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# **Recent research on actuated signal timing and performance evaluation and its application in SIDRA 5**

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# Recent research on actuated signal timing and performance evaluation and its application in SIDRA 5

Rahmi Akçelik, Edward Chung and Mark Besley

## ABSTRACT

This paper discusses some results of extensive research on actuated control methods conducted at ARRB Transport Research, Australia, in recent years (1-6). Other recent ARRB TR research on actuated and fixed-time signal timing and performance has produced a substantial body of related information (7-9). This work is related to established methods for signal timing and performance analysis in use in Australia (ARR 123), USA (Highway Capacity Manual) and the UK (10-12).

A detailed method for estimating average cycle time and green times for various types of actuated signal control was developed (1,2). The method was successfully adopted in the recent US research, and is now being incorporated into the 1997 version of the Highway Capacity Manual (13). Analyses using microscopic simulation models NETSIM (USA) and MODEL C (Australia) showed that this method predicts actuated signal timings satisfactorily (5,13).

Subsequently, a simpler method was developed for predicting actuated signal timings (3). The method, now implemented in version 5 of the SIDRA software package (14), is similar to the commonly used methods for pretimed (fixed-time) signals (10-12). It is based on the use of a target degree of saturation calculated from a regression model for estimating degrees of saturation at actuated signals.

The SIDRA method reflects the findings from simulation models and real-life observations that degrees of saturation at actuated signals can be well below the value of 0.95 suggested in the 1994 Highway Capacity Manual (HCM) (11). Equal degrees of saturation do not necessarily result, and the minor movements may get lower degrees of saturation than the major movements, indicating inefficient operation with long cycle times. Comparisons of degrees of saturation, cycle times and green times predicted by the simple method used in SIDRA with those predicted by MODEL C simulation are presented.

Recent research also produced analytical models for predicting various performance statistics (delay, queue length, queue clearance time, proportion queued, and so on) at actuated signals (5,14). The models, which have also been incorporated into SIDRA version 5, are based on an integrated modelling framework that provides consistency in modelling of different performance measures, and in modelling of different intersection types, including pretimed signals. Although the delay model is similar to the two-term model used in HCM, Chapter 9, it has some important differences. Comparisons of SIDRA predictions of delay, back of queue and queue clearance time with those predicted by MODEL C simulation as well as those observed at a real-life intersection are presented.

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## Actuated Signal Timing Method

The simple method for calculating average green and cycle times at actuated signals, makes use of estimates of degrees of saturation at actuated signals ( $x_a$ ) as target degrees of saturation in the practical cycle time and green split equations. An iterative method is used by calculating the target degree of saturation for actuated signals ( $x_a$ ).

For initial calculations when the red time ( $r$ ) is not known:

$$x_a = 1.5 y^{0.5} e_h^{-0.1} \quad (1)$$

subject to  $0.40 \leq x_a \leq 0.95$

For subsequent iterations when the red time ( $r$ ) is known:

$$x_a = 0.78 y^{0.5} e_h^{-0.1} r^{0.18} \quad (2)$$

subject to  $0.40 \leq x_a \leq 0.95$

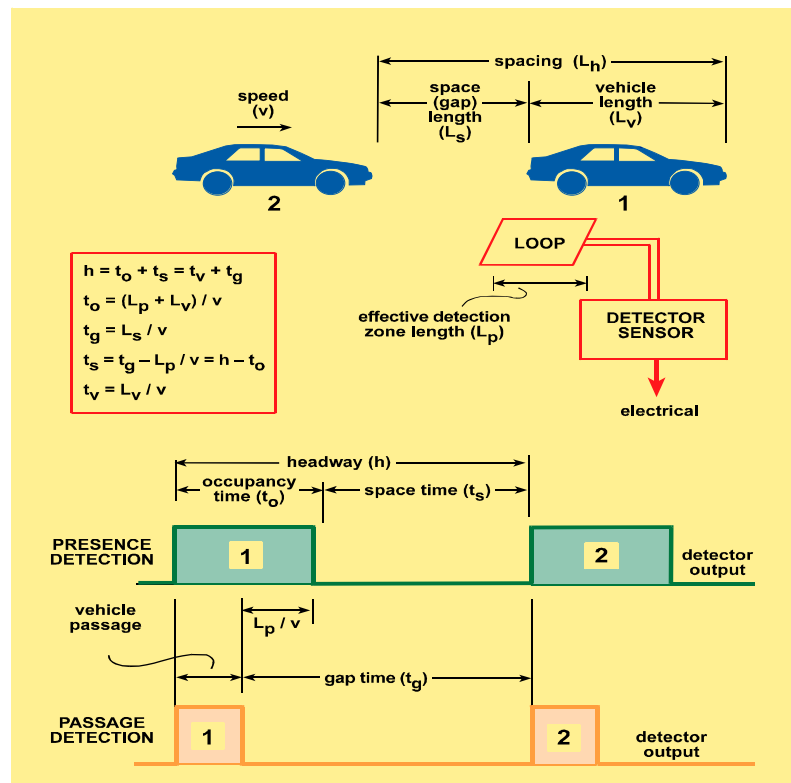
where  $y$  is the flow ratio ( $y = \text{arrival flow rate} / \text{saturation flow rate}$ ),  $e_h$  is the gap setting as a *headway time* value (seconds) and  $r$  is the effective red time (seconds).

The gap setting is specified as a *space time* value ( $e_s$ ) as used with presence detection. For use in actuated signal timing and performance calculations, SIDRA converts the gap settings from space time values to headway time values using the following formula:

$$e_h = e_s + t_{ou} = e_s + 3.6 (L_v + L_p) / v \quad (3)$$

where  $t_{ou}$  is the detector occupancy time (s/veh) during the unsaturated part of the green period (i.e. after queue clearance),  $L_v$  is the average vehicle length (m),  $L_p$  is the effective detection zone length (m), and  $v$  is the departure speed of vehicles after queue clearance. See Figure 1 which summarises basic parameters in actuated signal operations (developed from Figure 7.1 of AUSTRROADS 15).

**Figure 1**  
Basic parameters  
in actuated signal  
operation



The actuated signal timing calculations use the same method as for fixed-time signals (10,14,16) with the following major differences:

- (i) The actuated signal degrees of saturation ( $x_a$ ) are used instead of the practical (target) degree of saturation ( $x_p$ ) in calculating the *required green times*. This results in *unequal* degrees of saturation for critical movements (Non-EQUISAT method) reflecting the results of real-life actuated signal operations, and contrasts with the commonly used equal degree of saturation (EQUISAT) method for pretimed signals. Although SIDRA allows the user to specify unequal degrees of saturation for pretimed signals, it uses the EQUISAT method as a default solution.
- (ii) The maximum cycle time constraint is not used. Maximum green times determine the value of largest possible cycle time.

The actuated signal timings are highly sensitive to the maximum green time settings particularly under heavy demand conditions. Since a maximum cycle time is not used in actuated signal timing calculations, very long cycle times may result if large values of maximum green time settings are used, resulting in significant capacity losses due to short lane, permitted (filter) turn and lane blockage effects.

The variable cycle time method used in SIDRA for determining optimum cycle times applies to pretimed signals only. A possible method to optimise actuated signal timings is to determine an optimum cycle time specifying pretimed control, and translate the resulting green times to maximum green time settings for actuated signal operations.

