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CONTROL OF CONGESTION IN HIGHLY SATURATED NETWORKS

Development of Signal Timings

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CONTROL OF CONGESTION AT HIGHLY SATURATED NETWORKS:

DEVELOPMENT OF SIGNAL TIMINGS

1. Introduction

1.1 Context

This working paper is one in a series of four describing a study of the control of traffic congestion in a network of highly saturated signalised junctions in Bangkok. Other papers in the series are:

WP 248: Survey Design and Data Collection
250: Incidents and their Management
251: Experimental Results and Conclusions

The study itself was a follow-up to a previous study already 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 tha 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 attempt 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) was introduced as described in this paper, in order that a range of offsets can be specified which will avoid blocking of upstream junctions during critical parts of the cycle yet still allow optimisation within these constraints. Testing the usefulness of this modified TRANSYT program was one of the several aims of this follow-up study.

1.3 <u>Objectives</u>

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/8C program to a network of roads in which blocking of several junction 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.

1.4 Scope of Paper

WP 248 has described the collection and analysis of the standard data input requirements for the TRANSYT program. This paper now describes the new method of calculating options for signal timings which best avoid upstream junction blocking (i.e. Version 8C) and these are compared with the timings under (manual) police control, and with those timings which the standard version 8 of TRANSYT would normally recommend. A list of the junctions in the study area of Bamrungmuang and Luang Roads and their relative locations are shown in Table 1 and Figure 1. Figure 2 shows the layout and signal stages at each junction.

Table 1

List of Junctions

Survey No.	Description	ATC No.
1	Bamrungmuang/Manachai	70
2	Bamrungmuang/Worachark	44
3	Bamrungmuang/Yokhol 2	160
4	Bamrungmuang/Plupplachai	161
5	Bamrungmuang/Krungkasem	2
6	Luang/Mahachai	112
7	Luang/Worachark	80
8	Luang/Yokhol 2	30
9	Luang/Plupplachai	29
10	Luang/Krungkasem	114

2. TRANSYT/8 Analysis of September 1986 Data

(a) Cycle Time - the link flows from the data collected during September 1986 have been used in several TRANSYT/8 runs with various cycle times and flow levels. Figure 3 shows a plot of Performance Index against cycle time for a range of flow levels from 90% to 115% of the recorded flow levels.

At 100% flow level the optimum cycle time is 90 seconds. At 110% flow level the optimum cycle time (in terms of minimum 'Performance Index') is 110 seconds. The shape of the Curves illustrate how too short cycle times cause relatively larger increases in the Performance Index value compared with an over-estimated cycle time. Initially, given that the police used much longer cycle times in this area, it

