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16. Abstract

A computer program to detect vehicular incidents which occur on urban freeways operating at low volume conditions was developed, tested and evaluated. The type of "incidents" to be detected are those vehicles which entered but for some reason did not pass through a defined study section. The algorithm can operate in real-time and is based on an individual vehicle input-output process. It was tested on traffic data from a four-lane section of freeway in Houston, Texas. The algorithm's performance was evaluated over a wide range of traffic volumes (100 to 1200 vehicles per hour) and three different detector spacings - 500, 1000 and 1500 feet.

In the 500-foot section, the algorithm detected 65 percent (11/17) of the incidents that occurred. In the 1000-foot section, it detected 78 percent (14/18) of the incidents that occurred and in the 1500-foot section, it detected 49 percent (17/35) of the incidents that occurred. Numerous lane changes and a bad detector at the first detection station caused the relatively poor performance of the algorithm in both the 500-foot section and the 1500-foot section. The algorithm detected all incidents that occurred when the volume level was less than 400 vehicles per hour. It detected 61 percent (37/61) of the incidents that occurred when the volume level was between 800 and 1200 vehicles per hour.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

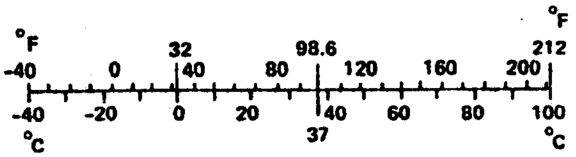
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

AUTOMATIC DETECTION OF FREEWAY INCIDENTS DURING LOW VOLUME CONDITIONS

by

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Research Report 210-1

Evaluation of Urban Freeway Modifications

Research Study Number 2-18-77-210

Sponsored by the Texas
State Department of Highways and Public Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
Texas A&M University
College Station, Texas

September 1979

ABSTRACT

A computer program to detect vehicular incidents which occur on urban freeways operating at low volume conditions was developed, tested and evaluated. The type of "incidents" to be detected are those vehicles which entered but for some reason did not pass through a defined study section. The algorithm can operate in real-time and is based on an individual vehicle input-output process. It was tested on traffic data from a four-lane section of freeway in Houston, Texas. The algorithm's performance was evaluated over a wide range of traffic volumes (100 to 1200 vehicles per hour) and three different detector spacings - 500, 1000 and 1500 feet.

In the 500-foot section, the algorithm detected 65 percent (11/17) of the incidents that occurred. In the 1000-foot section, it detected 78 percent (14/18) of the incidents that occurred and in the 1500-foot section, it detected 49 percent (17/35) of the incidents that occurred. Numerous lane changes and a bad detector at the first detection station caused the relatively poor performance of the algorithm in both the 500-foot section and the 1500-foot section. The algorithm detected all incidents that occurred when the volume level was less than 400 vehicles per hour. It detected 61 percent (37/61) of the incidents that occurred when the volume level was between 800 and 1200 vehicles per hour.

KEY WORDS: Incident Detection, Freeway Operations, Motorists' Aid Systems

SUMMARY

Although peak period operation deserves the majority of attention in freeway operations, "rush-hour" conditions only exist for a few hours each day. Even though the freeway is operating below peak volume conditions during the rest of the day, certain safety problems continue to exist. Accidents or disabled vehicles located in or adjacent to a freeway mainlane, (when approached by an unsuspecting driver at a high rate of speed), provide the potential for a severe collision or at least a sudden change in the operating characteristics of the approaching vehicle. Available incident detection algorithms, such as queueing and flow discontinuity models, are not able to detect these incidents under the low volume conditions characteristic of nighttime and weekend operation on urban freeways. The objectives of this research effort were to develop, test and evaluate a technique for detecting those vehicular incidents which occur on urban freeways operating at low volume conditions. The types of "incidents" to be detected were those individual vehicles which entered but for some reason did not pass through a defined study section.

As part of this study, a computer algorithm was developed to detect these low volume freeway incidents. The algorithm is capable of operating in real-time and is based on an individual vehicle input-output process. The following is a brief outline of the algorithm:

1. As vehicles enter a freeway section, the earliest and latest projected times at which they should arrive at the downstream detectors are calculated.

2. Based on these projected arrival times, vehicles are placed in one of three time accounting intervals.
3. All vehicles whose projected arrival times overlap are placed in the same accounting interval.
4. Each vehicle which exits the freeway section after the earliest projected arrival time in the first accounting interval is counted.
5. When the time-of-day is equal to the latest projected arrival time in the first accounting interval, the exit count is compared to the number of vehicles which were placed in that interval.
6. If the exit count is less than the projected number in the accounting interval, an incident is detected.
7. If the exit count is equal to the projected number in the accounting interval, no incident is detected.
8. If the exit count is greater than the projected number in the accounting interval, no incident is detected (i.e., an unknown situation exists).

It was recognized that the detectors available for this research were not always able to provide a perfect total volume count. Changes in detector sensitivity may eliminate some counting errors, but only at the risk of creating new ones. Because counting errors produce false alarms in the operation of the algorithm, any detector activation which cannot be explained by program logic will cause an unknown condition. Although some incidents were not detected, the number of false alarms was kept to a minimum, thus increasing the credibility of the algorithm. A high degree of credibility is considered essential to any nonredundant freeway surveillance system, particularly one without television.

The three main causes of "false" counts were tractor-trailer trucks, motorcycles and lane changes. To some detectors, large trucks appear as two cars following one another at very small headways. The examination of considerable freeway data led to the establishment of a minimum allowable headway between two vehicles. Headways smaller than this minimum denoted the passage of only one vehicle. Headways larger than this minimum denoted the passage of two vehicles. Motorcycles were observed to yield a much lower occupancy reading than other vehicles. Because of this characteristic, they were easily identified; however, some detectors were not sensitive enough to register their presence. For this reason, a motorcycle that was detected was neither projected downstream nor counted as having left the study section. Detector activations from a vehicle that is changing lanes are similar to those from two small cars that are traveling in adjacent lanes. Because of the great amount of additional programming needed to identify a lane change, the following guidelines were adopted. If a potential lane change was detected at the input station, one vehicle was projected. If a potential lane change was identified at the output station, two vehicles were counted.

Data from a four-lane section of Interstate Highway 610 North in Houston were used to test the algorithm's performance. Detector spacings of 500, 1000 and 1500 feet were evaluated. The accuracy of the algorithm was determined for different levels of traffic flow (100 to 1200 vehicles per hour). Thirty-five "mock incidents" were staged while data were being collected. In the 500-foot section, the algorithm detected 65 percent (11/17) of the incidents that occurred. In the 1000-foot section, it detected 78 percent (14/18) of the vehicles which stopped, and in the 1500-foot section, it detected 49 percent (17/35) of the vehicles which stopped. Numerous lane changes and a bad detector at the first detection station caused the relatively poor performance of the algorithm in both the 500-foot section and the 1500-foot section. For volume levels up to 400 vehicles per hour, the algorithm detected all of the vehicles which stopped in the three sections. For volume levels from 800 to 1200 vehicles per hour, the algorithm detected 60, 75 and 42 percent of the vehicles which stopped in the three sections, respectively. The maximum "average time" to detect an incident for any volume level - detector spacing combination was 40 seconds. At the lower volume level, the false alarm rate was one per 7 hours of operation. At the higher volume level, the false alarm rate was one per 2 hours of operation. A redundant surveillance system that provides additional information to the operating agency could reduce the number of false alarms.

Implementation

A low volume incident detection algorithm has been developed and tested. Satisfactory results were obtained; however, with minor improvements to the algorithm and a better maintenance program for the hardware, the algorithm's performance can be improved. The next step towards implementing the results of this study should be the evaluation of an "in-place" low volume incident detection system. Also, the reliability of the hardware components of such a system should be determined.

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INTRODUCTION

The Problem

Freeways frequently break down when operating at peak-flow conditions. It is during these periods of heavy flow that many problems arise. As traffic demands increase, operational problems associated with undesirable geometrics, insufficient freeway capacity and smaller headways are compounded. Accidents can be expected to increase in number. For these reasons, recent research (1, 2) in the field of automatic freeway incident detection has been primarily concerned with the development of algorithms to detect incidents under medium or heavy flow conditions.

Although peak-period operation deserves the majority of attention in freeway operations, the freeway is operable twenty-four hours a day, and during about twenty hours of each day most freeways operate below peak volume conditions. However, certain safety problems continue to exist. When approached by an unsuspecting driver at a high rate of speed, an accident or disabled vehicle located on or adjacent to a freeway mainlane provides potential for a severe collision or at least a sudden change in the operating characteristics of the approaching vehicle (3). Freeway drivers operating under low volume and high speed conditions expect the roadway to be clear of any obstructions. Thus, reaction time to an unexpected event such as a stopped vehicle on the freeway can be expected to be longer than it would under alerted conditions. This problem is even more severe on freeway sections where sight distance is restricted by geometric features such as horizontal or vertical curvature, median fences and/or retaining walls. Also, incidents which occur on elevated freeway sections, causeways and tunnels create greater hazards for unsuspecting motorists.

Available incident detection algorithms, such as queueing and flow discontinuity models (4), cannot detect incidents during the low volume traffic flow characteristic of nighttime and some weekend conditions on urban freeways. Closed circuit television is not a reliable primary incident detection device due to operator boredom. In addition, it is not very effective under most nighttime lighting conditions. Police and courtesy patrols are not able to provide the quick response required of an incident detection system, and call boxes require a voluntary response which an injured motorist might not be able to do. Thus, existing motorist aid systems seem inadequate for detecting freeway incidents during low volume conditions.

Scope

The objective of this research was to develop and test a technique for detecting vehicular incidents on urban freeways operating at low volume conditions. The types of "incidents" to be detected were those individual vehicles which entered but for some reason did not pass through a defined study section. A four-lane section of Interstate Highway 610 North in Houston was used to test the algorithm over a range of low volume traffic conditions. The performance of the algorithm was evaluated for detector spacings of 500, 1000 and 1500 feet.

DETECTION CONCEPT

Control Variables

Incident detection under low volume conditions requires a different approach than that used for high volume situations. Algorithms developed to operate during heavy flow conditions rely on the measurement of flow discontinuities resulting from the reduced capacity created by the incident. During light flow conditions, these stoppage waves will not readily propagate (5). Several variables, such as density, energy and occupancy, that are used in peak period incident detection algorithms are unsatisfactory as control variables for incident detection during low volume conditions.

When volumes are light, vehicle speeds are high and fairly constant along individual freeway segments. Therefore, some type of vehicle storage concept appears to represent a viable incident detection method. "Total" input-output appears unsatisfactory because during light flow, with ample maneuvering space and the potential for high speed passing, a vehicle could enter the control section at a very high rate of speed, overtake a slower vehicle in the section and actually emerge from the section before the slower vehicle. As a result, the speed variable must be considered in addition to the number of vehicles in the control section at any one time. To accomplish this, the input-output technique has been refined from a "total" input-output philosophy to an "individual vehicle" input-output analysis based on the time and speed of vehicles entering the control section and their predicted exit time from that section. The predicted exit time of each vehicle can be computed as shown in the equation on the following page:

$$t_e = t_i + d/v$$

where: t_e = Exit time, sec.

t_i = Entrance time, sec.

d = Section length, ft.

v = Entrance speed of vehicle, fps.

This relationship is based on the assumption that a vehicle's speed remains constant over short sections of freeway. Under this concept, the control variables are the speed and the times at which a vehicle enters and leaves the system. These variables can be measured by loop detectors in pattern arrangements now used in many freeway control systems. The operation of a low volume incident detection system, the time interval for vehicle accounting procedures, detector spacings and errors are discussed in the following section of this report.

