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# CONTROL OF CONGESTION IN HIGHLY SATURATED NETWORKS

## Incidents and Their Management

D J Quinn



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CONTENTS

# THE CONTROL OF CONGESTION IN HIGHLY SATURATED NETWORKS: INCIDENTS AND THEIR MANAGEMENT

## 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 of Data Collection
249: Development of Signal Timings
251: Experimental Results and Conclusions
The study itself was a follow-up to a previous study already reported in WP 220, WP 221 and WP222.

### 1.2 Background

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

If stationary vehicles remained in the junction, then drivers from the main feed (ie RAMA IV Road) entered the junction illegally and subsequent movements were disrupted.

The blocking of an upstream junction was most noticeable during the previous experiment on the east-bound link between Suriwong (SUR) and Silom (SIL) junctions along Rama IV Road. TRANSYT/8 recommended timings were employed on the first experimental day (2 July 1985) but these resulted in blocking of the upstream (SUR) junction and the offset between junctions SUR and SIL had

to be altered. The "successful" offset between SUR and SIL junctions was based on the time taken for a starting wave to move backwards from SIL to SUR along a queue on Rama IV Road. Under the original TRANSYT/8 recommended timings the main feed at the upstream junction (SUR) finished before the starting wave had arrived from the downstream junction (SIL); whereas the adjusted offset allowed approximately 25 seconds in which traffic was free to flow across the SUR junction before the green for RAMA IV Road terminated, hence the junction did not become blocked and cross-moving traffic was unhindered. (Technical Note 224 describes in more detail how video film for this critical link has been analysed).

1.3 Objectives

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

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

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

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

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

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

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

The earlier experiments on Rama IV Road (WP 220, WP 222) have demonstrated that it is possible to replace manual control of traffic signals with automatic control in conditions which are among the most severely congested in the world. A future benefit would be to redirect police manpower towards the enforcement necessary to avoid congestion-inducing incidents or to mitigate their effects. Technical Note 225 has described the results of a preliminary investigation into the effect of incidents in over-saturated conditions on Rama IV Road.

This paper has two objectives. The first is to document the incidents which occured during the main experimental period of this study. This information will be subsequently referred to in the examination of the survey results and it should be especially relevant to the analysis of journey times. The second objective is to draw some conclusions from the above information and the earlier study reported in TN 225 in order to provide guidance on how the police could best avoid or mitigate the delay caused by the occurence of incidents during automatic traffic control. Figure I shows the network for this second study.

## 2. Incidents During Main Experiment (20th April - 7th May 1987)

(a) Sources of Information: Enumerators concerned with three types of data collection during the survey period were equipped with additional forms on which incidents were recorded. Information on incidents was therefore acquired from the enumerators in the Moving Vehicle Survey, the Elevated Observer Survey and the Input/Output Count Surveys. This provided a wide coverage of incidents in the study area. Furthermore, important information was obtained by the three principal researchers who had radio contact with each other, the ATC centre and with the local police. Finally, one supervisor travelled around the study area by motorcycle with the dual aim of ensuring that all enumerators were in position and to record any incidents which he observed. The supervisor also visited the site of any major incidents which were reported during the survey period. Note that, despite this wide coverage, there may still have been some incidents which were not observed.

(b) Police Control (20th to 24th April 1987): Table 1 shows that a maximum of three incidents occurred on any one day during the observed period of police control. The worst single incident occurred on 24th April when a fire engine caused substantial delay to vehicles using Luang Road and Worachark Road. It might be expected, given the highly saturated conditions, that the journey times of vehicles on the 24th April were longer compared with other days under police control. The fewest incidents occurred on 20th April and 21st April.