Degrees of saturation estimated from Equation (2) for various values of effective red time ( $r$ ) and flow ratio ( $y$ ) with a gap setting of  $e_{\text{H}} = 3.5$  s are shown in Figure 2.

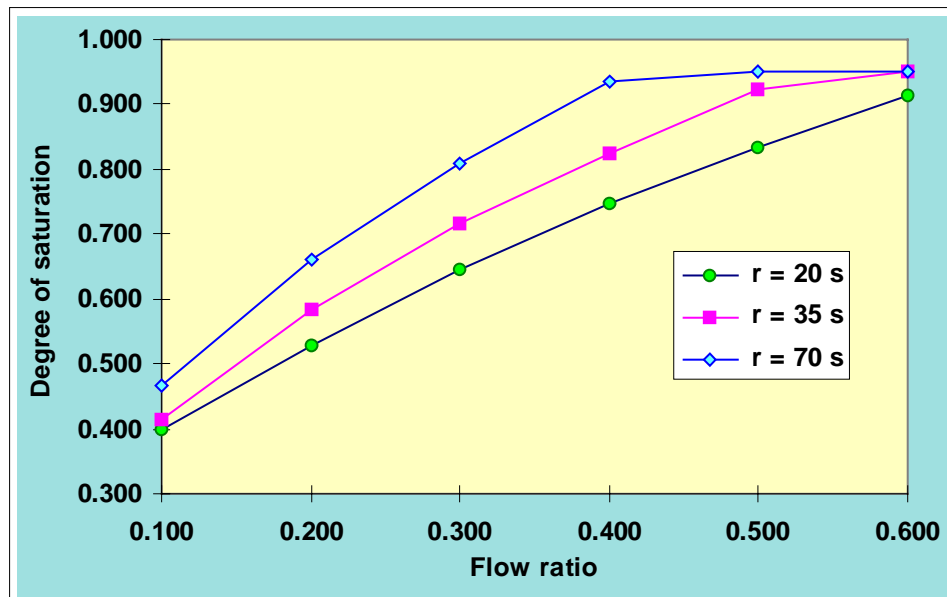
The 1994 Highway Capacity Manual, Chapter 9, p. 9-103 (13) states that "*An actuated signal is assumed to be extremely efficient in the use of available green time. Thus, the average cycle length should be estimated using a high critical v/c ratio (degree of saturation) of approximately 0.95. ... Green times will be computed on the basis of a constant v/c ratio of 0.95 because it is assumed that the actuated signal assigns green time proportionally.*"

It is seen from Figure 2 that degrees of saturation at actuated signals can be well below the value of 0.95 suggested by the 1994 HCM, and Equation (2) indicates that the equal degree of saturation method implied by the HCM statement is not substantiated. In fact, actuated signals are seen to produce green splits that result in unequal degrees of saturation with lower degrees of saturation allocated to movements with low demand (low  $y$  values). As a result of this, actuated signal cycle times tend to be longer than the cycle times obtained using the equal degree of saturation (EQUISAT) method. In practice, lower maximum green times and shorter gap settings are used for movements with low demand to overcome this inefficiency. However, this is not always possible due to variations in demand throughout the day. In any case, some inefficiencies in traditional actuated timings cannot be avoided as even the smallest possible gap setting ( $e_{\text{H}}$ ) may give degrees of saturation well below 0.95.

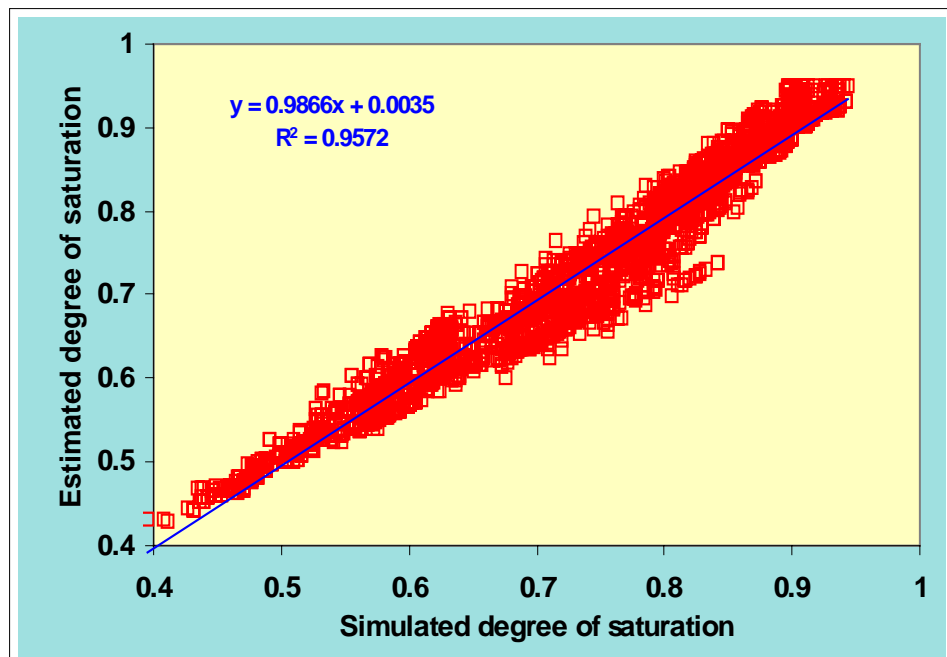
Figures 3 to 5 show the comparisons of degrees of saturation, cycle times and green times predicted by the SIDRA method with those obtained from MODEL simulation. Trend lines and associated regression statistics are also given in Figures 3 to 5 indicating satisfactory predictions. These results compare well with the predictions using the more detailed method (1-3).

**Figure 2**

Degrees of saturation at vehicle-actuated signals estimated from Equation (2) for various values of effective red time ( $r$ ) and flow ratio ( $y$ ) with  $e_h = 3.5$  s

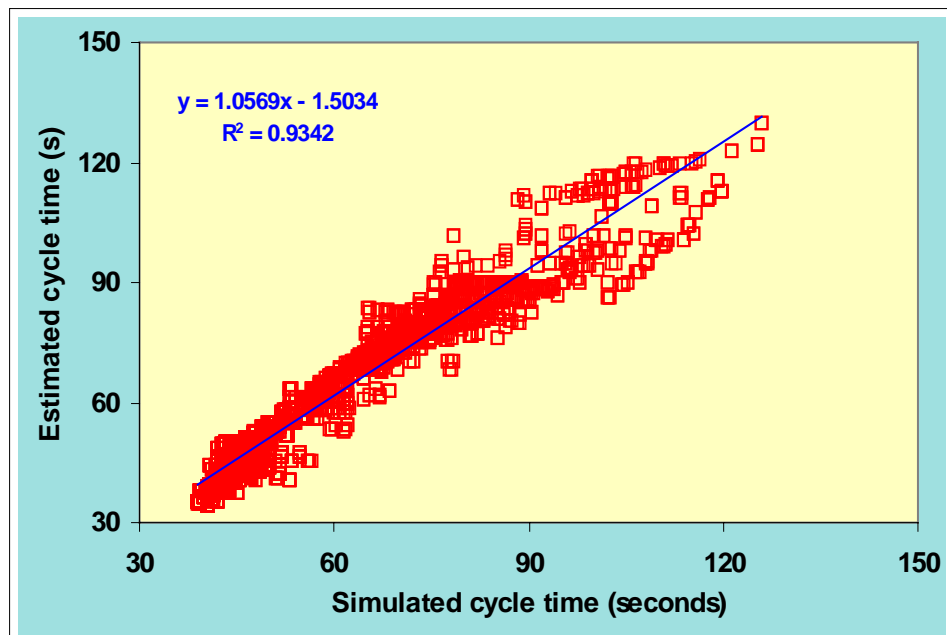
**Figure 3**

Comparison of estimated and simulated values of degree of saturation for actuated signals

