
Published paper

Quinn, D.J., Montgomery, F.O., May, A.D. (1988) *Control of Congestion in Highly Saturated Networks: Working Paper 251 – Experimental Results and Conclusions.* Institute of Transport Studies, University of Leeds. Working Paper 251

Working Paper 251

November 1988

CONTROL OF CONGESTION IN HIGHLY SATURATED NETWORKS:

WP 251 - Experimental Results and Conclusions

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This work was sponsored by SERC.

CONTENTS

1. Introduction

1.1 Context

This working paper describes the results and conclusions drawn from experiments in traffic control carried out in Bangkok, Thailand, during a study of the control of highly saturated networks.

Other papers in the series are WP 248 (Survey Design and Data Collection)
WP 249 (Development of Signal Timings)
and WP 250 (Incidents and their Management)

This study formed a follow-up to an earlier study reported in WP 220, WP 221 and WP 222.

1.2 Background

The TRANSYT program has been generally accepted as the most successful method for optimising the fixed-time control of signalised road networks. TRANSYT version 8 was used in the previous study to predict the timings for a series of four co-ordinated signalled junctions on a major east-west two way arterial road in Bangkok (namely, Rama IV Road). Before conducting the previous experiment it was, however, recognised that standard UK signal calculation methods were inappropriate because of high turning movement proportions, different p.c.u. values and high saturation flows maintained over long periods. The revised method of dealing with Bangkok traffic conditions has been described in WP 220 and WP 222. Despite these revisions an experiment in automatic co-ordinated signal control produced an average reduction in vehicle delay (veh-hours/hr) of 6% compared with manual police control. Although an improvement of 21% was recorded on one incident-free day, one would still have expected a greater overall reduction in delay through benefits of co-ordination. A likely explanation is that TRANSYT attempts to facilitate the "progression" of vehicles along a link, but when junctions are saturated then uninterrupted progression along a link is not possible since each vehicle will be delayed for at least one cycle at each junction. Instead, the key requirements are to avoid queues disrupting upstream junctions and to reduce the number of standing waves in a queue. Observations from the RAMA IV experiment indicated that problems did not occur in a junction provided that the tail of the queue was moving by the time the stage for its main feed had ended. If stationary vehicles remained in the junction, then drivers from the main feed (ie Rama IV Road) entered the junction illegally and subsequent movements were disrupted.

The blocking of an upstream junction was most noticeable during the previous experiment on the east-bound link between Suriwong (SUR) and Silom (SIL) junctions along Rama IV Road. TRANSYT/8 recommended timings were employed on the first experimental day (2 July 1985) but these resulted in blocking of the upstream (SUR) junction and the offset between junctions SUR and SIL had to be altered. The "successful" offset between SUR and SIL junctions was based on the time taken for a starting wave to move backwards from SIL to SUR along a queue on Rama IV Road. Under the original TRANSYT/8 recommended timings the main feed at the upstream junction (SUR) finished before the starting wave had arrived from the downstream junction (SIL); whereas the adjusted offset allowed approximately 25 seconds in which traffic was free to flow across the SUR junction before the green for Rama IV Road terminated, hence the junction did not become blocked and cross-moving traffic was unhindered. (Technical Note 224 describes in more detail how video film for this critical link has been analysed).

As a result of the above work and after discussions at TRRL it was recommended that the TRANSYT/8 program should be amended. A new card (type 39) has now been introduced in order that a range of offsets can be specified which will avoid blocking of upstream oversaturated conditions, will avoid blocking of critical links yet still optimise within the constraints imposed by card type 39. Testing the usefulness of this modified TRANSYT program was one of the several aims of this follow-up study.

1.3 Objectives

i) To conduct an experiment in automatic signal control on a two dimensional road network.

At an isolated intersection with degrees of saturation approaching 100%, a policeman can respond immediately to variations in input flow or saturation flow (often caused by incidents) and therefore reduce the random element of delay. In a network of junctions, however, coordinated fixed-time control is usually better than manual or isolated responses because of the benefits of progressing platoons through successive junctions. However, the smooth progression of vehicles through a network breaks down in highly saturated conditions.

Another objective therefore, was to apply the specifically amended TRANSYT/8 program (with card type 39) to a network of roads in which blocking of several junctions was a common occurence and where the manual calculation of offsets would be more difficult.

ii) To calculate automatic timings which are effective in variable flow conditions.

The variability of flows in Bangkok is one reason why the traffic police choose to manually control junctions during the peak periods. Hence, a further objective of this project was to implement signal timings which were sufficiently robust to accomodate variable demands. In particular, it was considered essential to calculate offsets between junctions which would ensure that stopping and starting waves arrived at upstream junctions at a desired point (or range of points) in each cycle, despite the expected variability in demand and hence the variability in the speed of stopping waves.

iii) To provide Bangkok Traffic Police with guidance on how to best approach incident management.

If automatic signal timings were successfully implemented then the traffic police could be released to perform "incident management" duties which should further reduce delay and minimise the disruptive influence of incidents on the effectiveness of the automatic timings.

The most important of these three objectives was to organise and conduct an experiment in automatic signal control on a two-dimensional road network. Once the police were satisfied that the automatic timings were working adequately, they could be encouraged to leave the vicinity of the control-box and patrol the streets in order to promptly deal with incidents. Instructions were to be given on the most effective way of dealing with incidents without reverting to manual signal control.

PART ONE - EXPERIMENTAL METHOD

2. Surveys

Five sets of surveys were carried out as listed in Table 1.

(i) Basic Data:

Input flows were counted cumulatively every 5 minutes, at all entry points to the network, just upstream of the maximum queue or at the next upstream junction if that was closer. All vehicles were counted, except motorcycles, but unclassified, for a period of 10 days. Turning movements were recorded on video for one day at each junction over the 10 day period. The video tapes were then analysed to obtain classified turning movement counts, and saturation flows (using the t.c.u. values obtained from the previous study, as reported in WP 222). Starting and stopping waves were timed by observation from the relevant buildings. Also, intergreens and start and end lags were obtained from site observation. These initial surveys are fully reported in Working Paper 248, where the method of dealing with 'Soi' movements is also explained.

(ii) Pilot Number Plate Survey:

Experience in the earlier study had warned us of the pitfalls of number plate surveys in very high flows. It being impossible to record the number plates of all vehicles passing a given point, it was necessary to define a subset (for example white cars), the requirements of which were that:

- it should be easily identifiable by all the observers.
- it should be small enough such that close to 100% of the number plates in the subset could be recorded even in the highest flow periods.
- it should be large enough to provide an adequate sample for estimating journey times and O-D patterns.
- it should be an unbiased sample of the total flow in terms of journey times and O-D patterns.

To this end a pilot survey was conducted in February 1987 using students from the Asian Institute of Technology. Several subsets were tested, and the final one chosen which satisfied the above criteria was 'Mercedes, BMW and Peugeot private cars' all of which are easily identifiable from their badges. The survey is reported in Technical Note 226.

(iii) Update Survey:

Because of the time lapse between the Basic Data Survey in September and the Main Experimental Surveys some seven months later, and the lack of any local data on the pattern of flows over the year, it was considered necessary to update the input flows used in the TRANSYT model. Turning movement proportions were, however, assumed to remain the same.

Starting and stopping wave speeds were also re-surveyed at this time, as the latter were dependent on the level of flow.

Table 1

Survey Timetable

Survey Title	Data Collected	Dates
Basic Data	Input flows, turning movement proportions, saturation flows, starting and stopping wave speeds, intergreens, start and end lags, manual control timings.	Sept 1986
		1987
Pilot	Number Plate Matching	February
Update	Input flows, starting and stopping wave speeds	March
Small-Scale	Number Plate Matching for journey times on key links.	2- 5 March (P) 18-22 May (A)
Main	Number Plate, input flows, output flows, moving vehicle, elevated observer, video, incidents.	20-24 April (P) 27-30 April (A) 6- 7 May (A)

P = Police Control   A = Automatic Control

(iv) Small Scale Survey:

As always, resources were limited, and in this case there was sufficient only for two weeks of full scale, in depth surveys. Moreover, the exigencies of the study program and the need to avoid a number of national holidays meant that the main surveys were, of necessity, carried out during the school holiday period. Therefore, in order to gain a better picture of the performance of the automatic control strategy during school term time, more limited surveys were carried out for one week (2-5 March) before the main experiment and one week (18-22 May) after it.

In these surveys number plates were recorded at either end and in the middle of the West-East route, plus one location in the Northbound link from junction 29 to 161. These locations were chosen to intercept the most heavily trafficked sections of the network.

(v) Main Survey:

During the main survey, number plates of selected vehicles (as described earlier) and total flow counts were recorded at all entries and exits from the network, as well as at two mid-block points (East of J160 and West of J30). In addition, two moving survey cars were used to carry out moving observer runs covering most links in the network. The latter survey was seen mainly as a fall-back option and a check on the number plate survey, as was also the elevated observer survey, which involved timing a sample of vehicle travel times along a selection of links as seen from a high building.

Four video-cameras were used during the main survey to record the most congested links and to record the behaviour of stopping and starting waves. Data collection during this main experiment is explained below in more detail.

At the end of the main experiment, assuming that the timings proved successful and that the police would continue to co-operate, it was intended to extend the operation of automatic timings throughout May 1987 to cover the period when the schools re-opened. Hence the smaller-scale survey was scheduled to start on 18 May when flows were expected to be at their highest level and when drivers had had time to become accustomed to the operation of automatic signal timings.

A test day before the main experiment was also scheduled for Friday 17 April 1987 to ensure that all enumerators fully understood their tasks and to supply the necessary forms, watches, etc.

3. Main Experiment

(i) Manpower:

The main surveys required 46 staff for number plate and input counts, 4 for the moving observers, 4 to tend the video cameras, record incidents and queue lengths. In addition, 4 engineers from the Ministry of the Interior were stationed at key junctions, with communication by two way radio to another engineer at the ATC Centre. Three Leeds University staff were also in radio contact and were positioned:

- on a high building halfway along Bamrungmuang Road with good observation of stopping and starting waves.
- at junction 5 (J002) in order to liaise with the police commander and to monitor reports of the queue on Rama I Road.
- a 'roving commission' on Luang Road.