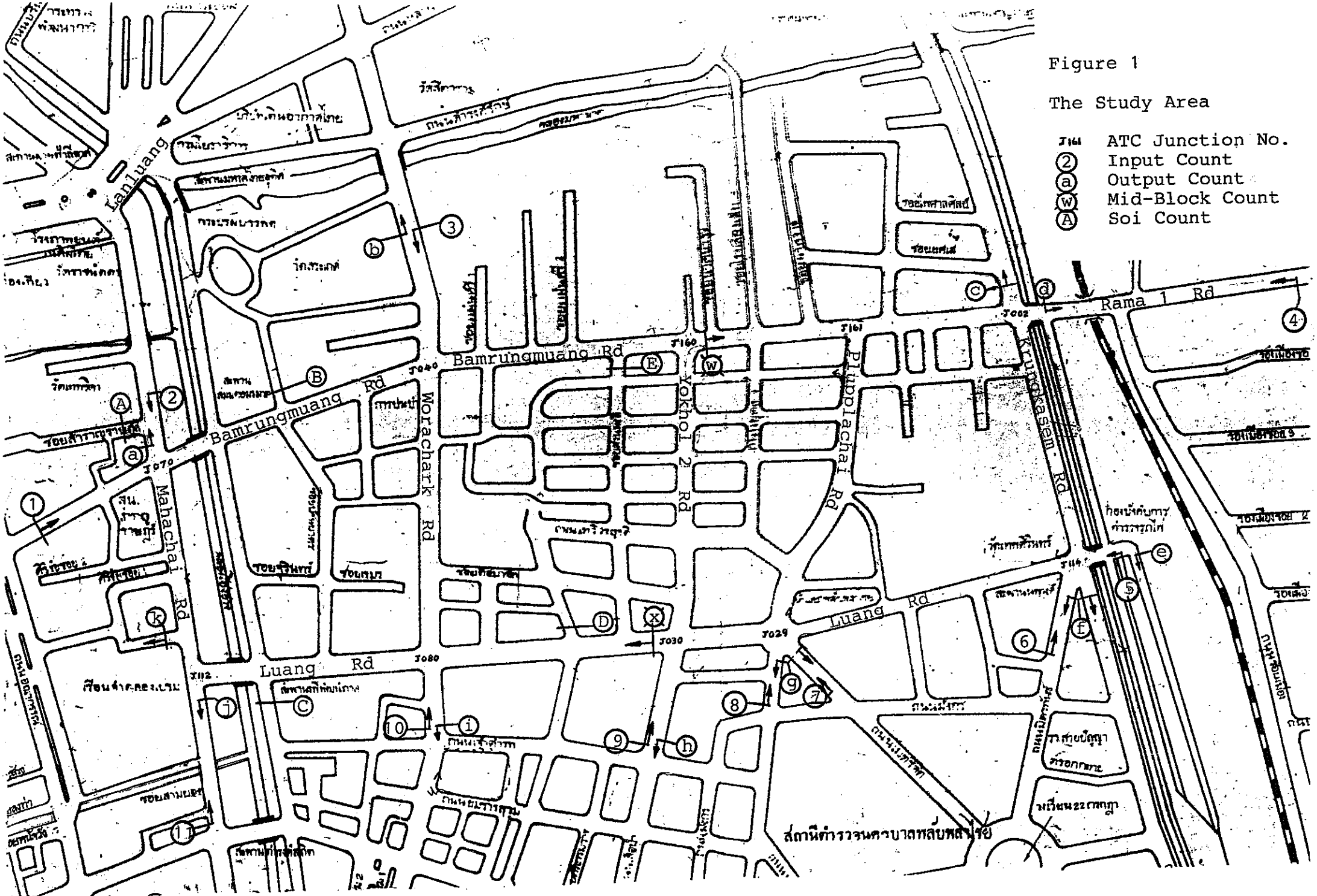



Figure 1

The Study Area

J161 ATC Junction No.
(2) Input Count
(a) Output Count
(w) Mid-Block Count
(A) Soi Count

Table 1

Incidents During Police Control

| Date | Time | Location | Nature of Incident | Duration |
|---|---|---|---|---|
| 20/4 | | | No major incidents | |
| 21/4 | 1742 | Jct3 J160 | Traffic signal light not working (police direct control) | 10 mins |
| 22/4 | 1549 | Jct4 J161 | Brokendown car in middle of Bamrungmuang | 2 mins & 3 secs |
| | 1600 | Jct5 J002 | Bus hit samlor. Only one lane on Bamrungmuang Rd can move | 15 secs |
| | 1650 | Jct3 J160 | Brokendown car in Bamrungmuang | 2 mins |
| 23/4 | 1641 | Jct3 J160 | Brokendown van in Bamrungmaung | 4 mins & 3 secs |
| | 1709 | Jct9 J029 | Taxi hit bus - restricted flow | 1 min & 39 secs |
| 24/4 | 1548 | Jct5 J002 | Stationwagon hit taxi. Vehicles block flow for short time | 45 secs |
| | 1546 | Jct7 J080 | A fire engine attends building at Jct7 (J080), causing congestion on all approaches to junction | 12 mins & 34 secs |
| | 1638 | Bamrungmuang Road | A motorcade proceeds down Bamrungmuang Rd. Motorcade given priority, but travelled "in-traffic" | |

(c) Automatic Control (27th April until 7th May 1987): Table 2 demonstrates that incidents occured more frequently on days when automatic control was in operation compared with days under police control. One of the most significant incidents was the storm on the 27/4 when the new automatic signal timings were first introduced. The high winds, lightning, thunder and torrential rain caused vehicle speeds and saturation flows to decrease. A similar but slightly less dramatic storm occurred before and during the survey period on 28/4. Another noticeable incident was the cement lorry which completely blocked the flow of traffic out of the study area at junction 5 (J002) on the 29/4. The least severe incidents during days with automatic control were reported on 30/4 and 6/5. On the final day of the main experiment (7/5) the frequency of incidents was again at a relatively high level. There were several occasions when junctions were blocked because of conditions outside of the study area (e.g. J070 blocked by events at LanLuang Road and Luang Road blocked by a queue from south of junction 7 (J080)).

