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CONTROL OF CONGESTION AT HIGHLY SATURATED SIGNALISED INTERSECTIONS: EXPERIMENTS ON RAMA 4 ROAD, BANGKOK

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Control of Congestion at Highly Saturated Signalised Intersections: Experiments on Rama 4

CONTENTS

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Control of Congestion at Highly Saturated Signalised Intersections: Experiments on Rama 4 Road, Bangkok

Introduction

1.1 Context

This working paper is the third in a series of three on the control of congestion at highly saturated signalised intersections. The other papers in the series are:

WP 220 Control of Congestion at Highly Saturated Signalised Intersections: 1 - Survey Methods

WP 221 Control of Congestion at Highly Saturated Signalised Intersections: 2 - Experiments at an Isolated Junction.

After a brief explanation of the purpose of the study, and the part played by the Rama 4 experiments, this paper describes how the input data for the experiments was collected, updated and prepared for use in standard signal setting programs. The conduct of the actual experiment is then described followed by results and conclusions thereof.

1.2 Background

As described more fully in the first paper of this series, the purpose of the study was to develop a method of determining fixed time signal settings for use in the highly saturated Bangkok network, which would perform at least as well as, if not better than, the existing system of police manual control. The project was carried out in three stages. Stage I involved the collection of basic data and its analysis to determine appropriate values for pcu factors, saturation flows etc.

Stage II used the above results to determine and apply fixed time settings for an isolated junction, and the results of this experiment are given in the second paper in the series.

Stage III involved determining the suitable fixed time settings for a network of four highly saturated junctions on Rama 4 Road. This process and the results of the subsequent experiments are described in the present paper.

The reasons for the choice of the particular junctions, and a physical description of them, are given in the first paper. Briefly, the isolated junction is a four way intersection of two dual carriageways in the north-east sector of Bangkok, 2km from the nearest signalised junction. The network of four junctions lie on Rama 4 Road, a major and highly congested east-west arterial just east of the city centre and south of the one-way system. Travelling eastbound, inter-junction spacings are 600, 350 and 900m.

2. Data Input

2.1 Turning Movement Proportions

Classified turning movements were obtained at each of the four junctions during the video surveys of February-March 1984, as described in paper one of this series. The main purpose of the data collected at that time was to establish the pcu values, turning movement penalties and saturation flows. These parameters would remain relatively constant over time, changing only very slowly as new vehicle types were introduced, or driving standards improved. However the actual turning movement flows can fluctuate greatly from day to day (see 5.2), and it was therefore inadequate to use the actual turning movements measured in 1984. Instead, the turning movement proportions were calculated for each approach to each junction, as these would vary less than the absolute flows. Figures 2.1 and 2.2 show the proportions calculated, in terms of all vehicles except motorcycles for the periods 5-5.30 p.m. and 5.30-6 p.m. The N-E movement at SIL is in two parts, a very minor part actually through the junction, and the major part which uses a separate road some way back from the junction in front of Lumphini Park gates. The latter movement was not measured from the video surveys (it was not in camera) but was manually counted during the April '85 update surveys. U-turning movements are quite substantial from some approaches, because of the lack of gaps in the central reservation and the need to gain access to mid block premises. However on a few approaches U-turns are prohibited, either entirely or during peak periods.

2.2 pcu Values

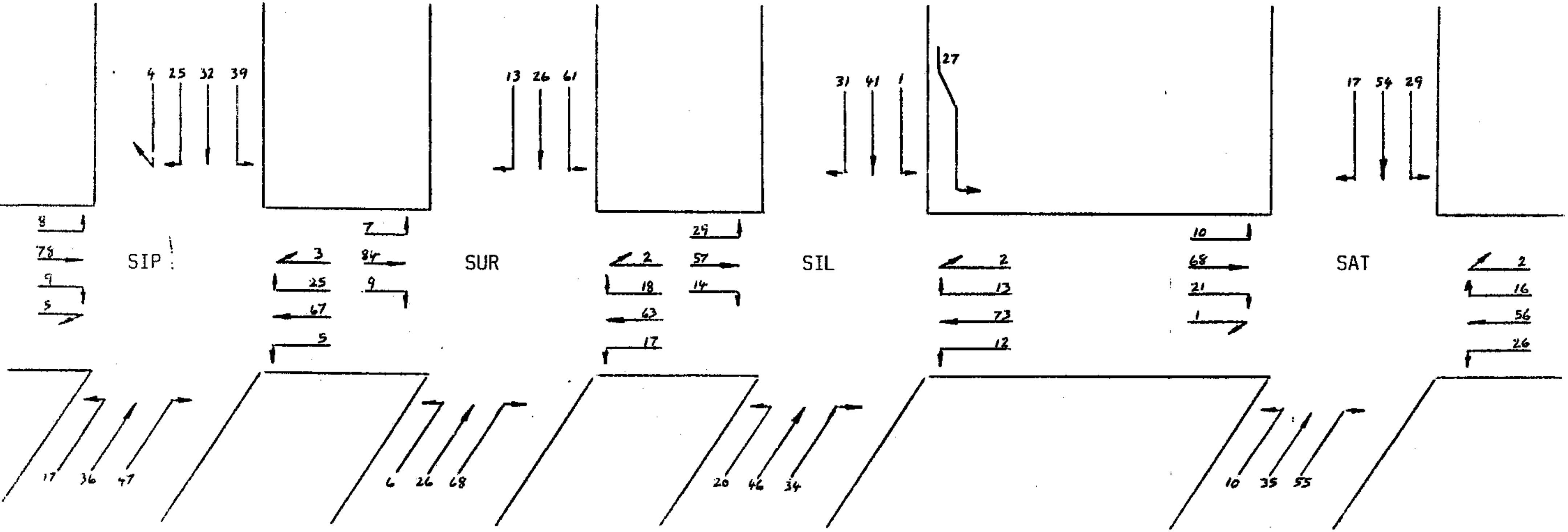
pcu values and turning movement penalties were calculated as described in the first paper, and summarised in Tables 2.1 and 2.2 below. These values in combination with the turning movement proportions were applied to the input flows described in 2.3.

TABLE 2.1 pcu Values Measured in Rama 4 Road Area, 1984

Vehicle Type	pcu
Samlor (3 wheel taxi)	0.89
Light/medium commercial veh	1.54
Bus	1.84
Right turn car (unopposed)	1.00
Acute left turn car	1.26
U-turn car	1.26

TURNING MOVEMENT PROPORTIONS (% ALL VEHS EX M/C) 5.00-5.30 pm

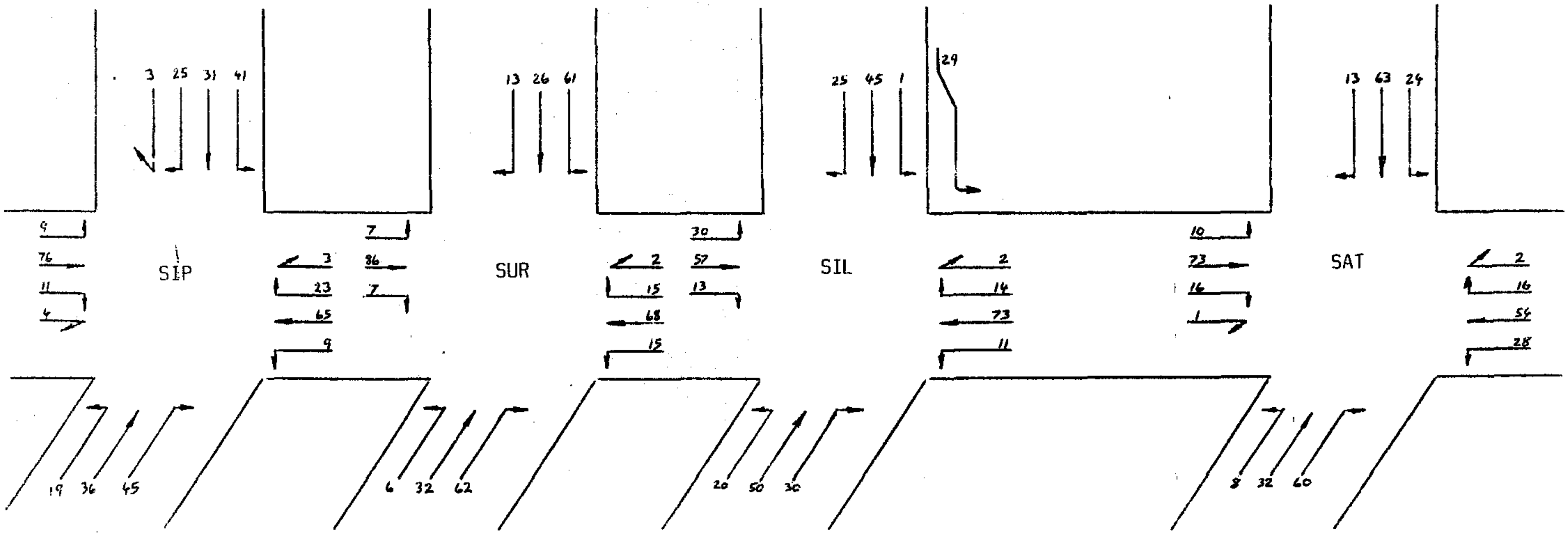
FIG 2.1



SOURCE:VISTA SURVEYS
SIP: 5-3-84
SUR:29-2-84
SIL: 7-3-84
SAT:12-3-84

TURNING MOVEMENT PROPORTIONS (% ALL VEHS EX M/C) 5.30-6.00 pm

FIG 2.2



SOURCE: VISTA SURVEYS
SIP: 5-3-84
SUR: 29-2-84
SIL: 7-3-84
SAT: 12-3-84

TABLE 2.2 pcu Values of Motorcycles Measured in Rama 4 Area, 1984

Position of motorcycle	pcu
At head of queue (1st 6 secs green)	0.0
Kerb lane or next to bus lane	0.65
Right turn lane	0.62
Other	0.53

2.3 Input Flows

Input flows of all vehicles except motorcycles were counted manually on all ten approaches to the network by one minute intervals (cumulatively, using tally counters) in April and June 1985, as described in 5.2.

2.4 Saturation Flows

Saturation flows were calculated from the video data of 1984 at each junction, using the headway ratio method as described in Working Paper 220.

3. Individual Junction Calculations

3.1 Method of Dealing with Motorcycles

Initially, signal settings were calculated for each of the four junctions individually, using the SIGSET and SIGCAP programs as for the isolated junction. The same method of dealing with motorcycles was used, as described in paper two of this series, which briefly summarised is as follows:

1) Using an assumed cycle time, and assuming the same g/c ratios as used by the police, the red/green ratios for each movement are calculated.

2) By applying the formula calibrated against the data of Rama 4:

$$MR = \frac{M}{(0.31\ \overline{R}/\overline{g} + 1)}$$

where M = Total flow of motorcycles per hour
MR = Hourly flow of motorcycles after 1st 6 secs of each green

$\bar{R}$ = Mean effective red for movement

$\bar{g}$ = Mean effective green " "

the value of MR for each movement was calculated.

3) The flow of each of the other vehicle types occuring after the 1st 6 seconds of green was calculated by subtracting from the hourly flow, the measured mean flow in the 1st 6 seconds, times the number of cycles per hour.

4) The flow of each vehicle type for each movement thus obtained is multiplied by the appropriate pcu value.

5) The summation of the pcu flows by turning movement thus gives the hourly demand flow to be accommodated after the first 6 seconds of each green.

6) In the signal calculations, the measured saturation flows are used unaltered, but the start lag is increased by 6 seconds for each movement.

3.2 SIGSET Early Runs

The results of applying the above procedure to the four junctions, using the mean April '85 input flows from 5-5.30 p.m., give the results as shown in Table 3.1.

TABLE 3.1 Summary of SIGSET early runs

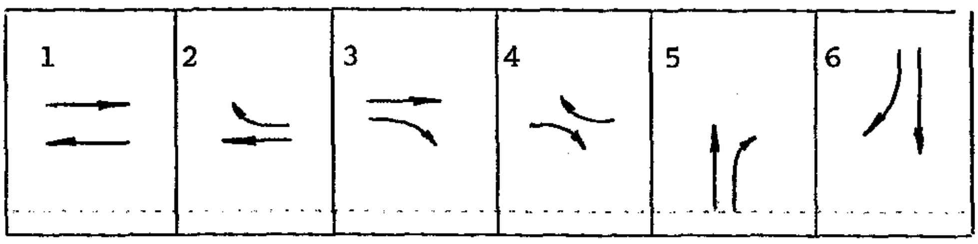
JUNCTION	CYCLE TIME	MAX % DEGREE OF SAT FROM			
		N	E	S	W
SIP	125	89	84	89	90
SUR	240	94	88	96	96
SIL	240	97	97	97	97
SAT	253	96	89	94	97

The sequences used in these runs were the most common sequences used by the police except for SIL where the most common sequence could not be used because of repeated stages. Figures 3.1 to 3.4 show these and the other sequences also used by the police.