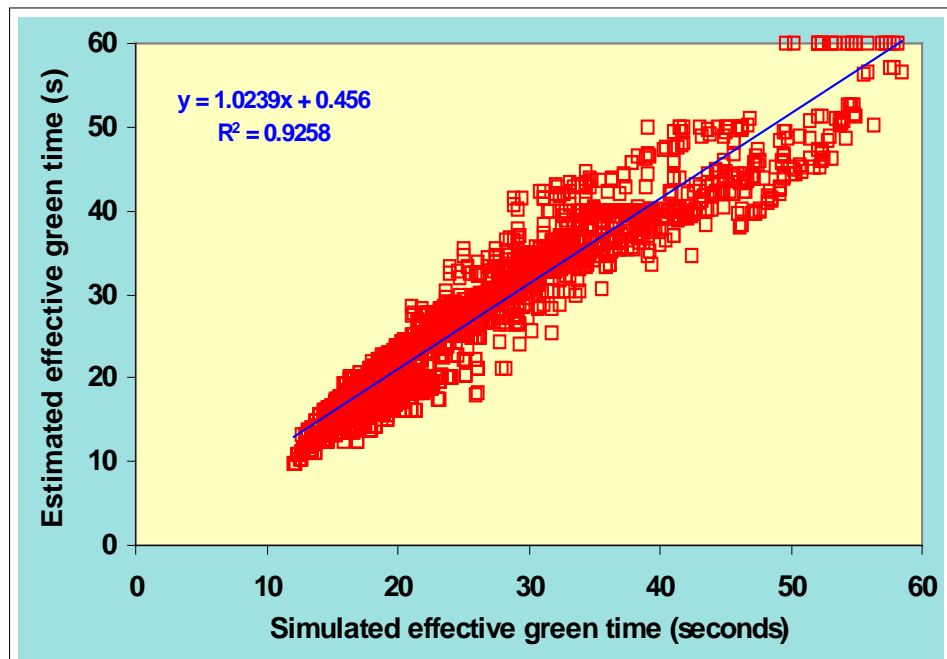


**Figure 4**

Comparison of estimated and simulated values of average cycle time for actuated signals

**Figure 5**

Comparison of estimated and simulated values of average green time for actuated signals



## SIDRA Delay Formula for Actuated Signals

The SIDRA models for performance measures such as average delay, average and percentile back of queue, queue clearance time, proportion queued, queue move-up rate, etc. for signalised and unsignalised intersections can be found in the SIDRA user guide (14). Only the SIDRA delay formula for actuated signals is given here:

$$d = d_1 + d_2 \quad (4)$$

$$d_1 = f_{d1} \frac{0.5 r (1 - u)}{1 - y} \quad \text{for } x \leq 1.0 \quad (4a)$$

$$= f_{d1(x=1)} 0.5 r \quad \text{for } x > 1.0$$

$$d_2 = 900 T_p \left[ z + \sqrt{z^2 + \frac{8k_d (x - x_0)}{Q_e T_p}} \right] \quad \text{for } x > x_0 \quad (4b)$$

$$= 0 \quad \text{otherwise}$$

$$f_{d1} = 1 + 0.4 (sg)^{-0.35} y^{0.1} \quad (4c)$$

$$x_0 = 0.42 e_h^{-0.1} G_{\max}^{0.2} \quad \text{subject to } x_0 \leq 0.95 \quad (4d)$$

$$k_d = 0.4 (sg)^{0.75} y^{1.1} \quad (4e)$$

where

d	average delay per vehicle considering all vehicles queued and unqueued, not including geometric delay (seconds)
d <sub>1</sub> , d <sub>2</sub>	first and second terms of the delay formula
f <sub>d1</sub>	non-overflow term parameter (allows for the effect of cycle-by-cycle variation in demand flow rates, considering cycles with no overflow queues)
f <sub>d1(x=1)</sub>	the value of f <sub>d1</sub> at capacity (x = 1) which can be determined by setting y = u in Equation (4c)
k <sub>d</sub>	overflow term parameter (allows for the effect of cycle-by-cycle variation in demand flow rates, considering cycles with overflow queues)
g, r, c	average effective green and red times, and cycle time (c = g + r) (seconds)
G <sub>max</sub>	maximum green setting for actuated signals (seconds)
e <sub>h</sub>	gap setting as a headway time value for actuated signals (seconds)
q <sub>a</sub>	arrival (demand) flow rate of the approach lane (veh/h)
s	saturation flow rate (veh/h)
s g	cycle capacity (veh) (s in veh/s, g in seconds)
Q <sub>e</sub>	capacity (veh/h): maximum arrival flow rate that can be serviced under prevailing flow conditions (Q <sub>e</sub> = s g / c)
Q <sub>e</sub> T <sub>p</sub>	throughput (maximum number of vehicles that can be discharged during the peak flow period)
T <sub>p</sub>	peak flow (analysis) period in hours
u	green time ratio (u = g / c)
x	degree of saturation, i.e. the ratio of arrival (demand) flow rate to capacity (x = q <sub>a</sub> / Q <sub>e</sub> = y / u)
x <sub>0</sub>	non-overflow degree of saturation below which the second terms of the formulae for delay, back of queue and stop rate are zero
y	flow ratio, i.e. the ratio of arrival (demand) flow rate to the saturation flow rate (y = q <sub>a</sub> / s)
z	a parameter used in the overflow term (z = x - 1)

The general form of the SIDRA delay model is a two-term performance formula. The first term (d<sub>1</sub>) represents *non-overflow* cases which occur under low demand conditions, and *includes the effect of randomness* in arrival (demand) flow rates under such conditions. This differs significantly from previous types of two-term models where the first term does not include any randomness effects, and hence referred to as the “uniform term” (10-12.16).

The second term ( $d_2$ ) is an incremental term associated with *overflow* queues. Overflow conditions (cycle failures) can occur when the average demand is below capacity (*temporary* cycle oversaturation due to random variations in arrival flow rates) or when average demand is above capacity (*permanent* oversaturation that lasts for a period of time).

Compared with the 1994 HCM delay formula that uses  $x_0 = 0$ , the SIDRA model structure is considered to be essential for improved quality of performance predictions, especially for actuated signals where overflow queues are negligible at high degrees of saturation. Also note that the SIDRA method differs from most other methods (including the HCM method) in applying the capacity and performance models on a lane-by-lane basis.

