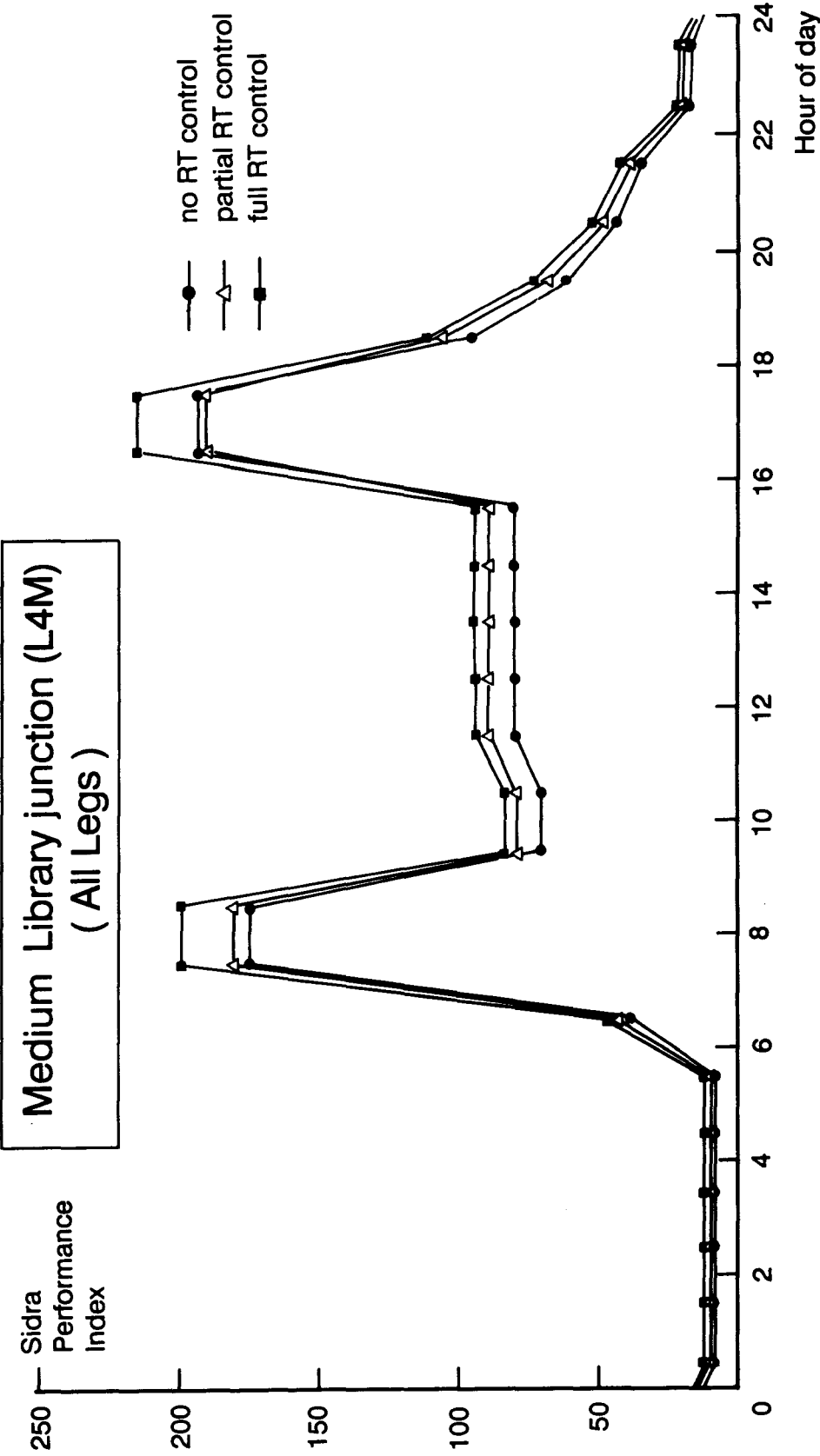


Table 4
Detailed Performance of Stereotype Intersection L4M during the Morning and Evening Peak Periods (SIDRA output)

	AM Peak			PM Peak		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	13.1	14.2	18.4	14.3	14.5	19.6
Number of stops (stops/h)	2844	3093	3336	3002	3313	3599
SIDRA Performance Index	175.25	180.95	198.71	192.90	192.21	215.57
Fuel used (L/h)	438.83	444.17	453.39	465.27	465.27	480.36
Throughput (veh/h)	4815	4815	4815	5070	5070	5070
Junction Capacity (veh/h)	11942	10925	10212	11857	10740	9968
Degree of saturation	0.894	0.649	0.829	0.897	0.706	0.920
Cycle time (s)	76	72	75	82	72	129

Figure 16
Performance of Stereotype Intersection L4M by Time of Day,
as represented by the SIDRA Performance Index (PI)



5.4 THREE-LEG HIGH STANDARD INTERSECTION (SIDRA LIBRARY JUNCTION L3B)

This SIDRA library intersection is shown in Figure 17. It represents a T-intersection of high design standard, with full channelisation. Assumed peak hour traffic flows are shown in Figure 18. The only right turn subject to variations in the level of control is that from the western leg of the main road. Figure 19 shows the phasing arrangements, while Figure 20 displays the PI values over a simulated 24 hour period. There is little difference in performance, except at peak hour. The result of no control giving superior performance to partial control and to full control is again found. Full control gave the worst performance under all conditions. Cycle times varied from 57 to 153 seconds, with most values about 67-70 seconds.

Table 5 provides a detailed indication of the traffic performance of L3B during the morning and evening peak periods.