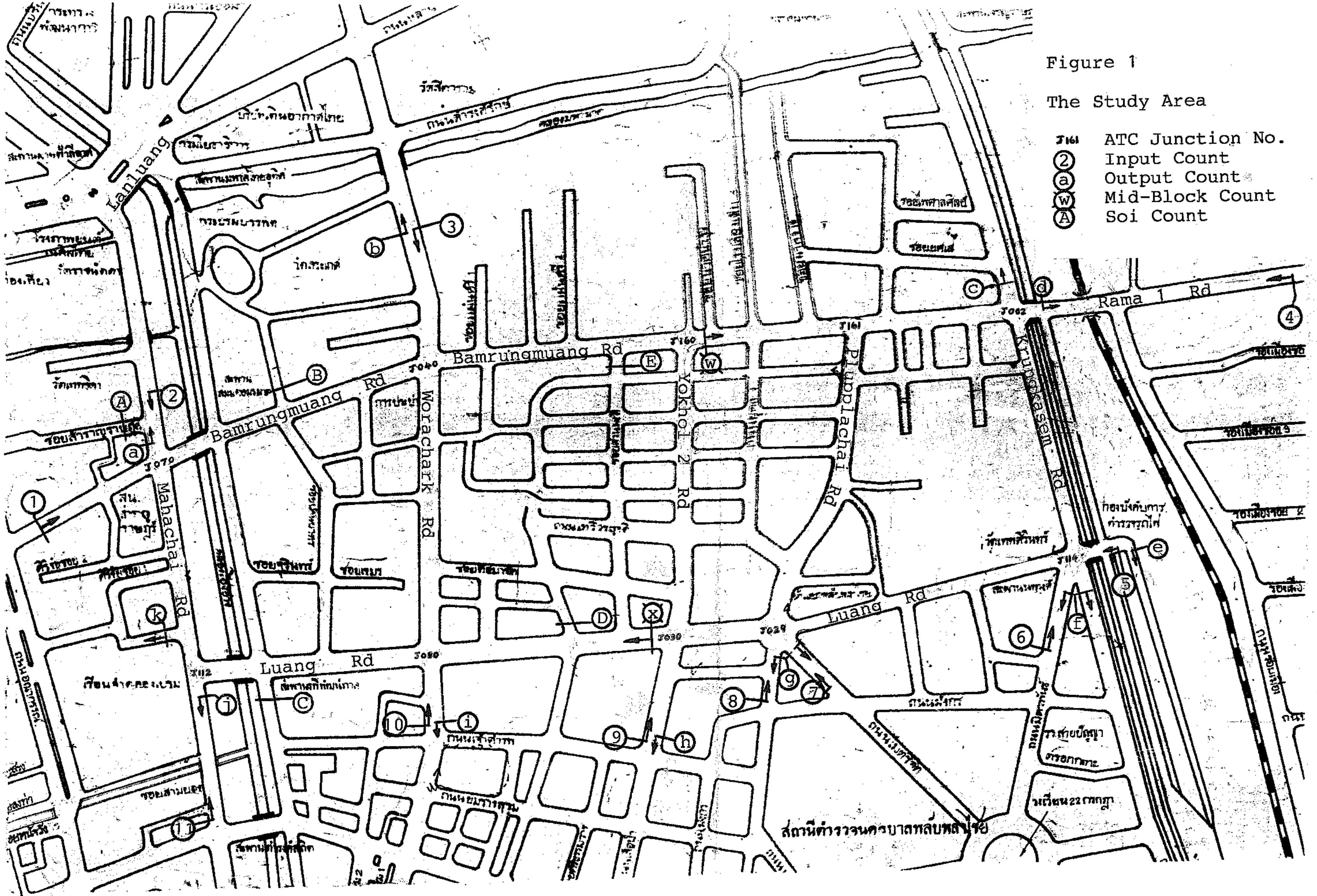


Figure 1

The Study Area

FIGURE 2 - LAYOUT OF JUNCTIONS AND SIGNAL STAGES

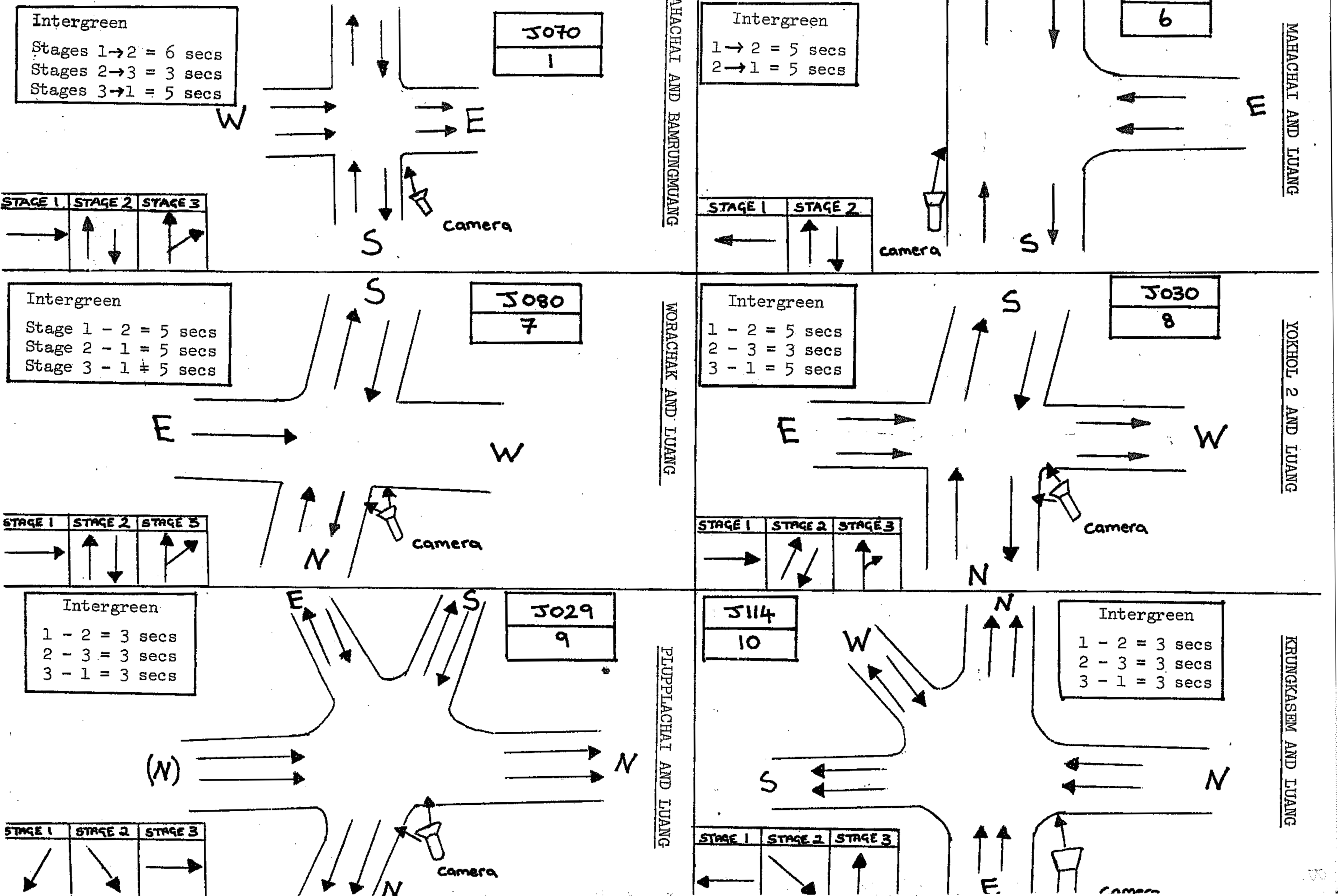


FIGURE 2 - CONTINUED

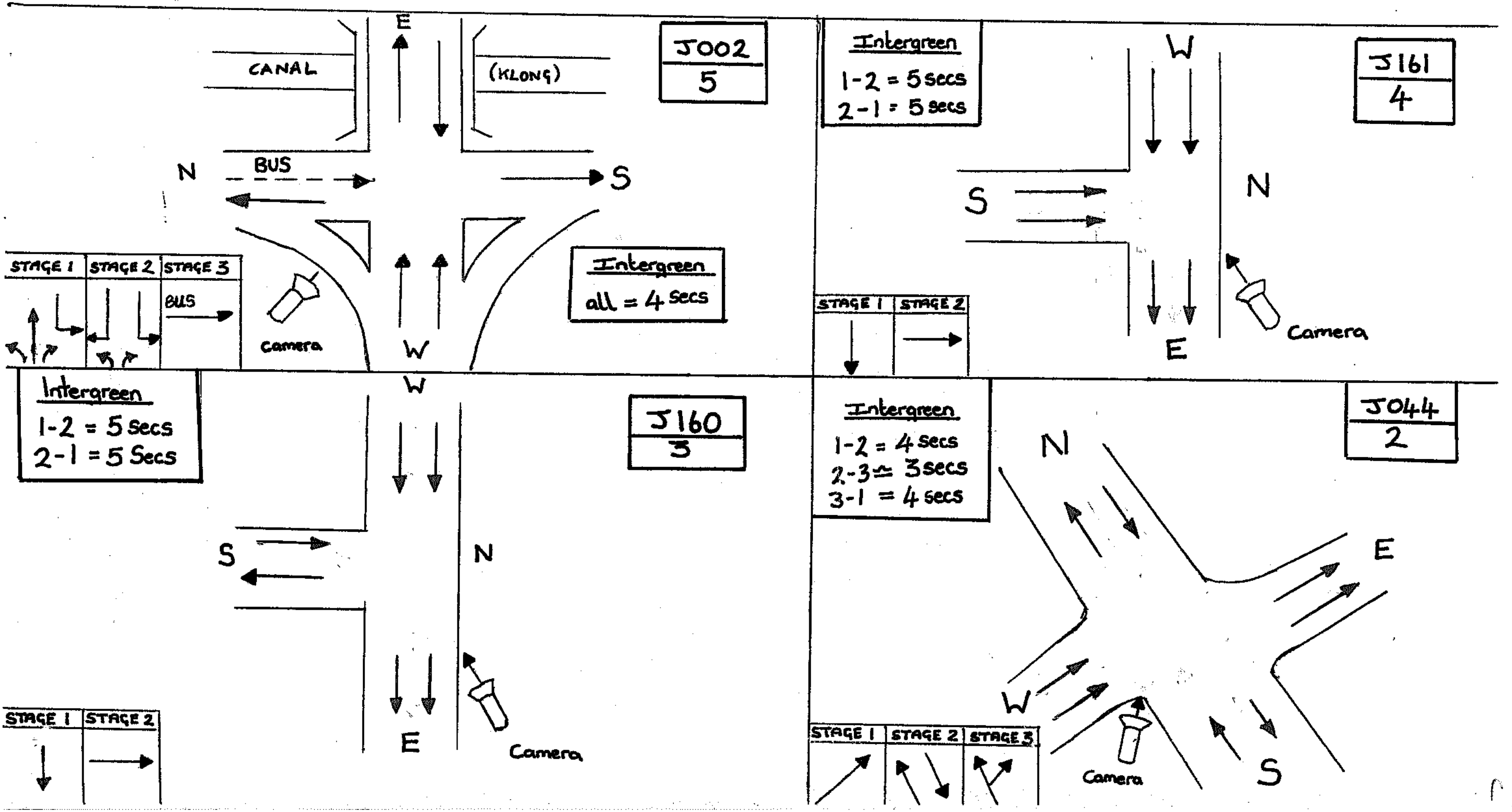
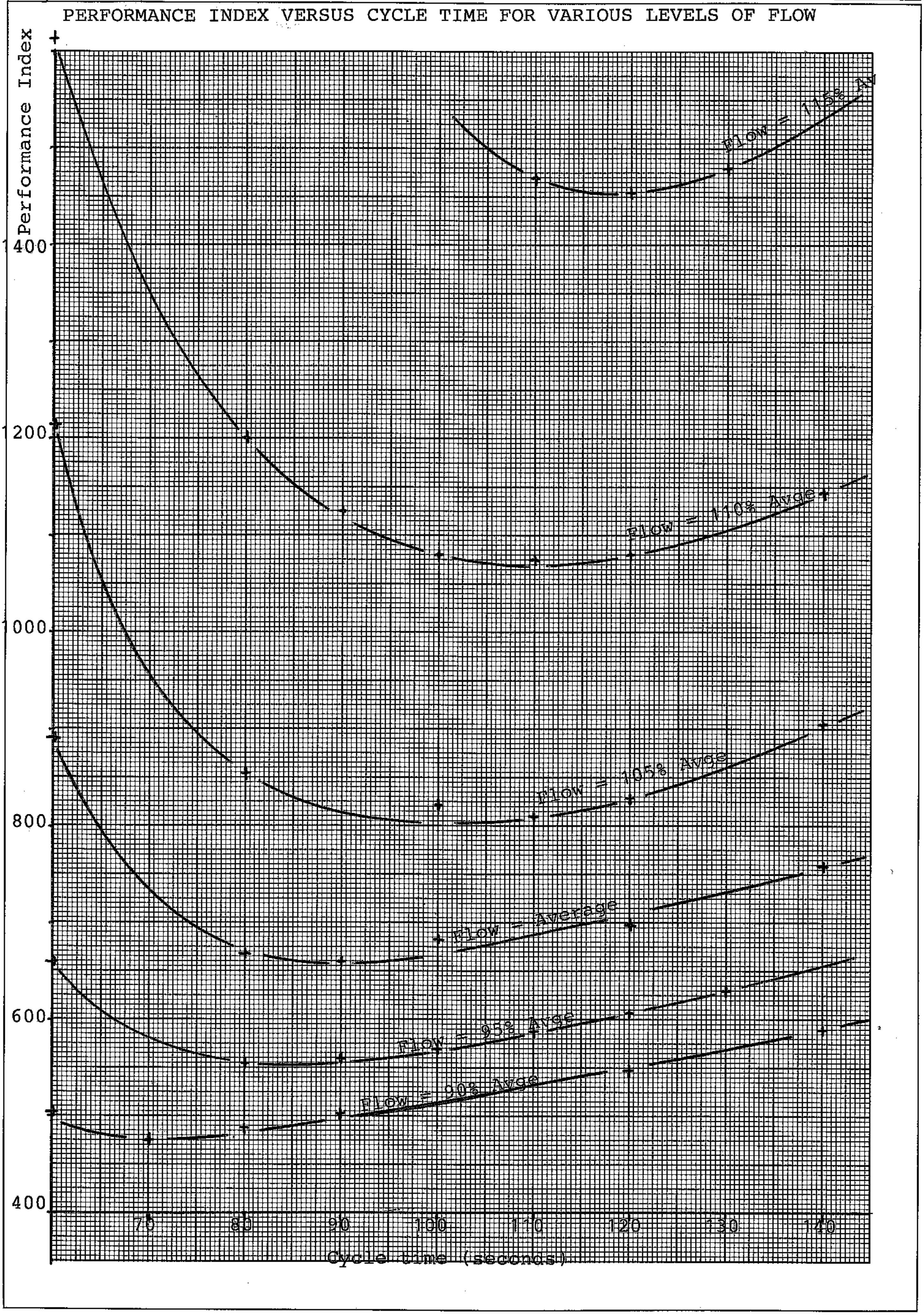


Figure 3


PERFORMANCE INDEX VERSUS CYCLE TIME FOR VARIOUS LEVELS OF FLOW
Performance Index
1400
1200
1000
800
600
400
70
80
90
100
110
120
130
140
Cycle time (seconds)
Flow = 115% Av
Flow = 110% Avge
Flow = 105% Avge
Flow = Average
Flow = 95% Avge
Flow = 90% Avge

seemed sensible to choose a 120 second cycle time.

(b) Signal Timings - The TRANSYT/8 recommended timings for 120 second cycle time at 100% flow level are listed below in Table 2.

Table 2

TRANSYT/8 Recommended Timings (120 sec. cycle)
September 1986 Flows

Junction	Stage 1			Stage 2			Stage 3		
	A	B	C	A	B	C	A	B	C
1 (70)	89	58	(.48)	27	32	(.27)	59	30	(.25)
2 (44)	2	58	(.48)	60	45	(.38)	105	17	(.14)
3 (160)	24	77	(.64)	101	43	(.36)			
4 (161)	49	85	(.71)	14	35	(.29)			
5 (2)	18	65	(.54)	83	45	(.38)	8	10	(.08)
6 (112)	101	43	(.36)	24	77	(.64)			
7 (80)	37	60	(.50)	97	60	(.50)			
8 (30)	6	59	(.49)	65	46	(.38)	111	15	(.13)
9 (29)	52	35	(.29)	87	32	(.27)	119	53	(.44)
10 (114)	89	50	(.42)	19	29	(.24)	48	41	(.34)

Notes:

A = Stage Start Time (sec)
B = Stage Length (sec)
C = % of Cycle

Performance Index = 695.5

Table 3 shows the average cycle time and split of the cycle time at each junction under police control on the particular day that each junction was video-filmed during September 1986.

Table 3

Manual Control During September 1986 Survey

4 to 5.30 p.m.

Film Date	Junction	Average Cycle (Secs.)	Stage 1	Stage 2	Stage 3
15/9/86	1 (070)	153	(.47)	(.26)	(.27)
12/9/86	2 (044)	130	(.45)	(.40)	(.15)
11/9/86	3 (160)	170	(.67)	(.33)	
10/9/86	4 (161)	262	(.75)	(.25)	
9/9/86	5 (002)	361	(.56)	(.36)	(.08)
16/9/86	6 (112)	118	(.53)	(.47)	
19/9/86	7 (080)	181	(.52)	(.48)	
22/9/86	8 (030)	105	(.48)	(.36)	(.16)
17/9/86	9 (029)	105	(.30)	(.27)	(.43)
18/9/86	10 (114)	120	(.42)	(.27)	(.31)

A comparison of Tables 2 and 3 reveals that TRANSYT/8 generally recommended splits of the cycle time similar to those used by the police, which suggests that the model is a reasonable representation of the actual network. It is noticeable, however, that the police gave proportionately more time to the main west-east movement along Bamrungmuang Road (Stage 1) at junctions 3 (J160) and 4 (J161). This was because these two junctions were frequently blocked by a queue from the critical junction, number 5 (J002). The manner in which the police arranged the offsets between these junctions is described next. In the meantime, the difference between the splits at junctions 3 and 4 serves as an early illustration of the shortcoming of TRANSYT/8 recommended timings under highly saturated conditions.

3. Police Operation On Bamrungmuang Road

Junctions 3 (J160) and 4 (J161) are inextricably linked to junction 5 (J002), which is the 'critical' junction because each junction provides an almost continuous feed of vehicles into J002. In peak periods this results in the inevitable jamming of upstream junctions. Just before a stopping wave arrives at J161 from the start of red at J002, the points policeman will ensure that at J161 Stage 1 (west to east) has priority. The green is then at J161 extended to cover the blocked period, while still allowing vehicles to continue to the free right and free left turns at J002. The same stopping wave moves back along Bamrungmuang Road from J002 through J161 and continues to J160. J160 is often on automatic control but the points policeman sometimes intervenes and he ensures that Stage 1 (west to east) is given priority during the blocked period. Again the green period is extended to cover this blocking at J160 and in this case vehicles turning right to the south should be free to move. When the west to east movement at J 002 receives the green signal, there is then a period when vehicles can exit from the network and the points policemen usually alternate between stages at J161 and J160 until a stopping wave again arrives from J002. Figure 4 illustrates the typical arrangement of police control under incident-free conditions. Table 3 shows how the different average cycle times at J002, J161 and J160 reflect the police operation.

Under automatic control it is not possible to vary the cycle time at a single junction and it is not common practice to operate adjacent intersections on different cycle times unless the cycle time is doubled or halved. But the arrangement under police control does indicate the blocking arrangement which is likely to be most acceptable. Namely, to block during Stage 1 at J161 and block Stage 2 at J160. (If Stage 2 at J160 is blocked by the stopping wave caused by Stage 2 at J161, then it is expected that the second stopping wave coming back from J002 should block J160 during its Stage 1.) This and other possible combinations have been tried using TRANSYT/8C on the updated March 1987 flows.

4. <u>Input Flows Update</u>

The input flows collected during September 1986 and used above for the initial data input into TRANSYT have been reported in WP 248. Immediately before the main experiment it was necessary to update the input flows. During March 1987 the input flow survey was repeated on five days (Monday to Friday) between 3.30 p.m. and 6.00 p.m. Table 5 shows a comparison between September 1986 and March 1987 flows. Figure 1 shows the location of the count stations.

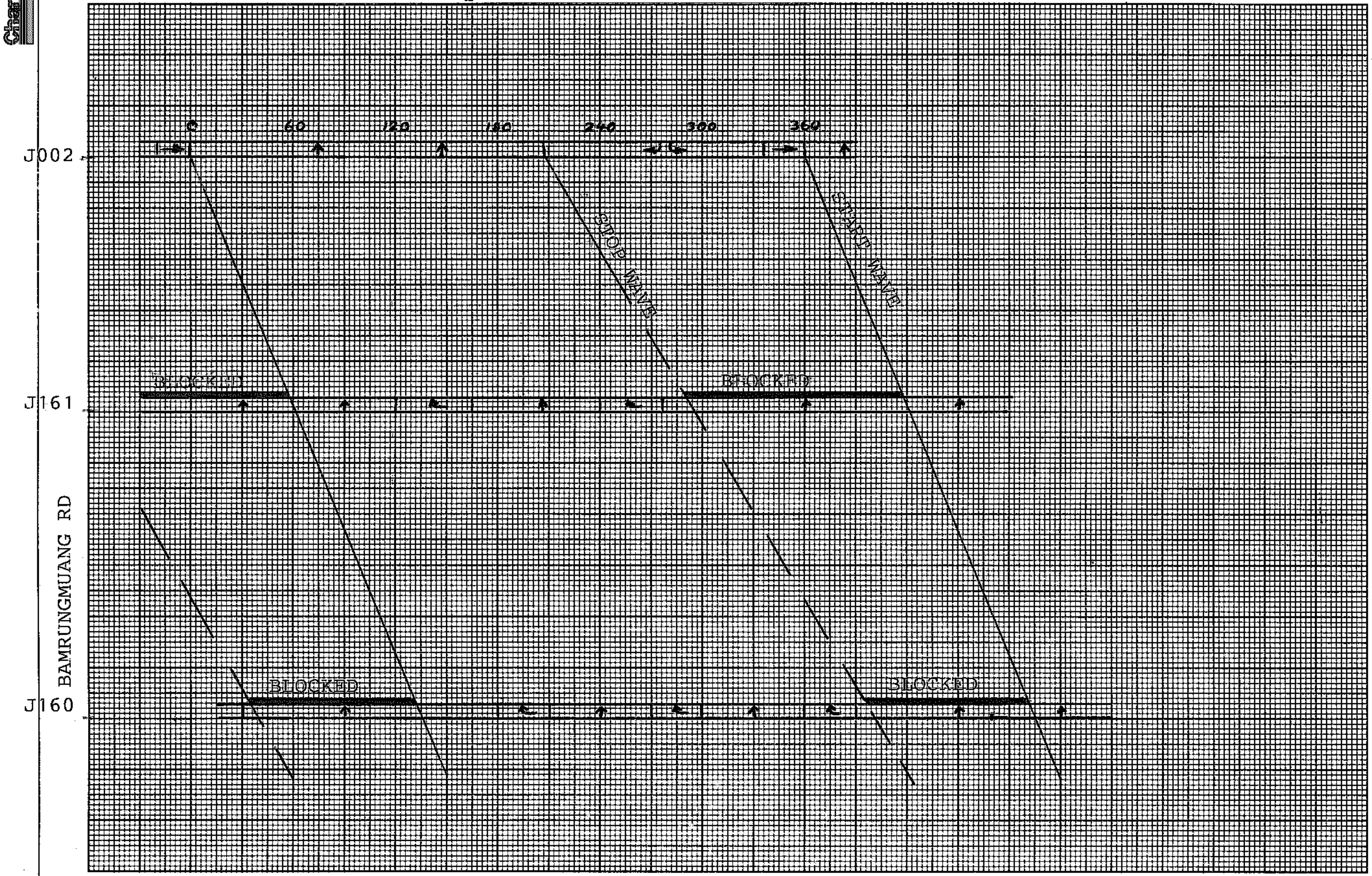
<u>Table 5</u>

<u>Input Flows - All Vehicles Except Motorcycles</u>

Count Station	September 1986 Peak Hour	March 1987 Peak Hour	March - September
A	1486	1359	- 127
B	873	844	- 29
C	1762	1788	+ 16
1	2310	2370	+ 60
2	805	722	- 83
3	428	306	- 122
4	738	667	- 71
5	703	776	+ 73
6	656	747	+ 91
7	476	405	- 71
8	1098	1050	- 48
Total	11335	11024	- 311

There was an overall decrease in 3% between September 1986 and March 1987. However during the September surveys it was known that several inputs required some adjustment because several 'Soi' movements between the count station and the junctions were later identified. There was generally a slight increase in the input flow from the east and south-east and the peak hour was later during March (i.e. March peak hourly flow was 16.30 to 17.30 while the September peak hour was 16.00 to 17.00). This

FIGURE 4 - TYPICAL SEQUENCE UNDER POLICE CONTROL



difference can be explained by the fact that the March flows were collected during the school holiday period (because the main experiment in automatic control was scheduled to take place during the long school holiday).