The SIDRA standard default values of the *maximum green setting* ( $G_{max}$ ) and *gap setting* ( $e_s$ ) parameters used in the delay formula as well as in actuated signal timing calculations are:

	Max. Green	Gap Setting
Major movement	50 s	2.5 s
Minor movement	20 s	2.0 s

For left-hand driving (Australia, New Zealand, UK), through and left turn movements are treated as the major movements, and right turns are treated as the minor movements. For right-hand driving (USA, Europe), through and right turn movements are treated as the major movements, and left turns are treated as the minor movements. In the case of permitted (filter) turns in a shared lane, the maximum green time and gap setting parameters of the through movement are used. In the case of permitted and protected turns from a shared lane, the through movement parameters are used for the permitted (filter) turn period.

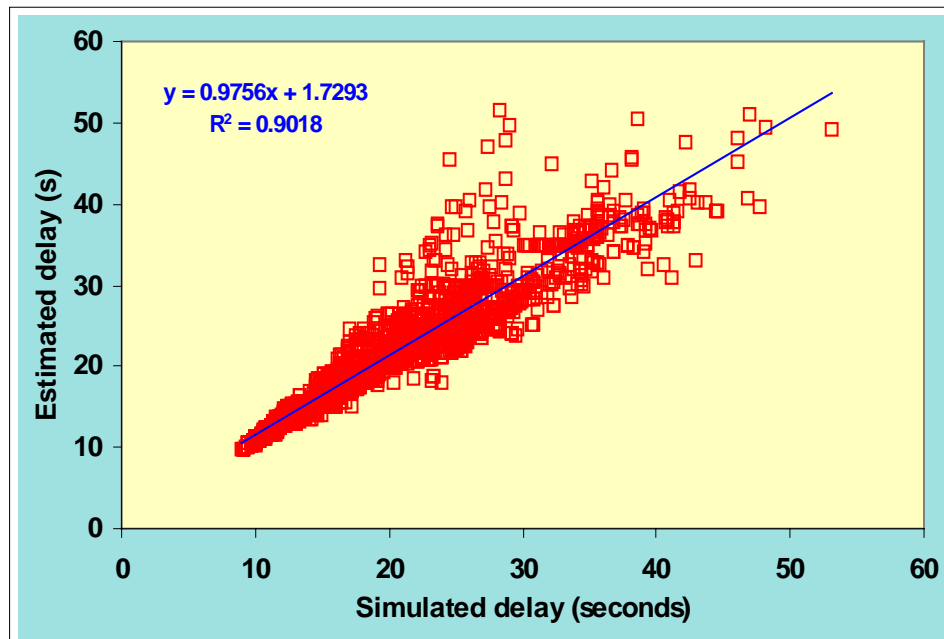
Importance of the maximum green time ( $G_{max}$ ) parameter in the model together with the gap setting ( $e_h$ ) parameter in determining the degree of saturation when non-zero overflow queues start ( $x_0$ ) is emphasised. Equation (4d) indicates that the value of  $x_0$  increases (i.e. the range of non-overflow conditions is increased) with increased  $G_{max}$  and decreased  $e_h$  values.

Figures 6 to 8 show the comparisons of average delay, average back of queue and average queue clearance time values predicted by the SIDRA method with those obtained from MODEL simulation. The estimates of delay and queue length were calculated using the steady-state model forms for consistency with the simulation method (degrees of saturation below 0.95 are used as required by this model form). Trend lines and associated regression statistics are also given in Figures 6 to 8 indicating satisfactory predictions.

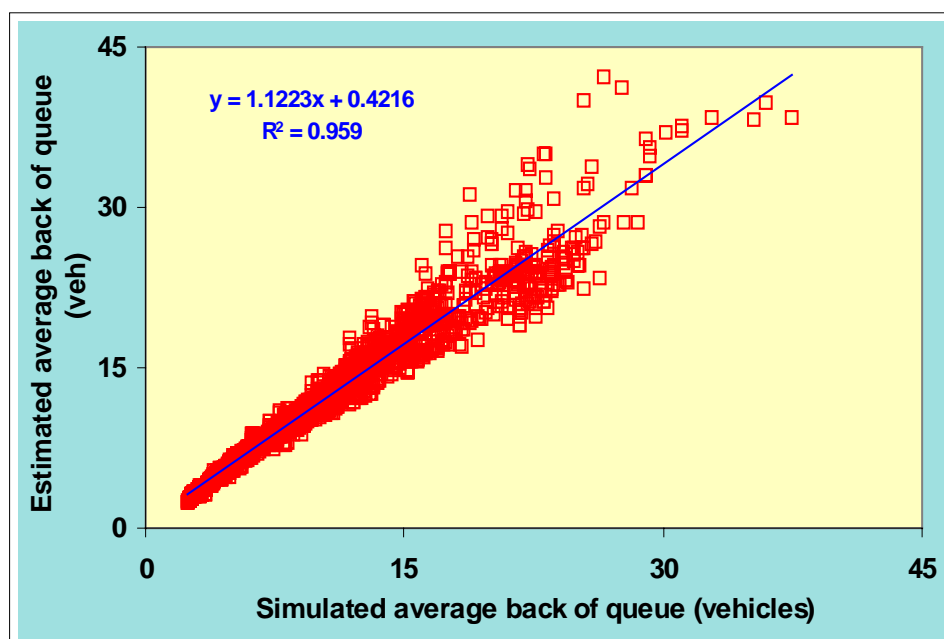


**Figure 6**

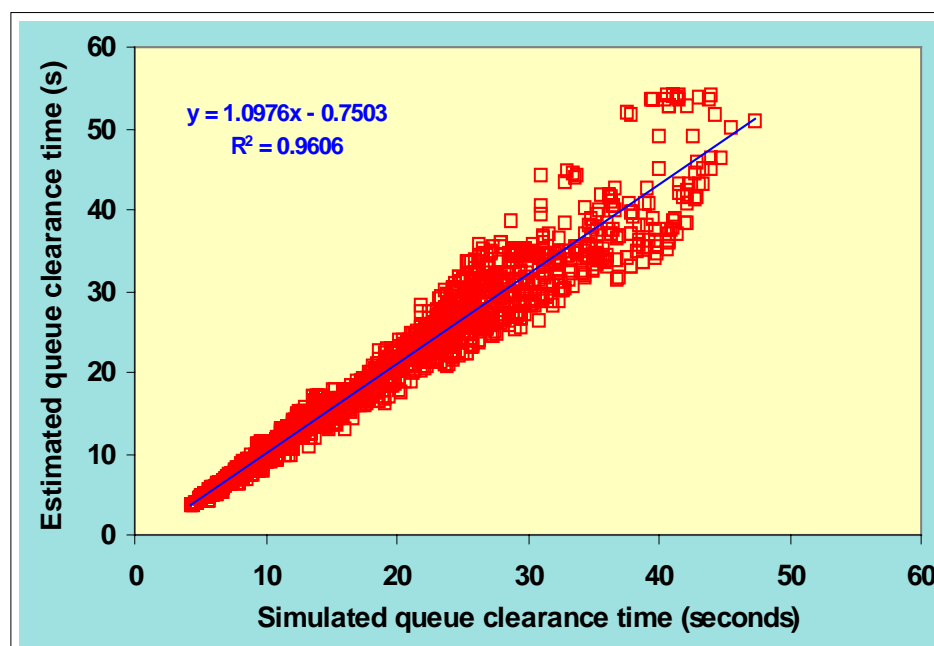
Comparison of estimated and simulated values of average delay for actuated signals

**Figure 7**

Comparison of estimated and simulated values of average back of queue for actuated signals



**Figure 8**  
Comparison of estimated and simulated values of average queue clearance time for actuated signals



## Field Survey Results

Comprehensive surveys of intersection timings, volumes, capacity and performance measures were carried out at the intersection of Ferntree Gully Road and Scoresby Road in Melbourne, Australia. This was part of a project to evaluate the performance of SCATS Master Isolated (SMI) and traditional actuated control methods. The SCATS Master Isolated control method is a unique isolated actuated control method which uses the EQUISAT principle unlike the traditional actuated control, and is in use in Australia and elsewhere (6,17,18).