Table 2
Incidents During Automatic Control

| Date | Time | Location | Nature of Incident | Duration |
|---|---|---|---|---|
| 27/4 | 1430 | All jcts | Very heavy rains & strong winds | 2 hrs |
| | 1450 | All jcts | Power failure - all signals non-operational. Automatic timings re-input. | 20 mins |
| | 1425 | Jct2 J044 | Lorry stationary in junction. Traffic moved slowly around obstruction. | 15 mins |
| | 1500 | Bamrungmuang Road | Accident causes large queue between jcts 1 (J070) and 2 (J040) at start of survey. | unknown |
| | 1715 | Jct1 J070 | Overturned vehicle in junction; minor obstruction to traffic flow | 5 mins |
| 28/4 | 1420 | All jcts | Heavy rain (reduced flow and sat.flow) | 1 hr & 3 mins |
| | 1530 | Jct5 J002 | Right lane on Bamrungmuang Rd approaching Jct5, blocked by vehicle making illegal maneouvre | 30 secs |
| | 1540 | Jct5 J002 | Brokendown car westbound from Rama I Road | 2 mins |
| | 1618 | Jct8 J030 | Bus hit taxi on Luang Rd | 3 mins |
| | 1630 | Jct1 J070 | Heavy congestion to north of survey area on LanLuang Rd. Queue blocked J070. Police resumed manual control. | 45 mins |
| | 1653 | Jct2 J044 & 3 J160 | Car brokendown. Blocked one lane of Bamrungmuang Rd | 3 mins |
| 29/4 | 1530 | Rama 6/ Rama I | Police stop all traffic at merge between Rama I and Rama 6, east of J002. | 15 secs |
| | 1532 | Jct7 J080 & 8 J030 | Disabled car blocked the right-lane on Luang Rd between J080 and J030. | 5 mins |
| | 1630 | Jct8 J030 | Accident to south of J030 caused queue to block into study area | 6 mins |
| | 1629 | Jct5 J002 | CEMENT LORRY - MAJOR INCIDENT Lorry became stuck at entrance into Mekong Project totally blocking eastbound exit from Junction 5. Traffic at standstill on Bamrungmuang Rd and Rama I Rd on both approaches to J002. Result - long queues, especially on Plupplachai Rd. All exits at J002 blocked for nearly 3 cycles. | 4 mins |
| | 1700 | Plupplachai Road | Procession for burial at Wat Plupplachai Rd (approx 150 cars) Increased flow into already large queues because of above incident. | |

Table 2 (continued)

| Date | Time | Location | Nature of Incident | Duration |
|---|---|---|---|---|
| 30/4 | 1430 | All jcts | Rain - short period. | 20 mins |
| | 1500 | Jct7 J080 | Illegally parked lorry blocks exit to south | 3 mins |
| | 1559 | Jct5 J002 | Westbound vehicle on Rama I unable to get onto correct side of carriageway at end of stage. Blocked eastbound exit at J002. (An example of the problem when using a shorter cycle time at J002). | 30 secs |
| | 1609 | Jct7 J080 | Motorcycle from S - N crossed on red and hit a truck. | 2 mins |
| | 1733 | Jct7 J080 | Exit to south at J080 blocked by congestion outside study area | 2 mins |
| 6/5 | 1510 | Jct8 J030 | Taxi brokendown. Repaired in-situ. One lane blocked on Luang but low flows. | 4 mins |
| | 1534 | Jct1 J070 | Manual control because of queue coming back from LanLuang to north. | 10 mins |
| | 1556 | Jct5 J002 | Accident on bridge causing delays to Bamrungmuang and Rama I. | 2 mins |
| | 1552 | Jct5 J002 | Eastbound traffic on Rama I again hindered by westbound vehicles trapped in wrong lane at end of stage (2 cycles) | 6 mins |
| | 1630 | Jct1 J070 | Blocking to north on LanLuang Rd (Police control) | 45 mins |
| 7/5 | 1445 | Jct1 J070 | Traffic signals on police control because of queue from LanLuang in north | approx. 1 hr |
| | 1501 | Jct6 J112 | Queue from LanLuang continued to extend back down Mahachai Rd. | |
| | 1445 | Bamrungmuang | Accident on bridge at Rama I before start of survey. Hence, extra congestion inherited at start of survey. | |
| | 1505 | Jct5 J002 | Vehicles on Rama I trapped on wrong side of carriageway. | 3 mins |
| | 1545 | Jct4 J161 | Accident east of J161. One lane blocked. | 1 min & 15 secs |
| | 1556 | Jct5 J002 | Vehicle on wrong side on Rama I Bridge. (Only one policeman at J002.) | 1 min & 30 secs |
| | 1621 | Bamrungmuang | Car brokendown 20 metres before approach from west at J002. Vehicle pushed into a non-obstructing position at J002. Still only one policeman on duty - inadequate. | |

