Evaluation Study

CONNECTICUT DEPARTMENT OF TRANSPORTATION

ADVANCED TRAFFIC MANAGEMENT SYSTEM

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July 1996

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1 INTRODUCTION

This study, prepared for the Connecticut Department of Transportation, presents the results of the evaluation of radar detectors and speed-based incident detection algorithms. These elements are used in the Hartford Area Advanced Traffic Management System (ATMS) which is an FHWA operational test. This report will provide information on the system design, the accuracy of the field equipment, and the effectiveness of the incident detection algorithms including a comparison with other incident detection algorithms currently in use.

1.1 Background

In 1989 the State of Connecticut Department of Transportation (ConnDOT) authorized a study to investigate the necessity for, and feasibility of, establishing a highway traffic management system. As a result of this study, the decision was made to install a surveillance system utilizing radar detectors and CCTV cameras to monitor traffic and detect incidents in the Hartford area. While this area was not shown to experience the greatest amount of congestion for the entire Connecticut highway system, the fact that other Intelligent Transportation System (ITS) components (such as variable message signs and computerized traffic signal systems) were already in place and functioning in the area, the presence of on-going reconstruction activity, and the proximity of the ConnDOT headquarters led to the Hartford area being the choice for this initial system.

As the feasibility study was nearing completion, the State began limited testing of a radar detector manufactured by Whelen Engineering. The TRACKER unit was designed to monitor vehicle speeds and direction. The system was originally developed to detect vehicles traveling the wrong way on interchange ramps and roadways. The initial tests conducted by the State consisted of a unit installed on a local roadway. These tests produced favorable results with regard to the unit's accuraw of determining vehicle speeds. Based on this initial data, personnel from ConnDOT and JHK & Associates, who were performing the statewide study, worked with Whelen Engineering on modifying the TRACKER unit so that it could be used to monitor speeds on highways. Along with being able to monitor vehicle speed, the TRACKER system also has other favorable features including being mounted above the roadway versus being embedded in the pavement. It also has the ability to monitor traffic flow from the side of the road when over the roadway mounting is undesirable, or not possible. Based on these features, ConnDOT decided to approach the Federal Highway Administration for approval of funding in order to initiate a demonstration project using radar detectors as the detection technology.

When originally developed, there was only one model of the TRACKER available; a wide beam unit that would detect vehicles traveling in all of the lanes along one direction of the highway. As the project was being designed, personnel from ConnDOT and JHK worked with Whelen Engineering to make modifications to the unit, including the development of a narrow beam unit. The narrow beam detector used a reflector dish to reduce the radar beam spread so that it would not extend outside of a single lane. Subsequent modifications made by ***Whelen*** included the development of a "long range" detector. This model is similar to the wide beam detector except that it casts the radar beam over a longer distance, allowing it to be mounted further off the edge of the pavement, or even on the opposite side of the roadway from the direction of traffic it is detecting.

2 SYSTEM DESIGN

2.1 Field Equipment

The Hartford Area ATMS includes approximately twelve miles of Interstates 84 and 91 as shown in Exhibit 1. These highways are subject to recurring congestion during both of the peak hours, and there are also ***major*** highway construction projects ongoing in this area. Along these sections of highway are twenty detector stations monitoring traffic speeds in both directions of the two highways. Of the twenty detector stations, thirteen utilize wide beam detectors, six utilize narrow beam detectors to monitor trafiic speeds in the individual lanes, and one detector station utilizes a long range detector. The installation of the long range detector was not part of the original project design, but was added to the project after construction commenced due to activities related to other construction projects. The long range detector is installed on the west side of I-91 and is used to detect northbound trafiic.

The narrow beam detectors are installed at various locations where the individual lanes have different purposes such as exit lanes or HOV lanes. It was felt that the use of wide beam detectors at these locations might provide incorrect "average" speeds due to the different lane uses, and the potential for the mainline lanes to be stopped and the HOV or exit lanes traveling at free flow or higher speeds. The narrow beam detectors were installed at these locations to separate the lane specific data and to minimize any skewed mainline speed samples. Exhibit 2 illustrates the operation of the different detector types.

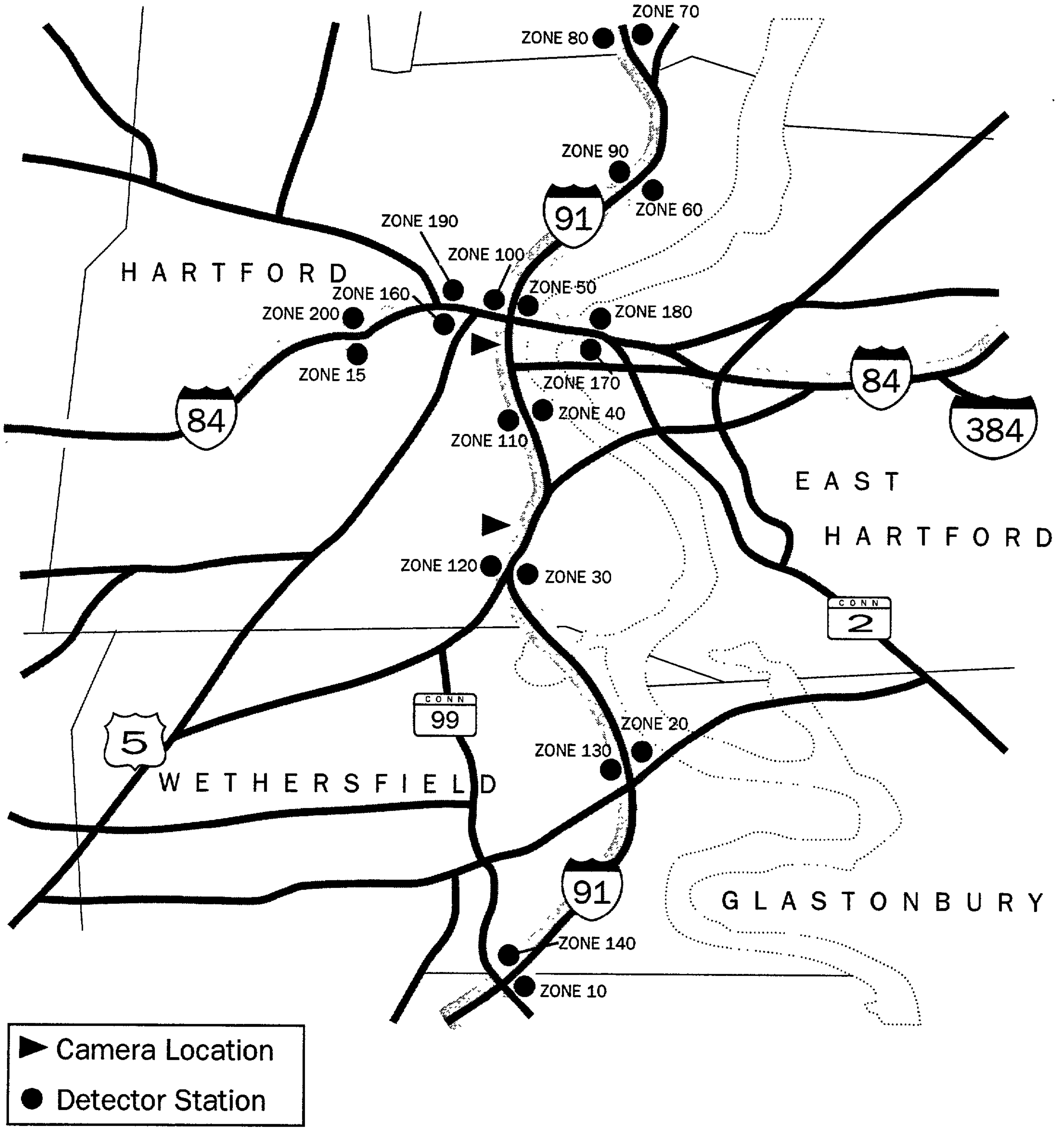


Exhibit 1: Project Area

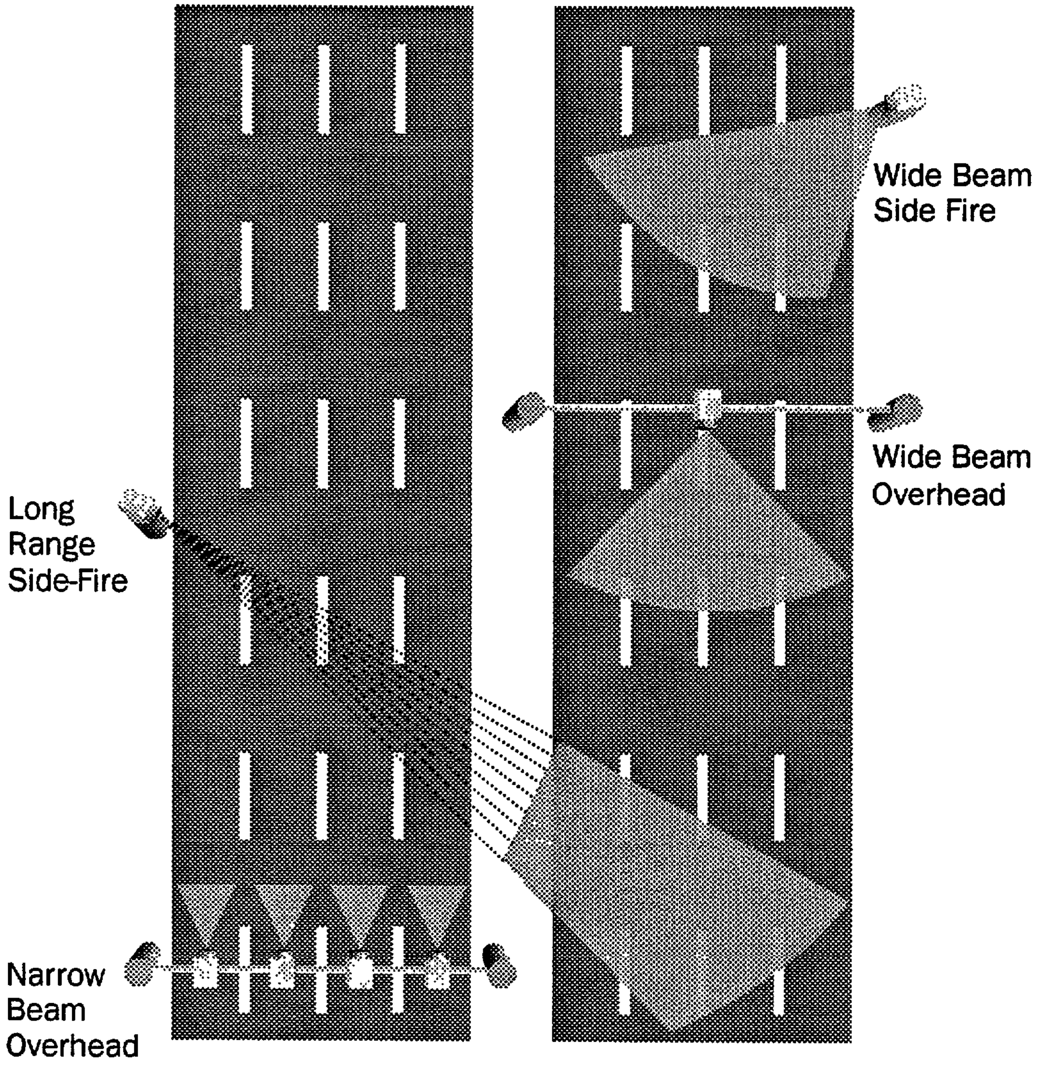


Exhibit 2: Detector Operation

The detectors provide for a great deal of flexibility in terms of installation and placement. The greatest concern of placement is with the narrow beam detectors and their relationship to the travel lane they are detecting. The narrow beam detector should be placed over the center of the lane, and aimed so that it will be pointing directly down the travel lane. Mounting height also has to be taken into consideration when installing the narrow beam detector because the size of the resultant detection zone is related to the height of the detector above the roadway. If the detector is mounted too high, then the resultant detection zone will be larger than the travel lane and can result in erroneous data For this project, all of the narrow beam detectors were mounted 18 to 20 feet above the roadway providng a detection zone approximately 8 feet in diameter.

At each site, the individual radar detectors are connected to a multiplexer installed in a nearby equipment cabinet. Originally, the TRACKER unit was designed so each detector unit communicated independently with the central computer. The use of the multiplexer allows data from up to eight detectors to be combined into a single communications stream to be sent back to the central computer.

The multiplexer also has a DC power supply which provides the power to the detectors. The power supply has an adjustable output level to account for the fact that not all of the detectors will be the same cable distance from the multiplexer and that different types of cable have different levels of resistance. The multiplexer also is adjustable to allow for either 1200 baud or 2400 baud communications.

In addition to the detector stations there are two CCTV cameras positioned to provide visual surveillance of major interchanges; the 1-84/I-91 interchange and the I-81/Route 15 interchange. From the two cameras, six (6) of the detector stations can be observed. These cameras are valuable to the overall system operation by providing a means of verifying the detector data. A block diagram of the system is shown in Exhibit 3.