The intersection of Ferntree Gully Road and Scoresby Road is an isolated T junction operating under a three-phase signal system with fully-controlled right turns and slip-lane left turns. The control method is normally SMI. For the purpose of surveys it was operated under traditional actuated control as well. This was readily available under the SCATS system. The intersection layout is shown in Figure 9, with lane numbers based on SCATS detector numbers. Lane 7 is a special U-turn lane with very light traffic.

In Figure 9, the critical lanes which are surveyed are indicated by an asterisk. The critical lanes were determined using SCATS data and carrying out SIDRA analysis prior to the surveys. Survey results confirmed the critical lane analysis. Signal phasing is shown in Figure 10 (SIDRA graphic screen).

In the morning peak, Lane 1 (Phases C+A) and Lane 8 (Phase B) were critical, and Lanes 3 and 6 (Phases C and A) operated as non-critical lanes overlapping with Lane 1. In the afternoon peak, Lane 3 (Phase C), Lane 6 (Phase A) and Lane 8 (Phase B) were critical, and Lane 1 operated as a non-critical lane. The intersection operated efficiently thanks to the short maximum green and gap settings ( $G_{max} = 45$  s for Phase A, 30 s for Phase B, and 16 s for Phase C;  $e_s = 2.5$  s for all phases).

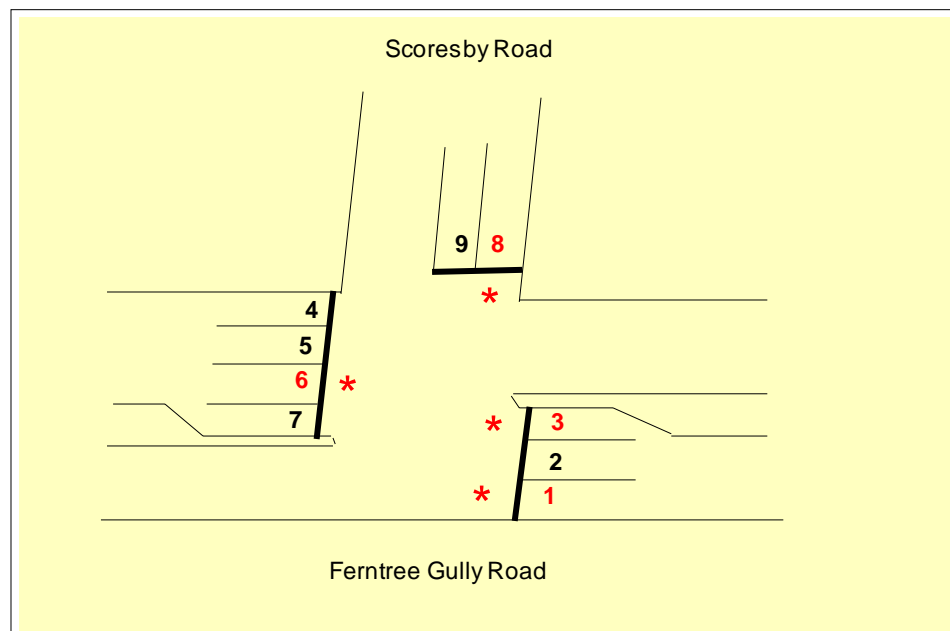
A new survey method was developed to produce a comprehensive set of performance measures. The method was used to collect data for traffic using Lanes 1, 3, 6 and 8 with two observers per lane conducting manual surveys. SCATS data were collected simultaneously with on-street surveys. The surveys were carried out during morning and evening peak periods (90 minutes each). In addition to the manual survey, vehicle headway and speed data were also collected at the stop line of Lane 6 using ARRB TR VDAS detectors (6.9).

The average flow rates, cycle times and green times from the manual surveys and from SCATS data showed very good agreement.

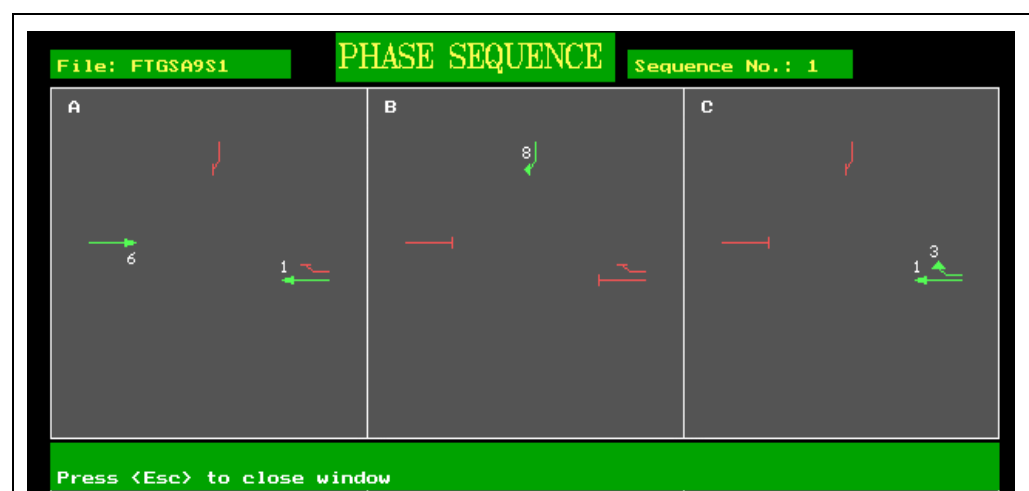
SIDRA analyses were carried out to compare SIDRA estimates of various performance statistics with the observed values. Measured demand flow rates, saturation flow rates and timing values were used for this purpose. SIDRA estimates of delay "without geometric delay" were used. The SIDRA "actuated signal" option was used for the purpose of performance estimation for the SMI control case as well as the traditional actuated control case.

Figures 11, 12 and 13 show graphs comparing SIDRA estimates and observed values of average delay, average back of queue and average queue clearance time together with trend lines and associated regression statistics. Satisfactory results were found for all statistics.