## 3. The Effects of Incidents

It is not an easy task to measure the true effect of incidents because it is difficult to instantaneously collect relevant data, and it is also difficult to isolate the influence of other factors. Analysis of video film along the lines of the investigation reported in TN 225 provides a useful indication of the nature and effect of certain incidents but it is prohibitively expensive to film an entire study area. At least a general guide towards recognising that major incidents which caused increased delay can be obtained from a simple comparison of system performance during certain time periods and a record of incidents, like the one outlined above. Indeed an area for further investigation would be an in-depth analysis of the system performance for every link, during short time intervals, when major incidents were known to have occurred. However, the aim of this current project was not to measure, in detail, the effect of each type of incident but rather to identify the worst incidents and suggest ways in which the police could best prevent or mitigate their effects. Two examples are given of the use of data to measure the effects of wet weather.

### (a) Saturation flows at junction 5 (J002)

Saturation flows for the two main movements at junction 5 (J002) were measured during and immediately after the storm. Between 16:15 and 16:45 on the 27/4/87 when heavy rain had been falling the average saturation flow for the east to north movement from Rama I into junction 5 (J002) was only 2073 vehicles per hour. At 17:11 three more measurements produced an average saturation flow of 2097 vehicles per hour after the storm had finished but when the roads were still wet. By 17:51 the roads were dry and two measurements produced an average saturation flow of 2663 vehicles per hour which was very similar to the figure of 2638 vehicles per hour measured under police control during good weather conditions. For the west to east movement from Bamrungmuang Road at J002 the saturation flow was also measured during the three types of conditions outlined above. While rain was falling the average figure was 3060 vehicles per hour, and immediately after the rain had finished one measurement was taken which was 2829 vehicles per hour. Once the road became dry the saturation flow was 3388 vehicles per hour which was again comparable with the saturation flow for this movement under police control during good weather (i.e. 3300 vehicles/hour).

The above illustrates that an unavoidable incident such as a storm will significantly influence the flow of traffic. The saturation flows were reduced by up to 20% for the east to north movement and by almost 10% for the west to east movement at the critical junction (J002). In TN 225 floods were included in category I of the list of incidents, and were considered to be beyond the scope of daily traffic management. Although a short storm may not have quite the same dramatic effect as a flood, it is nonetheless clear that, under highly saturated conditions, the change in saturation flows caused by heavy rains will result in the automatic timings becoming inappropriate. This is especially true in situations like J002 where the saturation flow for one movement is relatively more affected than another by wet road conditions. Future work could be to develop signal timings

appropriate to either wet or dry conditions. This would be particularly useful for cities in the developing world which experience monsoons each year.

(b) Journey times on eastern approach to junction 5 (J002)

It is useful to examine the journey times for the eastern approach to junction 5 (J002), measured from 4 to C, in order to obtain some indication of the effect of the reduced saturation flow on this link during the storm on 27/4. Table 3 shows the median journey times during the storm (1530 - 1630) and after (1630 - 1800) on the 27/4 in comparison with the average for all other days under automatic control and police control.

Table 3

Journey Times on Link 4C

| | 27/4 | All Other Auto Days | All Police Days |
|---|---|---|---|
| 1530 - 1630 | 225 | 145 | 134 |
| 1630 - 1800 | 166 | 148 | 192 |

(Source = Number Plate Matching Survey - see WP 251.)

The above table shows that journey times, on average, increased for all survey days except 27/4 after 1630. While these figures will have been influenced by the signal timings used on each day, or perhaps by an unobserved incident, it is still apparent that the journey times on the eastern approach to junction 5 (J002) were reduced during the wet road conditions on the 27/4 between 1530 and 1630.

4. Incident Management

(a) Location of Police Officers - One priority of an incident management strategy should be to identify those positions in which a disabled vehicle is likely to cause the greatest delay and to ensure the appropriate and speedy removal of the obstruction. In the study area it became clear, from experience on 29/4, that the eastbound exit to junction 5 (J002) over Rama I Road bridge was a critical location for a major incident to occur. It is not surprising therefore that the largest police presence was at this junction. The identification of 'delay-causing' locations is quite obvious to traffic engineers and more importantly, the traffic police in Bangkok appeared to be aware of these key locations.