5. TRANSYT/8C Analysis of March 1987 Flows

a) CARD TYPE 39 - Constraints on the offset between a pair of junctions can be included in the modified TRANSYT procedure by using the new data entry card type 39. In order to accurately specify the minimum and maximum acceptable offset, which should avoid upstream junction blocking, it is necessary to obtain an estimate of the blocking periods. This requires some measure of the speed of starting waves and, if possible stopping waves, and it is essential to know the length of the stage at the downstream junction which would cause the upstream blocking. The procedure for using card type 39 is thus as follows:

1. Run TRANSYT/8 without card type 39.

2. Run TRANSYT/8C a second time including:

   - an estimated extra blocking period added to the start lag for each appropriate link.

   - a card type 39 which specifies the offset range for pairs of junctions.

   - a set of initial stage change times specified in card types 12 to 15. These times should be taken from the first TRANSYT output but some alteration might be necessary to ensure that the offsets between stage change times are within those constraints specified in card type 39.

b) JUNCTION BLOCKING - Four of the ten junctions in the study area experience blocking during the evening peak period. These are junctions 4 (J161), 3 (J160), and occasionally, junction 2 (J044) on Bamrungmuang Road and junction 9 (J029) on Luang Road. The time for a starting wave to move back from each downstream stopline to upstream stopline was measured by elevated observer, and the average times are listed in Table 6. Where possible stopping wave times were also measured.

Table 6

Starting and Stopping Waves

Junction From	Junction To	Average Start Wave (Secs)	Average Stop Wave (Secs)
J002	J161	65	78
J161	J160	70	93
J160	J044	99	-
J030	J029	35	98

Deciding on which stage(s) at an upstream junction should or should not be blocked by a queue in an oversaturated link is more complicated for junctions 4 (J161) and 3 (J160) compared with junctions 2 (J044) and 9 (J029). It was clearly essential at the latter two junctions to avoid the situation whereby a queue on the main east-west blocked the cross movements to the north and south. This is very similar to the situation experienced on Rama IV Road (see Technical Note 224). In some respects Bamrungmuang Road was not the best choice for testing the timings recommended by TRANSYT/8C because the two most frequently blocked junctions were in fact the 'T' junctions; namely Plupplachai Road (J161) and Yokhol 2 Road (J160). In these two instances the so-called cross movements actually flow directly into the main west-east movement. Consequently a strategy which avoids blocking of the cross movement at these junctions only facilitates the flow of vehicles from the south into the main west-east movement, and this only adds to the already large queue on Bamrungmuang. Hence, the benefits from ensuring that cross-moving traffic is not obstructed by stationary vehicles on the main oversaturated links will be reduced at these two important junctions. It was therefore not obvious which of the stages at these two junctions should be blocked in order to minimise overall delay. By using the new card type 39 facility in TRANSYT/8C it was possible to test all combinations of when in each cycle starting and stopping waves should arrive at each junction.

c) BLOCKING COMBINATIONS - Figures 5, 6, 7 and 8 illustrate four possible arrangements at junctions 4 (J161) and 3 (J160). Figures 5 and 6 show that blocking during Stage 2 at J161 would produce only one stopping and starting wave moving back to J160. Here, the extra blocking lag has been added to Stage 2 at J160. If there was a reduction in flow, with a consequently shorter blocked period, then the lower demand from the south at J161 would receive disproportionately long green compared to the main west-east movement.

Figures 7 and 8 demonstrate the effect when the 'blocking' period occurs during Stage 1 at J161. The situation in Figure 7 is undesirable because the longer 'second' blocking period from J002 would arrive at J160 during Stage 2 and result in that stage being severely 'blocked' each cycle. Therefore Figure 8, which reflects the arrangement under police control, could be the best option. It is noted however, that the combination in Figure 6 has the best performance index, but the arrangement in Figure 8 permits vehicles to flow along Bamrungmuang to the uncontrolled left and right turns at junction 5 (J002) even during blocked periods. This was not modelled in TRANSYT, but if it had, it would have improved the performance index for the arrangement of Figure 8. A slight modification was necessary to the TRANSYT/8C run which produced Figure 8 because the estimated blocking period of 30 secs. had to be split between the two stages at J 160 in proportion to their green times. Thus the extra blocking lag for Stage 1 became 20 seconds and 10 seconds for Stage 2.

FIGURE 5 - 'BLOCKING' STAGE 2 (J161) AND STAGE 1 (J160)

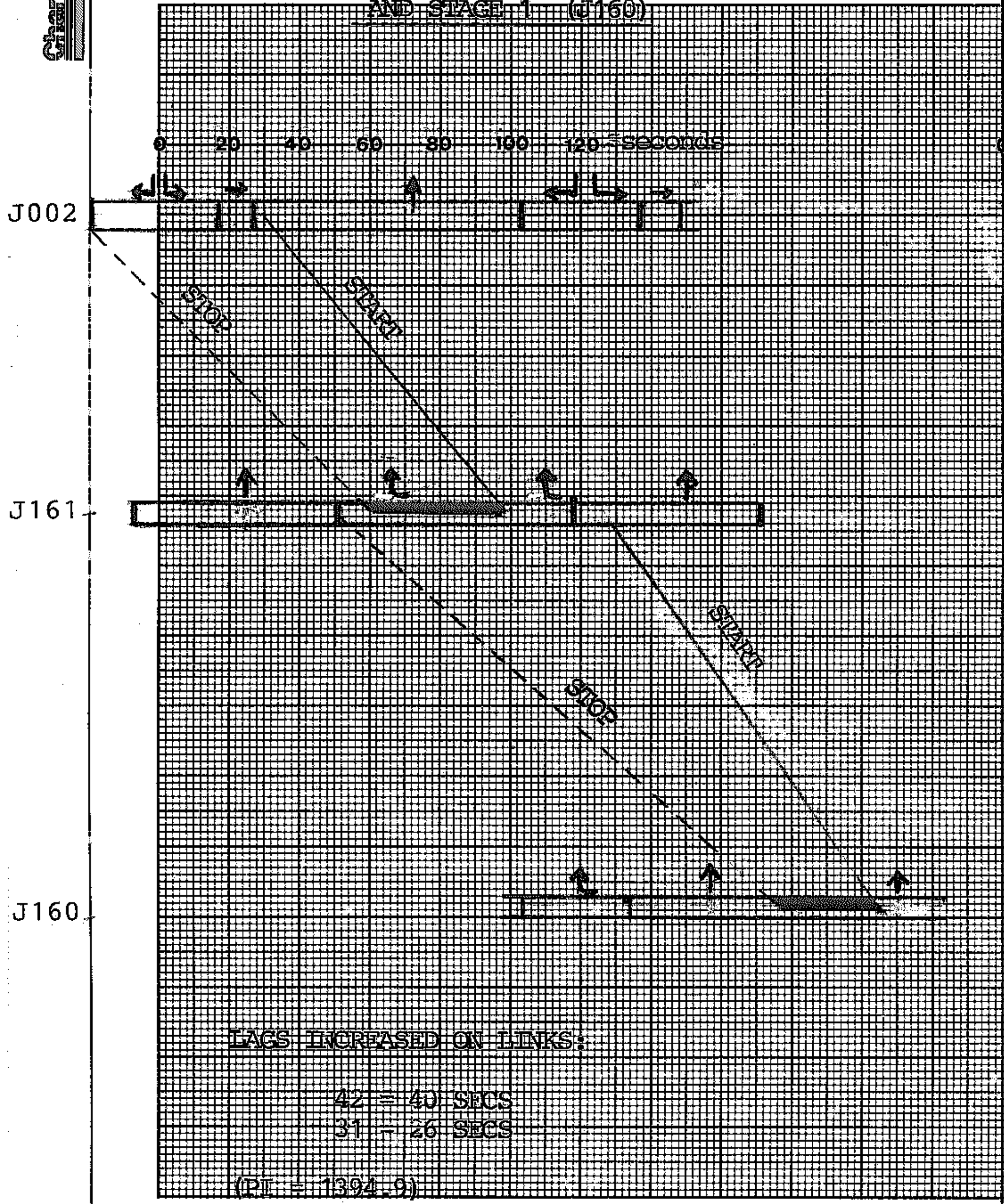


FIGURE 6 - 'BLOCKING' STAGE 2 (J161) AND STAGE 2 (J160)

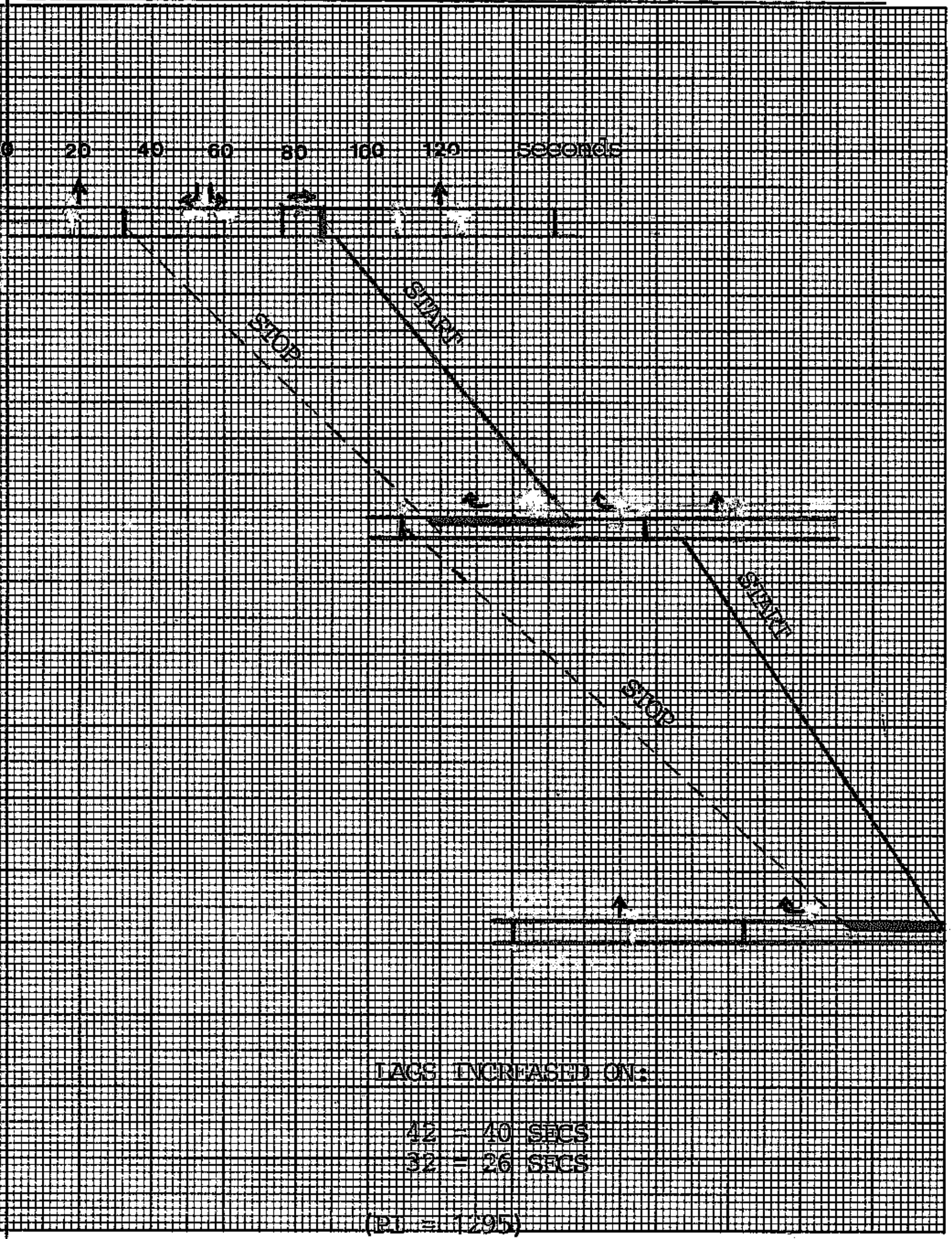


FIGURE 7 'BLOCKING' STAGE 1 (J161) AND STAGE 1 (J160)

