DETECTING FREEWAY INCIDENTS UNDER LOW-VOLUME CONDITIONS

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Two computer algorithms for automatic, freeway-incident detection under low-volume conditions were developed. The first approach uses a time-scan process. The second approach, considered to be superior to the first, operates on an event-scan principle. Computer simulations produced a family of curves that are useful in determining sensor-spacing requirements for an operational system using the event-scan algorithm. The results indicate that, when detector spacings of 1,000 ft (304.8 m) are used, all incidents on a 3-lane freeway section can be detected within 3 min for volumes up to 500 vehicles per hour. When volumes approach 1,000 vehicles per hour, 85 percent of the incidents can be detected within 3 min. Faster detection capabilities at the higher volumes would require closer detector spacings. Incident-detection operational considerations, particularly the manner in which software can be developed to recognize and compensate for vehicle-count errors produced by semitrailers and lane-change maneuvers, also are discussed.

•RECENT research has focused on the development of freeway-incident-detection algorithms for effective traffic management within freeway corridors. Work, notably that by Courage and Levin (1), Schaefer (2), Cook and Cleveland (3), Dudek and Messer (4), and Dudek, Messer, and Nuckles (5), has been directed primarily toward detecting incidents under medium- and heavy-flow conditions.

Although peak-period operation rightly commands most of the attention in freeway operations, the freeway operates 24 hours a day, and, during about 20 hours each day, most freeways operate below peak-volume conditions. However, certain safety problems continue to exist. One such problem is the accident or disabled vehicle on or adjacent to a main lane that, when approached by an unsuspecting driver at high speed, provides potential for a severe collision or at least a sudden change in the operating characteristics of the approaching vehicle. This problem is even more severe in freeway sections where sight distance is restricted by geometric features such as overpasses or horizontal curves coupled with median fences and retaining walls. In addition, freeway drivers operating under light-flow and high-speed conditions expect that the road ahead will be free of restriction; thus an unexpected event such as a stopped vehicle can create a greater hazard under these conditions than under alerted conditions. The problem is compounded when the incident occurs on elevated freeway sections, causeways, and tunnels. Two methods for detecting vehicular incidents under low-volume conditions are presented in this paper.

APPROACH

Control Variables

Incident detection under low-volume conditions requires a different basic approach than that used for high-volume situations. Basically, incident-detection algorithms for heavy-flow conditions rely on the measurements of flow discontinuities resulting from the reduced capacity created by the incident. During light-flow conditions, stoppage waves will not readily propagate (5). In selecting the control variable for incident detection under light-volume conditions, several variables used in incident-detection algorithms for peak periods are therefore unsatisfactory.

Because speeds are high and fairly uniform along each segment of the freeway when volumes are extremely light, the use of vehicle storage concepts appears to represent a favorable control method. Total input-output analysis appears to be unsatisfactory, however, because under light flow, which allows ample maneuvering space and potential for high-speed passing, a vehicle conceivably can enter the control section at a very high rate of speed, overtake a slower vehicle in the control section, and actually emerge from the section before the slower vehicle. Therefore, the speed variable should be considered in addition to the number of vehicles within the control section at any time. To accomplish this, the input-output technique was refined from total input-output analysis to individual-vehicle input-output analysis based on the time and speed entering the control section and time of exit from the control section as determined by a computer. The expected exit time would be

$$t_e = t_i + \frac{D}{V}$$

where

t_e = exit time in seconds,
t_i = entrance time in seconds,
D = distance between detectors in feet (meters), and
V = speed of vehicle in feet per second (meters per second).

This relationship is based on the assumption that vehicle speed remains constant between detectors.

Under this concept, the control variables are speed and the time that a vehicle enters and leaves the system. One can measure these variables by using lane detectors in pattern arrangements that are now used in many freeway-control systems.

Incident-Detection Algorithms

System A—Time-Scan Operation

Vehicle accounting in this system is accomplished on a fixed time interval. The relationship of time interval and detector spacing becomes quite critical to the expected results. Obviously, it would be desirable to place detectors at very short intervals throughout the control section. This would permit almost continuous monitoring of speed and vehicle count throughout the section with very small speed changes between consecutive detectors. Economics, however, prohibit such a luxury. Therefore, it becomes necessary to try to optimize the interval of detector spacing and accounting time to arrive at a compromise that is tolerable from both an economic standpoint and a false-alarm rate.

Figure 1 illustrates the operation of system A. Suppose that the system is turned on at T_0. All detectors are awaiting a vehicle actuation from which time of activation and vehicle speed can be recorded. At entrance time TA1, a vehicle crosses the detectors at location A and is registered in the system. Vehicle speed is measured, and predicted exit time, TB1, is computed. The slope of the line between TA1 and TB1 represents the speed. Another vehicle enters at TA2 traveling at a high rate of speed, and its exit time, TB2, is computed. As shown in Figure 1, this vehicle was traveling fast enough to pass the first vehicle in the system and would be expected to exit at location B before the first vehicle. Other vehicles entered the segment A-B as shown, and

Figure 1. System A, time-scan operation.