FIGURE 3.1 Summary of Police Control Sequences on Rama 4 (1984 data)

Junction: SIP

Stages available:



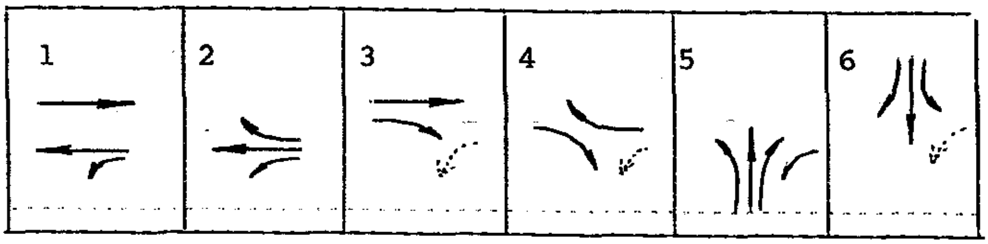
Sequence	Frequency
1456	37
12456	6
21356	2
13456	2

Mean cycle time	162 sec
Typical sequence	1456
Sequence for SIGSET	1456
" " TRANSYT	1456

FIGURE 3.2 Summary of Police Control Sequence on Rama 4 (1984 data)

Junction: SUR

Stages available:



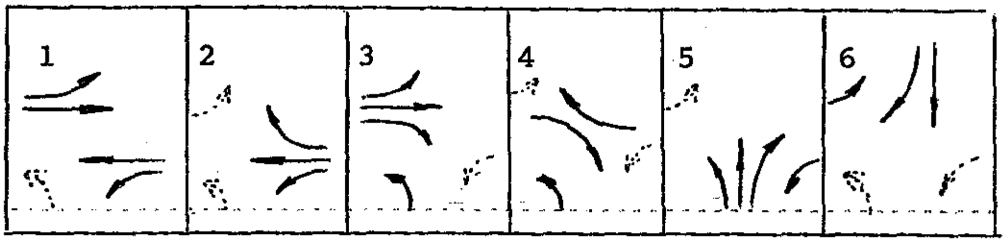
Sequence	Frequency
1456	14
4131456	1
131456	3
14565	2
141456	4
13456	2
145625	1
251356	1
2314356	1
21356	1
12451456	1
31456	1

Mean cycle time	209 sec
Typical sequence	1456
Sequence for SIGSET	1456
" " TRANSYT	1456

FIGURE 3.3 Summary of Police Control Sequences on Rama 4 (1984 data)

Junction: SIL

Stages available:



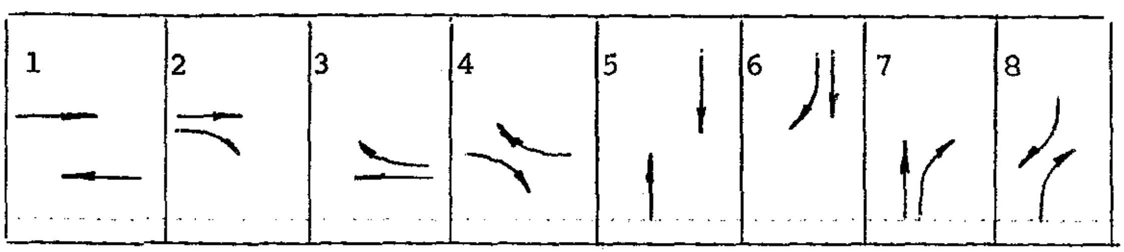
Sequence	Frequency
3121356	6
312131456	1
13121356	3
31213565	3
131256	1
131213565	4
314565	1

Mean cycle time	407 sec
Typical sequence	3121356
Sequence for SIGSET	31265
" " TRANSYT	31265
" " "	21365

FIGURE 3.4 Summary of Police Control Sequences on Rama 4 (1984 data)

Junction: SAT

Stages available: (only 1, 4, 6 and 7 until 1 July '85)



Sequence	Frequency
1476	20
121476*	5

Mean cycle time	280 sec
Typical sequence	1476
Sequence for SIGSET	1476
" " TRANSYT	12476

* Stage 2 by manual control

The results of these early runs showed that, under the tested sequences, the most saturated junctions were SIL and SAT, followed by SUR, with SIP undersaturated. On the basis of these runs and current police timings it was felt then that a cycle time of 240s would be appropriate to use in the TRANSYT8 runs. Note that the sequences used in the TRANSYT runs were different in some respects from those used for SIGSET, and that the final cycle time adopted was lower than the 240s indicated here.

4. Network Calculations Using TRANSYT8

4.1 Network Assumptions

Figure 4.1 shows the network diagram for the input of the initial runs to TRANSYT8. The following points are noteworthy:

Total flows As described in 2.3 and 5.2, the turning movement flows were obtained by factoring the updated total input flow on each arm by the turning movement proportions measured in 1984. 'Input' flows were not measured on the internal links of the network however, so that the total flows on each of these links were determined by summing the turning movements into the link from the three other arms (four where U-turns occurred). This process started with the E-W link from SAT to SIL, continuing to SIP and then returning eastwards to SAT. The resulting flows are shown at the heads of the arrows on Figure 4.1.

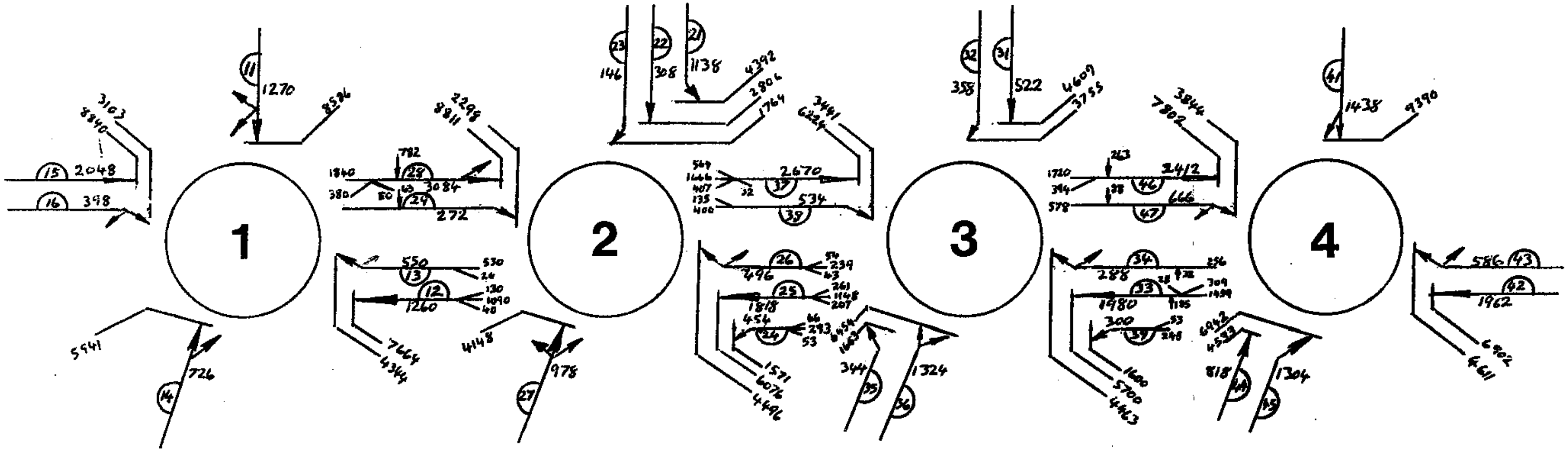
Link definitions The choice as to which movements could be combined into one link was based on observation of the video film, and more recent on site observation of changes made to lane markings and LTOR. Thus at SIP and SAT there are no links for left turns, because these all have separate left turn give-way lanes. At SIP, the NS, NW and NN movements are combined in one link because from observation none of the movements has an identifiably different degree of saturation from the others (all queues clear together approximately) and there is a degree of lane sharing between movements. The same applied to the NS and NW at SAT. The south approaches to SIL and SUR are shown as one link because there is only a one lane queue (although this is flared at the junction).

At SUR, the WN movement is combined with the WE because these movements share the kerb lane, whereas the NE and ES movements have dedicated lanes.

At SIL, the SN and SE movements share lanes and are therefore combined, whereas the SW has a dedicated lane. The NE movement was a separate slip road, so has no link. The WN movement has effectively almost permanent green (unofficial LTOR) and so has no link. The ES movement at the time of the video surveys shared the kerb lane with the EW, but during 1984 the lane markings were changed and LTOR introduced so that it now has a dedicated lane.

NETWORK DIAGRAM FOR RAMA 4 - INPUT TO TRANSYT 8

FIG 4.1



At SAT, the SN and SE movements used to be physically separated by a traffic island, but by 1st July 1985 this had been removed, so that there now is a certain amount of lane sharing. Two links have nevertheless been retained.

Routeing For TRANSYT, it is necessary to estimate for each link, the proportion of traffic which is feeding it from the upstream links. A proper estimate could only be obtained from O-D data, which was not available. Hence the estimates shown in Figure 4.1 are based on the following assumptions:

1) Drivers will not turn right through two consecutive junctions if that movement can be achieved by using another route. E.g. there is no flow from link 27 to link 38 because this can be more easily achieved using Patpong Road or Decho Road. However the reverse route using two left turns is easier and is therefore allowed (link 35 to link 24).

2) Input flows to each link were taken from the links deemed allowable, in proportion to the total outflow of those links. Hence for link 38, the total flow of 534 comes form links 21 and 28 in the ratio 1138:3084.

These assumptions are obviously not wholly satisfactory, and one would try to improve on them if progression through the network was possible, as then they could have an effect on the flow profiles in the TRANSYT model. However in the circumstances, with the high degree of saturation making progression impossible, the above assumptions are of minor importance.

Cruise speeds TRANSYT requires that cruise speeds be defined for each link. These are not free-flow speeds, but rather the mean speed of the given flow of traffic down the link, assuming that the signal controlling the link is green and there is no queue already in the link. Video tapes were available for the stretch of Rama 4 between SUR and SIL, and it was possible to use this to time a sample of vehicles along that section in both directions. The measured speeds were 40 kph for EW and 36 kph from WE. In the TRANSYT network therefore, all westbound and southbound links were coded 40 kph, all eastbound 36 kph. The northbound were coded 40 kph except for SIP, SUR and the SW at SIL where side friction was assumed to reduced cruise speeds to 30 kph.

Again, the cruise speeds were not in the event an important factor, as the degree of saturation prevented progression along the network.

Platoon dispersion factor The factor used was 35, as calculated using Bangkok data by Chiang Chien (1978).

4.2 Choice of Sequences, Cycle Times

The same sequences as for the earlier SIGSET runs were used in the initial TRANSYT runs except for SAT, where the extra stage 2 was added because it was by this time expected that the new controller would be installed by the experiment date. After the early runs the sequence at SIL was changed, as time distance diagrams suggested that the altered sequence would provide better progression. During the first survey day however it was obvious that upstream junction blocking was far more critical than platoon progression, and the sequence was changed back to the earlier form which, like the majority of the police forms, releases everything from the critical short SUR-SIL link before any traffic is sent towards the SUR junction.

The cycle time used in the early runs of TRANSYT was 240 seconds, based on the SIGSET results (Section 3.2).

4.3 Results of Early Runs

The pre-optimisation settings were exactly the same as those for SIGSET, for the junctions where the same sequence was used, and comparable for the others. Slight changes in the splits occured during the optimisation. The performance index (PI) did not improve as much as would normally be expected - an indication of progression problems.

4.4 Revised Method of Dealing with Motorcycles

It was realised from the start that the method devised to deal with motorcycles at an isolated junction was not appropriate for a network and indeed was not wholly satisfactory even for an isolated junction. This was because the method involved making the front of every platoon disappear, hence the flow profiles and platoon dispersion models, crucial parts of the TRANSYT program, would be operating on false information. Broadly speaking, unless the total traffic in the system was correct, the offsets would be calculated incorrectly even if the splits were correct. A revised method was therefore devised as follows. (Figures 4.2-4.3 and Table 4.1 refer).

> For each movement, the flow in the 1st 6 seconds was calculated, for all vehicles except motorcycles, in pcu (i.e. pcu of m/c = 0).
>
> This flow is represented by the area under the curved line in Figure 4.3 between 0 and 6 seconds, and can be represented as an average flow of f6 over that 6 seconds. Alternatively it can be represented by the saturation flow for a time T6 where 6 x f6 = T6 x S. Hence the start lag is 6 - T6.
>
> Note that f6 may be greater than S if there is a substantial flare, or the initial discharge flow falls off for any other reason. In this case the start lag will be negative.

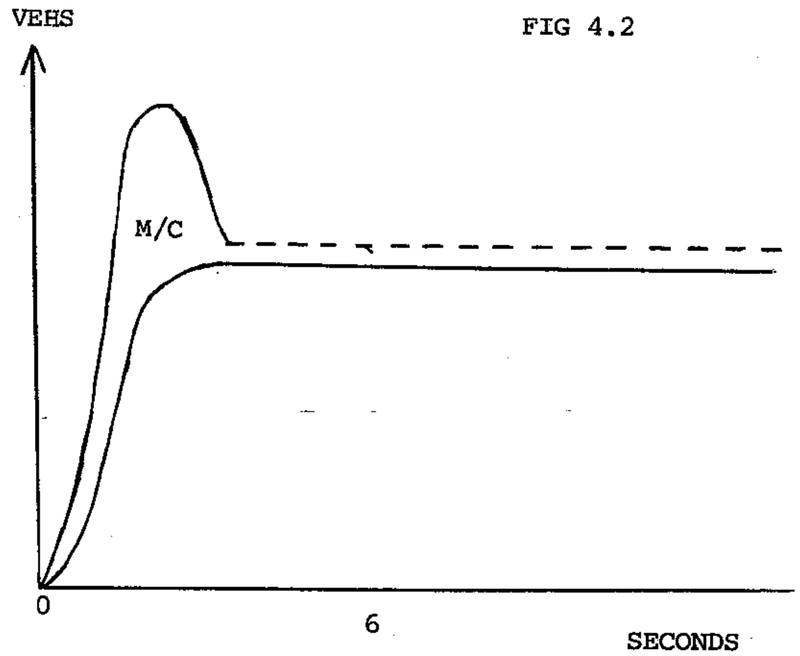


FIG 4.2

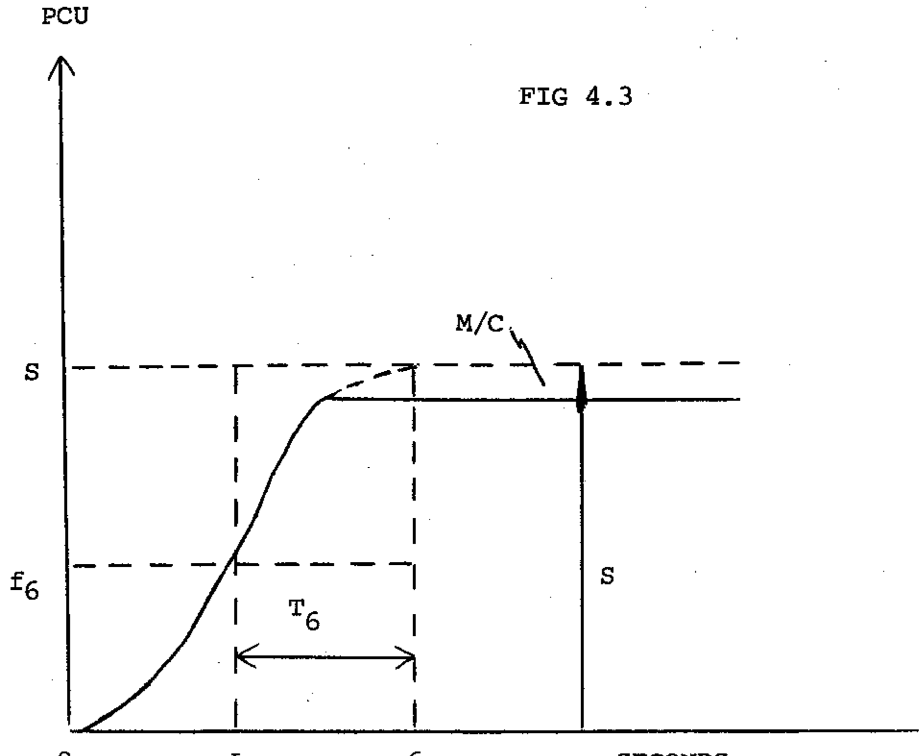


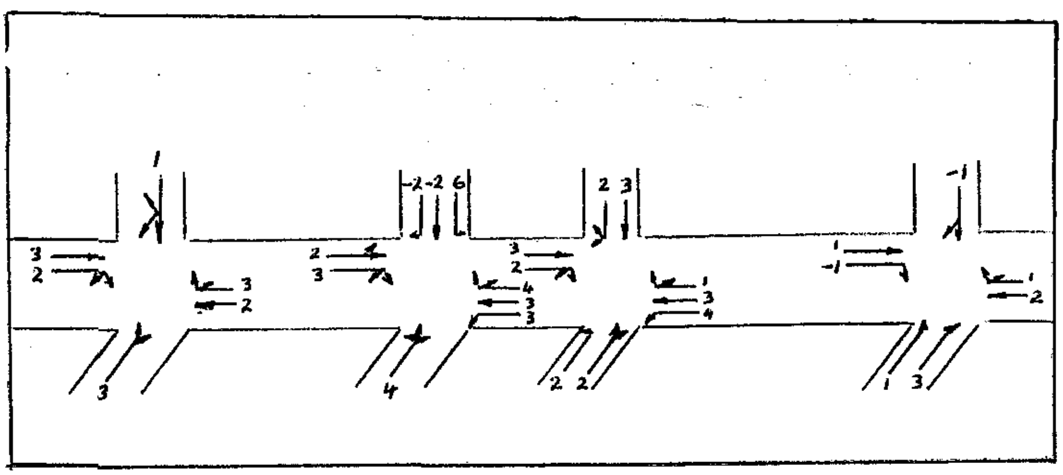
FIG 4.3

TABLE 4.1 CALCULATION OF START LAGS FOR SIP JUNCTION

	A	f6	S	T6	
Movement	Flow in 1st 6 sec. pcu ex m/c	Flow in 1st 6 sec (pcu ex m/c) /hr	Sat. flow pcu/hr	6 f6/S	Start lag 6 - T6
NS + NW + NN	12.65	7590	8586	5.30	1
EW	8.28	4968	7664	3.89	2
EN + EE	3.43	2058	4344	2.84	3
SN + SE	5.5	3300	5941	3.33	3
WE	7.32	4392	8840	2.99	3
WS + WW	3.76	2256	3103	4.36	2

Figure 4.4 shows the start lags calculated for each of the movements on the network.