There were 9 breakdowns and 11 accidents recorded during the survey period. Only 2 of the breakdowns and 4 of the accidents occurred within a junction. Breakdowns often involved a vehicle being unable to start after a period of being stationary in a queue, and consequently these tended not to occur within a junction. Four accidents involved vehicles from conflicting movements and therefore occurred in junctions, but

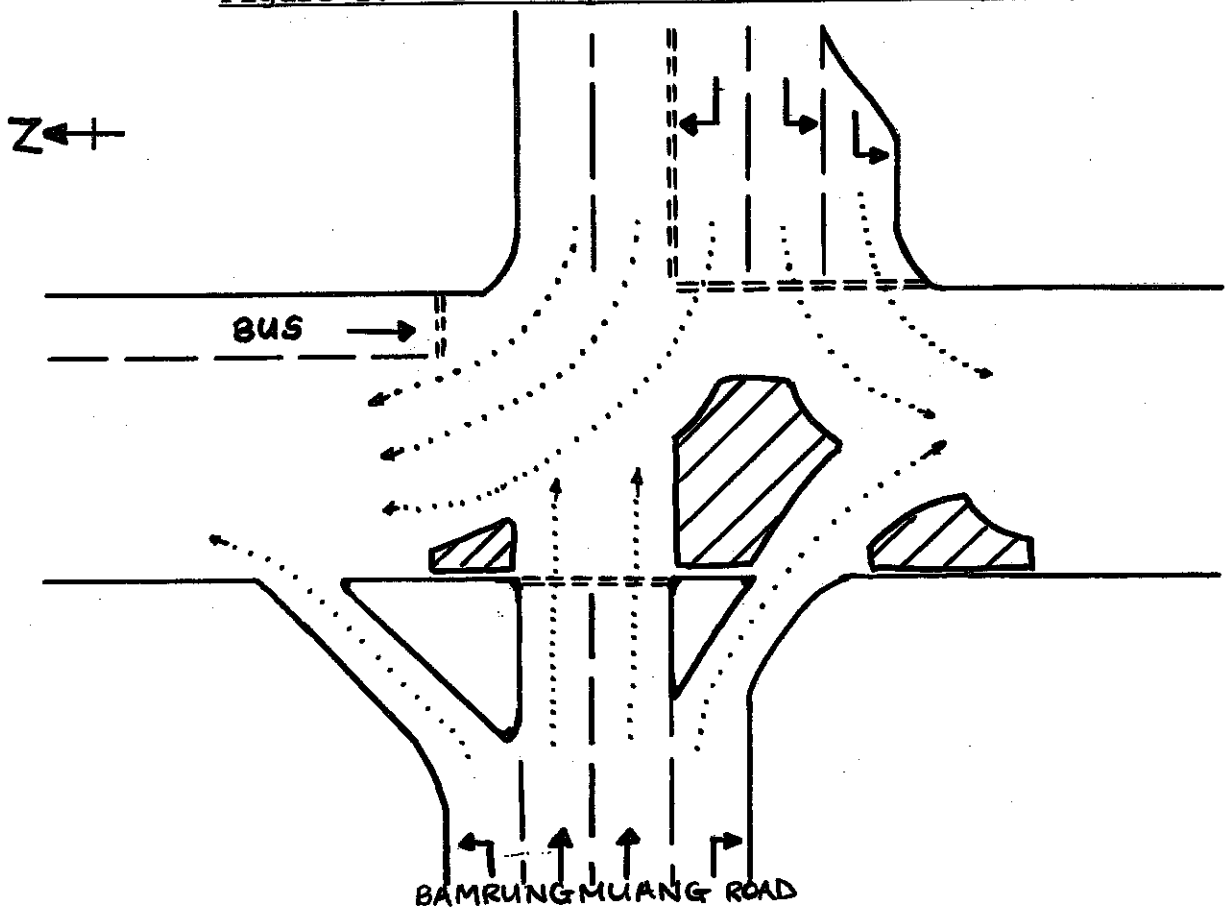
the majority of accidents occured within links and were 'rear-end' collisions or the result of poor lane changing.

It was observed that the police responded quickly to incidents close to a junction but they reacted more slowly to incidents which occurred mid-link (e.g. 1653 on 28/4 and 1510 on 6/5). However, there would be two disadvantages if traffic police were instructed to continually patrol the streets. Firstly, officers could frequently be in the wrong place at the wrong time and secondly, they would be unable to quickly effect changes (if necessary) to signal stages at a junction.

The implication for a police incident management strategy is that it seems sensible for police observation to be focussed at junctions, but individual officers should be free to leave these locations to rapidly attend to mid-link incidents. In addition, it would be advantageous to have an observer at an elevated position, with radio contact. Properly adjusted automatic signal timings would obviously facilitate this type of police strategy.