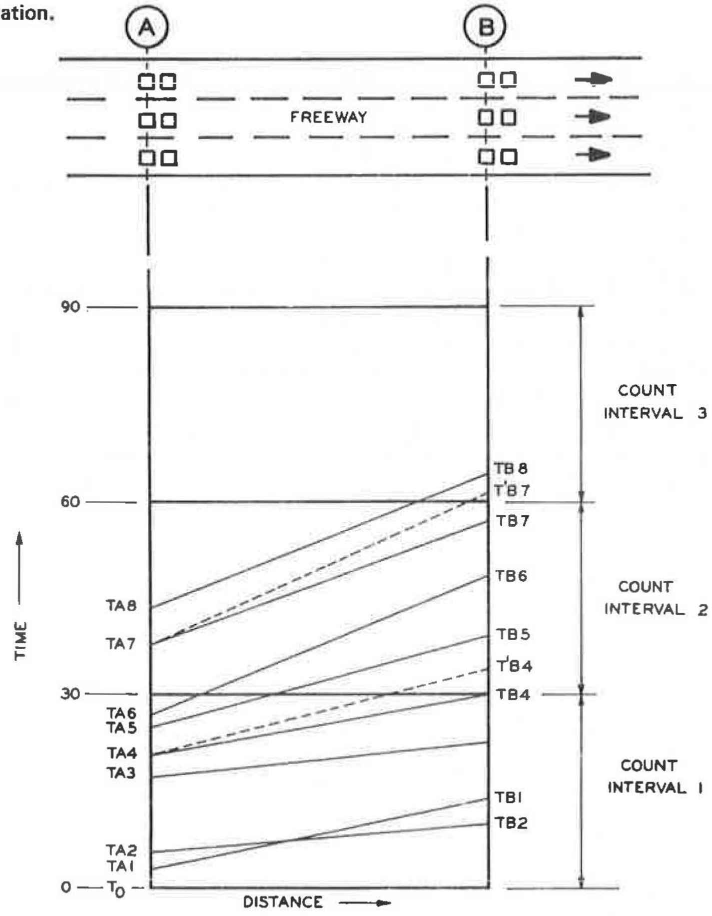
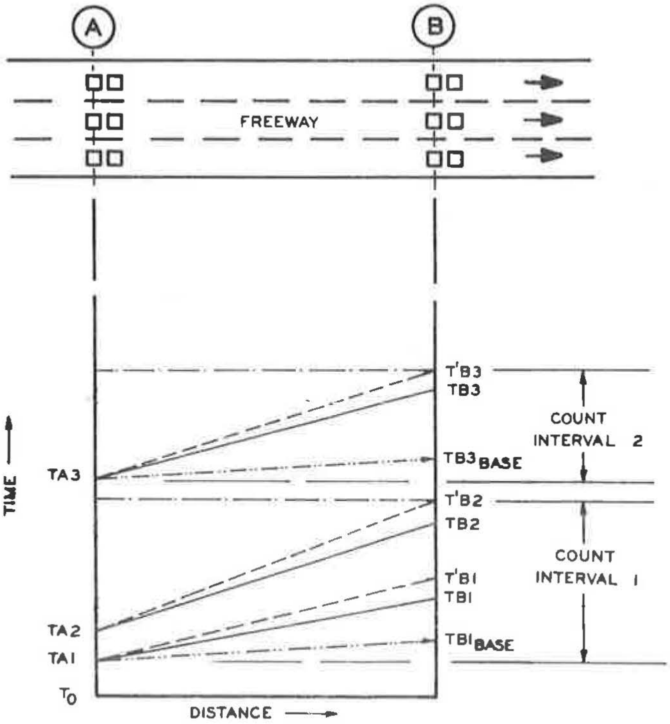


Figure 2. System B, event-scan operation.



expected exit times at B were computed.

Using a 30-s accounting interval, as shown in Figure 1, one can see that, within the first time interval, 6 vehicles entered at location A, and, within that same time interval, 4 would be expected to exit at B. The other 2 vehicles (vehicles 5 and 6) would be expected to arrive at B during the next 30-s interval, and they will be considered during that time interval. Expected exits are compared to actual exits at B. If the number exiting is less than expected, the assumption would be made that 1 or more vehicles, depending on the disparity, stopped between locations A and B. Theoretically, this logic appears to be valid. In practice, however, speeds vary, but the model assumes constant speed between detectors.

Consider vehicle 4 as an example of potential false alarm. Vehicle 4 was expected to arrive at B at TB = 30 s. Had the speed measurement been slightly high, or had vehicle 4 reduced speed slightly after passing the detectors at A, the actual arrival time at B would be slightly greater than the 30-s time point as shown by the dashed line in Figure 1. Thus, although it arrived without incident, a false alarm would have occurred. Detection delays could be incorporated to check the next accounting interval to determine whether the number of exiting vehicles was 1 more than expected to balance the system. However, the possibility does exist that the same phenomenon could occur during the next time interval. Therefore, the first late-arrival actuation would cancel out the second expected actuation and thus cause a false alarm. It becomes apparent that the false-alarm rate will increase as volumes and detector spacings increase.

System B—Event-Scan Operation

To alleviate the potential false-alarm problems associated with the time-scan operation, a variable time interval for vehicle accounting was developed.