Figure 17
Layout of Stereotype Intersection L3B

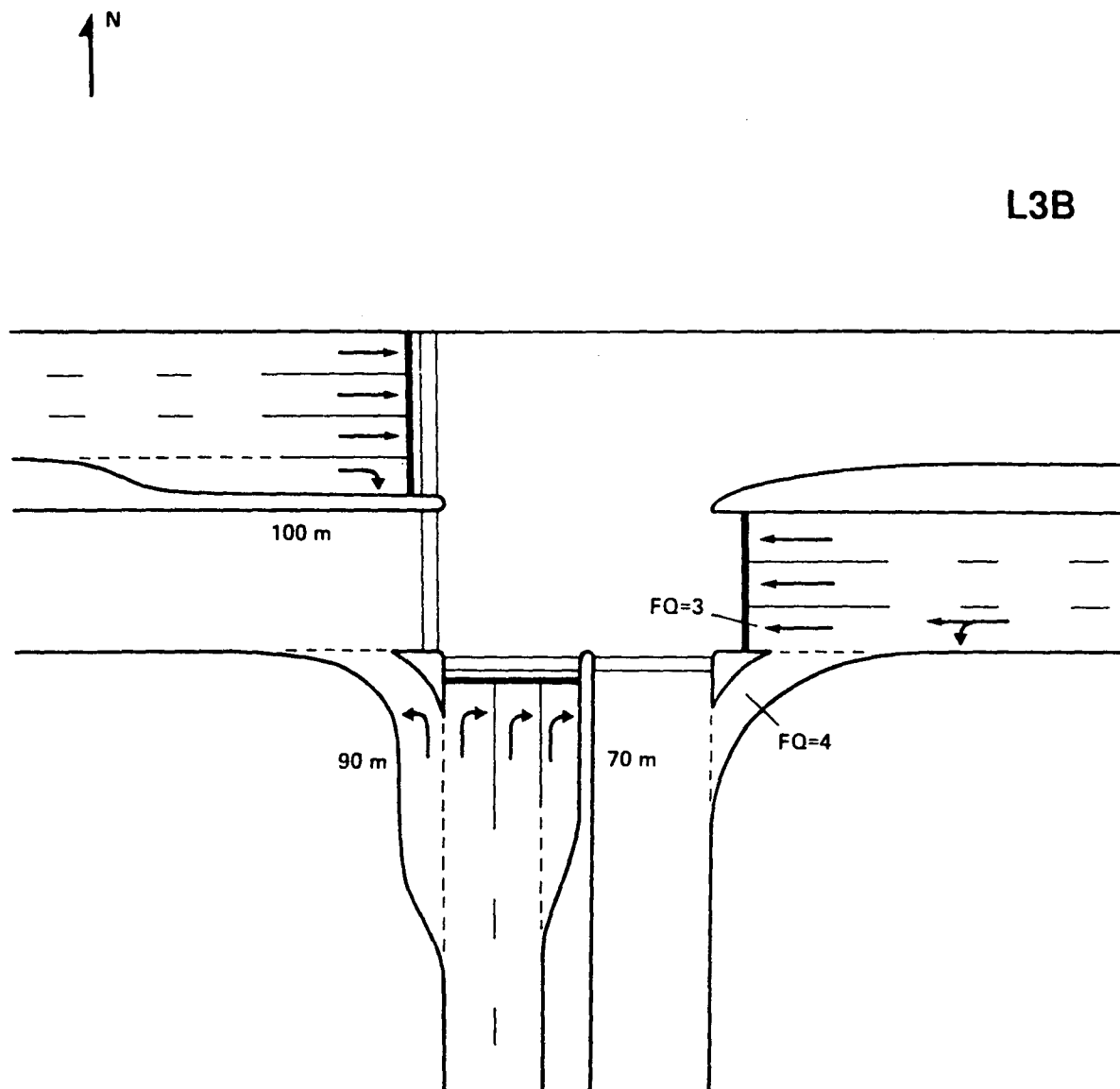


Figure 18
Assumed Peak Period Flows at Stereotype Intersection L3B

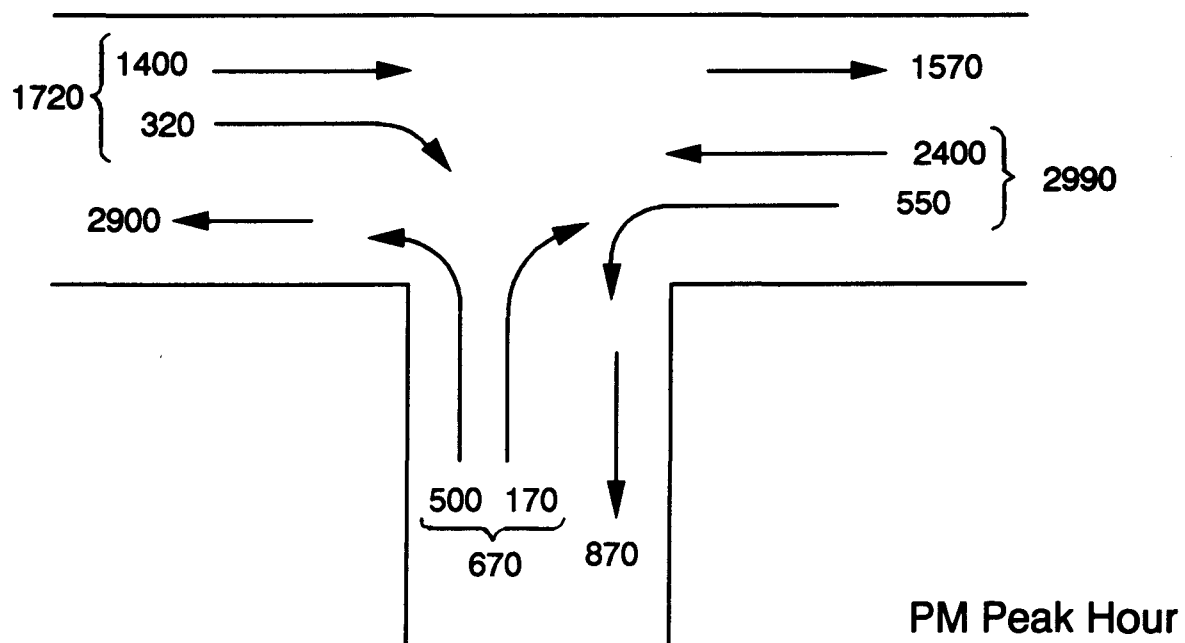
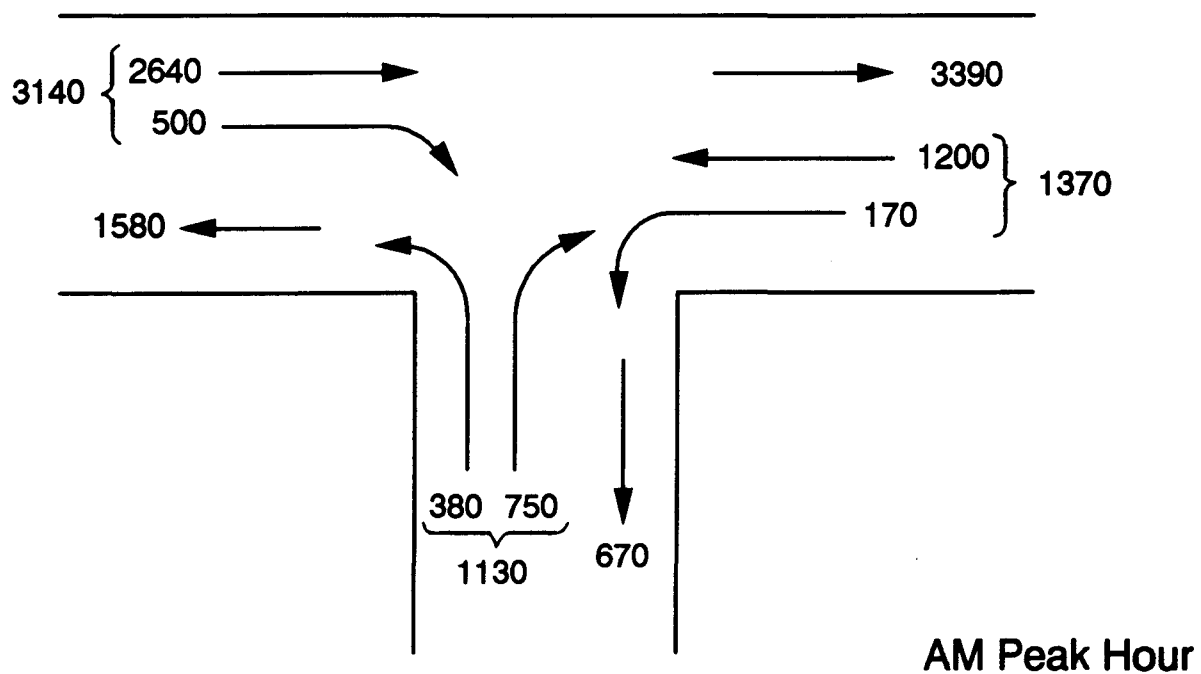
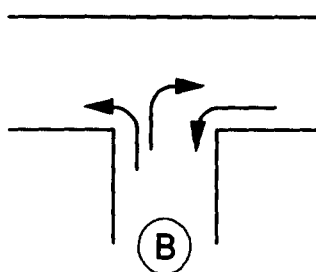
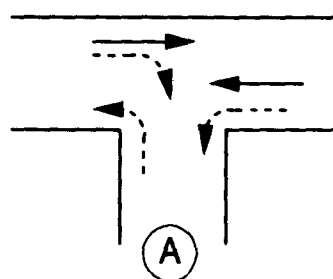
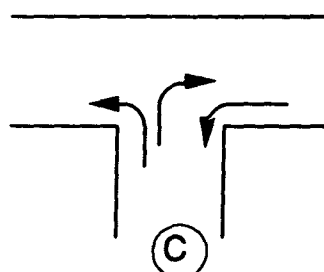
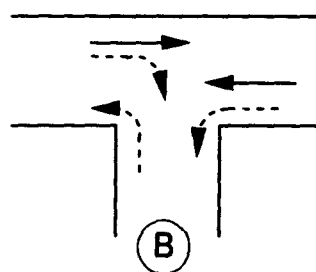
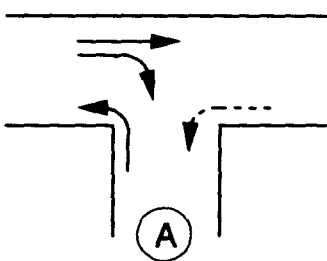


Figure 19
Phasing Systems at Stereotype Intersection L3B



No RT control
(2 phases)

Partial RT control (3 phases)



Full RT control (3 phases)

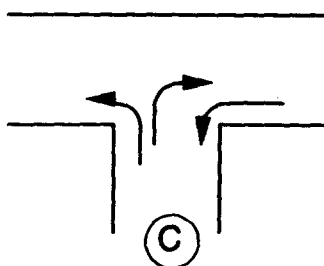
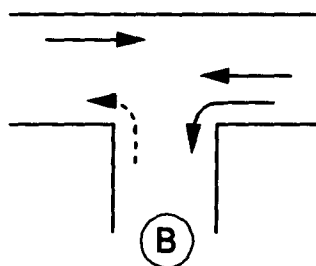
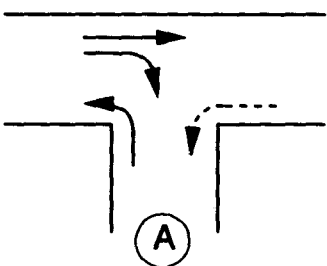


Figure 20
Performance of Stereotype Intersection L3B by Time of Day,
as represented by the SIDRA Performance Index (PI)

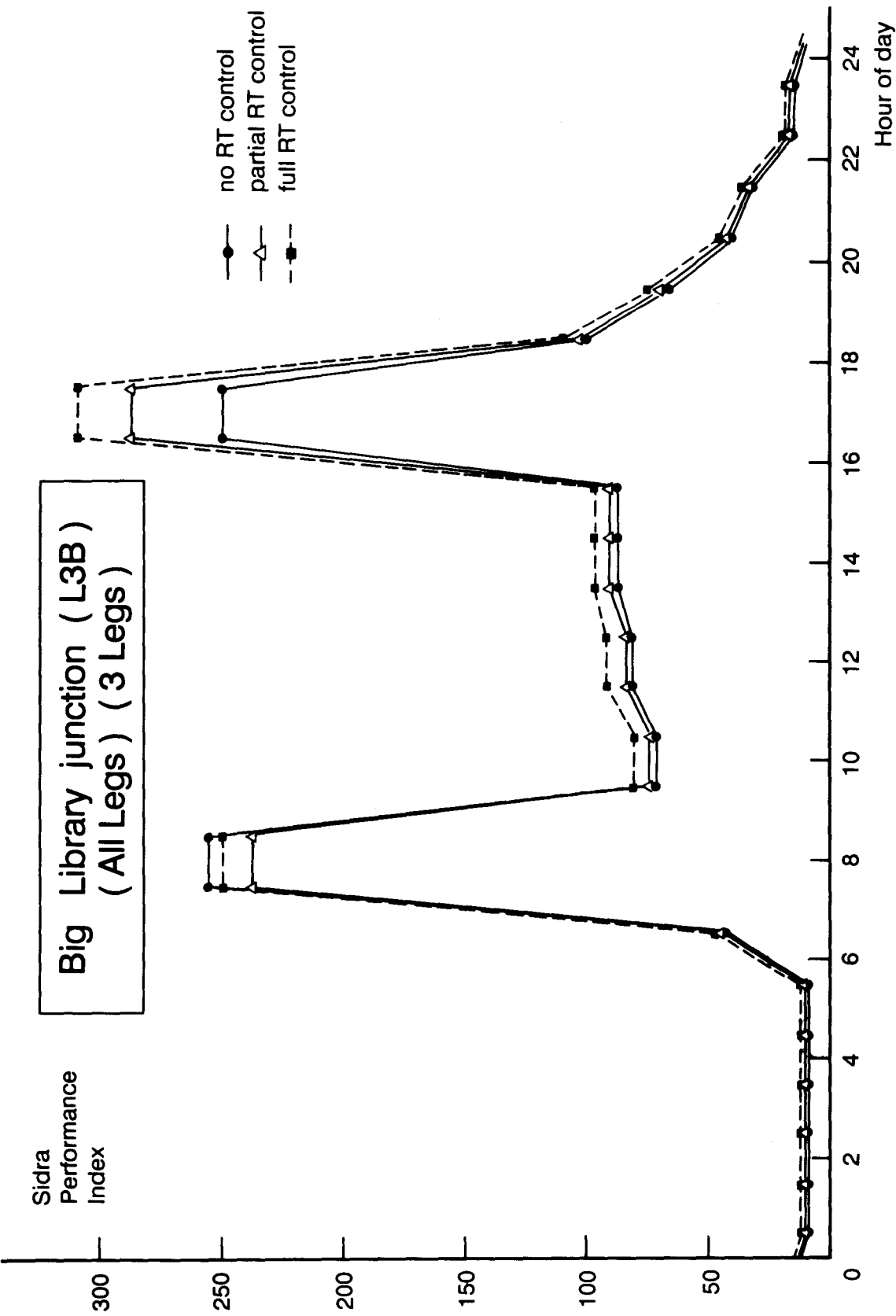


Table 5

Detailed Performance of Stereotype Intersection L3B during the Morning and Evening Peak Periods (SIDRA output)

	AM Peak			PM Peak		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	18.4	16.8	19.1	25.9	24.7	28.4
Number of stops (stops/h)	2737	4253	4064	2412	4263	4010
SIDRA Performance Index	255.25	237.66	250.05	249.74	287.61	309.48
Fuel used (L/h)	505.05	525.68	531.47	468.19	513.76	520.96
Throughput (veh/h)	5640	5640	5640	5340	5340	5340
Junction Capacity (veh/h)	10399	8646	8377	10101	9471	9403
Degree of saturation	1.001	0.867	0.871	1.382	0.902	0.961
Cycle time (s)	139	80	87	153	122	144

5.5 THREE-LEG LOW STANDARD INTERSECTION (SIDRA LIBRARY JUNCTION L3S)

This junction (see Figure 21) has short lanes and incomplete channelisation. It represents an intersection in an environment of restricted road space and significant on-street parking in its vicinity. Modelling was done using a 24-hour demand profile based on the peak period flows shown in Figure 22, with the alternative phasing arrangements as in Figure 19. The results of the analysis are shown in Figure 23, and follow those found for L3B. Cycle times ranged from 46 to 71 seconds.

Table 6 provides a detailed indication of the traffic performance of L3S during the morning and evening peak periods.