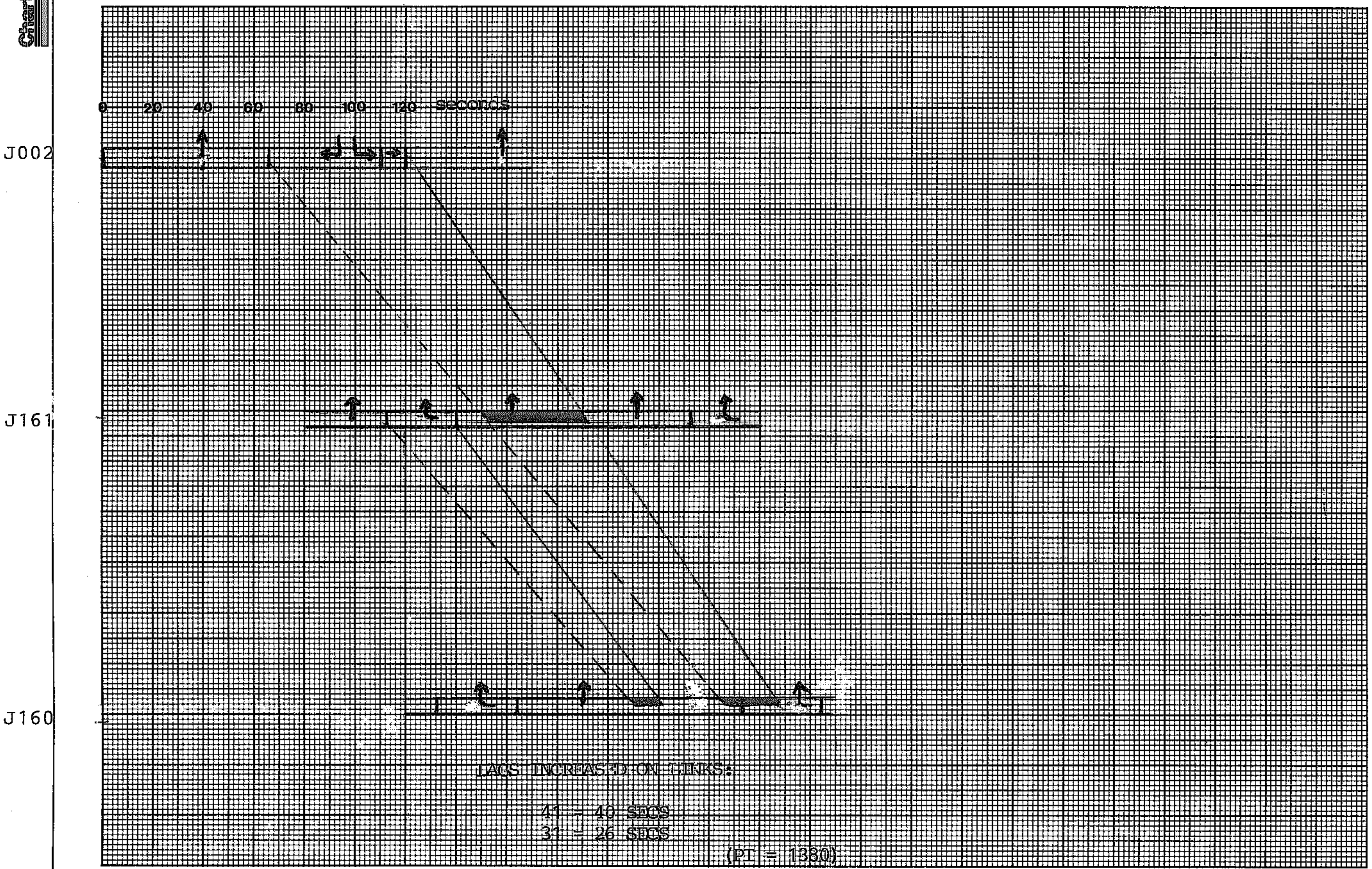


FIGURE 8 'BLOCKING' STAGEE 1 (J161) AND STAGE 2 (J160)

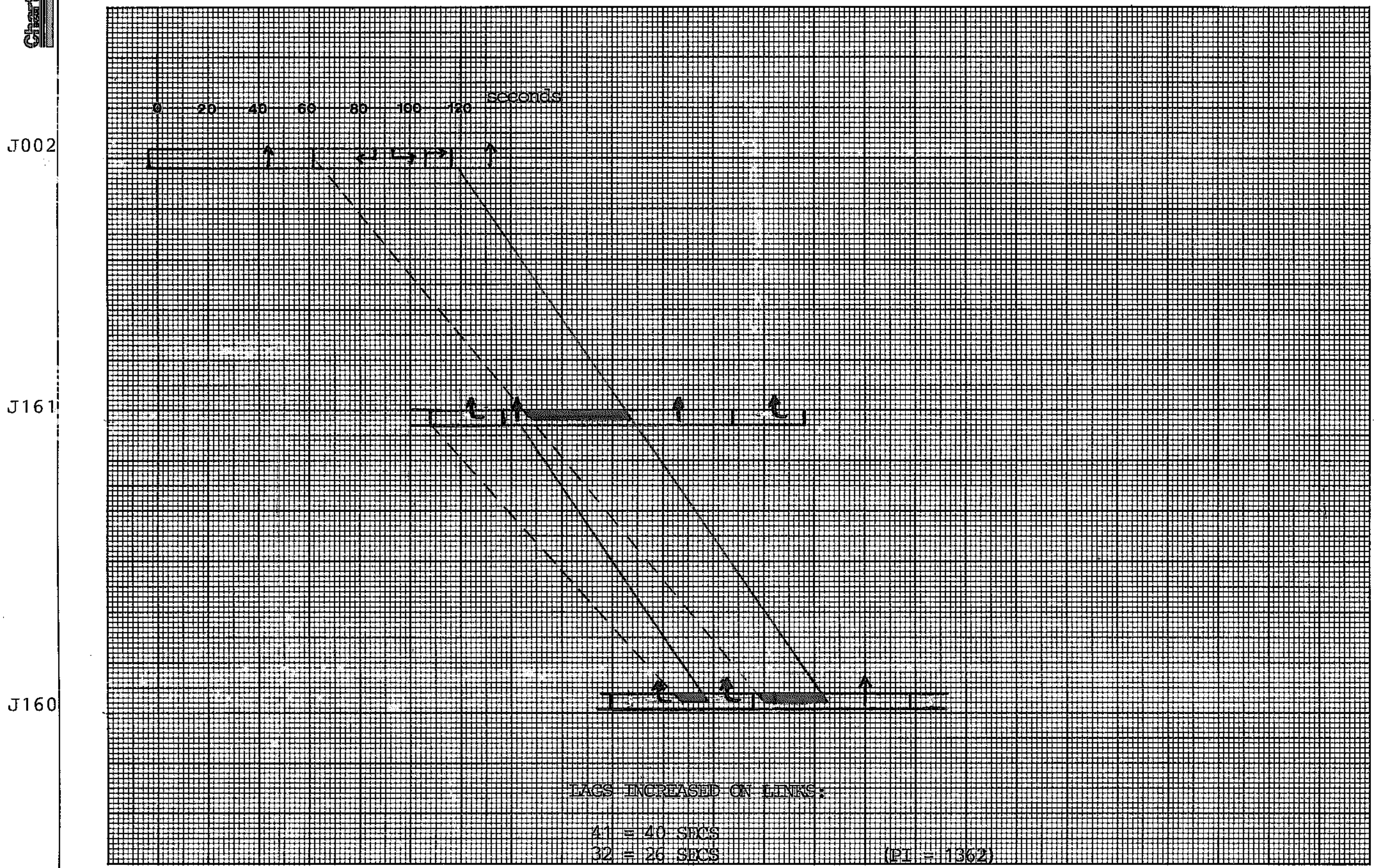


Figure 9 illustrates the finally recommended arrangement for the links between junctions J002, J161, J160 and J044 along Bamrungmuang Road. The recommended signal timings are listed below in Table 7.

Table 7

TRANSYT/8C Recommended Timings (120 sec. cycle) March 1987 Flows

Junction		Stage 1			Stage 2			Stage 3		
		A	B	C	A	B	C	A	B	C
1	(70)	34	54	(.45)	88	34	(.28)	2	32	(.27)
2	(44)	70	62	(.52)	12	44	(.37)	56	14	(.11)
3	(160)	94	80	(.67)	54	40	(.33)			
4	(161)	0	92	(.77)	92	28	(.23)			
5	(2)	2	66	(.55)	68	44	(.37)	112	10	(.08)
6	(112)	88	52	(.43)	20	68	(.57)			
7	(80)	28	58	(.48)	86	62	(.52)			
8	(30)	110	64	(.53)	54	44	(.37)	98	12	(.10)
9	(29)	32	36	(.30)	68	32	(.27)	100	52	(.43)
10	(114)	100	54	(.45)	34	26	(.22)	60	40	(.33)

Notes:

A = Stage Start Time (sec)
B = Stage Length (sec)
C = % of Cycle

In Figure 9 the 'starting' wave can be seen to arrive at J044 during the stage for the main west to east feed, hence avoiding any 'blocking' of north to south movements. Figure 10 shows the similar arrangement between junctions 29 and 30.