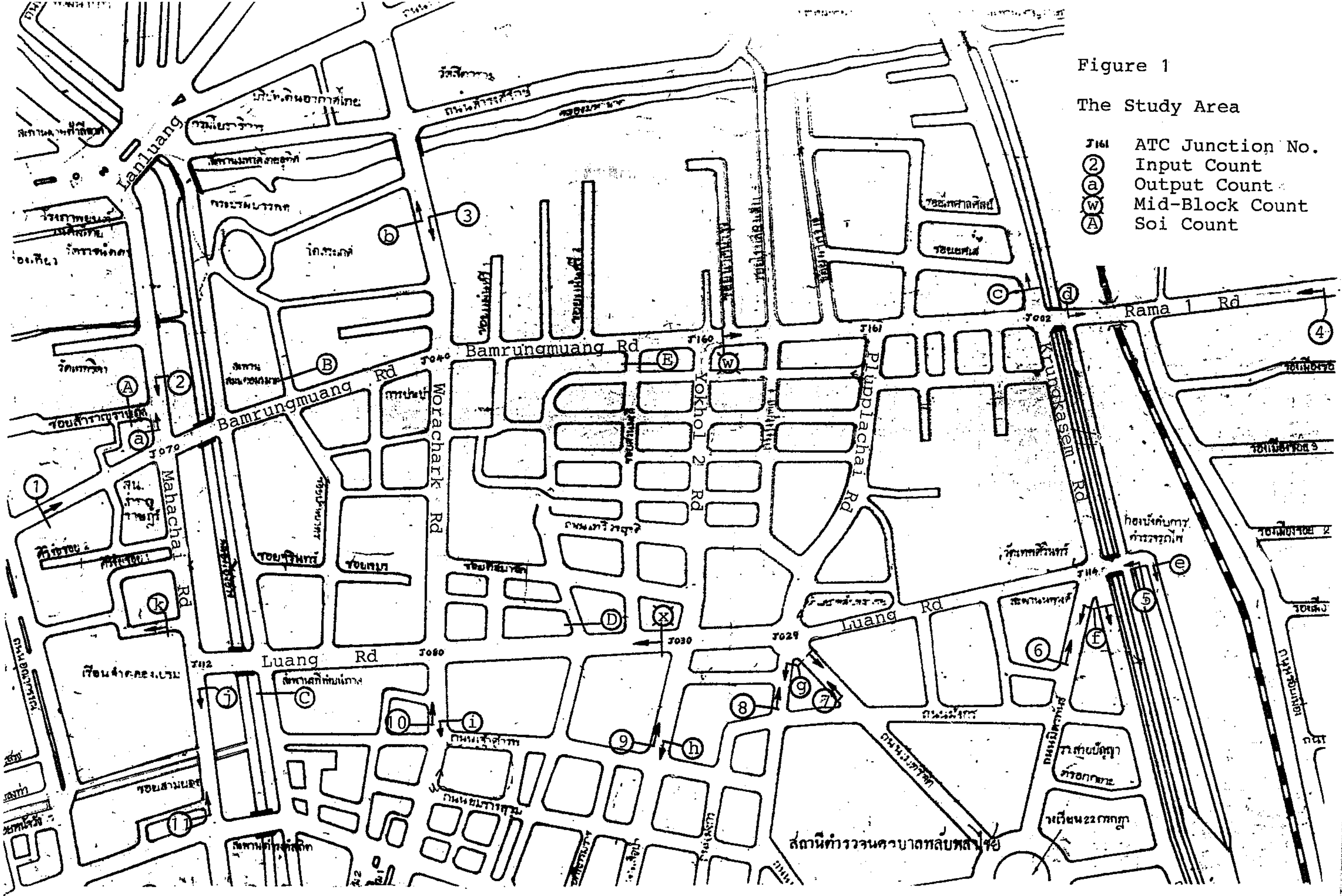
In total, there were over sixty personnel required for the main survey. Thirty two enumerators were from Chulalongkorn University with one supervisor and the remainder were recruited through the Ministry of Interior, again with one supervisor. The latter supervisor had a motorcycle which was used to take replacement enumerators to any unattended sites at the start of the survey. The motorcycle also proved very useful for getting quickly to the location of any reported major incidents.

(ii) Flow Counting and Number Plate Recording:

Figure 1 shows the locations of stations for counting input flow, output flow and number plate recording (see also plates 1 to 10). One enumerator was assigned to both an input and output count

Figure 1

The Study Area



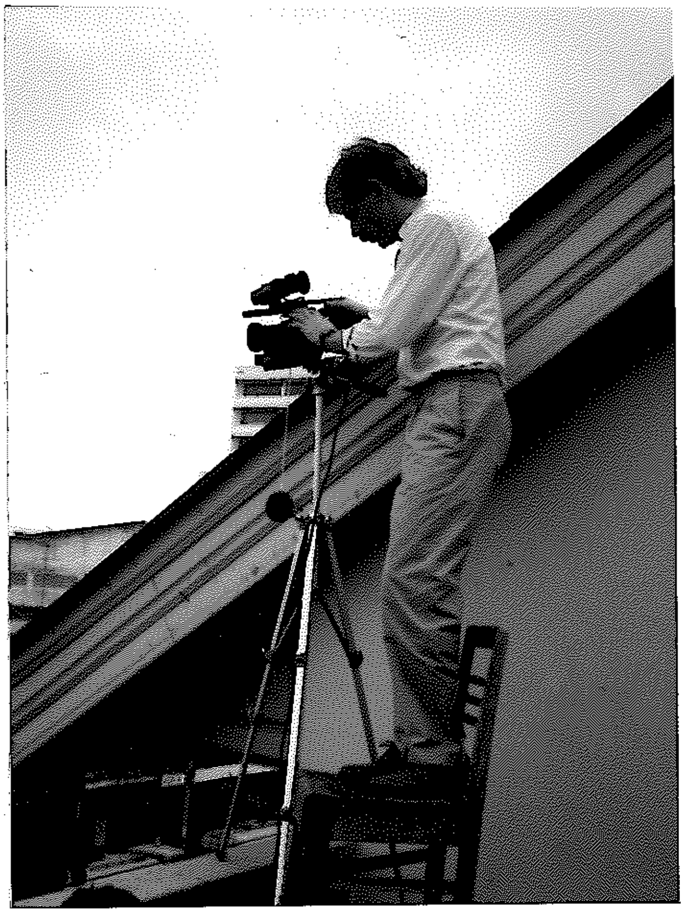


Plate 1   Video Equipment

Plate 2   Bamrungmuang Rd looking west from J002

Plate 3 Junction 5 (J002) looking east along Rama 1 Rd (Stage 1 running)

Plate 4 Junction 5 (J002) looking east along Rama 1 Rd (Stage 1 running)

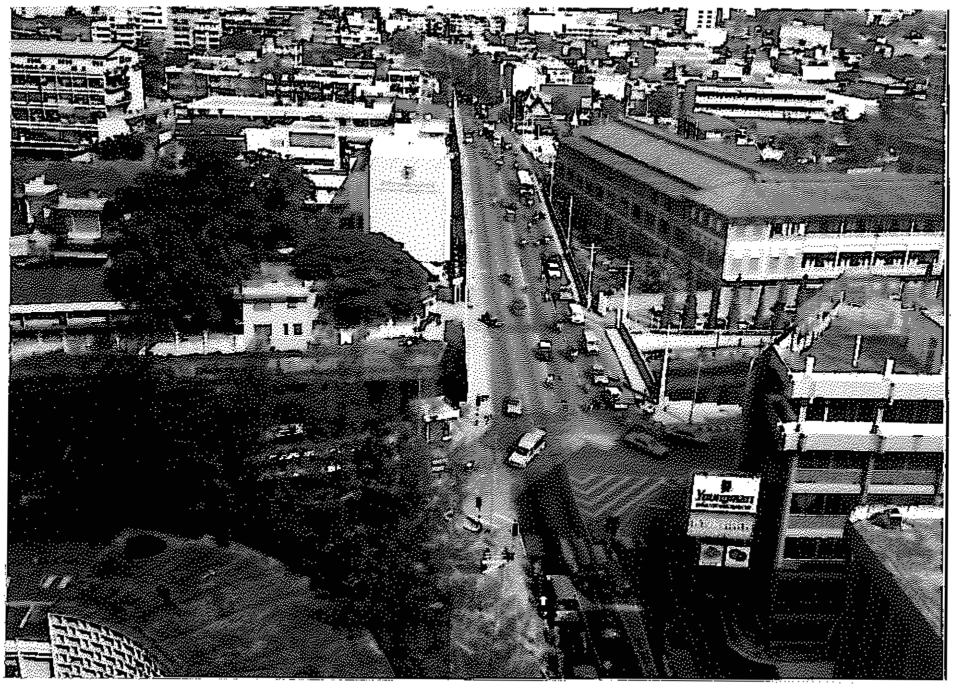


Plate 5 Junction5 (J002) looking east
along Rama 1 Rd (Stage 2 running)

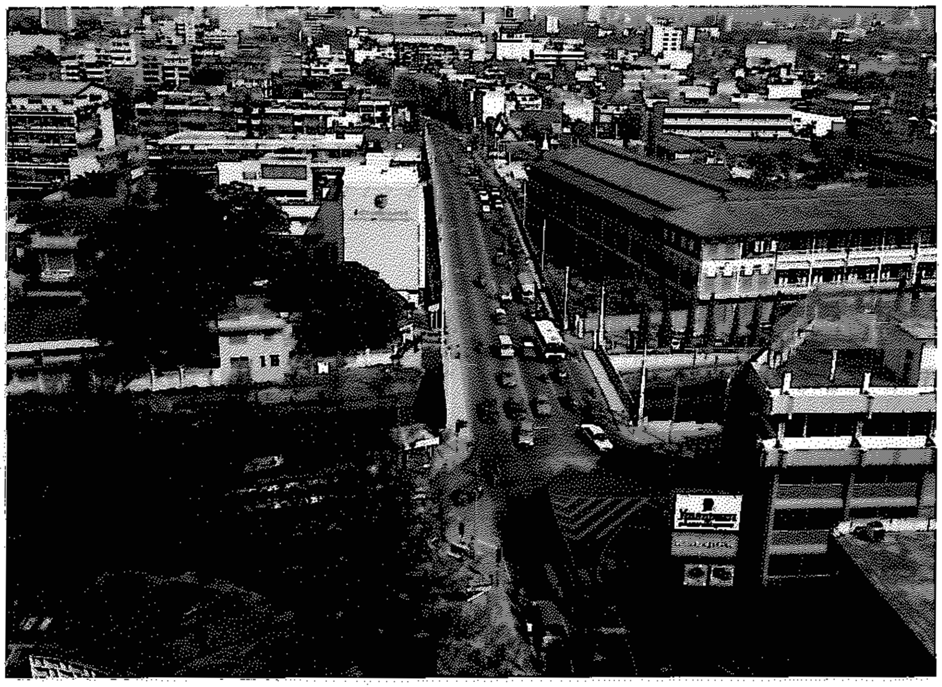


Plate 6 Junction 5 (J002) looking east
along Rama 1 Rd (Stage 2 running)

Plate 7   Junction 7 (J080) - looking south
(Stage 2 running)
Blocking from outside study area.

