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INCIDENT DETECTION EXPERIMENTS ON THE BOULEVARD PERIPHERIQUE IN PARIS

by

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INCIDENT DETECTION EXPERIMENTS ON THE BOULEVARD PERIPHERIQUE IN PARIS

ABSTRACT

To assist with a study into methods of detecting incidents, such as accidents, breakdowns or congestion, on the running lanes of motorways, a number of simulated incidents were organised on the Boulevard Périphérique in Paris by the Institut de Recherche des Transports. Analysis of the traffic data collected by the Transport and Road Research Laboratory during the simulated incidents has shown that, for such a site with high flow levels, an algorithm based on the detection of slow moving or stationary vehicles was able to detect all the simulated incidents without giving any false alarms.

1. INTRODUCTION

Methods of detecting interruptions in the traffic flow on motorways are being studied as part of a research programme to improve traffic control on high speed roads. In typical methods a number of traffic parameters, such as speed, flow and occupancy, are calculated continuously from data supplied by vehicle detectors. Algorithms are then used to determine whether changes in these parameters are consistent with the normal variations in traffic patterns or whether they could be attributed to an incident. The basic requirements are a reliable indication of all incidents and a low rate of false alarms. An essential step in research on incident detection is to obtain traffic data before and during incidents so that algorithms for interpreting disturbances in traffic behaviour can be developed and tested. To obtain such data, one could collect data continuously and wait for an incident to occur, or one could stage simulated incidents - the latter being the most efficient procedure.

The Institut de Recherche des Transports (IRT) in Arcueil was given permission by the Préfecture de Paris to stage a number of simulated incidents on the Boulevard Périphérique and TRRL were invited to take their data-recording equipment to Paris. This report describes the experiment and the subsequent analysis of data by TRRL.

2. THE EXPERIMENT IN PARIS

2.1 *Site*

The experiment was carried out on the westbound carriageway of the Boulevard Périphérique in Paris, near its crossing of the Avenue de la Porte de Clignancourt. At this point the Boulevard Périphérique had two 4-lane carriageways with no hard shoulders. Traffic flow during the experiment was approximately 7000 vehicles per hour on each carriageway.

The reasons for choosing this particular section of the Boulevard Périphérique were:-

(i) Its location relative to two sets of occupancy detectors operated by the Préfecture de Paris.

(ii) The proximity of a number of high buildings from which it was possible to see, and film, the test section and its approach.

(iii) The availability of a parking place for the mobile laboratory and other vehicles associated with the experiment.

The presence of an off-ramp and an on-ramp within the test section was a disadvantage but it would have been difficult to avoid this problem because the interchanges are closely spaced on the Boulevard Périphérique.

The layout of the test site is shown in Fig 1.

2.2 *The incidents*

IRT, the Préfecture de Paris (local authority), and the police arranged to stage 12 incidents, three at each of four positions in the test section. Table 1 shows the sequence used.

TABLE 1

Location and timing of incidents

Day	Position of Incident			
	A.M.		P.M.	
	9.30-10.00	10.15-10.45	14.30-15.00	15.30-16.00
Tuesday	1	2	3	4
Wednesday	4	1	2*	3
Thursday	3	4	1	2

Note: (i) The first simulated incident each day blocked two lanes

(ii) 1, 2, 3 and 4 refer to the incident location (see Fig 1)

* This incident aborted and was re-run at 16.30 hours.

Each 'incident' was caused by two vehicles, usually small vans, which gradually slowed down and finally stopped in the right hand lane at one of the selected positions. The vehicles stopped in such a way that the lane was blocked. For some tests part of the adjoining lane was also blocked. Almost immediately after they had stopped a police car positioned itself just upstream with its blue lamp and hazard warning lights switched on. Police from this car coned off the obstruction for the duration of the incident.

2.3 *Data collection*

2.3.1 TRRL: The equipment used by TRRL recorded on punched paper tape, every tenth of a second, the presence or absence of vehicles over six detector loops. The loops were installed in three of the four lanes at two sites 530 metres apart (Fig 1). The left hand lane at each site was not monitored because the equipment had been designed, and the analysis program written, for 3-lane roads and it was not possible to make modifications in the time available.

The detector loops used were single turn, 4m long x 1.7m wide buried in the road surface at a depth of 2.5cms. Sarasota Type 15A detectors were connected to the loops.

Throughout the experiment a TRRL observer was stationed on the roof of a nearby block of flats, recording the times of all occurrences in the test section and taking still photographs for reference purposes.

2.3.2 IRT: IRT used four time-lapse cameras to film each incident. The cameras obtained complete coverage of the experimental section from the roofs of dwellings overlooking the Boulevard Périphérique.

2.3.3 Préfecture de Paris: The Préfecture de Paris had a number of vehicle detector sites along the Boulevard Périphérique. The test section was spanned by two of these sites, 980m apart. Their detectors were small devices buried in the road surface which sensed changes in magnetic field as vehicles passed over them. The output from each detector gave the mean occupancy every 20 seconds.

2.4 *Experimental procedure*

Watches were synchronised at the start of each morning and afternoon session. The experiment then ran according to the timetable (Table 1) because there was no communication with the camera operators and observers on the roofs.

The film cameras and the TRRL recording equipment were started 10 minutes before the scheduled time for the incident. The duration of each incident was decided by the drivers of the incident vehicles in consultation with the attending police officers, their aim being to maintain the obstruction for about 10 minutes provided that congestion did not become too widespread. In practice, durations of 3 to 12 minutes were achieved. The cameras and recording equipment were left running for 15 minutes after each incident had been removed by which time the traffic had returned to normal.

The drivers of the incident vehicles were instructed not to stop if they felt that, for some reason, it would be dangerous to do so. Only one incident was aborted, this because the test section was congested by drivers slowing down to look at an accident on the opposing carriageway. The incident was re-run at the end of the day.

3. ALGORITHMS

Two algorithms were tested on the data from individual detectors to determine their ability to detect the simulated incidents. Their response times, ie, from the start of each incident to the first detection of that incident, and their false-alarm rates were also compared.