Communications to all of the field equipment (detectors and cameras) are accomplished through the use of leased telephone circuits. The detector data is continuously sent back from the field via dedicated data circuits at 1200 baud. The video from the cameras is brought back to the Operations Center over leased Tl lines at 334 kbps. The use of leased telephone lines to handle the system communications was chosen for a variety of reasons. The ilrst reason was cost; Southern New England Telephone has a very favorable tariff agreement with the State of Connecticut which also uses leased telephones for its UTCS signal system. The tariff is set **up so** the nqjority of the lease costs are included in an initial payment, which is **usually eligible for** federal reimbursement. The remaining costs are then spread out over the terms of the lease.

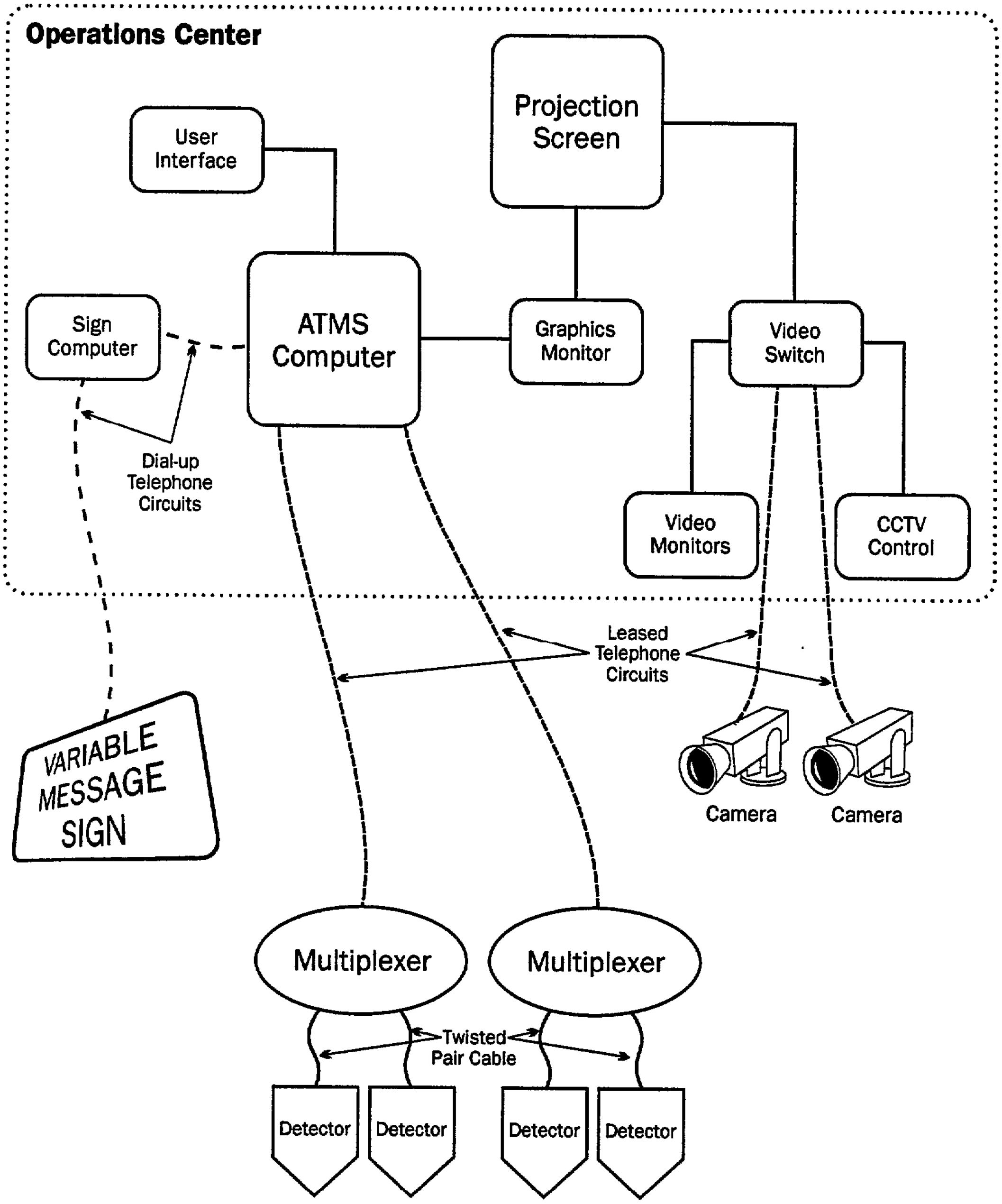


Exhibit 3: System Schematic

Another reason that leased telephone circuits were used was that the initial system was a demonstration project to test new technology, The use of leased telephone circuits allowed for a low cost communications network to be installed, versus dedicating funds to the installation of a communications plant. Lastly, when the project was being developed, ConnDOT was designing a new headquarters. The system was installed prior to ConnDOT moving from Wethersfleld to their new location in Newington. If a sepsrate communications plant was designed and installed as part of the project, the implementation of the project would either have to be delayed until ConnDOT moved to their new headquarters or the cable plant would have to be modified and extended to the new facility. The use of leased telephone lines allowed ConnDOT to move to their new facility, and have the system operational within a day.

2.2 System Software

The software developed for the Hartford Area ATMS provides two distinct functions: It provides an interface for the system operators to monitor vehicle speeds and traffic conditions in the project area; and through the use of various algorithms, it provides automated incident detection.

The ATMS is constantly updating information regarding the travel speeds for the various sections of highway covered by the system. Along with the speed data, the status of the incident algorithms is also being constantly updated. The primary means of relating this information to the operator is through the use of a graphical display. The different sections of the highways are shown as icons on the display. These icons change color based on the speed data being sent back for the various sections of highway covered by the system. Exhibit 4 shows the main system graphics screen. Other information shown on the graphics display is the status of the incident detection algorithms for the different zones and the status of the variable message signs. Higher level screens are also incorporated into the system to show detailed information for each detection zone. In zones having narrow beam detectors, the screens show speed information for the individual lanes, as well as information on the status of the algorithms and the variable message signs.

Along with the graphical display, the system also has an operator ternGal. Through this terminal an operator can enter information on system configuration, as well as threshold settings. The operator can also access various other screens, including a screen that shows the real-time data from the individual detectors, as well as generate reports for recorded data, historical data, and recorded incidents.

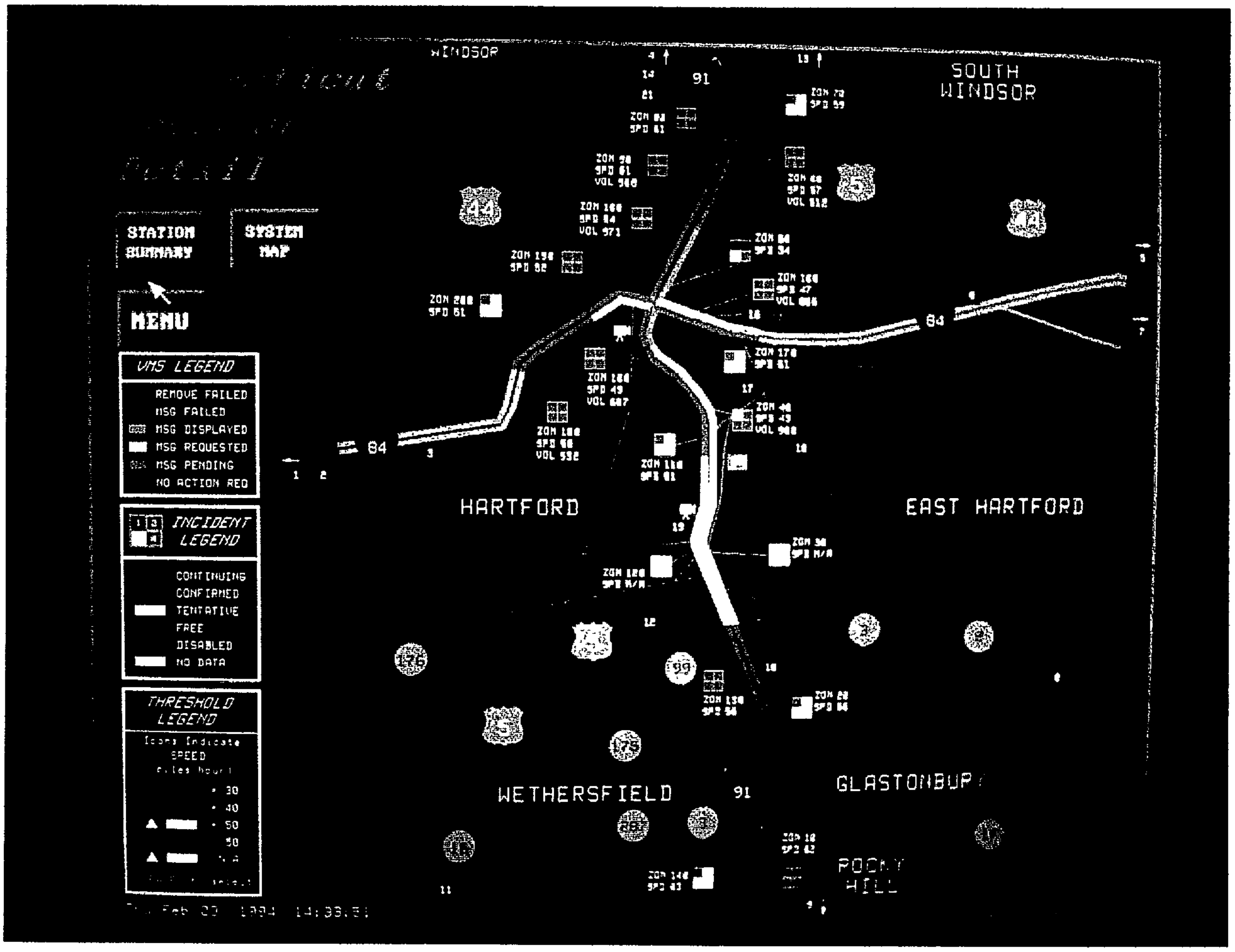


Exhibit 4 System Graphics Display

2.2.1 Incident Detection Algorithms

The detection logic most widely used in the United States are the algorithms developed for the Federal Highway Administration. These algorithms, also known as the "Califomia Algorithms" and described in the FHWA publication entitled "Development and Testing of Incident Detection Algorithms" (Payne, et al., 19761, look for congestion between detector stations by comparing traffic flow measurements at one station with the data from an adjacent downstream station. Since the California algorithms are predominantly based on occupancy data, they could not be used for the ATMS. Instead, three speed-based algorithms were developed for the system, as described below and shown in Exhibit 5. In addition, flow charts for each of the algorithms are included in Appendix A.

The "Mean Speed" algorithm monitors the speed at the individual detector stations (zone) and declares a potential incident whenever the average speed at a zone falls below a user defined threshold for that zone. 1b limit the number of "false calls", the system also allows the user to define a minimum time period for which the speeds shall be below the threshold before an incident will be declared. The system declares that the potential incident has dissipated when the speed at the zone has risen above another user defined threshold (which must be larger than the speed for which a potential incident was declared).

The "Difference In Speed" algorithm is similar to the California Algorithms in that it involves the comparison of speed data between adjacent zones. During an incident the speed downstream of the blockage is significantly greater than the speed at the upstream zone. This algorithm declares an incident when the difference in speed between a zone and its downstream zone exceeds a user defined threshold. Realizing that other factors besides the difference in speed need to be considered, there are two other thresholds associated with this algorithm. These thresholds include the minimum speed at the adjacent downstream zone, and the minimum ratio between the speed difference and the speed at the zone. With these two thresholds, the user can define the speed range within which the algorithm will respond. The minimum speed at the downstream zone sets the lower limit of the speed range, while the speed ratio will indirectly set the upper limit of the speed range. This algorithm, along with the Mean Speed algorithm, has persistence checks built into it which require that incident conditions be present for a user specified time period before an incident condition is declared.