FIGURE 9 - BAMRUNGMUANG ROAD

TRANSYT/9 RECOMMENDED TIMINGS J002/J161/J160/J44

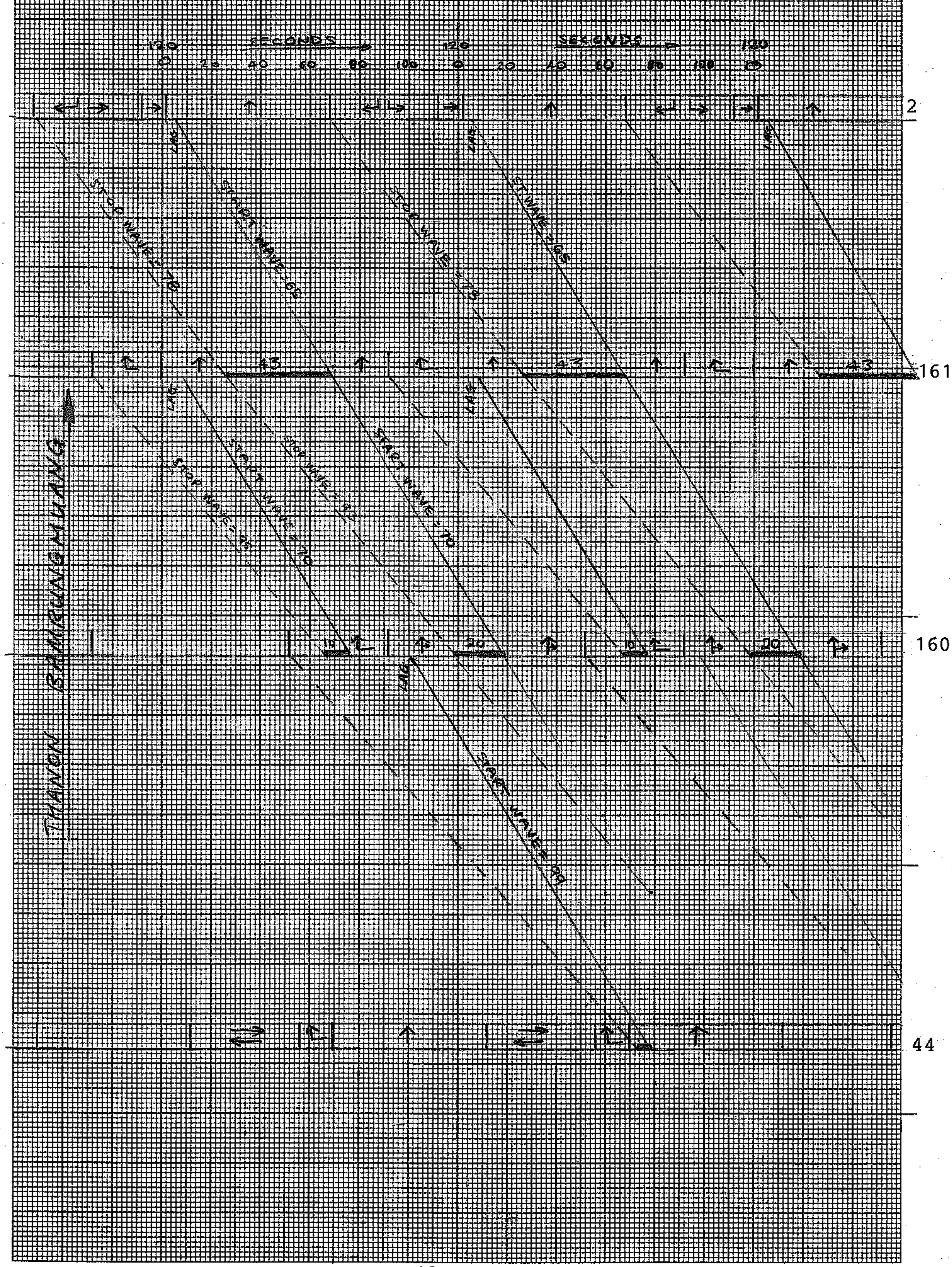
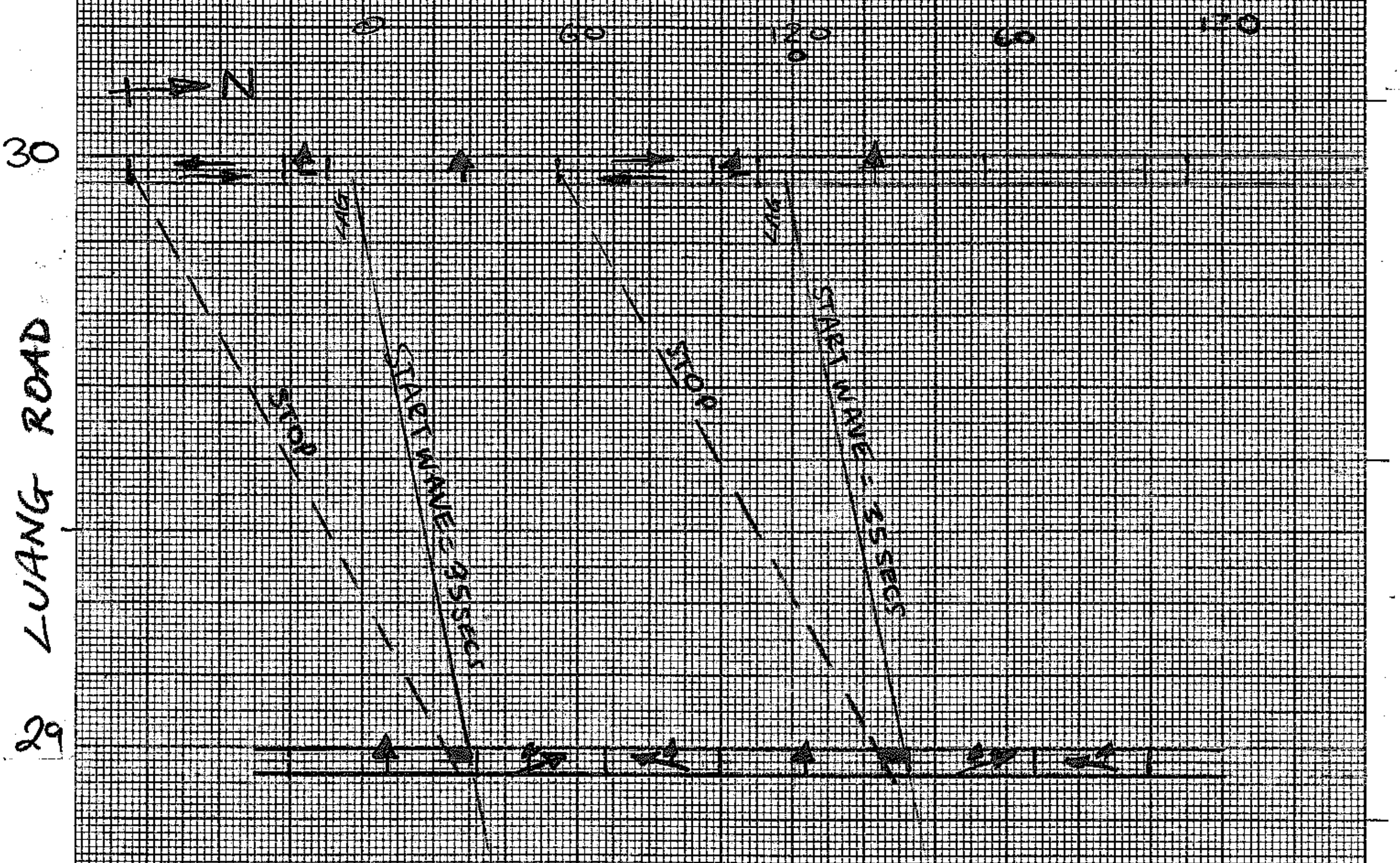


FIGURE 10 - TRANSYT/9 RECOMMENDED TIMINGS

LUANG RD - J030 TO J029



6. TRANSYT/8 Recommended Timings for March 1987 Flows

In order to illustrate the usefulness of card type 39 in the new TRANSYT/8C, it is informative to examine the signal timings recommended by TRANSYT/8 (without extra blocking lags or offset constraints). Table 8 lists the stage change times.

Table 8

TRANSYT/8 Recommended Timings (120 sec cycle)

March flows. No blocking lags.

Junction	Stage 1			Stage 2			Stage 3		
	A	B	C	A	B	C	A	B	C
70	94	50	(.42)	24	36	(.30)	60	34	(.28)
44	118	60	(.50)	58	46	(.38)	104	14	(.12)
160	20	80	(.67)	100	40	(.33)			
161	48	82	(.68)	10	38	(.32)			
2	14	64	(.53)	80	44	(.36)	4	10	(.08)
112	94	46	(.38)	20	74	(.62)			
80	28	60	(.50)	88	60	(.50)			
30	116	60	(.50)	56	46	(.38)	102	14	(.12)
29	40	38	(.32)	78	32	(.27)	110	50	(.41)
114	96	62	(.52)	38	22	(.18)	60	36	(.30)

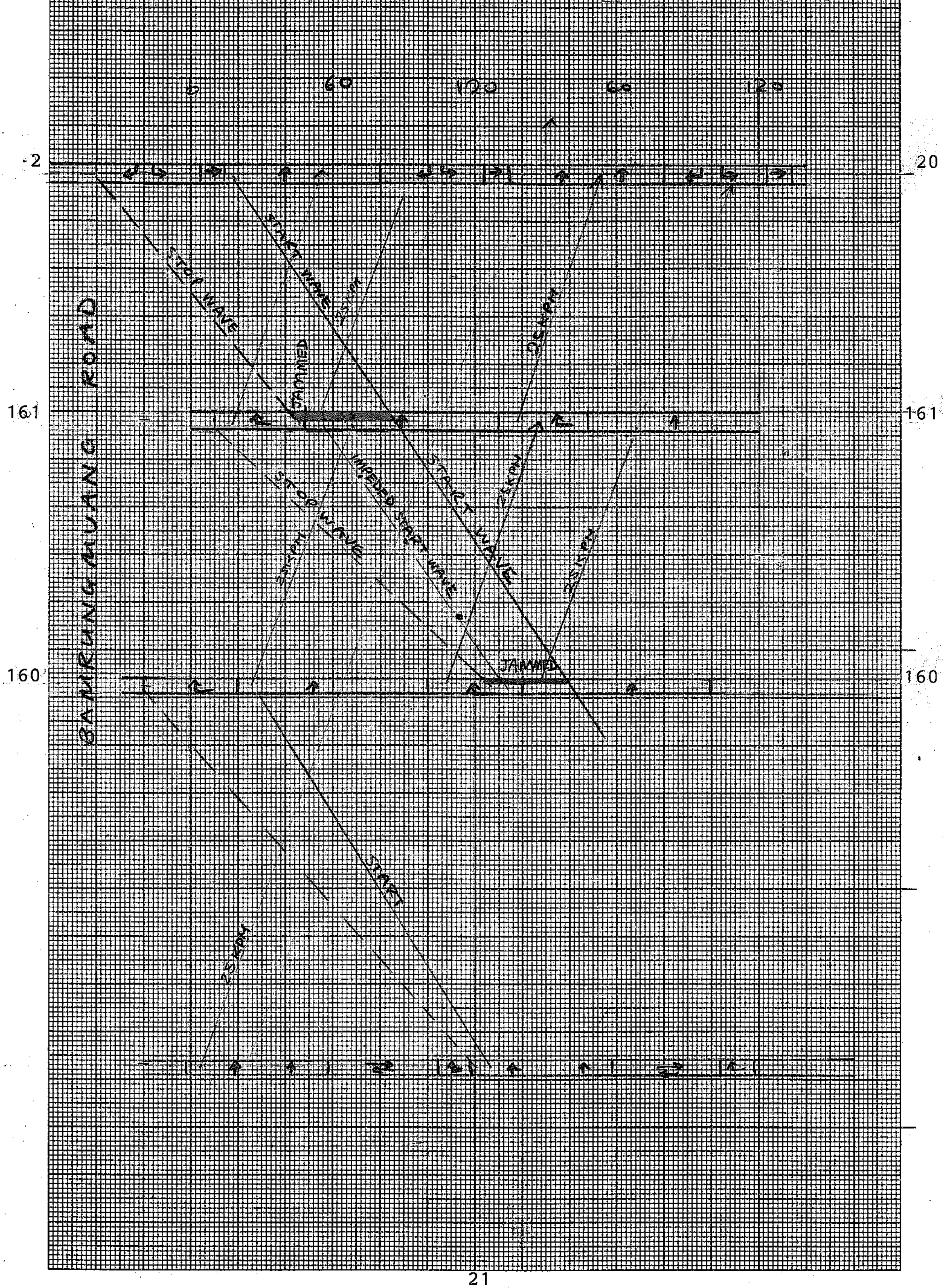
Notes:

A = Stage Start Time
B = Stage Length
C = % of Cycle

The percent of cycle time allocated under TRANSYT/8 is virtually the same as TRANSYT/8C with blocking lags. The main difference is that without the blocking lags, Stage 1 at J161 only receives 68% instead of 77% recommended by TRANSYT/8C with card type 39. This reflects the police arrangements shown earlier in Table 8.

The Space-Time diagram (see Figure 11) illustrates how TRANSYT/8 searches for signal offsets which facilitate progression along Bamrungmuang Road. However we know that the links are oversaturated and that progression in the normal sense is not possible. Consequently the offset recommended by TRANSYT/8 will result in J161 being blocked during a stage change. Similarly, J160 will be blocked during a stage change. It was however observed during the earlier study on Rama IV Road, that blocking during a stage change was the most important situation to avoid, firstly because the movement which had just received green would be unable to move, thus incurring unnecessary delay and spreading the congestion further afield. Secondly, the movements receiving green would usually attempt to enter the junction (specially motorcycles who would find gaps in the blocking flow) thus creating dangerous conflicts. Thirdly, once the starting wave reached the junction and it began to clear, there would often be a few vehicles which would illegally enter the junction on the tail end of the clearing queue thus extending the blocked time

FIGURE 11 – TRANSYT/8 RECOMMENDED TIMINGS – J002/J161/J160/J044



still further. Clearly the offsets must be altered in order to accommodate the stopping and starting waves. This, of course, is the purpose of TRANSYT/8C and card type 39.

7. Longer and Double Cycling Possibilities

a) 240 seconds cycle - The Traffic Police Divisional Commander responsible for junctions in the survey area suggested that 120 seconds cycle time was too short for junction 5 (J002) and he predicted that a large queue towards Rama I Road in the east would result. Police co-operation in the experiment was essential, and it was therefore sensible to calculate other plans based upon longer cycle times, particularly at junction 5 (J002).

TRANSYT/8 has the facility to double - cycle selected junctions. Therefore it was useful to calculate a plan which allocated a cycle of 240 seconds at junction 5 (J002). Figure 12 illustrates how a 240 seconds cycle at J002 would result in the complete blocking of Stage 1 during every second cycle at J161. This suggests that J161 and J160 should also have a 240 seconds cycle time. But this cycle time is too long for J160 where the flow from the south is only 500 vehicles per hour.

Figure 13 shows the possibility of operating 240 seconds cycle time at J002 and J161; and 120 cycle time at J160 and the remaining junctions. It can be seen from the figure that the offset at J160 would have to be finely adjusted in order that the two stopping and starting waves arrived at junction 160 at the desired point in each cycle.

The above arguments illustrate the complexity of the situation on Bamrungmuang Road, and it is evident that junction 4 (J161) and 3 (J160) are in fact tied to junction 5 (J002) by the blocking periods caused by the movement of stopping and starting waves emanating from the stage changes at this critical junction.

b) 180 seconds cycle - The cycle time recommended by the TRANSYT 'cycle time selection' option using March 1987 flows, was 90 seconds with a cycle of 180 seconds at junction 5 (J002). Figure 3 confirms that 90 seconds would, in theory, be the optimal cycle time for the study area.