Plate 8   Junction 10 (J114) looking south-west
(Stage 2 running)

Plate 9 Junction 2 (J044) looking north-east (Start of Stage 2)

Plate 10 Junction 6 (J112) looking north

station wherever the flows were low enough, otherwise one person had responsibility for one station.

Input and output counts were recorded, as before, unclassified by cumulative 5 minute intervals. Number plates and the exact time vehicles crossed the count stations were recorded on prepared forms. Each enumerator was provided with a digital watch. The watches were re-synchronised each day by telephoning the 'speaking clock'. Supervisors double-checked synchronisation on-site each day. The time when a stationary queue began and finished at a count location was recorded on the Number Plate sheets.

A detailed queue length survey was conducted on the Rama I Road approach to junction 5 (J002). This queue usually extends beyond the survey area and beyond the police precinct covering this area. Therefore this queue can cause increased delay to several movements to the east of the study area. The enumerator was instructed to record the length of the stationary queue at the start of each green for stage 2 at junction 5 (J002). Lamp-posts were numbered and the distance between them was used to estimate the queue length.

(iii) Video-Camera Positions:

Four video cameras were positioned in order to view:

- (a) - junction 5 (J002) and Rama I Road
- (b) - the link between junctions 5 (J002) and 4 (J161)
- (c) - the link between junctions 3 (J160) and 2 (J044)
- (d) - the link between junctions 8 (J030) and 9 (J029)

The two links on Bamrungmuang Road, (b) and (c), were filmed by looking east and west from the same high building (Saha Thai). The link on Luang Road (d) was recorded from the balcony over a shop, while camera (a) was located on the roof of the Department of Medical Sciences immediately above junction 5 (J002) looking to the east.

Three of the cameras were VHS and the fourth was Betamax type. One camera was owned by Leeds University while the remaining cameras were borrowed from the Ministry of Interior, the Department of Highways and Chulalongkorn University.

(iv) Elevated Observers:

Two enumerators were positioned with the two video cameras on the Saha Thai building on Bamrungmuang Road, while the third enumerator observed from the Medical Sciences Building. The position on the Medical Sciences Building facilitated observation of the link between junctions 4 (J161) and 3 (J160) which could not be seen from the Saha Thai Building. Each enumerator was instructed to select an easily identifiable saloon car and to time the passage of the vehicle as it crossed one stop-line until it crossed the next downstream stop-line. Enumerators were equipped with a stop-watch and prepared forms.

(v) Moving Vehicles:

Two cars, with driver and enumerator, were each assigned to a route through the survey area. Landmarks were identified before the survey and were used as timing points. The two routes are shown on Figure 2. Drivers were paid petrol and a negotiated sum per mile. It was impossible to arrange a route which passed through junction 5 (J002) because the one-way system to the east of the study area would cause the driver to 'waste' at least 30 minutes before re-entering the study network.

(vi) Incidents:

In highly saturated conditions the occurrence of incidents is likely to cause considerable delay and this was certainly the experience in the earlier study. Therefore a comprehensive record of incidents was collected on prepared forms which required information on the nature of an incident, its location and its duration. These forms were handed to all input/output count enumerators, engineers from the Ministry of Interior, elevated observers, moving vehicle observers and the principal researchers from Leeds University. With the aid of radio contact and direct communication with the local traffic police it was possible to learn about all major incidents within and affecting the study area. The supervisor with a motorcycle could also travel the area in order to identify and/or investigate particular incidents.

3. Typical Experimental Day

(i)	Before Noon	Analyse previous day's data in office and prepare plan of signal timings for the day. Ensure that 2 way radios function.
(ii)	Noon	Enumerators synchronise watches with 'speaking clock' on the telephone.
(iii)	1.30 p.m.	All filming crews leave for sites.
(iv)	2.00 p.m.	Enumerators leave Chulalongkorn University by bus/car/minivan
(v)	2.00 p.m.	Signal plan entered into Highwayman at ATC Centre, Ministry of Interior.
(vi)	2.15 p.m.	Drivers report to Ministry of Interior before driving pre-set routes. Hand in previous day's forms and mileage claims.
(vii)	2.25 p.m.	Enumerators from Ministry of Interior leave for sites.
(viii)	2.30 p.m.	Engineers from Ministry of Interior and Leeds University staff leave for sites with two-way radios.
(ix)	2.45 p.m.	Radio to ATC Centre to activate STATE*

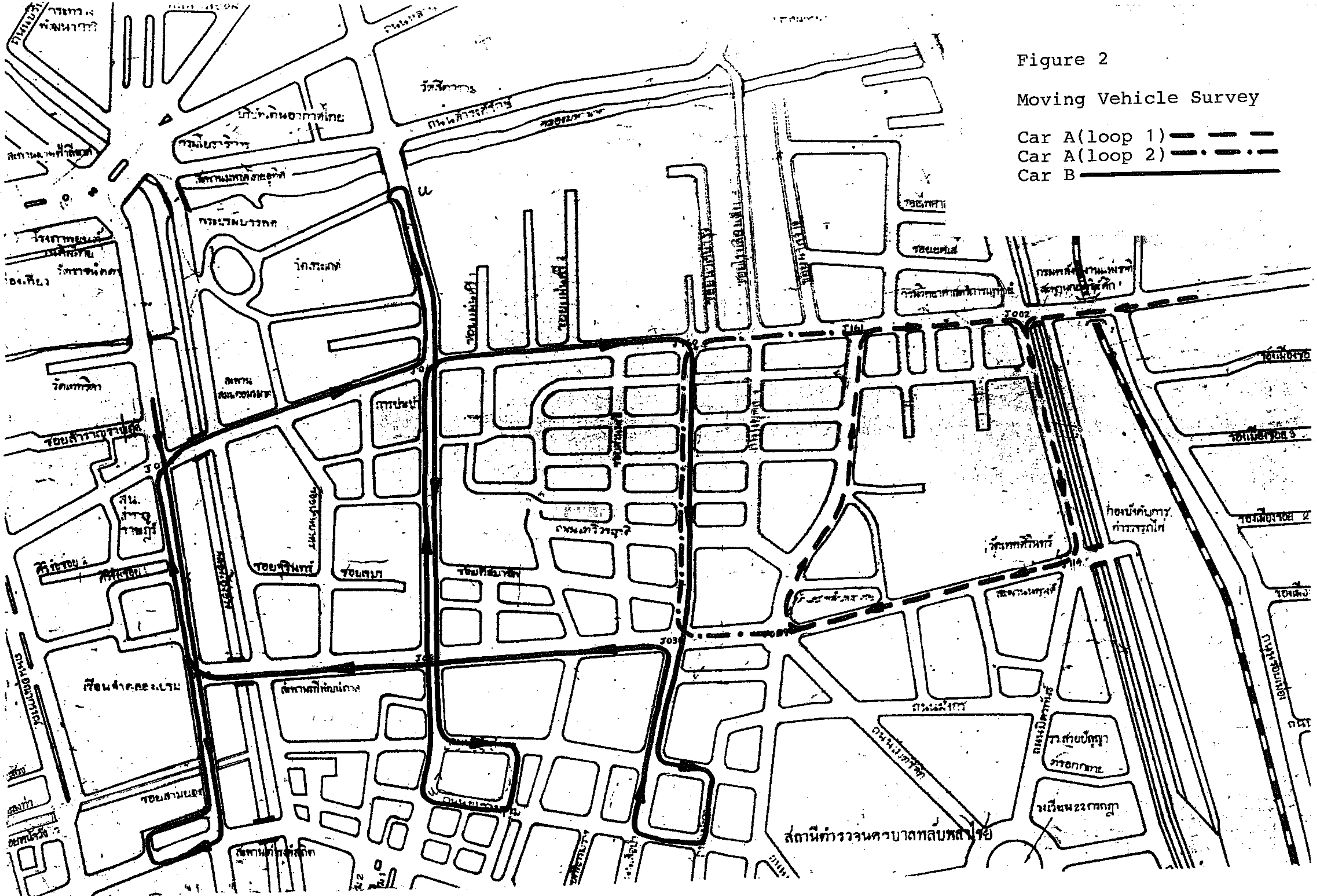


Figure 2

Moving Vehicle Survey

command with the new signal plan.

(x)	3.00 p.m.	Commence data collection and video filming.
(xi)	3.00 p.m.	Supervisors begin to check that all enumerators are in position and arrange replacements for any absentees. Supervisors also check watch synchronisation and that each enumerator has sufficient quantity of forms for the day. Collect previous day's forms.
(xii)	4.15 p.m.	Radio to ATC Centre to implement planned changes to signal timings.
(xiii)	6.15 p.m.	End of Data Collection. Enumerators keep forms until next day, when they will be collected by supervisors.
(xiv)	7.00 p.m.	Radio to ATC Centre to replace STATE command with standard off-peak 'plan'.

* See WP 249

PART TWO - RESULTS

5. Introduction

The experimental method, outlined in the previous section, was designed to facilitate the collection of data which could be used to evaluate the performance of manual police control compared with automatic control. The key measures of system performance can be derived from data on the average flows and journey times of vehicles within the study network. These two sets of data are described below and an evaluation of system performance in terms of 'vehicle-hours per hour', 'vehicle-kilometers per hour' and system speed is also discussed. Note that as fully described in WP250, extreme weather conditions and a higher than average number of disruptive incidents were experienced on 27th April, which was also the first day of the automatic timings. Data from this day is therefore unrepresentative and has been excluded from the summary statistics in Tables 3 to 8. The data itself is however shown in the tables for completeness.

6. Input Counts

The flows of vehicles (except motorcycles) into and out of the network were counted at eleven stations. These counts were used to estimate the number of trips between origin and destination pairs. The output and input counts are summarised in Tables 2, 3, 4, 5, 6 and 7.

The average input flow of vehicles during police days between 3.30 p.m. and 6.00 p.m. (Table 4) was only 1% (i.e. 282 vehicles) higher than the average for automatic days. Table 2 shows how most (90%) of this higher input during police days occurred in the first hour, 3.30 p.m. to 4.30 p.m. Between 4.30 p.m. and 6.00 p.m. there was no substantial difference in the overall level of input flows between police and automatic control.

The average total output of vehicles between 3.30 p.m. and 6.00 p.m. (Table 7) was almost equal for both police and automatic control. In fact, the average output was half a percent higher under automatic control. Table 5 shows that there was 1% (137 vehicles) greater average output during the first hour under automatic control, while there was very slightly less average output under automatic control between 4.30 p.m. - 6.00 p.m. (Table 6).