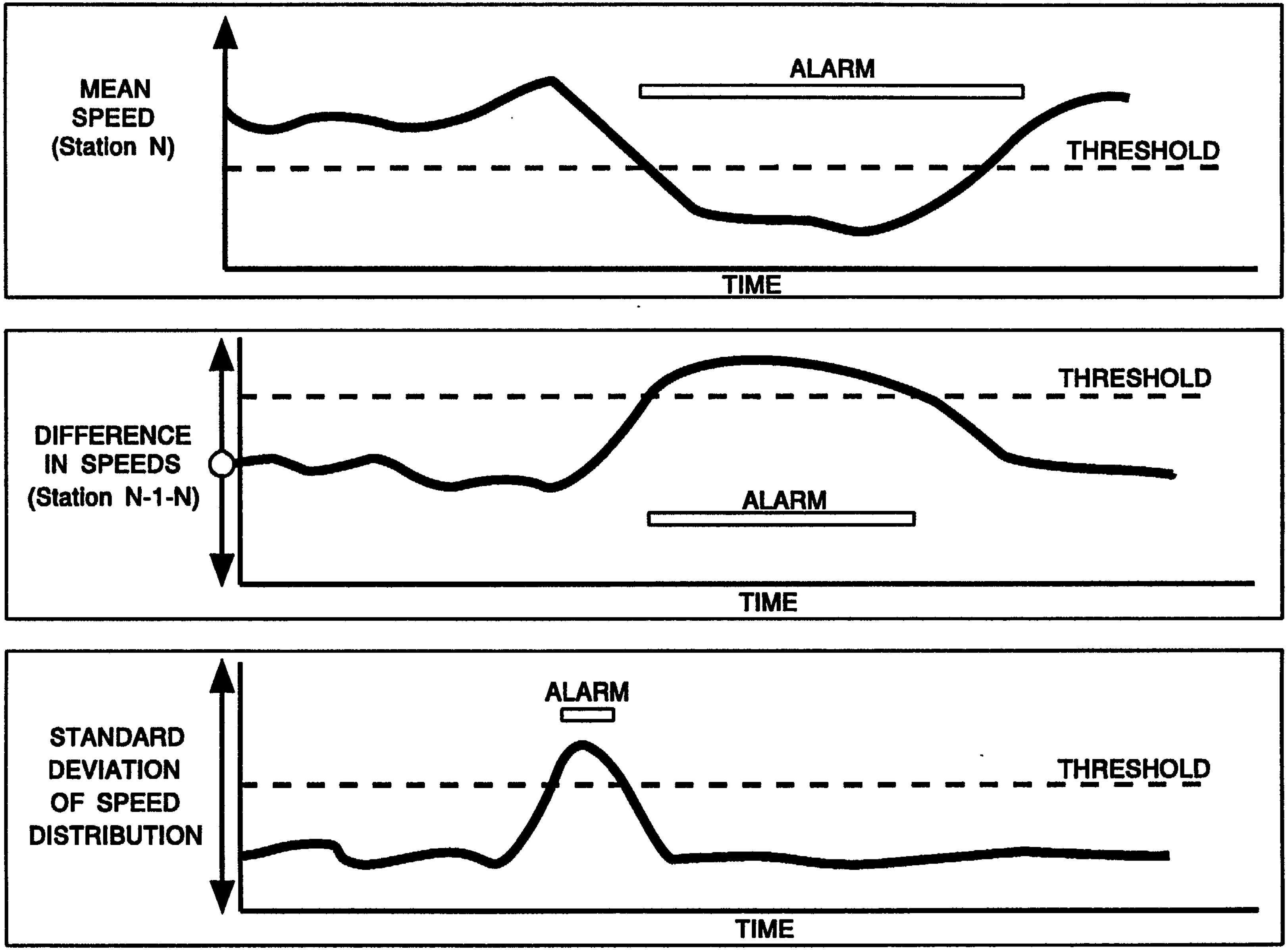


Exhibit 5: Incident Detection Algorithms

A third algorithm, which examines the standard deviation in speed, is also incorporated into the system A control strategy has been developed based on a continuum theory of traffic flow. Results of several studies performed in Germany show that the speed distribution broadens before trafEc bresks down. The standard deviation of the speed distribution, as a measure of the broadness of the speed variation at a zone, is therefore an early warning criterion for incident detection. The "Standard Deviation" algorithm differs from the previously mentioned algorithms in that it uses the actual speed data samples versus "smoothed" data which is used by the other algorithms. Along with monitoring the standard deviation of speeds, the slope of the standard deviation of speeds over time is also monitored so that incidents will be detected as speeds are declining, not increasing. Other thresholds included in this algorithm are the ratio of the standard deviation at a zone to the standard deviation at the adjacent downstream zone, and the ratio of the standard deviation during the current time interval to the standard deviation of the prior time interval.

2.2.2 VMS Intertie

As mentioned previously, one of the reasons that the ATMS was installed in the Hartford area was that ConnDOT had Variable Message Signs installed on the highways leading into the City, with additional signs planned for installation. These signs play the important role of providing real-time information to the motorists. The VMS system is controlled by a PC-based computer in the DOT's operations center where the ATMS is also located.

To expedite the process of displaying sign messages, the ATMS software was developed to interface with the sign system computer. When the ATMS detects an incident, it requests the sign computer to put a predetermined message on various signs applicable to which zone the incident was detected. Upon requesting a sign message, the system awaits approval from the operator before the message is displayed on the signs. This allows the operator to verify an incident before a message is displayed without having to be concerned with creating the message, or operating the sign system. As more information becomes available, the operator can create a specifk message regarding the incident and override the message requested by the ATMS system.

3 SYSTEM EVALUATION

This section discusses the **results** of various tests that were performed on the system components. These tests and evaluations focused on the accuracy of the detector data and the operation of the system software, including the incident detection algorithms.

3.1 Field Equipment

3.1.1 Reliability

The installation of a Freeway Traffic Management System involves a significant capital investment. Along with installation costs, there are maintenance costs which can escalate rapidly if numerous equipment failures occur. These equipment failures also compromise the system operation by limiting the information that is available.

Historically, the reliability of loop detectors, with regard to life cycles, has been limited. Due to their location in the roadway, they are subjected to the stress of traffic traveling on them, problems associated with pavement deterioration, and freeze-thaw cycles. The Connecticut Department of Transportation utilizes inductive loop detectors, and piezo devices for the monitoring of traffic on limited access highways. These loops and piezo devices are used by the Department's Bureau of Policy and Planning to determine vehicle classification and monitor vehicle speeds for federal compliance.

ConnDOT has approximately 370 loop detectors installed on the limited access highway network. Over the past five years 126, or 34%, of these loops have failed and had to be repaired or replaced. These are actual loop failures caused by normal wear or possible installation problems. In addition to these, there were an additional 46 loops (12%) where failures were related to construction activities damaging the loops.

ConnDCT has also been using piezo devices to monitor traffic on limited access highways. Approximately 192 of these devices are installed, and during the two-year period from 1992 to 1994,15 (8%) failed and needed to be replaced.

The 44 radar detectors for the Hartford Area ATMS have been installed for approximately 42 months. Over this time period there have been only two occurrences where a detector or its associated equipment failed, and one of them was the result of lightning.

3.1.2 Speed Accuracy

For any system to function properly and adequately monitor traffic conditions, it is necessary for the field equipment to provide accurate data. To determine the accuracy of the radar detectors in furnishing vehicle speeds a variety tests were performed.

As mentioned previously, various types of radar detectors and installation configurations are utilized on the system. Data has been gathered for these various detectors and installation configurations to determine the detector accuracy. The tests were performed by using test vehicles and a laser gun to measure vehicle speeds, and comparing this data with the data output from the radar detectors. Exhibit 6 shows the different detector types, installation configurations, and the average difference between vehicle and detector speed. The difference between vehicle and detected speed ranges from 2.5 miles per hour for the narrow beam detector to 3.5 miles per hour for the wide beam detector in a side-fire configuration, and up to 10 miles per hour for the long-range detector.

Detector Type and Installation	Average Difference (mph)
Narrow Beam Detector aimed towards approaching traffic	2.5
Narrow Beam Detector aimed towards departing traffic	2.6
Wide Beam Detector mounted over road aimed towards approaching traffic	3.1
Wide Beam Detector mounted over road aimed towards departing traffic	2:8
Wide Beam Detector on side of road aimed towards approaching traffic	3.5
Long Range Detector on side of road aimed towards approaching traffic	6.2
Long Range Detector on side or road aimed towards approaching traffic	10.0

(d Detector mounted at 20 degrees angle with respect to traffic flow.
o Detector mounted at 30 degrees angle with respect to traffic flow.

Exhibit 6: Speed Accuracy

For the narrow beam detectors, a test vehicle was used to measure the accuracy of the detectors. The speed of the test vehicle as it traveled through the detection zone was compared to the actual output from the detector. For the wide beam and long range detectors, a laser gun was employed to measure the vehicle speeds. Considering that the wide beam and long-range detectors do not detect every vehicle, but rather provide information on the general traffic flow, comparisons were made between 20-second samples of vehicle speeds obtained with a hand-held laser and the radar detectors.

provide accurate data regarding the overall traffic flow. The difference associated with the long range detector, while large, can be attributed to the operation and placement of the detector. The Whelen detector is based on the Doppler principle, and measms the time it takes for energy to be reflected back to the detector. The detector is most accurate when it is aimed directly at the traffic flow. Due to the offset location of the long range detector in relationship to the longitudinal distance, an error is factored into the data. This error is related to the cosine of the angle between detector beam and the traffic flow. This is evidenced by the data for the two tests performed for the long range detector. As the angle of the radar beam with respect to the traffic flow is reduced, the error in the speed data declines. While the data collected for the long range detector showed an average difference of 6 to 10 miles per hour, the data from the detector was consistently lower than the actual speeds. When a correction factor related to the cosine of the mounting angle was applied to the data samples, the difference between the vehicle speeds and detected speeds fell to under 4 miles per hour.

Considering that the detector is based on the Doppler principle, there have been concerns regarding how fast a vehicle needed to be traveling to be detected. While actual tests were not performed to determine this speed, visual observations and recorded data show that vehicles traveling as slow as 5 miles per hour have been detected by the system.

3.1.3 Volume Accuracy

The narrow beam detector has a detection zone that is up to 8 feet in diameter and, with proper installation, the detection zone can be centered in a single travel lane. Thus, the detector should be capable of detecting and providing a speed value for the individual vehicles that travel through the detection zone. Through logic that is incorporated within the detector, a single speed sample will be provided for each vehicle. By counting the number of speed samples over a given time period, volume data should also be able to be derived from the narrow beam detectors.

Tests for accuracy of the volume data were performed by logging the speed data output by the data multiplexer. Speed samples were logged for specific detectors and time periods, and compared to manual counts that were made for the same lane and time period. Exhibit 7 shows the results of these volume counts. As shown by the information, there is a large disparity between the actual volume and the volumes based on the detector data. These differences range from 9.8% to 59.6% with the detector data always underestimating the actual volume.

Detector	Actual Volume	Detected Volume	Difference
Detector #1	268	**158**	-41.04%
Detector #2	276	**181**	-34.42%
Detector #3	162	137	-15.43%
Detector #4	287	259	-9.76%
Detector #5	**348**	162	-53.45%
Detector #6	**299**	231	-22.41%
Detector #7	**446**	263	-41.03%
Detector #8	**448**	181	-59.60%
Detector #9	274	256	-9.86%

Exhibit 7: Volume Accuracy (through Multiplexer)

Tests being performed by Hughes Aircraft Company as part of an FHWA research effort showed the Whelen narrow beam detectors to have an accuracy of greater than 95% in providing volume data when in a "direct-connect" configuration[1]. In this conflguration, the detector is connected directly to the processor for logging data, eliminating any errors caused by the polling of detectors by the multiplexer. Similar tests performed in Connecticut, with errors ranging from 1.6% to 41.5%, provided results significantly different from the Hughes study. The results of these tests are shown in Exhibit 8.

Detector	Actual Volume	Detector Volume	Difference	Detector	Actual Volume	Detector Volume	Difference
Detector #1	405	314	22.47%	Detector #8	341	257	24.63%
Detector #2	232	184	20.69%	Detector #9	256	250	2.34%
Detector #3	316	198	37.34%	Detector #10	125	127	1.60%
Detector #4	566	331	41.52%	Detector #11	230	261	13.48%
Detector #5	295	316	7.12%	Detector #12	277	296	6.86%
Detector #6	344	367	6.69%	Detector #13	84	90	7.14%
Detector #7	346	222	35.84%	Detector #14	71	67	5.63%
Average Difference							16.67%

Exhibit 8: Volume Accuracy (Direct Connect)

Hughes Aircraft Company;Detection Technology for MB Final Report; July 1995

3.2 Incident Detection AIgorithms

The characterization of the performance of automatic incident detection methods is usually given by the following indices:

- Accuracy - The percentage of the total incident alarms that are confirmed incidents.
- Detection Rate - The percentage of incidents successfully detected by the algorithm from all the incidents that occur during a specified time period. In statistical terms, detection rate is the probability of detecting an incident when one is confirmed by any means.
- False Alarm Rate - A false alarm occurs when there is no incident but the algorithm signals an incident. A false alarm rate (FAR) is calculated by dividing the number of false alarms by the total number of executions made by the algorithm. An operational false alarm rate (OFAR) is the ratio of false alarms to total alarms (i.e., accurate indications of an incident plus the false alarms). Both are expressed in percentages. False alarms are not only annoying to the operator, but they can result in substantial recurring costs to dispatch personnel, especially where verification methods are not provided.
- Time-To-Detect - The average amount of time required by the system to detect incidents, given that there is a valid detection. Timely detection of incidents is one of the most important requirements for efficient incident management.