(b) Removal of disabled vehicles - Quite simply this involves pushing disabled vehicles from delay-causing positions to a situation where the flow of traffic is no longer obstructed. If signals are operating automatically then police officers are again free to assist in these situations. Quick and direct action could often avoid considerable delays as seen by the action of one policeman at 1621 on 7/5. Figure 2 illustrates how 'dead' spaces within junction 5 (J002) can be used to temporarily park disabled vehicles.

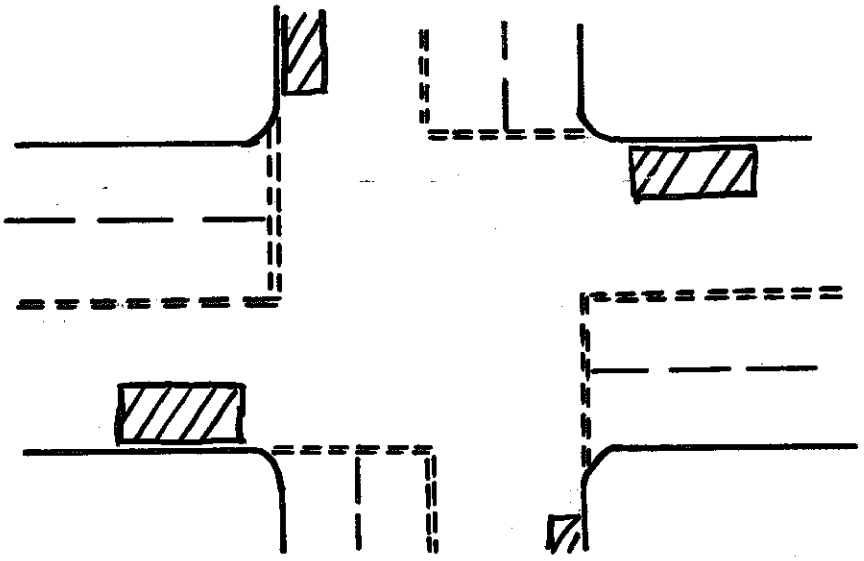
Figure 2: 'Dead' Spaces at Junction 5 (J002)



These 'dead' spaces are easily identified at an intersection by the build-up of dust and debris and less wear of the road surface.

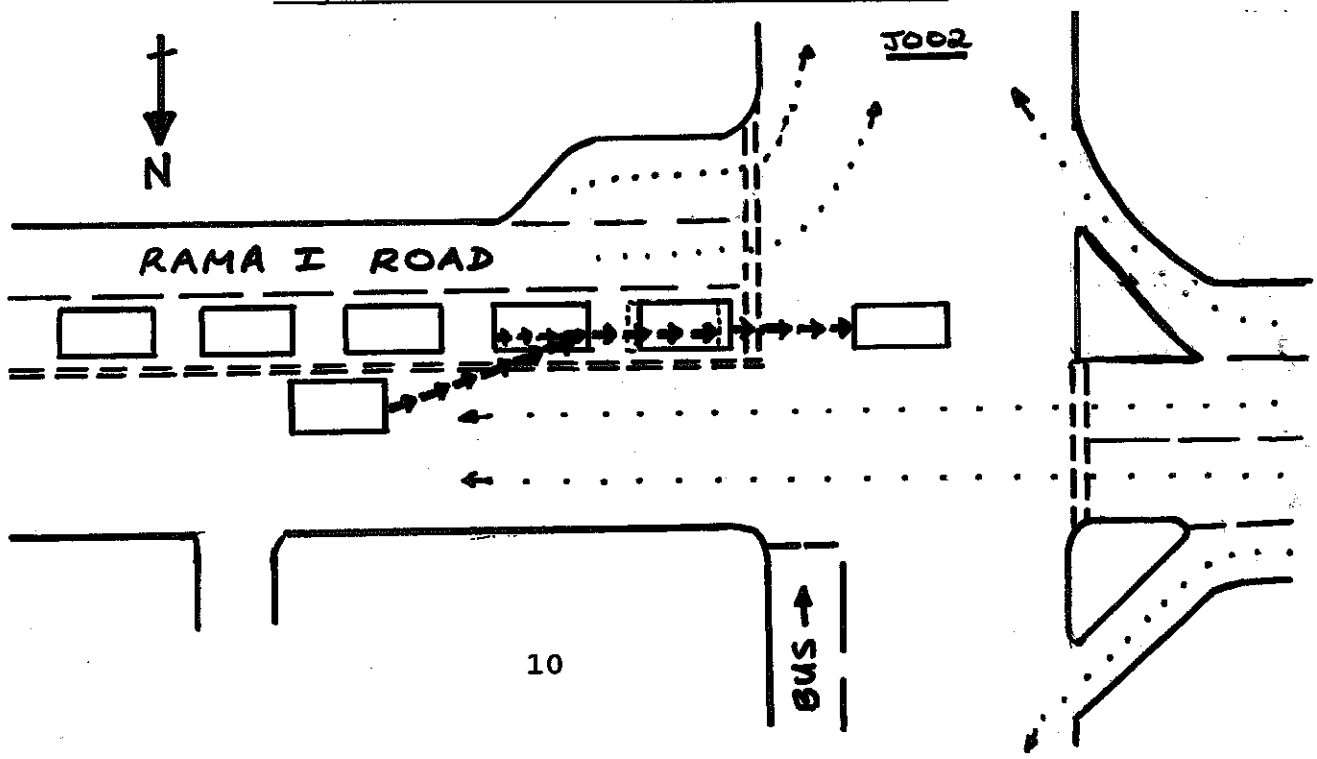
Another position to which disabled vehicles should be pushed in order to minimize delay is the exit link of a junction. An example is illustrated in Figure 3.