Figure 21
Layout of Stereotype Intersection L3S

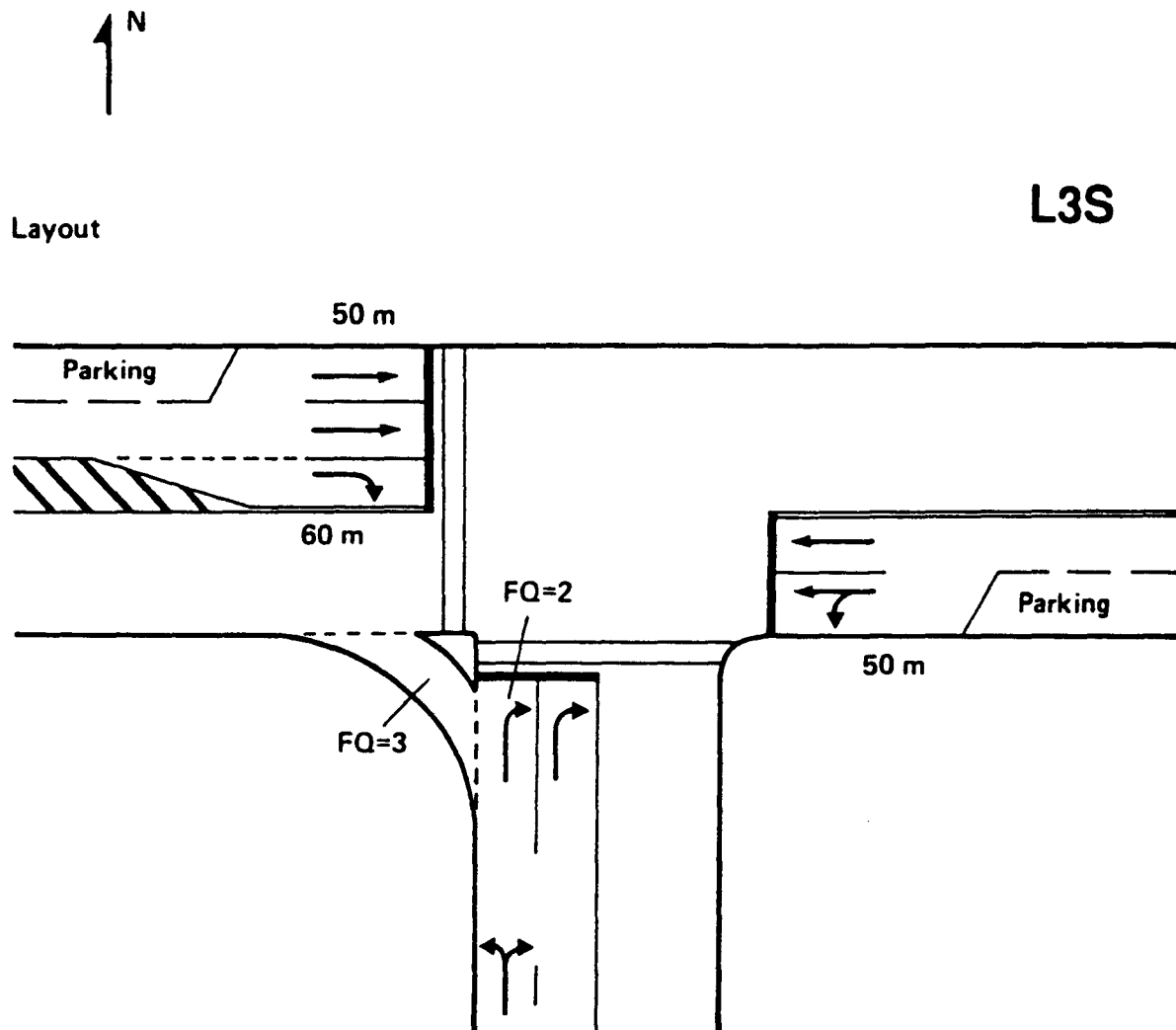


Figure 22
Assumed Peak Period Flows at Stereotype Intersection L3S

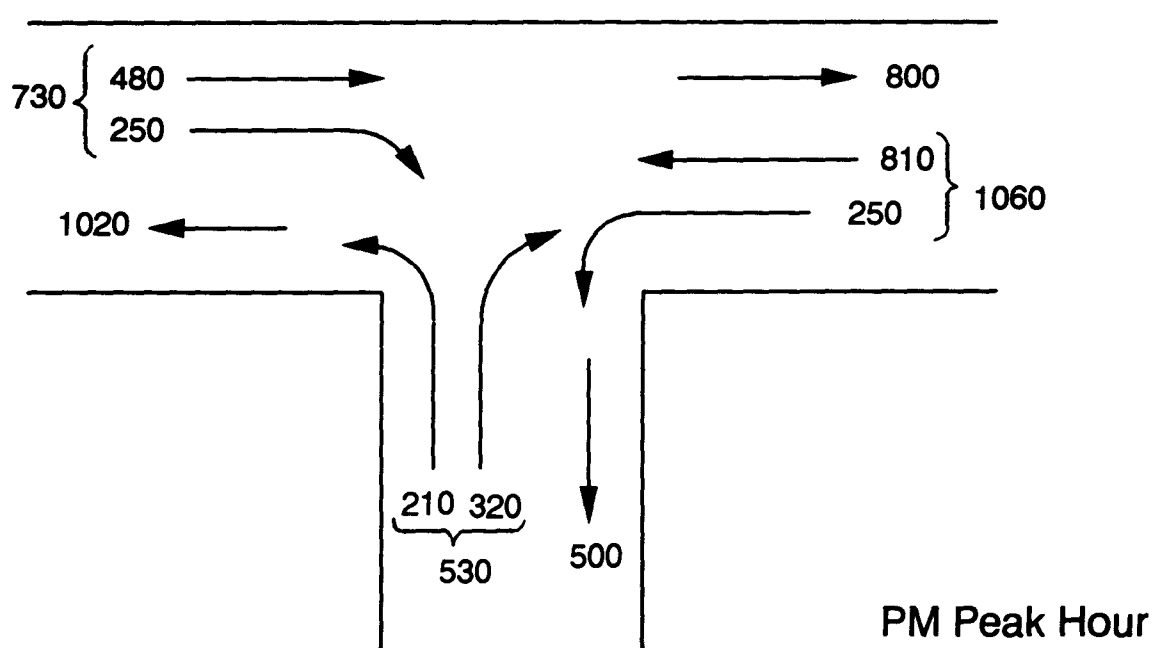
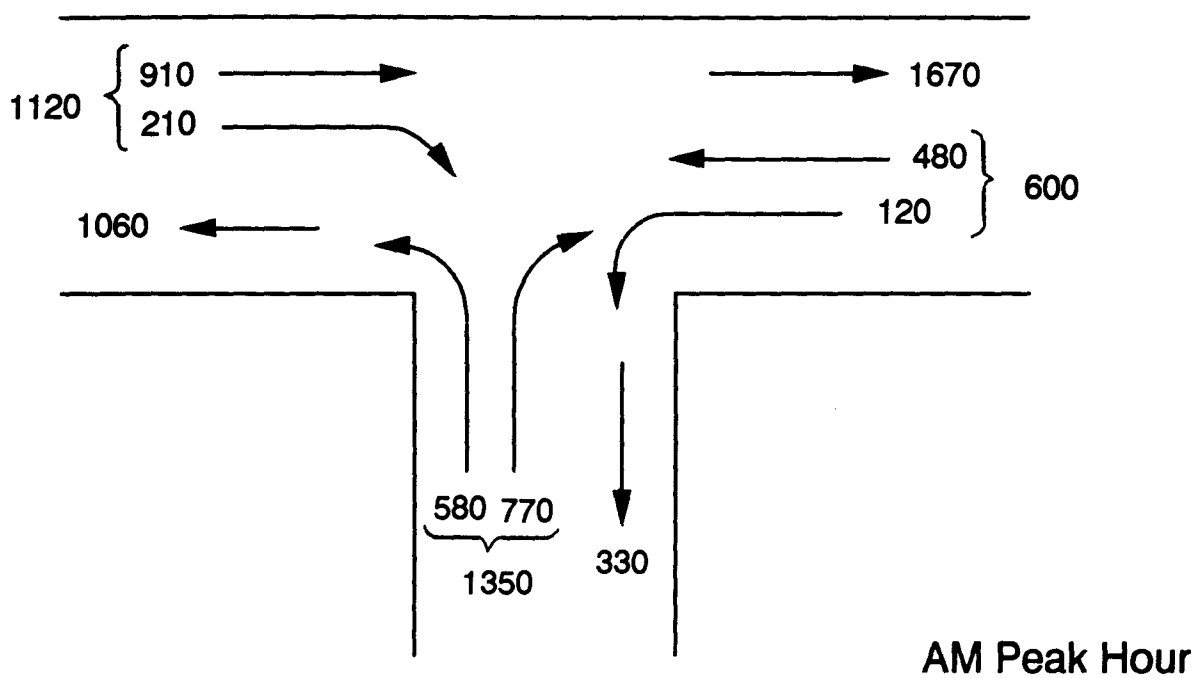


Figure 23
Performance of Stereotype Intersection L3S by Time of Day,
as represented by the SIDRA Performance Index (PI)

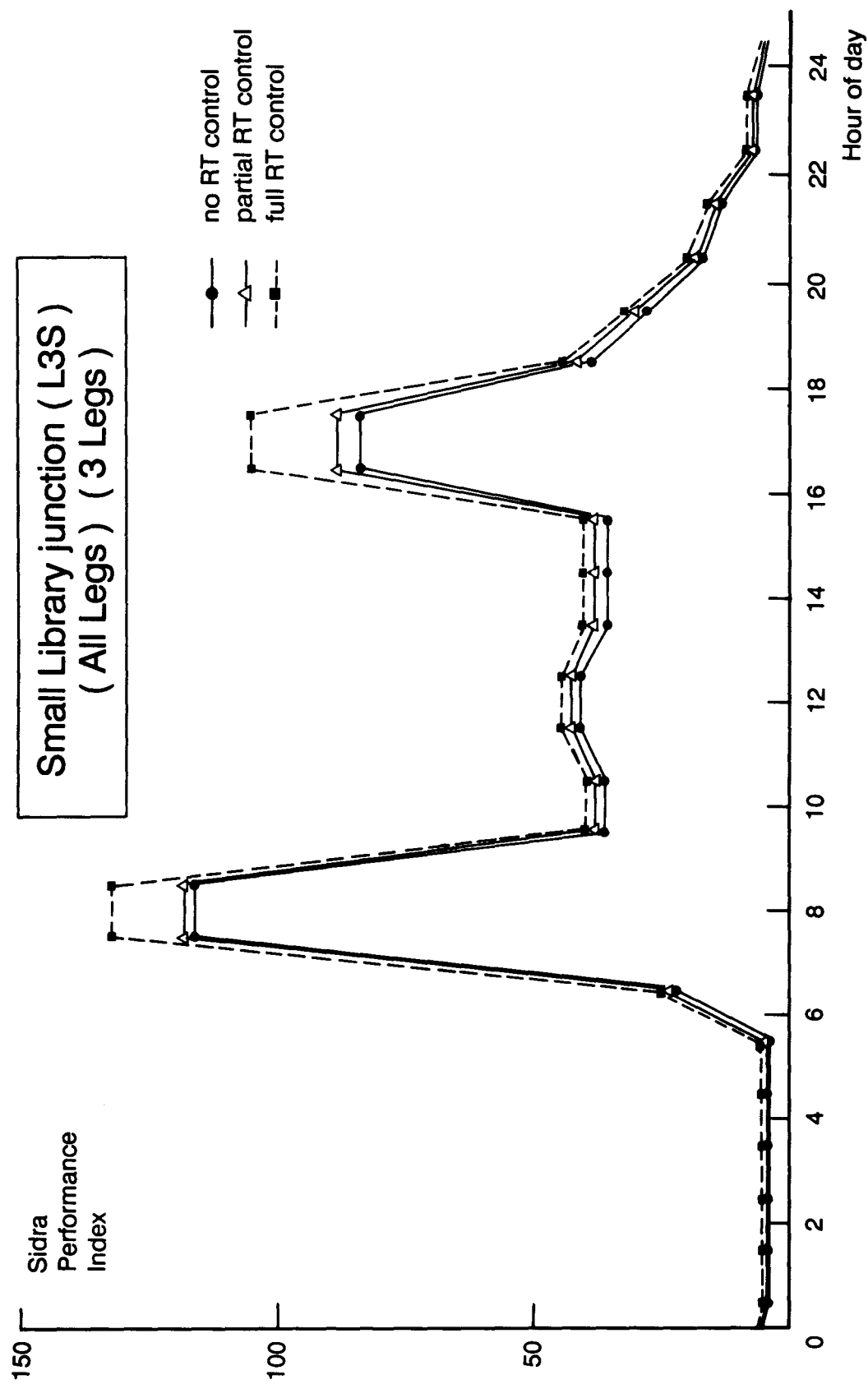


Table 6

Detailed Performance of Stereotype Intersection L3S during the Morning and Evening Peak Periods (SIDRA output)