The above results show that fewer vehicles entered the network through count stations during automatic control, but an equal number of vehicles left the network. One suggestion is that there were more vehicles inside the network at the start of data collection, especially as the input flows were lower during automatic control between 3.30 p.m. and 4.30 p.m. This could be explained by the fact that on 'experimental' days the police released control sometime after the morning peak period and not later, as requested. This meant that automatic signal timings which were known to be out-of-date were used immediately prior to implementation of the new co-ordinated timings. Consequently, the first few days of automatic control commenced with inherited

Table 2

Input Counts 15:30 to 16:30

(A) POLICE

DATE	1	2	3	4	5	6	7	8	9	10	11	Total
	LOCATION											
20/4	1279	835	1640	2211	679	436	674	497	770	547	1006	10,574
21/4	1277	879	1759	2353	788	448	630	618	771	427	1090	11,040
22/4	1279	873	1721	2400	736	437	628	602	644	425	1016	10,761
23/4	1304	885	1747	2476	803	422	727	562	791	332	1066	11,115
24/4	1265	890	1415	2476	697	369	694	594	718	566	875	10,559
Mean	1281	872	1656	2383	741	422	671	575	739	459	1011	10,810
Std. Dev.	14	22	143	110	54	31	42	48	59	97	83	258
Co.V.	1%	2%	9%	5%	7%	7%	6%	8%	8%	21%	8%	2.4%

(B) AUTOMATIC

DATE	1	2	3	4	5	6	7	8	9	10	11	Total
	LOCATION											
27/4	1204	633	1127	1533	705	344	581	475	628	298	897	8,425
28/4	1327	798	1309	2269	657	397	628	489	769	414	940	9,997
29/4	1349	1019	1510	2244	728	375	627	531	825	400	1126	10,734
30/4	1359	999	1641	2565	635	364	673	505	768	353	1027	10,889
6/5	1400	878	1696	2257	646	344	637	457	774	403	1120	10,612
7/5	1294	903	1526	2167	784	376	654	492	816	431	1111	10,554
Mean	1346	918	1536	2300	690	371	644	495	790	400	1065	10,557
*Std. Dev.	39	94	149	153	64	19	20	27	28	29	81	338
*Co.V	3%	10%	10%	7%	9%	5%	3%	5%	4%	7%	8%	3.2%

* excluding 27/4

Co.V. = Coefficient of Variation.

Table 3

Input Counts 16:30 to 18:00

(A) POLICE

DATE	1	2	3	4	5	6	7	8	9	10	11	Total
20/4	1868	1241	2557	3037	1131	626	1054	886	1161	897	1425	15,883
21/4	1850	1243	2741	3412	1244	578	983	803	1242	571	1566	16,233
22/4	1942	1202	2813	3521	1123	549	997	828	1308	544	1631	16,458
23/4	1995	1300	2701	3413	1068	507	978	927	1310	557	1604	16,360
24/4	1890	1314	2516	3527	1064	631	1101	947	1408	418	1404	16,220
Mean	1909	1260	2666	3382	1126	578	1023	878	1286	597	1526	16,231
Std. Dev.	59	46	125	201	73	52	53	62	92	178	105	218
Co.V.	3%	4%	5%	6%	6%	9%	5%	7%	7%	30%	7%	1.3%

(B) AUTOMATIC

DATE	1	2	3	4	5	6	7	8	9	10	11	Total
27/4	1614	1195	2127	2722	1115	491	904	754	1197	595	1399	14,113
28/4	1842	1480	2255	3583	1106	595	1011	868	1227	570	1488	16,025
29/4	1885	1367	2394	3387	1239	585	945	809	1311	547	1589	16,058
30/4	1897	1351	2535	3633	1300	602	1145	856	1157	553	1638	16,667
6/5	1925	1246	2612	3438	1084	500	1085	712	1260	536	1525	15,923
7/5	1943	1330	2343	3818	1281	544	1041	748	1238	565	1484	16,335
*Mean	1898	1355	2428	3572	1202	565	1045	799	1239	554	1545	16,202
*Std. Dev.	39	84	145	171	100	43	75	68	56	14	67	302
*Co.V.	2%	6%	6%	5%	8%	8%	7%	8%	5%	2%	4%	1.9%

* excluding 27/4

Table 4

Input Counts - 15:30 to 18:00

(A) POLICE

DATE	1	2	3	4	5	6	7	8	9	10	11	Total
20/4	3147	2076	4197	5248	1810	1062	1728	1383	1931	1444	2431	26,457
21/4	3127	2122	4500	5765	2032	1026	1613	1421	2013	998	2656	27,273
22/4	3221	2075	4534	5921	1859	986	1625	1430	1952	969	2647	27,219
23/4	3299	2185	4448	5889	1871	929	1705	1489	2101	889	2670	27,475
24/4	3155	2204	3931	6003	1761	1000	1795	1541	2126	984	2279	26,779
Mean	3190	2132	4322	5765	1867	1001	1693	1453	2025	1057	2537	27,041
Std. Dev.	71	60	255	302	102	49	75	62	87	221	174	413
Co.V.	2%	3%	6%	5%	5%	5%	4%	4%	4%	21%	7%	1.5%

(B) AUTOMATIC

DATE	1	2	3	4	5	6	7	8	9	10	11	Total
27/4	2818	1828	3254	4255	1820	835	1485	1229	1825	893	2296	22,538
28/4	3169	2278	3564	5852	1763	992	1639	1357	1996	984	2428	26,022
29/4	3234	2386	3904	5631	1967	960	1572	1340	2136	947	2715	26,792
30/4	3256	2350	4176	6198	1935	966	1818	1361	1925	906	2665	27,556
6/5	3325	2124	4308	5695	1730	844	1722	1169	2034	939	2645	26,535
7/5	3237	2233	3869	5895	2065	920	1695	1240	2054	996	2595	26,889
*Mean	3244	2274	3964	5872	1892	936	1689	1293	2029	954	2610	26,759
*Std. Dev.	56	103	290	229	142	58	92	85	77	36	110	558
*Co.V.	2%	5%	7%	4%	7%	6%	5%	7%	4%	4%	4%	2.1%

* excluding 27/4

Table 5

Output Counts - 15:30 to 16:30

(A) POLICE

DATE	A	B	C	D	E	F	G	H	I	J	K	Total
20/4	1377	1020	1565	1609	574	1225	264	540	1438	560	465	10,637
21/4	1381	1169	1485	1636	629	1230	310	598	1529	565	379	10,911
22/4	1323	1089	1540	1615	664	1223	287	484	1642	574	364	10,805
23/4	1318	1075	1561	1674	617	1062	311	577	1261	587	349	10,392
24/4	1269	1110	1527	1581	612	1254	297	634	792	604	534	10,214
Mean	1334	1093	1536	1623	619	1199	294	567	1332	578	418	10,592
Std. Dev.	46	54	32	35	32	77	19	57	332	18	79	288
Co.V.	3%	5%	2%	2%	5%	6%	7%	10%	25%	3%	19%	2.7%

(B) AUTOMATIC

DATE	A	B	C	D	E	F	G	H	I	J	K	Total
27/4	1257	1082	1112	1399	575	1038	214	468	1074	424	249	8,892
28/4	1123	1149	1432	1850	630	1198	253	597	1260	537	382	10,411
29/4	1392	1193	1640	1488	558	1242	282	661	1131	640	415	10,642
30/4	1364	1170	1649	1921	766	1289	265	659	1113	610	406	11,212
6/5	1384	1201	1471	1737	552	1158	252	691	1125	627	427	10,625
7/5	1364	1284	1506	1810	728	1195	274	610	870	667	447	10,755
*Mean	1325	1199	1540	1761	647	1216	265	644	1100	616	415	10,729
*Std. Dev.	114	51	99	167	97	50	13	39	142	49	24	297
*Co.V.	9%	4%	6%	9%	15%	4%	5%	6%	13%	8%	6%	2.8%

* excluding 27/4

Table 6

Output Counts - 16:30 to 18:00

(A) POLICE

DATE	A	B	C	D	E	F	G	H	I	J	K	Total
20/4	2059	1713	2192	2800	1123	1766	445	843	2460	784	577	16,762
21/4	2092	1642	2440	2911	1168	1665	444	964	2527	821	628	17,302
22/4	2076	1670	2464	2746	998	1697	428	970	2466	868	597	16,980
23/4	2158	1745	2338	3224	1033	1751	471	983	2404	858	604	17,569
24/4	2006	1693	2443	2681	1219	1807	462	1033	2075	806	714	16,939
Mean	2078	1693	2375	2872	1108	1737	450	959	2386	827	624	17,110
Std. Dev.	55	39	114	214	92	56	17	70	179	35	54	322
Co.V.	3%	2%	5%	7%	8%	3%	4%	7%	8%	4%	9%	1.9%

(B) AUTOMATIC

DATE	A	B	C	D	E	F	G	H	I	J	K	Total
27/4	1848	1722	1937	2587	934	1444	350	888	2245	787	682	15,424
28/4	2092	1840	2279	2939	1135	1773	504	990	2264	927	699	17,442
29/4	2195	1979	2390	3001	1012	1768	436	981	1742	906	679	17,089
30/4	2143	1900	2285	3239	1417	1819	407	1089	1716	844	713	17,572
6/5	2057	1741	2543	2928	1100	1683	401	971	1864	792	678	16,758
7/5	1876	1859	2227	3397	1195	1702	394	926	1584	816	619	16,595
*Mean	2073	1864	2345	3101	1172	1749	428	991	1834	857	678	17,091
*Std. Dev.	122	87	126	208	152	56	45	60	260	58	36	422
*Co.V.	6%	5%	5%	7%	13%	3%	11%	6%	14%	7%	5%	2.5%

* excluding 27/4

Table 7

Output Counts - 15:30 to 18:00

(A) POLICE

DATE	A	B	C	D	E	F	G	H	I	J	K	Total
20/4	3436	2733	3757	4409	1697	2991	709	1383	3898	1344	1042	27,399
21/4	3473	2811	3925	4547	1797	2895	754	1562	4056	1386	1007	28,213
22/4	3399	2759	4004	4361	1662	2920	715	1454	4108	1442	961	27,785
23/4	3476	2820	3899	4898	1650	2813	782	1560	3665	1445	953	27,961
24/4	3275	2803	3970	4262	1831	3061	759	1667	2867	1410	1248	27,153
Mean	3412	2785	3911	4495	1727	2936	744	1525	3719	1405	1042	27,702
Std. Dev.	83	37	95	247	82	94	31	110	506	42	121	427
Co.V.	2%	1%	2%	6%	5%	3%	4%	7%	14%	3%	12%	1.5%

(B) AUTOMATIC

DATE	A	B	C	D	E	F	G	H	I	J	K	Total
27/4	3105	2804	3049	3986	1509	2482	564	1356	3319	1211	931	24,316
28/4	3215	2989	3711	4789	1765	2971	757	1587	3524	1464	1081	27,853
29/4	3587	3172	4030	4489	1570	3010	718	1642	2873	1546	1094	27,731
30/4	3507	3070	3934	5160	2183	3108	672	1748	2829	1454	1119	28,784
6/5	3441	2942	4014	4665	1652	2841	653	1662	2989	1419	1105	27,383
7/5	3240	3143	3733	5207	1923	2897	668	1536	2454	1483	1066	27,350
*Mean	3398	3063	3884	4862	1819	2965	694	1635	2934	1473	1093	27,820
*Std. Dev.	164	98	153	313	243	103	43	80	386	47	21	581
*Co.V.	5%	3%	4%	6%	13%	3%	6%	5%	13%	3%	2%	2.1%

* excluding 27/4

congestion, whereas the data collected during police controlled days commenced after a continuous period of co-ordinated (police) control.