Incident Detection Algorithm

Accounting Procedures. The low volume incident detection algorithm, developed during this research, utilizes a variable time interval when counting vehicles. Basic operation of the algorithm is discussed below and illustrated in Figure 1.

Assume the system is turned on at time T_0. When the first vehicle arrives at Station 1 at time $A1_1$, two computations are made. First the vehicle's expected arrival time, $A2_1$, at Station 2 is computed based on measured speed. Second, to compensate for errors in speed measurements from the detectors, speed change factors are applied to the measured speed and an

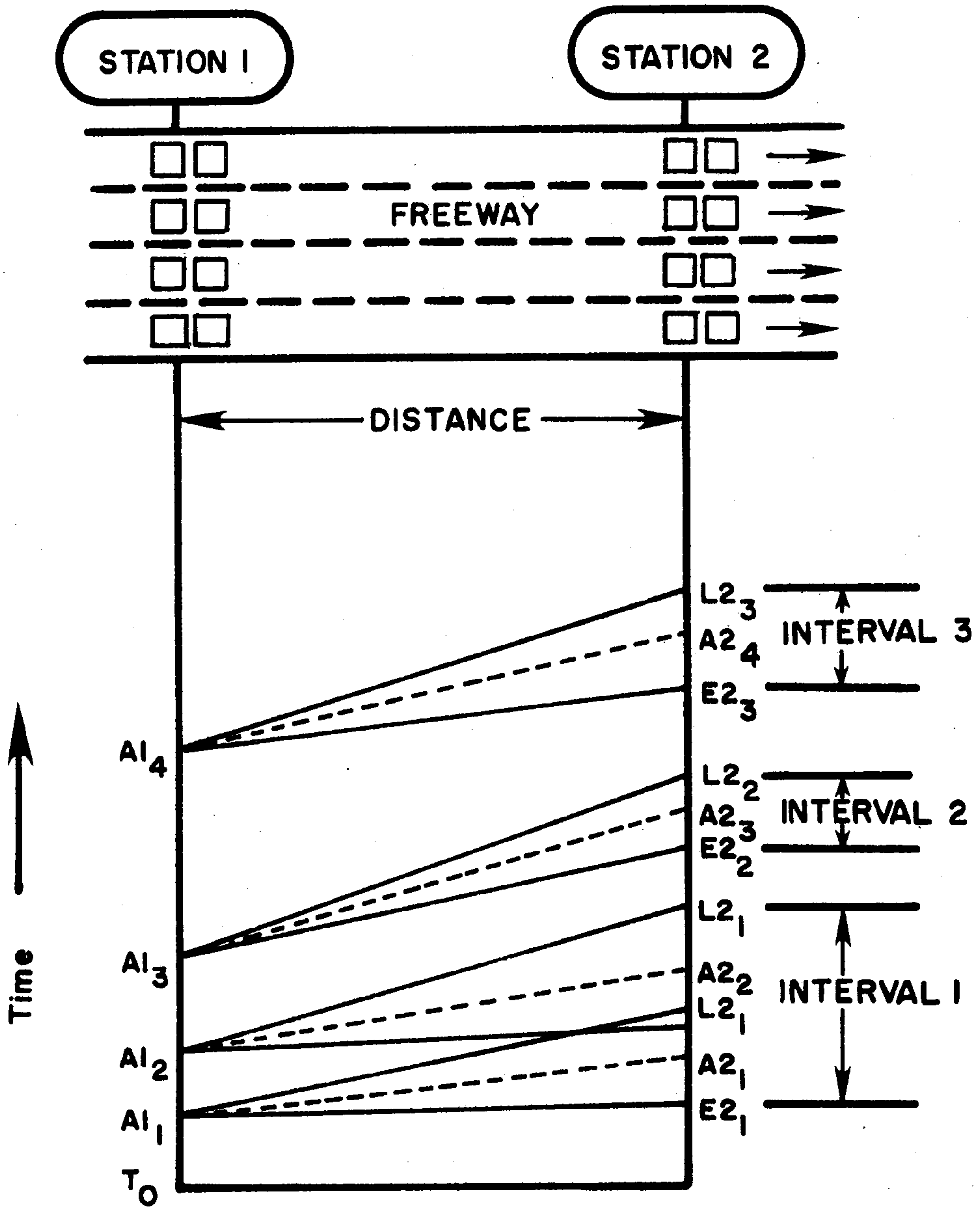

FIGURE 1. BASIC OPERATION OF THE ALGORITHM

"early" time, $E2_1$, and a "late" time, $L2_1$, are computed for the expected arrival time at Station 2. If a second vehicle does not arrive at Station 1 before the projected "late" arrival time of the first vehicle, the first accounting interval at Station 2 is established as the interval of time between $E2_1$ and $L2_1$. As shown in Figure 1, a second vehicle did arrive at Station 1 before time $L2_1$. Its "early" and "late" expected arrival times are computed and compared to the boundary times of the existing accounting interval. If the times overlap, the boundary times of the accounting interval are redefined. If the times do not overlap, the boundary times of a separate accounting interval are established. The example in Figure 1 shows that the expected arrival times of the third vehicle do not overlap the boundary times of the first accounting interval. Therefore, two vehicles would be expected to arrive at Station 2 between times $E2_1$ and $L2_1$. Only one vehicle should arrive at the downstream station during both the second and third time intervals shown in Figure 1. An incident is detected whenever fewer than the expected number of vehicles in a time interval exit the section during that interval. Time intervals will differ in length according to the speed of individual vehicles and their arrival rate at the upstream set of detectors.

<u>Detector Spacing</u>. In practice each consecutive set of detectors constitutes a subsystem and its accounting process is accomplished whenever vehicles clear that subsystem. As flow rates or detector spacings increase, the accounting time interval can be expected to increase in length. It would be desirable to place detectors at very short intervals throughout entire freeway systems. This would permit almost continuous monitoring of speed and vehicle counts in each subsystem with very small speed

changes between consecutive detectors. However, economics prohibit such a luxury. As a result, it is necessary to select detector spacings based on economic as well as operational criteria.

Possible Errors. Incident detection under low volume conditions places stringent requirements on surveillance systems that have not heretofore been necessary for other freeway operational control functions. Accurate vehicle counts and relatively accurate speed measurements are essential if the low volume incident detection algorithm is to operate effectively. Experience on the Gulf Freeway surveillance and control system in Houston indicates it is not always possible to obtain 100 percent vehicle count accuracy (3). The consequence relative to automatic incident detection with the algorithm is a false alarm or an undetected incident. Inaccurate speed measurements add to the operational inefficiency of the algorithm.

DATA COLLECTION

Freeway Test Site

Site requirements for testing the low volume incident detection algorithm were as follows: (1) multi-lane roadway section where constant speed could be assumed, (2) no entrance or exit ramps within the study section and (3) each lane instrumented with vehicle detectors at prescribed distances. Attempts were made to instrument the southbound lanes of Interstate Highway 45 on the Pierce Elevated section near the central business district of Houston by placing magnetometer sensors directly underneath each freeway lane. Tests conducted on a trial installation at this site indicated that adequate vehicle detection was not possible with the magnetometers. Also, saw cuts into the bridge decking for loop detector installation were not allowed. Therefore, a search for a study site where loop detectors could be installed was undertaken.

A section of Interstate Highway 610 North in Houston satisfied the site requirements, and because the section was under construction at the time, loop detectors could be installed without extensive barricading and traffic disruptions. The site chosen is located on the westbound lanes of Loop 610 North between Jensen and Hardy Streets (See Figure 2). As shown in Figure 3, the test site is longer than 1500 feet with four 12-foot lanes and emergency parking allowed on both the median and curb lane shoulders. Three loop detector stations were installed; the first two stations were separated by 500 feet and the third station was 1000 feet downstream from the middle station. Effectively, this created freeway sections of 500, 1000 and 1500 feet in length. Each station is composed of three 6-foot square loops

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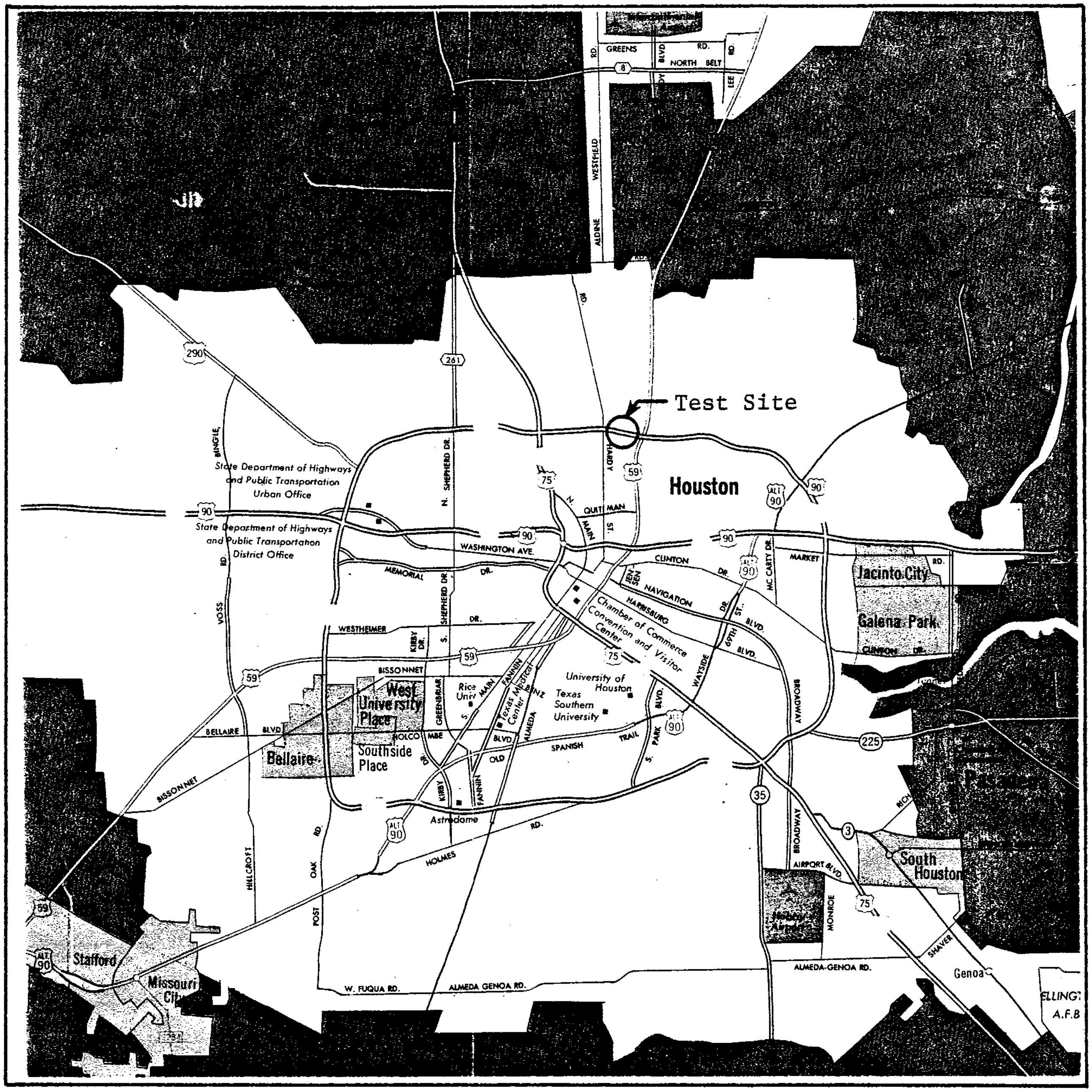