	AM Peak			PM Peak		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	16.4	16.0	21.4	20.8	14.8	23.5
Number of stops (stops/h)	2825	2594	2942	1911	1692	1911
SIDRA Performance Index	116.74	118.52	132.52	94.17	88.73	105.41
Fuel used (L/h)	288.66	287.12	293.45	217.40	215.15	224.81
Throughput (veh/h)	3070	3070	3070	2320	2320	2320
Junction Capacity (veh/h)	4200	4505	4144	4659	4636	4395
Degree of saturation	0.875	0.867	0.885	1.000	0.785	0.903
Cycle time (s)	46	57	59	58	70	71

5.6 SENSITIVITY TESTS

A general result from the analysis of the stereotype intersections was that, for light to medium traffic conditions (i.e. all time intervals other than the morning and evening peaks), no right turn control always gave less delay and better operating conditions than partial and full turn controls. Figures 5, 12, 16, 20 and 23 clearly indicate this effect. Further, as may be gauged from these figures, there were differences in performance between the three phasing systems for different intersections. Under some peak period traffic conditions, partial (and less often) full right turn control did lead to superior mobility performance at an intersection, as would be expected.

Sensitivity analyses were undertaken for all of the stereotype intersections, to see if levels of traffic flow producing changes in the relative performance of the turn control systems could be located. The sensitivity analyses were based on variations of the morning peak period flows by ± 5 , ± 10 and (in one instance) ± 20 per cent of the original values. Tables 7-11 indicate the results of the sensitivity tests.

Table 7 shows that partial flow became the preferred option (in mobility terms) for intersection L4B at a traffic demand level about eight per cent less than the morning peak flows in Figure 2.

For intersection L4S, Table 8 indicates that no cross-over point could be found. The no-control case always gave superior mobility performance, and the differences in relative mobility performance between the three control cases were not changing.

Table 9 indicates that partial flow became the preferred option for mobility performance for intersection L4M at flows about two per cent above the morning peak flows in Figure 15.

The cross-over point for intersection L3B was at about -10 per cent change in flow (Table 10), and for intersection L3S was about +10 per cent change in flow (Table 11).

Table 7

Sensitivity Analysis of Stereotype Intersection L4B for the Morning Peak Period (SIDRA output)

	-5% Change to AM Peak Flows			-10% Change to AM Peak Flows		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	34.5	22.0	35.7	18.0	20.3	31.4
Number of stops (stops/h)	4295	4517	5293	3786	4096	4731
SIDRA Performance Index	319.90	269.24	330.05	224.64	247.05	294.68
Fuel used (L/h)	590.35	569.94	602.88	525.75	535.56	560.76
Throughput (veh/h)	5939	5939	5939	5624	5624	5624
Junction Capacity (veh/h)	13019	10199	9815	13049	10263	9856
Degree of saturation	1.158	0.789	0.924	0.953	0.748	0.861
Cycle time (s)	112	83	94	75	83	92

Sensitivity tests were used to indicate the cross-over point for the preferred signal phase operations at the intersection. The two sets of flows used in the sensitivity tests were -5% and -10% changes to the am peak flows. The cross-over point lay between -5% and -10% change in flows.

Table 8

Sensitivity Analysis of Stereotype Intersection L4S for the Morning Peak Period (SIDRA output)

	+10% Change to AM Peak Flows			+20% Change to AM Peak Flows		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	16.1	25.2	36.9	18.8	37.8	99.2
Number of stops (stops/h)	2478	2605	2811	2827	2815	3121
SIDRA Performance Index	125.00	156.51	191.41	146.67	229.70	457.42
Fuel used (L/h)	302.50	315.02	330.86	334.32	363.58	442.71
Throughput (veh/h)	3234	3234	3234	3530	3530	3530
Junction Capacity (veh/h)	5414	4839	4423	5308	4773	4183
Degree of saturation	0.832	0.856	0.897	0.856	0.878	1.000
Cycle time (s)	59	84	104	65	140	300

Sensitivity tests were used to indicate the cross-over point for the preferred signal phase operations at the intersection. The two sets of flows used in the sensitivity tests were +10% and +20% changes to the am peak flows. For L4S no cross-over point could be found.

Table 9

Sensitivity Analysis of Stereotype Intersection L4M for the Morning Peak Period (SIDRA output)

	+5% Change to AM Peak Flows			+10% Change to AM Peak Flows		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	21.0	14.4	19.3	35.8	14.9	20.5
Number of stops (stops/h)	3163	3301	3602	3811	3543	3893
SIDRA Performance Index	217.37	191.74	214.06	274.70	203.62	229.33
Fuel used (L/h)	475.74	467.84	479.14	529.27	491.18	504.45
Throughput (veh/h)	5057	5057	5057	5299	5299	5299
Junction Capacity (veh/h)	12068	10868	10107	12030	10777	10051
Degree of saturation	1.106	0.681	0.808	1.320	0.714	0.849
Cycle time (s)	95	72	76	103	72	300

Sensitivity tests were used to indicate the cross-over point for the preferred signal phase operations at the intersection. The two sets of flows used in the sensitivity tests were +5% and +10% changes to the am peak flows. The cross-over point lay between 0% and +5% change in flows.

Table 10

Sensitivity Analysis of Stereotype Intersection L3B for the Morning Peak Period (SIDRA output)

	-10% Change to AM Peak Flows			+10% Change to AM Peak Flows		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	15.6	14.9	17.1	62.6	20.5	23.9
Number of stops (stops/h)	2356	3639	3442	3584	5080	4920
SIDRA Performance Index	211.67	200.33	212.07	518.06	285.57	302.81
Fuel used (L/h)	453.23	468.98	473.72	640.70	588.27	598.28
Throughput (veh/h)	5076	5076	5076	6204	6204	6204
Junction Capacity (veh/h)	10372	8540	8410	10147	8630	8348
Degree of saturation	0.999	0.871	0.878	1.160	0.887	0.896
Cycle time (s)	128	75	83	262	84	91

Sensitivity tests were used to indicate the cross-over point for the preferred signal phase operations at the intersection. The two sets of flows used in the sensitivity tests were -10% and +10% changes to the am peak flows. The cross-over point lay at about -10% change in flows.

Table 11

Sensitivity Analysis of Stereotype Intersection L3S for the Morning Peak Period (SIDRA output)

	-10% Change to AM Peak Flows			+10% Change to AM Peak Flows		
	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control	No Right Turn Control	Partial Right Turn Control	Full Right Turn Control
Mean delays (s)	11.1	12.2	15.1	20.2	19.6	26.4
Number of stops (stops/h)	2125	2051	2225	3037	3136	3286
SIDRA Performance Index	92.72	97.22	104.25	142.38	144.62	163.53
Fuel used (L/h)	254.76	254.67	257.70	321.43	320.72	329.97
Throughput (veh/h)	2763	2763	2763	3377	3377	3377
Junction Capacity (veh/h)	4264	4537	4210	4595	4328	4132
Degree of saturation	0.767	0.769	0.806	0.893	0.881	0.884
Cycle time (s)	46	57	57	61	63	71

Sensitivity tests were used to indicate the cross-over point for the preferred signal phase operations at the intersection. The two sets of flows used in the sensitivity tests were -10% and +10% changes to the am peak flows. The cross-over point lay at about +10% change in flow.

6.0 ANALYSIS OF CASE STUDY INTERSECTIONS

The following case study intersections were modelled, to test whether the general findings from the simulations translate into practice:

- (a) Clayton Road and Centre Road (SCRAM #3198);
- (b) Springvale Road and Maroondah Highway (SCRAM #0117), and
- (c) Centre Road and Warrigal Road (SCRAM #3694).

The modelling and analysis of the case study intersections considered the morning and evening peak periods before and after the change to the right turn controls. Analysis was performed for three separate conditions for both peak periods:

- (1) the 'before' case (i.e. the intersection with its *original turn controls* and signal phasings and the *before* turning movement flows);
- (2) the immediate 'after' case (i.e. the intersection with its *new turn controls* and signal phasings and the *before* turning movement flows). This case could be associated with the intersection immediately after the introduction of the new control system, and
- (3) the full 'after' case (i.e. the intersection with its *new turn controls* and signal phasings and the *after* turning movement flows). This case indicates the long-term performance of the intersection.

The first two case study intersections may be taken as 'extreme' cases, whilst the third is a good example of the intersection of two single carriageway urban arterial roads.

6.1 CLAYTON ROAD-CENTRE ROAD

Clayton Road-Centre Road is a severely-constrained junction of no more than local importance, with limited space available, narrow lanes throughout, and short turning lanes.