The evaluation of the incident detection algorithms was accomplished by comparing records of incident alarms generated by the ATMS to State Police logs which listed accidents and other events (disabled vehicles, etc.) that the State Police responded to during the same period. Prior to starting the evaluation, significant work was performed by ConnDOT and JHK personnel in setting up the various thresholds for the different incident detection algorithms. Among the three algorithms, there are nineteen different variables which can be defined by the user on a time-of-day, day-of-week basis. Default settings are used for the majority of the entries, but the system allows for the thresholds to be modified for specific detection zones, days of the week and fifteen minute time periods. Based on historical speed data collected by the system, the thresholds were adjusted to account for recurring congestion in an attempt to minimize the FAR.

The evaluation of the incident detection algorithms was performed over a four week period from June 12 through July 9,1995. In addition to comparing the system incident logs to State Police reports, comparisons to construction activity reports and operations logs provided by ConnDOT were also made. This allowed for incident alarms to be matched with either State Police or construction activity.

During the evaluation period, a total of 1499 incidents were declared by the ATMS. It should be noted that the system allows for multiple alarms to be declared for the same incident. Of the 1499 declared incidents, 455 (30%) were declared by the Mean Speed algorithm, 672 (45%) were declared by the Difference in Speed algorithm and 372 (25%) were declared by the Standard Deviation algorithm. Exhibit 9 illustrates the number of declared incidents for each detector zone, and further shows the number of incidents declared by each algorithm. As would be expected, detection zones in downtown Hartford (zones 40 and 160), which were subject to recurring congestion, had a large number of declared incidents. In addition, construction activity was present at zones 120 and 150 which led to the large number of declared incidents at these locations. It should be noted that four of the detector zones only utilize the Mean Speed algorithm. These zones (70, 140, 170, and 200) are at the edge of the project area and do not have downstream detector locations required by the Difference in Speed and Standard Deviation algorithms.

3.2.1 Algorithm Accuracy

The first analysis which was performed examined the accuracy of the incident detection algorithms . For this analysis, accuracy is defined as there being a reason for the incident being declared. As mentioned previously, a total of 1499 incidents were declared by the system over the 28 day evaluation period. Of these, a total of 937 (62.5%) were "confirmed", being attributed to either State Police or construction activity. Of the 1499 incidents declared by the system, State Police activity accounted for 505, while 432 were attributed to construction activity. In performing the evaluation, only those incidents where documented evidence of external events was available were counted as confirmed incidents. Thus, other events such as severe weather, which may cause disruptions in traffic, were not counted as confirmed incidents. Other situations, such as long term construction projects with shifts in traffic patterns and reduced travel lanes, were also not included as confirmed incidents unless there were additional lane closures. The accuracy of the individual algorithms ranged from 56.4% for the Standard Deviation algorithm to 66.5% for the Mean Speed algorithm. The number of system declared incidents attributed to construction activity and incidents for the individual algorithms is shown in Exhibit 10.

While the operation of the individual algorithms was similar, the accuracy of the incident detection algorithms at the individual zones varied signikantly. Algorithm accuracy at the individual detector locations ranged from 20% to 100%. The two locations with 100% accuracy had 0 and 1 incident declared by the system during the evaluation period. Exhibit 11 illustrates the