Figure 2 illustrates the operation of system B. Assume that the system is turned on at T_0. When the first vehicle arrives at location A at TA1, 3 computations are made. First, the base time at B is computed. This represents the shortest practical time that the vehicle could be expected to arrive at detector B. Assuming a maximum speed of 100 mph (160.9 km/h) would be feasible because few vehicles could be expected to exceed this speed. Second, the expected arrival time at B, TB1, is computed based on measured speed. Third, to compensate for errors in speed measurements from the detectors, an allowable, speed-reduction safety factor of 10 percent is applied to the measured speed and a late expected arrival at B, T′B1, is computed. From this, a time is projected back to location A that is a base time determined from the assumed base speed. If a second actuation did not occur at A before this projected base time, the accounting interval would be established at A as the interval between TA1 and $TA1_{Base}$ and at B as the interval between $TB1_{Base}$ and TB1. As shown in Figure 2, a second vehicle did arrive at A before the projected base time. Therefore, the process is repeated. The example in Figure 2 shows that a third vehicle did not arrive between TA2 and $TA2_{Base}$; therefore, the time intervals at A and B are established as indicated. The sequence begins again when vehicle 3 crosses the detectors at A. The second time interval shown in Figure 2 indicates that only 1 vehicle arrived in the interval. The time interval under system B will differ in length according to the arrival rate at the first set of detectors. In practice each consecutive pair of detector sets would constitute a subsystem, and the accounting process would be accomplished throughout each subsystem whenever the vehicles cleared each subsystem.

It can be seen that, as flow rates increase, extension of the time interval can be expected and may become so long that insufficient response time could be provided after vehicle accounting procedures. The simulation studies discussed in the next section identify probabilities of detection by using the event-scan algorithm for various sensor spacings.

DETECTOR SPACING REQUIREMENTS FOR EVENT-SCAN OPERATION

This section discusses the influence of detector spacing on automatic incident detection for low-volume conditions. Only the event-scan operation (algorithm B) is discussed because it is considered to be the superior approach.

A computer simulation program was developed and run for a 3-lane directional freeway section. Volumes of 100, 500, and 1,000 vehicles per hour (vph) were tested with detector spacings of 500, 1,000, and 1,500 ft (152.4, 304.8, and 457.2 m) respectively. Ten hours of simulated traffic flow were produced for each of the 9 combinations of volumes and sensor spacings. The program was developed with the assumption that each vehicle entering the system had an equal probability of becoming disabled or involved in an incident. Poisson arrivals were assumed, and speed distributions collected on each lane of the Gulf Freeway in Houston, Texas, for the selected volumes were incorporated into the program.

The percentage of incidents detected within given time periods based on the simulation results are shown in Figures 3, 4, and 5. The average, smallest, and largest detection times for each volume and detector spacing combination are given in Table 1. The results illustrate incident-detection capabilities under low-volume conditions for the event-scan operation.

The results indicate that for volumes of 500 vph or less detector spacings of 1,000 ft (304.8 m) would provide adequate incident-detection response on a 3-lane freeway section. At volumes of 1,000 vph and greater, detector spacings of less than 1,000 ft (304.8 m) should be considered.

SOME OPERATIONAL CONSIDERATIONS

Incident detection under low-volume conditions that uses the algorithms previously described places stringent requirements on the surveillance system that have not been necessary for other freeway-operational-control functions. These include ramp metering, shock-wave detection, and incident detection during medium- and high-volume conditions. Accurate vehicle counts and relatively accurate speed measurements are essential if the system is to operate effectively. Experiences on the Gulf Freeway surveillance and control systems have indicated that it is not always possible to obtain perfectly accurate vehicle counts. Preliminary studies have produced an average of 1 error per 10 min at 200 vph on the 3-lane directional freeway. For automatic incident detection, this would mean a false alarm or a failure to detect an incident. Therefore, special studies were conducted during light-flow conditions to determine the source of error and to develop methods to compensate for it. Data from detectors on the Gulf Freeway were automatically processed by the computer system and produced printout data in real time. Observers using television monitors viewed traffic passing across the detectors and noted any irregularities between the traffic and the computer output.

Equipment

Traffic data were collected from 1 of the many sets of loop detectors on the inbound Gulf Freeway. Two loop detectors are positioned in each of the 3 lanes. Each loop detector is composed of 3 coils of 14-gauge wire installed in a saw cut 6 ft (1.83 m) square centered in the 12-ft (3.66-m) lane. The leading edges of the lead and lag loops are separated by 18 ft (5.49 m).

Program

The data acquisition programs within the digital computer operate under a real-time,

Figure 3. Incident-detection algorithm performance for detector spacings of 500 ft (152.4 m).

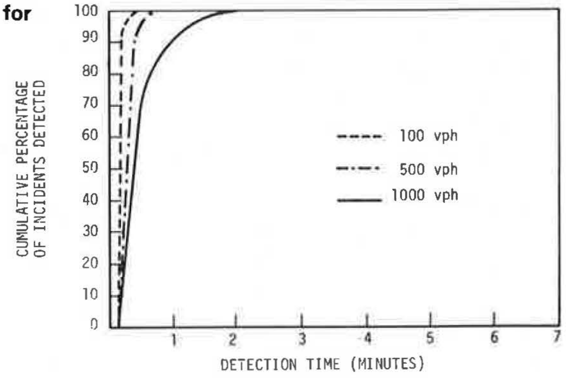


Figure 4. Incident-detection algorithm performance for detector spacings of 1,000 ft (304.8 m).

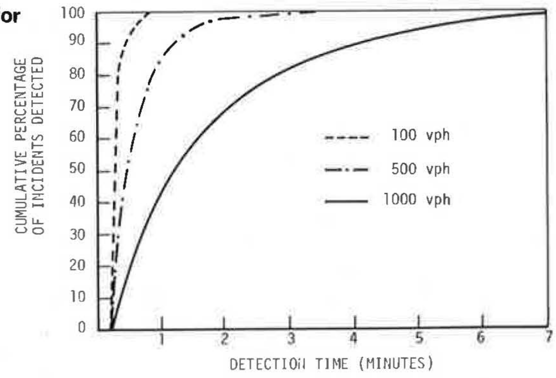


Figure 5. Incident-detection algorithm performance for detector spacings of 1,500 ft (457.2 m).