FIGURE 4.4 Start Lags for Movements on Rama 4 Road Used in TRANSYT8 Calculations (in seconds)



4.5 Queue Limit Facility

One of the extra features in TRANSYT8 over previous versions is the ability to specify maximum queue lengths for specified links. The purpose of the facility is to encourage the program to find settings which will avoid blocking junctions upstream. This is achieved simply by specifying extremely large penalites for each vehicle greater than a specified maximum on each link, thus settings which result in over long queues on these links will hopefully be avoided by the program's optimisation process.

One problem found immediately was that the maximum limit accepted by the program for any link was 200 pcu, which was lower than the queuing capacity of some of the links on the network. Nevertheless, for the remainder of the inter-junction links, a maximum queue length was entered (in pcu) corresponding to 80% of the link being queued. This value was chosen to allow for variations in input flow between cycles and from day to day.

4.6 Results of Pre-experimental Runs

These pre-experiment runs were identical to the earlier runs of TRANSYT8 except for the revised method of treating motorcycles, and the use of the queue limit facility. Examination of the output not surprisingly showed that the splits were the same, but the offsets were quite different.

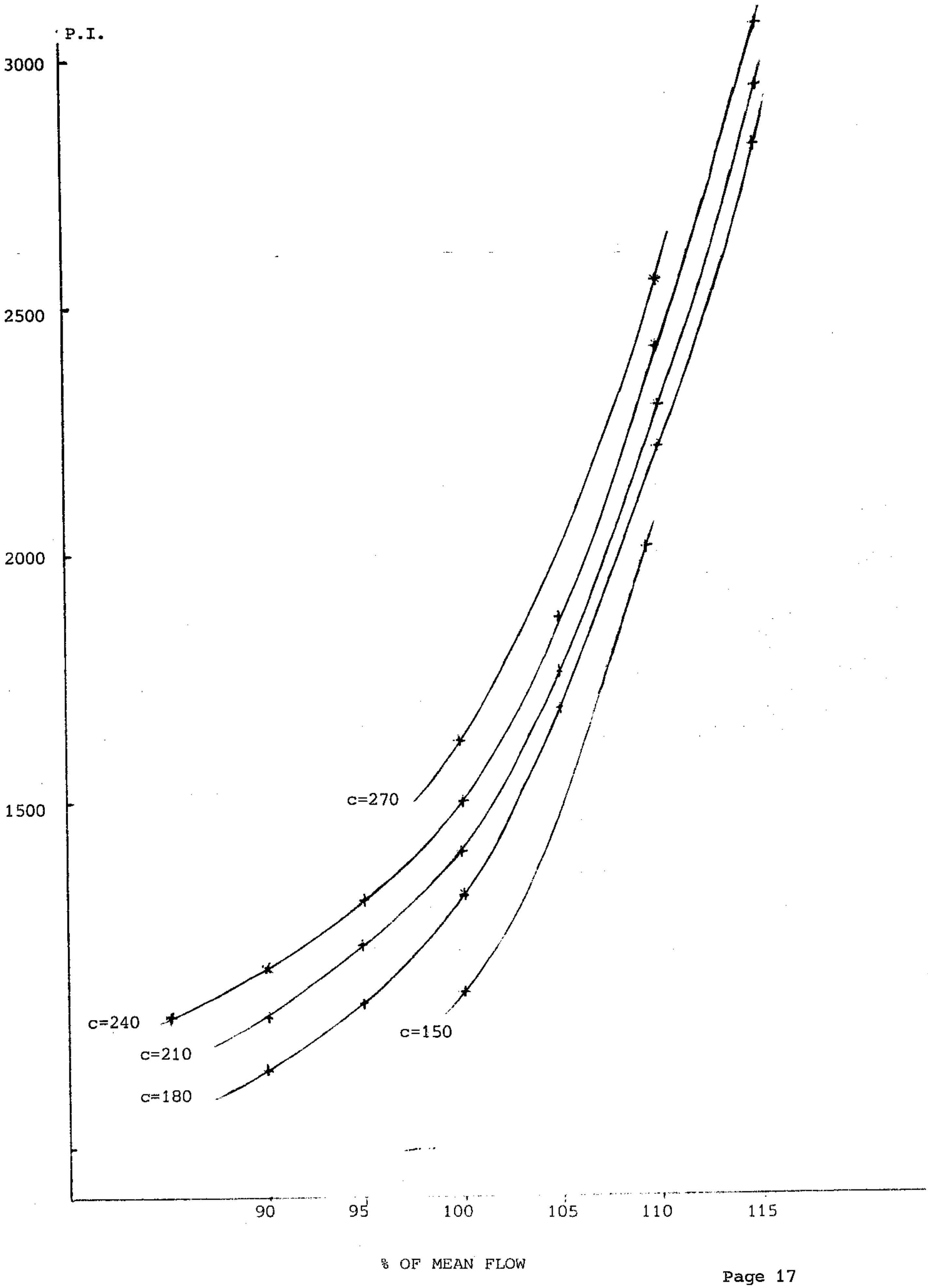
4.7 Sensitivity Test Runs of TRANSYT at Leeds

Following discussion at CCMRT it was felt advisable to test the effect of a lower cycle time, and in view of the variability found in input flow, to test the effect of varying levels of flow on the performance index (PI). Figure 4.5 shows the results of these sensitivity tests, which were carried out on the Amdahl computer at Leeds University rather than at AIT, in order to save costs. The input and output of a TRANSYT run on the AIT computer had previously been sent to Leeds and the same results replicated. It was therefore only necessary to telex Leeds with the percentage changes required in the flows, and the cycle times to be tested, and for Leeds to telex back the resulting PI's.

Figure 4.5 shows as expected the dramatic increase in PI as flow approaches saturation levels. It also showed, somewhat surprisingly, that a 180s cycle time was predicted to be better than a higher figure for all flow levels tested. In fact even 150s was apparently better up to 110% of mean flows. It was therefore decided to implement a 180s cycle during the first day of the experiment. A shorter cycle was not attempted, as day to day variations of more than 10% were not unexpected (see Table 7.17, where CoV for total input flows = 6%).

TRANSYT SENSITIVITY TESTS. PERFORMANCE INDEX VERSUS TOTAL FLOW FOR VARIOUS CYCLE TIMES.

FIG 4.5



5. Preparation for Experiment

5.1 Synchronisation of Junction Controllers

All four junction controllers were Erikson 8-stage controllers, and all were fitted with cableless linking units. These units operate by means of a quartz clock which runs synchronously with the mains supply frequency. The clock controls the stage change times set in the controller. Under normal circumstances therefore all the clocks will be synchronised. If the mains electricity supply is cut, a back-up battery keeps the quartz clock running, and the accuracy in this case is often stated to be within 1 second per year. The system works well in Europe, where both the frequency and the total number of cycles each day, of the public electricity supply must by law be maintained within very close limits.

In Thailand however, the limits are not so strict because none of the users require them to be so. Additionally electricity failures are more common (particularly in the rainy season) and the high levels of humidity and heat affect the accuracy of the quartz crystal back-up system.

Consequently if there was an electricity failure affecting only (say) the Silom junction for a period of only 1 hour, then a difference in frequency between the mains and the back-up quartz at Silom of only 0.25% would result in a drift out of synchronisation of 9 seconds.

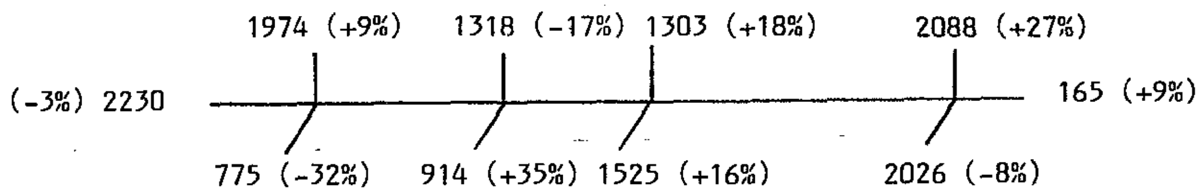
In the weeks immediately preceding the main experiments on Rama 4 the three cableless linking units then in operation (the Sathorn controller was of a different type until July 1st) were checked and resynchronised three times, at intervals of approximately one week. On the second visit it was found that all three clocks had drifted by 34 seconds, while on the third visit two had drifted by 25 and one by 43 seconds.

It became obvious that 1) cableless linking was an inappropriate method for maintaining synchronisation in Thailand and probably most developing countries; 2) it would be necessary to check and synchronise the controller clocks every day that the automatic settings were being implemented. This was in fact done.

5.2 Input Flows Update

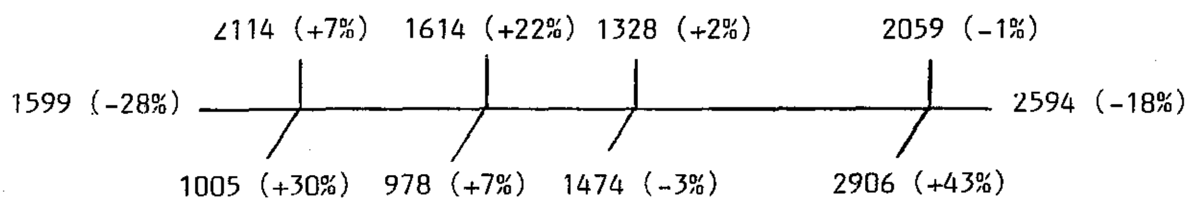
As described in 2.1, turning movements had been obtained at each of the junctions during the video surveys of February/March 1984, but it was obviously necessary to update this data to take account of the growth in traffic over the period. There was not the time or resources available to collect complete classified turning movement data again, but instead, input flows were collected on the 4 days 2-5 April 1985 on all ten approaches to the network, counting all vehicles except motorcycles, by one minute intervals. Figure 5.1 shows the means of these flows for the period 5-6 p.m., and the percentage increase over February/ March 1984.

FIGURE 5.1 Mean Input Flows 2-5 April '85 and % Change on February/March '84 (all vehs. ex. m/c, 5-6 p.m.)



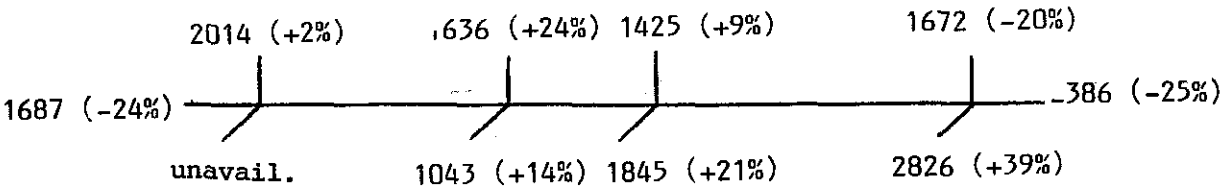
The general trend was obviously upwards, but there was concern at the size of some of the changes (up to 35%) and the great variability between different arms, suggesting that a degree of re-routeing was taking place. It was therefore decided to proceed with the signal calculations on the basis of the April 1985 flows, but to carry out a further updating survey immediately before the experiment. Figure 5.2 shows the results of this later survey on 25 June.

FIGURE 5.2 Input Flows 25 June '85 and % change on mean April '85 Flows (all vehs ex m/c 5-6 p.m.)



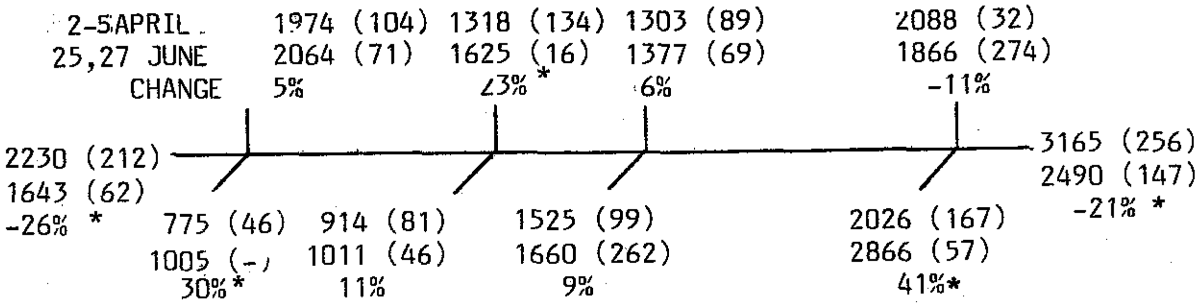
As can be seen there was again quite a lot of change from the mean April 1985 flows. It was suspected that the April flows may have been unusual in some way, and so further counts were carried out on 27 June 1985 as shown on Figure 5.3.

FIGURE 5.3 Input Flows 27 June '85 and % Change on Mean April '85 Flows (all vehs ex m/c 5-6 p.m.)