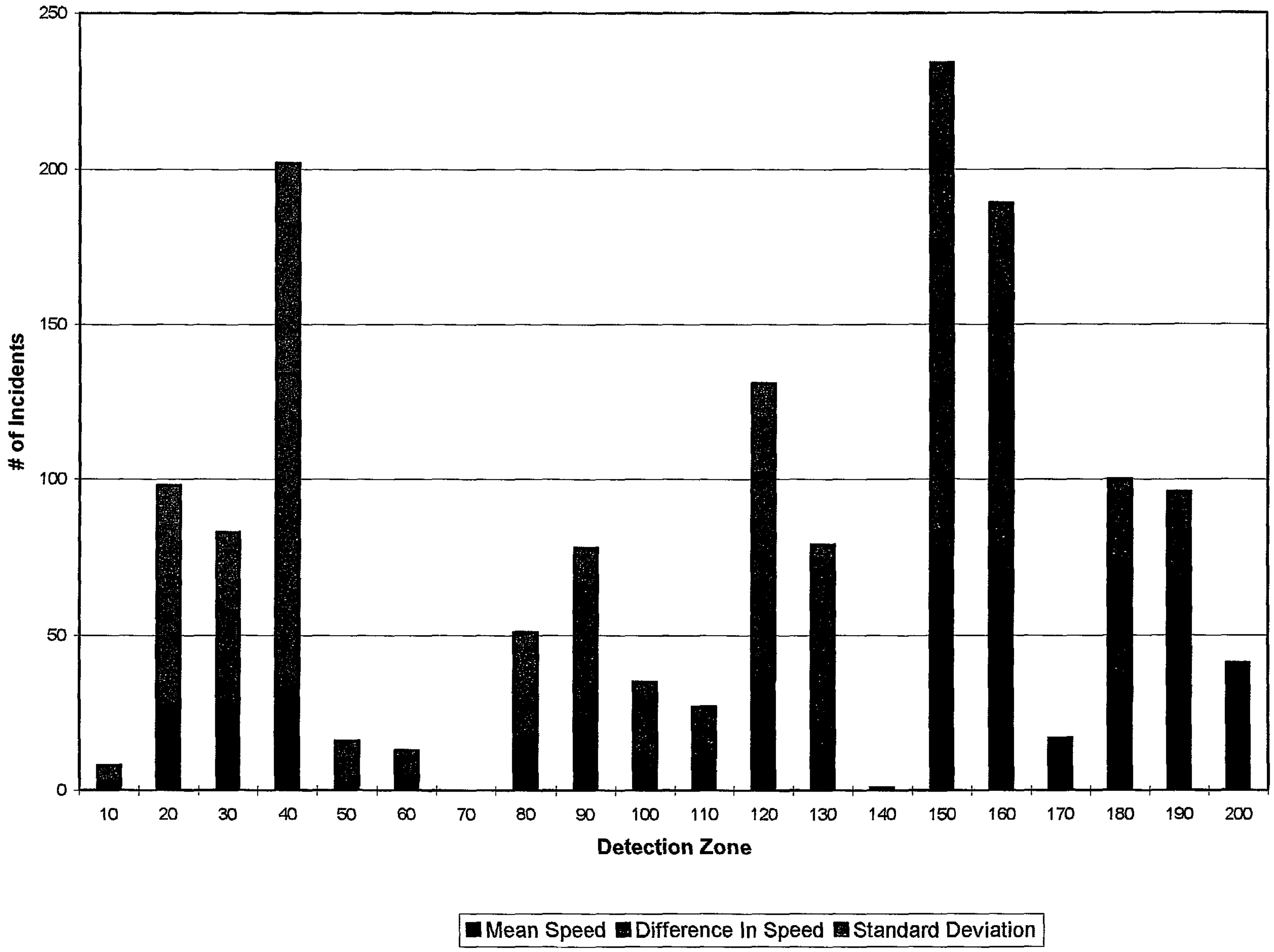


EXHIBIT 9 - ALARM DISTRIBUTION BY DETECTION ZONE

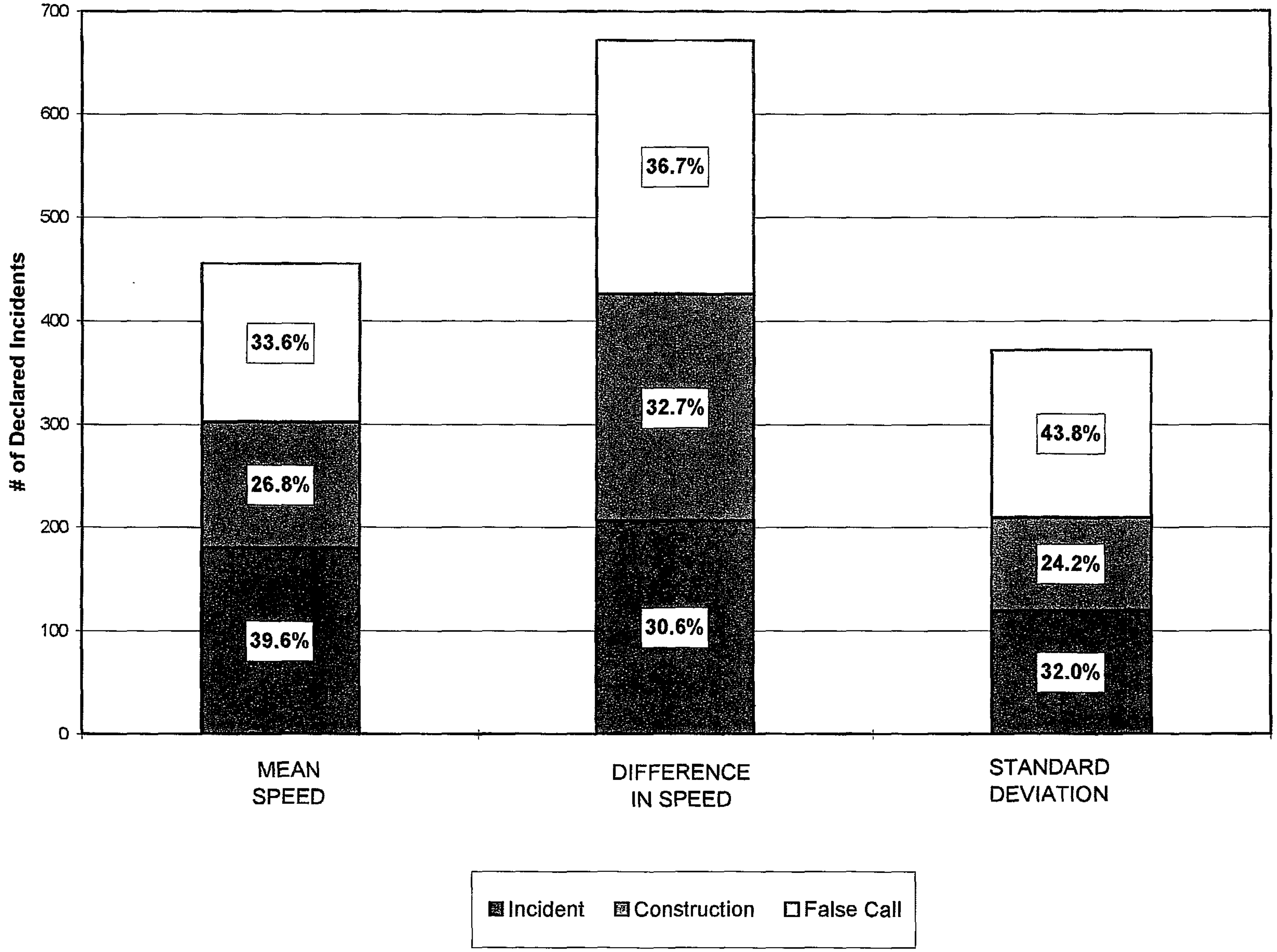


EXHIBIT 10 - REASON FOR INCIDENT

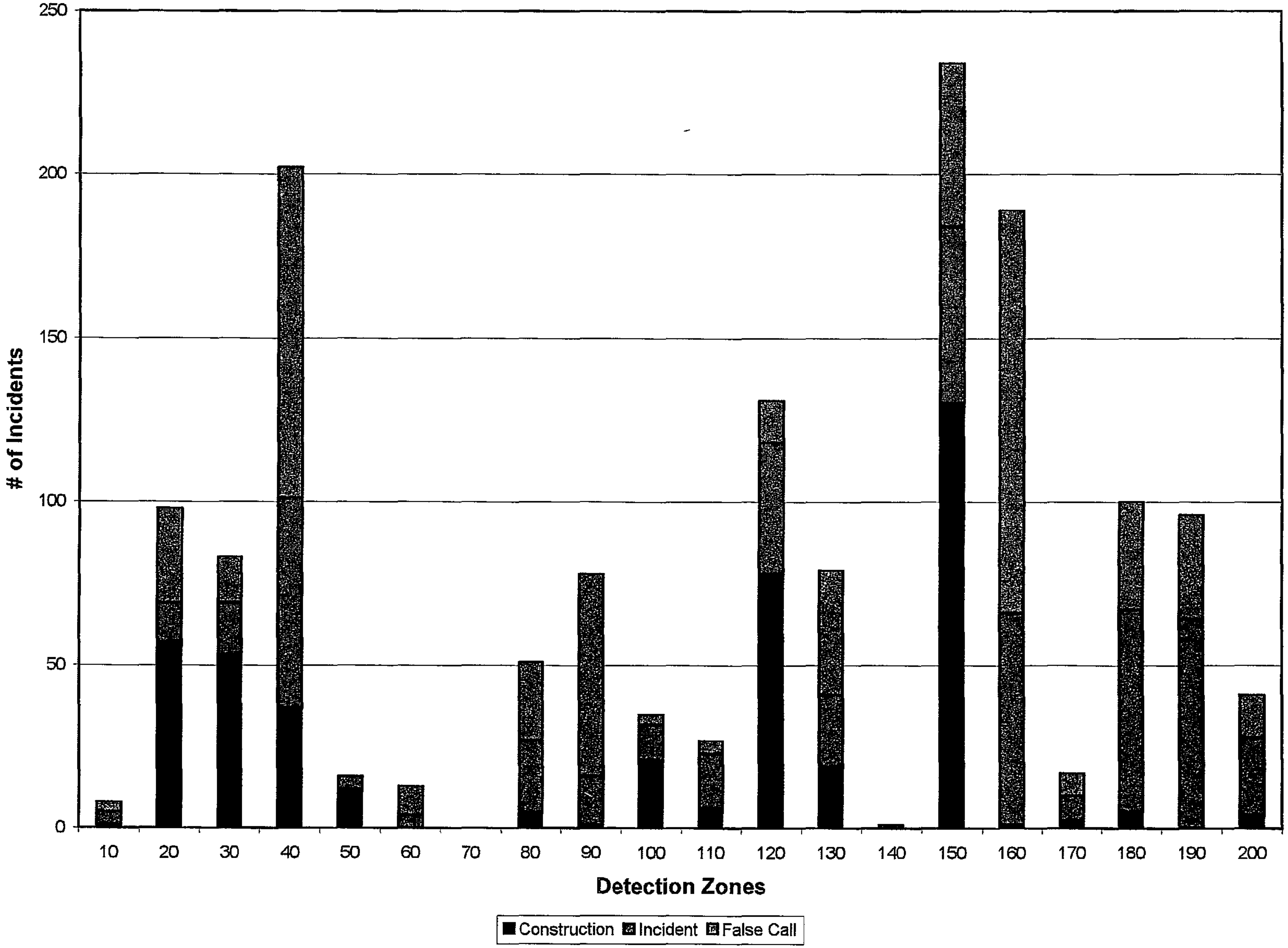


EXHIBIT 11 - REASON FOR INCIDENT BY DETECTION ZONE

cause of the declared incidents at the individual detection zones. As mentioned previously, zones 40 and 160 had some of the highest number of declared incidents, but they also had the highest number of false alarms. These two zones are located in downtown Hartford and are subject to extreme levels of recurring congestion. To further add to the number of false calls, zone 40 is in the midst of a construction zone. Due to the construction, there are reduced lane widths, and a minimal merge area for a downstream on-ramp. These factors increase the amount of recurring congestion that occurs in the area of this detection zone.

3.2.2 Combination of Algorithms

An analysis was also performed which looked at the accuracy of the different algorithms working in conjunction with one another. With the three different algorithms there are four possible combinations of algorithms as follows:

- Mean Speed & Difference in Speed (MS & DS)
- Mean Speed & Standard Deviation (**MS** & SD)
- Difference in Speed & Standard Deviation (DS & SD)
- Mean Speed, Difference in Speed & Standard Deviation (MS, DS & SD)

For this analysis, algorithms were grouped together if they declared an incident at a specific zone within five minutes of one another. Of the 1499 total incidents declared, only 353 involved one of the above combinations of algorithms. This low number is caused by a variety of reasons, most notably that four of the zones (zones 70,80,170, and 200) only use one algorithm. Other reasons include situations where only a single algorithm declared an incident, or the other algorithms were tripped more than five minutes after the first algorithm. Exhibit 12 shows in tabular format the number of occurrences for each detector zone when a combination of algorithms occurred, and the reason (i.e., incident, construction, or false call) for that occurrence. As shown in the exhibit, the accuracy for the different algorithm combinations was in the same range as the individual algorithms CXY%-65%), except for the combination of all three algorithms which had a higher accuracy of 76%.

3.2.3 False Alarms

A total of 562 false alarms were declared by the system during the evaluation period, equating to an Operational False Alarm Rate (OFAR) of 37.5% for the incident detection algorithms. The operational false alarm rate is defined by the following equation:

$$\mathbf{OFAR} = \frac{\textit{number of false alarms}}{\textit{number of declared alarms}}$$

Exhibit 12: Combination of Algorithms

	Mean Speed & Difference in Speed				Mean Speed & Standard Deviation				Difference in Speed & Standard Deviation				All Algorithms (MS, DS & SD)			
Zone	Total	Const.	Incident	False Call	Total	Const.	Incident	False Call	Total	Const.	Incident	False Call	Total	Const.	Incident	False Call
10					1			1					1		1	
20	6	2	1	3	8	2	4	2	6	3		3	7	5		2
30	8	6	2		3		1	2	1	1			10	8	1	1
40	10	1	3	6					12	1	5	6	18	8	6	4
50									2	2			2	2		
60	3			3									1		1	
70																
80	1			1	3		2	1	5		3	2				
90	15		3	12									7		2	5
100	2	2			2		1	1	1		1		3	3		
110	3	1	1	1	3		2	1	2	1	1		1		1	
120	12	6	4	2	3	1	1	1	4	2	2		16	11	4	1
130	7		3	4					3	1	1	1	3	1	1	1
140																
150	33	32	1		4		2	2	3		2	1	10	3	4	3
160	31		10	21	1		1		4			4	6		3	3
170																
180	15		8	7	7		6	1	1			1	5	1	3	1
190	9		6	3	11		6	5	3		1	2	5		4	1
200																
TOTAL	155	50	42	63	46	3	26	17	47	11	16	20	95	42	31	22
Per Cent		32.3%	27.1%	40.6%		6.5%	56.5%	37.0%		23.4%	34.0%	42.6%		44.2%	32.6%	23.2%

As mentioned previously the greatest amount of false alarms occurred at two zones; zones 40 and 160. These two zones accounted for 223 (39.7%) of the total false alarms. Exhibit 13 shows the number of false call occurrences by time-of-day, As shown, the majority of the false calls were during the morning and afternoon peak hours. Approximately 60% of the false calls occurred during the PM peak hour and 18.5% of the false calls were declared during the AM peak hour. The occurrence of false alarms was not limited to weekdays and peak hours. Of the 562 false alarms, 66 (11.7%) of the false alarms occurred on weekends.

Another methodology that has been used for determining false alarm rates is to compare the total number of false alarms to the total number of possible alarms (i.e., execution of the algorithm) that can be declared. This false alarm rate is defined by using the following equation:

$$FAR = \frac{number\ of\ false\ alarms}{Total\ number\ of\ algorithm\ executions}$$

Using this methodology, during the evaluation period there could have been a total of 6289,920 possible alarms declared by the system. With the 562 false alarms that occurred during the evaluation period, the Hartford ATMS had an FAR of 0.009%.

In essence, a false alarm occurs whenever some disruption or other anomaly occurs in the traffic flow that "trips" the incident detection algorithm; when, in fact, the disruption was not caused by an incident. How this can occur in each of the speed based algorithms is noted below:

- ***Mean Speed Algorithm*** - This algorithm looks at the speed at an individual detection zone, and compares it to a user defined threshold. If the smoothed speed at the detection zone is below the threshold for a preset time period, then an incident is declared. In setting the thresholds for this algorithm at the individual detection zones, historical speed data taken from the system were reviewed. When setting the algorithm thresholds, it was decided to set the threshold to be no lower than fifteen miles per hour. It was felt that with the operation of the detectors, and their reliance on vehicle motion, setting the threshold lower than this limit would result in no incidents being declared. At some zones, such as zone 150, which experience significant speed fluctuations during periods of recurring congestion, the speeds will momentarily fall below the 15 mph threshold triggering the incident detection algorithm. An example of this situation, based on actual data recorded by the system, is shown in Exhibit 14.

- ***Difference In Speed***- The operation of this algorithm compares the speed at a detection zone, with the speed at the downstream detection zone. When the speed at the detection zone is a user defined threshold lower than the speed at the downstream zone, an incident is declared. The default value for the "Speed Difference" is 15 mph and this value is modified for specific detection zones and