Another explanation for the above pattern of average input and output flows might be that there was a greater generation of trips from within the studied network during automatic control.

There was generally more variation in both average input and output flows during automatic compared with police control. One would have perhaps expected the opposite situation but this can be explained by the fact that the weather conditions were considerably more variable during the 'automatic' days and (as shown in WP 250) there were more incidents.

A brief examination of average flows for individual stations shows that the average input flows were noticeably greater under automatic control at stations 1, 2 and 4 but lower at stations 3, 8 and 11. The average output flows were noticeably greater under automatic control at stations B and D but lower than the police control at station I. Looking specifically at junction 5 (J002), it appears that the average output to stations C, E and F were very similar under both methods of control, but at station D the output under automatic control was greater. This increase during automatic control is obviously an important finding.

The largest variation in both input and output flows occurred on Worachark Road at stations 10 and I, during both types of control. The variability in output flows at station I can be explained by the frequent occurrence of congestion immediately south of the survey area. The higher level of variability of input flows at station 10 only occurred during police control and this may represent some route changing between stations 9, 10 and 11.

7. Queues

If a queue of stationary vehicles occurred at an input count station, then each occurrence and its duration was recorded. Table 8 demonstrates that the average duration of a stationary queue at an input count station was approximately equal under police and automatic control, but there were 17% fewer of these occasions under automatic control. This effect is due to the use, under automatic control, of cycle times which were substantially shorter yet still achieved the same capacity.

It should be noted that journey times under police control could have been under-represented in the number plate matching analysis. The time when a vehicle entered the network was recorded at each input station, and thus a vehicle waiting to enter the network could have incurred substantial delay before its origin time was recorded. Wherever possible, the location of each count station was beyond the longest queue but in some instances this was not possible because of the relatively long queues and short links. This is, of course, understandable if one remembers that we are dealing with an area where the blocking of junctions inside (and outside) the study area is a major problem.

Table 8

Stationary Queues at Input Count Stations
Duration in seconds

	15.30–16.30 No.	15.30–16.30 Duration	16.30–18.00 No.	16.30–18.00 Duration	15.30–18.00 No.	15.30–18.00 Duration	
POLICE							
20/4	76	3229	133	5546	209	8875	
21/4	70	3344	97	3662	167	7006	
22/4	67	2712	110	4956	177	7668	
23/4	93	4353	129	6846	222	11199	
24/4	101	5140	119	7072	220	12212	
Mean	81	3756	118	5616	199	9372	Average queue dur. = 47.1 sec
Std.Dev	15	976	15	1405	25	2251	
Co.V.	18%	26%	12%	25%	13%	24%	
AUTOMATIC							
27/4	14	661	38	1436	52	2097	
28/4	49	2510	99	4271	148	6781	
29/4	66	2942	130	4615	196	7557	
30/4	45	1782	91	3367	136	5149	
6/5	61	3429	109	6347	170	9776	
7/5	70	3602	105	6378	175	9980	
*Mean	58	2853	107	4996	165	7849	Average queue dur. = 47.6 sec
*Std. Dev	11	736	15	1328	24	2047	
*Co.V.	19%	26%	14%	26%	14%	26%	

* excluding 27/4.

The count stations most frequently blocked by a stationary queue (5, 7 and 9) were the same under both methods of control, but stations 4 and 8 were more frequently blocked during police control.

This analysis provides evidence that there was less likelihood of junctions outside the study network being blocked by a queue emanating from one of the junctions being controlled by the experimental timings. The benefit to vehicles outside the area was not monitored but it is reasonable to presume that there were some improvements.

One particularly important queue was that on Rama I Road to the east of junction 5 (J002). The Traffic Police Commander argued that a shorter cycle time would result in longer queues on Rama I Road which would in turn block the large junctions to the east of the study area. With the longer cycle time (e.g. 6 minutes) at junction 5 (J002) the police were able to encourage drivers to use the opposite carriageway on the eastern approach to junction 5 (J002). At the start of each green for this movement the length of the queue (stationary) on Rama I Road was measured. There were fewer green periods under police control because of the long cycle times and Table 9 demonstrates how automatic control produced shorter average queues. A substantial reduction in delay to vehicles which used roads crossing Rama I Road could have been expected, but again these roads were outside the study area and not measured.

In summary, it is evident that the shorter and regular cycle times under automatic control reduced the average length of queues of vehicles entering the study area and the flow of traffic outside this area should have received some benefit.

Table 9

Queues on Rama I Road to East of Junction 5 (J002) at Start of Each Green
Average Length in Metres

	15.30 16.30 Average Length	Total No.	16.30 18.00 Average Length	Total No.	15.30 18.00 Average Length	Total No.
POLICE						
20/4	n/a		n/a		n/a	
21/4	333	11	574	15	472	26
22/4	303	13	496	14	403	27
23/4	344	12	536	14	447	26
24/4	406	10	371	19	383	29
Mean	346		494		426	
Std.Dev.	43		88		41	
Co.V.	12%		18%		10%	
AUTOMATIC						
27/4	n/a		n/a		n/a	
28/4	n/a		n/a		n/a	
29/4	274	20	301	30	290	50
30/4	287	20	258	30	270	50
6/5	220	20	394	30	324	50
7/5	241	20	333	30	296	50
Mean	255		322		295	
Std.Dev.	30		57		22	
Co.V.	12%		18%		8%	

8. Journey Times

The main method, as described in the previous section, for collecting data on the journey times of vehicles was the number plate matching technique. To supplement this journey time data and as a means of checking the accuracy of the results from this technique it was decided to (a) record the times of selected vehicles from an elevated position and (b) record the times of journeys from inside a moving vehicle. Due to the small sample sizes however this secondary data may be unreliable and should only be treated as a check on the more detailed information obtained from number plate matching.

(a) Elevated Observer Method:

This survey was conducted on one of the few tall buildings in the study area, and selected vehicles were timed on journeys between junctions 2 (J044), 3 (J160), 4 (J161) and 5 (J002) travelling along Bamrungmuang Road. The survey method has already been explained. Table 10 summarises the data and it is clear that the average journey times were increased under automatic control. In

Table 10

Average Journey Times of Vehicles on Bamrungmuang Road from elevated position

	JUNCTION 2 (J044) TO 3 (J160)						JUNCTION 3 (J160) TO 4 (J161)						JUNCTION 4 (J161) TO 5 (J002)					
	15.30-16.30		16.30-18.00		15.30-18.00		15.30-16.30		16.30-18.00		15.30-18.00		15.30-16.30		16.30-18.00		15.30-18.00	
	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)	No.	Mean J.T. (secs)
POLICE																		
20/4	7	51	9	71	16	62							6	96	9	83	15	88
21/4	5	80	11	97	16	92	39	87	61	83	100	85	5	89	14	90	19	89
22/4	7	65	9	78	16	73	39	83	68	70	107	75	7	72	9	101	16	83
23/4	8	46	10	121	18	88	33	125	39	154	72	137	5	108	10	122	15	117
24/4	7	93	10	65	17	77	18	165	38	112	56	129	7	116	10	77	17	93
MEAN		66		87		79		106		98		100		96		94		94
Std.Dev		18		21		11		29		31		26		16		16		12
Co.V.		28%		24%		14%		27%		32%		26%		17%		17%		12%
AUTOMATIC																		
27/4	6	83	9	275	15	198							7	169	10	141	17	152
28/4	6	86	10	131	16	114	16	165	24	137	40	148	6	154	10	121	16	133
29/4	6	50	10	114	16	90	23	128	25	147	48	138	6	154	10	132	16	141
30/4	6	97	10	100	16	99	21	145	24	165	45	156	7	138	10	100	17	116
6/5	6	66	10	90	16	81	19	153	21	177	40	166	6	138	10	112	16	122
7/5	3	97	10	112	13	108	13	225	23	187	34	201	6	138	10	149	16	145
*MEAN		77		109		98		157		162		160		144		122		131
*Std.Dev.		19		15		12		30		19		21		8		19		11
*Co.V.		24%		14%		12%		19%		11%		13%		1%		15%		8%

* excluding 27/4

the period 15.30 to 18.00 the increase was 24% between J044 and J160 and nearly 40% between J161 and J002. The data for the link between J160 and J161 revealed a surprising 60% increase under automatic control. One encouraging aspect of the data in Table 10 is that there was less variability in journey times during automatic control, as shown by the co-efficients of variation.

(b) Moving Vehicle Method:

The drivers of two cars each with enumerator were assigned a route through the survey area. In each case the route comprised one or two loops as indicated in Figure 2. Table 11 shows a summary of the number of circuits completed each day and the journey times.

The total figures for all days show that journey times for car B were generally worse during days with automatic control. It is significant that on 24/4 during police control the average journey time was higher than on any other day. This was caused by one of the few major incidents which occurred during police control. For 15 minutes a fire-engine blocked 1.5 lanes of the carriageway on Luang Road at the approach to junction 9 (J080). Major incidents were more frequent during the week of automatic control particularly 29th April and 7th May, which is reflected in the higher journey times recorded for car B.

The 24/4 was clearly atypical as shown by the higher average journey time for car A (loops 1 and 2). Car A, loop 1, showed a marked improvement after 29/4 when there were known to be fewer incidents and better adjusted automatic signal timings in the area of Pluplachai Road and Bamrungmuang Road.

The average journey times for car A (loop 2) were slightly less during automatic control days. This is because the arrangement of signal timings and offsets along Bamrungmuang Road facilitated the movement of vehicles from junction 3 (J160) to the free right turn at junction 5 (J002).