The June 1985 counts showed variability from day to day comparable to that of April 1985, but nevertheless the mean difference between April and June was significant on most of the arms, as summarised on Figure 5.4.

FIGURE 5.4 Mean Input Flows April and June 1985 (With Standard Deviations). (All vehs ex m/c 5-6 p.m.)



* Significant at 5% level

It can be seen that the largest change by far both in percentage and absolute terms, is on the south arm of SAT.

Some of the changes are very substantial, and one may ask how it is possible that such changes in flow can occur on junctions which are supposedly saturated. The answer is of course that the police redistribute the green times to compensate for the changed flows, and the total throughput for a junction does not change as much as the individual arms. (The total throughput to the network of four junctions changes by +5% from April to June). With fixed time settings of course it is not possible to respond to variations in flow in the manner that the police do. This aspect was discussed in the second paper of this series. Coming back to the present problem however, it was decided to use the mean June 1985 input flows in the signal calculations to be implemented from July.

The method described in Section 4.1 was used to factor the input flows by turning movement proportions and pcu/veh ratios to obtain the link flows required for input to TRANSYT8.

5.3 Obtaining Cooperation of the Police

The cooperation of the police was essential to the execution and success of the experiment. A meeting was therefore arranged for 5th June at TPD headquarters at which the case for an experiment would be presented. It was anticipated that it might be difficult to convince the police, as the results of the isolated junction experiment had not shown automatic control to be more successful than manual. A preparatory meeting was therefore held on 24th May with the then resident British Police adviser to the TPD, at which it was agreed that our presentation should take the following form:

1) Review of the isolated junction experiment, stressing that queues and delays had not been significantly worse than under manual control, and that the final settings had worked successfully for two weeks during the extended trial.

2) There was a greater chance of success on the Rama 4 road because of the extra benefits of coordination.

At the meeting on 5th June the above arguments were presented along with supporting evidence in the form of diagrams of queue lengths and delays, and the TPD readily agreed to cooperate. The next stage, as with the isolated junction experiment, was to send an official letter from AIT to the Director of OPP, asking him to write to the Commissioner of the Metropolitan Police to seek his cooperation and that of his District Commanders. A copy of the letter to the Commissioner was useful on the first survey day to convince those points policemen who were unaware of the experiment.

5.4 Briefing OCMRT Engineers

OCMRT is responsible for the installation and maintenance of the signal controllers and the settings therein, and it was therefore necessary to obtain its agreement to our proposals. Furthermore, OCMRT was sufficiently interested in the project and its potential benefits to agree to provide several engineers to assist in the running of the experiment. As regular contacts had been maintained with OCMRT engineers since the inception of the project, many of them were already conversant with its aims and methods. On 11 April a half-day visit to AIT had been arranged for several of the OCMRT engineers, at which the analysis methods leading up to the calculation of saturation flows, pcu values etc were reviewed. Later, on 19 June a presentation was made at OCMRT of the TRANSYT program, including the results of the preliminary runs carried out by then. The main feedback at that time was a feeling that 240 seconds (the common cycle time being used in the runs then) was too long. This was felt to be a surprising reaction at the time, as the mean cycle time at the junction in question under manual operation ranged from 180 to 400 seconds. Nonetheless, the cycle time eventually used in the experiment was 180 seconds.

At a final pre-survey meeting in OCMRT on 27 June, the logistics of the experiment were outlined, and it was agreed that one OCMRT engineer would be stationed at each of the four junctions. He would be responsible for installing the settings in the controllers' Random Access Memory (RAM) synchronising the controller clock with the aid of his two way radio, and ensuring that the timings remained in operation without being over-ridden by the points policeman. It was however agreed in advance that calls for police manual operation would not be resisted if this was:

1) because of very severe congestion, blocking across the junction,
2) to allow the free passage of VIPs.

Two-way radio contact would be maintained during the experiment between each of the OCMRT engineers stationed at the junciotn controllers, and the three survey co-ordinators who would be located at high points overlooking Rama 4 Road. (These 2-way radios were the property of OPP, and operated on a different frequency from those used by the police).

5.5 Recruitment, Training, Organisation of Survey Staff

In contrast to all the earlier experiments where survey staff had been obtained from AIT, for the Rama 4 experiment the staff were recruited by OCMRT from a pool of survey staff which they maintained for their own survey and coding work. These staff were mainly pre-University high school students, and approximately 30 were recruited to work on the input flow and elevated observer surveys. Each job was referred to one of the junctions, and an OCMRT technician was placed in charge of the students at each of the junctions. Survey instructions written by the Leeds University staff in English, were translated into Thai by one of the OCMRT engineers, and relayed to the four technicians (whose English was weak). Each technician was then responsible for relaying the instructions to the survey staff (most of whom had no English), ensuring they were properly understood, and supervision during the actual experiment.

This admittedly somewhat roundabout method of communicating the survey instructions worked satisfactorily because 1) the surveys involved were very simple to perform, 2) many of the surveyors were supervised by the Leeds University staff on site for at least part of the time on the first day, so that any potential problems could be spotted early, 3) the survey data was inspected and manually summarised immediately after each day's survey. If more complicated surveys were being carried out however, some modification to the above proeedure would be required.

5.6 Installation of New Signals and Controller at Sathorn/Rama 4

Before the experiment, the controller at the Rama 4/Sathorn junction was an outdated 15 years old GEC 4-stage controller, which was unsatisfactory in many ways and was therefore due to be replaced during June/July 1985 with the same type of controller as already existed at the other junctions in the experimental area. The unsatisfactory points of the old controller were: only four stages were available, which was inadequate for such a junction; (in fact in peak hours the police often used to create an extra stage by physically holding back the E-W movement while E-W and W-E was signalled green, and simultaneously directing the W-S movement through the red signal); the controller was difficult to programme, this requiring the re-setting of brass pins on the control board; the maximum stage time was 62 seconds, unless "double cycling" was selected, when the maximum stage was 124 seconds and maximum cycle 248 seconds. However in this case the step size *1 became 4 seconds, which is rather coarse. A visit was arranged to the controller on 12 June with two OCMRT engineers, to test whether the proposed timings were feasible. It was discovered that not only was the cable-less linking unit faulty, but that the timing could not be implemented at all.

A meeting was therefore arranged for 17 June at OCMRT with the contractor for the new controller (Eriksons), to find out their work programme. The contractor's representative explained that their programme involved 1) moving some traffic islands and erecting new signal poles, 2) installing new signal heads, 3) installing new controller, 4) removing old equipment. It was explained that we wanted to avoid roadworks in progress during our experimental period, so that ideally the new system should be installed before 1 July. The alternative was to hold up work until after 12 July, but this would involve problems in trying to implement the automatic settings. The contractor stated that they could probably have everything ready by 1 July, but were being held up by the lack of a detailed plan for one of the moved islands. A site visit was immediately arranged with OCMRT and Eriksons at which the new island position was marked out.

Further site visits and telephone calls to the contractor were made every other day, and the new controller in fact came into operation on the morning of 1 July.

6. Testing of Survey Methods

6.1 Elevated Observer Method Testing

The search for and selection of suitable view points for the elevated observer surveys is described in the first paper of this series. During that selection process verbal agreement in principle was obtained from each of the building owners/managers to our carrying out a survey from their premises at a later date. It was necessary however to re-contact each of the owners in the weeks prior to the survey to make detailed arrangements. For some of the sites a telephone call was sufficient, but others required a personal visit; one (a bank) required a formal letter. One difficulty was that three sites wanted to know, for security reasons, the names of the survey staff who would be operating from their premises. This was not possible as the staff had not at that time been recruited. It was therefore agreed that, for those sites, the survey staff would be accompanied on their first arrival by one of the engineers/ supervisors whose names were given.

The method was tested for all of the links except Wireless Road, between 21 April and 10 June 1985 and was found to work satisfactorily as described in Working Paper 220. The only problem was that one of the sites, on the roof of the Standard Chartered Bank on Rama IV Road near Silom Road, had no parapet or railing to prevent the survey staff falling off the edge. As it was necessary to get fairly close to the edge to get a proper view of the link being surveyed, and as strong winds were sometimes a problem at that height, it was decided not to use that site on safety grounds. The section of Rama IV between Silom and Suriwong was observed instead from the Montien Hotel.

6.2 Number Plate Matching Method Testing

This survey method as described in paper one, had been extensively used at the isolated junction experiments and it was therefore not felt necessary to pilot it further for Rama IV. The flows on the Rama IV network are however much greater than those at the isolated junction, and this led to a problem which, in hindsight, could have been foreseen. Fig 6.1 illustrates (top) in simplified form the situation on an approach to the isolated junction, assuming white cars are 10% of the total flow. If the observers at both points identify 90% of the white cars, then the total number of matches to be expected is

$$100 \times .9 \times .9 = 81\%$$

As the total flow increases, the observers will then record more vehicles, but will eventually reach a maximum constrained by the rate at which they can work, and an increasing tendency for number plates to be obscured by other vehicles. Hence in the example shown, although the flow has more than doubled and more data is being collected, the expected number of matches has dropped by half.

FIGURE 6.1

total flow	1000	Total 1000
white cars	100	100
NPM	90	90

Matches 100 x 0.9 x 0.9 = 81

total flow	2500	2500
white cars	250	250
NPM	100	100

Matches 250 x 0.4 x 0.4 = 40

Fortunately the number of matches obtained on the survey was still adequate, but it is recommended that in any future surveys in high flow conditions the problem of a potentially low match-rate is investigated in advance. Ways of overcoming the problem are:

1) employ extra survey staff to increase the sample rate.
2) reduce the size of the target population (White cars) by adding some extra identifying feature (such as those with black roofs only).

Both of these suggestions have associated problems which have not yet been fully resolved.

6.3 Queue Length Estimation Method Testing

Queue length estimation as described in the first paper, was tested on a sample of links on 25 May 1985. It was found that some of the survey staff had difficulty with the method, both in determining exactly where was the end of the queue, and in spotting the start of the green period. It was also suspected that some observers were not very accurate in estimating the percentage of the link which was queued - the perspective from a high building could be quite misleading sometimes. It was therefore decided that in the actual experiment, this part of the survey would be carried out by the engineering/supervisory staff from Leeds University/OCMRT.

7. Results

7.1 Incidents

The following are the main incidents which occurred during the days when automatic control was in operation.

2 July 1985 No incidents

3 July 1985

4.50	Freight train east of Sathorn Road blocks exit from SAT to East for approximately 3 minutes
5.49	Samlor broken down in left lane of Rama 4 westbound at Surawong

4 July 1985

4.00	Light shower of rain
4.17	Freight train blocks exit from SAT to East for approximately 7 minutes
4.45	Samlor broken down east of Surawong
4.50	Blue car broken down eastbound W of Surawong
4.55	Freight train blocks exit from SAT to East for approximately 3 minutes

5 July 1985

3.30	Heavy rain for approximately 30 minutes
3.50	Exit from SIL to South restricted for approx 30 min by parked cars of parents picking up school children to avoid the rain
4.19	Accident between 2 cars making U-turn on Rama 4 between Siphraya and Surawong
4.26	Siphraya on manual control
4.32	" back on automatic
4.38	" on manual control
4.44	" back on automatic

8 July 1985

3.40	Signal fault at Sathorn - OK by 3.45
	Police hold up traffic at Silom E-bound to allow free passage for VIP
4.30	Freight train blocks exit from SAT to East for approximately 3 minutes
5.18	Car stalled at stop line on Rama 4 eastbound at Sathorn till 5.24
5.30	Car broken down in Sur-Silom link eastbound.

9-12 July 1985

No serious incidents

7.2 Signal Settings Applied

The signal settings actually applied are shown in Tables 7.1 to 7.5. The initial settings shown on each table were amended on site in response to prevailing conditions. The following extracts from the survey diary give an indication of the reasoning behind the changes.

2 July 1985

3.34	SIP blocked back briefly
3.41	Rama 4 blocked from E across SIP (blocking right turn briefly)
3.43	SIP blocked back reducing westbound briefly
3.46	ditto
3.47	as at 3.41
4.05	Right turns EN at SUR pushing through - blocking briefly
4.13	Eastbound blocked back through SUR blocking right turns
4.14	Eastbound " " " SIP " " " Should eastbound at SIL run after E-bound at SUR?
4.22	Left turn from property between SUR and SIL blocking queue discharge eastbound to SIL
4.23	Queue SUR-SIL only clearing during S-N
4.24	Queue from SIP into R4 eastbound cleared soon
4.25	Same problem SUR-SIL. Now long E-N queue
4.27	Sip turns blocked by eastbound queue from SUR
4.33	Right turn W-S at Silom seems to reduce Silom throughput
4.46	Right turns EN at SUR now queued in 3 lanes Turn blocked especially by WS queue for Silom
4.49	Right turn E-N at SUR now blocking SIL
4.53	(Frequently) major queue gap between SUR and SIL eastbound, caused by policeman enforcing yellow box outside exit from hospital
5.09	Eastbound at SIL blocked by right turn
5.16	Major problem now is non compliance eastbound at SUR

3 July 1985

4.01	SUR blocked briefly blocking right turn
4.04	as above
4.07	as above
4.23	Decision to advance SIL offset by 10 sec to solve above
4.27	In changing to new times, stage 3 at SIL skipped for one cycle hence no W-S move, long queue, completely blocking E-N at SUR
4.28	OK, but rest of N-S at SUR blocked W-E hence queue back to SIP
4.35	SIP blockage has blocked E-W for 1/2 cycle
5.10	Changed SUR times - 3 seconds moved from S-N to N-S.