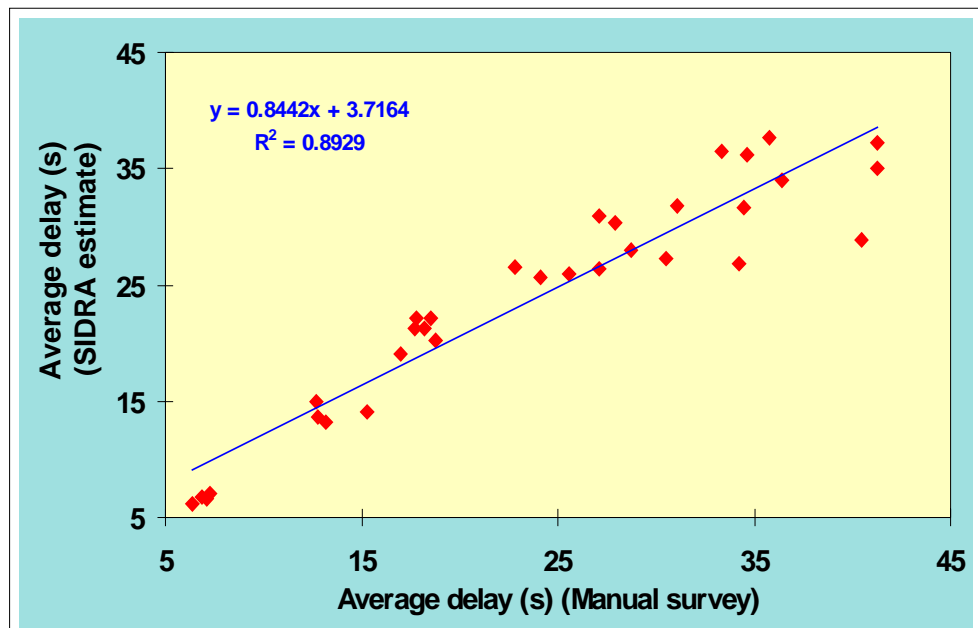
**Figure 9**  
Ferntree Gully  
Road - Scoresby  
Road:  
intersection  
layout



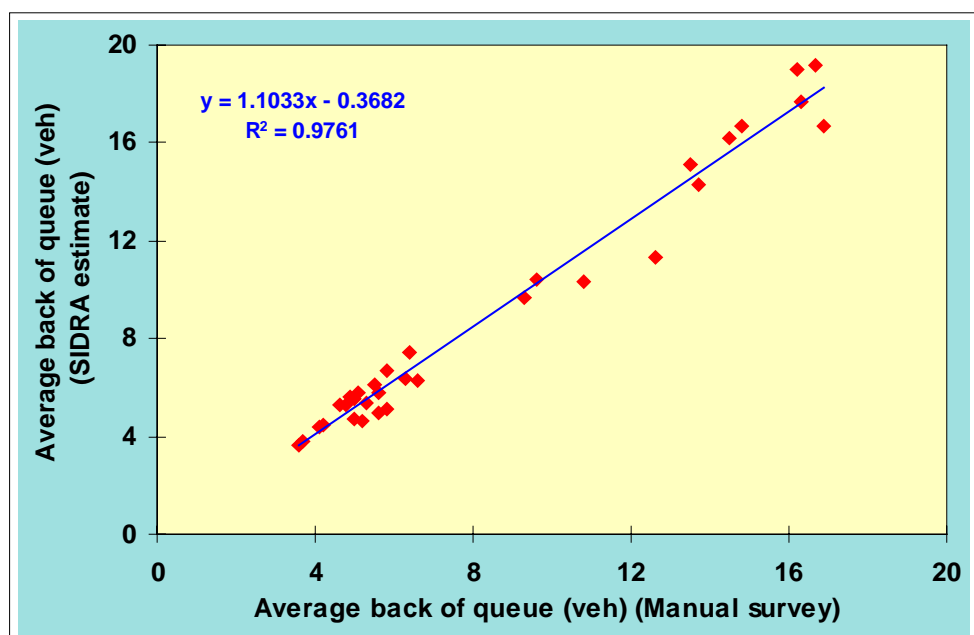
**Figure 10**  
Ferntree Gully  
Road -  
Scoresby Road  
intersection:  
signal  
phasing



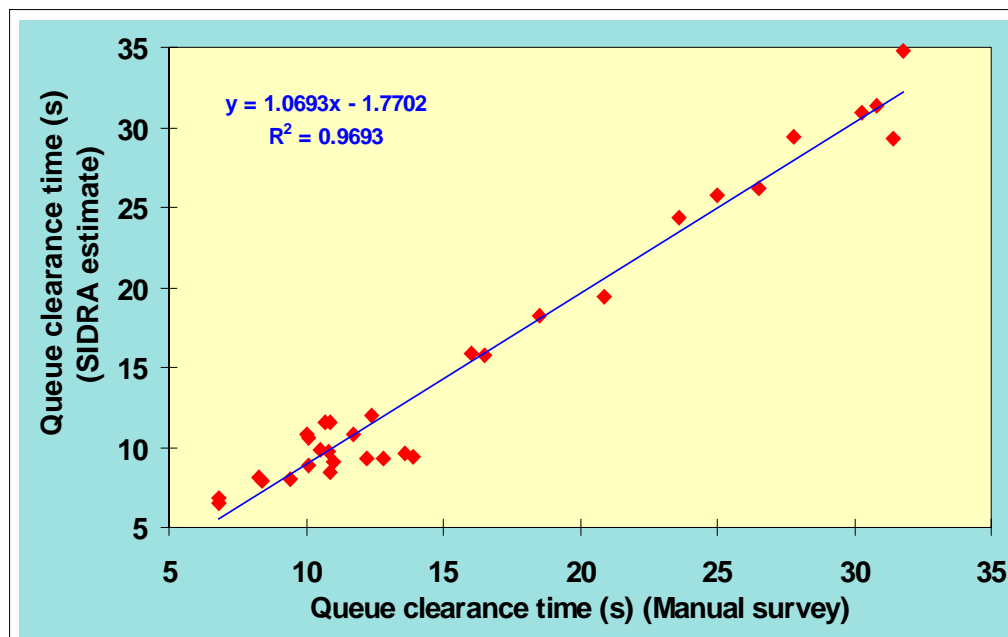
**Figure 11**  
Comparison of  
SIDRA delay  
estimates with  
those observed at  
the Ferntree Gully  
Road - Scoresby  
Road intersection



**Figure 12**  
Comparison of  
SIDRA average  
back of queue  
estimates with  
those observed at  
the Ferntree Gully  
Road - Scoresby  
Road intersection



**Figure 13**  
Comparison of  
SIDRA average  
queue clearance  
time estimates  
with those  
observed at the  
Ferntree Gully  
Road - Scoresby  
Road intersection



### An Example: HCM Chapter 9 Sample Problem 2

Sample Problem 2 of the Highway Capacity Manual, Chapter 9A (11) is used as an example to demonstrate the comparison of pretimed and actuated signal timing analysis using SIDRA. The option with the “protected-only” phase for the Eastbound Left movement is considered. Copies of SIDRA graphics screens showing the intersection geometry and signal phasing are given in Figures 14 and 15. The HCM delay formula option without geometric delays was used. The emphasis in this analysis will be on the effects of maximum green settings.