FIGURE 2. LOCATION OF THE FREEWAY TEST SITE

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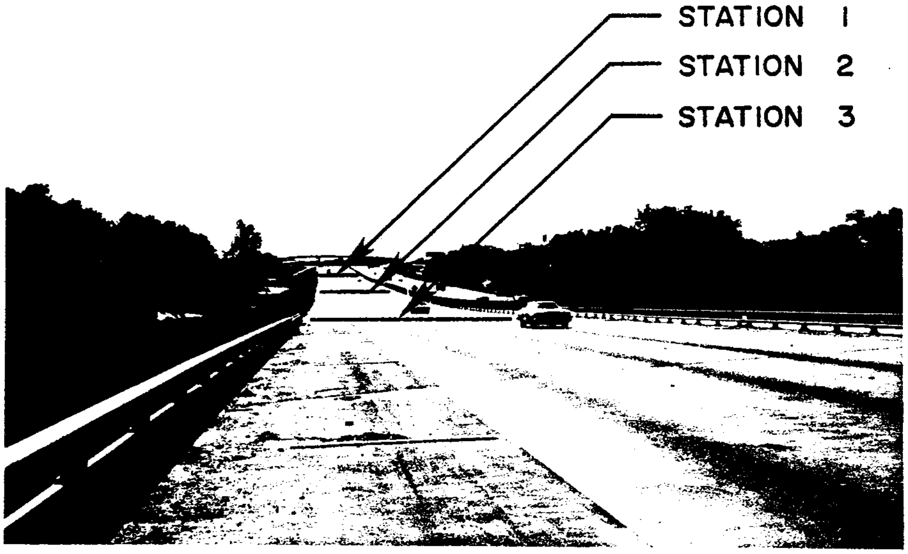
View Downstream From Station 1



View Upstream From Station 3

FIGURE 3. FREEWAY TEST SITE

in each lane with the leading edges of the loops 18 feet apart (See Figure 4). The third set of detectors at each station served as back-ups for the first two sets. As shown, the saw cuts were staggered so that the innermost loop wire could travel in a straight line to the curb lane shoulder without crossing adjacent lead-in wires. Saw cuts were centered in each lane and 24-gauge solid copper wire was used to provide the sensing coils for the loop detector amplifiers. All saw cuts and lead-in channels were packed and sealed with epoxy-type sealants. The layout of the three freeway test sections along with the detector numbering scheme are illustrated in Figure 5.

The detector amplifiers and the terminals for each of the 12 loop detector's lead-in wires were housed in pole-mounted weather proof controller cabinets installed adjacent to each of the three stations. One of the cabinets is shown in Figure 6. AC power for amplifier operations was provided by buried power lines from a source near the middle detection station. All detector outputs were brought to one location over a vinyl covered cable, composed of 15 twisted pairs of 24-gauge wire, buried along with the power line. Each amplifier had an output relay with normally-open contacts. One pair of wires was assigned to each relay. All 36 assigned wire pairs were installed in a large central cabinet on screw-down terminals (See Figure 7). Detector contacts were wired in a similar manner, and a variable voltage DC power supply provided positive DC voltage to the appropriate terminal in the central cabinet.

Initial plans were for all 36 detector indications to be transmitted over conditioned telephone circuits using a time division multiplexing device that was designed and implemented by a telecommunications representa-

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FIGURE 4. LOOP DETECTOR STATION

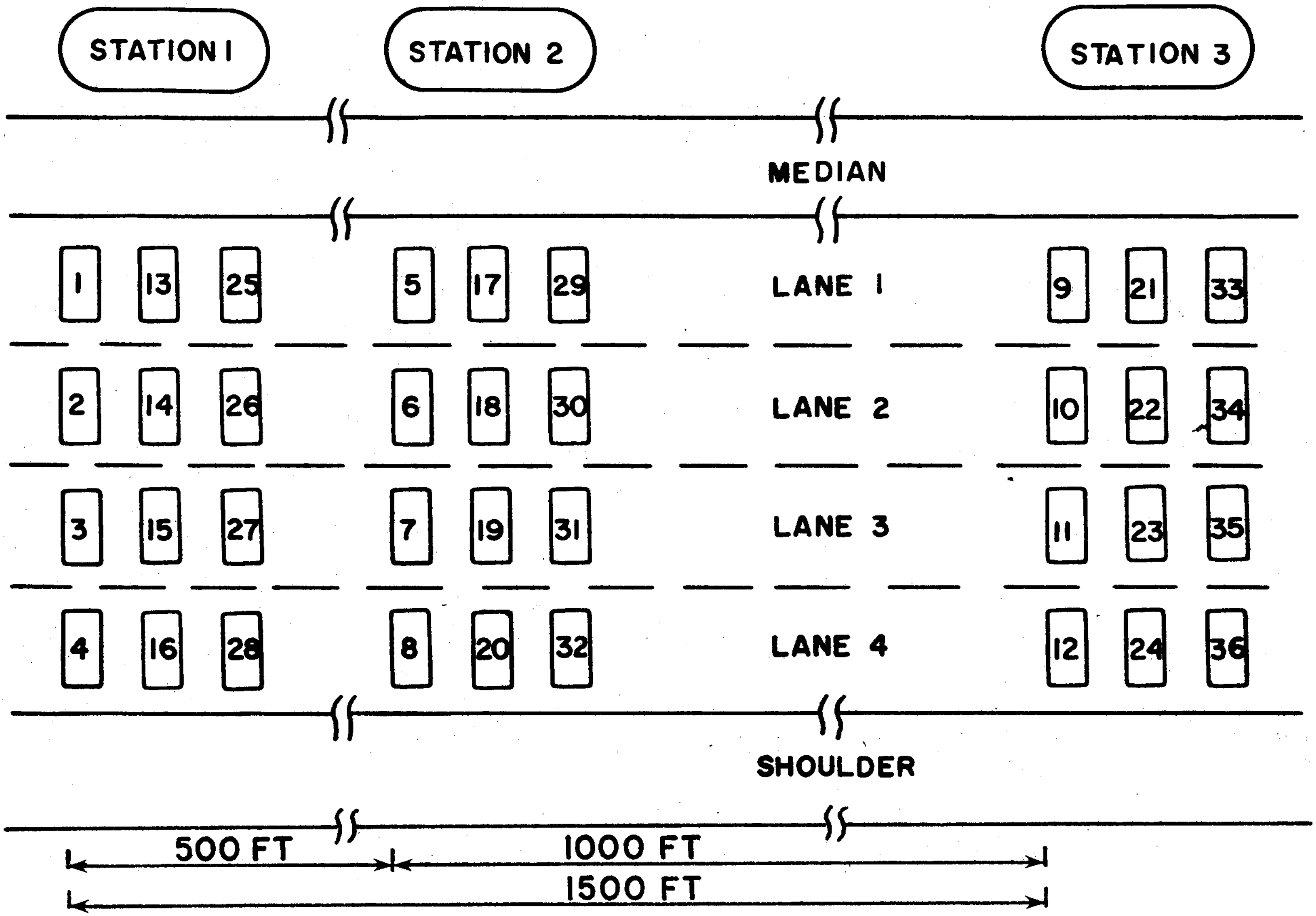

FIGURE 5. DETECTOR NUMBERING SCHEME AND LAYOUT OF THE THREE FREEWAY TEST SECTIONS

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FIGURE 6. CONTROLLER CABINET

FIGURE 7. CENTRAL CABINET

tive. The receiving point was to be the Gulf Freeway Surveillance and Control Center in Houston. An IBM 1800 digital computer was available for receiving the detector indications and developing the low volume incident detection algorithm. However, after long delays and months of problems with the telecommunications equipment, the control center was closed and the computer was transferred to Austin. As a result, alternate plans were developed for the collection of the detector indications.

Instrumented Vehicle

As the low volume incident detection site had already been instrumented with loop detectors connected by buried cable to the central cabinet, it was decided to collect data with some type of recording device. The TTI instrumented vehicle (I.V.) shown in Figure 8 was selected for this task. It is equipped with the following equipment: (1) a Data General Nova Minicomputer containing 4096 bytes (16 bits to the byte) of core memory, a programmable timer unit and an input/output (I/O) unit, (2) a paper tape read/punch unit and (3) an operator's console (See Figure 8).

The instrumented vehicle's primary function is to record the vehicle's operational characteristics while moving in a traffic stream. An on-board DC to AC power convertor supplied power to the Nova Minicomputer. Since the vehicle had to remain stationary to collect data at the low volume incident detection study site, AC power for the minicomputer was provided from the central cabinet. This allowed lengthy data collection periods to be conducted without running the vehicle's motor to power the minicomputer. In addition, the vehicle protected recording equipment and sheltered operating personnel.

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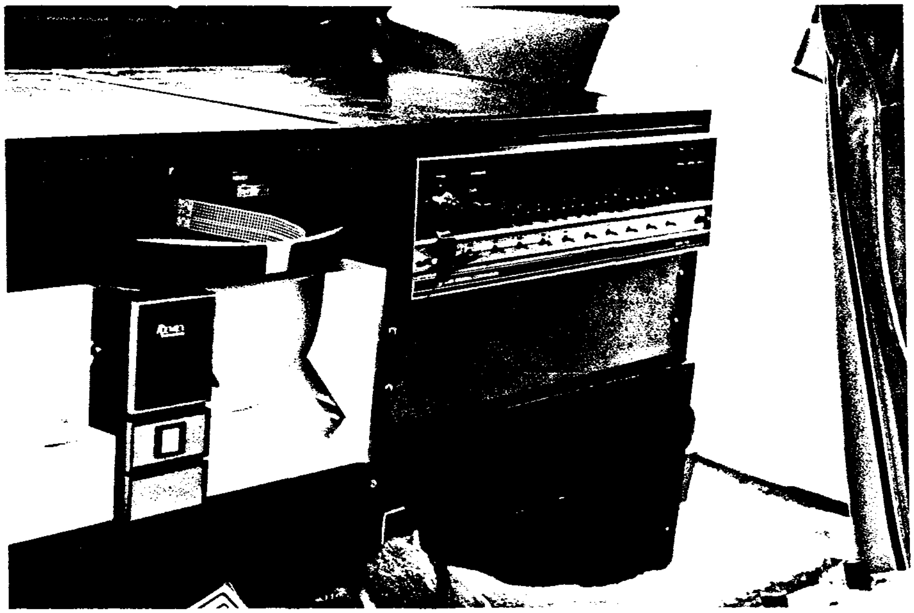
Instrumented Vehicle and Central Cabinet



Operator's Console

FIGURE 8. TTI INSTRUMENTED VEHICLE

A data collection program was prepared at Texas A&M University's Data Processing Center and punched in program object form on paper tape. The I.V. was driven to the study site and the data collection program was loaded via the paper tape unit into the Nova Minicomputer. In addition, several optional programs were available and could be activated by using the operator's console. Before the detector information could be received, processed and stored on a paper tape, a special interface device had to be designed and built. The general description and purpose of this device is discussed in the following section.

Interface Device

The Nova Minicomputer input/output unit has the capacity to transfer 16 bits of information into or out of the minicomputer during the execution of one instruction. As there are 36 loop detector actuations to be continuously monitored, a scanning method that enabled all actuations to be recorded with 10 millisecond accuracy was devised. This required a special solid state interface device (SID) to be designed and constructed by the TTI instrumentation group. The SID has provisions for up to 48 detectors, three groups of 16 detectors each. Monitoring was accomplished by addressing one of the three groups using the output side of the minicomputer's I/O unit (which is connected to the SID) and having the SID transfer the selected 16-bit group into the input side of the I/O unit. The entire selection/read process took only a few milliseconds. The lead detectors at all three stations were assigned to the first group, middle detectors to the second group and lag detectors to the third group. Only 12 bits in each group were assigned to monitor detector actuations. The remaining 4 bits were used to record special events from a push-button switch.