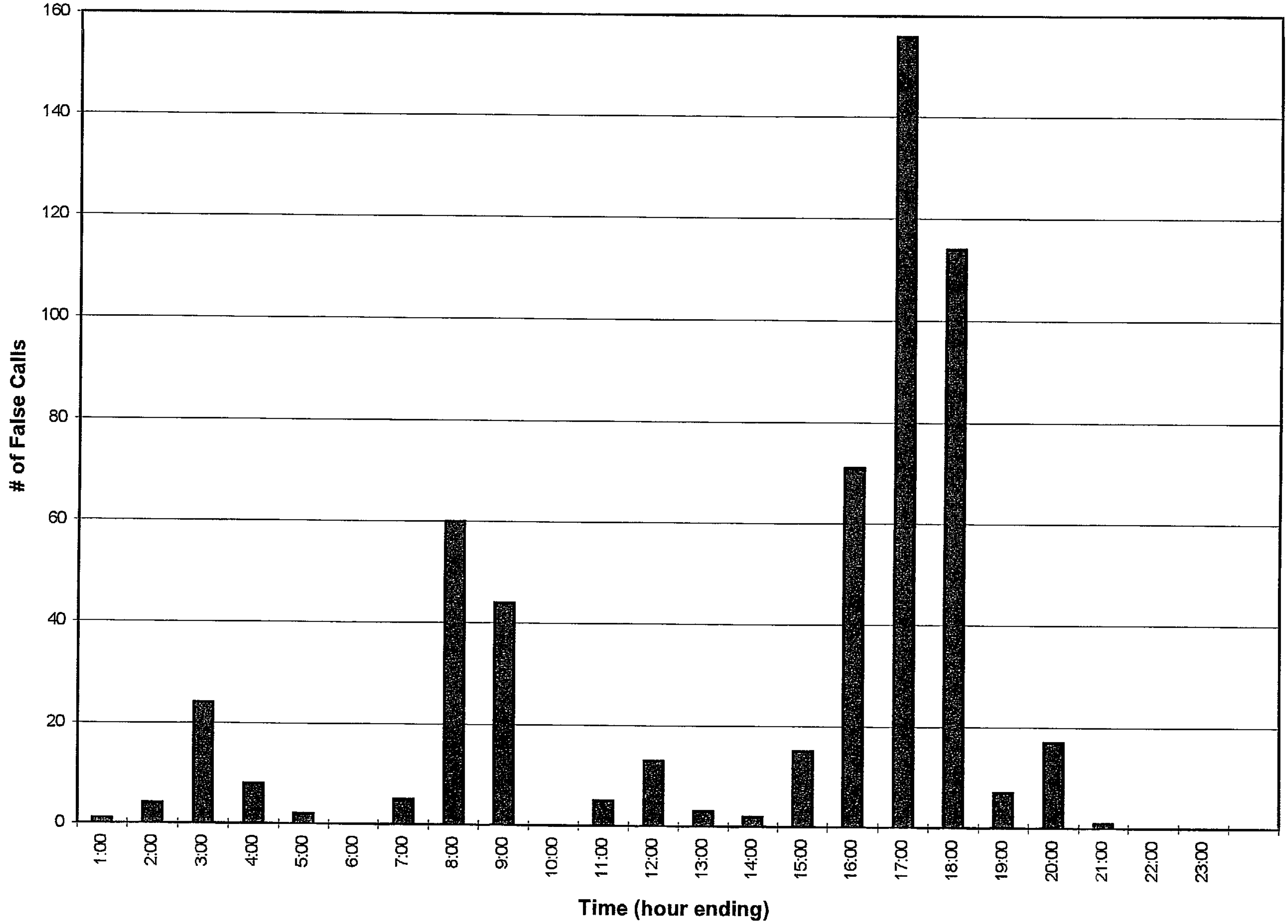


EXHIBIT 13 - FALSE CALL OCCURRENCES

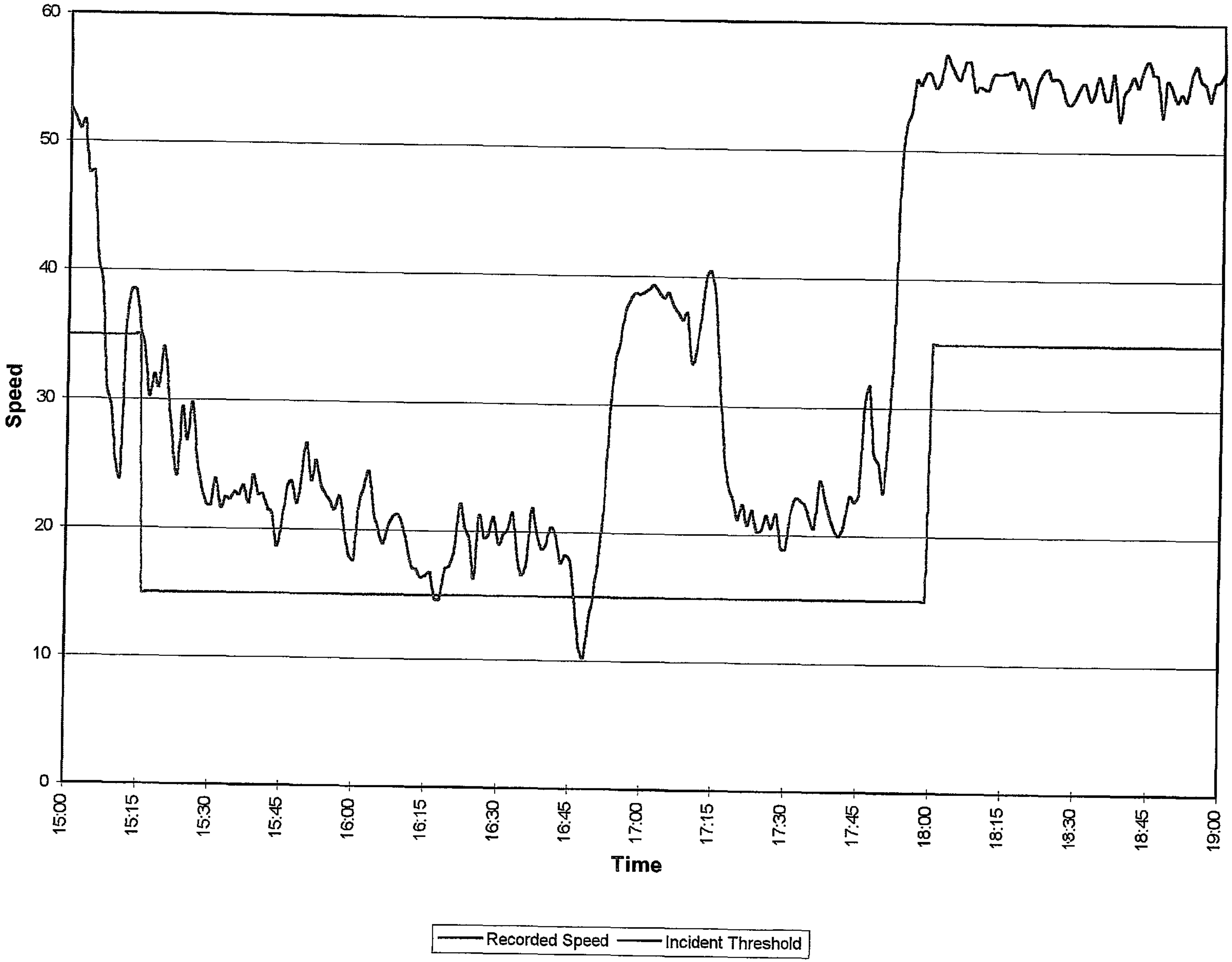


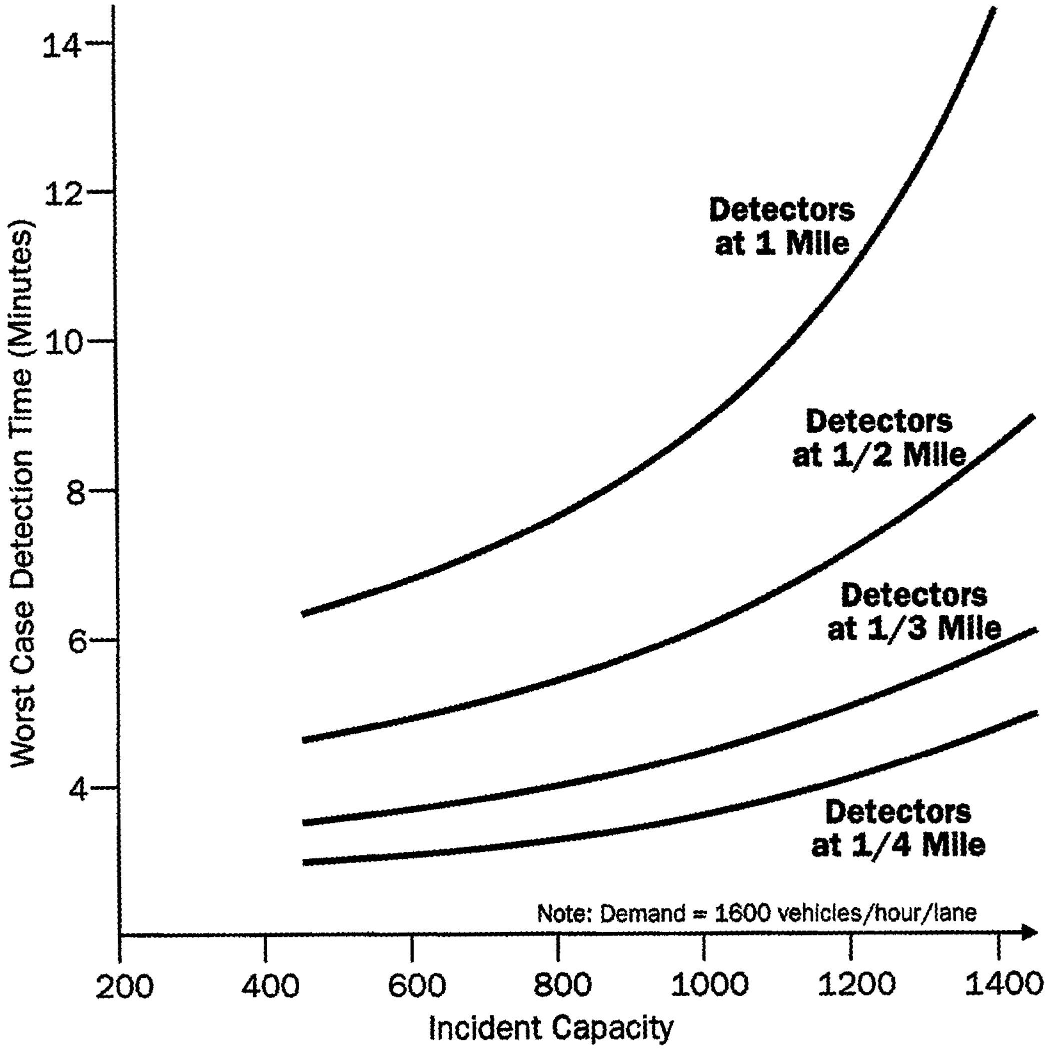
EXHIBIT 14 - MEAN SPEED ALGORITHM OPERATION

time periods based on historical data provided by the system. Considering the operation of the detectors and historical speed data, the maximum value used for this threshold was 40 mph. Similar to the Mean Speed algorithm, situations occur where brief fluctuations in speed at the detection zone, as well as the downstream detection zone, can cause the minimum speed difference to be exceeded. Zone 40 is one detection zone which experiences these occurrences. Exhibit 15 shows actual speed data from zone 40 and its downstream zone, zone 50. As shown in this exhibit, the speed at zone 50 is fairly constant, ranging from 55 to 60 mph. However, the speed at zone 40 fluctuates significantly, resulting in brief periods where the speed difference is greater than the 40 mph threshold, triggering an alarm.

- ***Standard Deviation Algorithm*** - This algorithm looks for variations in travel speeds to detect an incident. The theory behind this algorithm suggests that prior to traffic flow breaking down, there will be large variations in travel speeds, and thus a higher standard deviation. This algorithm is more difficult to set up because of the data that is being analyzed-the variation in speed instead of the actual speed as measured by the radar detectors. Through the analysis of recorded data, the basic theory of the algorithm appeared to be correct; the standard deviation typically increases before or as travel speeds are falling. However, there is no consistency in how much the standard deviation will rise, and it is extremely difficult to tie the rise in standard deviation to an incident, or recurring congestion. In reviewing the data from the system, it was found that the increased standard deviation due to recurring congestion was sometimes higher than the increased standard deviation due to an incident. Also, the increase in standard deviation occurs over a very short time frame, sometimes only a couple of minutes in length. Once the tratlic flow has broken down, and speeds have settled to a low level, the standard deviation will decrease as rapidly as it increased. This makes the standard deviation a difficult value to measure, and even more difficult to apply a persistence check.

  Exhibit 16 shows a graphical plot of the speed and standard deviation at a detector zone, and illustrates the sharp fluctuations in the standard deviation. This exhibit illustrates the other peculiarities of the Standard Deviation algorithm. At the time this data was being logged, an accident occurred downstream of zone 40. That accident was reported to the State Police at 4:26 PM. The effect that accident had on the traffic is shown by the sharp decrease in travel speeds and the increase in Standard Deviation that took place at approximately 4:30 PM. However, the increase in standard deviation that occurred, which is due to recurring congestion, is greater than the increase associated with the accident.

Another possible reason for false calls is unreported or unconfirmed incidents. A vehicle pulling over to the shoulder for a few minutes to check something, a minor rear-end collision with minimal or no damage (but still resulting in the drivers stopping their vehicles to assess the damage), or similar event constitutes an "incident" in the broadest definition of the term. The result is a disruption in the traffic flow which, in turn, may be detected by the algorithm. Such incidents, however, are seldom reported to the police. Without this or other confirmation (e.g., full



Source:
Preliminary Design Report, Highway 401
Ministry of Transportation and Communications
Province of Ontario, Canada

Exhibit 22: Incident Detection Time

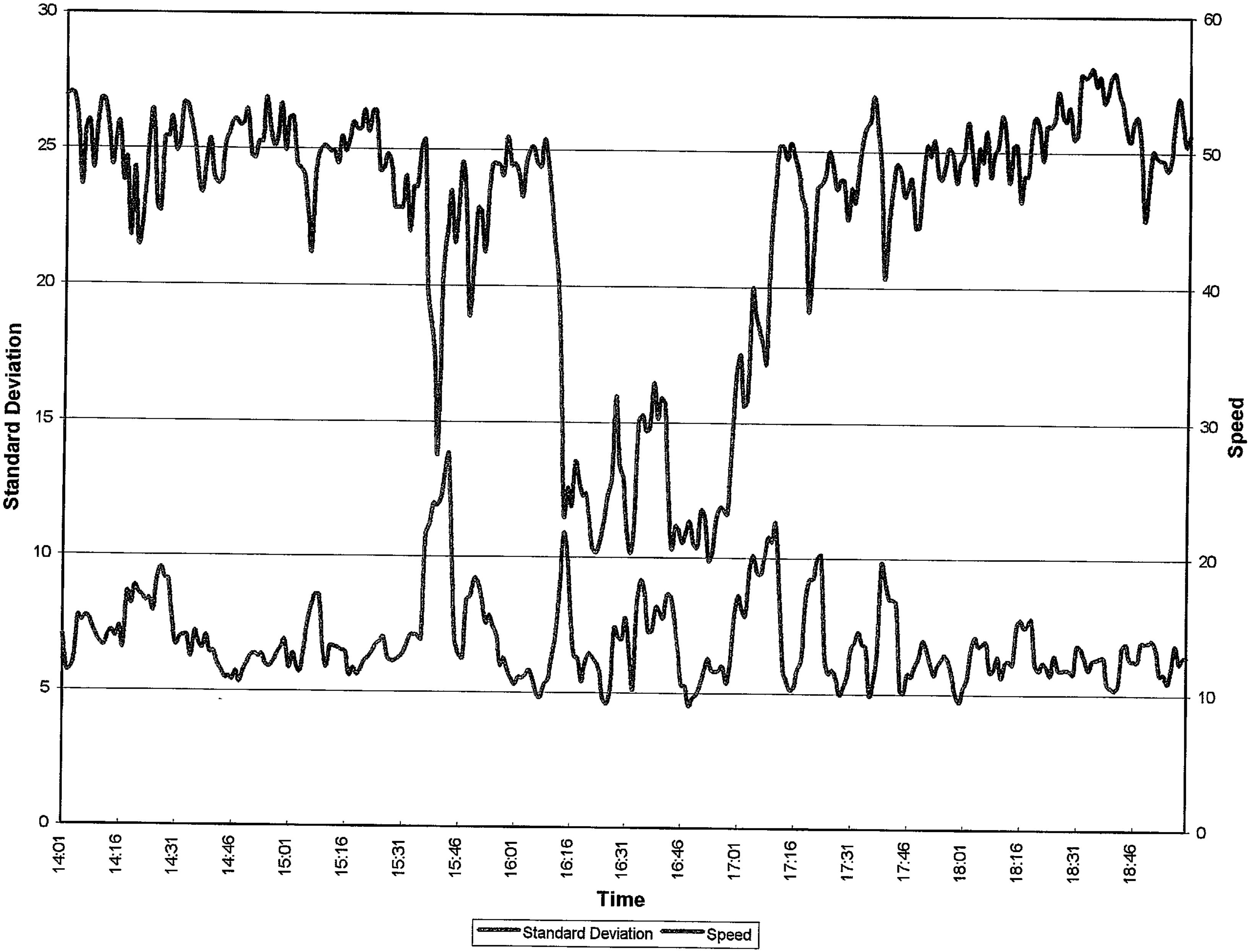


EXHIBIT 16 - STANDARD DEVIATION ALGORITHM OPERATION

coverage by CCTV subsystem), they are classified as false calls. (Note - This is an appropriate representation. Incident detection is only the first step in the overall incident management process. Incidents which quickly clear themselves are not a major concern in this regard.)