TABLE 7.1 STAGE START TIMES ON RAMA 4 ROAD DATE 2 JULY 85

CYCLE TIME = 180 s

(NORTH AT TOP OF PAGE)

SIPHRAYA	[1]	[4]	[5]	[6]
3.30	88 (51)	139 (34)	173 (41)	34 (54)

SURIWONG	[1]	[4]	[5]	[6]
3.30	12 (66)	78 (38)	116 (44)	160 (32)
5.00			116 (46)	162 (30)

SILOM	[3]	[1]	[2]	[6]	[5]
3.30	68 (37)	19 (49)	1 (18)	105 (25)	130 (51)
5.00	1 (54)	55 (41)	96 (10)	106 (24)	130 (51)
5.30	1 (47)	48 (44)	92 (10)	102 (24)	126 (55)

SATHORN	[1]	[2]	[4]	[7]	[6]
3.3	114 (54)	168 (11)	179 (27)	26 (57)	83 (31)
6.10	110 (61)	171 (8)	179 (27)	26 (53)	79 (31)

KEY
[3] STAGE NUMBER
14 STAGE START TIME
(25) STAGE LENGTH

* NB DIFFERENT SEQUENCE

TABLE 7.2 STAGE START TIMES ON RAMA 4 RD DATE 3 JULY 85

CYCLE TIME = 180 s

(NORTH AT TOP OF PAGE)

SIPHRAYA	[1]	[4]	[5]	[6]
3.30	86 (53)	139 (34)	173 (42)	35 (51)

SURIWONG	[1]	[4]	[5]	[6]
3.30	12 (66)	78 (38)	116 (46)	162 (30)
5.00			116 (43)	159 (33)

SILOM	[3]	[1]	[2]	[6]	[5]
3.30	19 (47)	66 (44)	110 (12)	122 (24)	146 (53)
4.30	6 (47)	53 (44)	97 (12)	109 (24)	133 (53)

SATHORN	[1]	[2]	[4]	[7]	[6]
3.30	114 (61)	175 (8)	3 (27)	30 (54)	84 (30)
4.45	112 (63)			30 (52)	82 (30)
5.30	82 (63)	145 (12)	157 (23)	180 (52)	52 (30)

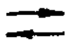
KEY
[3] STAGE NUMBER
14 STAGE START TIME
(25) STAGE LENGTH

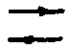
TABLE 7.3 STAGE START TIMES ON RAMA 4 RD DATE 4 JULY 85

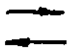
CYCLE TIME = 180 s

(NORTH AT TOP OF PAGE)

	[1]	[4]	[5]	[6]
SIPHRAYA				
3.30	96 (53)	149 (34)	3 (44)	47 (49)

	[1]	[4]	[5]	[6]
SURIWONG				
3.30	12 (66)	78 (38)	116 (46)	162 (30)

	[3]	[1]	[2]	[6]	[5]
SILOM					
3.30	6 (47)	53 (44)	97 (12)	109 (26)	135 (51)
3.42	6 (47)	53 (44)	97 (12)	109 (29)	138 (48)
4.06	7 (47)	54 (43)	97 (12)	109 (27)	136 (51)
4.25	6 (47)	53 (44)	97 (12)	109 (26)	135 (51)
5.30	6 (44)	50 (44)	94 (12)	106 (29)	135 (51)

	[1]	[2]	[4]	[7]	[6]
SATHORN					
3.30	77 (63)	140 (8)	148 (27)	175 (52)	47 (30)
4.00				175 (50)	45 (32)

KEY
[3] STAGE NUMBER
14 STAGE START TIME
(25) STAGE LENGTH

TABLE 7.4 STAGE START TIMES ON RAMA 4 RD DATE 5 JULY 85

CYCLE TIME = 180 s

(NORTH AT TOP OF PAGE)

SIPHRAYA

	[1]	[4]	[5]	[6]
3.30	111 (53)	164 (34)	18 (44)	62 (49)

SURIWONG

	[1]	[4]	[5]	[6]
3.30	20 (66)	86 (38)	124 (46)	170 (30)

SILOM

	[3]	[1]	[2]	[6]	[5]
3.30	6 (47)	53 (44)	97 (12)	109 (27)	136 (50)
5.25	6 (46)	52 (44)	96 (11)	107 (28)	135 (51)
5.55	6 (42)	48 (46)	94 (12)	106 (29)	135 (51)

SATHORN

	[1]	[2]	[4]	[7]	[6]
3.30	62 (63)	125 (8)	133 (27)	160 (51)	31 (31)
6.02	62 (65)	127 (6)			

KEY
[3] STAGE NUMBER
14 STAGE START TIME
(25) STAGE LENGTH

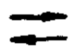
*1 POLICE CONTROL 4.26 - 4.32
4.38 - 4.44

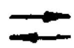
*2 SCHEDULED PLAN CHANGE TO 6, 50, 94, 106, 135 not implemented at 5.15 because of lack of radio contact

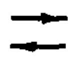
TABLE 7.5 STAGE START TIMES ON RAMA 4 RD DATE 8 JULY 85

CYCLE TIME = 180 s

(NORTH AT TOP OF PAGE)

	[1]	[4]	[5]	[6]
SIPHRAYA				
3.30	111 (53)	164 (34)	18 (44)	62 (49)

	[1]	[4]	[5]	[6]
SURIWONG				
3.30	20 (66)	86 (43)	129 (41)	170 (30)

	[3]	[1]	[2]	[6]	[5]
SILOM					
3.30	6 (46)	52 (44)	96 (13)	109 (27)	136 (50)
5.15	6 (42)	48 (45)	93 (12)	105 (30)	135 (51)

	[1]	[2]	[4]	[7]	[6]
SATHORN					
3.30	62 (65)	127 (7)	134 (26)	160 (51)	31 (31)

KEY

[3]	STAGE NUMBER
14	STAGE START TIME
(25)	STAGE LENGTH

7.3 Input Flows

Input flows of all vehicles except motorcycles were counted on the ten entry links to the network, as described in section 2.3. The actual counts were recorded cumulatively at one minute intervals, and are summarised by half hour and hourly periods in Tables 7.6 to 7.15.

Tables 7.16 and 7.17 summarise the periods 4-5 pm and 5-6 pm respectively for each survey day, and give statistics for the distribution of the flow on each arm over the 10 days. Looking at Tables 7.16 and 7.17 the following points can be seen:

1) The flow in the 4-5 pm period is in general higher than in the 5-6 pm period (by about 3.5%);

2) The above is true for all approach arms except the south arm at SUR;

3) the coefficient of variation from day to day on individual approaches ranges from as low as 4% to as high as 25%;

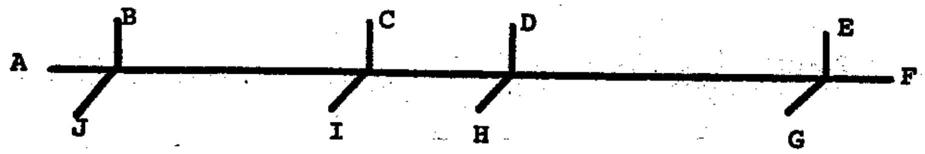
4) SIL, the most saturated junction, also has the most variable flows (CoV = 20-21% from the north, 11-25% from the south).

Table 7.18 summarises the flow data from 4-6.30 pm for each survey day. Flows on the ten entry links to the networks come directly from the input flow counts as above, whereas flows on the internal links are derived from these by applying the turning movement proportion of section 4.1. Inspection of the table shows a few outliers, as follows:

on 8 July, unusually high flow at SIP S-N
on 8 July, unusually low flow at SAT N-S
on 10 July, unusually low flow at SIL N-S

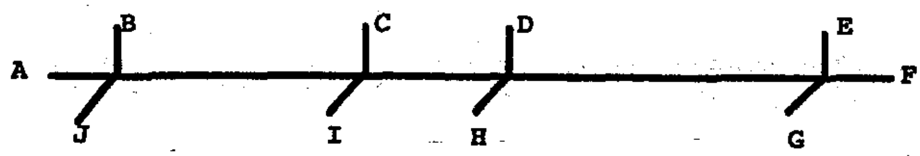
The day to day variation in the flows displayed on the foregoing tables is certainly in accord with subjective assessment of the situation in Bangkok. Unfortunately there is no long-term flow data available which may help to explain the variation and determine whether there is any pattern to it.

TABLE 7.6 INPUT FLOWS: RAMA IV DATE: 1/07/85



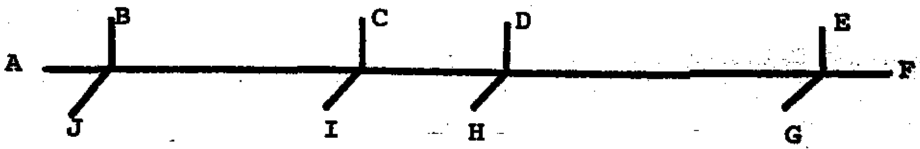
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	1081	1241	871	467	1106	1353	1407	790	400	460	9176
1630-1700	924	1316	801	433	921	1365	1358	848	385	530	8881
1700-1730	794	1125	739	422	669	1198	1296	627	461	526	7857
1730-1800	894	1027	751	429	906	1102	918	710	418	566	7721
1800-1830	862	998	696	362	783	1274	1116	923	410	484	7908
1600-1700	2812	2557	1672	900	2027	2718	2765	1638	785	990	18057
1630-1730	1718	2441	1540	855	1590	2563	2654	1475	846	1056	16738
1700-1800	1688	2152	1490	851	1575	2300	2214	1337	879	1092	15578
1730-1830	1756	2025	1447	791	1689	2376	2034	1633	828	1050	15629
1600-1830	4555	5707	3858	2113	4385	6292	6095	3906	2074	2566	41543

TABLE 7.7 INPUT FLOWS: RAMA IV DATE: 2/7/85



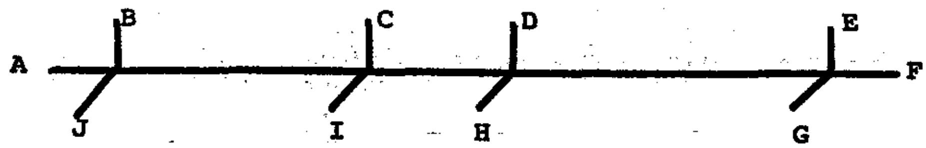
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	850	1255	916	692	887	991	1639	802	475	506	9013
1630-1700	496	1260	960	710	869	1102	1730	733	523	445	8828
1700-1730	782	1183	943	670	828	1083	1564	704	556	480	8793
1730-1800	971	1087	774	687	922	1081	1480	683	549	494	8728
1800-1830	910	1071	763	659	914	1162	1489	795	495	484	8742
1600-1700	1346	2515	1876	1402	1756	2093	3369	1535	998	951	17841
1630-1730	1278	2443	1903	1380	1697	2185	3294	1437	1079	925	17621
1700-1800	1753	2270	1717	1357	1750	2164	3044	1387	1105	974	17521
1730-1830	1881	2158	1547	1346	1836	2243	2969	1478	1044	978	17480
1600-1830	4009	5856	4356	3418	4420	5419	7902	3717	2598	2409	44104

TABLE 7.8 INPUT FLOWS: RAMA IV DATE: 3/7/85



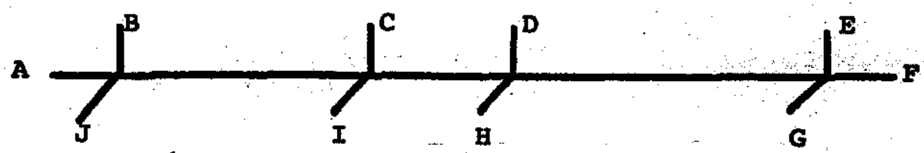
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	669	1337	900	613	932	1329	1701	848	404	468	9201
1630-1700	737	1168	944	722	808	1189	1778	907	468	463	9184
1700-1730	929	1115	842	660	759	1384	1750	729	521	464	9153
1730-1800	861	1189	791	547	803	1376	1397	797	478	471	8710
1800-1830	894	1090	751	562	698	1087	1245	784	417	526	8054
1600-1700	1406	2505	1844	1335	1740	2518	3479	1755	872	931	18385
1630-1730	1666	2283	1786	1382	1567	2573	3528	1636	989	927	18337
1700-1800	1790	2304	1633	1207	1562	2760	3147	1526	999	935	17863
1730-1830	1755	2279	1542	1109	1501	2463	2642	1581	895	997	16764
1600-1830	4090	5899	4228	3104	4000	6365	7871	4065	2288	2392	44302

TABLE 7.9 INPUT FLOWS: RAMA IV DATE: 4/7/85



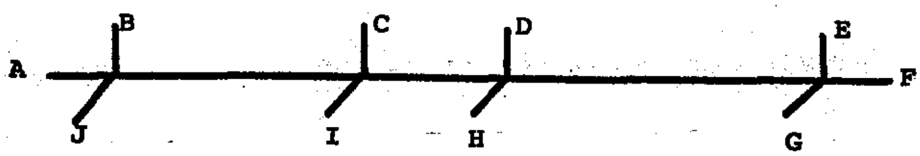
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	1003	1228	925	641	890	1308	1726	869	451	505	9546
1630-1700	817	1289	959	677	809	1254	1781	790	478	343	9397
1700-1730	852	1150	873	632	797	1124	1583	793	561	533	8898
1730-1800	843	1142	790	586	805	1247	1705	788	522	528	8959
1800-1830	918	1042	759	647	725	1263	1355	909	479	518	7475
1600-1700	1820	2517	1884	1318	1699	2562	3507	1659	929	1048	18943
1630-1730	1669	2439	1832	1309	1606	2378	3364	1583	1039	1076	18295
1700-1800	1695	2292	1663	1218	1602	2371	3288	1581	1083	1061	17854
1730-1830	1761	2184	1549	1233	1530	2510	3060	1697	1001	1046	17571
1600-1830	4433	5851	4306	3183	4026	5196	8150	4149	2491	2627	45402

TABLE 7.10 INPUT FLOWS: RAMA IV DATE: 5/7/85



TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	842	1133	867	507	953	956	1419	693	316	394	8080
1630-1700	838	1084	840	693	947	1201	1950	681	393	447	9074
1700-1730	851	1087	825	590	923	1245	1827	713	532	527	9120
1730-1800	874	1055	762	580	937	1343	1494	542	505	555	8647
1800-1830	862	1049	668	566	880	1192	1688	772	427	541	8645
1600-1700	1680	2217	1707	1200	1700	2157	3369	1374	709	841	16954
1630-1730	1689	2171	1665	1283	1670	2446	3777	1394	925	974	17994
1700-1800	1725	2142	1587	1170	1860	2588	3321	1255	1037	1082	17767
1730-1830	1736	2104	1430	1146	1817	2535	3182	1314	932	1096	17292
1600-1830	4267	5408	3962	2936	4640	5937	8378	3401	2173	2464	43566

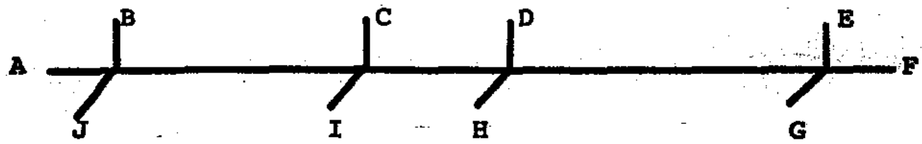
TABLE 7.11 INPUT FLOWS: RAMA IV DATE: 8/7/85



TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	966	1284	842	509	413	1436*	1359	811	409	648	8677
1630-1700	889	1264	789	520	410	1449*	1295	735	497	737	8585
1700-1730	880	1208	851	521	581	1340	1207	467	521	618	8194
1730-1800	903	1098	805	500	1041	1272	1155	744	532	513	8563
1800-1830	899	998	744	479	889	1181	1154	836	454	493	7457
1600-1700	1855	2548	1631	1029	823	2885*	2654	1546	906	1385	17262
1630-1730	1769	2472	1640	1041	991	2789*	2502	1202	1018	1355	16779
1700-1800	1783	2306	1656	1021	1622	2612	2362	1211	1053	1131	16757
1730-1830	1802	2096	1549	979	1930	2453	2309	1580	986	1006	16020
1600-1830	4537	5852	4031	2529	3334	6678	6170	3593	2413	3009	41476