These algorithms were:

(i) Algorithm A: Single exponential smoothing of the instantaneous occupancy values (ie those values obtained directly from the detector data, calculated at one second intervals and referring to one second periods of time) gave smoothed occupancy values which were compared to a threshold value, an incident alarm being given when the threshold value was exceeded.

(ii) Algorithm B: This algorithm detected stationary or slow-moving vehicles by looking for several consecutive seconds of 100 per cent instantaneous occupancy. An alarm was indicated when this occurred. The algorithm also calculated the exponentially smoothed occupancy values, and the alarm was terminated when the smoothed occupancy dropped to the average level which had prevailed for the 5 minutes preceding the alarm. However, to prevent 'hunting' of the alarm signal at the onset of an incident (ie rapid switching on and off in response to fluctuation of the value of the smoothed occupancy, around its pre-alarm average) the smoothed occupancy was arbitrarily raised to 90 per cent when an alarm was first indicated. This, of course, biassed the subsequent estimates of smoothed occupancy and ensured that the alarm condition was maintained for a reasonable period. As a further measure to avoid instability, the up-dating of smoothed occupancy was suspended after 8 seconds if no vehicle had passed over the detector during that time. This prevented mistaking stop-go movement of a queue for the resumption of free flow. The up-dating recommenced as soon as traffic flowed over the detector.

4. RESULTS

Only the results obtained by TRRL are discussed here. IRT provided copies of their time-lapse films which were used for confirmation of the general scene and timing of events.

4.1 *Processing of data*

Details of the analysis program used are given in Appendix 1.

4.1.1 Changes in flow and occupancy at a typical incident: Smoothed values of flow and occupancy were calculated for every second for each detector using the single exponential smoothing method, described in Appendix 1, with a smoothing factor of 1/64. The smoothed flow over each detector during one of the simulated incidents at Site 1 is shown in Fig 2. For this typical incident the flow over the downstream detector in lane 1 was reduced to zero because the location of the incident prevented traffic from crossing this detector. In addition, the upstream detector in lane 1 was not affected as lane 1 was used almost exclusively at this point by traffic leaving the Boulevard Périphérique via the exit ramp within the test section.

The smoothed values of occupancy corresponding to the above flow data are shown in Fig 3. The occupancy of all the detectors was increased as the congestion caused by the incident affected them, but it then rapidly fell to zero on lane 1 downstream because traffic ceased to cross this detector. The change in occupancy caused by a genuine incident which occurred just east of the upstream detector in lane 1 is also visible in Fig 3.

4.1.2 Detection of incidents: Examination of the occupancy data for all the incidents suggested that a threshold value of 35 per cent would be suitable for algorithm A. Using this threshold algorithm A failed to detect two of the three incidents at Site 4 but detected the third, and detected all incidents at other sites. Algorithm B was able to detect all the incidents at all the sites.

One hundred per cent instantaneous occupancy for 2 consecutive seconds was selected as the alarm threshold required by algorithm B to give a fast incident response time with a minimum of false alarms. Figure 4 shows the effect of algorithm B on the smoothed occupancy calculations for the incident illustrated in Fig 3. The occupancy plot for lane 1 downstream includes an illustration of the second part of algorithm B in operation, viz, the suspension of the smoothed occupancy calculation while the detector was not occupied subsequent to the incident occurrence.

Figures 5 and 6 show similar results for an incident at Site 3.

4.1.3 Response times: Table 2 gives the response times for algorithm A using a threshold value of 35 per cent smoothed occupancy, and algorithm B with the threshold of 100 per cent occupancy for 2 seconds.

4.1.4 False alarms: The number of false alarms produced by a detection system is dependent, amongst other factors, on the threshold values chosen in the algorithm. A low threshold will improve the response time and detection ability but increase the number of false alarms. Traffic flow, the number of detectors used and the distance between detectors will also affect the number of false alarms given.

In this experiment, data was recorded for 372 minutes, of which 150 were judged to be incident free and were used to test the algorithm for false alarms. With a threshold of 35 per cent, algorithm A gave a total of 30 false alarms for this installation; equivalent to 13 false alarms per hour; whereas algorithm B, using the threshold values described in 4.1.2 gave no false alarms. The traffic flow was reasonably constant during the experiment at approximately 1700 vehicles per hour per lane.

4.2 *Journey time estimation*

Attempts to calculate the journey times between the two detector sites, using the pattern recognition technique described in Appendix 1, were not successful. Subsequent work at a site on the M4 motorway confirmed that the technique breaks down as the flow per lane approaches 1500 vehs/h. In addition, the Paris site had the disadvantage of an interchange between the detector locations, which helped to break up the regular flow pattern. The

TABLE 2

Response times of algorithms

Position of Incident	RESPONSE TIME					
	Tuesday		Wednesday		Thursday	
	A	B	A	B	A	B
1	50sec	20sec	45sec	20sec	50sec	30sec
2	4min 50sec*	4min 20sec*	3min 20sec	1min 40sec	5min 20sec	2min 30sec
3	50sec	2min 10sec	30sec	60sec	40sec	20sec
4	Not detected	30sec	Not detected	50sec	6min	60sec

Note. Algorithm A, threshold = 35 per cent smoothed occupancy
Algorithm B, threshold = 100 per cent occupancy for 2 seconds

* Severe congestion through the experimental site just prior to the incident caused difficulty in interpreting these results.

pattern recognition technique of journey time estimation is satisfactory in lower flow situations where there is a more consistent flow pattern.

5. DISCUSSION

Comparison of flow and occupancy values during an incident, as illustrated in Figs 2 and 3, confirms findings from previous work that occupancy generally gives a more positive indication of an incident situation than flow. Consequently, occupancy was used by both of the algorithms under test.

