Traffic Detector Errors and Diagnostics

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The results from research into the use of vehicle detectors, with an emphasis on the diagnosis and correction of detector errors, are described. Of primary interest is the development of a diagnostics scheme in which the average vehicle on time is examined as a test statistic. By comparing this value against the average on times for a station of detectors, the validity of detector operation can be checked. This scheme has been tested at the San Francisco-Oakland Bay Bridge and has been found to yield good results. The false-alarm rate is low compared with that for the occupancy diagnostic method, and sensitivity to true detector failures is improved. This test has also been carried out on inductive loop data from Los Angeles and Chicago. Other experimental work has shown that for magnetometers, the measurement of occupancy is greatly influenced by the manner in which the detector is tuned. Thus methods for improving the consistency of detector tuning and minimizing errors are suggested. It has also been found that pulse breakups are a common operational problem, especially in congested conditions and with heavy vehicles. This can lead to errors in measured occupancy and counts of several percent. Tests have shown that breakups are inherent in the design of the hardware, but that compensation can occur with software. An algorithm for this has been designed and implemented that reduces these errors and improves estimation of vehicle lengths. Missed vehicles, spurious pulses, and lane changes have been found to constitute a small fraction of abnormal detector signals.

Many freeway projects incorporate electronic surveillance equipment in their design. An important device in these installations is the vehicle detector. Detectors can supply fundamental traffic data, such as vehicle flows and occupancies. In addition, detector information can be used to evaluate the operation of a freeway segment by providing measures of system effectiveness.

Detector systems can also take more active roles. Ramp control algorithms frequently use local on-ramp and mainline measurements as input to a metering system. Incident detection systems also use segmentwide measures to automatically signal congested conditions. Detection can also be integrated with ramp control, feeding back information under severe conditions.

The successful implementation of automatic detection and control is dependent on its reliability. Removing the human operator from the control loop allows a computer system to continuously monitor large numbers of detectors over wide areas. A drawback is that incorrect detector information can lead to erroneous signaling of incidents.

In this paper problems related to vehicle detector reliability in surveillance systems and methods for compensating for undesirable behavior are discussed.

DETECTOR RELIABILITY

Several studies have examined the reliability of detectors on freeways and at signalized intersections and determined empirical rates of failure. Tarnoff and Parsonson, for example, accumulated considerable information from the maintenance records of agencies in different parts of the country. They report failure rates between 0.13 and 0.29 failure/detector-year (*1*).

In a separate study, Dudek obtained empirical information from the Gulf Freeway to calculate a failure rate of 1.18 failures/detector-year. Approximately 100 detectors were studied over the period of 5 months (*2*).

As part of the current research project, a study was conducted using the computerized surveillance in Los Angeles. On a section of freeway with 115 detectors, the performance of the loops was monitored for 4 1/2 hr on each of 2 days. It was found that between 10.5 and 14.8 percent of the detectors were unavailable and that between 1.7 and 11.3 percent showed error flags during the experiment. Because the detector error algorithm used by the California Department of Transportation (Caltrans) occasionally flags on congestion as well as detector failure, these figures may not be correct. Conversely, there could be problems that are not evident from the computerized record and diagnostics. It is clear that a significant proportion of detectors can be out of order at any one time. During discussion with personnel from other areas, these figures were found to be considered normal.

Hale summarized loop failures in a survey of maintenance records from 26 states. According to this report, causes for failure include moisture, loop sealant deterioration, pavement cracking, broken wires, deteriorated insulation, corroded splices, and detuned amplifiers. This agrees with information from an FHWA report (*3*) that lists as causes of loop failure detector unit failure, utility construction, poor sealant, pavement cracking and moving, inadequate electrical connections, and lightning surges.

In addition, Ingram cites detuned amplifiers and loops as a cause of detector lockup (*4*). In his 1979 report, he states that loop inductance changes and amplifier tuning point drift affect the operation of the equipment. These may be due to changes in temperature, which cause thermal expansion. Interestingly enough, Ingram has also investigated the accuracy of the detectors. An average loop may give occupancy errors of 7 to 40 percent. A good system is cited as accurate to approximately 5 percent.

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DETECTOR ERROR DIAGNOSTICS

For automatic surveillance systems, incorrect information may be worse than the lack of data. In order to flag the correctness of input signals, a number of methods have been developed by traffic engineers to test detector data. Many of these are described in Table 1.

This summary is the result of an investigation of the literature and a research survey. The latter was a questionnaire completed for 32 major freeway projects in North America. One question in this survey was the ranking of detector diagnostics in surveillance. For 19 projects, it was indicated that diagnostics was a high research priority. Of these, it is noted that 17 were operational, with some form of data acceptability test already in place. Current experience with detectors clearly establishes the need for improved error checking (*5*).

Information was provided by most projects on how they monitor the validity of their data. These are categorized in Table 1 according to the data parameter being examined. It is clear from the maximum and minimum limits shown in the table that most checks are fairly primitive. The ratio of the upper and lower limits of acceptable values for the count tests is often 10:1 or more. The occupancy comparisons also accept a wide range of values. A commonly defined range allows values from 1 to 95 percent.

Rough checks such as these are necessary because the tests do not change with traffic conditions. A few of the algorithms are dynamic. The Maryland test uses historical values. The Caltrans occupancy test compares an individual lane with other detectors at the same station. Thus detectors check against each other, independent of the traffic conditions. This allows the test window of values to be restricted to 4 to 1. A few exceptional systems are those in Ohio or New Jersey, where longitudinal checks can easily be made.

For a few projects the actual pulses are checked for validity. For the Maryland project the rate of short and long pulses coming in is checked to make sure that upper limits are not violated. The Surveillance Control and Driver Information (SCANDI) system validates a count of long pulses. The Chicago system accumulates the count of short pulses, but only as information for the operator, not as part of an automatic diagnostic. Finally, the New York system computes the average on time of the incoming data, which is a useful statistic, but only provides it for the operator, and not as part of an on-line diagnostic.

TABLE 1 MAINLINE DETECTOR CHECKS

	Data Parameter			
State or Project	Counts	Occupancy	Pulses	Other
I-83, Maryland	Upper/lower based on historical 15 min 15 min < 1 15 min > UDUL	—	Percent long > UDUL; percent short > UDUL	—
QEW, Canada	5 min < 1; 5 min > 250	30 sec > 95 percent; 5 min < 1 percent; 5 min > 95 percent	—	—
Howard Frankland Bridge	1 min < UDLL; 5 min > UDUL	1 min < UDLL; 1 min > UDUL; 5 min < UDLL; 5 min > UDUL	—	Speed: 5 min > UDUL
Caltrans Districts 4, 7, 11	—	1 min > UDUL; 1 min > twice station avg; 1 min < half station avg	—	No count within allotted time, based on avg flow
Colorado	UDLL UDUL	—	—	—
Chicago, Ill.	—	—	Short pulse count for operator	—
SCANDI System	UDUL	—	Pulse length > UDUL	No count within allotted time
Minnesota	5 min < 20; 5 min > 250	5 min < 3 percent; 5 min > 80 percent	—	—
New Jersey	—	Longitudinal difference 10 percent	—	—
New York	—	—	15 min avg length for operator	—
Ohio	Closely spaced longitudinal difference > 3 percent	Closely spaced longitudinal difference > 3 percent	—	—

Note: UDUL = user-defined upper limit; UDLL = user-defined lower limit; QEW = Queen Elizabeth Way; SCANDI = Surveillance Control and Driver Information system. Dashes indicate data not applicable.