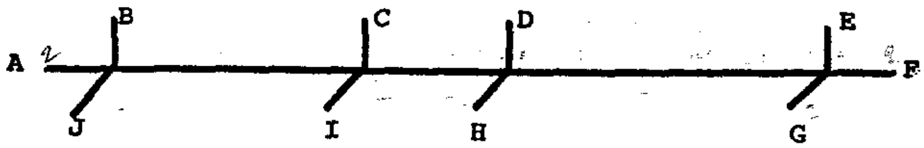
* Estimated from 1/7/85

TABLE 7.12 INPUT FLOWS: RAMA IV DATE: 9/7/85



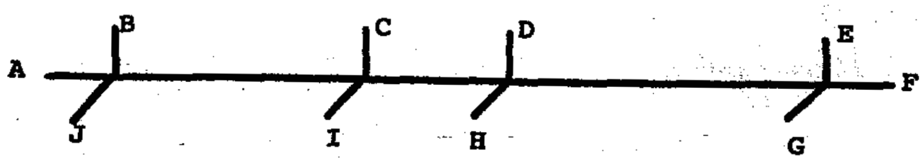
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	949	1248	902	530	877	1448	1432	950	416	495	9247
1630-1700	921	1312	866	571	943	1301	1561	912	494	571	9452
1700-1730	959	1234	897	474	856	1278	1054	917	600	416	8685
1730-1800	940	1122	916	493	843	1311	998	905	513	477	8518
1800-1830	918	1090	737	497	961	1179	1224	938	497	576	8617
1600-1700	1870	2560	1768	1101	1820	2749	2993	1862	910	1066	18685
1630-1730	1880	2546	1763	1045	1799	2579	2615	1929	1094	987	18243
1700-1800	1899	2356	1813	967	1699	2589	2052	2422	1113	893	17833
1730-1830	1858	2212	1653	990	1804	2490	2222	2343	1010	1053	17725
1600-1830	4687	6006	4318	2565	4480	6517	6269	4622	2520	2535	44519

TABLE 7.13 INPUT FLOWS: RAMA IV DATE: 10/7/85



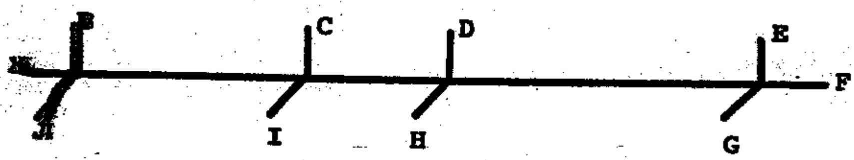
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	1030	1260	921	420	919	1220	1502	837	471	564	9144
1630-1700	951	1321	939	283	821	1397	1442	869	465	527	9015
1700-1730	932	1143	914	347	1016	1444	1204	1036	558	491	9085
1730-1800	1011	1049	752	332	820	1391	1093	1157	555	571	8731
1800-1830	921	1077	745	353	702	1279	1119	1081	512	514	8303
1600-1700	1981	2581	1860	703	1740	2617	2944	1706	936	1191	18259
1630-1730	1883	2464	1853	630	1837	2841	2646	1905	1023	1018	18100
1700-1800	1943	2192	1666	679	1836	2835	2297	2193	1113	1062	17816
1730-1830	1932	2126	1497	685	1522	2670	2212	2238	1067	1085	17034
1600-1830	4845	5850	4271	1735	4278	6731	6360	4980	2561	2667	44278

TABLE 7.14 INPUT FLOWS: RAMA IV DATE: 11/07/85



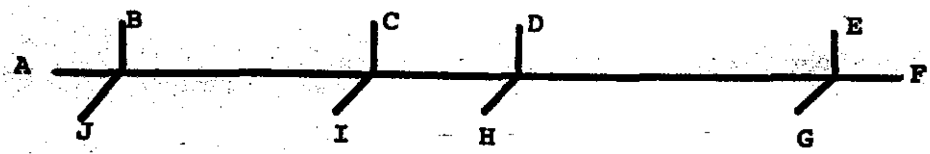
TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600–1630	775	1300	955	525	936	1360	1402	921	538	561	9273
1630–1700	879	1343	932	592	876	1277	1485	1043	546	514	9487
7100–1730	867	1177	941	719	816	1339	1247	982	453	517	9058
1730–1800	770	1028	819	623	877	1479	1127	774	501	495	8493
1800–1830	856	1074	867	599	799	1079	1087	854	577	564	8356
1600–1700	1654	2643	1887	1117	1812	2637	2887	1964	1084	1075	17780
1630–1730	1746	2520	1873	1311	1692	2616	2732	2025	999	1031	19086
1700–1800	1637	2205	1760	1342	1693	2818	2374	1756	954	1012	19135
1730–1830	1626	2102	1686	1222	1676	2558	2214	1628	1078	1059	20204
1600–1830	4147	5922	4514	3058	4304	6534	6348	4574	2615	2651	44667

TABLE 7.15 INPUT FLOWS: RAMA IV DATE: 12/07/85



TIME	A	B	C	D	E	F	G	H	I	J	TOTAL
1600-1630	700	1116	846	631	982	1281	1247	965	431	492	8691
1630-1700	949	1230	867	750	887	1245	1636	904	446	517	9431
1700-1730	1015	1179	743	733	824	1326	950	804	497	532	8603
1730-1800	889	884	806	680	875	1628	1054	782	536	427	8561
1800-1830	871	854	732	665	679	1463	962	875	512	585	8198
1600-1700	1649	2346	1713	1381	1869	2526	2883	1869	877	1009	18122
1630-1730	1964	2409	1610	1483	1711	2571	2586	1708	943	1049	18034
1700-1800	1904	2063	1549	1413	1699	1760	2004	1586	1033	959	15970
1730-1830	1760	1738	1538	1345	1554	3091	2016	1657	1048	1012	16759
1600-1830	4424	5263	3994	3459	4247	6943	5849	4330	2422	2553	43484

TABLE 7.16 Input Flows Rama 4 Summary 1 - 12 July 1985



Time Period 4 - 5 pm

Date	A	B	C	D	E	F	G	H	I	J	TOTAL
1.7	2005	2557	1672	900	2027	2718	2765	1638	785	990	18057
2.7	1346	2515	1876	1402	1756	2093	3369	1535	998	951	17841
3.7	1406	2505	1844	1335	1740	2518	3479	1755	872	931	18385
4.7	1820	2517	1884	1318	1699	2562	3507	1659	929	1048	18943
5.7	1680	2217	1707	1200	1700	2157	3369	1374	709	841	16954
8.7	1855	2548	1631	1029	823	2885	2654	1546	906	1385	17262
9.7	1870	2560	1768	1101	1820	2749	2993	1862	910	1066	18685
10.7	1981	2581	1860	703	1740	2617	2944	1706	936	1191	18259
11.7	1654	2643	1887	1117	1812	2637	2887	1964	1084	1075	17780
12.7	1649	2346	1713	1381	1869	2526	2883	1869	877	1009	18122
MEAN	1727	2499	1784	1149	1699	2546	3085	1691	901	1040	18031
MIN	1346	2217	1631	703	823	2093	2654	1374	709	841	16954
MED	1750	2532	1806	1159	1748	2590	2969	1683	908	1029	18090
MAX	2005	2643	1887	1402	2027	2885	3507	1869	1084	1385	18943
RANGE/ MED	38%	17%	14%	60%	69%	31%	29%	31%	41%	53%	11%
SD	223	125	98	227	323	249	315	179	104	158	605
COV	13%	5%	5%	20%	19%	10%	10%	11%	12%	15%	3%

TABLE 7.17 Input Flows Rama IV Summary 1 - 12 July 1985

Time Period 5 - 6 pm

Date	A	B	C	D	E	F	G	H	I	J	TOTAL
1.7	1688	2152	1490	851	1575	2300	2214	1337	879	1092	15578
2.7	1753	2270	1717	1357	1750	2164	3044	1387	1105	974	17521
3.7	1790	2304	1633	1207	1562	2760	3147	1526	999	935	17843
4.7	1695	2292	1663	1218	1602	2371	3288	1581	1083	1061	17854
5.7	1725	2142	1587	1170	1860	2588	3321	1255	1037	1082	17767
8.7	1783	2306	1656	1021	1622	2612	2362	1211	1053	1131	16757
9.7	1899	2356	1813	967	1699	2589	2052	2422	1113	893	17833
10.7	1943	2192	1666	679	1836	2835	2297	2193	1113	1062	17816
11.7	1637	2205	1760	1342	1693	2818	2374	1756	954	1012	19135
12.7	1904	2063	1549	1413	1699	1760	2004	1586	1033	959	15970
MEAN	1782	2228	1653	1123	1690	2480	2610	1625	1037	1020	17407
MIN	1637	2063	1490	679	1562	1760	2004	1211	879	893	15578
MED	1772	2233	1660	1189	1696	2589	2368	1554	1045	1037	17792
MAX	1943	2356	1813	1413	1860	2835	3321	2422	1113	1131	19135
RANGE/ MED	17%	13%	19%	62%	18%	42%	56%	78%	22%	23%	20%
SD	103	92	96	238	103	337	526	399	76	77	1038
CoV	6%	4%	6%	21%	6%	14%	20%	25%	7%	8%	6%

TABLE 7.18 RAMA 4 EXPERIMENT INPUT FLOWS 4.00-6.30 p.m. ALL VEH EX M/C

DATE	SIP				SUR				SIL				SAT				TOTAL ENTRY FLOW
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
1/7	5707	3672	2566	4555	3858	4686	2074	7532	2113	4710	3906	10148	4385	6292	6095	7646	41546
2/7	5856	3849	2409	4009	4356	4811	2598	7074	3418	4423	3717	10419	4420	5419	7902	8119	44104
3/7	5899	4004	2392	4090	4228	5103	2288	7154	3104	4864	4065	10199	4000	6365	7871	8013	44302
4/7	5851	4023	2627	4433	4306	5098	2491	7530	3183	4805	4149	10704	4026	6196	8150	8352	45402
5/7	5408	3817	2464	4267	3962	4880	2173	7119	2936	4786	3401	9927	4640	5939	8378	7597	43566
8/7	5852	3775	3009	4537	4031	4779	2413	6239	2529	4756	3593	9387	3334	6678	6170	7234	41476
9/7	6006	3995	2535	4687	4318	5051	2520	7751	2565	4863	4622	10918	4480	6517	6269	8446	44519
10/7	5850	3927	2667	4845	4271	4950	2561	7877	1735	4955	4980	11025	4278	6731	6360	8381	44278
11/7	5922	4107	2651	4147	4514	5175	2615	7348	3058	4854	4574	10862	4304	6534	6348	8590	44667
12/7	5263	4147	2553	4424	3994	5358	2422	7243	3459	5014	4330	10224	4247	6943	5849	8217	43484

7.4 Travel Times

Link travel times were measured either by the elevated observer method (14 links) or by number plate matching (2 links) as described in sections 6.1 and 6.2. The resulting mean travel times for the whole survey period are shown on Table 7.19. It can be seen that on the first survey day (1 July, police control) four links were not measured, due to lack of survey staff. The only other missing data is on 8th July for SIP W-E. This was because the vantage point used till that date (a hotel bedroom under redecoration) suddenly became unavailable. Number plate matching was therefore used for that link for the remainder of the survey.

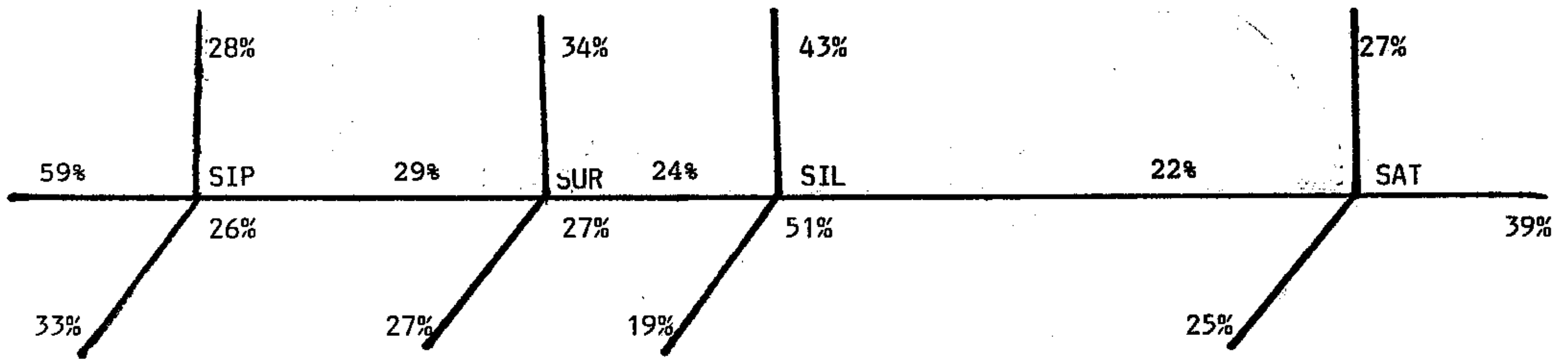
The day to day variation in link travel times is obviously much greater than that of the flows, with coefficients of variation ranging from 19% to 59%. Figure 7.1 shows these CoV for each link, where the following features become apparent:

- External links in general have higher variation than internal links
- The low CoV for SIL S-N is probably because the queue on this approach often extended beyond the timing point
- the CoV for SAT E-W is lower than expected, probably due to the high proportion of free left turning traffic at the junction, as well as the long queue which extended beyond the timing point
- the variation appears to reduce as one progresses along the network from either direction, probably due to the "gating" effect of each junction.

TABLE 7.19 RAMA 4 EXPERIMENT 1-12 JULY 1985

MEAN TRAVEL TIMES (SECONDS) 4.00-6.30 p.m.