During April 1987 meetings were held at Plupplachai Police Station between the Principal Researcher and the Commander of Traffic Police responsible for 8 of the junctions in the study area. (Junctions 1 and 6 are the responsibility of Sam-ran-Rat Police Station.) The Commander, was aware of the need to control queues in order to avoid upstream junction blocking and he had little difficulty in understanding the concept of stopping and starting waves. Meetings were often held at the station for discussion amongst the officers on how to best deal with the queues which resulted from the over-saturated conditions. Consequently the police in this area of Bangkok provided a

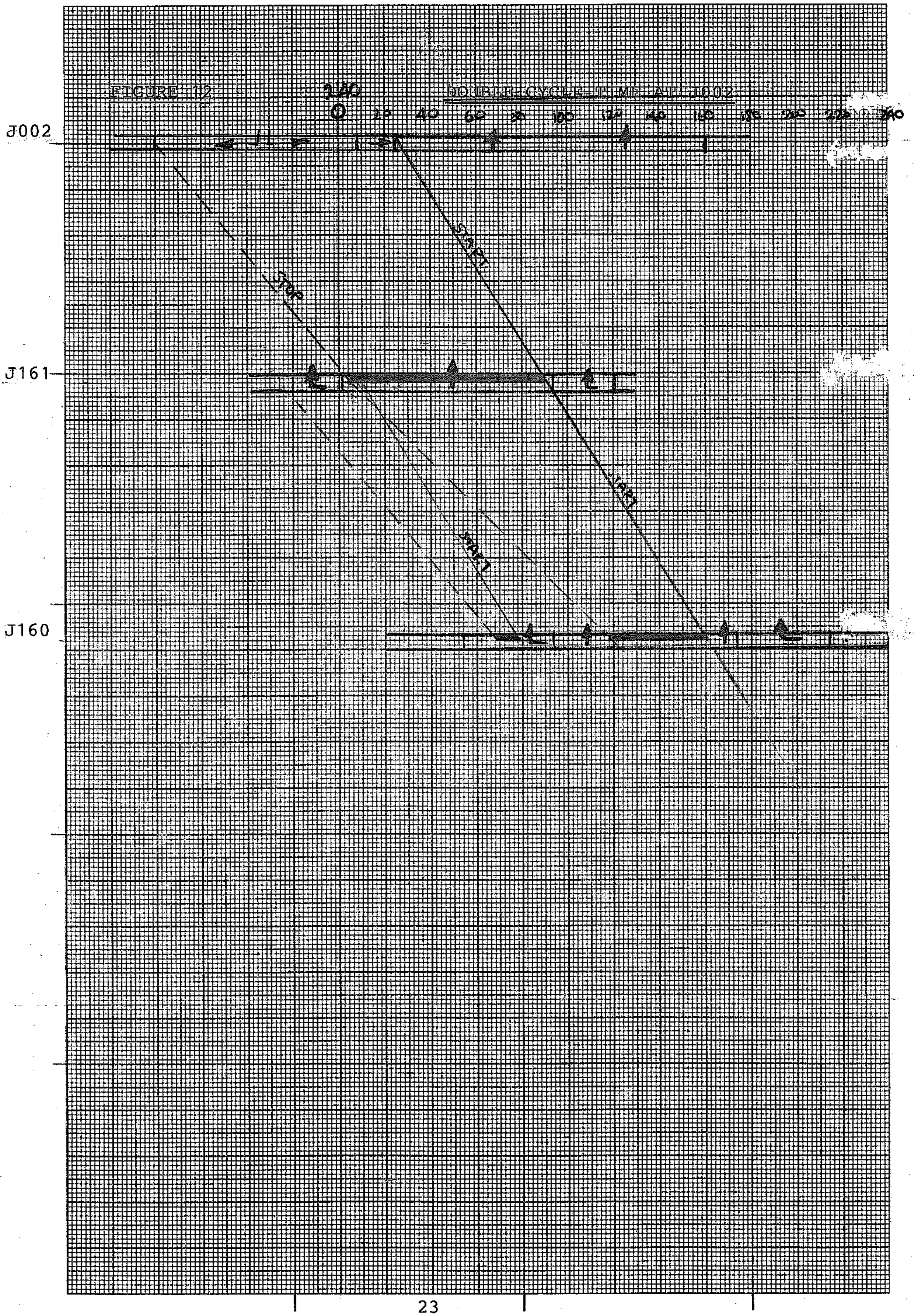


FIGURE 12
2A0
DOUBLE CYCLE TIME AT J002
0
20
40
60
80
100
120
140
160
180
200
220
240
J002
J161
J160
START
STOP
START
START

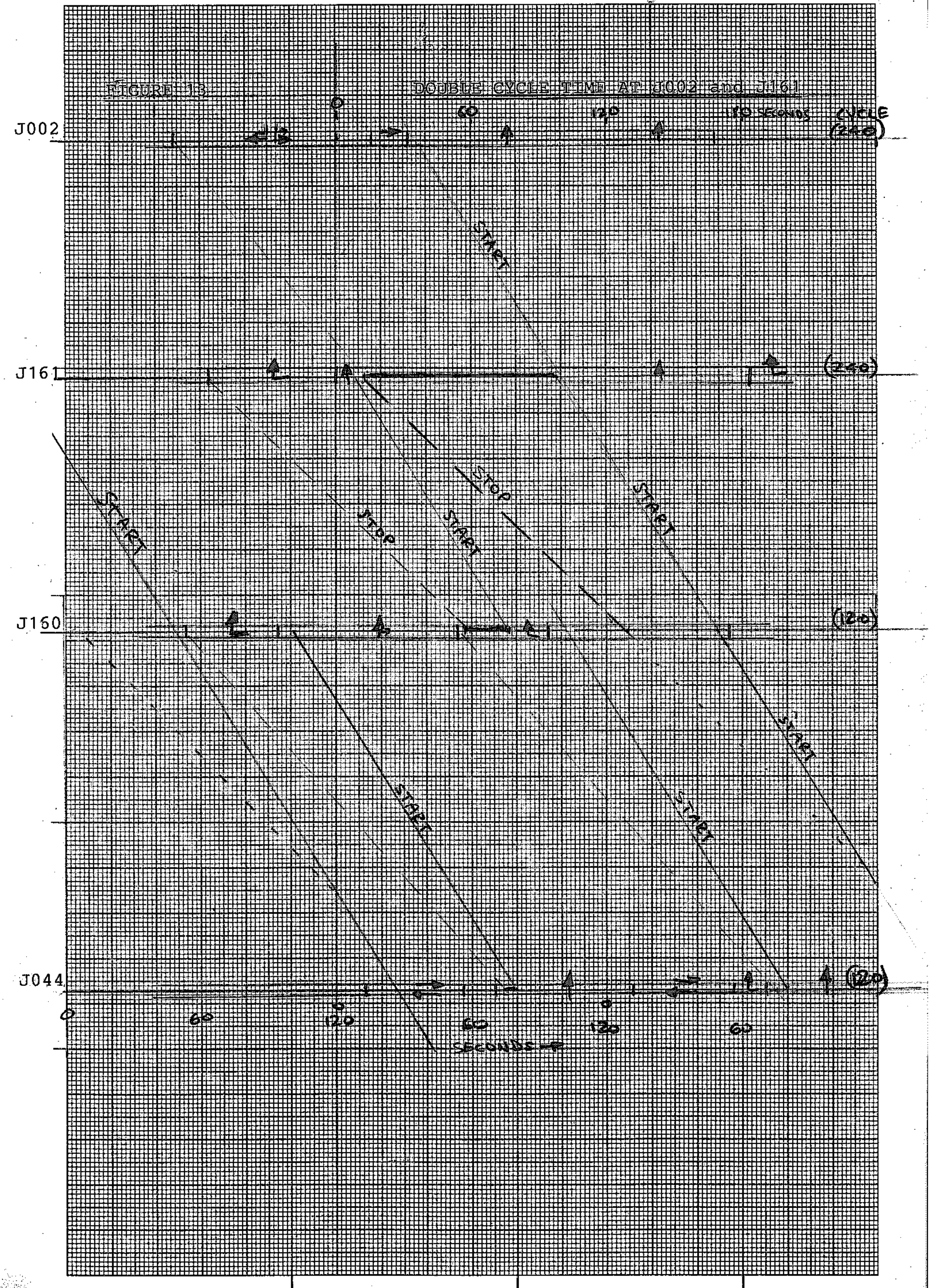


FIGURE 13 DOUBLE CYCLE TIME AT J002 and J161

relatively efficient and co-ordinated system of traffic control especially along Bamrungmuang Road. When the Commander suggested that a cycle time of 120 seconds at junction 5 (J002) would be too short, his advice was heeded. The main reason for his advice was that the police usually employed a cycle time of 6 minutes at junction 5 (J002) which allowed adequate time for westbound vehicles on Rama I Road turning right (i.e. north) at junction 5 (J002) to be directed onto the opposite carriageway. It was considered that a cycle time of 180 seconds would be sufficient for these vehicles to use the opposite carriageway for at least 50 metres from the eastern approach to junction 5 (J002), and therefore maintain the same saturation flow level. Hence it was decided to select a cycle time of 180 seconds for junctions 5 (J002), 4 (J161), 3 (J160) with all remaining junctions 'double-cycled' at 90 seconds. The March flows were input with a 'liberal' and 'conservative' estimate of blocking periods at junctions upstream from junction 5 (J002).

Figures 14 and 15 illustrate the signal timings and expected behaviour of starting and stopping waves on Bamrungmuang Road for both liberal and conservative estimates of blocking periods. Table 9 shows the resulting TRANSYT 8C recommended timings for the signals at junctions 5 (J002), 4 (J161), 3 (J160) and 2 (J044).

Table 9

TRANSYT/9 Timings Recommended to Avoid Upstream Junction Blocking on Bamrungmuang Road

Junction		Liberal Stage 1	Liberal Stage 2	Liberal Stage 3	Conservative Stage 1	Conservative Stage 2	Conservative Stage 3	Cycle
J002	Change Time	126	46	114	126	46	114	180
	Length (%)	100	68	12	100	68	12	
		(.55)	(.38)	(.07)	(.55)	(.38)	(.07)	
J161	Change Time	58	20		54	20		180
	Length (%)	142	38	146	34			
		(.79)	(.21)		(.81)	(.19)		
J160	Change Time	152	100		140	92		180
	Length (%)	128	52		132	48		
		(.71)	(.29)		(.73)	(.27)		
J044	Change Time	34	78	22	22	66	10	90
	Length (%)	44	34	12	44	34	12	
		(.49)	(.38)	(.13)	(.49)	(.38)	(.13)	

It can be seen from the two figures that the speed of stopping and starting waves, and the stage lengths determine the periods of upstream junction blocking. This blocking, in turn, influences the length of stage. The requirement is therefore, to proportionately split the remaining unblocked cycle time between each stage. Clearly, any reduction in the speed of the starting wave (caused by an incident) or an