ON-LINE DATA COLLECTION SYSTEM

To study the behavior of detectors under a variety of conditions, the Institute for Transportation Studies (ITS) developed an on-line data collection system with the aid of Caltrans District 4. This allows data to be gathered under experimental control, with the history and adjustment of the detectors known and changeable. Off-line data supplemented the results obtained from the on-line tests.

The surveillance system at the San Francisco-Oakland Bay Bridge (SFOBB) was chosen for this work. The average daily traffic (ADT) for the bridge is approximately 228,000 vehicles/day, with a two-directional peak hourly flow of about 20,500 vehicles/hr (*6*). There are four magnetometer stations located downstream from the metering station that controls westbound traffic. These are named the O, A, B, and C stations. The surveillance system uses a configuration with a single probe in each of five lanes. The O, A, and B stations are approximately two-thirds of a mile from the SFOBB toll plaza. They are closely spaced, with a longitudinal separation of 10 ft.

The on-line data collection system brings the signals from the magnetometers to a microcomputer at ITS. The data are sampled and stored 60 times per second. In addition, single-pulse error checking or diagnostics may be performed according to user-specified parameters.

OFF-LINE DATA SETS

Los Angeles

In order to generalize the results from the SFOBB experiments, two sets of loop data were obtained from the surveillance system in Los Angeles.

In 1974 the Los Angeles system brought in from the field information from individual detector loops sampled at 1/15 sec. The specific data set studied here is from the westbound Santa Monica Freeway from 6:30 to 9:30 a.m. on a weekday. This section of roadway is covered by 128 detectors on the mainline, collector-distributors, and ramps (*7*).

The new data set was recorded from Orange County Route 22 at 2:30 to 7:00 p.m. on April 15 and 16, 1986. This tape contains 1-min summaries of the loop counts and occupancy times for the eastbound and westbound traffic. Because the current Los Angeles surveillance system aggregates data in the field, it is not possible to replicate all the SFOBB analyses.

Chicago

Another source of loop detector data was the surveillance system in Chicago. The Traffic Systems Center (TSC) is able to bring in and record information from a single lane. This allows TSC personnel to record data from a four-lane station, sequentially switching from one lane to the next, at half-hour intervals. Data were taken from Monday, April 14, 12:00 noon, to Thursday, April 18, 5:00 a.m. In all, 63 hr of data was analyzed for this project. The collection site was a four-lane section of the Eisenhower Expressway.

SFOBB TUNING EXPERIMENTS

Several tuning experiments were carried out at the SFOBB in order to examine the behavior of detectors under normal and unusual conditions. There are a variety of reasons why these were important.

First, in examining collected traffic data, it became apparent that the detectors did not always provide comparable information. This was evident when the detector pulse on-time distributions for the A and B stations were compared. The average on times for the two stations varied by 5 to 10 percent for the five pairs of detectors. This can also be seen in the loop data from Chicago, which were taken over a period of 4 days. Figure 1 shows the distribution of on times for the four lanes studied. The average on time for Lane 1 is significantly longer than that for Lane 2. The difference in modal value for the two lanes is 50 percent. Although differences are expected when lateral comparisons are made, these loops clearly register vehicle presence in different fashions. From the Los Angeles data, Figure 2 shows a similar discrepancy between two lanes on a connector to the Santa Monica Freeway.

Second, the consistency of a measurement is important. The SFOBB metering system is configured to begin control at an average occupancy of 11.5 percent. Other projects use occupancy as an important measure of traffic conditions for control surveillance and incident detection systems. It is thus valuable to know the reliability of the equipment and the consistency of its adjustment and measurement.

Third, in examining detector pulses, it was found that several unusual types of signals were being recorded. Pulse breakups appear as a detection dropout during the passage of a single vehicle. "Misses" are indicated by a signal on one detector with no corresponding signal on a nearby detector.

Finally, in the preceding discussion of detector reliability, it was indicated that sensitivity drift is a common detector failure mode. The primary causes of detector failure (*1-4*) often result in degraded performance because of a detuning effect.

Tuning Experiment 1

The Canoga magnetometers used at the SFOBB are adjusted by a specific procedure developed by District 4 personnel. The steps are as follows:

1. Tuning is best carried out under light to medium flow conditions;
2. The detector is placed in the calibration mode;
3. The knob is turned counterclockwise until the indicator light is off;
4. The knob is turned clockwise until the indicator light flashes steadily;
5. The knob is then turned counterclockwise one-quarter of a turn (referred to as a "turn-back" in the following discussion); and
6. The detector is put into the presence mode. It is now tuned.