DATE	SIP				SUR				SIL				SAT			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
1/7	190	220	-	-	260	68	-	261	421	265	235	140	-	322	438	374
2/7	92	218	441	878	193	67	346	449	848	199	323	134	788	449	228	196
3/7	101	174	415	579	185	58	173	411	996	600	209	141	547	364	335	430
4/7	96	125	159	170	131	128	255	251	430	414	300	108	347	327	411	302
5/7	175	148	353	298	71	51	166	267	763	697	325	116	417	456	376	291
8/7	134	105	184	-	158	85	223	467	360	232	276	53	743	940	549	283
9/7	187	158	313	235	183	74	216	262	392	263	211	87	552	767	507	341
10/7	158	148	267	276	208	73	289	209	385	254	217	102	490	646	529	279
11/7	194	122	231	834	255	89	334	425	342	236	221	112	563	563	506	424
12/7	130	124	296	443	296	82	325	433	520	241	215	101	742	818	587	393
MEAN	146	154	295	464	194	78	259	344	546	340	253	109	577	565	447	331
CoV.	28%	26%	33%	59%	34%	27%	29%	29%	43%	51%	19%	24%	27%	39%	25%	22%



Coefficients of Variation of travel time between days

Fig. 7.1

7.5 System Performance Measures

Table 7.20 shows the veh-hours/hour for each link during the period 4-6.30 p.m., obtained by multiplying each element in Table 7.18 by the corresponding element in Table 7.19 and dividing by 2.5 x 3600. The row sums then give the total veh-hours/hr spent in the network. Looking at these row totals, one can see that after the first two days of automatic control during which it was known that the settings were non optimal, and many changes were still being made to them, the veh-hours spent in the network fell markedly (4th July) to the lowest figure of the experiment even though total input flows were highest on that day. The subsequent rises on Friday 5th and Monday 8th were doubtless in part caused by the higher than normal number of incidents occuring on those days, as listed in 7.1. The last four days of the experiment, under police manual control, on which no serious incidents occurred, incurred on average 5.7% more veh-hours/hr than the 5 automatic days.

Table 7.21 shows veh-km/hr for each link during the period 4-6.30, obtained by multiplying each element in Table 7.18 by the length of its link.

Each element of Table 7.21 is then divided by the corresponding element of Table 7.20 to produce Table 7.22 showing the mean system speeds on each link. The averages column of Table 7.22 is the result of dividing the row totals of Table 7.21 by the row totals of Table 7.20, and gives the average system speed on the network. From this it can be seen that the mean system speed under automatic control, (7.68 kph) is 4.3% faster than the mean system speed (7.37 kpm) during the subsequent four days of manual control. If however we exclude the two Mondays from comparison, on the basis that total travel (in veh-km) was substantially lower on those days and data was missing for day 1, we obtain the results of Table 7.23.

TABLE 7.20 RAMA 4 EXPERIMENT VEH HRS/HR 4.00-6.30 p.m.

DATE	SIP				SUR				SIL				SAT				TOTAL
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
1/7/85	120	90	-	-	111	35	-	218	99	139	102	158	-	225	297	318	
2/7/85	60	93	118	391	93	36	100	353	322	98	133	155	387	270	200	177	2986
3/7/85	66	77	110	263	86	33	44	327	343	324	94	160	243	257	293	383	3103
4/7/85	62	56	46	84	63	73	71	210	152	221	138	128	155	225	372	280	2336
5/7/85	105	63	97	188	31	27	40	211	248	371	123	128	215	301	350	246	2744
8/7/85	87	44	62	190*	71	45	60	324	101	123	110	55	275	697	376	227	2847
9/7/85	124	70	88	122	88	42	60	226	112	142	108	106	275	555	353	320	2791
10/7/85	103	65	79	149	99	40	82	183	74	119	120	125	234	483	374	260	2589
11/7/85	128	56	68	384	128	51	97	347	116	127	112	135	269	409	357	405	3189
12/7/85	76	57	84	218	131	49	87	348	200	134	103	115	350	631	381	359	3323

* ESTIMATED FROM 5/7/85

TABLE 7.21 RAMA 4 EXPERIMENT VEH. KMS/HR 4.00 - 6.30 p.m.

DATE	SIP				SUR				SIL				SAT				TOTAL
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
1/7	1370	881	683	1458	617	656	543	1808	490	1696	640	1421	1544	1510	2438	2753	20508
2/7	1405	924	641	1283	697	674	681	1698	793	1592	610	1459	1556	1301	3161	2923	21398
3/7	1416	961	636	1309	676	714	599	1717	720	1751	667	1428	1408	1528	3148	2885	21563
4/7	1404	966	699	1419	689	714	653	1807	738	1730	680	1499	1417	1487	3260	3007	22169
5/7	1298	916	655	1365	634	683	569	1709	681	1723	558	1390	1633	1425	3351	2735	21325
8/7	1404	906	800	1452	645	669	632	1497	587	1712	589	1314	1174	1603	2468	2604	20056
9/7	1441	959	674	1500	691	707	660	1860	595	1751	758	1529	1577	1564	2508	3041	21815
10/7	1404	942	709	1550	683	693	671	1890	403	1784	817	1544	1506	1615	2544	3017	21772
11/7	1421	986	705	1327	722	725	685	1764	709	1747	750	1521	1515	1568	2539	3092	21776
12/7	1263	995	679	1416	639	750	635	1738	802	1805	710	1431	1495	1666	2340	2958	21322

TABLE 7.22 RAMA 4 EXPERIMENT LINK TRAVEL SPEEDS KM/HR 4.00-6.30 p.m.

DATE	SIP				SUR				SIL				SAT				AVERAG
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
1/7	11.42	9.79	-	-	5.56	18.74	-	8.29	4.95	12.20	6.27	8.99	-	6.71	8.21	8.66	
2/7	23.42	9.94	5.43	3.28	7.49	18.72	6.81	4.81	2.46	16.24	4.59	9.41	4.02	4.82	15.81	16.51	7.17
3/7	21.45	12.48	5.78	4.98	7.86	21.64	13.61	5.25	2.10	5.40	7.10	8.93	5.79	5.95	10.74	7.53	6.95
4/7	22.65	17.25	15.20	16.89	10.94	9.98	9.20	8.60	4.86	7.83	4.93	11.71	9.14	6.61	8.76	10.74	9.49
5/7	12.36	14.54	6.75	7.26	20.45	25.30	14.23	8.10	2.75	4.64	4.54	10.86	7.60	4.73	9.57	11.12	7.77
8/7	16.14	20.59	12.90	7.64	9.08	14.87	10.53	4.62	5.81	13.92	5.35	23.89	4.27	2.30	6.56	11.46	7.04
9/7	11.62	13.70	7.66	12.30	7.85	16.83	11.00	8.23	5.31	12.33	7.02	14.42	5.73	2.82	7.10	9.50	7.82
10/7	13.63	14.49	8.97	10.40	6.90	17.33	8.18	10.33	5.45	14.99	6.81	12.35	6.44	3.34	6.80	11.60	8.41
11/7	11.10	17.61	10.37	3.46	5.64	14.22	7.06	5.08	6.11	13.76	6.70	11.27	5.63	3.83	7.11	7.63	6.83
12/7	16.62	17.46	8.08	6.50	4.88	15.31	7.30	4.99	4.01	13.47	6.89	12.44	4.27	2.64	6.14	8.24	6.42

TABLE 7.23 Linked Junctions Results Summary

Dates	veh-km/hr	Index	Km/hr	Index
9-12 July (Police)	2973	100	7.29	100
2-5 July (Auto)	2792	94	7.74	106
4 July (Auto)	2336	79	9.49	129

This shows that for the four automatic days Tuesday-Friday, total travel time was 6% lower and average system speed 6% higher than on the four police days. This is despite the fact that the automatic days included 2 July '85 on which the signal settings were clearly non-optimal, 3 July '85 when the main output from the system to the east was blocked for approximately 7 minutes at the height of the peak, and 5 July on which there was a half hour tropical rainstorm and a subsequent half hour reduction in output on one arm caused by parents collecting children from school. There were no serious incidents on police days 9-12 July.

On 4 July, there were also no serious incidents, and although total travel was 3% higher than average, total travel time (veh-hr/hr) was reduced by 21% and system speed increased by 29%. This suggests that in incident-free conditions, substantial savings in travel time are possible.

7.6 Queue lengths

Queue lengths were recorded primarily for the benefit of the police, as the opinion of both JMP and OCMRT engineers was that the police would be more convinced by a shortening of queues (which were clearly visible) than a shortening of journey times. The method employed to estimate queue lengths is described in section 6.3. During the days of automatic control, it was possible for one person to estimate the queue lengths on 6 links from one elevated position (Montien Hotel) because the synchronisation enabled the observer to look at each queue in turn, knowing when the start of green on each link was about to occur. During manual control, however, this was obviously impossible, and an extra person was therefore required at this location.

Table 7.24 shows a summary of the results of the queue length surveys, giving median queue lengths at the start of green during the period 4.00 - 6.30 pm on Wednesday through Friday automatic and manual. Some data is missing, and the interpretation of that which exists is not straightforward. Table 7.25 shows, according to the queue length and the travel time survey, whether police or auto control was best on each link. Comparing the two

Wednesdays, we find that the queue length survey is in agreement with the travel time survey (table 7.20) with regard to which is the better day, on 8 arms, and disagrees on 5, with missing data on the rest. For the two Thursdays there is agreement on 7 and disagreement on 8, and for the two Fridays 10 agree and 6 disagree. It would seem therefore that there is little correspondence between the two surveys which is disappointing but not surprising given the difficulties of estimating queue lengths with any accuracy and the fact that different observers on different days may, for example, have slightly different interpretations of exactly where is "the back of the queue" and exactly where are the mid points, quarter points etc. of each link.

Table 7.24 Queue length survey results summary. Percentage of link length queued at start of green (Median 4 - 6.30)

Date	SIP				SUR				SIL				SAT			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
W 3.7.85	30	60	45	40	75	80	25	50	-	60	-	40	-	90	65	150
Th 4.7.85	20	20	30	20	50	60	25	40	25	60	100	55	-	80	60	130
F 5.7.85	70	50	50	30	30	90	30	40	60	70	100	70	50	30	100	150
W 10.7.85	50	20	30	15	50	60	40	40	55	100	55	40	50	55	95	140
Th 11.7.85	40	70	45	20	60	100	70	50	33	100	75	40	30	90	90	130
F 12.7.85	50	70	35	20	60	90	55	50	50	100	80	40	60	80	90	150

Table 7.25 Comparison of queue length and travel time surveys showing best day (P = Police, A = Auto) according to Tables 7.20 and 7.24

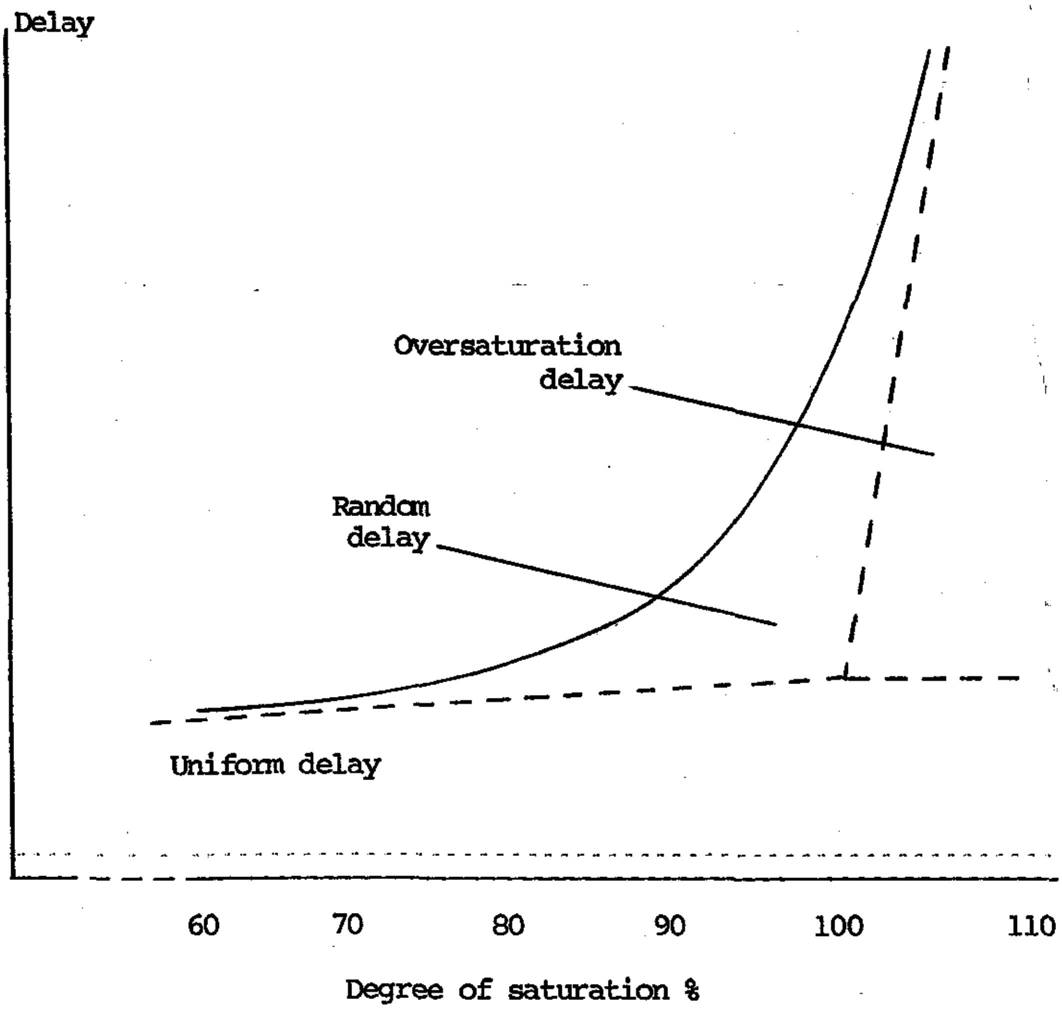
Date		SIP				SUR				SIL				SAT			
		N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
W	Q	A	P	P	P	P	P	A	P		A		=		P	A	P
	TT	A	P	P	P	A	A	A	P	P	P	A	P	P	A	A	P
Th	Q	A	A	A	=	A	A	A	A	A	A	P	P		A	A	P
	TT	A	=	A	A	A	P	A	A	P	P	P	A	A	A	P	A
F	Q	P	A	P	P	A	=	A	A	P	A	P	P	A	A	P	=
	TT	P	P	P	A	A	A	A	A	P	P	P	P	A	A	A	A

8. Conclusions

8.1 Discussion of Results

Comparing Tuesday - Friday under automatic control with the same days under police control, veh-hours/hr were reduced by 6% and speeds increased by 6%. this is a rather modest improvement, partly due to the fact that serious incidents were more common during the automatic days. If the only incident-free automatic day is compared to the average police days an improvement of 21% in veh-hrs, and 29% in speeds, is observed perhaps indicating the potential benefits to be obtained if police were redeployed to deal with incidents more speedily. In summary then, the reduction in delay achieved by co-ordinated fixed time control over police control, although substantial, was not as high as one normally associates with the introduction of UTC systems.

FIGURE 8.1 Traffic Delay on a Link



The reason for this can perhaps best be explained by reference to Figure 8.1 (Vincent et al (1980)). This figure shows the relationship between delay and degree of saturation for one approach to an isolated fixed time junction. The 'uniform' and 'oversaturated' elements of delay are those which would be incurred if the input flow in every cycle was the same. The 'random' delay element is that attributable to the fact that flow varies between cycles. The relative size of these elements obviously depends on the amount of variation in the traffic flow, but it can be seen that the random element is at a maximum around 100% saturation. It can also be seen that, at degrees of saturation around 100%, very small changes in input flow or saturation flow will produce large changes in the delay.