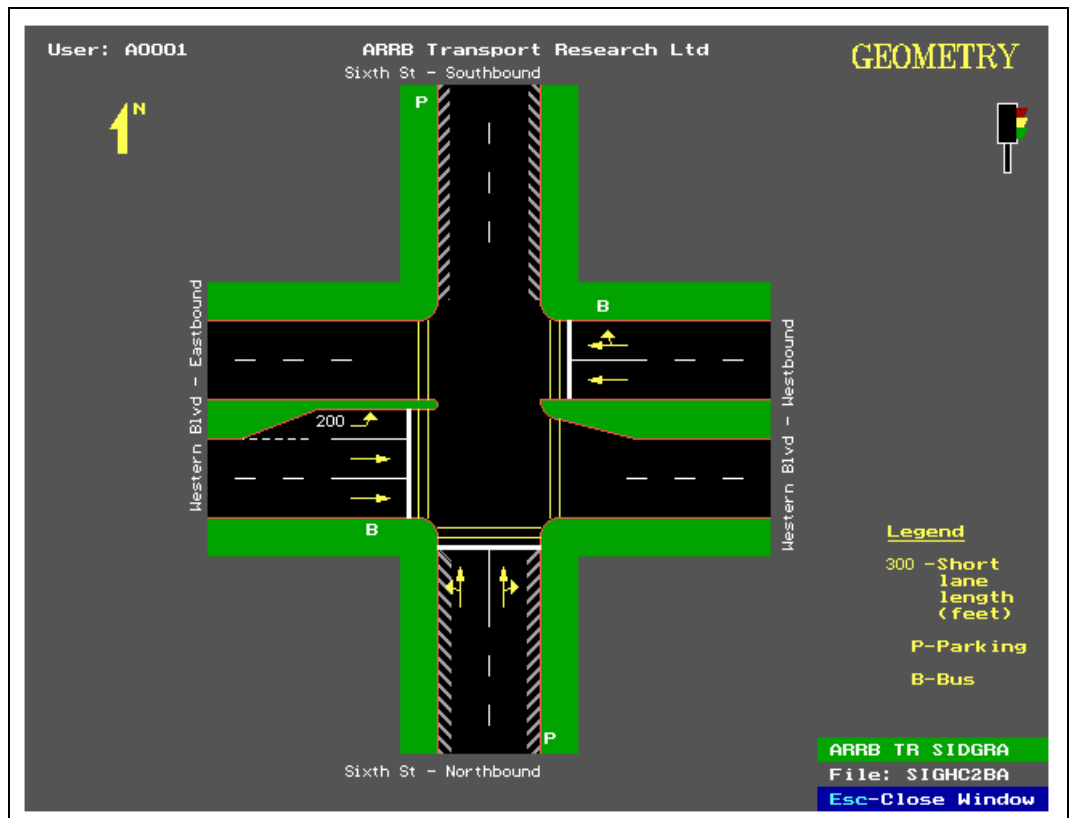
The lane-by-lane analysis results (SIDRA output table S.7) for various cases are given in Figures 16 to 19. In all cases analysed, the critical movements in this example are Eastbound Left (EB\_L), Northbound Through (NB\_T) and Westbound Through (WB\_T). All approaches are affected by unequal lane utilisation as specified by HCM. In Figures 16 to 19, the critical lanes are marked by an asterisk to the left of the lane number.

For the case with **pretimed signals**, SIDRA determines an optimum cycle time of  $c = 54$  s using the variable cycle time facility, resulting in an intersection degree of saturation,  $X = 0.830$  and average intersection delay,  $d = 18.3$  s. HCM specifies  $c = 70$  s as a minimum cycle time. Specifying this cycle time, pretimed green times found by SIDRA are practically the same as the HCM values (Figure 16).

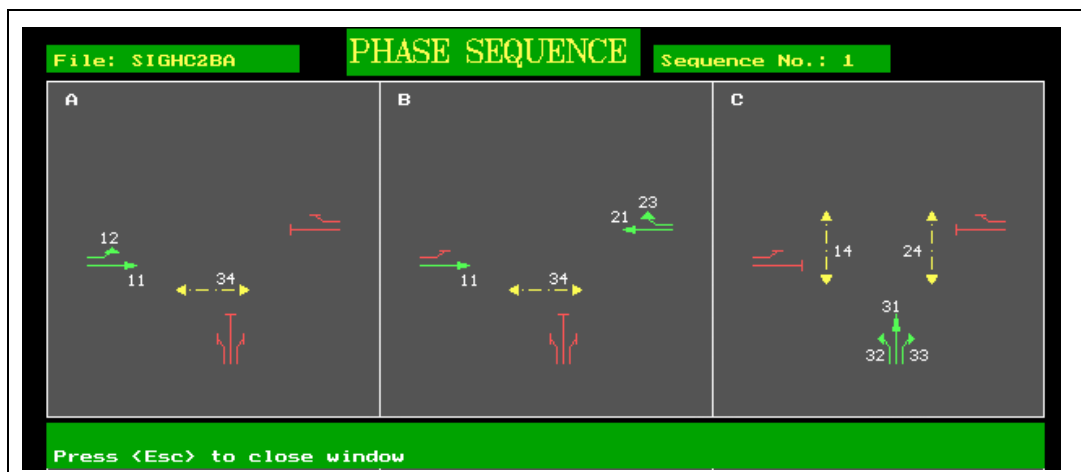
In this solution, intersection degree of saturation,  $X = 0.768$  and average intersection delay,  $d = 20.0$  s are found. EB\_L receives minimum green time, and as a result, its degree of saturation is lower than the other critical movements that receive an EQUISAT solution (EB\_L:  $x = 0.672$ ,  $d = 37.6$  s, LOS D, NB\_T:  $x = 0.768$ ,  $d = 22.0$  s, LOS C, and WB\_T:  $x = 0.765$ ,  $d = 24.1$  s, LOS C).

Figure 17 shows the SIDRA performance results for the HCM Sample Problem 2 as **actuated signals** with the timings found for pretimed signals specified as actuated signal timings ( $c = 70$ ). Comparison with Figure 16 shows the differences in SIDRA pretimed and actuated signal performance models (average intersection delay:  $d = 18.1$  s, EB\_L:  $x = 0.672$ ,  $d = 33.2$  s, LOS D, NB\_T:  $x = 0.768$ ,  $d = 19.3$  s, LOS B, and WB\_T:  $x = 0.765$ ,  $d = 21.2$  s, LOS C).

**Figure 14**  
 Highway Capacity  
 Manual, Chapter 9,  
 Sample Problem 2:  
 intersection  
 geometry



**Figure 15**  
 Highway Capacity  
 Manual,  
 Chapter 9,  
 Sample Problem 2:  
 signal phasing



**Figure 16**  
Highway  
Capacity  
Manual,  
Chapter 9,  
Sample  
Problem 2:  
pretimed  
signal solution  
with  $c = 70$  s

HCM Signalized Example 2 - Protected-only option \* SIGHC2B \*  
Pretimed signals  
Intersection No.: US2  
Cycle Time = 70

Table S.7 - LANE PERFORMANCE

Lane No.	Mov No.	Effective Red and Green Times (sec)				Arv Flow Cap		Deg. x	Aver. Delay (sec)	Eff. Stop Rate	Q u e u e		Shrt Lane (ft)
		R1	G1	R2	G2	(veh /h)	(veh /h)				95% Back (vehs)	(ft)	
West: Western Blvd - Eastbound													
*1 L	12	62	8	0	0	127	189	0.672	37.6	0.85	6.1	165	200
2 T	11	34	36	0	0	564	888	0.635	13.7	0.69	15.3	413	
3 T	11	34	36	0	0	467	817	0.571	12.6	0.65	12.6	341	
South: Sixth St - Northbound													
*1 LT	32, 31	42	28	0	0	469	610	0.768	23.5	0.89	16.5	430	
2 TR	31, 33	42	28	0	0	425	615	0.691	20.4	0.87	14.0	363	
East: Western Blvd - Westbound													
*1 T	21	45	25	0	0	472	617	0.765	25.0	0.89	16.7	451	
2 TR	21, 23	45	25	0	0	371	539	0.688	22.5	0.88	12.9	349	