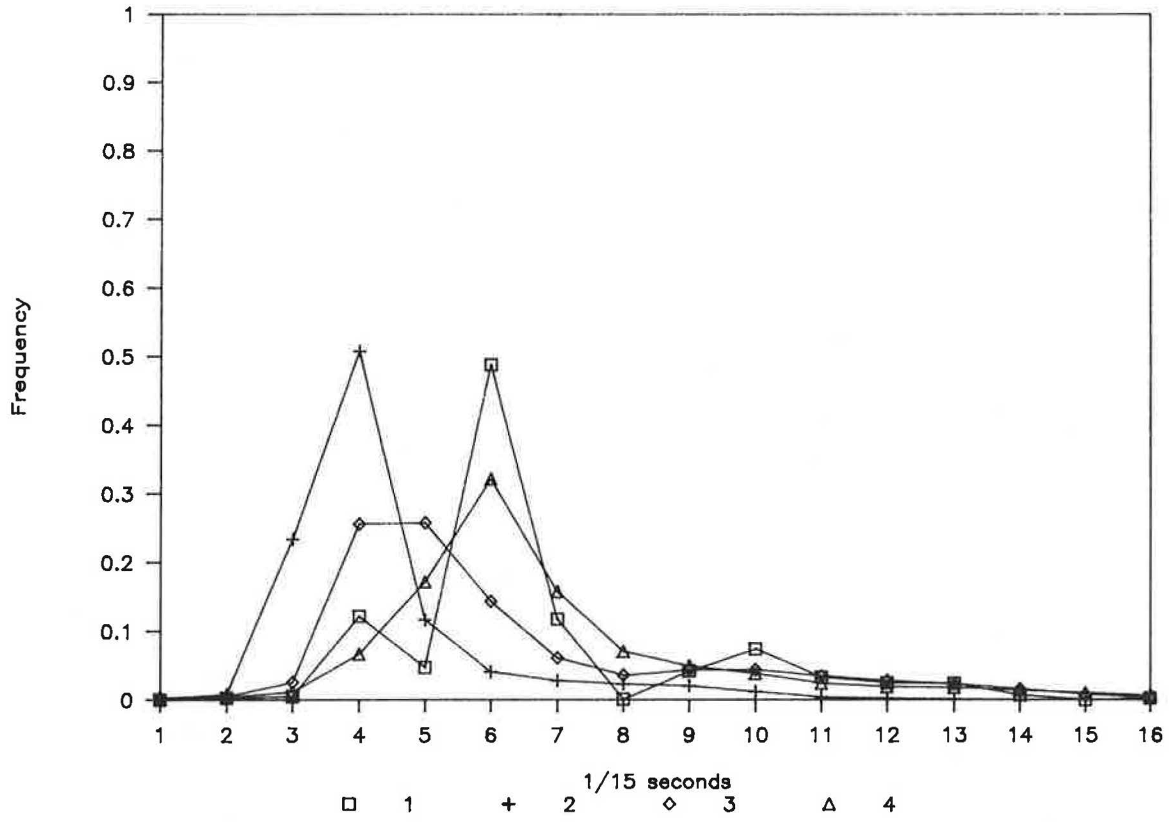

FIGURE 1 On-time distributions, Chicago loop data (April 14, 12:00 noon, to April 18, 5:00 a.m.).

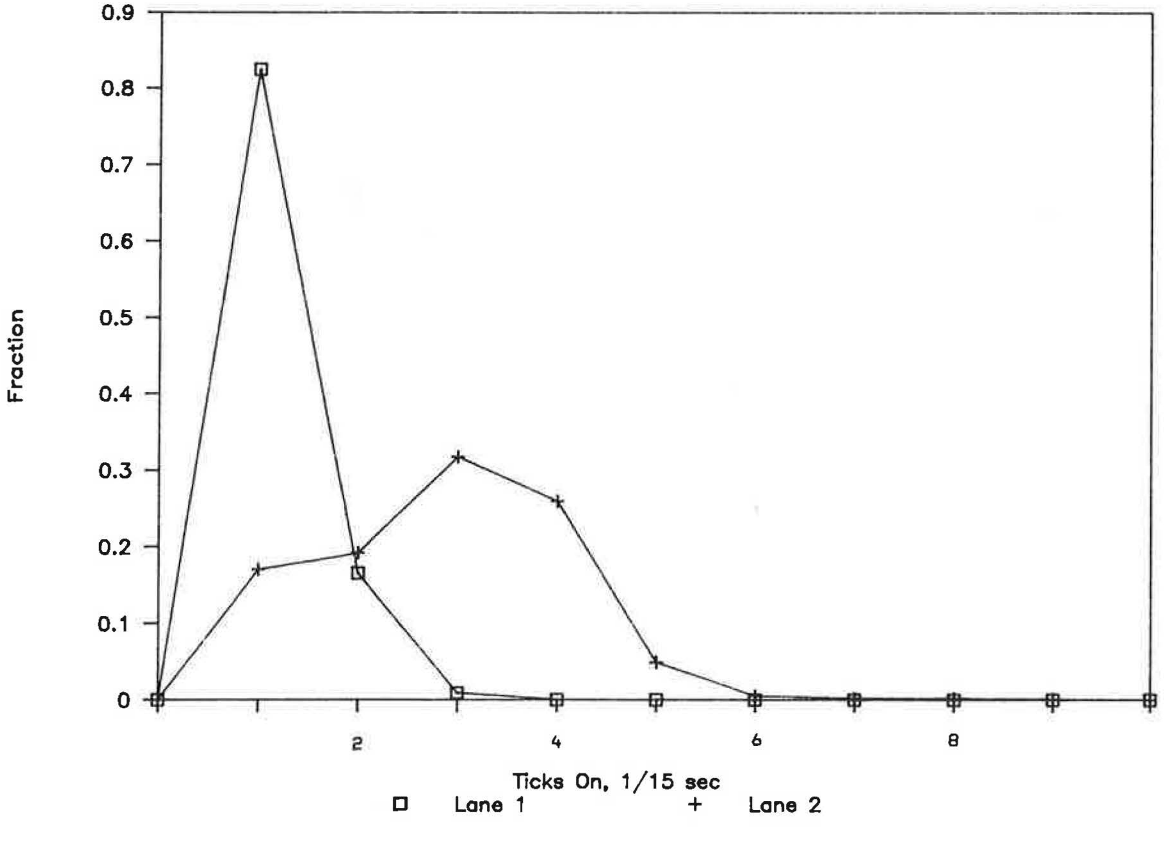

FIGURE 2 On-time distributions, Los Angeles loop data (weekday, 6:30 to 9:30 a.m.).

Two points are important to note at this time. First, the "detuning" in Step 5 has been added by SFOBB personnel. Second, the adjustment knob, supplied by the manufacturer, is normally a one-turn potentiometer. All SFOBB magnetometers have replaced this by a 10-turn potentiometer. This is done because the original design is considered exceptionally difficult to tune.

The first experiment took place on two afternoons with moderate traffic flows. After the A and B stations had been adjusted according to the SFOBB procedure, the detectors of Station A were "turned back" by specified amounts. Station B was always held constant. The data collection system was used to record occupancies for the two stations at 1-min intervals for 2 to 8 min. This procedure was carried out for six different degrees of turn-back, from zero to three-fourths turn.

Results

The data from the first tuning experiment are shown in Figure 3. The horizontal axis gives the turn-back setting of detector Station A. Thus the data at zero are taken with Station A at the manufacturer's tuning and B, as always, is at the Caltrans standard tuning. The vertical axis shows the ratio of the occupancy measurements from Station A versus that from Station B.

The graph thus shows how tuning of a detector affects occupancy values. Near the typical operating point of the detectors, a change of one-eighth turn causes a 10 percent change in measured occupancy. A polynomial least-squares fit is shown. The upward curvature of the fit provides a good explanation for the turn-back procedure used by the SFOBB personnel. Near the manufacturer's tuning, at zero turn-back, an error in adjustment creates a large variation in occupancy. This sensitivity is quantified by the slope of the fitted curve at zero, which is 1.31. At the SFOBB setting, an error in adjustment is still penalized by a large error in the occupancy, but the slope of 1.01 is less.

Conclusions and Recommendations

Experiment 1 clearly shows that the tuning process is central to obtaining comparable occupancy values. A slight misadjustment of a detector amplifier can account for significant differences in occupancy readings between detectors. This is noteworthy because the Caltrans amplifiers, with 10-turn potentiometers, are easier to tune.