In summary, although the journey times of these two vehicles were generally longer during automatic control, there is evidence that the occurrence of major incidents resulted in considerable delay under either method of signal control. This finding suggests that the influence of incidents may distort journey times in this highly saturated area to such an extent that it is difficult to make meaningful comparisons between the performance of police and automatic control. This argument is supported by the fact that journey times (see Table 11) were noticeably increased by incidents during police control (i.e. 24/4) and not just during days when automatic control was in operation. It should be noted that the input flows were not higher on the 24/4, and therefore higher flows cannot be an explanation for the extreme increase in average journey times of car B.

(c) Number Plate Matching:

The journey times of vehicles were derived by matching vehicle registrations using a program supplied by TRRL and used on a PRIME computer. The median journey times (after truncation of extreme values caused by spurious matches) for the twenty-one

<u>Table 11</u>

<u>Journey Times of Moving Observers</u>

<u>POLICE CONTROL</u>	MON 20 Apr	TUE 21 Apr	WED 22 Apr	THU 23 Apr	FRI 24 Apr	AVERAGE
CAR A	427	644	617	403	453	
LOOP 1	476	673	568	569	799	
(1,2,3,4,5,	724	521	516	849	1163	
6,7)	928	804	601	571	792	
	766	761	646	1204		
AVERAGE	664	681	590	719	802	691
	640	890	749	1264	845	
CAR A	690	649	726	718	1144	
LOOP 2	729	930	790	654	1230	
(1,2,3,4,9,	915	887	709	843	1256	
10,11,12,13,	884		672			
8)						
AVERAGE	772	839	729	870	1119	866
		1483	1117	1476	2641	
CAR B		1615	1117	1649	2857	
(2,3,4,5,6,		1658	1151	1689	1704	
8,9,11,12,13,		1782	1392	1717		
14,15)		992	1686	1392		
			1580			
AVERAGE	-	1506	1341	1585	2401	1708

<u>AUTOMATIC CONTROL</u>	MON 27 Apr	TUE 28 Apr	WED 29 Apr	THU 30 Apr	WED 6 May	THU 7 May	AVERAGE
	639	929	662	709	603	664	
CAR A	685	823	759	635	608	569	
LOOP 1	967	794	879	624	448	373	
	893	1716	1497	698	480	659	
	905			885	554	617	
AVERAGE	818	1066	949	710	539	576	776
	690	708	595	751	720	890	
CAR A	685	928	1147	858	697	820	
LOOP 2	1156	1215	746	1158	896	742	
	648			911	957		
AVERAGE	795	950	829	920	818	817	855
	1248	2128	1362	1531	1261	1997	
CAR B	1215	2312	2569	1496	1411	1944	
	1475	1909	1932	2195	1376	2326	
	2046			1832	1584		
	1280				1548		
AVERAGE	1453	2116	1954	1764	1436	2089	1802

most important origin and destination pairs are shown in Tables 12, 13 and 14. Figure 1 illustrates the locations of each counting station.

The median journey times for all O-D pairs on each day throughout the entire survey period (3.30 pm - 6.00 pm) are shown in Table 11. The results support the findings from the analysis of elevated observer and moving observer surveys that the journey times were generally increased during automatic control. Further, the data for 24/4 again demonstrate that the performance of police control deteriorated considerably with the occurrence of major incidents. Similarly, the total journey time under automatic control continued to decrease after the first day and this downward trend (which resulted from the improved signal timings and fewer incidents) continued until the sudden increase on 7/5, when incidents again presented major problems.

The average journey times for each O-D pair for all police days and all automatic days are shown in Table 12. The average has not been weighted by the number of matches (see next section), but it provides an indication of the relative difference in the journey times for each O-D pair during the two methods of control. The general pattern is that the average journey times under automatic control were higher than police control for O-D pairs on Bamrungmuang Road, but lower for pairs associated with Rama I and Luang Road.

The data for 'police' days again shows the poor performance on the 24/4 at O-D pairs associated with junction 9 (J080), namely 3I, XI, 4X and 5X. The data for 'automatic' days demonstrate how the journey times for O-D pairs 8D and 9D associated with Plupplachai Road (i.e. junction 4 (J161) began very poorly but improved each day. The journey times for Bamrungmuang Road, 1W and WD, were a little higher under automatic control but the total average was increased by the incidents and longer times on 7/5/87. The journey time from 4 to C was generally lower when junction 5 (J002) operated automatically and we should also not forget the probability that the total delay during police control was under-recorded because of longer queues.

A comparison of the average total journey times shows that automatic control was 3% higher during the first hour of the survey but this figure increased to nearly 16% for the remainder of the survey. This increase was not caused by an increase in the total number of O-D pairs which had longer average journey times under automatic control. In fact the journey times of two O-D pairs became less under automatic control during the second part of the survey (4C and 2J) while two pairs became worse (5X and 9X). The main cause of the overall increase between 4.30 and 6.00 pm was the relative increase in the difference for specific pairs, namely 8D, 9D, WD on Bamrungmuang Road and XA to the north-west of the survey area. The increase for these O-D pairs can be explained by the exceptionally high median journey times recorded for 8D and 9D on the 28/4 and 29/4. It is interesting to note also that the figures for WD during police control show a decrease in journey time after 4.30 pm (while automatic control figures show an increase), yet the figures for 4C demonstrate the complete opposite. This reveals that after 4.30 pm the police who controlled the critical junction 5 (J002) provided relatively

Table 12

Median Journey Times in seconds
(15.30 - 18.00)

O-D PAIR	POLICE CONTROL DAYS 21/4	22/4	23/4	24/4	AV.	AUTOMATIC CONTROL DAYS 28/4	29/4	30/4	6/5	7/5	AV.	DIFFERENCE (A-P)
WD	255	277	218	245	249	311	305	294	314	364	313	64
WF	235	243	237	257	243	216	248	244	253	260	244	1
WE	211	238	207	213	217	221	242	253	248	273	248	31
8D	499	414	388	373	419	873	629	466	393	432	559	140
9D	403	475	502	472	463	750	749	646	602	584	666	203
9W	178	185	240	203	202	250	355	296	279	283	293	91
1W	248	224	250	247	242	290	263	283	279	321	287	45
2W	182	181	207	213	196	240	241	225	223	358	257	61
3W	132	118	128	126	126	194	184	134	143	251	181	55
3I	256	255	317	550	345	246	452	281	238	259	295	-50
4C	189	153	186	143	168	131	146	145	159	157	148	-20
4X	294	285	327	470	344	416	282	313	244	250	301	-43
5X	176	203	263	455	274	312	317	229	153	144	245	-29
7X	120	120	176	215	158	187	168	142	103	118	144	-14
9X	65	73	84	86	77	78	83	77	84	62	77	0
11A	135	144	137	128	136	192	155	155	202	322	205	69
XA	263	257	293	376	297	348	280	305	362	472	353	56
XI	172	152	185	314	206	226	150	161	169	190	179	-27
XK	223	199	243	298	241	273	185	213	219	228	224	-17
XB	244	229	249	273	249	313	207	290	220	240	254	5
2J	127	122	133	134	129	139	133	138	98	119	125	-4

Table 13

Median Journey Times in seconds
(15.30 - 16.30)

O-D PAIR	POLICE CONTROL DAYS 21/4	22/4	23/4	24/4	AV.	AUTOMATIC CONTROL DAYS 28/4	29/4	30/4	6/5	7/5	AV.	DIFFERENCE (A-P)
WD	274	301	187	324	272	300	254	288	296	343	296	24
WF	245	248	197	287	244	241	260	245	266	299	262	18
WE	248	363	162	231	251	282	244	268	277	246	263	12
8D	451	428	344	335	390	584	579	519	436	349	493	103
9D	426	501	451	478	464	711	606	685	559	439	600	136
9W	189	184	208	245	207	196	232	226	188	365	241	34
1W	242	232	199	267	235	225	195	263	268	324	255	20
2W	185	187	140	249	190	193	184	185	213	391	234	44
3W	171	119	95	139	131	105	145	145	121	257	155	24
3I	188	236	326	819	392	167	333	352	243	257	270	-122
4C	163	103	104	166	134	133	147	147	138	160	145	11
4X	281	271	303	393	312	270	267	283	230	243	259	-53
5X	176	235	225	449	271	148	179	158	136	138	152	-119
7X	115	174	186	204	170	179	121	86	98	125	122	-48
9X	72	64	89	119	86	74	89	66	76	50	71	-15
11A	135	141	132	141	137	251	211	145	156	287	210	73
XA	278	232	298	382	298	321	264	270	273	403	306	8
XI	136	116	129	296	169	199	120	125	172	199	163	-6
XK	197	172	266	198	208	282	174	181	198	217	210	2
XB	244	192	262	229	232	241	204	242	213	266	233	1
2J	90	99	130	129	112	142	127	146	93	119	125	13

Table 14

Median Journey Times
(16.30 - 18.00)

	POLICE CONTROL DAYS					AUTOMATIC CONTROL DAYS						DIFFERENCE
O-D PAIR	21/4	22/4	23/4	24/4	AV.	28/4	29/4	30/4	6/5	7/5	AV.	(A-P)
WD	247	269	258	207	245	325	311	297	322	374	326	81
WF	224	231	253	210	230	209	237	244	244	255	238	8
WE	201	231	297	205	234	216	239	251	261	248	243	9
8D	508	414	443	379	436	973	714	466	354	462	594	158
9D	402	464	541	467	469	750	822	583	630	616	680	211
9W	172	188	247	201	202	278	449	316	350	242	327	125
1W	268	220	338	242	267	308	319	297	291	320	304	37
2W	178	151	274	206	202	856	309	252	235	340	298	96
3W	122	107	159	126	129	220	227	133	146	244	194	65
3I	259	349	316	346	318	278	523	215	232	260	302	-16
4C	207	204	219	136	192	130	146	145	164	156	148	-44
4X	315	299	358	570	386	480	306	332	279	261	332	-54
5X	175	201	285	455	279	419	486	278	158	148	298	19
7X	121	118	169	218	157	207	183	154	104	110	152	-5
9X	61	76	83	79	75	86	83	98	109	66	88	13
11A	126	146	154	126	138	157	131	166	258	354	213	75
XA	248	263	291	371	293	351	288	324	387	503	370	77
XI	209	194	207	314	231	230	155	183	169	188	185	-46
XK	226	236	235	318	254	272	187	282	246	240	245	-9
XB	242	242	242	282	252	315	207	299	224	239	257	5
2J	131	140	140	134	136	136	137	132	105	118	126	-10

shorter journey times to vehicles which used Bamrungmuang Road, (for example 1W, 2W, 3W and 8D, 9D) at the expense of increased journey times to vehicles which entered the survey area (and junction 5 (J002)) along Rama I Road. The disbenefits of this police strategy were however underestimated as the queue approaching this junction from the east extended well beyond the data collection point.