FIGURE 14 - TIMINGS FOR BAMRUNGMUANG ROAD
- LIBERAL ESTIMATES

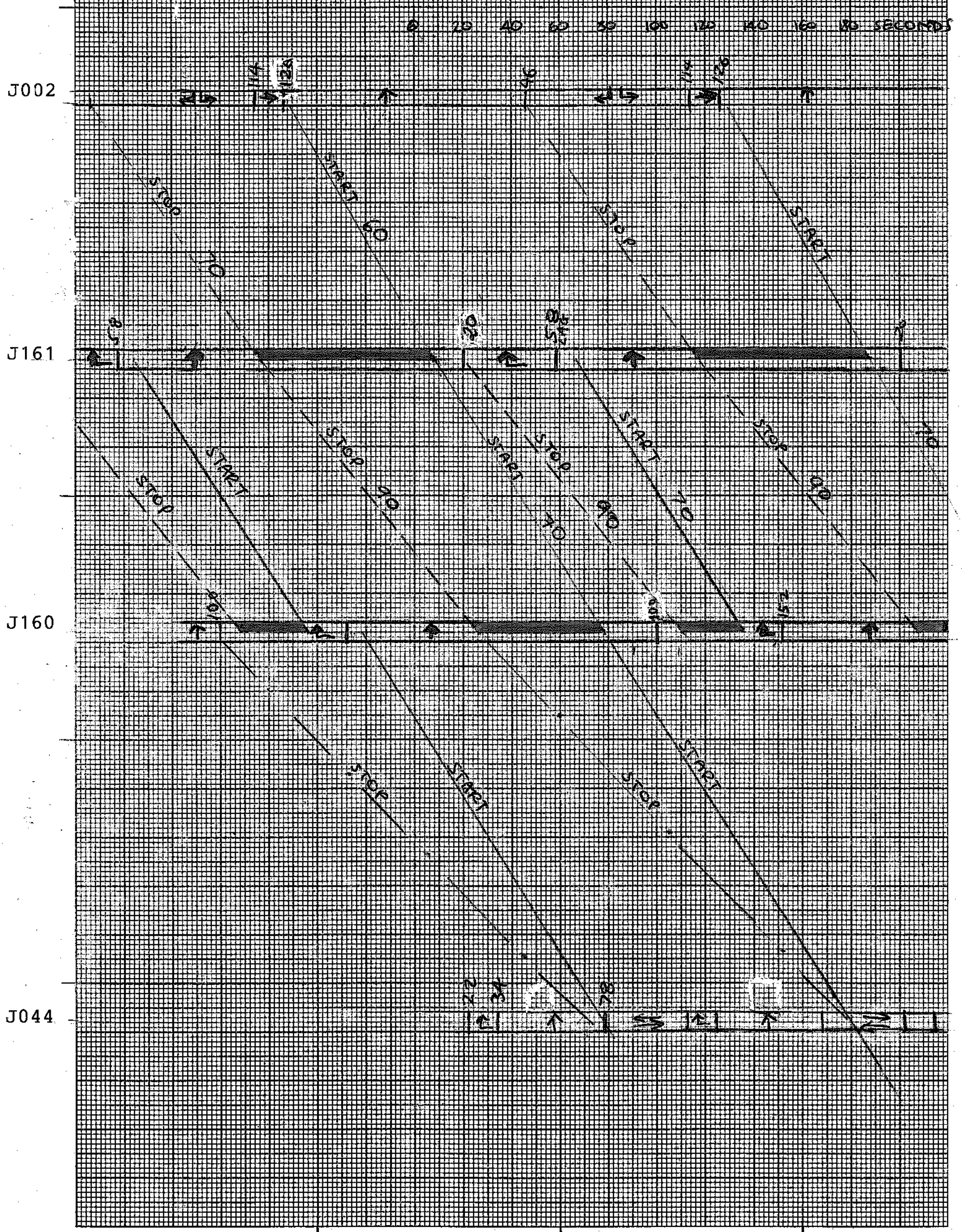
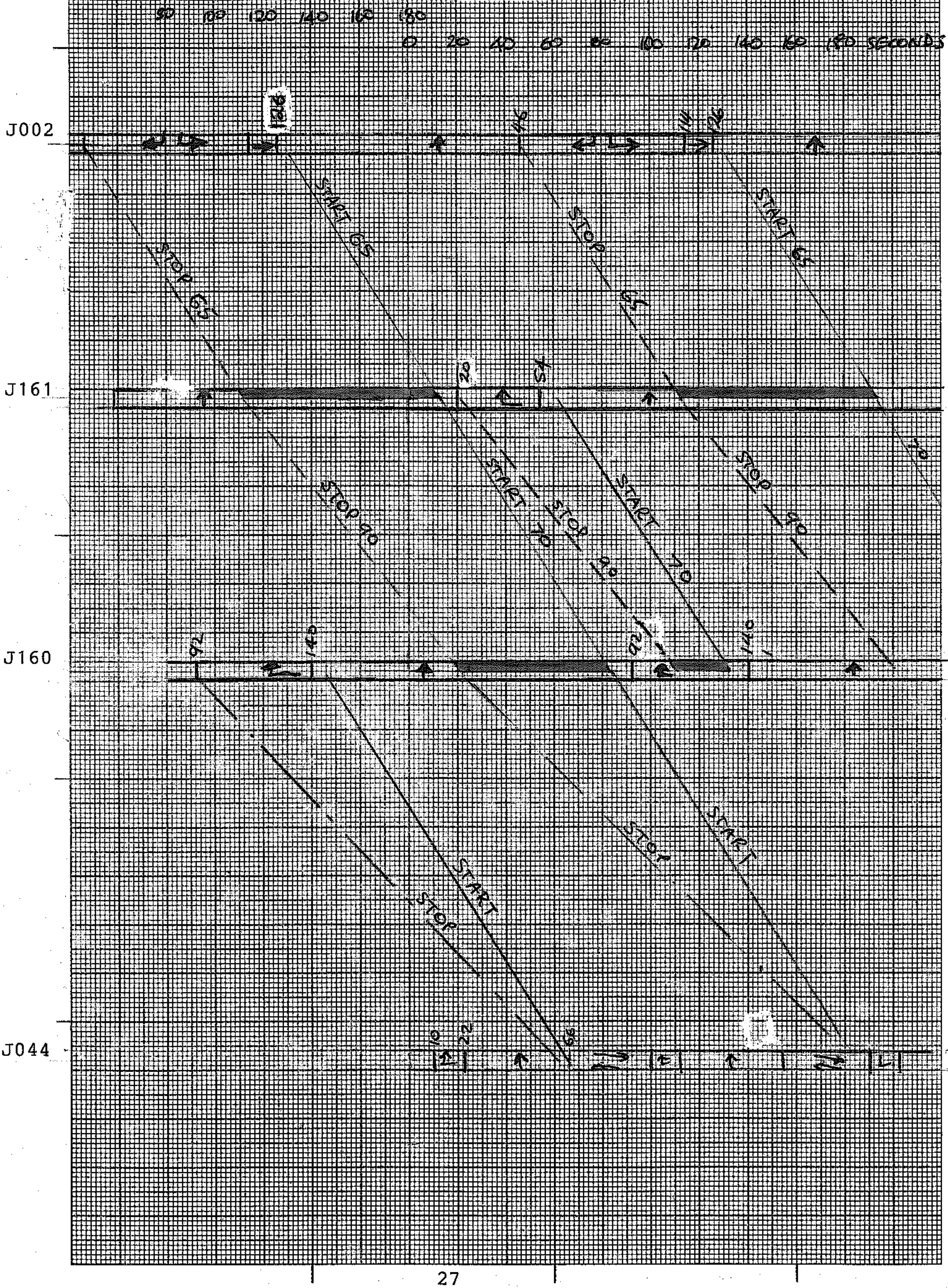


FIGURE 15 - TIMINGS FOR BAMRUNGMUANG ROAD

- CONSERVATIVE ESTIMATES



increase in the speed of the stopping wave (caused by heavier input flows) could cause a complete stage to be blocked. It seemed prudent to re-arrange the offsets between junctions in order to ensure the minimum likelihood of a stage change or complete stage being blocked, irrespective of the 'optimal' offset recommended by TRANSYT/8C.

The signal timings which were used on the first day of the experiment (27 April 1986) are listed in Table 10. These timings represent a compromise between conservative and liberal estimates and the offsets were selected to minimize the possibility of blocking during a stage change. Figure 16 displays the predicted behaviour of stopping and starting waves and the position of stage changes with respect to blocking periods on Bamrungmuang Road.

Table 10

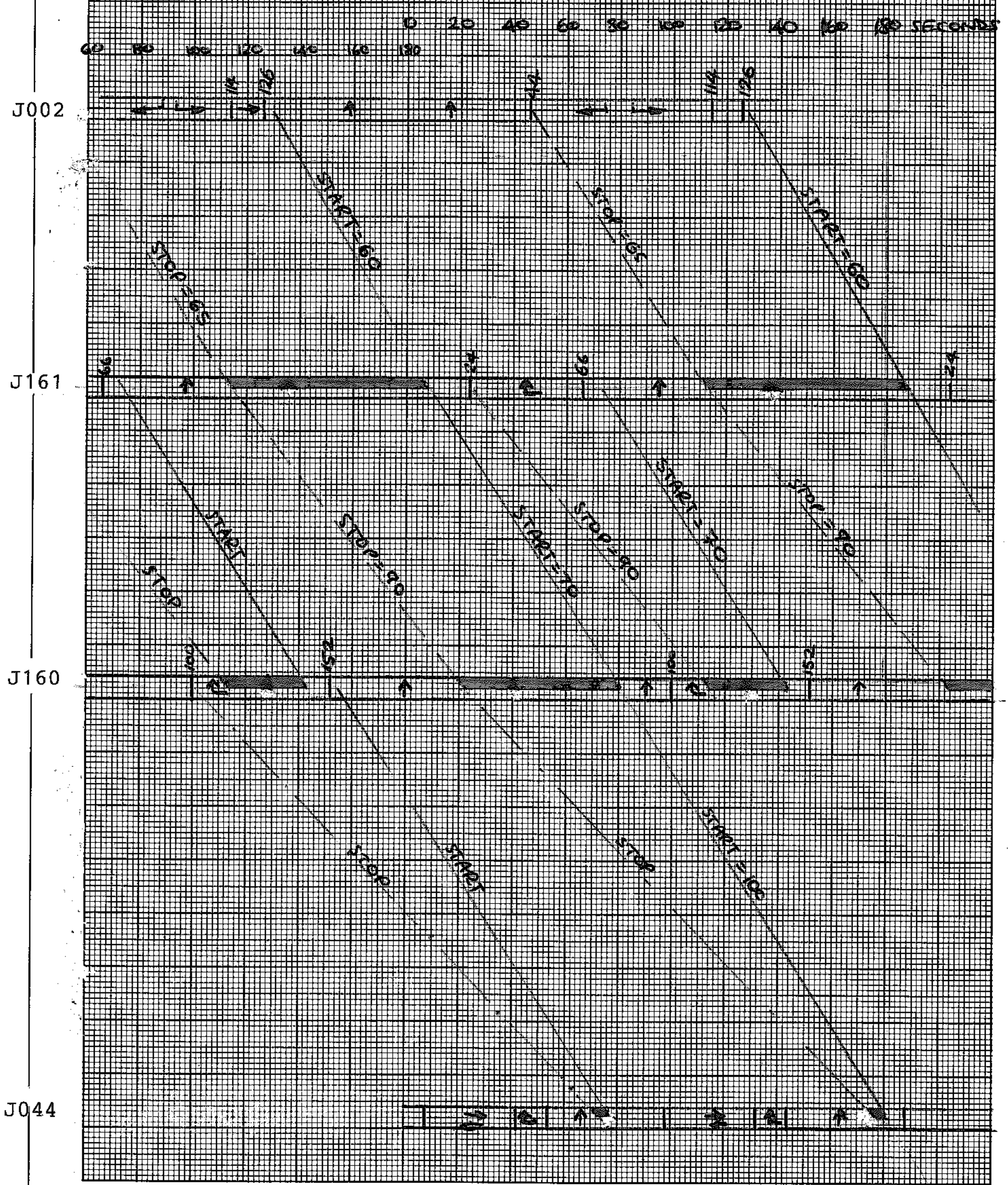
Experimental Signal Timings for 27 April 1986

ATC No.	Jct.	Stage 1 Change Time	Stage 1 [Length]	Stage 1 (%)	Stage 2 Change Time	Stage 2 [Length]	Stage 2 (%)	Stage 3 Change Time	Stage 3 [Length]	Stage 3 (%)	Cycle Time
J070	1	26	[38]	(.42)	64	[26]	(.29)	0	[26]	(.29)	90
J044	2	54	[44]	(.49)	8	[34]	(.38)	42	[12]	(.13)	90
J160	3	152	[128]	(.71)	100	[52]	(.29)	-			180
J161	4	66	[138]	(.77)	24	[42]	(.23)	-			180
J002	5	126	[100]	(.55)	46	[68]	(.38)	114	[12]	(.07)	180
J112	6	84	[38]	(.42)	32	[52]	(.58)	-			90
J080	7	32	[44]	(.49)	76	[30]	(.33)	16	[16]	(.18)	90
J030	8	36	[48]	(.53)	84	[32]	(.36)	26	[10]	(.11)	90
J029	9	80	[26]	(.29)	16	[24]	(.27)	40	[40]	(.44)	90
J114	10	26	[40]	(.45)	66	[20]	(.22)	86	[30]	(.33)	90

On Sunday 26th April 1986 a pilot test was conducted at junctions 5 (J002), 4 (J161) and 3 (J160) in order to ascertain whether or not a cycle time of 180 seconds and the long stage times could be implemented by a planned change from the ATC centre. The cycle length presented no problems but the maximum acceptable green was found to be only 122 seconds. Consequently, Stage 1 for junctions 4 (J161) and 3 (J160) invoked an extended maximum green response from the Highwayman; the effect of which was that the signal remained green indefinitely. To be able to operate these two controllers with stages greater than 122 seconds it was

FIGURE 16 - TIMINGS FOR BAMRUNGMUANG ROAD

- 27 APRIL 1986 - FIRST EXPERIMENTAL DAY



necessary to use the 'STATE' command which directly sends impulses from the Highwayman to each controller. In other words the normal plan was over-ridden by the STATE commands. Although this enabled extra long stage lengths it meant that a change of plan could no longer be initiated automatically by the Highwayman. Engineers at the ATC centre were, therefore, responsible for ensuring that the STATE command was de-activated and that the Highwayman was returned to normal operation at the end of the experimental period each day. This was of course, a problem because if Engineers forgot to remove the STATE command, then the long green times would continue during periods when queues did not block upstream junctions. Drivers would then tend to enter junctions on red because no vehicles would be using the 2 minute green for the other movement.

A cycle time of 160 seconds with exactly 122 seconds for Stage 1 at junction 4 (J161) could be used in the normal Highwayman plans. However, a cycle time of 160 seconds and 80 seconds was considered to be too short and difficult to check during the experimental period. Therefore, the experiment commenced on 27th April 1986 with those timings shown in Table 10 using a 180 second and 90 second cycle.

8. Development of Signal Timings During April/May 1987 Experiment

(a) 27 April - Heavy traffic was recorded from the east at junction 5 (J002) before 4 pm. After 4 pm there was a relative increase in flow from the west on Bamrungmuang Road. A temporary one-way system to the east of the study area changed each day at 4 pm which resulted in a reduced demand on the eastern approach to junction 5 (J002) after 4 pm. However, the long queue on Rama I Road before 4 pm was exacerbated by the reduced saturation flow for the east to north movement (stage 2) at junction 5 (J002) which was caused by a heavy storm. WP 250 on 'Incidents and their Management' describes how saturation flow for this movement was reduced by 20% during wet road conditions. This was because of two factors:

(i) Drivers had to turn right on a downward slope, and slowed down to avoid skidding, (Adhesion of tyres and road surface being rather less than in UK)

(ii) Drivers did not use the opposite carriageway on Rama I Road during periods of heavy rain.