3.24 Detection Rate

The setting of the algorithm thresholds is a delicate balance of detecting incidents by measuring disruptions in traffic flow and minimizing false calls. In a simplistic sense, one can ensure that an algorithm has no false calls by setting the thresholds at such a level that the system will only declare an incident in the most extreme circumstances. While this will reduce the FAR, it will also lead to a system which will miss the majority of incidents which actually occur on the roadway. Conversely, the thresholds can be set so that an incident is declared at the most minute disruption in traffic flow. This, however, will lead to a high FAR, and operator confidence in the system will be reduced. The previous discussions have focused on the accuracy of the algorithms with respect to the reason an incident was declared. This section discusses the success of the algorithms at actually detecting incidents which have occurred.

This analysis focused on accidents which occurred within the project area during the evaluation period. The limiting of the analysis to accidents was done to provide a measure of those incidents which are most likely to have an impact on traffic flow and are most likely to be reported and confirmed. Trying to determine the system's ability to detect construction activity would show little value because construction and maintenance activities are typically scheduled to have minimal disruption on traffic.

During the evaluation period there were 199 accidents within the project area. Of these 169 accidents, 61 were detected by the ATM & detection rate of 61%. The detection of an accident depends on a number of factors including the time of day, the nature of the accident, and the location of an accident with respect to a detector station. Accident information provided by the State Police for this analysis provided limited data on the nature of the accidents. The information provided included date, time and approximate location of accident between interchanges. Exhibit 17 illustrates the distribution of 39 undetected accidents that occurred on weekdays by time-of-day. As shown, the majority of undetected accidents occurewd during the non-peak hours, with only two peak hour accidents being undetected by the system. During the AM (7:00~9:00) and PM (3:00-6:00) peak hours, there were a total of 35 accidents. With only two of these accidents being undetected, the system had a detection rate of 94% during the peak periods when incident detection is most crucial.

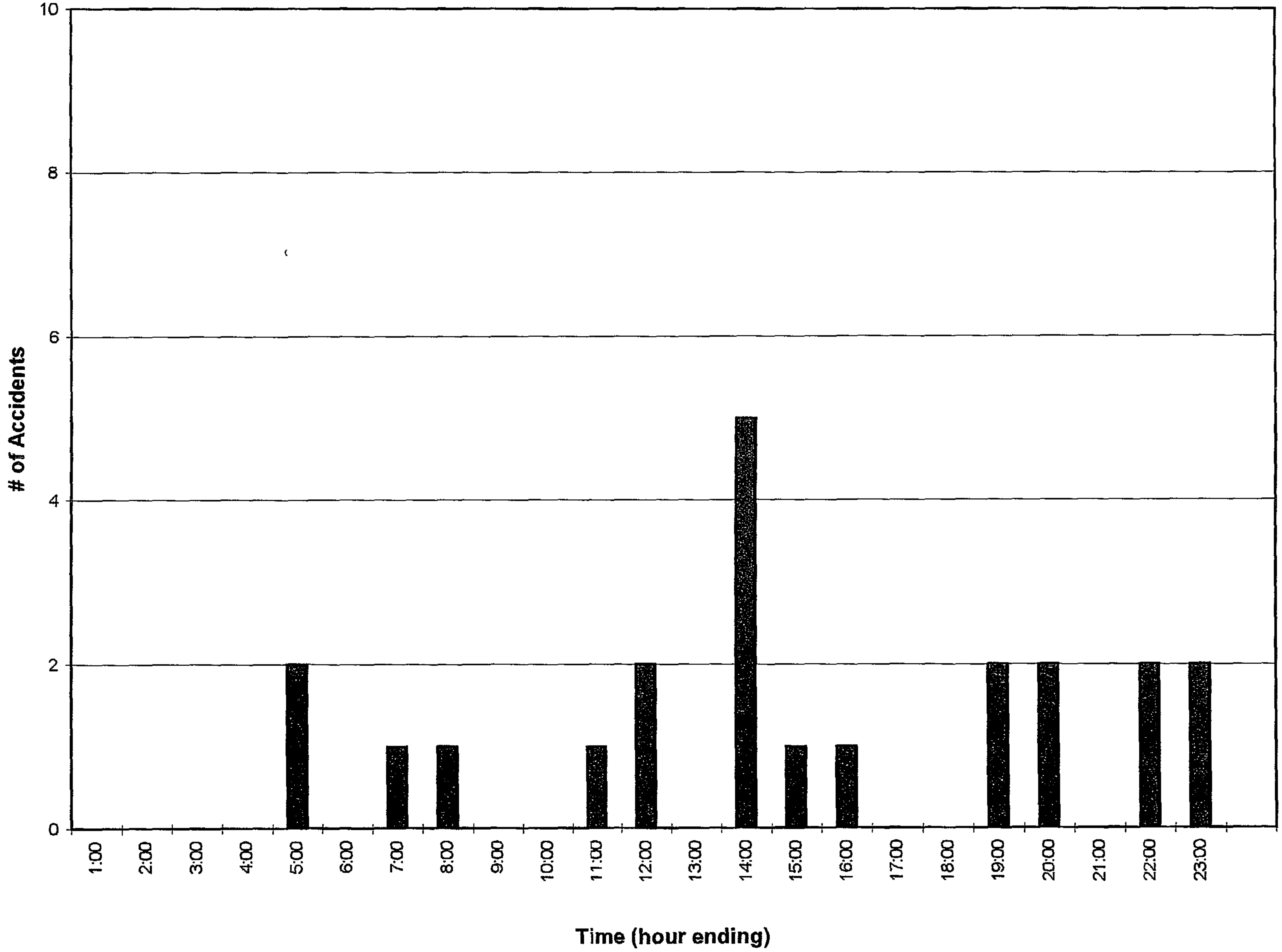


EXHIBIT 17 - MISSED ACCIDENTS - WEEKDAYS

The ability of the algorithms to detect accidents showed results similar to the accuracy of the individual algorithms. In both cases, the Standard Deviation showed the lowest potential of the three algorithms. Exhibit 18 shows the number of accidents detected by each of the individual algorithms. As shown, the Difference in Speed algorithm detected the greatest number; 46 accidents. The Mean Speed algorithm showed similar results, detecting 41 of the accidents. The Standard Deviation algorithm showed the lowest potential for detecting accidents, detecting only 25 of the accidents that occurred.

Algorithm	# of Accidents Detected	#of First Call Accidents
Mean Speed	41	18
Different speed	46	23
Standard **Deviation**	25	20

Ekhibit 18: Accident Detection

Also shown in Exhibit 18 is the number of times each algorithm was the firet to detect an accident. In this analysis all of the algorithms showed similar results with the Mean Speed, Difference in Speed, and Standard Deviation algorithms being the first to detect 18-23, and 20 accidents respectively. Interestingly, while the Standard Deviation algorithm detected the lowest number of accidents, it was the flrst algorithm to detect 80% of the time when it detected an accident. This is compared to 44% and 51% respectively for the Mean Speed and Difference in Speed algorithms. Thus, while the Standard Deviation algorithm detected the least amount of the accidents, when it did detect an accident, it was typically the first algorithm to do so.

When a combination of algorithms was used to detect accidents, only 40 of the accidents were detected. The number of accidents detected by the four different algorithm combinations are shown in Exhibit 19. The results for the combination of algorithms corresponds with the results for the individual algorithms, with the Mean Speed/Difference in Speed combination detecting the greatest number of accidents, 20.

Algorithm : Combination	#of Accidents Detected
Mean Speed : Difference in Speed	20
Mean Speed : Standard Deviation	4
Difference in Speed: Standard Deviation	**6**
Mean Speed, Difference in Speed : Standard Deviation	10

Exhibit 19: Accident Detection-Combination of Algorithms

The fact that 40 accidents were detected by multiple algorithms leaves 21 accidents that were detected by a single algorithm only. Of these 21 occurrences the difference in speed accounted for 10, the mean speed accounted for 7 and the standard deviation algorithm accounted for 4.

3.2.5 Detection Time

Through the use of incident detection algorithms, system operators can find out about incidents on the highways in a more timely fashion, and can take steps to initiate the proper response. Without such a system in place, the primary means of learning about an accident is via phone calls.

Data provided by the State Police detailed when the initial phone call was received for each of the accidents. This data was compared to data from the system to determine detection times for the incident detection algorithms. The comparison of detection times only shows a comparison of when the system detected an accident to when the State Police were first informed about an accident. Detection times from when the accident actually occurred are not possible because accurate information on the actual time of the individual accidents is not available.

For all three of the algorithms the average detection time was twelve minutes after the State Police received a call regarding the accident. The detection times for the individual accidents ranged from 10 minutes prior, to 165 minutes after the State Police received a call regarding the accident. Exhibit 20 is a plot of the detection time versus time of day. As shown, accidents which occurred during the peak hours had the lowest detection times, with an average of four minutes, and in many cases, were detected by the ATMS prior to the State Police receiving a call about the accident.

Like the other incident detection performance measures, the time it takes to detect an accident is dependent on many different variables. These include nature of the accident, the traffic conditions at the time the accident occurred, and the location of the accident with respect to a detector location. For the accidents detected by the incident detection algorithms, the accidents which had the longest detection times typically occurred during the evening or early morning hours, or on weekends. This is the case for the accident which had a detection time of 165 minutes. This accident occurred at 0090 AM and was not cleared until approximately 4:00 AM. The low volumes that are present during the early morning hours when this accident occurred led to a situation where it took an extended period of time for the resultant queue to extend back to the upstream detector zone. During these time periods, traffic demand is reduced, which increases the time to detect an incident. In some cases it is even possible for the incident detection algorithms to miss the accident all together if the nature of the incident and the trafiic

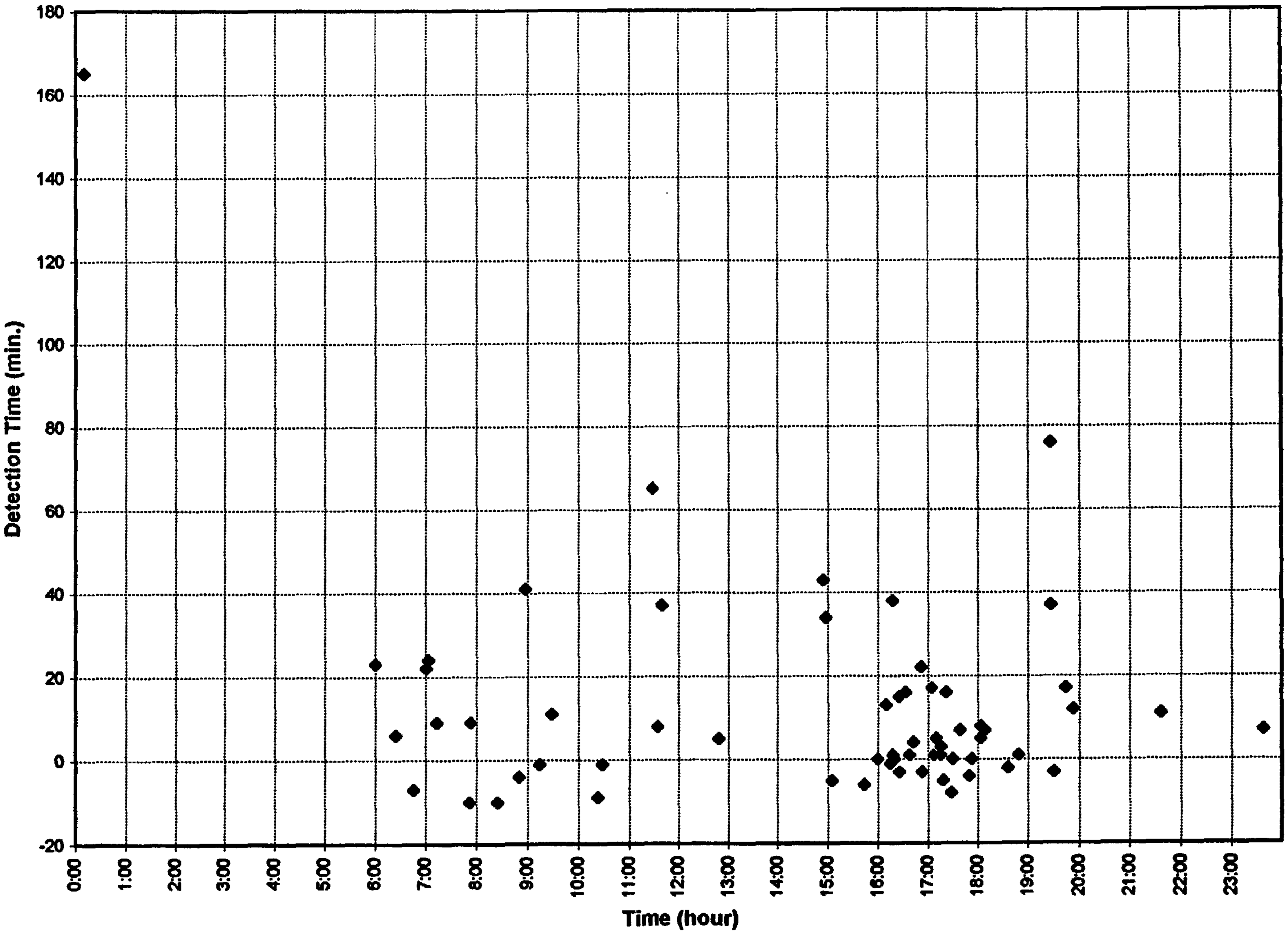


EXHIBIT 20 - DETECTION TIME (all accidents)

demand are such that the queue (i.e., area of reduced speed) from the incident never extends back to the detection zone.