A comment should be made about O-D pairs XA and 11A. Junction 1 (J070) was almost always under police control during the days of automatic control because severe congestion on Lan Luang Road to the north of the study area frequently caused a queue which blocked through junction 1 (J044) and back along Mahachai Road to junction 10 (J112). The cause of this congestion and increased journey times was beyond the control of the experiment, but it should be remembered that the journey times and queues on Rama I were less during police control and it is intriguing to suggest that an improved circulation of traffic to the north and est of the study area may have influenced the increased congestion at junctions north of junction 2 (J044).

One would have expected less variability in journey times between vehicles and between days under automatic control. A brief examination of Tables 12, 13 and 14 does not reveal this trend but the influence of incidents will have tended to disguise any underlying distributions of journey times. For example, the figures for 3I in Table 13 (police 24/4) and Table 14 (automatic 29/4) illustrate how certain days were clearly atypical and, in this case, the result of conditions outside of the survey area.

Table 12

Median Journey Times in seconds
(15.30 - 18.00)

O-D PAIR	POLICE CONTROL DAYS 21/4	22/4	23/4	24/4	AV.	AUTOMATIC CONTROL DAYS 28/4	29/4	30/4	6/5	7/5	AV.	DIFFERENCE (A-P)
WD	255	277	218	245	249	311	305	294	314	364	313	64
WF	235	243	237	257	243	216	248	244	253	260	244	1
WE	211	238	207	213	217	221	242	253	248	273	248	31
8D	499	414	388	373	419	873	629	466	393	432	559	140
9D	403	475	502	472	463	750	749	646	602	584	666	203
9W	178	185	240	203	202	250	355	296	279	283	293	91
1W	248	224	250	247	242	290	263	283	279	321	287	45
2W	182	181	207	213	196	240	241	225	223	358	257	61
3W	132	118	128	126	126	194	184	134	143	251	181	55
3I	256	255	317	550	345	246	452	281	238	259	295	-50
4C	189	153	186	143	168	131	146	145	159	157	148	-20
4X	294	285	327	470	344	416	282	313	244	250	301	-43
5X	176	203	263	455	274	312	317	229	153	144	245	-29
7X	120	120	176	215	158	187	168	142	103	118	144	-14
9X	65	73	84	86	77	78	83	77	84	62	77	0
11A	135	144	137	128	136	192	155	155	202	322	205	69
XA	263	257	293	376	297	348	280	305	362	472	353	56
XI	172	152	185	314	206	226	150	161	169	190	179	-27
XK	223	199	243	298	241	273	185	213	219	228	224	-17
XB	244	229	249	273	249	313	207	290	220	240	254	5
2J	127	122	133	134	129	139	133	138	98	119	125	-4

Table 13

Median Journey Times in seconds
(15.30 - 16.30)

O-D PAIR	POLICE CONTROL DAYS 21/4	22/4	23/4	24/4	AV.	AUTOMATIC CONTROL DAYS 28/4	29/4	30/4	6/5	7/5	AV.	DIFFERENCE (A-P)
WD	274	301	187	324	272	300	254	288	296	343	296	24
WF	245	248	197	287	244	241	260	245	266	299	262	18
WE	248	363	162	231	251	282	244	268	277	246	263	12
8D	451	428	344	335	390	584	579	519	436	349	493	103
9D	426	501	451	478	464	711	606	685	559	439	600	136
9W	189	184	208	245	207	196	232	226	188	365	241	34
1W	242	232	199	267	235	225	195	263	268	324	255	20
2W	185	187	140	249	190	193	184	185	213	391	234	44
3W	171	119	95	139	131	105	145	145	121	257	155	24
3I	188	236	326	819	392	167	333	352	243	257	270	-122
4C	163	103	104	166	134	133	147	147	138	160	145	11
4X	281	271	303	393	312	270	267	283	230	243	259	-53
5X	176	235	225	449	271	148	179	158	136	138	152	-119
7X	115	174	186	204	170	179	121	86	98	125	122	-48
9X	72	64	89	119	86	74	89	66	76	50	71	-15
11A	135	141	132	141	137	251	211	145	156	287	210	73
XA	278	232	298	382	298	321	264	270	273	403	306	8
XI	136	116	129	296	169	199	120	125	172	199	163	-6
XK	197	172	266	198	208	282	174	181	198	217	210	2
XB	244	192	262	229	232	241	204	242	213	266	233	1
2J	90	99	130	129	112	142	127	146	93	119	125	13

Table 14

Median Journey Times
(16.30 - 18.00)

O-D PAIR	POLICE CONTROL DAYS 21/4	22/4	23/4	24/4	AV.	AUTOMATIC CONTROL DAYS 28/4	29/4	30/4	6/5	7/5	AV.	DIFFERENCE (A-P)
WD	247	269	258	207	245	325	311	297	322	374	326	81
WF	224	231	253	210	230	209	237	244	244	255	238	8
WE	201	231	297	205	234	216	239	251	261	248	243	9
8D	508	414	443	379	436	973	714	466	354	462	594	158
9D	402	464	541	467	469	750	822	583	630	616	680	211
9W	172	188	247	201	202	278	449	316	350	242	327	125
1W	268	220	338	242	267	308	319	297	291	320	304	37
2W	178	151	274	206	202	856	309	252	235	340	298	96
3W	122	107	159	126	129	220	227	133	146	244	194	65
3I	259	349	316	346	318	278	523	215	232	260	302	-16
4C	207	204	219	136	192	130	146	145	164	156	148	-44
4X	315	299	358	570	386	480	306	332	279	261	332	-54
5X	175	201	285	455	279	419	486	278	158	148	298	19
7X	121	118	169	218	157	207	183	154	104	110	152	-5
9X	61	76	83	79	75	86	83	98	109	66	88	13
11A	126	146	154	126	138	157	131	166	258	354	213	75
XA	248	263	291	371	293	351	288	324	387	503	370	77
XI	209	194	207	314	231	230	155	183	169	188	185	-46
XK	226	236	235	318	254	272	187	282	246	240	245	-9
XB	242	242	242	282	252	315	207	299	224	239	257	5
2J	131	140	140	134	136	136	137	132	105	118	126	-10

9. System Performance

The main parameters of system performance can be measured from the flow and journey time data described above. Similar data was also collected during the small scale surveys before the main experimental period and after a prolonged period of automatic control. In this section the system performance during the main survey is discussed and then compared with the analysis of trends and performance from the small scale surveys.

(a) Main Surveys - 20th April to 7th May:

'Vehicle-Kilometers/Hour' provide a measure of the level of use (or the satisfied demand); while 'Vehicle-Hours/Hour' provide a measure of the system performance in terms of the delay, or the total time spent in the network by a certain number of vehicle trips. Table 15 summarises the total figures for the twenty-one O-D pairs over three time periods during days with police and automatic control.

During the first hour the automatic timings resulted, on average, in a 10% increase in vehicle-hours, but there was also a 7% increase in vehicle-kilometers compared with police control. This is consistent with the analysis of input and output counts which revealed that between 3.30 pm and 4.30 pm there were more vehicles inside the survey area. During the remainder of the survey period (4.30 pm - 6.00 pm) the difference in vehicle-hours/hour increased to 16% while the difference in vehicle-kilometers/hour fell to a figure which was, on average, only 3% greater for automatic compared with police control. The overall result for the entire survey is that the system of automatic control produced an average increase in vehicle-kilometers/hour of 4.5% at a cost of an increase in vehicle-hours/hour of 15%.

The input flows (see Tables 2 to 7) were not significantly different between police and automatic days. However, the main survey and in particular the automatic control, took place on days before and after national holidays (as well as being during school holidays) which meant that the demand may not have been 'typical'. It could be argued that more of the total demand was satisfied by 6.00 pm on days with automatic control. This is reflected in the reports from contented policemen who stated that they could leave the junctions earlier than normal after a day of automatic control. The police generally remained in control of junctions on Bamrungmuang Road later than 7.00 pm, yet on automatic days they considered that the peak conditions were over between 6.15 and 6.30 pm.

It must be re-emphasised that the performance of automatic control improved with each day of operation up until 7/5/87. This is reflected in the system speed for each day (3.30 pm - 6.00 pm) which increased daily by 0.5 kilometers/hour as weather conditions and signal timings improved. In fact, the system speed on 6/5/87 was very similar to the average for all police days and on this day the vehicle-kilometers/hour were 10% higher than the average police performance and over 5% higher than the best recorded police day.

The performance of both methods of control during the two smaller

Table 15

Summary Of Vehicle-Hours/Hour And Vehicle-Kilometers/Hour During The Main Survey For 21 O-D Pairs

	3.30pm - 4.30pm			4.30pm - 6.00pm			3.30pm - 6.00pm		
	VEH-HRS/HR	VEH-KMS/HR	SYSTEM SPEED KM/HR	VEH-HRS/HR	VEH-KMS/HR	SYSTEM SPEED KM/HR	VEH-HRS/HR	VEH-KMS/HR	SYSTEM SPEED KM/HR
POLICE									
21/4	377	4795	12.7	416	5097	12.3	403	4987	12.4
22/4	349	4524	13.0	420	4897	11.7	381	4758	12.5
23/4	293	3945	13.5	491	5088	10.4	397	4616	11.6
24/4	480	4455	9.3	460	4778	10.4	472	4660	9.9
AVERAGE	375	4430	11.8	447	4965	11.1	413	4755	11.5
AUTOMATIC									
28/4	403	4611	11.4	584	5383	9.2	516	5076	9.8
29/4	387	4738	12.2	510	4693	9.2	457	4714	10.3
30/4	378	4350	11.5	486	5164	10.6	444	4814	10.8
6/5	417	5150	12.4	500	5293	10.6	466	5240	11.2
7/5	485	4933	10.2	519	5044	9.7	504	4995	9.9
AVERAGE	414	4756	11.5	520	5115	9.8	477	4968	10.4

surveys will be discussed later in order to obtain an indication of how the performance of the fully automated traffic control compared with police control after a continued period of operation.

It is useful now to highlight the most critical pairs. The 24/4 (police) 29/4 and 7/4 (automatic) have been excluded because of the influence of major incidents known to have occurred on these days and because the remaining dates included in the examination provide data for one Tuesday, Wednesday and Thursday under each method of control. (However, it should be remembered that weather conditions were still very poor on 28/4/87.)

Table 16 shows the vehicle-hours, vehicle-kilometers, and system speeds for the period 3.30 - 6.00 pm. The O-D pair 1D covers the entire length of Bamrungmuang and has been obtained from a combination of data for 1W and WD. O-D pairs 1D, 9D, 8D and 4C are influenced by the performance of the junctions on Bamrungmuang Road and in particular junction 5 (J002), while O-D pairs 3I, 2J and 11A reflect the performance of the major north-south movements which cross the main west and east flows.