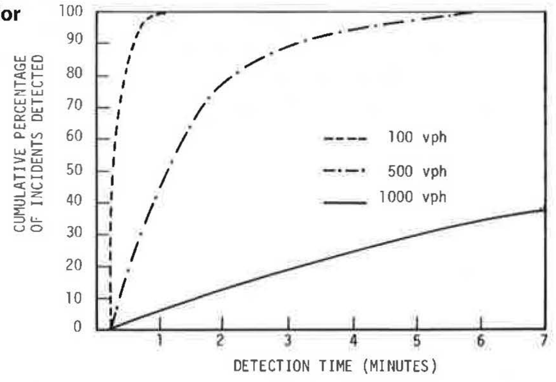


Table 1. Incident-detection times.

	Detection Time (s)		
Spacing Combination	Average	Smallest	Largest
Detectors 500 ft apart			
100 vph	7	4	20
500 vph	7	4	40
1,000 vph	13	4	133
Detectors 1,000 ft apart			
100 vph	15	9	50
500 vph	25	9	216
1,000 vph	74	9	518
Detectors 1,500 ft apart			
100 vph	24	13	80
500 vph	62	13	427
1,000 vph	590	15	3,000

Note: 1 ft = 0.3048 m.

multiprocessing, operating system. For each loop-detector-relay operation, programs are initiated that establish the time a vehicle enters or leaves the field of influence. Program timings are accurate to the nearest millisecond.

Table 2 gives the output format of the program timings. The clock time in column 1 in milliseconds is cyclic in nature; it increments from 0 to 32 575 ms and then decrements from 32 576 to 0 ms. It is used to establish an event occurrence. In this case, it is the time when a vehicle enters or leaves a loop detector.

Columns 2 through 7 indicate the headways in milliseconds between operations of lead and lag detectors for the inside, middle, and outside lanes. These values are significant when one determines whether more than 1 detector activation occurred for a given vehicle. If a headway of less than 500 ms is found, detector multiactivation or malfunction is suspected and should be further analyzed.

Columns 8 through 13 indicate the passage time or occupancy in milliseconds of a vehicle over a loop detector. These timed values are useful as vehicle "signatures" for identification purposes.

Volumes, headways, and occupancies registered by the lead and lag detectors can be compared on each lane to determine whether discrepancies exist. For example, at 374 ms in Table 2, the system indicates that a vehicle arrived at the lead detector on the middle lane 3651 ms after the previous vehicle. At 775 ms, the vehicle occupancy over the lead detector is 331 ms. Similarly, the headway and vehicle occupancy over the lag detector are 3731 and 305 ms. Comparison of the successive data in Table 2 reveals consistent results between the lead and lag detectors.

Columns 14 through 16 indicate the individual vehicle speeds in miles (kilometers) per hour in each lane. They are calculated values. The travel time between the lead and lag detectors is divided into an effective distance although the actual distance is 18 ft (5.49 m). The distance between loop detectors had to be changed to some value other than 18 ft (5.49 m). This was based on previous research work on the Gulf Freeway. A loop-tuning program in the computer was executed during free-flow traffic conditions. The effective distance was changed so that the calculated speed fell within the known free-flow traffic speed [48 to 56 mph (77.2 to 90.1 km/h)]. Unreasonable speed values in columns 14, 15, and 16 may exist because loop-detector amplifiers were changed and the effective distances were not recalibrated. The actual effective distances used for all data samples included in this report were 18.44, 19.55, and 19.65 ft (5.62, 5.96, and 5.99 m) for the inside, middle, and outside lanes respectively.

Using the above data acquisition program with real-time printout capabilities, we were able to observe traffic flow by closed-circuit television and compare the observed events to the data output.

Trucks

Table 2 serves to illustrate the normal actuation of semitrailers. Note the large occupancy values in the middle lane (columns 9 and 12) at 6260 and 6488 ms.

On many occasions, large trucks will cause double actuations by the lead or lag detectors or both. The data given in Table 3 indicate that a semitrailer caused the lead detector to register 1 actuation and caused the lag detector to register 2 actuations. Scrutiny of the headway and speeds provides a means for correcting for the double actuation. Although occupancies of 306 and 196 ms are within the range of acceptable data, the headway resulting from the lag detector registering the trailer as a second vehicle was computed at 441 ms. This is below normal expectations. Also the speed of 23 mph (37.0 km/h) reinforces the fact that a double actuation on the lag detector occurred. This information will allow development of software to compensate for double actuations.

Lane Changing

Another factor affecting the accuracy of the input or output vehicle count is lane

Table 2. Data acquisition program output.