In addition to providing the capacity for more than 16 detector units, the SID served as an isolation point between the electrical voltages and operations of the detector amplifiers and the minicomputer's I/O unit. Within the SID on the amplifier contact side, the optical isolation components operated in a range from 9 to 20 volts DC. The power source for the input side was the variable voltage supply in the central cabinet, the same power source that provided field voltages. A multiconductor cable was used to connect the amplifier contact terminals in the central cabinet to the input terminals in the SID. The output side of the SID was compatible with and supplied by the 5 volt DC logic levels of the Nova Minicomputer. By using mated connectors, an umbilical cable attached the SID to the minicomputer. During the initial testing phase, several of the solid state components within the SID failed. After repair, no other operating failures occurred.

Data Acquisition Program

The data acquisition program initiated a scan of each traffic detector's status every centisecond. The first input group was addressed and then read in from the special interface device. This routine was repeated twice more in order that all three groups of traffic data were recorded. The status of each bit in a group was compared with the status of that bit in the last scanning period. A bit that changed from a "0" status to a "1" status was said to be "just on". A bit that changed from a "1" status to a "0" status was said to be "just off". One computer word (16 bits) was formed and retained each time a detector bit changed status (See Appendix).

In forming stored information, a maximum of 512 centiseconds could be accommodated. Therefore, a dummy event was processed at 512 centisecond intervals. A detector status change stored the quantity of elapsed time since the end of the last interval. In this manner, continuous time could be reconstructed with the aid of the conversion program.

Each vehicle which traversed the entire study section passed over a minimum of nine detectors and caused 18 events to be recorded. Whenever the storage area was full, the program began a transfer of the stored data to the paper tape punch unit. During the punching operation, the data aquisition program continued to function. All incoming data (and time marks) were retained in a special save area. At the conclusion of the punching operation, all current data stored in the special save area were moved to the general storage area and normal operations continued.

The traffic study data, stored on paper tape, were then used as input information for a conversion program. The computer facilities of the Data Processing Center at Texas A&M University, were used to reshape each event recorded on paper tape into two items of information. First, the time intervals were added together so that a continuous time variable was available. And second, the detection station, detector number and activation status were combined. A detector being "just" activated was stored as a negative value; one "just" deactivated was stored as a positive value. The two data items were stored on 9-track magnetic tape. Once the data were on magnetic tape in the form of stored event times and detector number, any number of different programs could use the information. No matter at what point in the data string a program might start, the detectors would always perform in an identical manner.

"LVID" PROGRAM

Software Problems

Vehicle Speeds. Individual vehicle speeds were calculated values. Initial testing indicated that in order to calculate reasonably accurate speeds, the actual distance between some detectors should be changed to an effective distance. Therefore the speeds were computed by dividing an effective distance by the travel time between the lead and lag detectors. A loop tuning program which adjusted the effective distance between detectors was run during free flow traffic conditions. The effective distances were changed so that the calculated speeds would fall within the known free flow traffic speed. The actual effective distances used in this study ranged from 16 to 21 feet.

Tractor-Trailers. Table 1 illustrates the recorded actuations of several tractor-trailer trucks. Note that occupancies ranged from 6 to 98 centiseconds. In many instances, large trucks such as the ones shown in Figure 9 resulted in double actuations by one or more detectors. The circled data in Table 1 indicate those tractor-trailer trucks which registered double actuations. Although both occupancies were within the range of acceptable data, the second headway was usually much less than normal. Based on this information, software was developed to distinguish between a double actuation caused by a large truck and two actuations caused by vehicles following closely behind one another.

In 108 recorded double actuations, the maximum headway at any detector between the first and second actuations was 0.72 seconds. Therefore, 0.75 seconds was selected as the maximum headway between the double actuations

TABLE 1. OCCUPANCY AND HEADWAY CHARACTERISTICS OF TRACTOR-TRAILER TRUCKS

Data File Number	Station 1					Station 2						Station 3				
	Occupancy			Headway		Lane No.	Occupancy			Headway		Occupancy			Headway	
	Ld	M	Lg	Ld-M	M-Lg		Ld	M	Lg	Ld-M	M-Lg	Ld	M	Lg	Ld-M	M-Lg
5	78	74	75	25	21	3	76	69	77	26	19	77	80	77	21	27
5	48	50	48	17	20	1		51	51	00	19	51	45	22/9	25	18/37
5	62	68	64	17	22	2	65	27/10	68	22/49	17	63	68	24/8	23	19/52
5	68	63	66	25	19	3	65	28/11	66	25/48	18	69	72	65	20	27
5	56	62	59	20	24	2	61	29/11	65	26/43	19	57	61	26/9	20	29/43
5	57	63	60	17	21	2	59	20/13	62	22/39	18	58	36	21/14	19	23/40
5	79	86	82	19	24	2	83	74	86	24	17	79	84	75	20	25
5	61	67	63	19	23	2	67	59	69	23	18	65	69	61	20	25
5	64	61	62	21	17	3	63	55	63	23	15	63	66	59	12	23
5	92	96	94	22	25	2	95	88	98	26	20	93	96	89	23	26
5	64	69	66	19	24	2	65	57	68	24	19	68	74	63	20	29
6	71	68	69	24	20	3	70	35/12	70	26/50	18	70	74	65	19	27
6	44	51	55	20	20	4	53	52	55	23	20	51	54	54	21	22
6	79	82	86	79	21	4	84	83	85	22	19	82	85	86	20	20
6	66	68	74	19	17	4	75	75	77	20	18	71	78	79	19	20
6	73	68	70	24	20	3	70	63	72	26	18	74	77	72	21	27
6	75	73	72	25	22	3	76	28/12	73	28/55	20	79	81	72	22	27
6	20/8	44	40	19	23	2	42	14/6	44	24/29	18	16/7	41	12	20	15
6	82	78	79	27	21	3	81	71	79	29	18	80	83	74	21	28
6	69	65	67	24	20	3	70	30/10	70	27/52	19	73	76	36/14	22	29/54
6	50	53	18/58	20	7/27	4	56	54	57	21	20	55	56	57	21	20
6	66	71	67	18	23	2	67	62	70	22	18	66	70	63	19	24

Note: Occupancy and headway values are given in centiseconds.

(20/8) = 2.5 - First Occupancy/Second Occupancy = Occupancy Ratio.

Ld - Lead detector.

M - Middle detector.

Lg - Lag detector.

metal plate

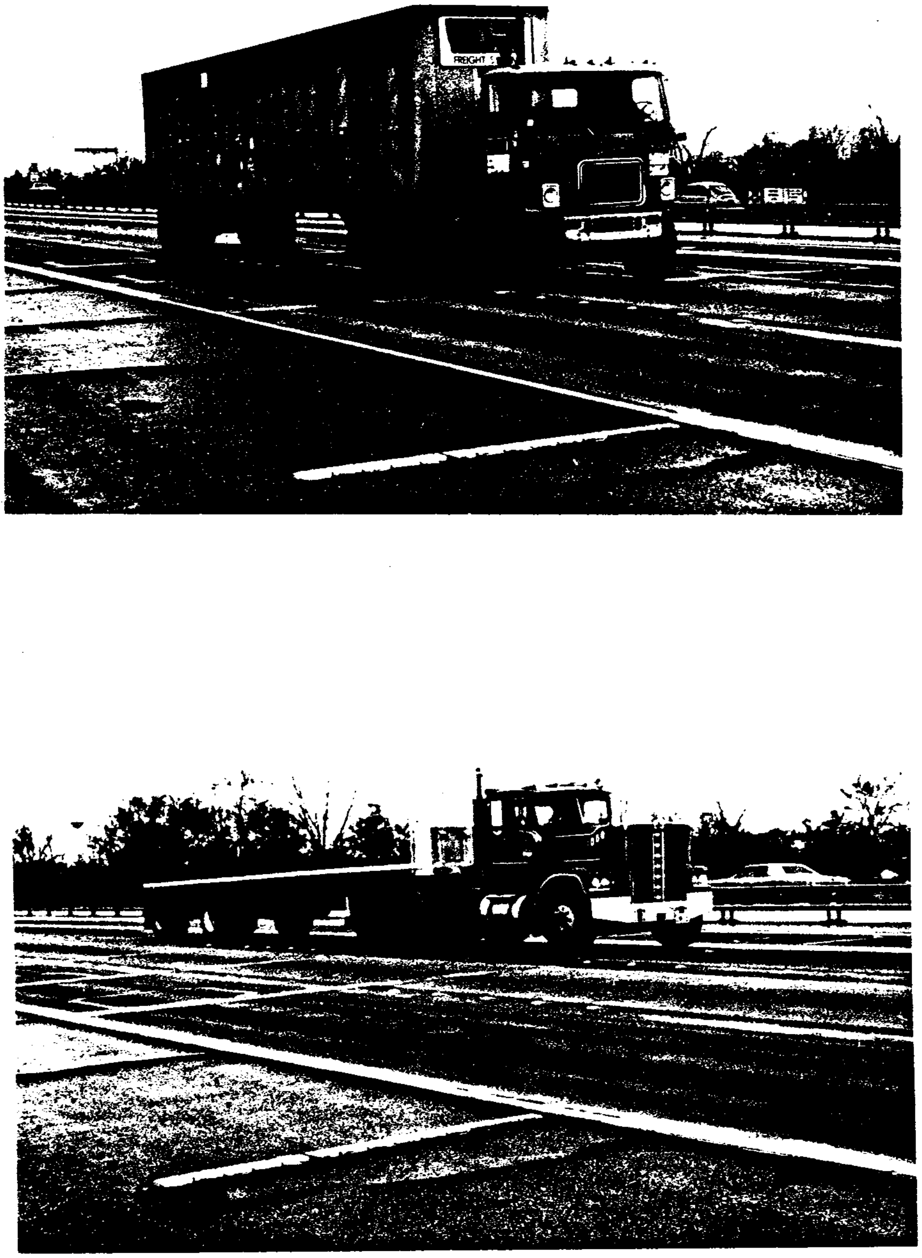


FIGURE 9. TRACTOR-TRAILER TRUCKS AT STATION 2

caused by a large tractor-trailer truck. Whenever headways less than this value were recorded, an occupancy ratio (ratio between the first and second occupancies) was calculated. In the data set, this ratio was either ≤ 0.5 or ≥ 2.0 approximately 92 percent of the time. For decision making purposes, headways less than 0.75 seconds and an occupancy ratio ≤ 0.5 or ≥ 2.0 indicated a large truck (one vehicle). Headways less than 0.75 seconds and an occupancy ratio ≥ 0.5 and ≤ 2.0 indicated two vehicles.

Lane Changing. Another factor which affected the accuracy of input or output vehicle counts was a lane change or straddle in the vicinity of the detectors. Resultant characteristics of these activities are illustrated in Table 2. Note the wide disparity in occupancy patterns. Several of the occupancy and headway values are similar to those that would be recorded as the two vehicles shown in Figure 10 pass over the detectors. However, one distinguishing characteristic of all lane changes or straddles was a small adjacent lane headway (ALH) value. In 39 different situations, the maximum ALH that a single vehicle could generate was < 0.10 seconds 95 percent of the time. Based on these observations, an ALH < 0.10 seconds was selected as the identifying feature of a potential lane change or straddle situation. As no reliable pattern was found to differentiate between one or two vehicles, the following operational guidelines were developed. If an ALH < 0.10 seconds was recorded at the input station, one vehicle was projected. If and ALH < 0.10 seconds was recorded at the output station, two vehicles were counted.