Immediately following tuning, the between-station discrepancies are reduced to a few percent. Because occupancy is an important measure for operations, it is advantageous to minimize any source of discrepancy. There are several recommendations to help the tuning process:

1. The judgment of "steadily flashing" can be problematic, especially for inexperienced personnel and in heavy flow conditions, because vehicle triggerings cause flashing. If possible, flashing should be calibrated to a standard frequency in minimal traffic.

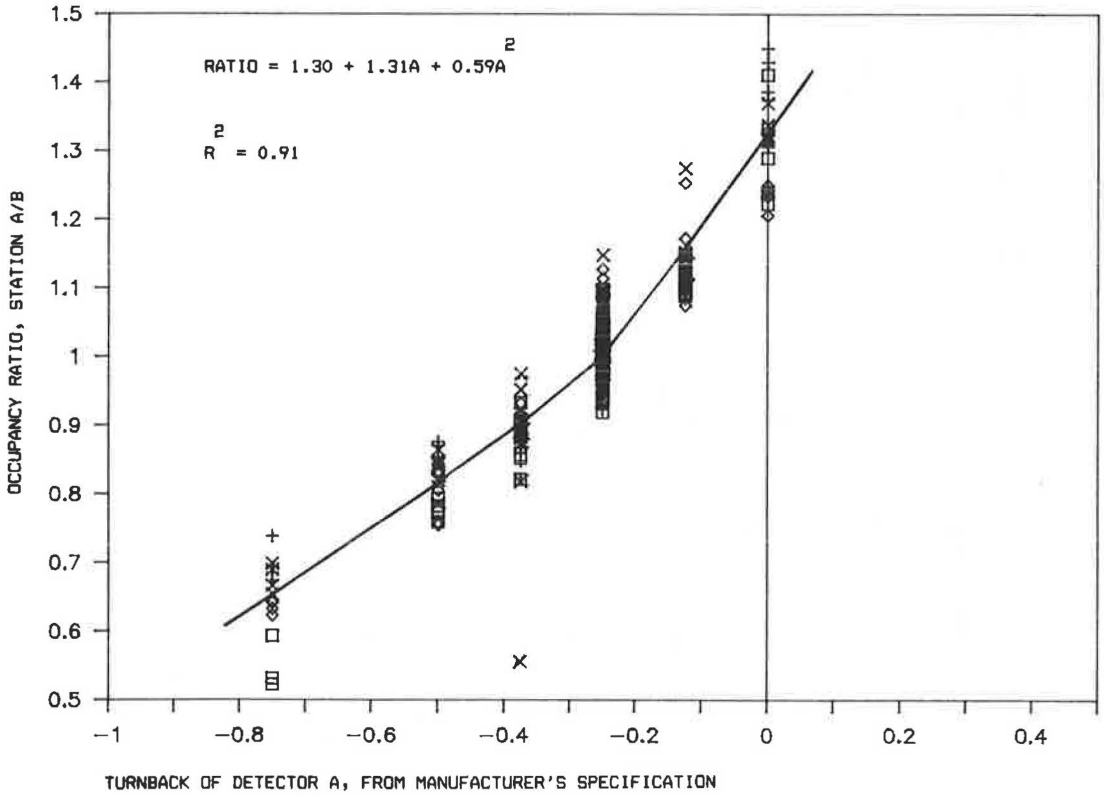

FIGURE 3 Tuning experiment results.

2. It is helpful to modify the original equipment to facilitate the tuning process. The replacement of the standard potentiometer is an example. Additional resistive circuitry could be added for more sensitivity.
3. The turn-back is important and should be standardized. A dial could be added to the knob to make the turn-back more consistent.

Tuning Experiment 2

The second tuning experiment at the SFOBB was carried out to see if pulse breakups were due to tuning. Because they were occurring regularly, it was postulated that the reduced sensitivity of the SFOBB detectors, due to the tuning procedure, might be responsible for these failures.

Procedure

The effect of tuning on pulse breakups was examined in two data sets of 2 hr each. The first set was taken with one-half turn-back on Station A while Station B was held at one-fourth turn-back. The second data set was taken with zero turn-back on Station A while Station B remained at one-fourth turn-back.

The gap-time distribution of each data set was then examined. Other experimental work, described later, indicates that short gap times are clear indicators of pulse breakups. The count of gap times less than one-fourth of a second is then a count of pulse breakups.

Results and Conclusions

It was found that there are no significant differences in the frequency of short gap times, regardless of whether the detector is at the manufacturer's specification or the SFOBB setting of lessened sensitivity. Thus breakups are inherent in the use of magnetometers. The hardware deficiency may be correctable with software or a different probe configuration with more sensors.

SFOBB VIDEO SURVEILLANCE EXPERIMENT

The video surveillance experiment at the SFOBB permitted a comparison of the recorded detector data with a visual record of the traffic. As indicated earlier, unusual detector signals were found during close examination of the pulses. In addition to breakups and misses, the sources of short and long on times as well as short gap times were of interest.

Procedure

Three mechanisms were used for observing the traffic near the SFOBB detectors. A video camera recording provided the basic evidence for each vehicle passage. The computerized data collection system provided the detector's indication of vehicular occupancy. Finally, an observer noted and recorded the traffic conditions at the site. These will be described in more detail later.

The video was filmed from a lift truck located on a frontage road adjacent to the A and B detector stations. While the filming took place, the data collection system recorded the detector information every 1/60 sec. To maintain synchronization between the data collection clock and the video clock, a circuit was designed to give a simultaneous pulse in the computer record and a visible indicator in the film.

The Data Set

The video experiment took place from 10:00 a.m. to 12:00 noon in clear, dry weather. On this day there were two incidents, one major and one minor. This gave approximately 20 min of congestion data; during the remaining time there was free flow at a volume of approximately 8,000 vehicles/hr.

Data Analysis

The experimental data were analyzed in several steps. First, unusual detector data were selected from computerized records for extended investigation. Second, the selected computer data were matched with the video film to log vehicle movement and type, and the detector behavior was checked for correctness. Finally, incorrect detector behavior was cross-tabulated with vehicle movement and type.

Suspicious detector data were extracted from the computer data set by examining the individual signals and by comparing the pulses at the upstream and downstream detectors. For the individual pulse check the following criteria were used:

1. Short on times (less than 1/12 sec),
2. Long on times (longer than 1/2 sec),
3. Short gap times (less than 1/4 sec), and
4. Long gap times (longer than 1 min).

The short on time is equivalent to the Chicago surveillance system loop detector criterion adjusted to the smaller detection zone of magnetometers. The long on-time value selects approximately 2 percent of the pulses from a newly tuned SFOBB detector under free-flow conditions. The long gap-time figure is based on the existing Caltrans detector lockup tests for heavy flow conditions. The short gap time picks out an apparent mode that was seen at the low end of the experimental off-time distribution.

Comparisons also are made between the signals recorded from the A and the B stations. If there is an apparent miss or breakup on one of the stations, it is marked for further examination.