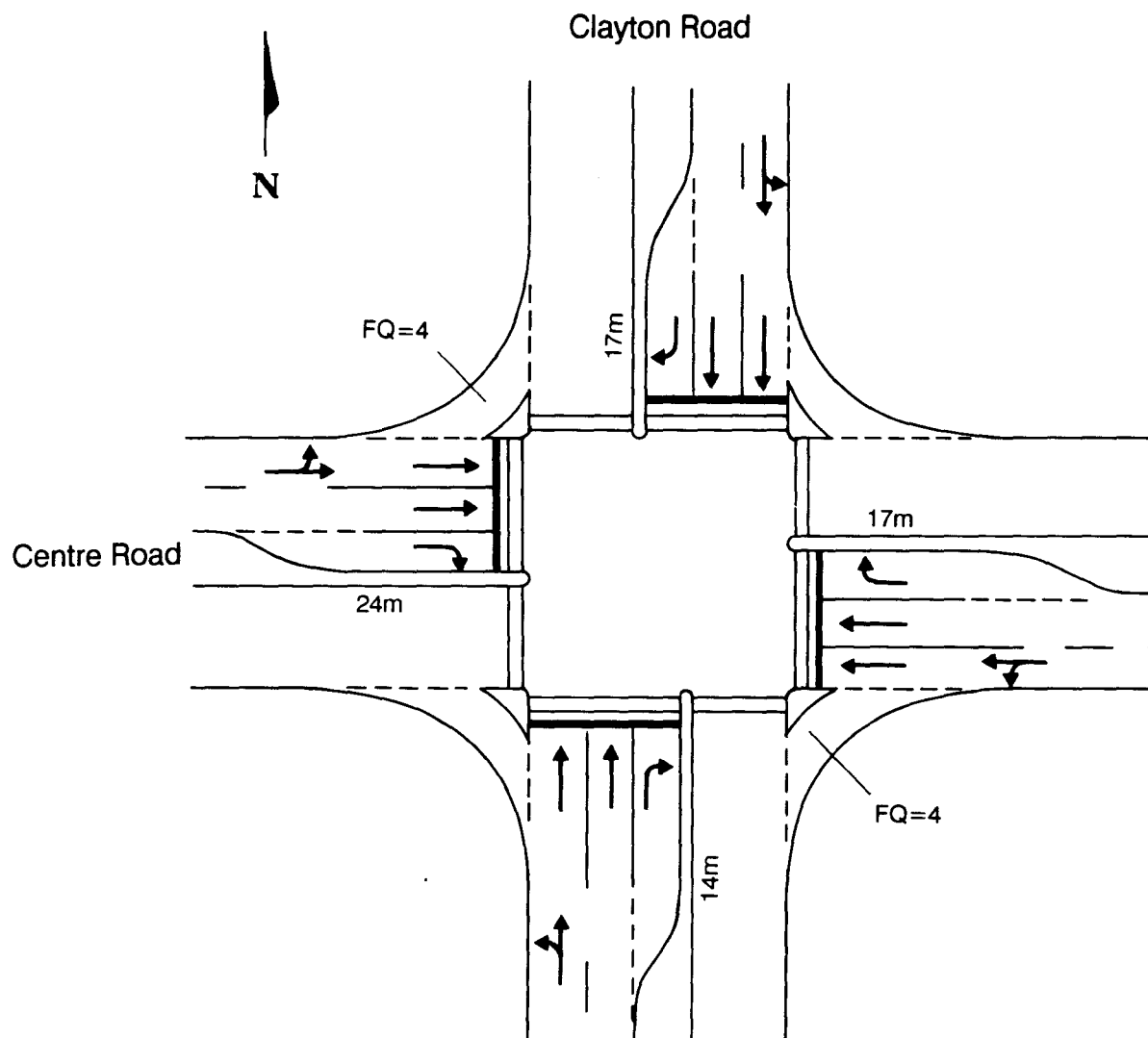
On 30/01/86 partial controls were introduced for the right turns from the west (to south) and from the south (to east). Previously there was no control for any turns at the intersection.

Figure 24 provides a schematic representation of the intersection and Figure 25 shows the turning movement flows before (11/06/85) and after (24/03/88) the change of right turn controls.

Table 12 indicates the results for SIDRA analysis of Centre Road-Clayton Road. This shows increased delays and lessened performance quality with the introduction of the right turn controls. The additional phases led to

significant increases in cycle times, which could be held to account for increased delays and degrees of saturation. Traffic throughput of the intersection from the after turning movement count was slightly lower than the after case (3458 veh/h before, 3399 veh/h after).

Figure 24
Schematic Plan of the Centre Road-Clayton Road Intersection (SCRAM #3198)



- No parking on any leg within 40m of junction
- All T lanes 2.6m wide
- R lanes 2.5m wide

Figure 25
Before and After Turning Movement Flows at the Centre Road-Clayton Road Intersection
(SCRAM #3198)

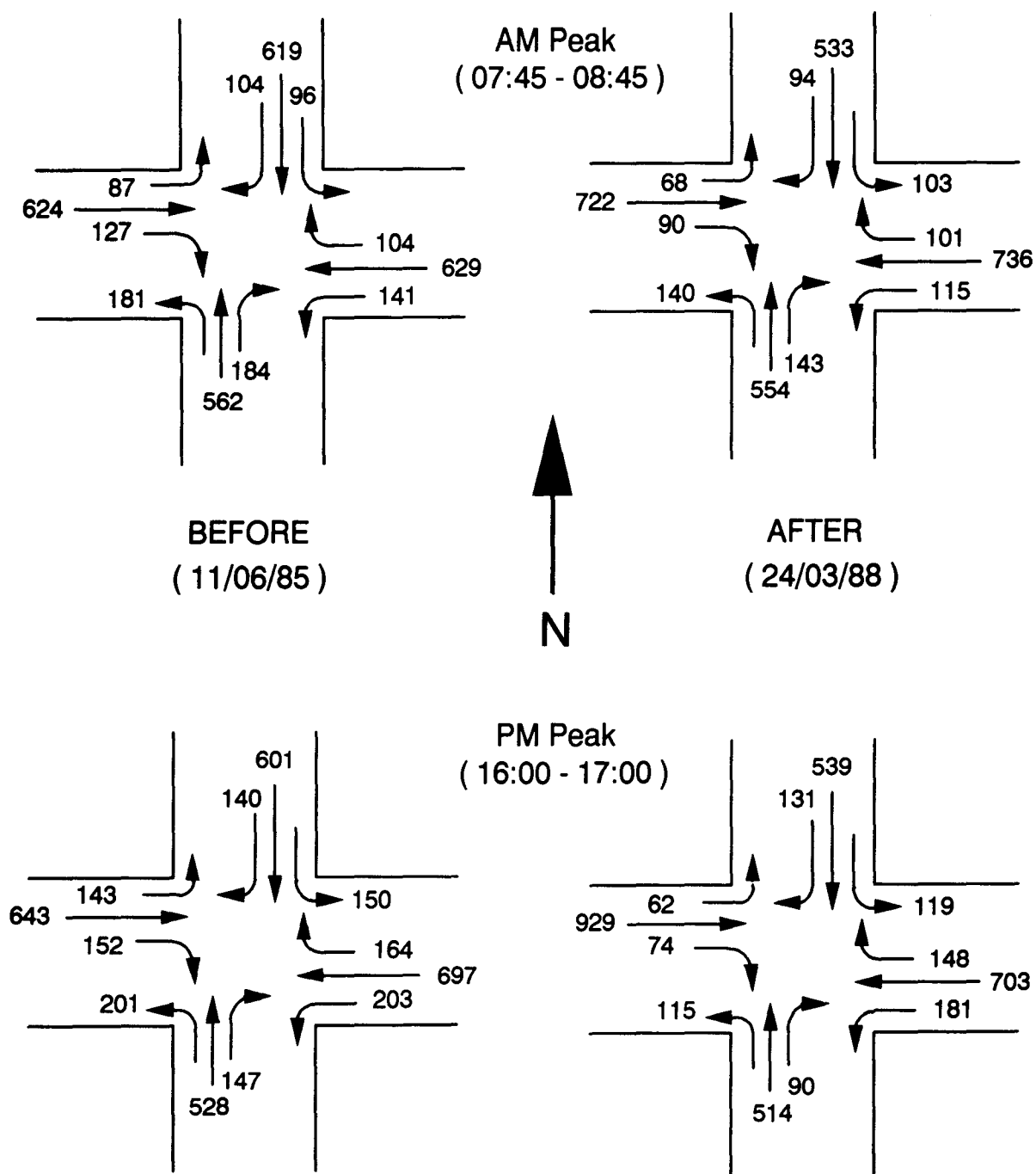


Table 12
Analysis Summary for Centre Road-Clayton Road Intersection (SCRAM #3198)

	AM Peak			PM Peak		
	Before	After phasing with before flows	After	Before	After phasing with before flows	After
Mean delays (s)	6.1	26.8	25.2	6.4	31.9	32.7
Number of stops (stops/h)	2450	3161	3327	2777	3157	3447
SIDRA Performance Index	96.00	169.45	156.37	106.00	210.97	194.71
Fuel used (L/h)	316.05	338.03	331.73	345.42	362.85	358.85
Throughput (veh/h)	3458	3458	3399	3769	3769	3660
Junction Capacity (veh/h)	6534	4545	4719	6516	5453	4915
Degree of saturation	0.657	1.000	0.882	0.646	1.001	1.001
Cycle time (s)	31	81	64	31	116	87

6.2 SPRINGVALE ROAD-MAROONDAH HIGHWAY

The junction of Maroondah Highway and Springvale Road (see Figure 26) is perhaps one of the major intersections in the metropolitan area, and is of a high standard capacity and design. On 24/06/86 full controls were imposed on all right turn movements at the intersection. Previously, the turn from the north (to west) had no control, whilst the other three turns had partial controls.

Figure 27 gives the before (02/05/85) and after (14/09/89) turning movement counts at the intersection.

Table 13 provides a summary of the analysis of this intersection. Again the increased complexity and rigidity of the phasing arrangement in the after case contributed to increased delays and saturation levels. The after-case cycle times found by SIDRA were 145 s (am peak) and 107 s (pm peak), which compare favourably with the observed cycle times of 140 s (7-9 am) and 130 ± 10 s (4-6 pm) recorded by SCRAM (data supplied by Ray Malins, Signal Operations, Vic Roads).

Figure 26
Schematic Plan of the Springvale Road-Maroonah Highway Intersection
(SCRAM #0117)

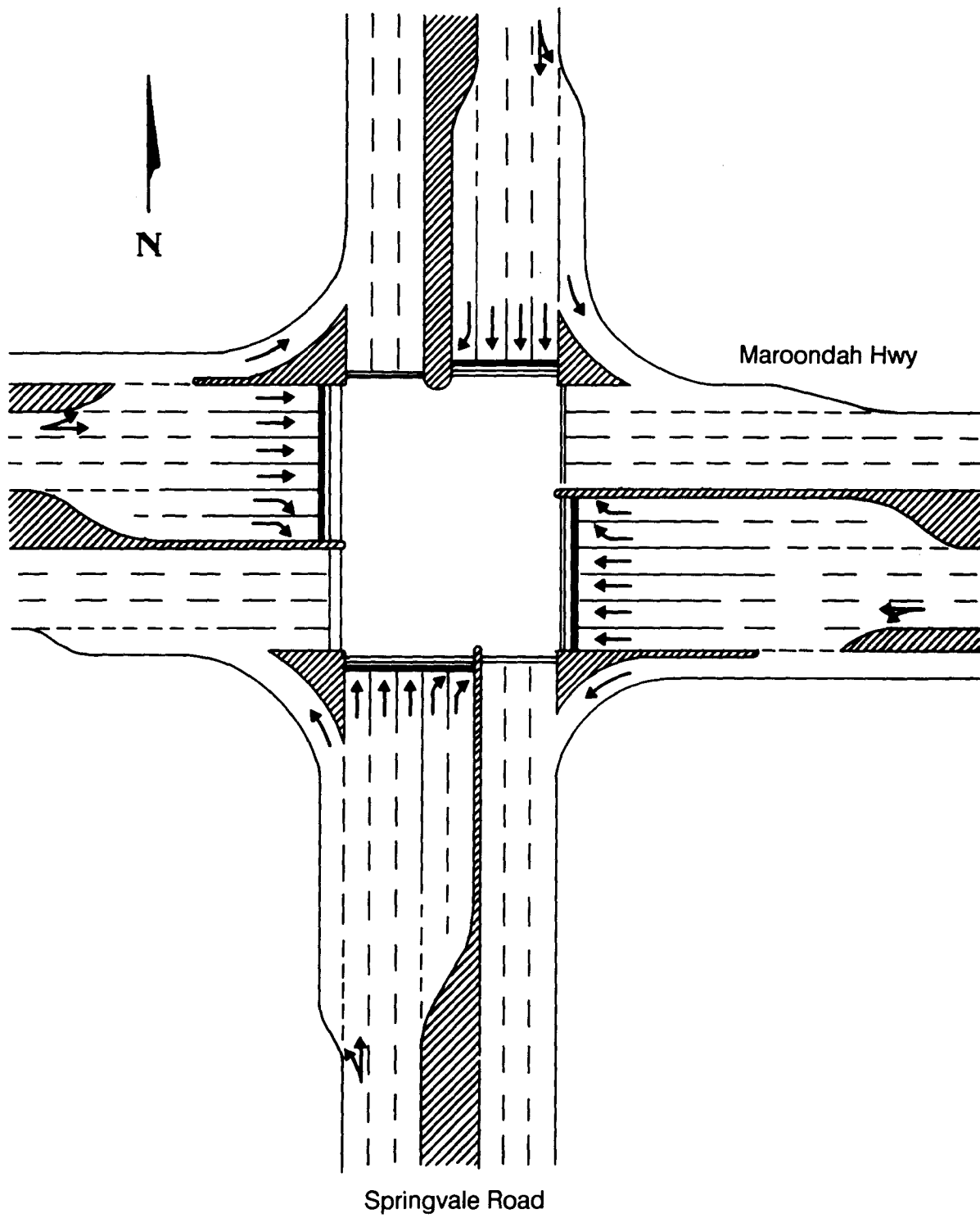


Figure 27
Before and After Turning Movement Flows at the Springvale Road-MaroonDAH Highway
Intersection (SCRAM #0117)