Motorcycles. Although detector occupancy values less than ten centiseconds are generally suspect, motorcycles such as the one shown in Figure 11 may produce such values. Some detectors will not detect motorcycles.

TABLE 2. OCCUPANCY AND HEADWAY CHARACTERISTICS OF LANE CHANGES AND LANE STRADDLES

Data File Number	Station 1						Lane No.	Station 2						Station 3					
	Occupancy			ALH				Occupancy			ALH			Occupancy			ALH		
	Ld	M	Lg	Ld	M	Lg		Ld	M	Lg	Ld	M	Lg	Ld	M	Lg	Ld	M	Lg
6	24	27	25				2	15	8	13	10	-	-						
							1	2	13	88	-	1	1	31	25	24			
6	14	17	15				2	11	5	10	-	-	-						
							3	-	-		4	-	3	15	16	12			
6	19	23	22				2	13	27	12	-	-	-						
							3	13	-	14	0	-	1	25	26	21			
6	-	34	32				4	15	12	15	-	-	-						
							3	25	18	29	4	2	5	37	40	34			
6	24	34	24				2	12	-	7	-	-	2						
							3	17	11	19	3	-	-	28	3	25			
5	19	13	15	6	-	-	3	16	-	17	-	-	-	20	20	11	-	2	-
	8	15	19	-	1	1	4	21	21	25	3	-	5	15	16	28	2	-	9
5							2	12	-	15	-	-	-	10	18	-	-	1	-
	20	18	21				3	19	7	18	3	-	2	16	18	8	3	-	-
5	14	16	16	-	-	-	1	1	19	19	-	6	-	24	11	14	-	-	-
	14	20	16	-	2	-	2	16	7	18	1	-	0	-	15	-	-	2	-
5	18	10	12	4	-	-	3	17	6	18	-	-	-	17	18	5	-	0	-
	10	16	21	-	3	5	4	19	19	22	1	8	3	19	19	-	2	-	-
5	9	14	8	-	-	-	2	15	-	15	-	-	1	12	17	-	-	-	-
	18	16	19	5	0	6	3	18	-	18	-	-	-	14	17	4	1	1	-

Note: Occupancy and Adjacent Lane Headway(ALH) values are given in centiseconds.

metal plate

FIGURE 10. TWO CARS SIDE-BY-SIDE AT STATION 2

FIGURE 11. MOTORCYCLE AND SMALL CAR AT STATION 2

Occupancy and headway characteristics of several cars and motorcycles are illustrated in Table 3. These observations indicated that a general identifying feature of a motorcycle was at least one occupancy < 0.10 seconds. As several detectors missed some of the motorcycles, it was decided to neither project nor count any vehicle which had an occupancy value < 0.10 seconds.

General Logic

The Low Volume Incident Detection (LVID) Program is composed of a mainline routine and 20 subroutines. Due to the fact that this program is a research tool, many variations of the program have been attempted in all phases or levels. It was written in American Standard Fortran Level H and required 512K bytes of computer memory for compilation. The various phases or levels that constitute the LVID program will be discussed in a general sense in the following subsections. For the sake of clarity and delineation, program operations have been separated into distinct levels of operations based on time requirements and the priority of required service. Those subprogram variables which require exact timing measurements must be responded to immediately while other less demanding program parts can be serviced on a time sharing basis. As the LVID program should have operated in real time, but could not because of the manner in which the traffic data had to be collected, it became necessary to create a "Master Scheduler" program to provide an ever increasing time base for the LVID program. This timing element was used to establish every servicing point-in-time required by the logic in the program. Therefore, this establishment of a "do something when time equals to" approach provided a means in which the overall program could be described (See Table 4).

TABLE 3. OCCUPANCY AND HEADWAY CHARACTERISTICS OF NORMAL SIZED CARS AND MOTORCYCLES

Data File Number	Station 1					Lane No.	Station 2					Station 3				
	Occupancy			Headway			Occupancy			Headway		Occupancy			Headway	
	Ld	M	Lg	Ld-M	M-Lg		Ld	M	Lg	Ld-M	M-Lg	Ld	M	Lg	Ld-M	M-Lg
Cars																
5	29	26	28	21	18	3	28	22	28	23	16	27	30	24	18	25
5	21	23	23	15	17	1	-	24	23	-	17	24	19	19	22	16
5	22	26	24	17	21	2	25	19	28	22	16	23	26	19	18	22
5	29	26	27	21	18	3	26	22	28	21	16	27	29	24	17	22
5	23	28	30	18	17	4	32	39	34	22	19	31	33	43	21	15
5	19	28	20	14	18	2	22	18	24	18	14	21	30	17	16	18
6	25	29	31	20	21	4	30	39	33	22	20	32	33	34	23	22
6	21	25	22	19	24	2	24	19	27	24	19	21	24	18	21	24
6	33	32	31	22	23	3	29	22	28	26	18	32	32	33	22	21
6	24	36	26	18	21	2	28	23	31	23	18	25	31	22	19	22
6	31	30	28	22	24	3	29	23	29	26	19	30	32	26	21	26
6	24	27	28	17	18	1	-	27	106	-	17	29	22	23	24	17
M.C.																
5	7	3	6	24	19	3	7	-	6	44		6	9	-	19	-
5	3	9	12	19	22	4	12	12	13	24	23	11	14	22	24	21
5	14	10	13	26	23	3	12	4	10	29	21	12	15	8	24	31
5	8	10	10	17	18	1	-	5	6	-	18	9	3	3	21	18
5	4	9	6	17	23	2	7	-	8	41		6	8	-	20	-
5	3	7	4	18	23	2	7	1	9	25	16	5	2	7	26	30
5	15	12	14	27	25	3	15	6	15	30	21	6	7	-	18	-
5	4	8	6	19	24	2	10	5	13	25	19	4	7	-	21	-
5	5	9	6	15	20	2	7	4	10	20	15	7	9	3	18	22
6	-	-	-	-	-	4	7	7	10	18	18	7	8	8	16	16
6	-	-	4	-	-	2	-	-	-	-	-	8	8	8	18	18
6	1	5	2	12	17	2	3	-	5	-	-	-	4	-	-	-
6	7	9	7	21	25	2	8	-	8	-	-	-	9	-	-	-

Note: Occupancy and headway values are given in centiseconds.

TABLE 4. LOW VOLUME INCIDENT DETECTION DISTRIBUTED PROGRAM LOGIC

Highest Priority	Level 1 - Service Detector Functions
	Level 2 - Determine Vehicle Status
	Level 3 - Process Time Band Boundaries
	Level 4 - Determine Volume Closures
	Level 5 - Provide Incident Status Report
Lowest Priority	Error Analysis Procedures

Level 1 - Service Detector Functions. The general theme of the program was a continuous comparison of an ever increasing program time value against an event time value in the traffic data file stored on magnetic tape. If the program time value was less than the next event time, the program entered the Level 2 section of the program logic. Whenever the program time was equal to or greater than the event time, the associated detector number was checked for activation or deactivation and location. The location was determined as to the input or output station, lane designation and lead or lag detector. The lead detector was considered to be the first detector activated by the vehicle while the lag detector was considered to be the next detector activated by the vehicle at the same station.

The essential processes performed for a lead detector activation were as follows: (1) record the lead "just on" time; (2) perform adjacent lane headway checks; (3) determine if this is multiple actuation within an elapsed time period; and (4) establish a maximum elapsed time in which multiple actuations are to occur. A lag detector being activated performs the same logic as administered to the lead detector. In addition, the time difference between lead "just on" and lag "just on" was recorded as the travel time, TT. This travel time over a known distance (assumed to be the effective distance from the leading edge of the lead loop to the leading edge of the lag loop) was used (if at the input station and not a multiple actuation situation) to derive a projected arrival time, PAT, using the equation on the following page:

$$PAT = TT \left(\frac{SD}{TD}\right)$$

where: PAT = Projectd arrival time, sec.

TT = Travel time, sec.

SD = Length of study section, ft.

TD = Length of trap, ft.

The projected arrival time was retained by lane for Level 2 processing because at this point in the vehicle's movement across the station, the determination of whether it is 0, 1 or 2 vehicles has not been verified. A lag detection at the output station did not perform the projection function as it was not needed.

A detector becoming deactivated causes the time "just off" to be recorded. By subtracting the "just on" and "just off" times, the vehicle's occupancy was known. All occupancies less than a predetermined value were disregarded. Single and double occupancies were retained from each lead and lag detector by lane for further processing at Level 2.

Level 2 - Determine Vehicle Status. Entry into the second level of the program logic was determined by the elapsed times established in Level 1. Two separate timing functions were processed based on the lengths of these elapsed times. The more critical segment in the determination of a possible lane straddle or lane change was the first part; the other process enabled the placement of vehicles into input and output classes. Elapsed times varied and were established by the physical size and separation distance of the detectors and the sensitivity and susceptibility of the detectors to multiple actuations.

A critical judgement was made when determining if a lane change or lane straddle was occurring or if two vehicles were actually passing over the detection station. The logic performed in Level 2 determined if adjacent lane actuations, either on the lead or lag detectors, had occurred within a known time period. If side-by-side actuations were evident, this fact was recorded and elapsed time values were set. If any of the affected detectors were not deactivated before this set time expired, the final determination of the vehicle's status was held until the final stage of Level 2 processing. When an affected detector did deactivate, this small occupancy time was recorded as being meaningless and all traces of the adjacent lane headway check were erased. This logic applied both to the input and output station logic.

The second part of the elapsed times was concerned with the processing of the occupancy data. To ensure that sufficient time had expired for all possible multiple actuations to occur for this vehicle, Level 2 program logic set time limits at the start of each detector actuation. Therefore, when the elapsed time had expired, all information about the last vehicle that passed over the lead and lag detector in each lane had been processed. The elapsed time at the lead detector caused the lead data to be stored for processing when the lag detector timed out. Multiple actuations on either detector are discussed in the Error Analysis section.

At the expiration of each lag detector's elapsed time, condition tests were executed to determine the validity of a vehicle's passage. The tests were based on the activity in adjacent lanes as well as multiple actuations in the same lane. Adjacent lane headways at the input station would project only one vehicle whereas the output station, using slightly different logic, would count two vehicles. Multiple actuations in the same lane cause the occupancies to be compared against ratio limits. The limits determined if a tractor-trailer combination was responsible for the multiple actuation or if two vehicles were passing with a very small (in time) headway between them. The results of the conditional tests were used to set an indicator for the Level 3 logic.

Level 3 - Process Time Band Boundaries. Entry into this level of the program logic was gained by one of three methods. The first method was governed by the indicator status that was set in Level 2. An indication at the input station enabled the projection of a vehicle based on the travel time calculated in Level 1. Due to possible inaccuracies in detection measurements and speed changes over the study section distance, a time interval was created around the projection time. These upper and lower time values were compared against the last vehicle's projection boundaries. If an overlap was found, new upper and lower boundary limits were established and two vehicles were included in the projected time band. If no overlap was found, the vehicle was placed into a separate (later in time) time band. Also included in this program section was logic that enabled the combining of time bands if overlap between them was found.

The indicators at the output station did not require projection limit checks and were used simply to register the existing volume. Therefore, each time band contained an upper and lower time value. When the program time value reached the upper boundary time, all projected vehicles in the time band should have been detected (and recorded) at the output station. In case some vehicles decreased speed within the study section and to be sure that each band had a minimum time separation, a small amount of extra time was added to the upper boundary. This revised time was called the stop time. At the point where the program time value reached the stop time, final input and output volumes were recorded for processing in Level 4.