It should be made clear at this point that the saturation flow for stage 2 at junction 5 (J002) was necessarily calculated from film of police control when vehicles were encouraged to use the opposite carriageway on Rama I Road. Although the police used cycle times at junction 5 (J002) in excess of 6 minutes, it was considered that a cycle time of 3 minutes would provide sufficient time for the east to north (stage 2) traffic to use the opposite carriageway and hence maintain the same level of saturation flow. The police were requested during automatic control to continue to encourage vehicles to use the opposite carriageway on the eastern approach, at least from the apex of the bridge on

Rama I Road. The police agreed, but in practice they were reluctant to co-operate and argued that the green time for this movement was too short to allow vehicles, as before, to use the opposite carriageway from 100 to 150 metres from the junction. However, it was only necessary to use 50 metres of carriageway in order to maintain the increased saturation flow. The problem was that when the police did not encourage the vehicles to use any of the opposite carriageway on Rama I Road, then the saturation flow was noticeably reduced.

The changes in saturation flow and the changes in demand after 4 pm at junction 5 (J002) resulted in the amendments to stage change times at junction 5 (J002) during the first experimental day, as shown in Table 11.

<u>Table 11</u>

<u>Signal Timings at Junction 5 (J002) on 27 April 1987</u>

Cycle = 180 sec

Time	Stage 1		Stage 2		Stage 3	
	Start Time	(Length)	Start Time	(Length)	Start Time	(Length)
2.45 pm	126	(100)	46	(68)	114	
4.08 pm	126	(96)	42	(72)	114	
5.00 pm	126	(98)	44	(70)	114	
5.30 pm	126	(100)	46	(68)	114	

Table 12 show the changes made to the signal timings at junction 4 (J161) during the 27th April 1987. These amendments were implemented in order to reduce the length of queue on Bamrungmuang Road, especially as Plupplachai has a larger storage capacity.

<u>Table 12</u>

<u>Signal Timings at Junction 4 (J161) on 27th April 1987</u>

Cycle = 180 secs

Time	Stage 1		Stage 2	
	Start Time	(Length)	Start Time	(Length)
2.45 pm	66	(138)	24	(42)
5.00 pm	64	(140)	24	(40)
5.30 pm	60	(144)	24	(36)

The fairly minor changes outlined in Tables 11 and 12 were made mainly in response to weather conditions. It is significant that no other changes seemed necessary on this day when the TRANSYT/8C recommended timings were first introduced. It was particularly encouraging that changes in the offset between junctions on Bamrungmuang Road and between junctions 8 (J030) and 9 (J029) on Luang Road were not required. During the previous experiment (using TRANSYT/8) the offsets between junctions were found to be inappropriate and they were substantially modified during the first experimental day. This demonstrates that card type 39 and the new TRANSYT/8C was successfully used to predict timings which avoid upstream junction blocking. Modifications to the split of cycle times at other junctions were not required during this initial day of automatic control.

(b) <u>28th April</u> - The stopping and starting waves observed on-site (27/4) and analysed in the office were more variable than initially expected. Hence, the offsets between junctions on Bamrungmuang Road were changed in order to produce a better safety margin between stage change times and the occurence of blocking periods. Further, the starting wave between junction 5 (J002) and junction 4 (J161) had been under-estimated at 60 seconds. The average starting wave, measured on 27/4, was 63.5 seconds. Table 13 shows the timings used at the beginning of the second day of the experiment.

<u>Table 13</u>

<u>Signal Timings for 28th April 1987</u>

Junction		STAGE 1 Start Time	(Length)	STAGE 2 Start Time	(Length)	STAGE 3 Start Time	(Length)	Cycle Time
								90
1	J070	26	(38)	64	(26)	0	(26)	90
2	J044	52	(46)	8	(34)	42	(10)	180
3	J160	168	(128)	116	(52)			180
4	J161	82	(144)	46	(36)			180
5	J002	130	(98)	48	(72)	120	(10)	90
6	J112	84	(38)	32	(52)			90
7	J080	32	(44)	76	(30)	16	(16)	90
8	J030	36	(48)	84	(32)	26	(10)	90
9	J029	80	(26)	16	(24)	40	(40)	90
10	J114	26	(40)	66	(20)	86	(30)	90

At 2.23 pm there was again heavy rain and a long queue was reported on Rama I Road. Consequently, the stage change times at junction 5 (J002) were altered to 130, 44, 120 for stages 1, 2 and 3 respectively. The timings were returned to those listed in Table 13 after 4.30 pm, except the change time for stage 2 was 50, thus making the stage 2 length only 70 seconds.

The timings for junction 4 (J161) in Table 13 were deliberately designed to incur a longer queue on Plupplachai Road in order to reduce the queue on Bamrungmuang which, on 27th April, occasionally stretched back to junction 2 (J044). Table 14 shows how these signal settings were altered during the 28th April.

Table 14

Signal Timings at Junction 4 (J161) on 28th April 1987

Time	Stage 1 Start Time	Stage 1 (Length)	Stage 2 Start Time	Stage 2 (Length)	Cycle Time
2.45 pm	82	(144)	46	(36)	180 secs
4.20 pm	84	(142)	46	(38)	180 secs
5.40 pm	86	(140)	46	(40)	180 secs

The change time for the start of stage 2 was kept constant in order to maintain the desired relationship between stopping and starting waves from junction 5 (J002). The settings were changed at 4.20 pm because the queue on Plupplachai Road had nearly filled the link back to junction 9 (J029).

Queues began to form in most links on Luang Road because of severe congestion south of the survey area. This congestion resulted in a long northbound queue on Mahachai Road which blocked junctions 1 (J070) and 6 (J112). The new offset strategy had only been applied to the short link between junction 8 (J030) and 9 (J029), but the unexpected long queues facilitated a useful examination of how to best calculate offsets between junction 8 (J030) and 7 (J080). The original timings were based on a TRANSYT/8 output without constraining the offsets on this link. At junction 8 (J030) it was desirable that the starting wave arrived from junction 7 (J080) during stage 1 (i.e. the main east to west feed). The same arrangement was required at junction 9 (J029). However, with the initial timings, the starting wave arrived at junction 8 (J030) towards the beginning of stage 1 which meant that any extra blocking would occur during the period when stage 1 began. It was preferable, therefore, that the starting wave from junction 7 (J080) arrived closer to the end of stage 1 at junction 8 (J030). Hence, the following changes (Table 15) were made during 28/4 on Luang Road.

Table 15

Signal Timings on Luang Road - 28th April 1987
STAGE START TIMES

Junction	Initial (2.45 pm) St1	St2	St3	3.47 pm St1	St2	St3	5.20 pm St1	St2	St3	Cycle Time
7 (J080)	32	76	16	32	76	16	32	76	16	90
8 (J030)	36	84	26	82	40	72	2	50	82	90
9 (J029)	80	16	40	36	62	86	46	72	6	90
10(J114)	26	66	86	72	22	42	82	32	52	90

(c) 29th April - The stopping and starting wave data for Luang Road collected on 28/4 was examined more closely on the morning of 29/4 and the offset of junctions 8, 9 and 10 relative to junction 7 (which remained the same) was altered once more, as shown in Table 16.

The average starting wave from junction 3 (J160) to junction 2 (J044) took 92 seconds. Previously, this time had only been estimated and consequently the start of stage 1 at junction 3 (J160) was delayed by 6 seconds. The stopping wave from the end of stage 1 at J161 reached J160 before the end of its stage 1 during operation on 28th April. Hence, as shown in Table 16, the timings for J161 were advanced by 8 seconds relative to J160. No change was made to the relative offset betwen junction 5 (J002) and 4 (J161). However, stage 2 at J002 was given more time before 4.15 pm, but a planned change was scheduled at 4.15 pm in response to the change in demand at 4.00 pm. The timings changed to 140, 62, 130 for stages 1, 2 and 3 respectively, at 4.15 pm.

Table 16

Signal Timings for 29th April 1987

Junction		STAGE 1 Start Time	(Length)	STAGE 2 Start Time	(Length)	STAGE 3 Start Time	(Length)	Cycle Time
1	J070	26	(38)	64	(26)	0	(26)	90
2	J044	52	(46)	8	(34)	42	(10)	90
3	J160	174	(128)	122	(52)			180
4	J161	96	(142)	58	(38)			180
5	J002	146	(92)	58	(78)	136	(10)	180
6	J112	84	(38)	32	(52)			90
7	J080	32	(48)	80	(26)	16	(16)	90
8	J030	14	(48)	62	(32)	4	(10)	90
9	J029	58	(26)	84	(24)	18	(40)	90
10	J114	4	(40)	44	(20)	64	(30)	90

These timings were produced after two days of detailed analysis of the speed of stopping and starting waves. This illustrates that considerable effort is required in order to fully understand the behaviour of these waves and to predict the most suitable timings which avoid upstream junction blocking. It was felt, after this detailed analysis, and after the un-typical storms on 27th and 28th April that the timings implemented on the third day of the experiment would be close to optimal. This would have proven to be the case were it not for the unexpected major incidents which were to occur on 29 April (see WP 250).

During the 29th April the start of stage 1 at J161 was changed from 96 to 98 at 5 pm, and again to 100 at 5.30 pm which gave a further increase to Plupplachai Road (stage 2).

(d) 30th April - The timings were the same as 29/4 except that it was planned to begin with 98 and 58 at J161 and to change to 100 and 58 at 4.15 pm along with the same changes as before at 4.15 pm at junction 5 (J002). It was also decided to change the start of stage 2 at junction 7 (J080) from 80 to 76 at 4.15 pm in order to provide more time to the large north to south movement (stage 2) on Worachark Road.

(e) 6th and 7th May - The signal timings used in 30/4 appeared to be very successful and the queue on Bamrungmuang Road rarely extended beyond junction 3 (J160). The queue on Plupplachai Road did, however, nearly extend to junction 9 (J029) at 5.15 pm and so it was decided to implement stage change times of 100 and 58 at the beginning of operation on 6/5/87. Exactly the same plan was repeated on 7/5/87. The final plan is listed in Table 17.

Table 17

Final Plan for Automatic Control

Junction		STAGE 1 Start Time	STAGE 1 (Length)	STAGE 2 Start Time	STAGE 2 (Length)	STAGE 3 Start Time	STAGE 3 (Length)	Cycle Time
1	J070	26	(38)	64	(26)	0	(26)	90
2	J044	52	(46)	8	(34)	42	(10)	90
3	J160	174	(128)	122	(52)			180
4	J161	100	(138)	58	(42)			180
5	J002	146	(92)	58	(78)	136	(10)	180
	(4.15 pm)	140	(102)	62	(68)	130	(10)	
6	J112	84	(38)	32	(52)			90
7	J080	32	(42)	78	(28)	16	(16)	90
	(4.15 pm)			76	(30)			
8	J030	14	(48)	62	(32)	4	(10)	90
9	J029	58	(26)	84	(24)	18	(40)	90
10	J114	4	(40)	44	(20)	64	(30)	90

(f) 8th May - 22nd May - The automatic timings were considered, by the police and traffic engineers, to be successful throughout May. During this period the main schools in Bangkok re-opened and it was expected that increased flow levels might result in the return to police control. On the contrary, the police did not attempt to take over from automatic control, and in fact queue lengths were visibly less. From 18th May until 22nd May a small-scale survey was conducted on Bamrungmuang Road and Plupplachai Road.

As a result of observation between 17th May and 18th May it was decided that there would be some benefit in co-ordination by a slight modification to the offsets between junctions 5, 4 and 3. Table 18 lists these minor changes. The new timings further reduced the likelihood of upstream junctions being blocked during a stage change and a further two seconds was provided for stage 1 at junction 5 (J002) after 4.15 pm.

Table 18

Changes to Offset - 18th May 1987

Junction	STAGE 1 Start Time	(Length)	STAGE 2 Start Time	(Length)	STAGE 3 Start Time	(Length)	Cycle Time
3 J160	176	(128)	124	(52)			180
4 J161	100	(138)	58	(42)			180
5 J002	146	(92)	58	(78)	136	(10)	180
5 J002 (4.15 pm)	138	(104)	62	(66)	128	(10)	180

9. Conclusions

At a final meeting with the Traffic Police Commander for this area, it was agreed to continue using automatic signal control in this area in conjunction with incident management. However, the STATE command still had to be input each day by traffic engineers at the Ministry of Interior. The problem of trying to incorporate extra long stage lengths into a standard 'plan' could not be resolved. The responsibility for traffic signals was transferred in June to Bangkok Metropolitan Administration, and it became obvious that the STATE command would no longer be implemented each day, and that the vicious circle would return whereby inappropriate signal timings encouraged the police to resume control. Contrary to a commonly held view that 'Bangkok's traffic congestion could be relieved if only the police would relinquish control', it became clear through this study that the police were perfectly willing to relinquish control to properly adjusted automatic settings. However in most areas of the city the automatic timings are completely inadequate and therefore the police, as the body responsible for day to day traffic control, are forced to take over.

WP249.dq (disk 42)
DQ/rww
5 December 1988

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