Algorithm A (smoothed occupancy with a threshold for incident alarm) was included to test the operation of a simple algorithm in heavy traffic conditions, where the effect of an incident is particularly pronounced and hence easy to detect. The optimum threshold value would, ideally, vary with flow levels, being selected to avoid false alarms but still detect all real incidents in a reasonable time. However, the traffic flow was consistently heavy during the tests at about 1700 vehicles per hour per lane through the test section, so the threshold value was kept at the selected level of 35 per cent. This resulted in failure to detect two incidents out of the twelve and gave a false alarm rate of 13 false alarms per hour for the installation. Clearly this would not be acceptable, so the simple algorithm A is not a satisfactory method.

Algorithm B (smoothed occupancy with 100 per cent instantaneous occupancy for 2 seconds to initiate the alarm) showed greater promise as a method of incident detection. At this busy site all the incidents were detected and no false alarms were recorded. The response time was generally shorter than that for algorithm A (see Table 2).

A particular advantage of Algorithm B was that no calibration of the smoothed occupancy threshold was required because the incident was detected by the occurrence of 100 per cent values of instantaneous occupancy. An additional feature was the identification of stop-go conditions after the initial alarm so that the alarm condition could be maintained in spite of detectors indicating zero occupancy for long periods when not covered by a vehicle. The termination of an incident was signalled when the smoothed occupancy returned to the free-flow level before the incident. The effect on the calculated values of smoothed occupancy can be seen in Figs 4 and 6. This algorithm, which is described in more detail in Appendix 1, seemed to be promising enough to warrant further testing over a range of traffic flows, especially in UK motorway conditions.

6. CONCLUSIONS

1. This work confirmed that a simple algorithm using single exponential smoothing of occupancy values with a calibrated threshold was not a satisfactory way of detecting incidents.

2. An algorithm based on the detection of slow moving or stationary vehicles to initiate the incident alarm showed promising results at a busy site. It included special features for maintaining the alarm condition during subsequent 'stop-go' congestion and for signalling the end of the incident. Further testing is necessary in a wider range of traffic conditions.

3. The use of a pattern recognition technique to measure journey times, which could then be monitored as a way to detect incidents, did not work at flows higher than 1500 vehs/h per lane.

7. ACKNOWLEDGEMENTS

The work described in this report was carried out as part of the research programme of the Highway Traffic Division (Division Leader: Mr J A Hillier) of the Traffic Engineering Department of TRRL. The author is grateful to the Institut de Recherche des Transports, both for the invitation to take part in this experiment and for the assistance given during it, and also to the Préfecture de Paris for giving their permission for the experiment and for their active support.

8. APPENDIX 1

Detector analysis program (DETAN)

The DETector ANalysis program (DETAN) - written by P D Whiting at TRRL in 1973 - is used in the development of incident detection algorithms. It accepts raw data from six single loop detectors in a configuration of two sets of three, which corresponds to an upstream and a downstream measuring site on a 3-lane carriageway.

The program performs the following routines:

(i) The processing of detector data to obtain instantaneous* values of flow and occupancy for each detector, or combination of detectors.

(ii) The calculation of smoothed 'averages' of the instantaneous flow or occupancy values by means of single-stage exponential smoothing.

(iii) An incident-detection algorithm which uses the occurrence of a sequence of 100 per cent instantaneous flow or occupancy values to identify an incident.

(iv) The estimation of average journey time (or speed) between any two detectors by a method of pattern recognition.

(v) The presentation of data by line printer or graph plotter.

The program was written in Fortran IV for the ICL 4/70 computer at TRRL. Its basic concepts and analytical procedures are outlined in the following notes.

8.1 *Flow and occupancy calculations*

The first step is to obtain instantaneous values of flow and occupancy from the detector data. These instantaneous values are used in all the subsequent routines, including the provision of smoothed average values of flow or occupancy.

8.1.1 Data measurement and sampling rates: For reliability and minimum cost in the computing and data transmission elements of an incident detection system, it is advantageous to use as low a data rate as possible. The latter was determined by the minimum demands of that part of the program dealing with the estimation of journey time by a pattern recognition technique. This required instantaneous values of flow or occupancy for each consecutive period of one second in order to provide sufficient detail of the traffic stream perturbations for the pattern recognition method to function. In addition, it was decided that 10 samples of the detector data within the one second period would provide sufficient system accuracy. Few fast vehicles

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*Note: The description 'instantaneous' is used here to indicate parameters measured over short, successive periods of time such as one second, with the latest value being available at the end of its measurement period (see 8.1.2) would be missed completely because in the TRRL system a typical detector 'on' time was about 0.2 seconds for the worst case situation, such as a small car travelling at 70 miles/h (113 km/h).

8.1.2 Instantaneous values of flow and occupancy: During every one-second time period all the detector outputs are scanned at 0.1 second intervals for the presence or absence of vehicles. If a detector is occupied when sampled, its occupancy value for that second is increased by one; if it is occupied and was not occupied at the previous sampling time, its flow count for that second is also increased by one. In this manner, values of flow and occupancy during successive one-second time periods are obtained at one-second intervals. These are the values referred to as 'instantaneous'.

Alternative parameters, such as the proportion of carriageway flow per lane, are produced by combining in an appropriate manner the individual lane values at a measuring site.

8.1.3 Smoothed values of instantaneous parameters: Parts of the program use 'average' or smoothed values of various parameters - the 'averaging' period may be tens of seconds with an up-dated value every second. For this purpose the program employs single stage exponential smoothing of the instantaneous values and this is carried out by the standard procedure:

$$\text{New smoothed value} = P \times \text{present instantaneous value} + (1-P)\ \text{previous smoothed value}$$

where P, the smoothing factor, must be positive and less than unity. In theory, each smoothed value is the sum of all the previous instantaneous values after being exponentially weighted with time, the greater weighting being given to the recent values. This procedure is simpler and more economical for computer processing than a direct averaging process which gives equal weighting to all the instantaneous values.

In choosing the value of P, the smoothing factor, a compromise usually has to be made between the achievement of a well-smoothed 'average' value for the parameter and a rapid response to meaningful changes. For example in the case of occupancy, small values of P give a smoothed 'average' value with a relatively sluggish response to real changes in traffic flow, whereas large values are over-responsive to random fluctuations.