Clock Time (ms) (1)	Headway (ms)						Occupancy (ms)						Speed (mph)		
	Lead			Lag			Lead			Lag					
	Inside (2)	Middle (3)	Outside (4)	Inside (5)	Middle (6)	Outside (7)	Inside (8)	Middle (9)	Outside (10)	Inside (11)	Middle (12)	Outside (13)	Inside (14)	Middle (15)	Outside (16)
0	0	0	0	0	0	1083	0	0	317	0	0	0	57	59	53
374	0	3651	0	0	0	0	0	0	0	278	0	268	57	59	53
775	0	0	0	0	3731	0	0	331	0	0	305	0	57	51	53
1273	1426	0	0	1416	0	0	247	0	0	0	0	0	59	51	53
1572	0	1219	0	0	0	0	0	0	0	244	0	0	59	51	53
1972	0	0	0	0	1188	0	0	251	0	0	233	0	59	56	53
3238	0	1577	0	0	1553	0	0	296	0	0	0	0	59	52	53
3473	0	0	0	0	0	0	0	0	0	0	275	0	59	52	53
4546	0	1332	0	0	1324	0	0	273	0	0	0	0	59	54	53
4772	0	0	0	0	0	0	0	0	0	0	250	0	59	54	53
5662	4305	1356	0	4321	0	0	331	0	0	0	0	0	55	54	53
5856	0	0	0	0	0	0	0	0	0	306	0	0	55	54	53
6260	0	0	0	0	1345	0	0	630	0	0	0	0	55	57	53
6488	0	0	0	0	0	0	0	0	0	0	621	0	55	57	53

Note: 1 mile = 1.61 km.

Table 3. Double actuation from semitrailer.

Clock Time (ms) (1)	Headway (ms)						Occupancy (ms)						Speed (mph)		
	Lead			Lag			Lead			Lag					
	Inside (2)	Middle (3)	Outside (4)	Inside (5)	Middle (6)	Outside (7)	Inside (8)	Middle (9)	Outside (10)	Inside (11)	Middle (12)	Outside (13)	Inside (14)	Middle (15)	Outside (16)
22 844	0	0	0	2 418	0	0	279	0	0	0	0	0	59	58	59
22 647	0	0	0	0	0	0	0	0	0	272	0	0	59	58	59
12 017	10 740	0	0	10 750	0	0	276	0	0	0	0	0	56	58	59
11 909	0	0	0	0	0	0	0	0	0	255	0	0	56	58	59
9 848	0	12 959	0	0	12 969	0	0	0	0	0	306	0	56	58	59
9 743	0	0	0	0	0	0	0	647	0	0	0	0	56	58	59
9 511	2 783	0	0	0	441	0	0	0	0	0	196	0	56	23	59
9 319	0	0	0	2 776	0	0	280	0	0	0	0	0	58	23	59
9 050	0	0	0	0	0	0	0	0	0	268	0	0	58	23	59
8 491	0	1 625	0	0	1 188	0	0	273	0	0	0	0	58	56	59

Note: 1 mile = 1.61 km.

Table 4. Double actuations from lane change and detector amplifier differences.

Clock Time (ms) (1)	Headway (ms)						Occupancy (ms)						Speed (mph)		
	Lead			Lag			Lead			Lag					
	Inside (2)	Middle (3)	Outside (4)	Inside (5)	Middle (6)	Outside (7)	Inside (8)	Middle (9)	Outside (10)	Inside (11)	Middle (12)	Outside (13)	Inside (14)	Middle (15)	Outside (16)
17 965	0	0	0	0	0	5 848	0	0	0	0	0	297	59	61	55
17 756	0	0	0	0	0	0	0	0	256	0	0	0	59	61	55
15 978	7 767	0	2 067	0	0	0	0	0	0	0	0	0	59	61	55
15 827	0	0	0	7 779	2 393	2 098	317	0	0	0	0	163	55	06	49
15 792	0	0	0	0	0	0	0	0	0	0	0	0	55	06	49
15 573	0	0	0	0	0	0	0	0	328	299	58	0	55	06	49
12 392	0	0	3 518	0	0	3 482	0	0	0	0	0	298	55	06	56
12 175	0	0	0	0	0	0	0	0	0	0	0	0	55	06	56
10 636	0	7 647	0	0	0	0	0	168	0	0	0	0	55	06	56
10 399	0	0	0	0	5 271	0	0	0	0	0	162	0	55	56	56
9 829	0	834	0	0	0	0	0	140	0	0	0	0	55	56	56
9 600	0	0	0	0	829	0	0	0	0	0	132	0	55	57	56

Note: 1 mile = 1.61 km.

Table 5. Low occupancy resulting from a motorcycle.

Clock Time (ms) (1)	Headway (ms)						Occupancy (ms)						Speed (mph)		
	Lead			Lag			Lead			Lag					
	Inside (2)	Middle (3)	Outside (4)	Inside (5)	Middle (6)	Outside (7)	Inside (8)	Middle (9)	Outside (10)	Inside (11)	Middle (12)	Outside (13)	Inside (14)	Middle (15)	Outside (16)
18 820	0	0	4 226	0	0	4 197	0	0	330	0	0	0	51	59	56
19 013	0	0	0	0	0	0	0	0	0	0	0	275	51	59	56
19 350	0	4 800	0	0	0	0	0	56	0	0	0	0	51	59	56
19 588	0	0	0	0	4 818	0	0	0	0	0	51	0	51	54	56
20 408	3 825	980	0	3 799	0	0	290	0	0	0	0	0	57	54	56
20 539	0	0	0	0	977	0	0	270	0	0	0	0	57	55	56
20 624	0	0	0	0	0	0	0	0	0	295	0	0	57	55	56
20 818	0	0	0	0	0	0	0	0	0	0	249	0	57	55	56

Note: 1 mile = 1.61 km.

changing in the vicinity of the sensors. The resultant characteristics of lane changes are given in Table 4. A vehicle traveling in the inside lane changed to the middle lane and entered the area of the middle-lane lag detector. This caused a vehicle occupancy computation on the middle-lane lag detector without a corresponding activation on the middle-lane lead detector. Note also an extremely low speed value on the middle lane. These patterns can be readily recognized by the computer to automatically adjust for discrepancies, which ensures a higher degree of accuracy at the input and output count stations.