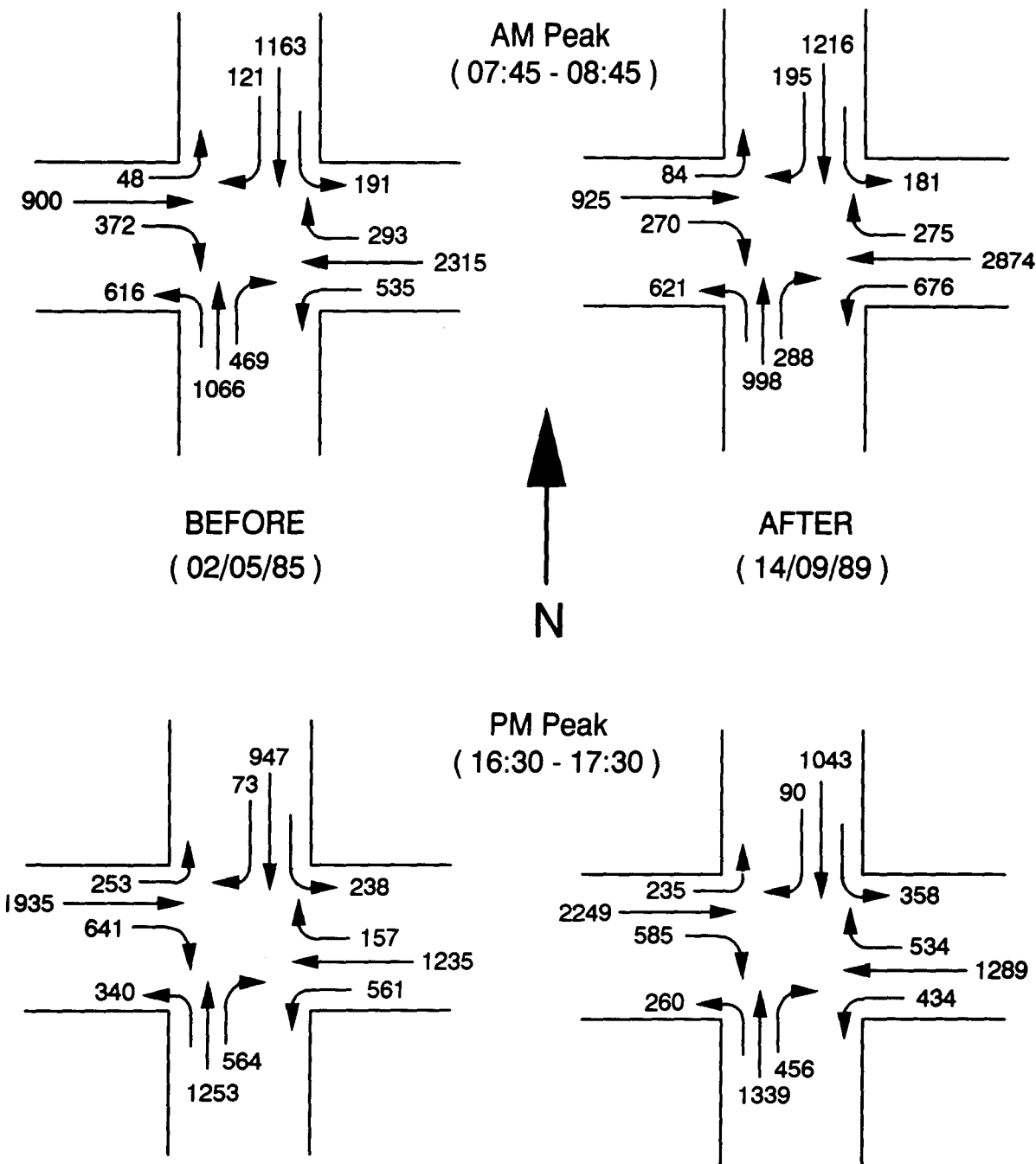


Table 13
Analysis Summary for Springvale Road-Maroonadah Highway Intersection (SCRAM #0117)

	AM Peak			PM Peak		
	Before	After phasing with before flows	After	Before	After phasing with before flows	After
Mean delays (s)	41.1	53.6	102.1	29.4	34.6	69.5
Number of stops (stops/h)	7228	9114	11973	8261	7614	10396
SIDRA Performance Index	509.18	550.52	852.18	398.47	451.15	697.26
Fuel used (L/h)	843.90	882.32	1048.55	813.86	830.82	1024.83
Throughput (veh/h)	8089	8089	8593	8197	8197	8872
Junction Capacity (veh/h)	13126	12725	12786	12218	12565	12453
Degree of saturation	0.978	0.971	1.025	0.914	0.915	1.014
Cycle time (s)	115	95	145	63	90	107

6.3 CENTRE ROAD-WARRIGAL ROAD

This junction is typical of many signalised intersections in the Melbourne metropolitan area. Both of the intersecting roads are four-lane single carriageway arterial roads. Short turning lanes are provided for each turning movement (see Figure 28). On 18/01/89 full controls were imposed on all right turns at the intersection, replacing the partial controls that had existed previously.

A turning movement count was available before (12/07/88) the change to the right turn controls, and after data were supplied by Vic Roads, based on data recorded by SCRAM on 05/09/90. SCRAM cannot record data for turning movements that do not cross a detector loop, so that no left turns were recorded. Left turning flows were estimated from the turning proportions from the before count. The before and after turning movement counts shown in Figure 29 were used in the analysis.

Table 14 summarises the results of the study. The full controls on right turns led to increased cycle times and hence delays and degrees of saturation at the junction.

Figure 28
Schematic Plan of the Centre Road-Warrigal Road Intersection
(SCRAM #3694) [shows 'after' phasing systems]

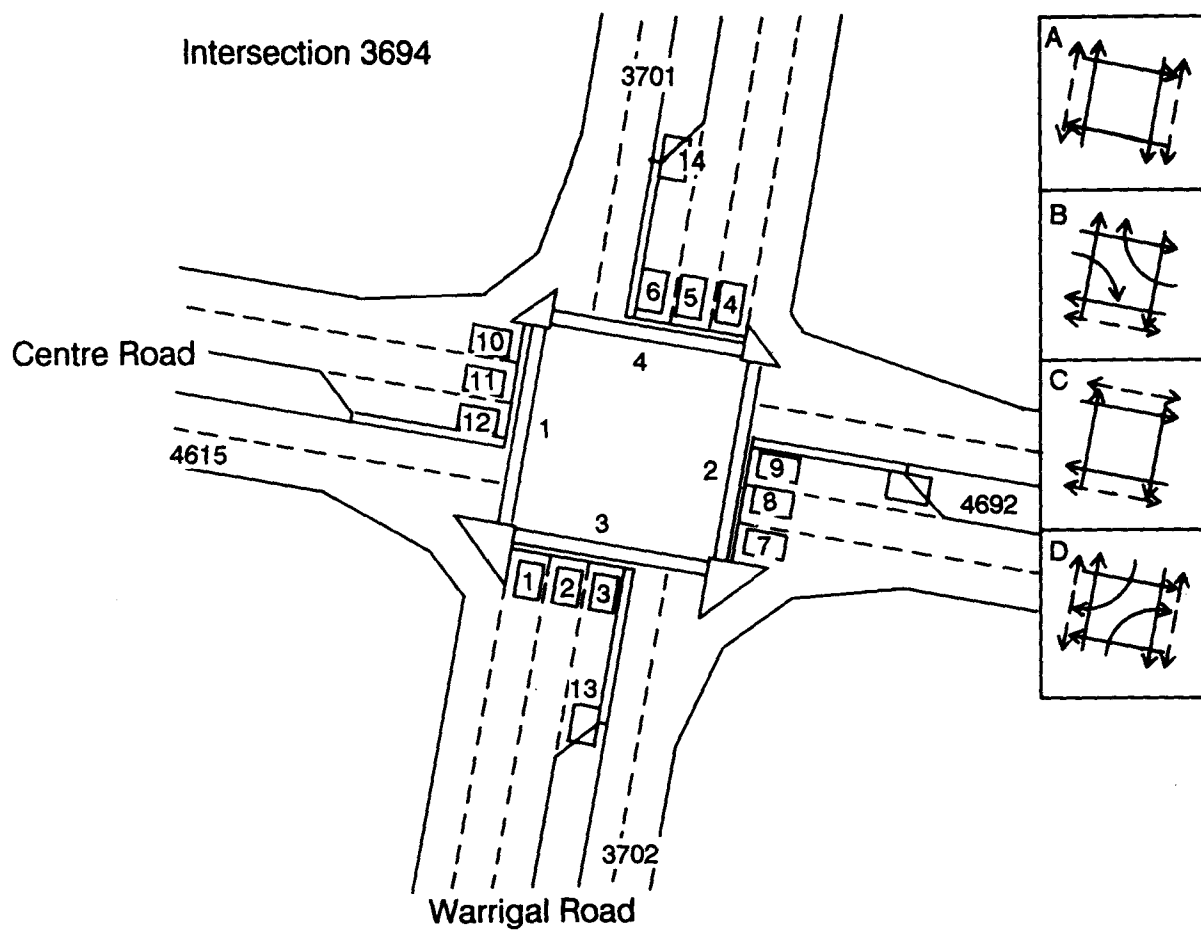


Figure 29
Before and After Turning Movement Flows at the Centre Road-Warrigal Road Intersection
(SCRAM #3694)