If a pulse is selected as suspicious, the preceding and following pulses for the two longitudinal detectors are written into a file for the next step, which compares the pulse with the video record.

To compare the two sources of information, software was developed that graphically displays the pulse sets in conjunction with the estimated time of vehicle passage according to the video clock. This allowed the observer to match virtually all vehicles with their accompanying pulse. In the comparison, it is possible to deduce detector behavior and vehicle type and movement. The information on the detector performance and vehicle information are cross-tabulated in a database. Lanes 1, 2, 3, and 5 were examined. Lane 4 was omitted, because only one station was functional, which precluded the paired-detector-data screening step.

Results

A primary finding of this experiment is that pulse breakups are an important mode of detector failure. This applies to both passenger cars and trucks in both congested and free-flow traffic. Table 2 summarizes the data for the four lanes studied. These breakups were all selected from the data set by the short-gap-time criterion. Overall, a short gap was found to be a reliable predictor of breakup, correctly flagging signal dropout 94.6 percent of the time under both free-flow and congested conditions.

TABLE 2 SHORT GAPS DUE TO BREAKUP

Condition and Lane	Percentage by Vehicle Type and Station			
	Passenger Cars		Trucks and Buses	
	A	B	A	B
Congested				
1	20.5	10.9	NA	NA
2	14.5	12.8	10.0	10.0
3	10.5	9.4	10.0	27.0
5	9.4	11.6	32.0	46.0
Free flow				
1	2.0	0.84	30.0	25.0
2	1.2	1.1	26.5	29.0
3	1.7	2.3	29.6	32.0
5	0.96	0.5	49.0	47.0

It is evident that congestion causes a higher rate of breakup errors for passenger cars in all lanes. It is also suspected that this is the case for trucks, but this is not obvious from the statistics. It is believed that the short-gap-time criterion fails to diagnose breakups with the slower speeds because the dropout times begin to exceed 1/4 sec. The short-gap-time criterion also does not indicate the triple or quadruple triggerings that occur occasionally. These are regularly caused by the passage of a twin trailer truck.

A second interesting finding is that unusual vehicle movements account for few of the unusual detector pulses. An example of this would be a lane change over the detector stations, which might give a short on time or a pulse breakup. Occasionally a short gap time was the result of close vehicle headways. Suspicious detector pulses were rarely caused by vehicle movement.

A third finding is that few pulses are due to adjacent-lane triggering or are spurious signals. Of the 3,061 pulses examined, only 18 were due to a truck in an adjacent lane when no vehicle was in the lane for which the pulse was triggered. Only 10 pulses could not be accounted for by the vehicle. These were all less than 5/60 sec long.

Finally, motorcycles do not appear to account for many of the short pulses being recorded. This is because there are less of them in proportion to other vehicle types, and it appears that they are often not registered at all by the detector. This is probably due to their small size and the fact that motorcycles generally drive away from the lane center.

Conclusions and Recommendations

The primary finding of the surveillance experiment is that pulse breakups are prevalent and thus require compensation in software. As indicated in the tuning-experiment discussion, breakups do not appear to be caused by incorrect hardware adjustment. They may be due to probe number and layout. In District 4, correction is accomplished by a specific counting algorithm. In order to register a valid vehicle count, a minimum gap time is required, followed by minimum on time. For different installations, the gap time requirement is 0.2 to 0.5 sec, and the on-time requirement is 0.07 to 0.1 sec.

SFOBB calculations include all detector on time in the occupancy accumulation, but a count does not occur until the foregoing conditions are satisfied. This generally works, but has drawbacks that are important for detector error diagnostics, described later. First, the dropout time is not accumulated in the occupancy figure. Second, vehicle length is not accurately recorded, because the on-time count ceases as soon as the detector turns off.

A counting procedure can be used to correct these problems. Short gaps can be interpreted as dropouts from a pulse breakup. Because of this, the detector is altered to the on state for the gap. Short pulses that are not part of a breakup are converted to the off state, and are effectively ignored. These rules use the finding that most short gaps are the result of a breakup and that short pulses are usually part of a breakup or a spurious signal. The consequence of this new procedure is to correct the occupancy and count calculations for breakups. Error under different scenarios without this compensation is shown in Table 3. The numerical differences are not large when compared with District 4 methodology, but an important result is the generation of a correct pulse length for later analysis. This is important in vehicle identification and detector diagnostics.

ON-TIME DIAGNOSTIC TEST

As discussed earlier in this paper, Caltrans has several tests to examine the functioning of mainline detectors. The lockup test flags an error if a detector fails to change state in a designated amount of time. The occupancy test looks for a detector that reads significantly higher or lower than other detectors at the same station.

Several results from the preceding experiments are important in the development of a more advanced diagnostic scheme. As such, they bear repeating:

TABLE 3 MEASURED ERROR FROM PULSE BREAKUPS WITH DIFFERENT COMPENSATION TECHNIQUES

	Percentage by Type of Traffic			
	Typical Mix		Rightmost Lane	
	Free Flow	Congested	Free Flow	Congested
No compensation				
Count error	+1.97	+12.7	+5.8	+14.0
Occupancy error	-0.4	-1.6	-0.85	-1.6
Caltrans District 4 compensation				
Count error	0.0	0.0	0.0	0.0
Occupancy error	-0.4	-1.6	-0.85	-1.6

Note: Assumptions for calculations, based on SFOBB experimental data, are as follows: Typical mix is 98 percent passenger cars, 2 percent trucks and buses. Rightmost lane is 86 percent passenger cars, 14 percent trucks and buses. Average pulse length, 12/60 sec for passenger vehicles, 25/60 sec for trucks and buses. Average breakup gap, 3/60 sec. Congestion speed, 30 mph; breakup gap, 3/60 sec.

Percentage of breakups is as follows: passenger cars—free flow, 1.33 percent; congested flow, 12.5 percent; trucks—free flow, 33.5 percent; congested flow, 24.0 percent.

1. Variations in sensitivity and tuning account for shifts in the distribution of on times. This variation can be quite large.
2. Pulse breakups can be identified and corrected by an algorithm that modifies short gaps and pulses. This yields correct pulse lengths and allows identification of long vehicles.
3. The on-time distribution appears quite similar to a normal distribution, although the normal is slightly less peaked in the center.

The Caltrans occupancy test often fails to pick up shifts in sensitivity because of the wide error margins, which allow for normal variations in occupancy. The average on time appears to be a good measure when compared with occupancy, because occupancy directly varies with flow rate. On time per vehicle eliminates this variability.

Occupancy also increases when trucks and buses are in the vehicle mix. By filtering out long vehicles from the on-time average test statistic, the resulting variance can also be reduced. This makes compensation for truck pulse breakups important in the data-processing procedure.

In general, a particular lane will yield higher or lower average on-time values on the basis of the speed distributions and amplifier tuning. This can be eliminated by using a historical factor that accounts for these long-term differences. This allows direct comparisons to be made between lanes.