Detector Amplifier Differences

Table 4 illustrates differences in amplifier measurements. Amplifiers produced by a different manufacturer than the one that produced those used on the inside and outside lanes were placed in the middle lane. The traffic moved over all lanes at free-flow speed, yet the middle lane (columns 9 and 12) clearly indicates much smaller travel times across the lead and lag loops. The detection operations are usable except when very small values (50 to 100 ms) occur. The existence of a vehicle or the occurrence of a lane change poses problems that must be solved. Using an amplifier with this characteristic could make the establishment of data limits very difficult.

Motorcycles

Although detector occupancies of less than 100 ms generally are suspect, motorcycles produce low values (some detector amplifiers will not even detect motorcycles). For example, a motorcycle traveling on the middle lane had occupancies of 56 and 51 ms registered by the lead and lag detectors respectively (Table 5). Examination of the headways, speeds, and number of activations reveals no unusual patterns. Thus the system could be designed to recognize the presence of motorcycles.

SUMMARY

Two computer algorithms for automatic freeway-incident detection under low-volume conditions were developed and presented. Both approaches used input-output techniques that require accurate vehicle counts. Vehicle speeds were computed at the input station, and times of departures at the output stations were determined. One approach used a time-scan process. The second, considered to be the superior of the 2 approaches, operated on an event-scan principle.

The computer simulations produced a family of curves that are useful in determining sensor-spacing requirements for an operational system that uses the event-scan algorithm. The results indicate that 1,000-ft (304.8-m) detector spacings will provide adequate response to incidents for volumes up to 500 vph on a 3-lane freeway section. At volumes of 1,000 vph and greater, detector spacings of less than 1,000 ft (304.8 m) should be considered.

Because accurate counts are essential at both the input and output sensor stations, the study results have shown that volume counts must be supplemented by pattern recognition of headway, vehicle occupancy, and speed data to compensate for volume errors produced by semitrailers and lane-change maneuvers.

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facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration.

REFERENCES

1. K. G. Courage and M. Levin. A Freeway Corridor Surveillance, Information, and Control System. Texas Transportation Institute, Texas A&M Univ., Research Rept. 488-8, Dec. 1968.
2. W. E. Schaefer. California Freeway Surveillance System. California Division of Highways—District 7, Nov. 1969.
3. A. R. Cook and D. E. Cleveland. Detection of Freeway Capacity-Reducing Incidents by Traffic Stream Measurements. Transportation Research Record 495, 1974, pp. 1-11.
4. C. L. Dudek and C. J. Messer. Detecting Stoppage Waves for Freeway Control. Highway Research Record 469, 1973, pp. 1-14.
5. C. L. Dudek, C. J. Messer, and N. B. Nuckles. Incident Detection on Urban Freeways. Transportation Research Record 495, 1974, pp. 12-24.

DISCUSSION

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Dudek et al. have started research efforts into a new and very difficult area: incident detection under conditions of low freeway volumes. Most incident detection has been incorporated into peak-period freeway-surveillance and freeway-control systems and has used large changes (or discontinuities) in 1 or more of the macroscopic flow variables (flow, speed, and density). Past research in incident detection has concentrated on the high-volume area because of the overall concern for peak-period problems and because incident detection is easier to accomplish during peak periods.

As Dudek et al. point out, incident detection is more difficult during low-volume conditions. Discontinuities in the traffic stream are smaller than they are under heavy-flow conditions and shock waves generally are not propagated readily under low-volume conditions. The traditional approaches to incident detection have been techniques in which either the affected motorist or a passing motorist reports the incident to the appropriate authorities. In some areas call boxes have been installed to facilitate the reporting of incidents; patrolling vehicles also have been used for this purpose. Little has been done to apply electronic-detection principles to low-volume incident detection.

Dudek et al. have made a pioneering effort into the low-volume incident-detection problem. They have investigated 2 low-volume incident-detection schemes: time-scan methods and event-scan methods. They have recommended the event-scan techniques. Basically, a set of freeway detectors senses each vehicle that crosses it and predicts its arrival time at the next detector station. When a vehicle does not arrive at the downstream detector station as predicted, the incident-detection logic classifies the event as an incident. Thus, the incident-detection system relies on an individual-vehicle-accounting system.

I have no questions about the theoretical validity of this approach, but I would like to raise the question of practicability based on current detector technology. It is generally accepted that a detector station will not provide a perfect total volume count. The count will be either high or low, and the detector configuration can be changed to make the detected count higher or lower, but errors are not eliminated. In other words, if the configuration or sensitivity is changed to reduce overcounting errors, undercounting errors will be increased. In any case, it does not appear at this time that there is a counting station that will yield perfect counts.

Any incident-detection system must decide between 2 types of errors:

1. Missing a real incident and
2. Identifying a nonincident as an incident.

The latter is a false alarm. If we assume an error rate percentage, E, an hourly volume, V in hundred vehicles per hour, and N detector stations per mile (kilometer), we would expect E × V × N false alarms per hour per mile (kilometer). For example, if we assume an average detector station error rate of 1 percent, a volume of 200 vph and 5 detector stations per mile (3 detector stations per kilometer), we would expect 10 false alarms per hour per mile (6 false alarms per hour per kilometer). Thus, even though there is a relatively low error rate and a low volume, a high generation rate of false alarms is experienced.