Under automatic control the system speed was 1.1 km/hr slower for the total flow on these 7 routes, but the flow was 452 (9%) more than on police days. The veh-hours/hr increased by 22% during automatic control. The system speed for all three police controlled days was between 1.4 km/hr and 2.0 km/hr faster than automatic control for the three O-D pairs on the western approach to J002, namely 8D, 9D and 1D; while the speed of 4C on the eastern approach improved under automatic control by 1.5 km/hour. This is despite the fact that there was not a long 'green' time for the vehicles to use the opposite side of the carriageway on Rama I Road compared with the normal police operation.

Junction 5 (J002) is clearly very critical because it is located at the intersection of two one-way systems. However the O-D matrix only covered the area on the western approaches to junction 5 (J002) and excluded the area to the east, with the exception of link 4C. If, from the preceding evidence, we assume that the decrease in system speed under automatic control within the study area is balanced by an increase in system speed outside the study area then it can be argued that the performance of automatic control was better than would initially appear because there was an overall increase in vehicle-kilometers (trips) for all O-D pairs. This argument is supported by the fact that the commander of the Traffic Police Precinct which covers Rama I Road did not complain, as was normally the case, about an extra long queue during the experimental period. With hindsight, it is evident that given sufficient funds it would have been beneficial to collect data from sites adjacent to the experimental network.

Table 16

System Performance For 7 Main O-D Pairs (3.30pm - 6.00pm)

	1D		9D		8D		4C		11A		2J		3I		TOTAL		SYSTEM SPEED
	V-H/H	V-K/H	V-H/H	V-K/H	V-H/H	V-K/H	V-H/H	V-K/H	V-H/H	V-K/H	V-H/H	V-K/H	V-H/H	V-K/H	V-H/H	V-K/H	
POLICE																	
21/4	46.0	458	33.1	319	19.0	117	26.4	221	15.6	246	8.9	117					
AUTOMATIC																	
28/4	50.0	430	49.7	327	32.0	116	20.0	234	24.9	257	11.3	128	30.3	343	218.2	1835	8.4
30/6	60.0	550	45.7	307	19.0	119	22.0	220	17.7	233	10.6	127	30.6	308	205.6	1864	9.1
6/5	67.0	610	43.8	296	15.0	116	27.0	241	25.9	261	9.8	146	23.4	278	211.9	1948	9.2
TOTAL	177.0	1590	139.2	930	66.0	351	69.0	695	68.5	751	31.7	401	84.3	929	635.7	5647	
TOT. SPEED	9.0		6.7		5.3		10.1		11.0		12.6		11.0		8.9		8.9

The O-D pair 11A provides a good example of how the performance of junctions adjacent to the survey area can influence vehicle-hours and vehicle-kilometers within the area. On 28/4 and 6/5 considerable congestion was reported at the main intersection of Lan Luang Road immediately north of junction 1 (J070). Although a major incident was not recorded, a queue blocked back into junction 1 disrupting the west-east movement, as well as completely blocking exit 'A' from the study area. Figures for 11A on the 29/4 for veh-hrs/hr and veh-km/hr were 19.5 and 265 respectively, which suggests that 11A was restricted on 28/4 and 6/5 (see Table 16). It is possible that an improvement in the flow of 4C (leading to Lan Luang) might have caused the unexpected congestion at the police controlled junction on Lan Luang Road.

The two other major movements which cross the study area are 2J and 3I. For 2J there was little difference between police and automatic control which is not surprising because during the experimental period the police insisted on taking control of Junction 1 (J070) due to the influence of problems on Lan Luang Road, described above.

O-D pair 3I represents a movement which runs along Worachark Road from the north across Bamrungmuang and Luang Road to the south and over Memorial Bridge. This is the second largest flow of traffic in the survey area and, as it is a cross-movement, its relative performance under automatic control will provide a very useful indicator of how well the queue management strategy handled the formation of queues along Bamrungmuang Road and Luang Road. (The opposite movement 10B is an extremely small undersaturated flow.) Table 16 shows that under automatic control there was a decrease in veh-hrs/hr of over 10%, with a slight increase in veh-km/hr and a significant increase in speed (1.2 km/hr on average).

Movements 11A and 2J were influenced by 'external' circumstances and 9D and 8D were not true cross-movements. Consequently, OD pair 3I provides the only movement within the survey area which could have directly benefitted from the new signal timings designed to avoid up-stream junction blocking. In this case, the strategy was successful.

(b) Small Surveys (2-6 March 1987 and 18-22 May 1987):

A small survey of the major movements along Bamrungmuang Road was conducted during police control (2-6 March) before the main survey and before the school holidays. The same survey was repeated after a prolonged period of automatic control (18-22 May) and after the school-holiday period. Two points should be made at this stage: (i) The police were not aware of the small scale survey and (ii) the performance during the main week of experimental automatic control showed a continued improvement until 7/5/87.

Table 17 shows the analysis of the two small-scale surveys in context with each other and the relevant O-D links from the main experimental period.

Table 17

Bamrungmuang/Plupplachai/Rama I

Average Day

	VEH-HR/HR	VEH-KM/HR	SYSTEM SPEED KM/HR	
O-D PAIR 1D	110	880	8.0	*POLICE (MARCH)
	83	899	10.8	POLICE (APRIL)
BAMRUNGMUANG RD	116	986	8.5	AUTO (APRIL)
	101	973	9.6	*AUTO (MAY)
O-D PAIR 8D	42	225	5.4	*POLICE (MARCH)
	27	211	7.7	POLICE (APRIL)
PLUPPLACHAI RD	45	250	5.6	AUTO (APRIL)
	49	261	5.4	*AUTO (MAY)
O-D PAIR 4C	24.7	214.1	8.7	POLICE (APRIL)
RAMA I ROAD	23.6	231.1	9.8	AUTO (APRIL)

* small scale survey

Table 17 shows how the police performed especially well during the main survey The performance of automatic control improved during May, as might be expected, particularly on Bamrungmuang Road. The signal timings remained the same from 30/4, 6/5 and 7/5 throughout May. This improvement in performance can be attributed to improved weather, fewer incidents and perhaps because drivers became more accustomed to the automatic timings.

The performance of police control during March (2-6) was comparable with the automatic control performance during the main survey in April/May. Further, the improved performance of automatic control during May demonstrates that automatic signal timings can perform better than police control.

The vehicle-kilometers on all links were higher under automatic control. This is consistent with earlier findings which repeatedly demonstrate that there were more trips associated with co-ordinated automatic control.

The vehicle-hours/hour from police control during the small scale survey were similar to those for all periods of automatic control, but veh-hrs/hr were exceptionally low on Bamrungmuang Road and Plupplachai Road during the main surveys. It is also noted that the data in Table 17 includes all days, including those when major incidents were known to have occurred (e.g. 29/4). Fewer incidents occurred during police (main survey) control.

Data was not collected on Rama I Road during the small-scale surveys. However, it can be seen that the performance was better under automatic control during the main survey compared with the police operation. Excessive queues on Rama I were not reported during the smaller scale surveys (in fact the opposite was reported by the Police Commander who actually recommended still further time be given to Bamrungmuang Road.) It is reasonable to argue therefore that the improvement on Bamrungmuang Road did not cause a deterioration on Rama I.

The Traffic Police Commander was satisfied with the performance of the automatic timings, especially after the clear improvement following the first few days of operation. The Traffic Engineers from the Ministry of Interior were also impressed with the automatic control, again, especially during May when the schools re-opened. The plan for automatic control required the 'STATE' command to be used in the 'Highwayman' and this meant that the continued operation of these timings with extra-long green times at junctions 4 (J161) and 3 (J160) relied upon Engineers activating and de-activating the STATE command each day. At the end of the project the engineers at the Ministry of Interior were still searching for ways to incorporate the implementation of these signal timings within the normal procedure of automatic plan changes by the Highwayman at the ATC Centre.

10. Conclusions

Several conclusions, and important lessons can be learnt from the preceding analysis.

Firstly, the queue management strategy successfully improved the main cross-movement (3I) and it was also successful in controlling the complex situation on Bamrungmuang Road at junctions 4 (J161) and 3 (J160) where it was essential to be able to predict the arrival of stopping and starting waves in order to avoid the complete blocking of some stages at upstream junctions. In other words, although links 9D and 8D were not strictly cross-movements the queue management strategy was suitable even for this type of network.

Automatic control can perform better than manual police control but it is very clear that, unlike the previous study on Rama IV Road where each junction was the responsibility of a different police precinct, the police in this study area offer good co-ordination of traffic within their own precinct. However this may be to the deteriment of adjacent precincts as indicated in the analysis of Rama I Road.

In TN 224 the calculations of offsets to avoid upstream junction blocking was first discussed in the context of a case study of a short link on Rama IV Road. It was argued that the increase in delay caused by offsets which fail to prevent upstream junction blocking during saturated conditions will be greater, on average, than any increased delay to vehicles caused by offsets which do not facilitate progression during periods of undersaturation. This assumption seems, intuititively, to be correct but it is not proven. Perhaps, given the nature of the study area, insufficient data was available on cross-movement traffic within and immediately outside of the study network, which would have benefitted most from the queue-management strategy.

Incidents remain a major obstacle to the success of automatic signal timings in highly saturated conditions. Although the police listened to advice on how best to deal with incidents without returning to manual control, it was clear that the easier option open to each policeman was simply to revert to manual control of junctions. Considering the difficulty of dealing with traffic in such harsh conditions this choice is hardly surprising.

It is unclear exactly how the movement of vehicles in an area of police control will be influenced by the behaviour of traffic in adjacent areas under automatic control, and vice-versa. But, this highlights the necessity to collect data from a wider area when implementing experimental automatic control in a limited section of the city.

Other improvements in the data collection procedure would be to wait until about 5 days of operation before commencing a survey of a newly implemented system of signal control. It would also be wise to continue data collection until after the main peak period in order to establish the rate at which the peak demand has been satisfied. Finally, fewer anomalies in the data would occur if the surveys were scheduled during 'typical' flow conditions avoiding any periods known to have several public and private holidays.

To summarize, it has been demonstrated that the new queue management strategy successfully coped with highly saturated conditions in a two dimensional network. However, the performance of automatic control has been compared, not with ad-hoc police control, but with a well-co-ordinated and disciplined system of manual traffic control. Having said this, it is clear that the police were quite keen for suitable automatic signal timings to replace manual control. This was demonstrated by their continued acceptance, and confidence in the experimental timings throughout May.

WP251.dq (disk41)
DJQ/rww
22 November 1988

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