The choice of an initial trial value for P is made difficult by the fact that there is no direct equivalent to the averaging period as used in a direct averaging process. However, it can be of help to know the elapsed time or, more generally, the number of measuring intervals from which instantaneous values are drawn in contributing to a smoothed value, because the number of measuring intervals contributing in practice depends upon the value of P. This effective number of intervals may be estimated by taking a single instantaneous value, q, and examining the exponential decay of its weighted magnitude with the passage of measuring intervals (equivalent to time). Initially the weighted value used is Pq but subsequently this reduces as follows: after 1/P intervals the magnitude becomes 37 per cent of Pq; after 3/P intervals it reaches 5 per cent and after 5/P intervals it is less than one per cent. A typical value for P used in this program is 1/64 so that with the one second measuring interval used, the initial weighted value of q/64 would be reduced to 37 per cent in 64s, 5 per cent in 192s and under one per cent in 320s.

8.2 *Incident detection algorithm*

An experimental incident detection algorithm is included in the DETAN program. This is the algorithm B referred to in the main text. Its aim is to identify the occurrence of an incident by detecting the presence of stationary or slow moving vehicles over a detector. This is achieved by examining the one second instantaneous occupancy values for all detectors and looking for a short sequence, usually 2 or 3 seconds long, of 100 per cent occupancy. When this occurs an incident alarm is given and the smoothed occupancy value for the detector involved, which has been up-dated every second in the normal manner, is immediately forced to a high figure, usually 90 per cent. This is done to prevent the rapid switching on and off of the alarm signal at the start of an incident, caused by the value of smoothed occupancy fluctuating around the value which will terminate the alarm.

The original DETAN program has been modified with respect to the termination of an incident. The algorithm now terminates the alarm condition when the value of the smoothed occupancy reaches either the average level of smoothed occupancy which existed before the incident, or an alternative predetermined level. The pre-incident average level is calculated from the values which occurred at the end of each of the five one-minute periods preceding the alarm. The pre-determined termination level is intended to cover the case when the incident may have happened in below-average traffic flows. In this situation it is likely that by waiting for the smoothed occupancy to fall to this low average level, the duration of the alarm condition may be prolonged unnecessarily and, consequently, the alternative limit is provided to correspond to normal high traffic flows for the particular site.

In order to maintain the continuity of the alarm condition during an incident, allowance is made for the situation where vehicles may be stopped clear of the detector for periods of time. Such conditions frequently arise during 'stop-go' traffic flow at incidents. Consequently, every time the instantaneous occupancy is zero for a period of, say, 8 seconds during an alarm condition, the recalculation of the smoothed occupancy is suspended and only restarted when vehicles pass over the detector again.

8.3 *Average speed estimation*

A sub-routine, PATREG, is included in the program to test the feasibility of estimating the average journey time (and hence speed) between measuring sites which are only equipped with single detectors in each lane. Its working is based upon the presumption that there is some recognisable continuity in the traffic pattern at two consecutive sites under steady, incident-free conditions. In the ideal case, the patterns of flow (or occupancy) with time, which are obtained simultaneously from an upstream and from a downstream detector, would be found to match exactly if the downstream pattern were advanced by a time interval equal to the journey time between the detectors. Consequently, the average journey time may be found by means of a pattern recognition technique which determines the relative time delay between the patterns. In practice, allowance must be made for some variation in the flow pattern between detectors since the speeds of individual vehicles will vary.

Given the flow patterns corresponding to the upstream and downstream detector sites in a lane, expressed as instantaneous flows at one second intervals, the following cross correlation procedure is implemented every second on the two series of flow values to determine the relative time displacement which gives the best match between them:

1. The 40 most recent values of upstream flow, which are stored, are up-dated when the latest value is available.

2. DU(I), defined as the product of the latest downstream flow and the upstream flow for I seconds ago, is calculated for each of the 40 stored upstream flow values, giving values of DU(I) for I ranging from 1 to 40 seconds ago.

3. Single exponential smoothing is now employed to give a weighted sum (MATCH) of the present and past values of DU(I) for each time interval I, ie,

New MATCH(I) = Q x present value DU(I) + (1 - Q) x old MATCH(I)

where Q has a typical value of 1/128.

The above process gives a set of 40 values of MATCH(I), each value corresponding to a particular time displacement (I), between the two flow patterns, from the range 1 to 40 seconds. Ideally, the maximum value of MATCH(I) in this set would now correspond to the value of I which is the relative time displacement giving the best match, ie, the journey time. However, as vehicle speeds are not usually constant between measuring sites, an allowance is made for the resulting spread in journey times by combining the set of MATCH(I) values with journey time weighting factors.

The weighting factors used have been given a symmetrical distribution and values of 1, 2, 4, 6, 8, 9, 9, 9, 8, 6, 4, 2 and 1. This group of 13 weights is stepped along the 40 MATCH(I) values and at each step the 13 products (weight x MATCH value) are totalled. The highest scoring total will be that when the weighting factors are distributed symmetrically about the particular MATCH(I) value corresponding to I (seconds) which is the journey time. Since MATCH(I) has 40 values and the weighting factors 13, the range of journey times covered with the present program arrangement is 7 to 34 seconds.

The use of the variables DU(I) and MATCH(I) as described above is equivalent to a basic cross correlation process which may be outlined as follows:

Given two series of flow values, U_{t-I+n} and D_t, consisting of discrete values, and where I = time displacement between the series (secs)
and t = 1,2,3,4 .... (secs)

the equation

$$S_n = \sum_{t=1}^{\infty} U_{t-I+n} \cdot D_t$$

may be evaluated for values of n from 1 to, say, 40 secs.

The value of n corresponding to the maximum value of S_n is the displacement required to give the best match between the two series ie $n = I$.

The modified cross correlation procedure employed in PATREG is convenient and economic for computer use.

8.4 *Values of program constants*

The values of smoothing factors, algorithm thresholds and other constants are still the subject of experimentation and may be capable of further optimisation for different traffic situations. The values quoted in the text are given for guidance.