The other two methods of entry into Level 3 logic concerned the relationship of the program time value to values of the primary upper boundary limit and the stop time. Since the indicators from Level 2 signaled the establishment of the time bands and their limits, it would be some time before the program time equaled the upper boundary. Therefore, the logic concerning the ending of the upper boundary and establishing of the stop time was to be entered when the program time reached both.

Level 4 - Determine Volume Closures. As soon as the stop time was reached, all input and output volume data were recorded. This level determined if the input and output volumes matched. If more vehicles were projected than exited, an incident was detected. The reverse situation meant an error had occurred and will be discussed in the Error Analysis section. Equal volumes indicated a balanced system.

Level 5 - Provide Incident Status Report. As the purpose of the program's logic was to detect an incident with a certain degree of confidence, the logic in Level 5 was assigned the critical task of coordinating the results of the time band clearances and volume comparisons. It was through this logic that successive volume closures and results of Error Analyses were combined to yield the definitive stages of the incident status. For example, successive time bands might indicate an incident (undercount at the output station) in the first time band and an overcount at the output station in the second time band. Level 5 logic was used to coordinate these closures and provide cautionary exhibits to the controller. Additionally, any of a host of detector errors could cause an incident to be detected, except that the conditional Error Analysis logic was used to modify the results.

Error Analysis Procedures. The analysis of errors was executed at the point-in-time at which they occurred. Basically, there were two types of errors: 1) errors that were the result of detector activations/deactivations and time limit comparisons and 2) errors that were generated when comparing occupancy results of lead/lag detector pairs. Whenever an adjacent lane headway was found to be within the minimum time expectancy, the pairs of affected detectors and the program time were recorded in the appropriate time band. Headways in the same lane (using logic similar to that logic in the adjacent lane test) that violated minimum time expectancies gave rise to multiple actuation errors and were recorded as to lane, detector, and program time. Also, detectors that were still activated (because of a malfunctioning detector or a very slow vehicle) past the elapsed time standards were recorded.

Multiple actuations in the same lane provided occupancy ratios that produced errors when compared to ratio limits. Other occupancy patterns, such as the lead detector occupancy showing less than a minimum value with a normal lag occupacy generated error codes. All error analysis results were used by the Level 5 program logic so that contingency statements would be available for time band and volume closures.

FIELD STUDY

Outline

One of the objectives of this research was to evaluate the performance of the incident detection algorithm. Ideally, a wide range of low volume traffic conditions would be tested for detector spacings of 500, 1000 and 1500 feet. As shown in Figure 12, volumes at the test site ranged from an average of 100 vehicles per hour at 2:00 a.m. to an average of 2400 vehicles per hour at 3:00 p.m. Traffic data were collected on six days during February through May of 1977. In order to provide the maximum range of conditions, at least one data collection session was conducted during each of the four time periods - morning, afternoon, evening and night. Unfortunately, hardware malfunctions rendered the evening data useless.

Three people were needed to collect the traffic data for this study. In addition to supervising the conduct of each session, the study coordinator recorded significant traffic events and monitored the weather conditions. The primary responsibility of the instrumented vehicle operator was the calibration and operation of the data collection equipment (loop detectors, amplifiers and minicomputer). He was also responsible for two-way radio communication with the test car driver. The test driver staged mock traffic incidents in the three freeway test sections, entered but did not pass through.

Incidents

The incident detection algorithm was designed to detect those vehicles which entered but for some reason did not pass through the study section.

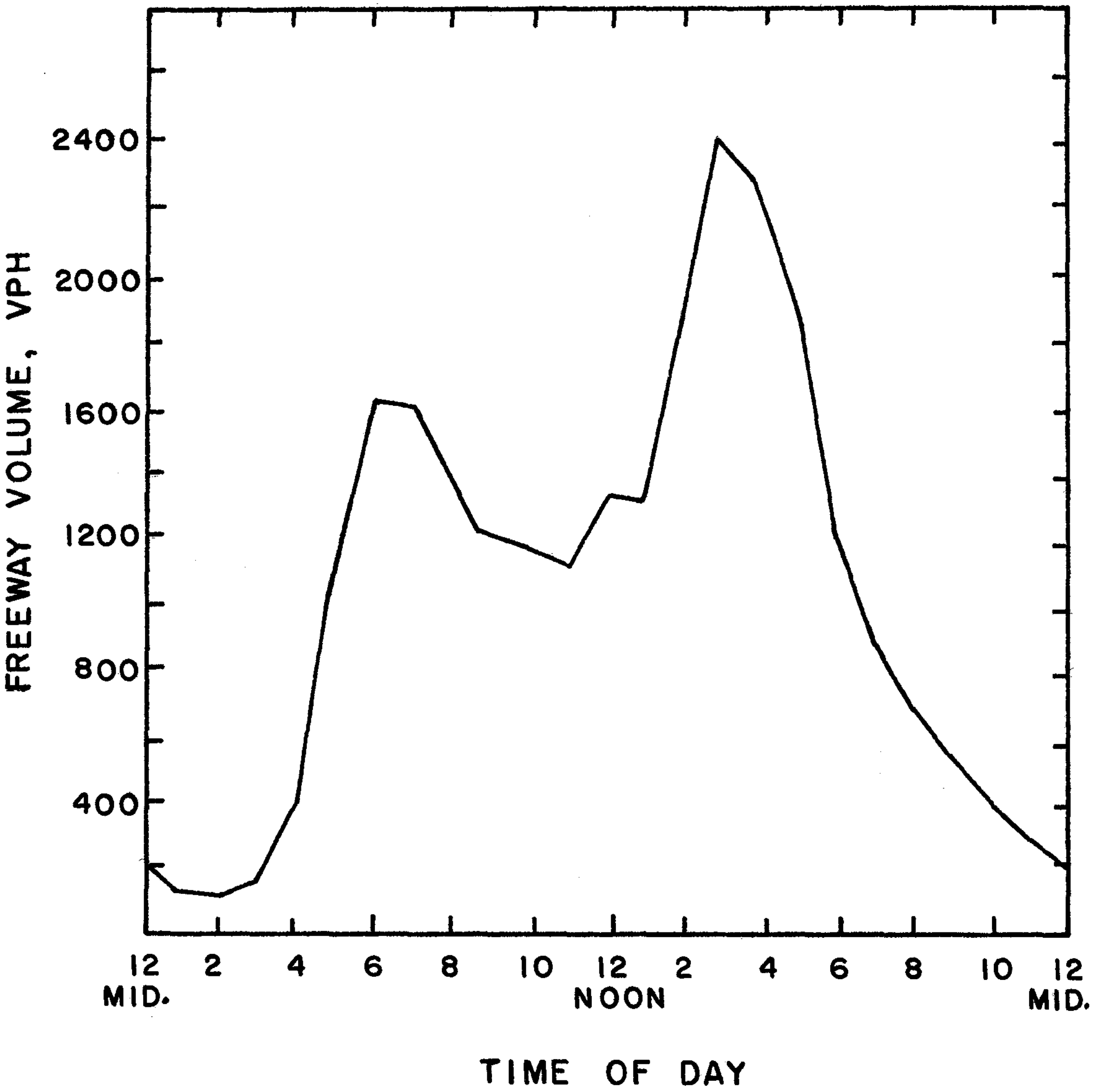


FIGURE 12. AVERAGE HOURLY VOLUMES AT THE FREEWAY TEST SITE DURING THE SPRING OF 1977

As incidents are infrequent events on short sections of freeway, it was possible that none would occur while data were being collected. To ensure that incidents would occur, a method of creating them was developed - test vehicles would enter the study section and then stop before they reached the output station. Using this method, thirty-five incidents were staged during the twenty-one hours that data were collected.

In order to create incidents, it was first necessary to know some of their characteristics. Running out of gas (14.8%), flat tires (23.6%), mechanical difficulty (34.0%), accidents (5.7%) or other problems (21.9%) are the major reasons motorists stop on a freeway (6). The algorithm cannot distinguish between types of incidents. However, the length of time a motorist was stopped might have an impact on the algorithm's performance. The distribution of stopped times for all incidents on a freeway in Houston was known (6). The stopped time for each incident that was staged was randomly assigned based on this known distribution. Table 5 presents the distribution of stopped times for both the actual and the staged incidents.

In staging the mock incidents, stringent safety precautions were taken. To avoid conflict with moving vehicles, the test driver always stopped on the outside shoulder of the freeway as far away from the traffic stream as possible. Whenever the vehicle was stopped as shown in Figure 13, its emergency flashers were on at all times. To avoid having to change lanes in order to stop, the test vehicle was always in the outside lane of the freeway prior to the study section. Instructions concerning the location and duration of each mock incident were received on a two-way radio. If necessary, the test driver could abort the incident at any time.

TABLE 5. DISTRIBUTION OF STOPPED TIMES FOR ACTUAL AND STAGED INCIDENTS

	Actual Incidents (6)			Staged Incidents		
Stopped Time (Min.)	Frequency	Percent	Cumulative Percent	Frequency	Percent	Cumulative Percent
< 1	102	25.1	25.1	8	22.9	22.9
1-2	55	13.5	38.6	5	14.2	37.1
2-3	31	7.6	46.2	2	5.7	42.9
3-4	19	4.7	50.9	0	0.0	42.9
4-5	14	3.4	54.3	0	0.0	42.9
5-6	20	4.9	59.2	2	5.7	48.6
6-7	8	2.0	61.2	2	5.7	54.3
8-14	51	12.5	73.7	7	20.0	74.3
> 14	107	26.3	100.0	9	25.7	100.0

TABLE 6. SUMMARY OF THE STAGED TRAFFIC EVENTS DURING THE STUDY

	Detector Spacing	File 1 2/26/77	File 2 2/28/77	File 3 3/1/77	File 4 3/1/77	File 5 5/14/77	File 6 5/15/77
Study Length (hrs.)		4.70	3.09	0.46	2.02	3.65	6.87
Number of Incidents Staged	500 ft. 1000 ft. 1500 ft.	5 5 10	6 7 13	- - 0	4 4 8	- - -	2 2 4
Number of Lane Changes Staged	500 ft. 1000 ft. 1500 ft.					9 3 8	
Number of Lane Straddles Staged	500 ft. 1000 ft. 1500 ft.					6 6 6	

metal plate

FIGURE 13. STOPPED LOCATION OF THE TEST VEHICLE DURING A MOCK INCIDENT

Results

Usable traffic data were collected on five days during the time period from February through May of 1977. Thirty-five mock traffic incidents were staged while data were being collected (See Table 6). The low volume incident detection algorithm developed during this research was used to analyze the data. The following section summarizes the results of this analysis for each day of the study.

File 1. Data were collected for approximately 3700 vehicles during a 4.70 hour period on a Saturday morning. In the 500-foot section, the algorithm detected two of the five incidents that were staged. In the 1000-foot section, it detected all five of the incidents that were staged, but in the 1500-foot section it detected only two of the ten incidents that were staged.

File 2. Data were collected for approximately 4300 vehicles during a 3.09 hour period on a Monday afternoon. In the 500-foot section, the algorithm detected three of the six incidents that were staged. In the 1000-foot section, it detected five of the seven incidents that were staged, but in the 1500-foot section, it detected only four of the thirteen incidents that were staged.