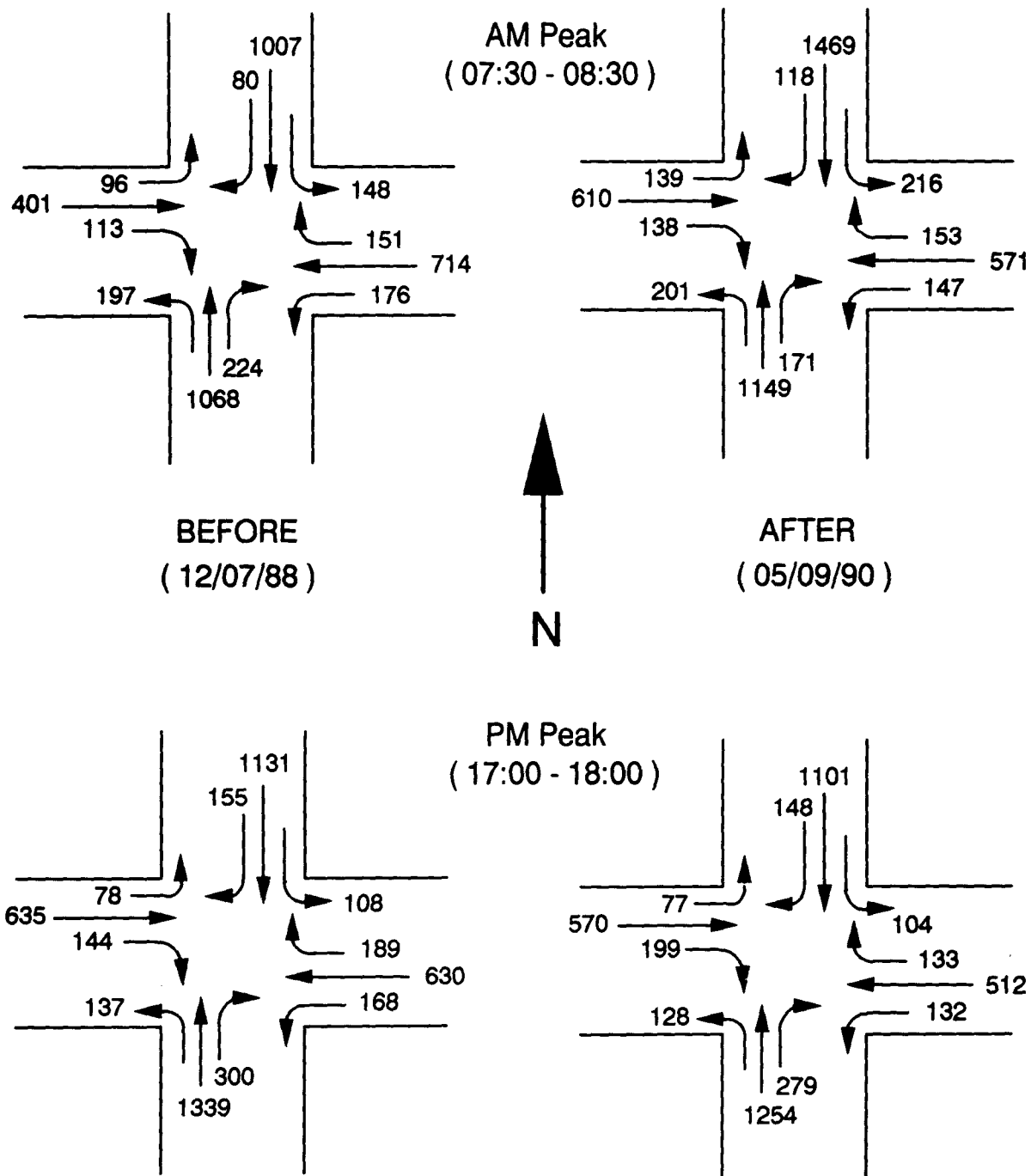


Table 14
Analysis Summary for Centre Road-Warrigal Road Highway Intersection (SCRAM #3694)

	AM Peak			PM Peak		
	Before	After phasing with before flows	After	Before	After phasing with before flows	After
Mean delays (s)	34.0	82.8	83.4	63.6	114.1	91.3
Number of stops (stops/h)	4014	5104	6120	5194	6475	5491
SIDRA Performance Index	245.38	423.97	499.43	405.34	564.20	465.08
Fuel used (L/h)	443.76	500.03	590.90	553.39	614.20	531.21
Throughput (veh/h)	4375	4375	5082	5014	5014	4637
Junction Capacity (veh/h)	5741	5131	5426	5654	5295	4978
Degree of saturation	0.948	1.000	1.000	1.000	1.059	1.023
Cycle time (s)	94	160	160	135	160	87

6.4 SUMMARY OF CASE STUDIES

The junctions were chosen because changes had recently occurred to their turn control, and before-and-after turning movement data were already available. Figures 25, 27 and 29 show these flows. One immediate conclusion is that the changes in turning controls have had little or no systematic effect on turning traffic flows, as assessed at the level of the individual intersection. There may be other factors such as urban development and growth, and corresponding network effects, that may help to explain the variations in the patterns of turning movement flows. Investigation of such effects was, however, outside the scope of the current project, and would require system-wide data that may not yet be available.

The change of turning controls at Centre Road-Clayton Road involved the installation of partial controls on right turns from the west and south legs, all other right turns were uncontrolled. At Springvale and Maroondah, full controls were introduced on all right turns, where there had previously been partial control on right turns from the west, east and south, and no control on the turn from the north. At Centre Road-Warrigal Road, full controls were imposed on all right turns, instead of the partial controls previously used.

The results for each of the case study intersections show increased delays and lessened performance quality with the introduction of more stringent turning controls, as indicated in the simulations. The results, from a limited number of case study intersections - there was insufficient time to cover more junctions - give strong support to the results and findings from the analysis of the stereotype intersections.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This report needs to be considered in conjunction with the report on Part 1 of the Safety-Mobility Study, which considers the safety performance of signalised intersections with right turn controls, and provides strong evidence of the significant safety benefits of fully controlled right turn phases.

The results found were based on modelling analysis of a set of typical (stereotype) junctions and some case studies, with the modelling undertaken using the SIDRA computer model.

This study of traffic mobility under various forms of right turn controls at signalised intersections indicates that there are reductions in mobility when right turn controls are introduced, for most traffic conditions except some instances of peak period operations. Further, full control of right turns yields poorer intersection performance than partial control under virtually all conditions. The differences in performance, particularly between partial and full control, were slight, especially under off-peak conditions, and are unlikely to negate the safety advantages reported in Part 1 of this study. Under peak conditions, right turn phases gave mobility benefits for unsaturated intersections (i.e. those where the degree of saturation for no control was less than 0.9). Introduction of turning controls leads to increased cycle times and more complex phasing arrangements, so that once saturation was reached the use of more stringent turn controls exacerbated the level of saturation so that no advantage in mobility performance could be found. Thus there is a band of traffic demand levels for a given intersection that will give positive mobility benefits (perhaps this band is for degrees of saturation between 0.7 and 0.9 - the exact range needs further investigation, not possible during the exploratory work described in this report). There is a need for further research to undertake economic analysis of the possible

trade-off between the safety and mobility effects. This study should provide the basic data on which an economic analysis could be based.

Off-peak (i.e. degrees of saturation less than 0.5), the differences in Performance Index and average delays between alternative right turn control regimes are small, suggesting that the considerable safety benefits found for full control (see Part 1 of this study) should be of primary concern. At peak periods, partial control may offer mobility advantages, but at all other times the gains from partial control instead of full control are not significant.

The modelling study produced a large database containing intersection performance and design parameters (for individual turning movements, traffic lanes (by lane type), approach legs and whole junctions) under a variety of traffic conditions that could be used for further investigations.

The study concentrated on safety and mobility performance of isolated intersections, and was unable to consider network-wide effects. The traffic diversion effects of various turn controls at the network level are of interest in area-wide traffic control and in traffic demand management, and these effects should be the subject of further research. In particular, there is a compelling need for further research and development to draw together the safety and mobility findings from this study, so that the research results may be translated into practical design guidelines. This further study should be undertaken after a period of 2-3 months for comment on the research findings. Comments should be sought from within Vic Roads and from other road and traffic authorities so that maximum value can be extracted from the research completed to date.

8.0 ACKNOWLEDGEMENT

The author would like to thank Gary Veith (Layout Design/Investigations), Ray Malins (Signal Operations) and Tim Strickland (Road Information Services) of Vic Roads for their assistance and advice in providing traffic count and traffic signal data.