Finally, under heavy congestion and incident conditions, there can be large short-term fluctuations in any microscopic traffic characteristic. It is therefore desirable to flag the detector diagnostic as questionable in those situations. A simple test for congestion is the average speed at the station. This can be estimated from the station volume and occupancy.

In sum, this procedure has similarities to the Caltrans occupancy check, but has many extensions. It should be noted that vehicle speeds change the on time. The algorithm compensates by comparing against a station average, which reflects aggregate vehicle speeds. Thus, a lane speed bias will generate a false alarm only if it is marked and not compensated for by the historical lane factor.

Statistically, the algorithm is similar to a two-sample problem in which a sample from one lane is compared with samples from other lanes, as represented by the station average. This is appropriate, because the on time is distributed as a normal random variable. The test determines whether the detector in one lane is behaving significantly differently from those in others.

A convenient sampling interval is 5 min. Under moderate traffic conditions, this gives a lane sample of 50. With a typical on time of 12/60 sec, the diagnostic flags an error if the sample differs from the station mean by approximately 15 percent. The designed test will signal if a lane is greater than 115 percent or less than 85 percent of the station on-time average.

SFOBB Experiments

In order to evaluate the described on-time algorithm, several blind tests and an extended implementation were run. For the blind tests, on two mornings arrangements were made for Caltrans engineers to alter the tuning of an arbitrary detector by one-fourth turn while the data collection system was running. The on-time algorithm was then used to pick out the simulated failure. The results of the diagnostic were then checked with SFOBB personnel.

SFOBB Results

During the 2 1/2 hr of the first test, the traffic flows were heavy, but not congested. Figure 4 shows the test statistics derived from the on-time ratio diagnostic algorithm. The results clearly show the time and lane of the detector failure without ambiguity.

By contrast, Figure 5 shows an occupancy ratio test applied to this same data set. Given a time-series view of the data, it is possible to see the abrupt "failure" of Lane 5. But at any given point in time, it would not be possible to distinguish it from the remaining lanes. In fact the "failed" detector measures

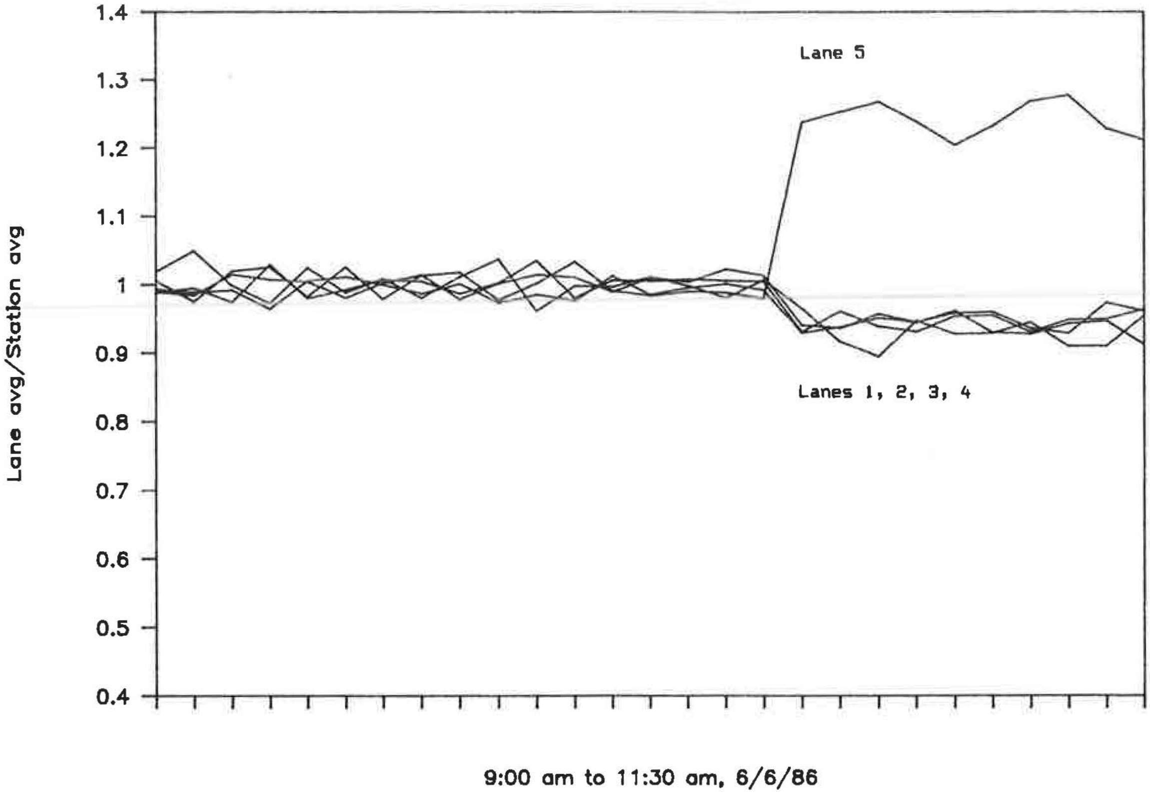

FIGURE 4 On-time diagnostic test: lane versus station average (2.5 hr, 9:00 to 11:30 a.m., June 6, 1986, 5-min averages).