Figure 3: Position of Disabled Vehicle in Exit Link



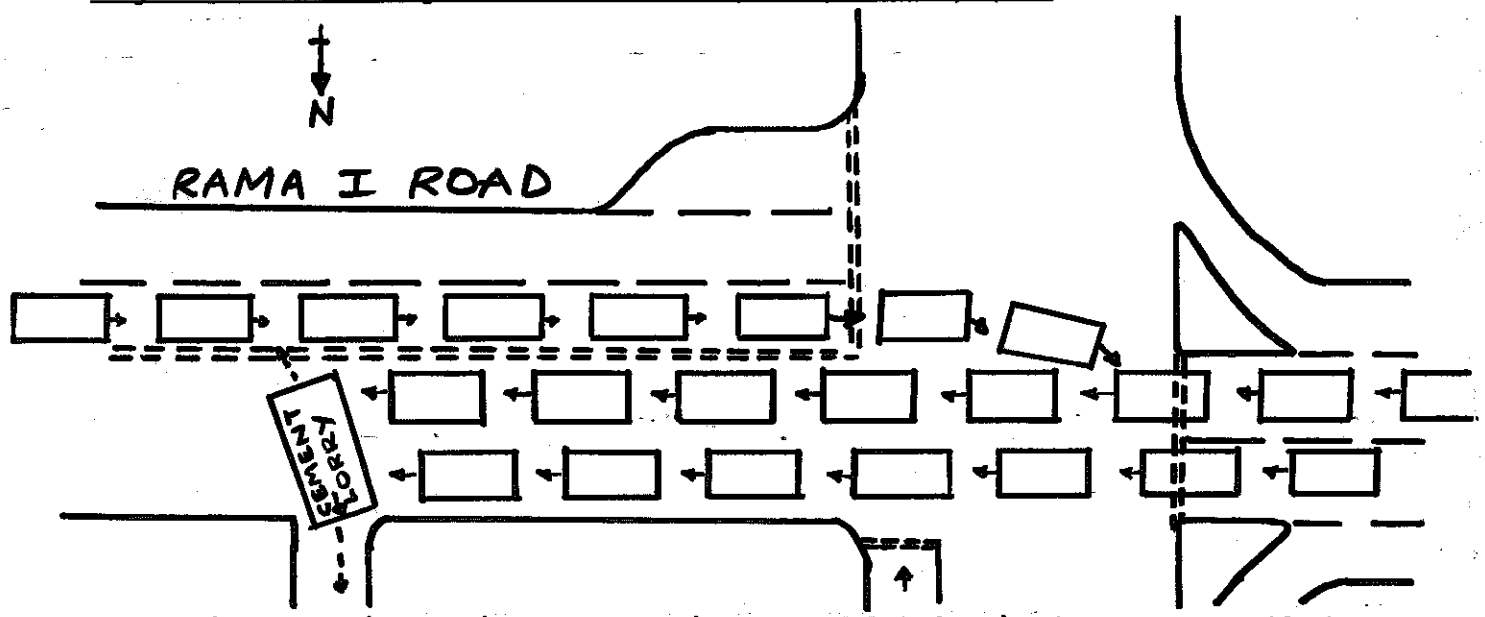
In highly saturated conditions vehicles occasionally cannot get into the correct lane because of the rapid formation of a tightly packed queue. This occurred on the eastern approach to junction 5 (J002) because the police encouraged drivers to use the opposite (eastbound) carriageway on Rama I Road. In these instances (e.g. 1559 on 30/4) the dead-space inside a junction can again be used to good effect. Figure 4 shows how during a 'red' signal vehicles can shuffle forward in order to allow a vehicle to enter a stationary queue and hence return to the correct side of the carriageway thus avoiding causing delay to on-coming traffic.