**Figure 17**  
Highway  
Capacity  
Manual,  
Chapter 9,  
Sample  
Problem 2:  
actuated  
signals with  
pretimed  
signal timings  
specified

HCM Signalized Example 2 - Protected-only option \* SIGHC2BA \*  
Actuated signals  
Intersection No.: US2  
Cycle Time = 70

Table S.7 - LANE PERFORMANCE

Lane No.	Mov No.	Effective Red and Green Times (sec)				Arv Flow Cap		Deg. x	Aver. Delay (sec)	Eff. Stop Rate	Q u e u e		Shrt Lane (ft)
		R1	G1	R2	G2	(veh /h)	(veh /h)				95% Back (vehs)	(ft)	
West: Western Blvd - Eastbound													
*1 L	12	62	8	0	0	127	189	0.672	33.2	0.79	5.5	150	200
2 T	11	34	36	0	0	564	888	0.635	11.8	0.68	16.1	434	
3 T	11	34	36	0	0	467	817	0.571	10.9	0.64	13.0	351	
South: Sixth St - Northbound													
*1 LT	32, 31	42	28	0	0	469	610	0.768	20.8	0.80	16.3	423	
2 TR	31, 33	42	28	0	0	425	615	0.691	17.8	0.85	14.3	372	
East: Western Blvd - Westbound													
*1 T	21	45	25	0	0	472	617	0.765	22.0	0.81	16.7	450	
2 TR	21, 23	45	25	0	0	371	539	0.688	19.6	0.85	13.0	352	

Figure 18 shows the performance results for actuated signals with the timings found using SIDRA defaults for actuated signal control settings ( $G_{\max} = 50$  s and  $e_s = 2.5$  s for Thorough and Right-turn movements,  $G_{\max} = 20$  s and  $e_s = 2.0$  s for Left-turn movements). A cycle time of  $c = 109$  s, intersection degree of saturation,  $X = 0.817$  and average intersection delay,  $d = 26.4$  s are found. EB\_L receives maximum green time, and as a result, its degree of saturation is lower than the other critical movements that receive a Non-EQUISAT solution (EB\_L:  $x = 0.539$ ,  $d = 35.2$  s, LOS D, NB\_T:  $x = 0.817$ ,  $d = 31.8$  s, LOS C, and WB\_T:  $x = 0.784$ ,  $d = 31.9$  s, LOS C). Comparison with the solution given in Figure 17 indicates a less efficient solution due to a longer cycle time with green splits that favour minor movements.

To achieve actuated signal timings close to the pretimed solution, shorter maximum green settings need to be used. Figure 19 shows the performance results for actuated signals with the timings found using control settings of  $G_{\max} = 25$  s and  $e_s = 2.5$  s for Thorough and Right-turn movements,  $G_{\max} = 10$  s and  $e_s = 2.0$  s for Left-turn movements. These settings give a cycle time of  $c = 72$  s, intersection degree of saturation,  $X = 0.851$  and average intersection delay,  $d = 19.2$  s. All critical movements receive the maximum green times resulting in a Non-EQUISAT solution that favours minor movements (EB\_L:  $x = 0.503$ ,  $d = 25.6$  s, LOS C, NB\_T:  $x = 0.851$ ,  $d = 26.1$  s, LOS C, and for WB\_T:  $x = 0.756$ ,  $d = 21.1$  s, LOS C). This is a more efficient solution than that shown in Figure 18 due to the reduced cycle time, but less efficient than the solution using pretimed signal timings (Figure 17) although the improvement in the level of service of EB\_L movement is interesting to note. An issue relevant to the optimisation of actuated signals is whether such short maximum green settings for actuated controllers are acceptable or practical in signal operations practice.

**Figure 18**  
Highway  
Capacity  
Manual,  
Chapter 9,  
Sample  
Problem 2:  
actuated  
signal solution  
with  $G_{\max} =$   
50, 20 s

HCM Signalized Example 2 - Protected-only option											* SIGHC2BA *			
Actuated signals														
Intersection No.: US2														
Cycle Time = 109														
Table S.7 - LANE PERFORMANCE														
Lane No.	Mov No.	Effective Red and Green Times (sec)				Arv Flow (veh/h)	Cap (veh/h)	Deg. Satn x	Aver. Delay (sec)	Eff. Stop Rate	Q u e u e		Shrt Lane (ft)	
		R1	G1	R2	G2						95% Back (vehs)	(ft)		
West: Western Blvd - Eastbound														
*1	L	12	88	21	0	0	127	236	0.539	35.2	0.79	7.4	199	200
2	T	11	47	62	0	0	564	983	0.574	13.6	0.61	21.1	571	
3	T	11	47	62	0	0	467	904	0.517	12.8	0.57	17.1	463	
South: Sixth St - Northbound														
*1	LT	32,	68	41	0	0	469	574	0.817	34.2	0.84	24.7	641	
		31												
2	TR	31,	68	41	0	0	425	578	0.735	29.3	0.86	21.7	565	
		33												
East: Western Blvd - Westbound														
*1	T	21	71	38	0	0	472	602	0.784	33.1	0.83	24.6	665	
2	TR	21,	71	38	0	0	371	527	0.705	29.9	0.86	19.4	523	
		23												



**Figure 19**  
Highway  
Capacity  
Manual,  
Chapter 9,  
Sample  
Calculation 2:  
actuated  
signal solution  
with  $G_{\max} =$   
25, 10 s

HCM Signalized Example 2 - Protected-only option													* SIGHC2BA *	
Actuated signals														
Intersection No.: US2														
Cycle Time = 72														
Table S.7 - LANE PERFORMANCE														
Lane No.	Mov No.	Effective Red and Green Times (sec)				Arv		Deg. x	Aver. Delay (sec)	Eff. Stop Rate	Q u e u e		Shrt Lane (ft)	
		R1	G1	R2	G2	Flow (veh/h)	Cap (veh/h)				95% Back (vehs)	Back (ft)		
-----														
West: Western Blvd - Eastbound														
*1	L	12	61	11	0	0	127	253	0.503	25.6	0.79	5.4	145	200
2	T	11	32	40	0	0	564	960	0.588	9.9	0.62	15.2	409	
3	T	11	32	40	0	0	467	883	0.529	9.2	0.59	12.2	331	
-----														
South: Sixth St - Northbound														
*1	LT	32,	46	26	0	0	469	551	0.851	29.0	0.93	19.4	504	
		31												
2	TR	31,	46	26	0	0	425	555	0.766	23.0	0.88	16.0	416	
		33												
-----														
East: Western Blvd - Westbound														
*1	T	21	46	26	0	0	472	624	0.756	22.0	0.82	17.3	468	
2	TR	21,	46	26	0	0	371	545	0.681	19.7	0.85	13.3	359	
		23												
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