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APPENDICES

APPENDIX A: CONSOLIDATED LIST OF INTERSECTIONS WITH RIGHT TURN
CONTROLS AND POST-1984 TURNING MOVEMENT COUNTS

APPENDIX B: CANDIDATE SITES FOR THE COLLECTION OF AFTER-
CHANGE TURNING MOVEMENT DATA

APPENDIX A

CONSOLIDATED LIST OF INTERSECTIONS WITH RIGHT TURN CONTROLS AND
POST-1984 TURNING MOVEMENT COUNTS

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
117	Maroondah/ Springvale	02/05/85	N to W	2	24/06/86	
		14/09/89	S to E	3	24/06/86	
			W to S	3	24/06/86	
			E to N	3	24/06/86	
121	Maroondah/Mitcham	30/05/85	W to S	2	02/08/88	
		20/07/89	E to N	2	02/08/88	
125	Maroondah/Heatherdale/ Dampier	05/05/87	E to N	3	15/02/89	
			W to S	3	15/02/89	
136	Maroondah/Kent	09/11/88	W to S	3	05/06/89	
145	Maroondah/Anderson	01/10/85	W to S	1	22/01/87	
		28/20/86				
151	Manchester/Bellars	31/07/86	N to W	3	10/08/89	
164	Burwood Hwy/Springvale	09/05/85	N to W	3	01/11/82	
			S to E	3	01/11/82	
			E to N	3	01/11/82	
			W to S	3	01/11/82	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
170	Burwood Hwy/Stud	18/04/85	N to W	3	27/02/85	
			S to E	3	27/02/85	
			E to N	3	27/02/85	
			W to S	3	27/02/85	
174	Burwood Hwy/Scoresby	23/04/85	N to W	3	10/10/86	
			E to N	3	10/10/86	
			W to S	3	10/10/86	
179	Burwood Hwy/Lysterfield	26/11/85	S to E	1	18/09/89	
192	PHE/Gladstone	28/05/85	NW to S	3	28/11/83	
			SE to N	3	28/11/83	
196	PHE/Foster	24/02/89	N to W	1	05/05/81	
		24/11/89	N to W	3	in 83	
			S to E	3	05/05/81	
199	PHE/Plunkett	28/04/88	E to N	3	08/05/89	
204	PHE/Magid	21/11/86	E to N	3	24/02/89	
206	PHE/Webb	01/08/89	S to E	1	18/05/89	
			E to N	2	01/09/87	
			W to S	2	01/09/87	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
228	Nepearl Hwy/Seaford	02/06/87	S to E	1	28/11/89	
239	Nepearl/Main/Morn-Tyabb	21/09/89	W to S	2	29/05/87	
281	Spr'vale/Edithvale/Wells	28/11/85	NW to SW	2	23/12/87	
		17/03/88	NE to NW	2	23/12/87	
		04/10/88	SE to NE	2	23/12/87	
			SW to SE	2	23/12/87	
369	Stud/Boronia	05/03/85	S to E	1	20/08/87	
			E to N	2	26/06/89	
			W to S	3	26/06/89	
417	Canterbury/Springvale	04/03/86	W to S	3	17/12/84	
			E to N	3	17/12/84	
			S to E	3	17/12/84	
			N to W	3	17/12/84	
422	Springvale/High St Rd	18/02/88	S to E	3	15/09/81	
			N to W	3	15/09/81	
426	Springvale/Waverley	02/07/85	N to W	3	15/09/81	
			S to E	4	not yet installed	
432	Springvale/Wellington	16/02/88	N to W	3	24/06/85	
			S to E	3	24/06/85	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
438	Springvale/Heatherton	27/06/85	N to W S to E	3 3	03/12/87 03/12/87	
629	Mt Dandenong/Dorset	25/07/89	E to N W to S N to W S to E	1 1 1 2	21/07/87 21/07/87 21/07/87 21/07/87	
650	Chelt'ham/Foster/Thomas	24/02/89	SW to E	2	18/09/88	
651	Cheltenham/Hammond	17/09/85 13/05/87 25/05/87	W to S	3	27/08/86	
657	Gladstone/Heatherton	27/08/87	E to N N to W S to E W to S	1 1 1 1	05/07/89 05/07/89 05/07/89 05/07/89	
659	Police/Jacksons	04/03/86	E to N W to S	3 3	17/02/87 17/02/87	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
664	Frankston-Dande/Greens	25/02/86	E to N	1	18/07/89	
			W to S	1	18/07/89	
			N to W	2	18/07/89	
			S to E	2	18/07/89	
668	Cheltenham/Bennett	29/07/87	E to N	3	17/04/89	
680	Manningham/Thompsons	04/06/85	N to W	2	16/10/83	
775	Boronia/Mountain Hwy	18/06/85	NE to W	3	20/04/84	
			SW to E	3	20/04/84	
849	Can'bury/Mitcham/Boronia	13/08/86	W to S	3	27/05/88	
			E to N	3	27/05/88	
853	Canterbury/Wantirna	30/05/85	N to W	1	13/01/86	
			S to E	1	13/01/86	
			E to N	2	13/01/86	
			W to S	2	13/01/86	
860	Canterbury/Bayswater	09/05/85	E to N	2	22/04/87	
			N to W	2	22/04/87	
			S to E	2	22/04/87	
923	Cheltenham/Corrigan	20/03/86	E to N	3	09/09/88	
			W to S	3	09/09/88	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
970	High St Rd/Warrigal	18/02/88	N to W	1	01/03/84	
			S to E	1	01/03/84	
			N to W	4	27/10/89	
			W to S	4	27/10/89	
2158	Hume/Somerset	24/09/85	S to E	4	14/09/84	
			S to E	3	17/03/89	
2206	Maroondah/Station	14/06/85	S to E	1	31/10/84	
2208	Maroondah/Middleborough	11/06/85	S to E	1	16/10/82	
			N to W	1	16/08/82	
			E to N	2	01/09/81	
			W to S	2	01/09/81	
2316	Nepean Hwy/North	06/05/85	N to W	2	19/06/80	
			S to E	2	19/06/80	
			E to N	2	19/06/80	
			W to S	2	19/06/80	
2327	Nepean/Charman/ Chesterville	04/06/85	SE to N	3	23/09/87	
			NW to S	3	23/09/87	
2404	Kingsway/Park	02/10/86	S to E	1	not yet installed	
			W to S	2	not yet installed	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
2407	Queens/Lakeside	18/06/85 03/10/86	S to E	2	22/11/84	
2417	PHE/Tooronga	02/08/88 21/03/89	E to N	3	21/06/85	
2419	PHE/Burke/Railway	16/08/88	E to N	3	16/09/87	
2425	PHE/Warrigal	11/08/88 18/04/89 14/06/89	S to E	1	20/07/86	
3003	Barkers/Glenferrie	26/03/85	W to S	1	18/12/86	
3059	Bell/St George	18/04/85	N to W S to E	3 3	16/06/87 16/06/87	
3198	Centre/Clayton	11/06/85 24/03/88	W to S S to E	1 1	30/01/86 30/01/86	
3229	High/Mahoneys	04/06/85	W to s	3	29/01/88	
3265	Albert/Dundas	23/04/85	S to E N to S(?)	1 4	11/03/86 11/03/86	
3306	Heidelberg/Station	30/05/85	E to N	1	31/10/84	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
3333	Gre'borough/Lwr Plenty	11/02/88	N to W	3	07/04/88	
3360	Lwr Heidelberg/Banksia	11/02/88	E to N	3	24/02/86	
			W to S	4	24/02/86	
			S to E	4	24/02/86	
3382	Hoddle/Johnston	09/05/85	E to N	2	07/08/85	
			W to S	2	07/08/85	
			N to W	3	07/08/85	
			S to E	3	07/08/85	
3385	Victoria/Hoddle	25/11/86	E to N	2	28/02/86	
			N to W	4	28/02/86	
3393	Punt/Swan	02/10/85	E to N	3	23/11/89	
3399	Punt/Commercial	19/08/86	N to W	1	24/09/86	
3502	Millers/Mason	08/08/89	N to W	2	11/04/88	
3554	North/Bambra/Thomas	07/05/85	E to N	3	06/12/89	
			W to S	3	06/12/89	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
3680	Warrigal/Waverley	04/03/87	S to E E to N W to S	4 1 3	18/09/87 02/11/89 02/11/89	
3682	Warrigal/Riversdale	21/11/85	N to W	1	30/12/88	
3690	Batesford/Warrigal	21/11/85	N to W	3	08/06/89	
3693	North/Warrigal	29/06/88	N to W E to N W to S	1 2 2	14/07/87 14/07/87 14/07/87	
3694	Centre/Warrigal	30/04/85 19/02/87 12/07/88	N to W S to E W to S E to N	3 3 3 3	18/01/89 18/01/89 18/01/89 18/01/89	
3698	Warrigal/Kingston	10/03/88	N to W S to E	2 3	15/11/85 15/11/85	
3700	Centre Dande/Warrigal	09/05/85 14/07/88	E to N	1	17/12/84	
4172	Grimshaw/Watsonia	02/05/85	S to E W to S	1 4	21/10/85 28/06/85	

Control Group:

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CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
4115	Sydney/Gaffney	20/06/85	E to N	4	29/08/85	
4206	Mt Alexander/Ormond	05/03/85	S to E	1	18/06/87	
4230	Williamstown/Francis	20/06/85	S to E	4	16/06/88	
4273	Toorak/Tooronga	14/07/88 14/02/89	S to E	1	08/05/87	
4382	Fitzroy/Princes	02/05/85	NW to SW	4	02/09/87	
4506	Peel/Victoria	18/03/86	N to W S to E	1	18/03/86	
4539	St Kilda/Toorak	28/03/85	N to W S to E	2 2	16/07/86 16/07/86	
4567	Spencer/Flinders	25/03/86	S to E N to W	2 2	19/11/87 19/11/87	
4644	Darebin/Victoria	07/05/85	S to E	1	06/08/86	
4682	High/Westgarth	19/03/87	W to S	1	17/10/84	
4694	Centre/Huntingdale	26/05/87	E to N W to S	1 1	11/08/88 11/08/88	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
4710	Waverley/Huntingdale	03/04/86	W to S	3	24/07/85	
4711	Normanby/Howley/Monash	12/06/86	?	1	?	
4723	Bay/Beach	11/07/85 10/05/88 22/02/89	SE to NE	3	13/02/87	
4716	FTG/Forster	15/06/88	S to E E to N W to S	1 1 1	08/09/89 08/09/89 08/09/89	
4796	Kingsbury/Waterdale	27/02/86	E to N W to S	2 3	14/11/89 14/11/89	
4805	Bridge/Burnley	20/06/85 23/05/89	S to E W to S	1 2	27/06/89 29/07/89	
4821	Victoria/Burnley	17/04/85	W to S	1	27/05/85	
4826	Church/Highett	Early 84	E to N	1	22/08/85	
4832	Fitzroy/Princes	02/05/85	SW to SE	3	02/09/87	
4883	City/Clarendon	08/09/88	NE to NW	1	03/09/82	

Control Group:

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CANDIDATE SITES FOR RIGHT TURN CONTROL STUDY - SITES WITH EXISTING T.M. COUNTS

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SCRAM NO.	SITE NAME	SURVEY DATES	LEG	CONTROL GROUP	INSTALLATION DATE	COMMENTS
4930	Kings/Main	13/03/86	N to W S to E	2 2	23/06/89 23/06/89	
5002	Fitz/Leakes/Kororoit Ck	08/03/86	S to E	1	20/10/88	
5013	PHW/Mackey	08/09/86	S to E	2	15/12/86	
5014	PHW/Victoria	12/09/86	S to E N to W	2 2	16/10/87 16/10/87	
5017	PHW/Gordon	09/09/86	?	2	?	
5018	PHW (L Tce)/Aber/Ryrie	10/09/86	NE to NW	1	03/09/82	
5020	Latrobe Tce/McKillop	05/08/86	S to E	1	09/05/86	

Control Group:

1 = None to partial, 2 = none to full, 3 = partial to full, 4 = partial, change in loop location

APPENDIX B

CANDIDATE SITES FOR THE COLLECTION OF AFTER-CHANGE TURNING
MOVEMENT DATA

RIGHT TURN CONTROL STUDY - CANDIDATE SITES FOR NEW DATA COLLECTION

SCRAM No.	Melway Ref.	Name (Installation date)	Layout	Control Group
125	049 D9	Maroondah Hwy/Heatherdale Rd (15/02/89)		(3)
136	050 H1	Maroondah Hwy / Kent Av (05/06/89)		(3)
151	037 G9	Manchester Rd/Bellara Dr (10/08/89)		(3)
179	074 C4	Burwood Hwy/Lysterfield Rd (18/09/89)		(1)
199	090 F11	PHE/Plunkett Rd (08/05/89)		(3)
204	110 C4	PHE/Magid Dr (24/02/89)		(3)
228	099 D5	Nepean Hwy/Seaford Rd (28/11/89)		(1)
657	090 B2	Gladstone Rd/Heatherston Rd (05/07/89)		(1)
664	095 D3	Frankston-Dandee Rd/Greens Rd (18/07/89)		(1,2)
668	090 A8	Cheltenham Rd/Bennet St (17/04/89)		(3)
2158	007 F7	Hume Hwy/Somerset Rd (17/03/89)		(3)

RIGHT TURN CONTROL STUDY - CANDIDATE SITES FOR NEW DATA COLLECTION

SCRAM No.	Melway Ref.	Name (Installation date)	Layout	Control Group
2404	002K G2	Kingsway/Park St (not yet installed ?)		(1,2)
3393	002G F9	Punt Rd/Swan St (23/11/89)		(3)
3554	068 B8	North Rd/Bambra Rd (06/12/89)		(3)
3680	069 F2	Warrigal Rd/Waverley Rd (02/11/89)		(1,3)
3690	069 G12XBatesford	Rd/Warrigal Rd (08/06/89)		(3)
3694	078 D2	Centre Rd/Warrigal Rd (18/01/89)		(3)
4716	070 E7	FTG Rd/Forster Rd (08/09/89)		(1)
4796	019 G8	Kingsbuy Dr/Waterdale Rd (14/11/89)		(2,3)
4805	002H E6	Bridge Rd/Burnley St (27/06/89 (1), 29/07/89 (2))		(1,2)
4930	013 F12	Kings Rd/Main Rd West (23/06/89)		(2)

Control Group: 1 = None to partial, 2 = none to full, 3 = partial to full

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RIGHT TURN CONTROL STUDY - CANDIDATE SITES FOR NEW DATA COLLECTION

SUMMARY DATA

Intersection Type	Sites (SCRAM nos)	Total
	0125, 0179, 0204, 0657, 0664, 2404, 3393, 3554, 3680, 3690 3694, 4716, 4796, 4805, 4930	15
	0136, 0151, 0199, 0228, 0668, 2158	6
		21

CROSS-TAB OF LEGS WITH CONTROL CHANGES AND INTERSECTION TYPE

Intersection Type	Legs with Control Change Type			Total
	1	2	3	
	13	7	13	33
	1	0	5	6
All	14	7	18	39

PRIORITY LIST - FIRST CHOICE SITES (SCRAM NOS) FOR DATA COLLECTION

	
3694	0228
0664	0136
4805	0151
3680	
0125	