It would appear that the problem of low-volume incident detection should be subjected to a traditional systems analysis in which all reasonable alternatives would be explored. It would seem that other alternative schemes might be possible.

The detection scheme called for by the authors involves a pair of detectors in each lane of the freeway at each detector station, and the recommended spacing of the detector stations is every 1,000 ft (30.48 m). This would require about 32 detectors per mile (20 detectors per kilometer) for a 3-lane freeway section and 42 detectors per mile (26 detectors per kilometer) for a 4-lane freeway. Alternatively, these same detectors could be located on the shoulders of the freeway about every 200 ft (60.96 m). This system might provide a higher level of accuracy in detecting incidents that used the shoulders and almost certainly would have a much lower false-alarm rate.

Another possibility appears to be worth pursuing. Rather than use an input-output accounting procedure with its proven error problems, it might be better to look into the use of a detection system that would directly detect a stopped vehicle. The air traffic control radar system at the Tampa International Airport shows the movement of vehicles across the Howard Franklin Bridge. It probably is not able to discriminate between 2 vehicles in a platoon, but it most likely would be able to discriminate between stopped and moving vehicles, and it could identify stoppages. Further refinements of this area-detection system might produce a usable technique for detecting incidents under low-volume conditions.

In conclusion, Dudek et al. have made a worthwhile start into the area of low-volume incident detection. There is clearly much more work to be done, and the authors are encouraged to continue their efforts.

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The authors have proposed 2 algorithms for detecting freeway incidents under low-volume conditions. These algorithms may have merit for tunnels, bridges, and freeway sections without shoulders, but their application elsewhere requires considerable refinement. They need to distinguish critical from noncritical stoppages and integrate detection and response into a cost-effective system.

All incidents will be detected with no false alarms if the proposed detection system can be tuned and operated perfectly (a practically impossible and unrealistic event), if logic refinements can be incorporated to handle normal exit and entrance ramp changes along the freeway, and if lane changing at the detection points can be accounted for. The detected incidents, however, will include all vehicle stoppages along the freeway, including those made on the shoulders.

Numerous studies of stoppages and freeway shoulder use, including urban studies in Chicago, Detroit, and Houston, have shown that vehicle stoppages occur quite frequently, are usually on shoulders, and are of short duration; they usually do not involve disabled vehicles and usually require no assistance (6, 7, 8, 9, 10). For example, one 3-day Chicago-area study on an urban freeway section with 120,000 average daily traffic reported 1 vehicle stoppage for reasons other than congested traffic for every 2,500 vehicle miles (4023 vehicle kilometers) of travel, an average of 1 stopped vehicle per directional mile per hour (1.6 stopped vehicles per directional kilometer per hour) (7). The right shoulder handled 84.1 percent of the stopped vehicles, the left shoulder handled 7.4 percent. The main lanes accounted for 4.5 percent. The remaining 4.0 percent were on ramps and auxiliary lanes. Disabled vehicles of various types totaled 19 percent. Nondisabled vehicles totaled 81 percent. It usually was not known why the nondisabled vehicles stopped.

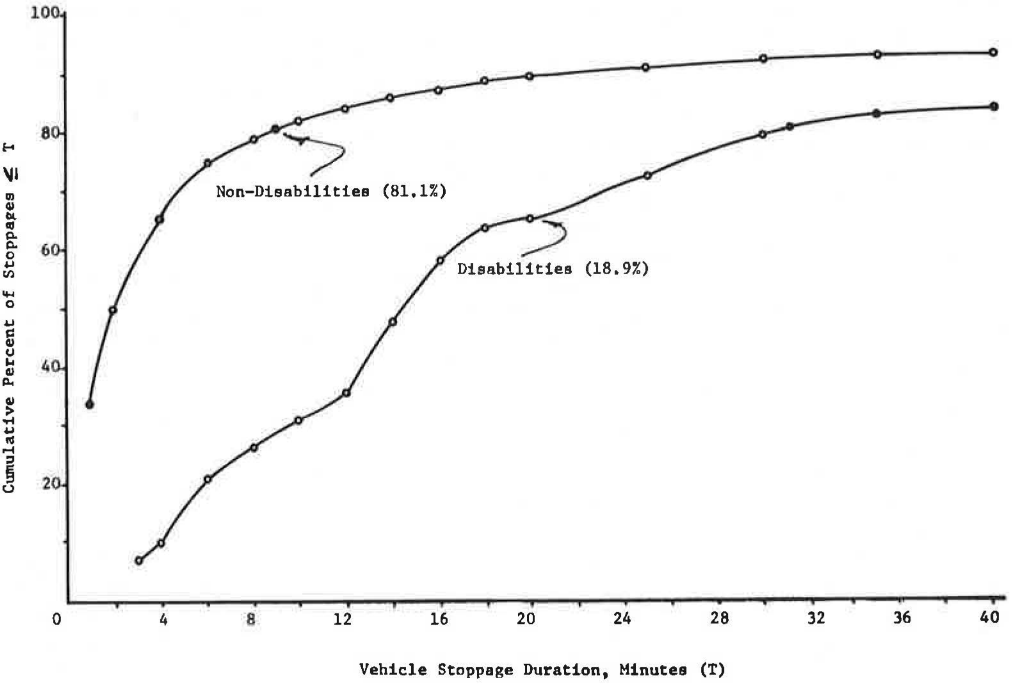
All of the nondisabled vehicles and 60 percent of the disabled vehicles required no assistance. Figure 6 shows the time duration of all stoppages; it suggests that any algorithm that initiates incident-response forces for noncritical short stoppages would introduce a high rate of operational false alarms into a system whose detection component has been optimized at the zero-false-alarm level.