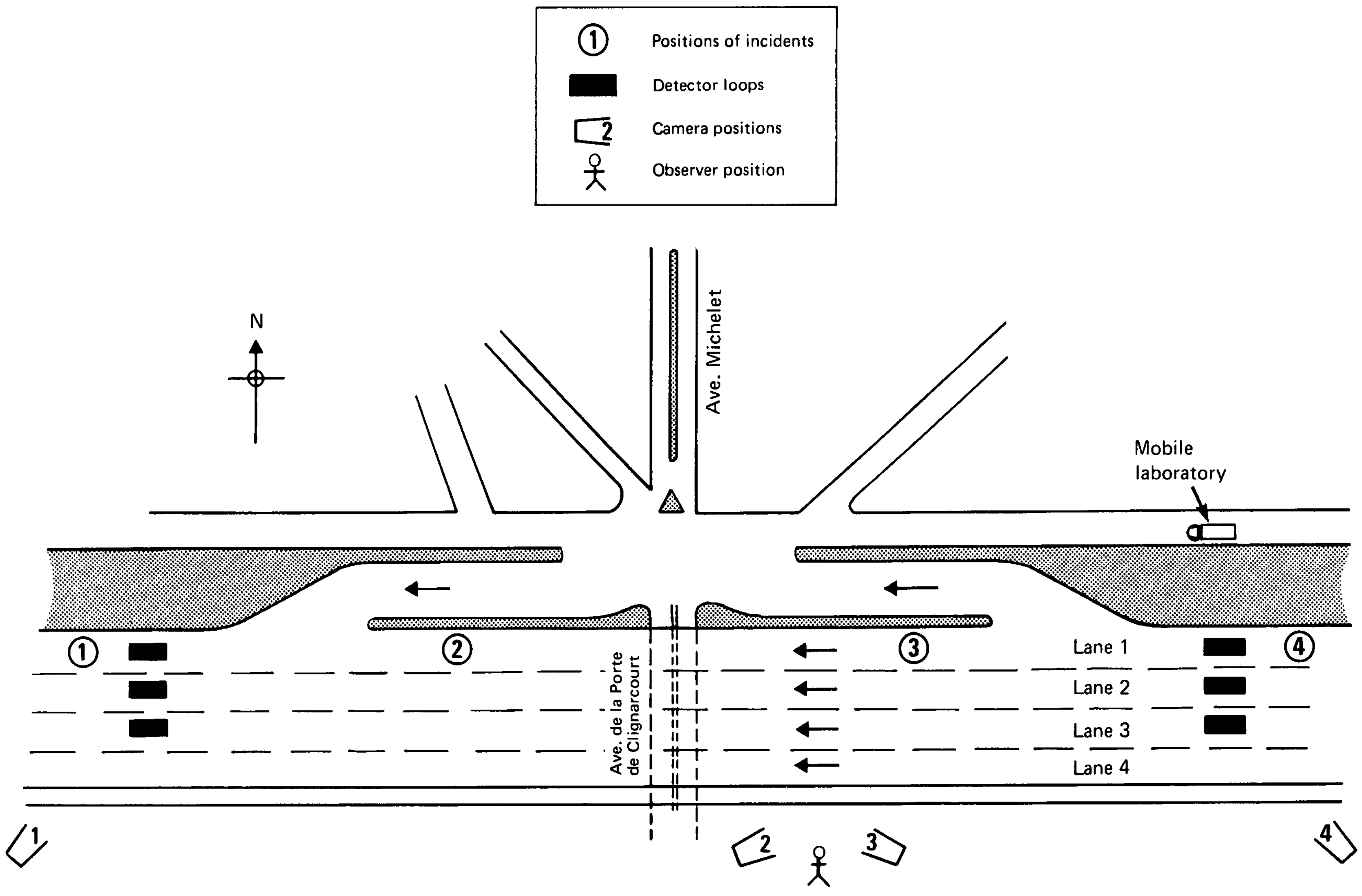

Fig. 1 EXPERIMENTAL SITE

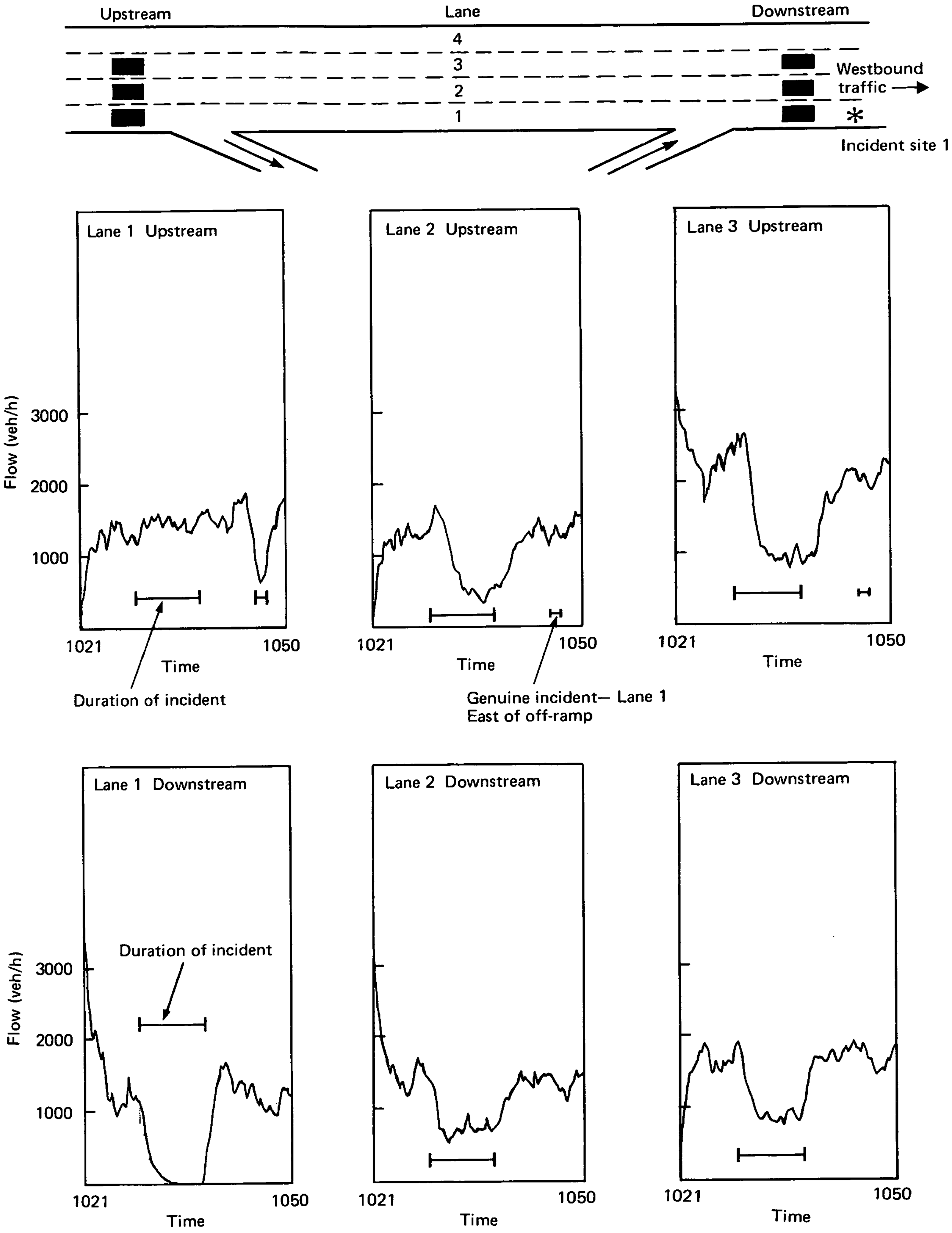

Fig. 2 FLOW –v– TIME FOR AN INCIDENT AT SITE 1