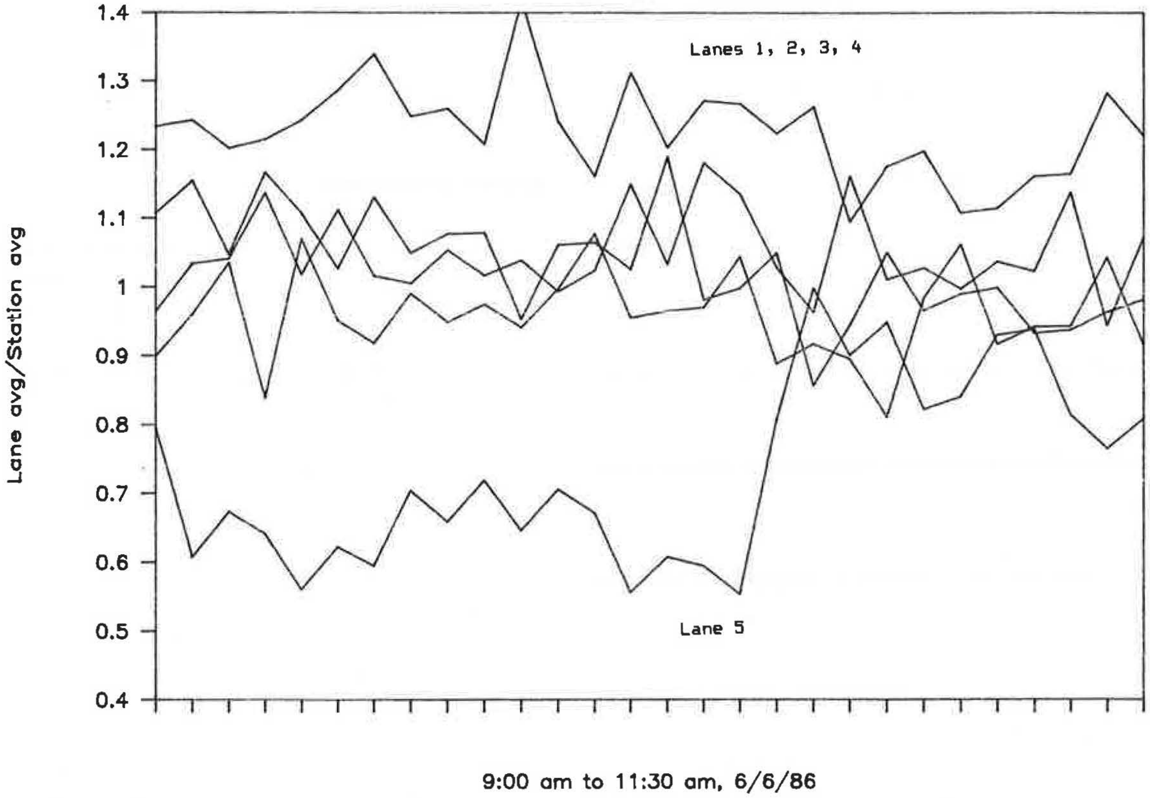

FIGURE 5 Occupancy diagnostic test: lane versus station average (2.5 hr, 9:00 to 11:30 a.m., June 6, 1986, 5-min averages).

occupancies close to those of the other lanes. In addition, the occupancy test presented here was derived with a 5-min average, not the Caltrans 1-min average. This larger sample period always serves to reduce statistical noise, and is thus a conservative modification to this comparison. This change was made to facilitate the programming of the two tests.

The SFOBB implementation of the occupancy ratio test uses the Caltrans criterion of 50 or 150 percent variation for Lanes 1 to 4. For Lane 5, however, they have been forced to extend the range to 25 and 175 percent because the occupancy varies more with heavy truck and bus traffic. There is almost a false alarm in Lane 2, and it is also clear that Lane 5 never fails the occupancy ratio test.

During the second blind test of the on-time ratio algorithm, the SFOBB personnel were not able to get out in the field to alter any of the detectors, as had been planned. The data, however, were unknowingly recorded and processed by ITS. As a consequence, the results were examined with the expectation of a simulated detector failure. It was clear that no detector had "failed," and this assessment was verified by the District 4 engineers.

The extended run of the diagnostic scheme involved a longer-term implementation of the on-time and occupancy ratio tests to compare performance under a wide range of flow conditions. A total of 94 hr of comparison were carried out. As with the former test, the occupancy diagnostic was averaged over 5 min rather than the usual 1 min, a conservative modification.

Given this, the occupancy and on-time tests were examined, and summary statistics are shown in Table 4. Comparing the number of flags for each lane, it is very clear that the on-time test yields a much smaller number of false alarms; it is known that the magnetometers are in good working order. For Lanes 2, 3, 4, and 5, the on-time diagnostic gives only 11 percent of the flags when compared with the occupancy test.

Of additional interest is the last row in Table 4, which gives the number of on-time flags that would have occurred if low vehicle count and congestion conditions were not excluded in the suggested algorithm.

There are clearly an unusual number of potential flags in Lane 1 that were not counted because of the count check. This lane was occasionally closed for maintenance work during the test. The lane closures show that it is important to perform a count check before running any diagnostics. This prevents a large number of false alarms when the detector is in fact working. This also shows that the on-time test can run correctly with three- and four-lane stations.

Off-Line Tests

The on-time average for loop data was also checked by using several of the off-line data sets. With the Garden Grove Freeway data, the occupancy test was run with 1-min averages and the on-time test with 5-min averages. Figures 6 and 7 show the occupancy and on-time statistics for the Bristol station, which has four detectors. There is a large amount of variation in these figures because of congestion during the 4 1/2-hr period. The occupancy statistic shows values outside the 50 to 150 percent range, whereas the on-time statistic does not extend beyond 85 and 115 percent.

Figure 2 shows the on-time distributions for the 1974 Los Angeles data. This is 3 hr of data from a two-lane connector entering the Santa Monica Freeway. Each lane differs from the station on-time average by more than 50 percent, showing that one of the two detectors has probably failed. The difference in behavior between the lanes is also enough to trigger an occupancy test flag.

Conclusions

The two SFOBB blind trials show that the on-time ratio test provides a reliable indication of detector status. Because the on times for average-length vehicles are used for the test sample, there is a minimum of noise obscuring important information about the detector status. For loop detectors, the equipment is susceptible to problems with wire insulation, splices, and installation. Magnetometers, as recorded data sets show, easily drift from their desired adjustment over time. Thus it is important for an algorithm to respond to sensitivity changes.

The long-term test for false alarms and results from the off-line data sets show that the on-time average gives a statistic that is more robust under varied traffic conditions. This would give a more reliable indicator of detector failure to surveillance systems implementing incident detection or control.

FURTHER RESEARCH

In order to extend the applicability of the current research, additional experimentation will be carried out to help generalize to other facilities. At this time, field work similar to that just described is being carried out at a set of 16 loop detectors in Pleasanton, California.

TABLE 4 FALSE ALARMS FOR ON-TIME AND OCCUPANCY TESTS

	Station A					Station B				
	1	2	3	4	5	1	2	3	4	5
No. of occupancy flags	342	235	151	—	110	426	64	4	24	67
No. of on-time flags	5	5	4	—	1	5	2	5	6	50
No. of flags without count or speed check	158	7	7	—	80	170	9	7	5	15

Note: Dash indicates data unavailable because of detector failure.