The concept of detecting incidents through detecting individual stopped vehicles is based partially on safety considerations. Some idea of the magnitude of the hazard can be obtained from accident records. The 1972 Chicago-area accident records for 135 expressway miles (216 expressway kilometers) showed that only 52 out of 16,302 (0.3 percent) reported accidents involved vehicles on either the right or left shoulders. Of these 52, none involved fatalities, and only 9 occurred in the 1:00 to 6:00 a.m., low-volume period.

The costs of the proposed detection system should consider detection, verification, staffing, and response costs. Whenever an incident is detected, a response mechanism must begin. If closed-circuit television or other measures are to be used to help verify the nature of the incident, considerable additional costs are introduced. The proposed algorithms require detector and equipment factors representing, at 1,000-ft (304.8-m) spacings, about 15 times as many detectors as traffic stream monitoring in 1 lane at 0.5-mile (0.8-km) directional intervals.

All in all, the operational value of the proposed system appears to limit the application to those roadways, such as tunnels, where all stoppages block travel lanes (11).

Figure 6. Vehicle stoppage duration, cumulative frequency distribution.



REFERENCES

6. S. E. Bergsman and C. L. Shufflebarger, Jr. Shoulder Usage on an Urban Freeway. John C. Lodge Freeway Traffic Surveillance and Control Research Project, Study 417, Jan. 1962.
7. Disabled and Non-Disabled Vehicle Stoppage on the Congress Street Expressway. Illinois Department of Transportation, Chicago Area Expressway Surveillance Project Rept. 8, Nov. 1962.
8. A. Kuprijanow, S. Rosenzweig, and M. A. Warskow. Motorists' Needs and Services on Interstate Highways. NCHRP Rept. 64, 1969.
9. M. P. Pekala and J. M. McDermott. Summary Analysis: "Before" Study Data Collection for the I-80 Motorist Aid Communication System. Illinois Department of Transportation, Interim Rept., March 1974.
10. M. E. Goolsby and W. R. McCasland. Evaluation of an Emergency Call Box System. Texas Transportation Institute, Texas A&M Univ., Research Rept. 132-1F, Dec. 1969.
11. R. S. Foote. Intensive Traffic Management for Critical Roadways. Traffic Engineering and Control, Oct. and Nov. 1974.
12. F. DeRose, Jr. An Analysis of Random Freeway Traffic Accidents and Vehicle Disabilities. Highway Research Record 59, 1964, pp. 53-65.
13. M. E. Goolsby. Influence of Incidents on Freeway Quality of Service. Highway Research Record 349, 1971, pp. 41-46.

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Incident-detection algorithms generally fall into 2 classes: (a) those that are dependent on the propagation of a queue upstream of the incident site and (b) those that depend on a disruption in the pattern of traffic at successive detector stations. Most algorithms are members of the first class and find their greatest success under medium- and high-flow conditions, or, more precisely, under conditions in which the incident reduces the capacity to a level that is less than the approaching volume.

There are only a few representatives of the second class, and the paper of Dudek et al. is in this class. The earliest suggestion of an algorithm based on this principle is apparently that of Barker (14), and further work along these lines recently has been done by Sakasita and May (15). This class of algorithms is attractive for 2 reasons. First, it offers hope of detecting incidents under conditions in which the incident does not reduce the capacity below the level of approaching volume and hence is well suited for incident detection under low-volume conditions. Second, the phenomenon that is the basis for this class of algorithms is generally manifested in the data much sooner after the incident occurs than is the queue backup, which is the basis for the vast majority of presently available incident-detection algorithms.

Despite the attractive nature of this second class of algorithms, the development of effective algorithms that do not require an unreasonable number of detectors, such as detector stations placed at 500-ft (152.4-m) intervals, has proved to be quite difficult. A complicating operational problem, noted by Barker (14), is the presence of an on-ramp or an off-ramp between the detector stations. A further complication, discussed at some length by Dudek et al., is vulnerability to detector errors. The results presented by Sakasita and May (15) and by Dudek et al. appear promising, but it should be borne in mind that these results are based on simulations that do not consider the major problems presented by the complications cited.

The structure of the event-scan version of the algorithm presented in this paper does not appear to allow for modifications that might accommodate these practical considerations. In particular, there is no adjustable parameter to provide a trade-off between detection performance and false-alarm rate. In its present form, the algorithm is certainly not ready for operational use. Although the authors apparently recognize this, they do not indicate how the shortcomings can be overcome except to demand a heretofore unachieved quality in detectors.

Consideration of algorithms that identify a discrepancy between actual downstream flow conditions and a forecast of downstream flow conditions based on upstream flow conditions certainly is warranted. Development along these lines must proceed, however, with respect for known operational problems.

REFERENCES

14. J. L. Barker. Determination of Discontinuities in Traffic Flow as a Factor in Freeway Operational Control. Traffic Engineering, Nov. 1961, pp. 11-17.
15. M. Sakasita and A. D. May. Development and Evaluation of Incident Detection Algorithms for Electronic Detector Systems on Freeways. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, Spec. Rept., Aug. 1974.