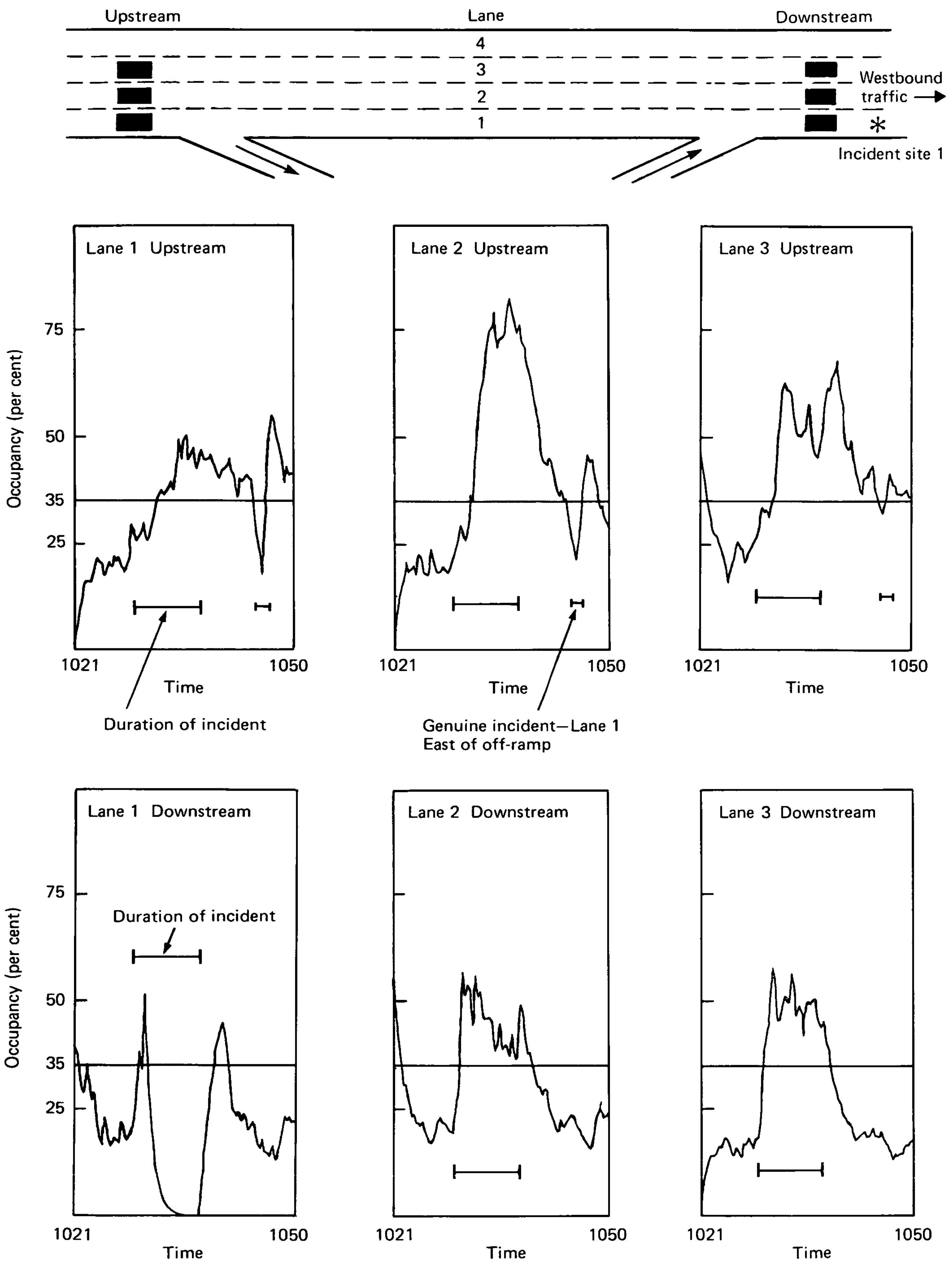

Fig. 3 OCCUPANCY –v– TIME FOR AN INCIDENT AT SITE 1

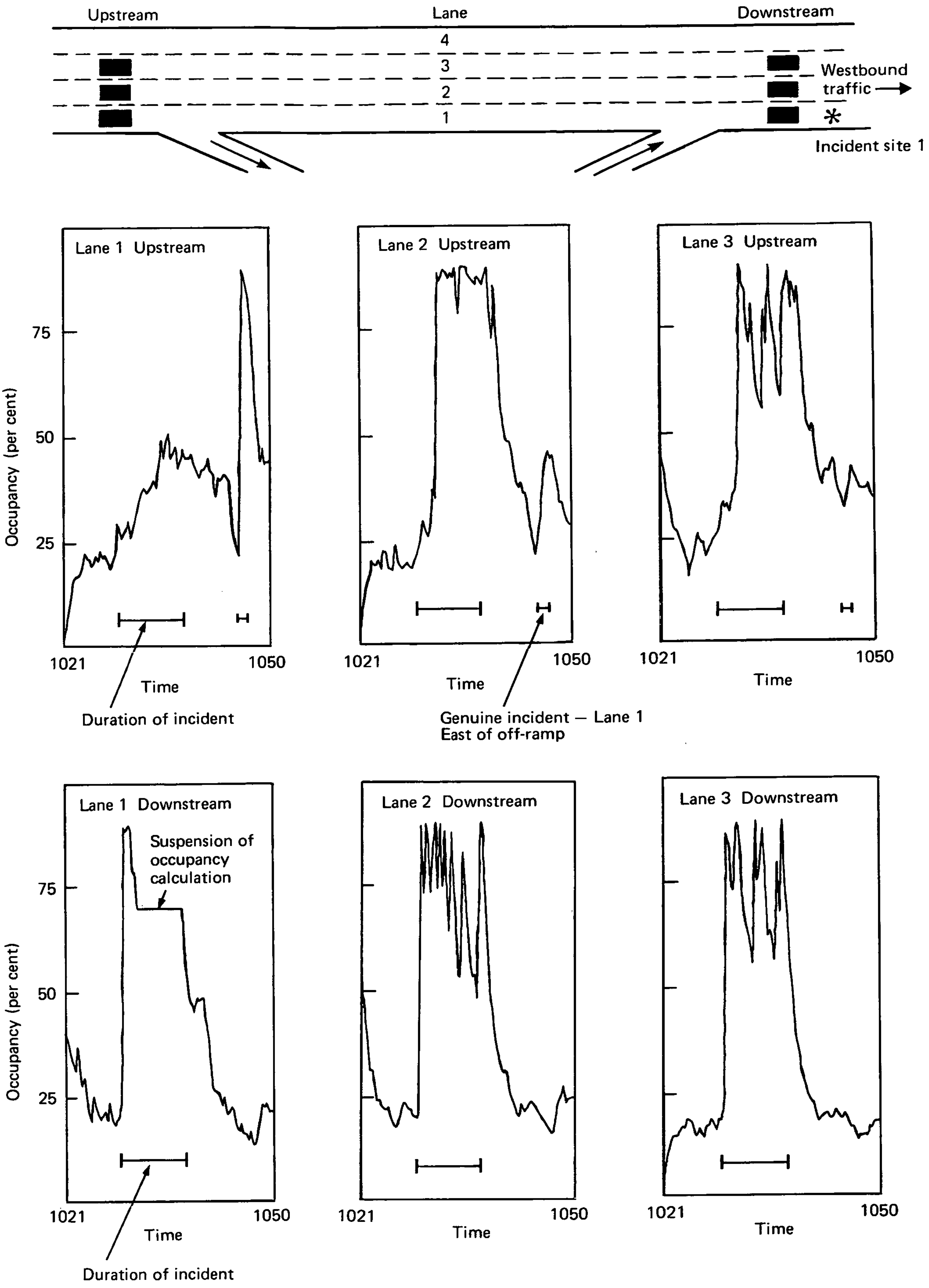

Fig. 4 OCCUPANCY — MODIFIED