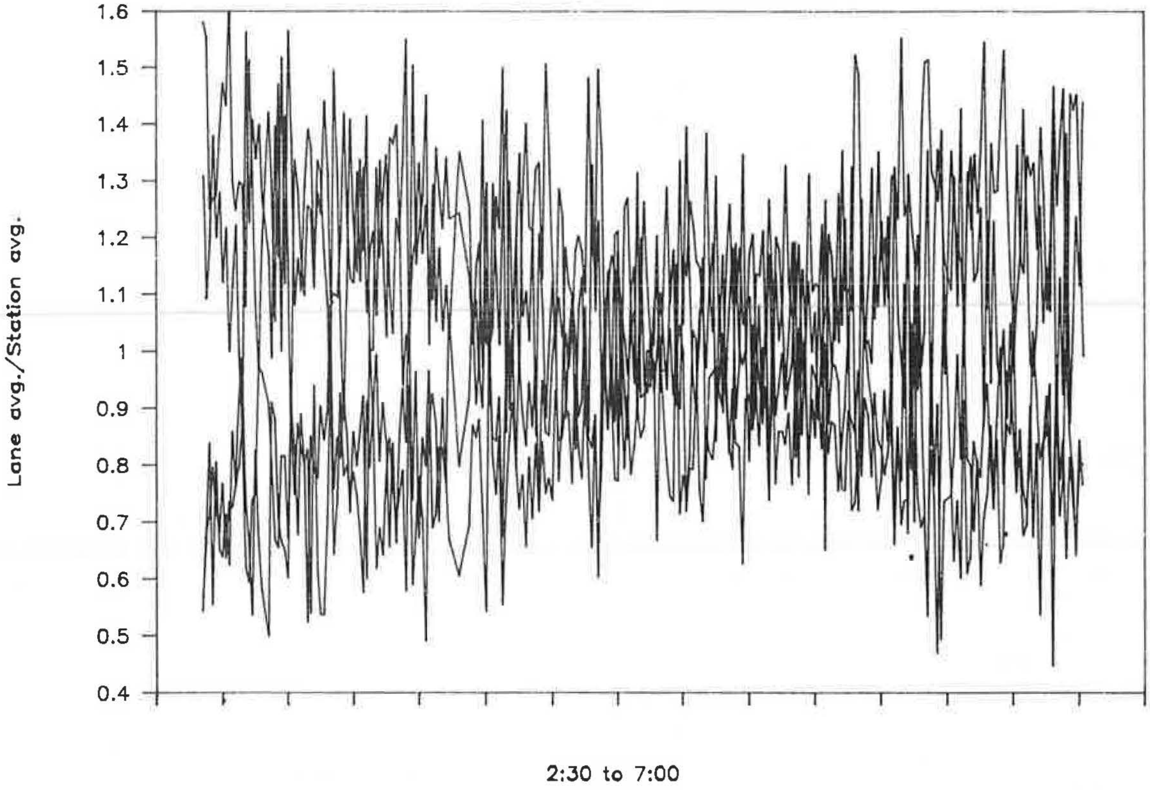

FIGURE 6 Occupancy test for Bristol station: lane versus station average (Orange County Route 22, eastbound, April 16, 1986, 2:30 to 7:00 p.m.).

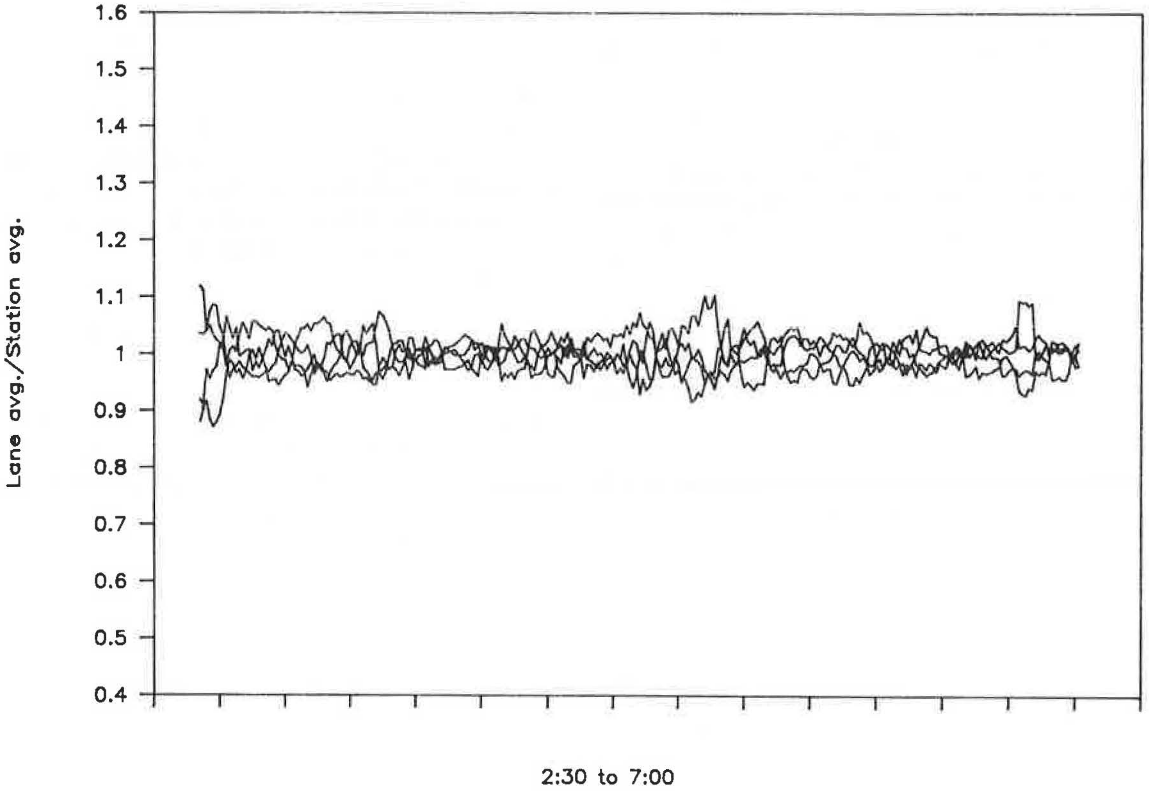

FIGURE 7 On-time test for Bristol station: lane versus station average (Orange County Route 22, eastbound, April 16, 1986, 2:30 to 7:00 p.m.).

CONCLUSIONS AND SUMMARY

A number of important tests examined the behavior of detectors under a variety of traffic conditions. From the study of on-line magnetometers and loops from off-line sources, it is clear that detectors can give misleading information. Some findings have illustrated ways in which basic data can be incorrect. But means have been developed to diagnose and compensate for these errors. First, closely spaced longitudinal detectors at the SFOBB can give occupancy measurements that vary significantly. The same phenomenon is seen when comparisons of data from adjacent loop detectors are made. Results from turning experiments at the SFOBB indicate that this can be due to small changes in tuning and detector sensitivity. Because of this, recommendations for detector tuning and modification are made in this paper.

Second, another form of inaccuracy has been verified by videotaping experiments. Pulse breakups are confirmed to occur with magnetometers at rates between 2 and 33 percent. The highest rates are with trucks and buses, and in congested traffic. The breakups give incorrect measurement of vehicle length, counts, and occupancy unless compensating software is used. A method for doing this is presented and has been implemented on line. Additional tuning experiments have shown that breakups are inherent in the detector design. Examination of inductive loop data indicates evidence of similar behavior.

Finally, a new diagnostic algorithm has been tested that checks the on time per vehicle against a station average. Experiments show good accuracy in flagging changes in detector sensitivity, but the occupancy test does not. An extended run over 94 hr also showed fewer false alarms than the occupancy test, indicating that the on-time ratio is a more robust diagnostic. This is verified with experimental data from Santa Monica and Garden Grove.

By improving the manner in which the basic traffic data are examined, the overall performance of a control, incident detection, or system evaluation scheme can be ignored.

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