Files 3 and 4. Data were collected for approximately 2500 vehicles during a 2.48 hour period on a Tuesday morning. In the 500-foot section, the algorithm detected all four of the incidents that were staged. In the 1000-foot section, it detected only two of the four incidents that were staged, and in the 1500-foot section, it detected seven of the eight incidents that were staged.

File 5. Data were collected on approximately 3700 vehicles during a

3.65 hour period on a Saturday morning. No incidents were staged during this time period; however, the test driver did simulate several lane changes and lane straddles.

File 6. Data were collected on approximately 1500 vehicles during a 6.87 hour period early on a Sunday morning. In the 500-foot section, the algorithm detected both incidents that were staged. In the 1000-foot section, it also detected both incidents that were staged and in the 1500-foot section it detected all four incidents that were staged.

Summary. Data were collected for approximately 15,700 vehicles during a 20.79 hour time period. Results of the low volume incident detection algorithm's analysis of this data are presented in Table 7. In the 500-foot section, the algorithm detected 65 percent (11/17) of the incidents that were staged. In the 1000-foot section, it detected 78 percent (14/18) of the staged incidents and in the 1500-foot section, it detected 49 percent (17/35) of the staged incidents. An adjacent lane headway (< 0.10 sec.) in the same time band as the incident prevented the algorithm from detecting 27 of the 28 staged incidents that were not detected. The other incident was not detected because the test vehicle was driving on the shoulder prior to the input station. As far as the algorithm could determine, the test vehicle never entered the study section. Numerous lane changes and a bad detector at the first detection station caused the relatively poor performance of the algorithm in both the 500-foot section and the 1500-foot section.

To study the effects of volume on the ability of the algorithm to detect incidents, the data were divided into 2 groups (See Table 7). Volumes up to 400 vehicles per hour were assigned to the first group. The

TABLE 7. SUMMARY OF THE LOW VOLUME INCIDENT DETECTION ALGORITHM'S ANALYSIS OF THE TRAFFIC DATA

	Detector Spacing	100-1200 vph (Files 1-6)	100-400 vph (File 6)	800-1200 vph (Files 1-5)
Study Length (hrs.)		20.79	6.87	13.92
Study Volume (veh.)		15,700	1,500	14,200
Number of Incidents Staged	500 ft.	17	2	15
	1000 ft.	18	2	16
	1500 ft.	35	4	31
Number of Incidents Detected	500 ft.	11	2	9
	1000 ft.	14	2	12
	1500 ft.	17	4	13
Percent of Incidents Detected	500 ft.	65	100	60
	1000 ft.	78	100	75
	1500 ft.	49	100	42
Average Response Time (sec.)	500 ft.	11	21	9
	1000 ft.	23	25	22
	1500 ft.	36	31	39

number of incidents staged when data were collected during these volume levels was two in the 500-foot section, two in the 1000-foot section and four in the 1500-foot section. The algorithm detected all of the incidents. The average time of detection was 21 seconds in the 500-foot section, 25 seconds in the 1000-foot section and 31 seconds in the 1500-foot section. In the second group were volumes from 800 to 1200 vehicles per hour. The number of incidents staged when data were collected during these volume levels was 15 in the 500-foot section, 16 in the 1000-foot section and 31 in the 1500-foot section. The algorithm detected 9, 12 and 13 of the staged incidents in the 500-, 1000- and 1500-foot sections, respectively. The average time of detection was 9 seconds in the 500-foot section, 22 seconds in the 1000-foot section and 39 seconds in the 1500-foot section.

Conclusions

The results were not surprising. In fact, they were predictable. The principle reason incidents were not detected was because adjacent lane headways occurred in the same time band as the incident. Intuitively, the higher the volume, the more frequently small adjacent lane headways occur. It follows that the more frequently they occur, the greater the probability of their occurring in the same time band as an incident. This probability also increases as the number of time bands decrease. If a negative exponential distribution could be assumed for headways, the frequency of occurrence of small adjacent lane headways could be estimated by using the equation on the following page:

$$N\ (h > t) = Q \cdot e^{-qt}$$

where: N = Expected number of headways per hour greater than t.

Q = Average traffic volume veh./hr.

q = Average traffic volume, veh./sec.

t = Time between vehicle arrivals (headway), sec.

The expected number of occurrences for one small headway (0.10 seconds) is shown in Figure 14. Note that adjacent lane headways < 0.10 seconds theoretically occur 4, 18 and 39 times an hour at volume levels of 400, 800 and 1200 vehicles per hour, respectively.

The same equation could be used to estimate the average time required to detect an incident. Figure 15 illustrates the frequency of occurrence of a six second gap over a wide range of volumes. This gap corresponds to the headway required for no overlap of the projection windows at detector spacings of 1000 feet. This means that for this detector spacing an average of 205, 211 and 162 decisions per hour can be made at volume levels of 400, 800 and 1200 vehicles per hour, respectively. The average time to make a decision (detect an incident) at this detector spacing is <u>18</u>, <u>17</u> and <u>22</u> seconds. The average response time is longer at low volumes because fewer decisions are made. It is longer at high volumes because projections of successive vehicles overlap. In between is a volume level that will result in an optimal response time. For detector spacings of 1000 feet, this volume level is approximately 600 vehicles per hour. The average response time to an incident would be <u>16</u> seconds (221 decisions per hour).

To see how close the study results were to this theoretical distribution, the number of decisions (incidents, okays and unknowns) per hour made

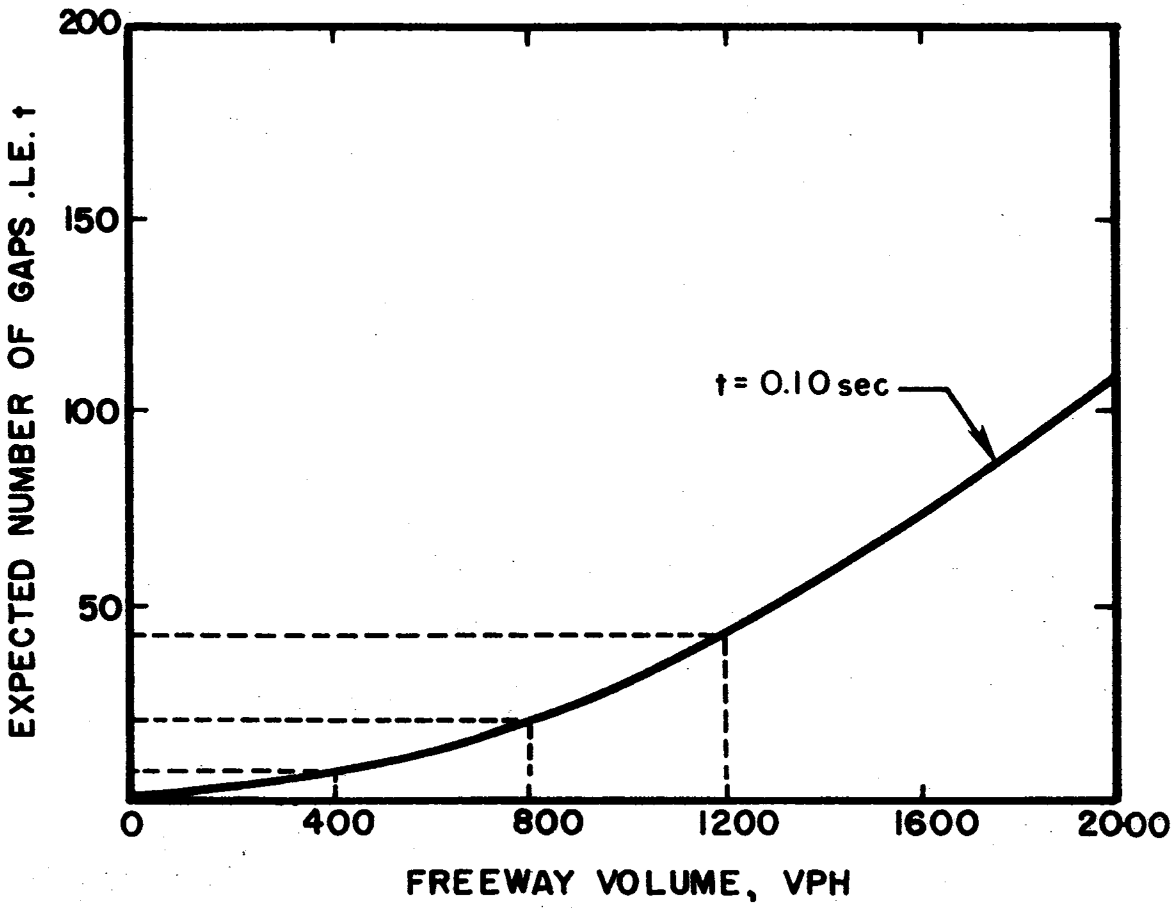


FIGURE 14. EXPECTED NUMBER OF ONE SMALL GAP (HEADWAY) FOR A RANGE OF FREEWAY VOLUMES

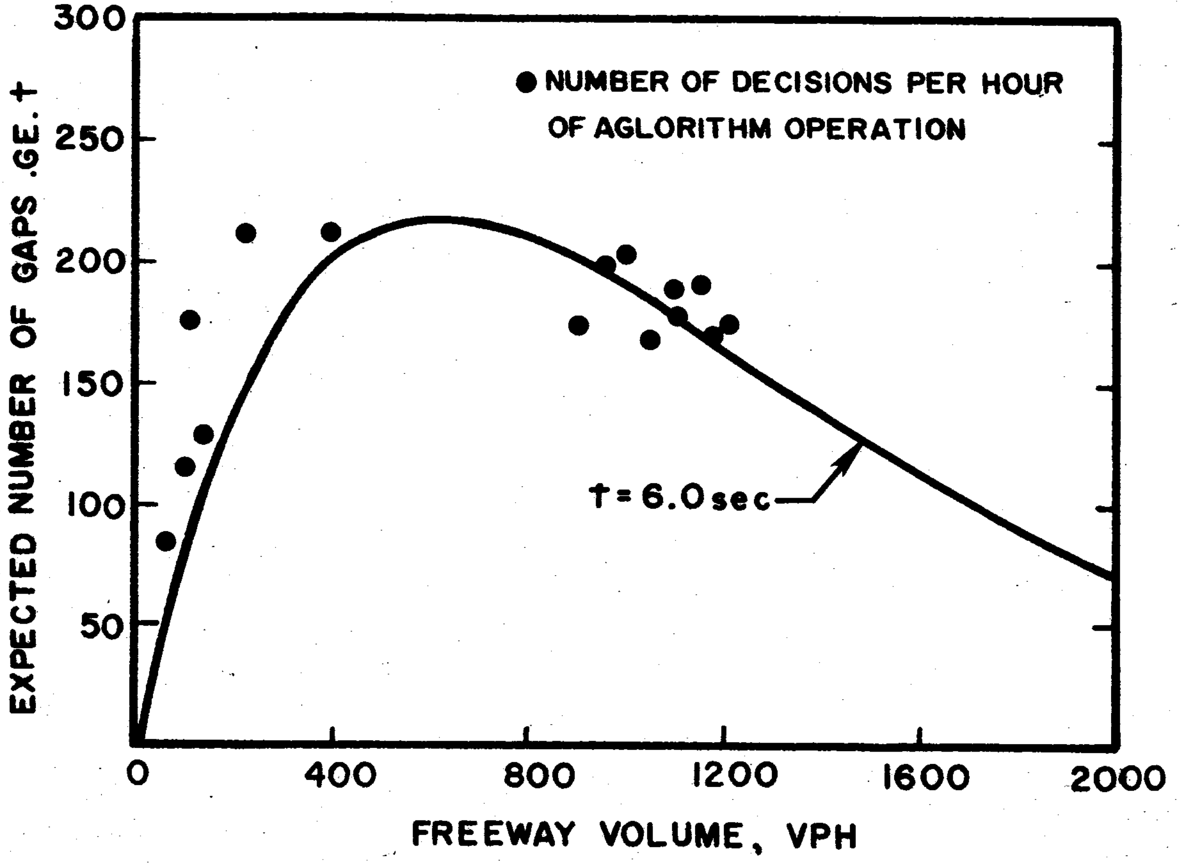


FIGURE 15. COMPARISON OF THE ACTUAL AND THEORETICAL PERFORMANCE OF THE ALGORITHM

by the algorithm was plotted versus the volume during that time period. As shown in Figure 15, a relatively high degree of correlation appears to exist between theory and the performance of the algorithm.