BY THE OPERATION OF ALGORITHM 3 INCIDENT AT SITE 1

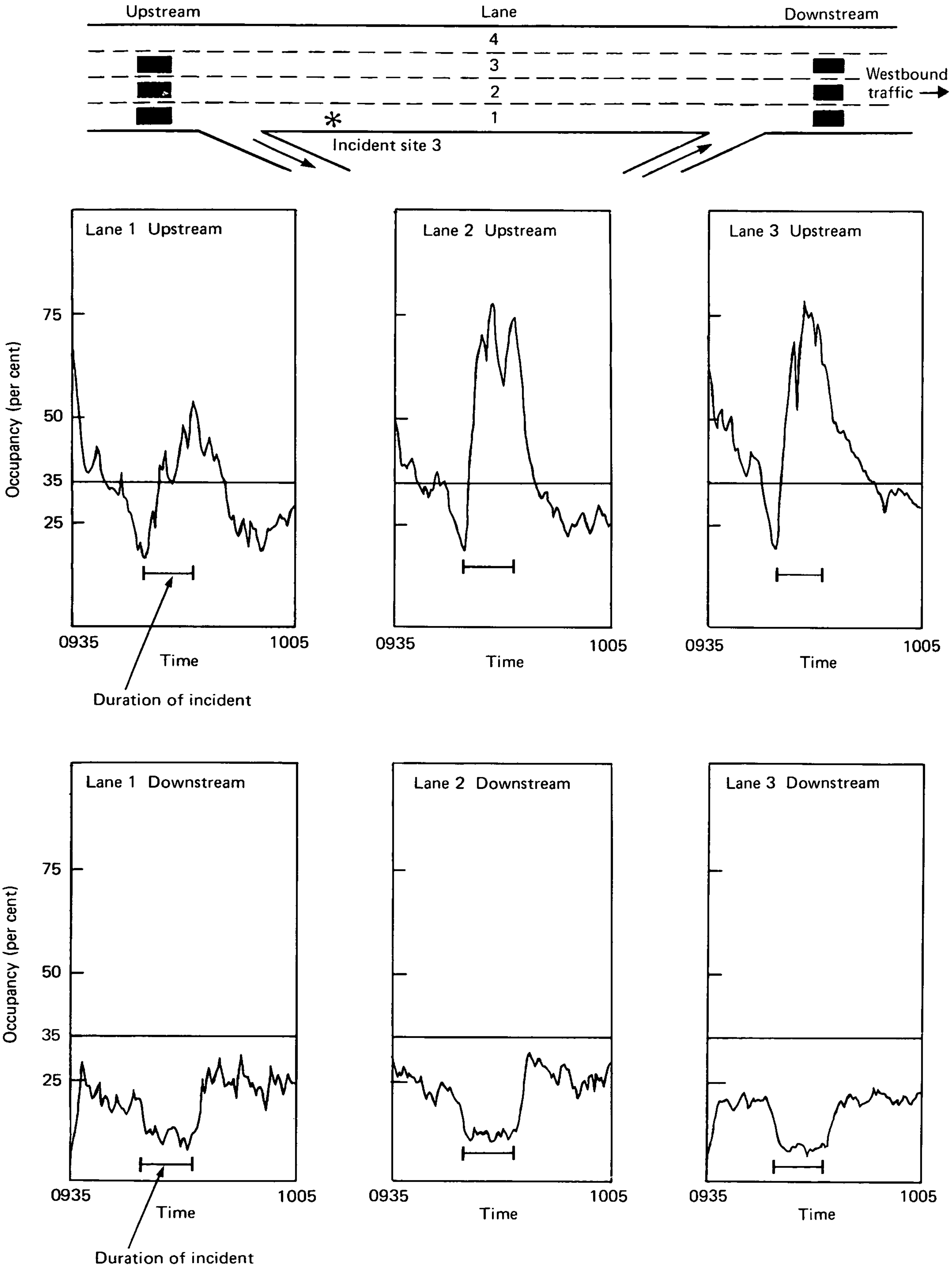

Fig. 5 OCCUPANCY —v— TIME FOR AN INCIDENT AT SITE 3