Figure 4: Forward Shuffle of Queue



Driving behaviour in Bangkok tends to result in the use of every available piece of road-surface but there is often a problem caused by drivers who insist on entering a junction although their exit is blocked. On 29/4 at 1629 when the eastbound exit from junction 5 (J002) was blocked by a cement lorry, drivers continued to enter the junction. Consequently the east to north movement during the next stage could not move and because this queue remained stationary the cement lorry causing the obstruction could not conduct a reversing movement in order to enter the grounds of the Mekong Project. Figure 5 shows this 'locked' situation.

Figure 5: Locking of Junction 5 (J002) on 29/4/87




The vital action which the police should take is to ensure that vehicles do not fill a junction when an exit is blocked. In the above instance this would have resulted in the free movement of east to north traffic and the lorry would have subsequently been able to reverse and then more quickly enter the Mekong Project premises.

(c) Signal timings after a major incident - During manual control the most common method used by the police to deal with an incident was to lengthen the signal stage over which the incident occurred. The same stage during subsequent cycles was also often increased. This practice sometimes simply transferred the delay to another movement and it was not common for the police to take direct action to remove the delay-causing obstruction. This is understandable because the police already had control of the signals and pushing buttons is easier than pushing cars! There does however appear to be some merit in altering the stage lengths after an incident in order to ensure that the queues on the approaches to a junction regain balance after an incident which severely restricted flow in one direction.

When the cement lorry blocked Rama I Road on 29/4 the police wanted to take control of the signals at junction 5 (J002). The police were asked not to take control because they would have used variable and long cycle times which would have disrupted the co-ordinated movement of traffic under automatic control upstream

on Bamrungmuang Road. However it would have been beneficial to increase the stage for the movement from Bamrungmuang, but still maintain the same cycle time.

A suitable strategy for dealing with incidents without switching off the signals or operating them manually, would be as follows:

i) Prevent the blocked movement entering the junction, by hand signals from policeman one, while

ii) Policeman two helps to remove the obstruction.

iii) Policeman one extends the 'green' time for unblocked movements by waving them through the junction after their signal has turned red, while continuing to prevent the conflicting blocked movement from entering. This will reduce the queues on the unblocked movements.

iv) Once the obstruction has been removed, reverse (iii) by extending the 'green' time for the previously blocked movement. Again, this is done by waving vehicles through after the signal has turned red, while policeman two holds back the traffic which has just received green. This procedure will reduce the queues on the movement that was blocked and restore the queue on the unblocked movements.

v) Repeat (iv) for several cycles until queue balance restored.

The result of implementing this type of strategy should be to spread the increased delay caused by a major incident between movements, while continuing to maintain the co-ordination of upstream junctions.

(d) Police reaction to incident management ideas - After the main experimental period, the Local Commander of the Traffic Police agreed to allow the continued operation of automatic traffic signal timings. The approaches to incident management, described above, were discussed with the Commander and, not surprisingly he said that his officers already knew where to push broken-down vehicles! However, the automatic control was considered to be successful and the Commander agreed that, as his officers would be released from controlling each junction, they should therefore respond promptly to any incidents. The above method for modifying signal timings after a major delay-causing incident was discussed and the Commander also agreed that the method would be employed at junction 5 (J002) if the need arose during the extended period of automatic control.

A smaller-scale survey was conducted from 18th May until 22nd May after four weeks of automatic control. The results, which are presented in WP 251, suggest that the performance of automatic control may have improved during this week. In any case, the operation of the strategy for modifying automatic control after an incident was successfully executed at junction 5 (J002) on 22 May 1987. At 4.30 pm an accident on the Rama I Bridge stopped the flow of traffic on Bamrungmuang for 2 minutes. The time, location and effect of this incident was the same as that caused by the cement lorry on 29/4/87. On this occasion the police reacted very quickly and they:

(a) ensured that a gap remained in the queue of eastbound vehicles across junction 5 (J002), and

(b) extended and reduced the appropriate stages, while automatic timings continued to operate.

There is insufficient data to prove that the incident management strategy was successful on this day, but unlike 29/4, the queue on Plupplachai Road was only 100 meters and on Bamrungmuang Road the queue did not grow more than 20 meters beyond junction 3 (J160).

## 5. Conclusion

Incidents are likely to cause considerable delay to traffic when roads are fully saturated, and they present a major obstacle to the successful operation of automatic traffic signals under these conditions. The experiment conducted throughout May 1987 has demonstrated that it is possible to replace manual control with automatic control in highly congested conditions, and that incident management is likely to further assist in the performance of automatic control.

The police in this area of Bangkok have accepted that automatic signal timings can replace manual control, and they have demonstrated a willingness to conduct an incident management strategy under the guidelines described in this paper. Further work is required in order to be able to measure the amount of delay caused by specific types of incidents and further discussions with the police would continue to enhance the incident management programme.

WP250
dq/plh (pc)
3 November 1987

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