OPERATIONAL CONSIDERATIONS

Basic Philosophy

The algorithm developed in this research for the detection of freeway incidents during low volume conditions required more accurate speed measurements and volume counts than have been needed for other freeway operational control functions. Program logic was designed to compensate for many of these inaccuracies. The consequences of no compensation were detecting incidents that did not occur - (false alarms). Because false alarms destroy confidence in the operation of a system, it was desirable to keep their rate of occurrence as low as possible. Unfortunately, logic which lowers the false alarm rate also lowers the probability of detecting an incident.

In addition to calibrating the effective distance of each detector, speed projection logic was developed. Acceleration and deceleration factors were applied to the measured speed of each vehicle, to define the earliest and latest arrival times of that vehicle at the output station. This established a time interval rather than a point in time for the vehicle to exit the system. In this way, vehicles which slowed down or sped up while they were in the system would not necessarily cause the algorithm to make a false decision.

Logic was developed to compensate for possible inaccurate volume counts caused by potential double actuations, lane changes and motorcycles. Even so, the algorithm could not determine the number of vehicles passing over the detectors with 100 percent confidence. As it was desirable to keep the false alarm rate as low as possible, some basic guidelines for counting vehicles were adopted. If the algorithm could not with certainty determine the number of vehicles at the input station, one fewer than the number of possible vehicles was projected. If it could not with certainty determine the number of vehicles at the output station, all of the possible vehicles were counted. In other words, this logic reduced the probability of projecting too many or counting too few vehicles. Thus, the false alarm rate was reduced at the expense of incident detection capability.

False Alarms

A false alarm can be defined as the detection of an incident that did not occur. As false alarms were very undesirable, the basic operating philosophy of the algorithm was to detect as few of them as possible. Initially, the two major causes of false alarms were inaccurate speed measurements and vehicle counts. Software logic was developed to compensate for counting errors which might cause a "false" incident to be detected. Therefore, inaccurate speed measurements were the probable cause of the false alarms which did occur. Table 8 presents some of the algorithm's evaluation statistics after all the traffic data had been analyzed. When the data were divided into two groups, several interesting trends were observed.

As discussed previously, the average times to detect an incident for volume levels up to 400 vehicles per hour were 21, 25 and 31 seconds in the 500-, 1000- and 1500-foot sections. As shown in Table 8, (data from File 6), the corresponding false alarm rates per 1000 decisions made were 6, 0 and 11. For the three detector spacings, a false alarm could be expected to occur every 58, "unknown" and 47 minutes. For volume levels between 800 and 1200 vehicles per hour, the average times to detect an incident were 9, 22 and 39 seconds in the 500-, 1000- and 1500-foot sections. The correspond-

TABLE 8. COMPARISON OF THE FALSE ALARM RATES FOR TWO DIFFERENT OPERATING PHILOSOPHIES

Standard Operation

	Detector Spacing	100-1200 vph (Files 1-6)	100-400 vph (File 6)	800-1200 vph (Files 1-5)
Number of False Alarms	500 ft.	214	7	207
	1000 ft.	20	0	20
	1500 ft.	79	9	70
False Alarm Rate - Per 1000 Decisions	500 ft.	31	6	36
	1000 ft.	6	0	9
	1500 ft.	38	11	55
False Alarm Rate - Freq. of Occurrence	500 ft.	6 min.	58 min.	4 min.
	1000 ft.	61 min.	?	42 min.
	1500 ft.	16 min.	47 min.	12 min.

Improved Operation

	Detector Spacing	100-1200 vph (Files 1-6)	100-400 vph (File 6)	800-1200 vph (Files 1-5)
Number of False Alarms	500 ft.	30	1	20
	1000 ft.	7	0	7
	1500 ft.	15	0	15
False Alarm Rate - Per 1000 Decisions	500 ft.	9	2	10
	1000 ft.	4	0	6
	1500 ft.	15	0	23
False Alarm Rate - Freq. of Occurrence	500 ft.	42 min.	6.9 hr.	30 min.
	1000 ft.	174 min.	?	114 min.
	1500 ft.	84 min.	?	54 min.

ing false alarm rates per 1000 decisions made were 36, 9 and 55. For the three detector spacings, a false alarm could be expected to occur every 4, 42 and 12 minutes.

It was not surprising that the false alarm rates for all three detector spacings were greater at the higher volume level. Vehicle interaction increases as the volume level rises. Slowing down or speeding up to avoid other vehicles could cause an inaccurate projected arrival time. If this error was large enough, a false alarm would occur. In addition, it was expected that the false alarm rate would increase as the detector spacings increased. The longer the spacing, the more chance there is for vehicle interaction. However, the results indicated a different trend. The algorithm consistently produced fewer false alarms with detector spacings of 1000 feet. Several reasons exist for these unexpected results. First, the input detectors for the 1000-foot section were more reliable than those for the other two sections. Second, the input detectors for both the 500-foot and the 1500-foot sections were just past the interchange with another freeway and vehicles were still changing lanes and adjusting their speeds. At the input detectors for the 1000-foot section, traffic flow was much more stable. If these problems were corrected, the algorithm might perform better in the 500-foot section than it did in the 1000-foot section.

Improved Operation

To improve the reliability of the algorithm, software to further decrease the false alarm rate was developed. False alarms were being detected because of inaccurate vehicle projection. Visual observation showed that the "missing" vehicle was arriving in either the previous or the following time band. This indicated that two decisions should be made before an incident was detected. Therefore, the following operational guidelines were defined:

1. If extra vehicles were not indicated in the time band previous to or following the one in which an incident was detected, a probable incident had been found.
2. If extra vehicles were indicated in the time band previous to or following the one in which an incident was detected, a possible incident had been found.
3. If extra vehicles were indicated in a time band that was not adjacent to one in which an incident was detected, a probable adjacent lane headway check had been found.

Based on these operating guidelines, resultant evaluation statistics are illustrated in Table 8. The number of "false" incidents which were detected has been reduced from 214 to 30 in the 500-foot section, from 20 to 7 in the 1000-foot section and from 79 to 15 in the 1500-foot section. Because two decisions were made before an incident was detected, the response time to a real incident was doubled. However, the average times to detect an incident were still very good. For volume levels up to 400 vehicles per hour, the average times to detect an incident were <u>42</u>, <u>50</u> and <u>62</u> seconds in the 500-, 1000- and 1500-foot sections respectively. A false alarm could be expected to occur every <u>6.9</u>, "<u>unknown</u>" and "<u>unknown</u>" hours. "Unknown" rates resulted whenever no false alarms occurred during the study period. For volume levels between 800 and 1200 vehicles per hour, the average times to detect an incident were <u>18</u>, <u>44</u> and <u>78</u> seconds for the three detector spacings. A false alarm could be expected every 30, 114 and 54 minutes of operation.

The type of incident detection system available to the operating agency would govern to some extent the kinds of incidents to which they would respond. If the algorithm was the only method of detecting incidents, response would be provided for probable incidents only. If the algorithm was part of an overall freeway management system, response would be provided not only for probable incidents but also for those possible incidents that could be verified. Courtesy patrols and/or television surveillance could be used for this purpose.

CONCLUSIONS AND RECOMMENDATIONS

A computer algorithm was developed, tested and evaluated to detect vehicular incidents which occur on urban freeways operating at low volume conditions. The type of "incidents" to be detected are those individual vehicles which entered but for some reason did not pass through a defined study section. The algorithm can operate in real-time and is based on an individual vehicle input-output process. It was tested on a four-lane section of freeway in Houston, Texas. The algorithm's performance was evaluated over a wide range of traffic volumes and three different detector spacings (500, 1000 and 1500 feet).

Traffic data were collected for approximately 15,700 vehicles on six days in February through May of 1977. Thirty-five vehicles "stopped" within the study section. In the 500-foot section, the algorithm detected 65 percent of the vehicles which stopped. In the 1000-foot section, it detected 78 percent of the vehicles which stopped and in the 1500-foot section, it detected 49 percent of the vehicles which stopped. Numerous lane changes and a bad detector at the first detection station caused the relatively poor performance of the algorithm in both the 500-foot section and the 1500-foot section. To study the effects of volume on the algorithm's performance, the data were divided into two groups. The first group had volume levels up to 400 vehicles per hour. For all three sections, the algorithm detected 100 percent of the vehicles which stopped. The second group had volume levels from 800 to 1200 vehicles per hour. The algorithm detected 60, 75 and 42 percent of the vehicles which stopped in the three sections. The maximum average time to detect an incident for any volume level - detector spacing combination was 40 seconds.

Reliability of the algorithm was another operational feature which was evaluated. False alarms were undesirable and logic was developed to minimize their occurrence. At the lower volume level, the false alarm rate was one per _7_ hours of operation. At the higher volume level, the false alarm rate was one per _2_ hours of operation. A redundant surveillance system could further reduce the number of false alarms.

A low volume incident detection algorithm has been developed and tested. Satisfactory results were obtained; however, with minor improvements to the algorithm and a better maintenance program for the hardware, they can be improved. In addition, because of the decreased probability of adjacent lane headways, the algorithm should perform better on both two- and three-lane freeway sections than it did on the four-lane study sections. The algorithm could be used in conjunction with other incident detection algorithms within the same surveillance system. The next step towards implementing the results of this research should be the evaluation of an "in-place" low volume incident detection system. The following site characteristics are recommended for testing such a system.

1. At least eight hours of daily operation where volume levels are less than 1200 vehicles per hour.
2. No exit or entrance ramp in the freeway section.
3. Two loop detectors per lane per station.
4. Spacings between stations of 1000 feet.
5. Freeway sections with constant or predictable speeds.
6. Freeway sections with restricted sight distance.
7. Method for daily calibration of the detectors.

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The contents of this paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification or regulation.

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APPENDIX

Word Storage Format Within Data General Nova Minicomputer

BITS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DATA ITEM	A		B	C				D								

DATA ITEM A - Station Location

Bits 1 & 2	= 00	Time Check
	= 01	Station 1
	= 10	Station 2
	= 11	Station 3

DATA ITEM B - Detector Activation Indicator

Bit 3 = 0	Off
Bit 3 = 1	On

DATA ITEM C - Detector Number

Bits 4-7	= 0001	Lead Inside	1_{10}
	= 0010	Lead Inside Middle	2_{10}
	= 0011	Lead Outside Middle	3_{10}
	= 0100	Lead Outside	4_{10}
	= 0101	Mid Inside	5_{10}
	= 0110	Mid Inside Middle	6_{10}
	= 0111	Mid Outside Middle	7_{10}
	= 1000	Mid Outside Middle	8_{10}

= 1001 Lag Inside 9_{10}
= 1010 Lag Inside Middle 10_{10}
= 1011 Lag Outside Middle 11_{10}
= 1100 Lag Outside 12_{10}

DATA ITEM D - Time Mark

Value from 0_{10} to 511_{10}