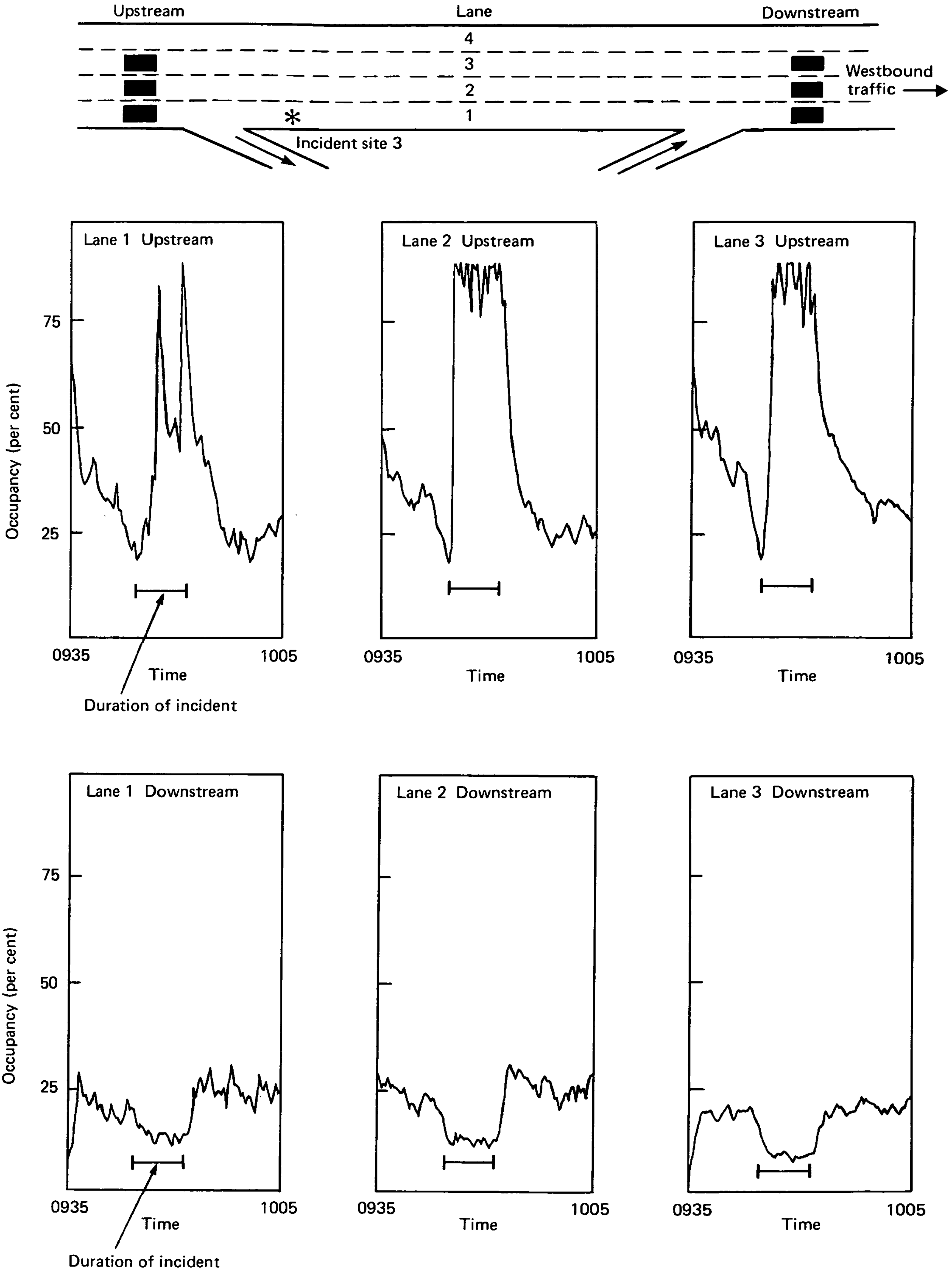

Fig. 6 OCCUPANCY – MODIFIED BY THE OPERATION OF ALGORITHM 3
INCIDENT AT SITE 3

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