This, of course, assumes that the timings are fixed. At police controlled signals in Bangkok we have a situation where the degree of saturation is close to 100%, but because the policeman can respond immediately to variations in input or saturation flow, the random element of delay is substantially reduced. Hence, even if he is imposing a greater uniform delay than necessary (by the use of over-long green times for instance), the total delay imposed by a reasonably competent policeman will be less than that imposed by a correctly set fixed time automatic controller. This explains why even our best efforts at the isolated intersection imposed more delay than the police. Moving to a network of junctions, however, the balance changes in favour of fixed time control because of the benefits of co-ordination which the police are unable to achieve.

Table 8.1 summarises these points, and also shows an advantage which both police and UTC operation have over isolated or cableless linked fixed time control, namely the ability to use any sequence of stages. This can be an important advantage where, for example, at SIL, (the critical junction of the four) the normal police sequence allows the southern approach to run twice per cycle. This is a sensible compromise between a very long green (which would entail a drop in saturation flow because of upstream constrictions) and a much shorter cycle time with consequent loss in overall capacity.

TABLE 8.1 Comparison of Signal Control Systems

	Worst	---		Best
	Unlinked Fixed time	(Bangkok) Police Controlled	Co-ordinated Fixed time Automatic	UTC system
Optimised for average flows	Yes	No	Yes	Yes
Short term response to flow variations	No	Immediate	No	No
Long term response to changes in flow	Periodic updates	Immediate	Periodic updates	More frequent updates
Co-ordination	No	No	Yes	Yes
Choice of sequences	Limited by controller	Unlimited	Limited by controller	Limited only by central computer

8.2 Further Analysis

The experiments have demonstrated that automatic control is capable of controlling traffic even with saturation levels of virtually 100%, variable flows and frequent incidents. It was noticeable, however, that several adjustments had to be made to the timings calculated by standard analysis tools, and that occasional incidents might well encourage local staff to introduce manual operation. Work will be starting soon on a further project which will concentrate on these issues. In particular it will pursue three areas of study.

The first concerns the determination of signal settings which are sensitive to a range of flows. It is clear that the range of input flows observed, particularly for the linked junctions, would in practice merit a range of signal settings. In a fixed time system, such variations are not practicable, and the settings selected could be determined on a number of different bases. One possibility is to use average flows, but this could lead to excessive delays on high flow days. Another is to use the maximum flows, but it may well be that different distributions of flow arise even for a given high total flow. A third is to develop timings which minimise the delay experienced over the range of conditions. It is on the last of these that further analysis is concentrating. For a seminal paper on this issue see Heydecker (1986).

The second concerns the calculation of offsets. When junctions are saturated, progression in the normal sense is impossible, since each vehicle will be delayed for a cycle at each junction. The key requirement, instead, is to avoid queues disrupting upstream junctions and, if possible, to reduce the number of standing waves in a queue. Detailed observation indicated that problems did not occur in junctions provided that the tail of the queue was moving by the time that the stage for its main feed ended. If stationary vehicles remained in the junction, other drivers were encouraged to enter the junction illegally, and other movements were disrupted. Attempts were made to increase the offset on the shortest link to avoid this happening, but were not wholly successful because queue lengths fluctuated considerably from cycle to cycle. The whole of this length was filmed, and the film will be analysed further to identify a basis for offset calculation. On longer links queue lengths were rarely sufficient to block junctions, but it was noticeable that queue formation was impaired when a standing wave occurred. This suggests determining offsets so that the new platoon joins the queue just as it starts to move, in accordance with the advice of TRB/NCHRP Report 194 (Pignataro et al 1978). As part of these offset recalculations it is intended to assess the need for gating of flows, and the most appropriate basis for doing so.

The third deals with incident management. Experience suggests that capacity reducing occurences are likely to be frequent, and that at high levels of saturation, they will have potentially serious effects on congestion. If police can be diverted from regular manual control, there is a clear merit in using them to avoid incidents occurring and to assist them in determining when to intervene and how to do so. As an input to this process it is intended to use the video record to provide advice, and to test the effects of a range of intervention tactics.

8.3 Summary

The major conclusions from the study to date are:

i) it is possible to use automatic control of traffic signals in the conditions observed, which are among the most congested in the world;

ii) while the travel time savings at an isolated junction may be small or non-existent, the benefits of achieving good co-ordination at a complex set of junctions are likely to be substantial; analysis suggests that a saving of up to 10% may be achievable, and it is probable that there are further savings from reduced variablity;

iii) a further major benefit is in the release of police manpower for other duties; it appears in particular that there is merit in diverting their attention to the enforcement necessary to avoid congestion-inducing incidents or to mitigate their effects;

iv) while standard analysis tools provide a suitable starting point for determining timings, considerable further adjustment is likely to be required; means of improving the initial predictions are being investigated;

v) the major emphasis in highly congested conditions must be on queue regulation, and existing analysis procedures need to be modified to deal more adequately with queue prediction and limitation;

vi) at levels approaching 100% saturation, performance is very dependent on fluctuations in traffic conditions and on the occurrence of incidents; further work is needed to develop methods for determining delay-minimising settings for such conditions;

vii) the substantial variations in flows from day to day and month to month, coupled with the sensitivity of performance to such variations, place major demands on survey design;

viii) the use of video-based survey techniques was of considerable benefit in simplifying data collection, permitting flexibility in analysis, and providing illustrative material for training purposes.

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Appendices

A. Experimental Method

A.1 Typical Survey Day

Table A.1 below shows the list of personnel involved in the survey during the manual control days and (starred) the automatic control days. The timetable for a typical survey day during automatic control follows.

TABLE A.1 List of Survey Personnel on Site

NAME	AFFILIATION	SURVEY JOB	LOCATION
F O MONTGOMERY	ITS LEEDS	OVERALL SUPERVISION/Q LENGTHS	ROOF CATHAY TRUST
* PROF A D MAY	" "	" " "	FIRE ESCAPE MONTIEN
R D BRETHERTON	TRRL	" " "	ROOM IBM
* PROF J H JONES	AIT BANGKOK	ADVICE	NOT FIXED
CHAMROON	OCMRT	OVERALL STAFF SUPERVISION; LIAISON WITH ENGINEERS & POLICE	FIRE ESCAPE MONTIEN
* SANGUAN	OCMRT	I/C OF SIP JUNCTION	AT CONTROLLER
* TONG	"	" " " "	"
* CHAMCHAI	"	I/C OF SUR JUNCTION	"
* PHUMPHAN	"	I/C OF SUR OR SIL "	"
* SUPACHAI	"	I/C OF SIL	"
* SUJIN	"	I/C OF SAT	"
* KITTI	"	ASSIST TO RDB	ROOF IBM
* KALYA	"	ASSIST TO FOM	ROOF CATHAY TRUST
* TONGPREO	"	ASSIST ADM/CHAMROON	FIRE ESCAPE MONTIEN
4 SUPERVISORS	"	SUPERVISION OF STAFF	VARIOUS
30 STAFF	"	INPUT COUNTS; TRAVEL TIMES	VARIOUS

* automatic days only

TYPICAL SURVEY DAY DURING AUTOMATIC CONTROL

9.00	ALL	Arrive OCMRT office, offload 4 VCR machines
9.15	FOM	Check tapes properly recorded
9.15	ALL	Discuss previous day's results
9.30	FOM	Start copying of one tape from Beta-VHS
10.00	ALL	Decisions on strategy for today
11.50	ALL	Agree plan for day with OCMRT engineers
12.00	ALL	Lunch
13.00		Load equipment to vehicle
14.15	FOM/ADM/RDB + 2 OCMRT	Leave for Montien viewpoint
14.15	Other OCMRT engineers	Leave for respective sites
14.45	FOM	Drop ADM + 1 OCMRT at Montien with equipment
14.55	OCMRT	Arrive at controllers
14.55	FOM	Drop RDB + equipment at IBM. Set up camera
15.00	30 survey staff	Arrive at OCMRT - briefing
15.10	FOM	Arrive with 1 OCMRT at Cathay Trust Bldg. Set up camera
15.15	30 survey staff + 4 supervisors	Leave OCMRT for sites in 2 minibuses
15.15	OCMRT engineers	Synchronise controller clocks and activate settings
15.25		All cameras in position
15.45		Start video recording
15.55	30 survey staff	Arrive on site
16.00	" " "	Start recording
18.30	ALL	Finish surveys and video recording. Pack up camera equipment
18.40	Survey staff	Hand over data to junction supervisor. Then go home
18.40	ADM	Walk to Mandarin Hotel lobby
18.50	FOM	Pick up RDB and camera equipment at IBM
18.55	Supervisors	Supervisors deliver data to ADM in Mandarin Hotel lobby
19.00	FOM/RDB	Pick up cameras and 2 OCMRT at Montien
19.10	FOM/RDB	Arrive Mandarin Hotel. Brief discussion of events
19.15	Supervisors OCMRT engineers	Return to OCMRT by minibus
21.00		Copy one videotape Beta-VHS overnight.

A.2 Location of Survey Personnel

Figure A.1 shows the location of all the survey staff, supervisors, OCMRT engineers etc.

A.3 Survey Equipment

The equipment for the survey comprised 4 vehicles, 30 digital watches, 14 tally counters, 40 clipboards, 8 two-way radios, 4 sets of video camera/recorder, 40 x 3 hour video cassettes.

Vehicles

The 30 survey staff plus the 4 supervisors were picked up each day at OCMRT and taken to the sites in two Songtau (converted pick-up truck). These were hired locally on a contract basis at ฿200 per trip.

Most of the OCMRT engineers went to the site in an official OCMRT minibus (pool vehicle with staff driver).

The UK contingent plus up to 2 remaining OCMRT engineers used the principal investigator's own car.

Digital Watches

These were required for all survey staff, to maintain co-ordination. Eleven had already been obtained for the isolated junction experiment, and the balance were purchased locally at approximately ฿160 each.

Tally Counters

Approximately 10 were borrowed from AIT stocks, the remainder were borrowed from OCMRT.

Clipboards

Approximately 10 were borrowed from AIT, 15 from OCMRT, and 15 purchased specially.

Two-way Radios

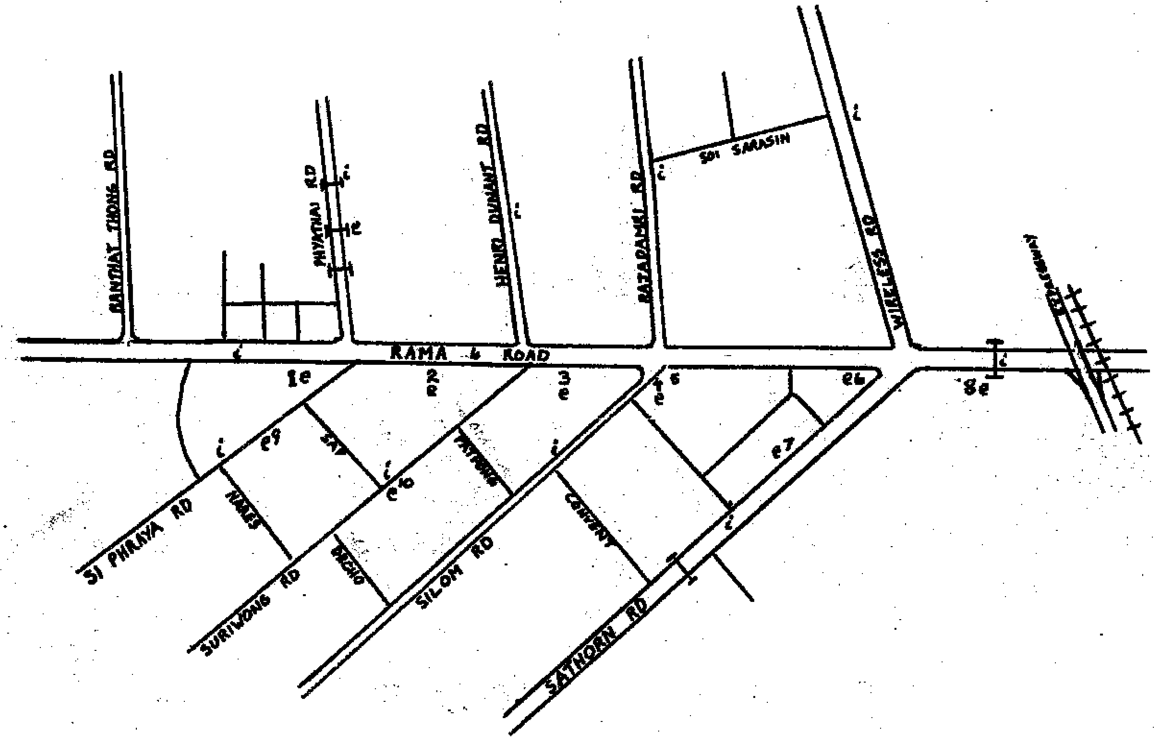
OPP owned a total of 9 two-way radios, and 8 of these were made available for use on the survey.

Video Cameras etc.

The project already owned one video camera and two portable VHS recorders. A further three cameras and two recorders were hired from the Audio Visual Unit of AIT for the duration of the experiment, for ฿7000. One problem was that the two recorders on hire were Beta-format (there were no VHS portables available for hire). It was therefore necessary to copy each of the Beta-tapes on to VHS, to

LOCATION OF SURVEY STAFF

FIG A.1



KEY:

1. MANDARIN HOTEL
2. MONTIEN HOTEL
3. CHARN ISSARA TOWER
4. IBM BUILDING
5. DUSIT THANI HOTEL
6. CATHAY TRUST BUILDING
7. THAI FARMERS BANK
8. JARDINE'S
9. KAESIRI MOTORS
10. OCEAN INSURANCE

i INPUT COUNTS
e ELEVATED OBSERVERS

maintain compatibility. This process was done as far as possible during the survey (in the mornings and overnight) so that only 10 Beta-tapes were actually required, earlier ones being re-used. The Beta-tapes were borrowed from AIT. The 40 VHS tapes (3 hours each) were purchased locally at ฿175 each approximately.

B. Abbreviations

AIT	Asian Institute of Technology, Bangkok
BMA	Bangkok Metropolitan Authority
BMTA	Bangkok Mass Transit Authority
ERTAT	Expressway and Rapid Transit Authority of Thailand
ITS	Institute for Transport Studies, University of Leeds
JMP	Jamieson Mackay & Partners (Now JMP Consultants Ltd.)
LTOR	Left turn on Red
OCMRT	Office of the Committee for the Management of Road Traffic (part of OPP)
OPP	Office of Policy and Planning, Ministry of Interior, Bangkok
SERC	Science and Engineering Research Council, UK
TPD	Traffic Police Division
TRRL	Transport and Road Research Laboratory, UK

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