Relying on a combination of algorithms to detect an accident would result in an average detection time of twenty six (26) minutes. The detection times for the combination algorithms ranged from 7 minutes prior, to 166 minutes after the State Police received a call regarding an accident.

4 CONCLUSIONS

Based on the analysis discussed above, the use of radar detectors and speed-based incident detection algorithms are very effective for monitoring traffic conditions, and detecting incidents. The accuracy of the detectors for measuring vehicle speeds provides system operators with a real-time display of traffic conditions on the highways in the project area. The real time information provided by the system has produced many benefits in addition to automated incident detection. One of the greatest benefits provided by the system is the ability to quickly inform the system operators of the extent of queues caused by accidents after the accident has occurred. This allows the operators to relay this information to the traveling public through the use of variable message signs. Some of the local television stations have also recognized the benefits of the information provided by the system and have started broadcasting from the Control Center during snow storms.

4.1 Radar Detectors

The use of radar detectors to monitor vehicle speeds, and thus traffic conditions, provides not only accurate data, but also provides data which is easily understood by the system operators, and the traveling public. The accuracy of the detectors for monitoring vehicle speeds is very high. Moreover, the aforementioned FHWA Study identified the Whelen detectors as the best at providing vehicle speed data, with the caveat that they do not detect stopped or near-stopped (less than 5 mph) traffic The major drawback of the radar detectors is that they are only able to provide accurate speed data, and have not shown the ability,-on this system, to provide accurate data on other traffic flow parameters such as traffic volume. The FHWA testing performed on the narrow beam Whelen detectors has shown impressive accuracy results with regard to traffic volume. The reason those accuracies are not being achieved in the Hartford area is unknown. It should be noted that the low volume accuracy found in the Hartford Area ATMS has not been limited solely to this system. Limited testing performed on ConnDOT's I-96 freeway management system, which uses the same detection technology, has shown similar results for volume accuracy The ability to provide accurate traffic volume, at those sights with narrow beam detectors, would enhance the operation of the system by giving the operators information on traffic demand, and also providing data for other units within ConnDOT, such as the Bureau of Policy and Planning Department.

4.2 Incident Detection Algorithms

To draw a conclusion on the operation of the incident detection algorithms, their false alarm rates, and ability to detect accidents, a comparison to other algorithms provides the greatest measure of their operation. Incident detection algorithms have been in use for many years with poor to moderate success. In some cases, such as the INFORM system on Long Island, the poor operation of the incident detection algorithms has led to their discontinued use. Similar experiences have occurred on other systems throughout the country In addition to the California algorithms, numerous other incident detection algorithms have been developed, or are undergoing development, to try and find the "perfect" algorithm. The "perfect" algorithm is defined as one that is easy to implement, gives no false alarms, detects every incident as soon as it occurs, and does not require extensive calibration. The speed-based algorithms developed for the Hartford ATMS, while showing very favorable results, still fall short of being "perfect".

4.2.1 Operational False Alarm Rate (OFAR)

As discussed previously, the incident detection algorithms had a combined operational false alarm rate (OFAR) of 37.5%.

The Mean Speed and Difference in Speed algorithms had similar OFARs; 33.6% and 36.7% respectively. The OFAR for the Standard Deviation algorithm was slightly higher at 43.8%. While these false alarm rates may appear to be high, they are extremely low compared to the OFAR of other algorithms. One algorithm, which is being used and continually mod&d, is the McMaster algorithm. This algorithm is used by the COMPASS system in Toronto. The algorithms used for that system are operating with an OFAR of 97.67%. This includes both alarms which were declared when there was no congestion, as well as alarms that were declared for recurring congestion. In addition to its use on the COMPASS system, testing was done using the McMaster algorithm by the University of Minnesota. This testing, which was done to evaluate the AutoScope video detection technology, showed the McMaster algorithm with an OFAR of 87%. Another algorithm used in this evaluation, AutoScope Incident Detection Algorithm (AIDA), had an OFAR of 81%. The results of the tests for these two algorithms are included in Appendix B.

Through the use of simultaneous detection on multiple algorithms, the OFAR was approximately equal to the operation of the individual algorithms. The only significant difference being with the combination of all three algorithms, which had an OFAR of 24%. This improvement in the OFAR however, is offiet by decreased ability to detect incidents which will be discussed later.

4.2.2 False Alarm Rate (FAR)

Another methodology of determining the false alarm rates is to compare the number of false alarms to the total number of possible alarms that could be declared. As mentioned previously, when combii all three algorithms, the FAR for the Hartford ATMS was 0.009%. The FARs for the individual algorithms are shown in Exhibit 21. These FARs show considerable improvement over other algorithms that are currently being used. On-line testing of the California algorithms resulted in a FAR ranging from 0.63% to 0.74%2. Another algorithm which has undergone testing is the High Occupancy (HIOCC) algorithm. This algorithm had a FAR of 4% for on-line tests(2) As shown the speed based algorithms used for the Hartford Area ATMS perform much better than these other algorithms when the FAR is used as a performance measure.

Algorithm	False Alarm Rate
Mean Speed	0.006%
Difference in Speed	0.012%
Standard Deviation	0.008%
All Algorithms	0.009%

Exhibit 21: Algorithm False Alarm Rates

4.2.3 Incident Detection

As their name implies, the primary purpose of incident detection algorithms is to detect traffic incidents. Focusing on accidents which occurred in the project area during the evaluation period, the three algorithms used on the ATMS detected 61% of the recorded accidents. This shows favorable results when compared to data from the other systems and tests mentioned

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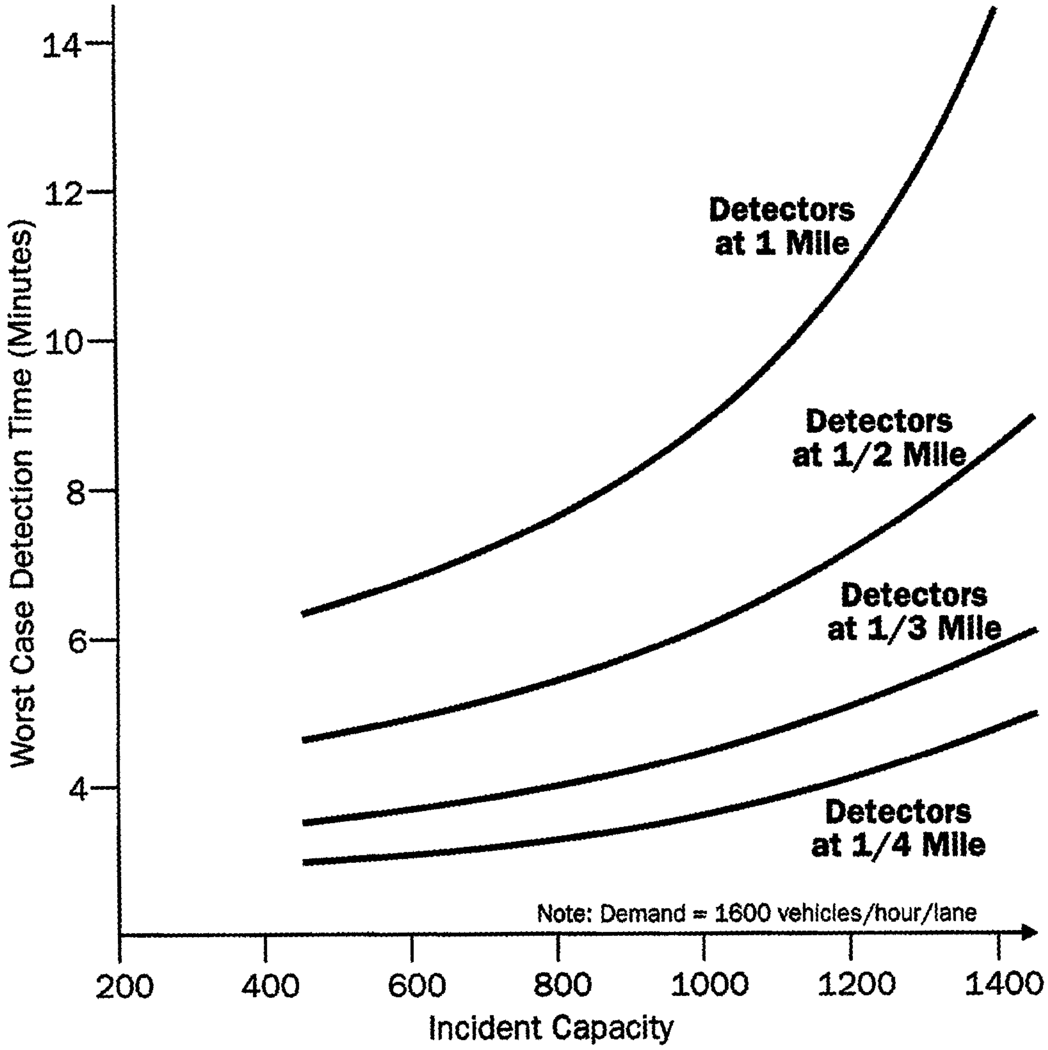
2Ball Engineering Incident Detection Issues Task A Report, Automatic Freeway Incident Detection, Drafl Interim Report; October 1993 previously. On the **COMPASS** system, 84.7% of the incidents were detected by the system. However, the **COMPASS** data may be misleading because the operation of the system does not allow for automated incident detection once the incident has been detected by other means. The testing performed by the University of Minnesota showed the McMaster algorithm to detect 28% of the incidents that occurred, In those same tests, the AIDA algorithm detected 14 out of 18, or 78% of the incidents. Appendix B contains reports which detail the results of the McMaster and AIDA algorithms. In addition, on-line testing of the California Algorithms showed a detection rate of 41%-56%. The High Occupancy (HIOCC) Algorithm had a detection rate of 94% in on-line tests. While the results of the HIOCC algorithm are impressive, one must keep in mind that this detection rate was achieved at the expense of FAR as discussed in the previous section. The HIOCC algorithm had an FAR over 400 times greater than the speed-based algorithms.

For the individual algorithms, the Difference in Speed algorithm functioned the best, detecting 48 of the 100 accidents that occurred. The Mean Speed algorithm was a close second, detecting 41 of the accidents, and the Standard Deviation algorithm showed the worst detection rate, only detecting 25 of the accidents.

When a combination of algorithms was used, the incident detection rate fell sharply, with the combination of the mean speed and difference in speed algorithms performing the best, detecting 20% of the accidents that occurred during the evaluation period. The combination of all three algorithms detected only 10 of the 100 accidents which occurred. Thus, while this means of detection had the lowest false alarm rate, it also had one of the lowest incident ***detection rates,*** The detection rate, however, is so low that it is not made up for by the improved FAR

4.2.4 Detection Time

As discussed, the average time to detect an accident for the three algorithms was twelve minutes after a call was received by the State Police. This detection time, however, is more a factor of the detector spacing than the incident detection algorithms themselves. With the one mile detector spacing that is currently used on the ATMS, this detection time is not out of line. Exhibit 22 shows the detection time for various detection spacings and volume/capacity ratios. On a roadway functioning slightly over capacity, it will take approximately fourteen munutes to detect an accident with one mile detector spacing. This value decreases significantly as the demand increases and the capacity of the roadway is further exceeded. The Hartford Area ATMS showed similar characteristics, with those accidents which occurred during peak hours being detected by the system much quicker, and in many cases, prior to the State Police receiving a phone call about the accident.



Source:
Preliminary Design Report, Highway 401
Ministry of Transportation and Communications
Province of Ontario, Canada

Exhibit 22: Incident Detection Time

As a matter of comparison, on-line testing of the California Algorithms showed a Mean Time to Detect of 5.3-7.5 minutes. It should be noted, however, these on-line tests were performed during rush hour traffic conditions and with a l/2-mile detector spacing.

4.2.5 Summary

Exhibit 23 provides a summary of the various performance measures for the speed based incident detection algorithms and a comparison against other algorithms which had on-line test data available.

Algorithm	OFAR	FAR	Detection Rate	Time-To-Detect During Peak Hours
Mean Speed	33.6%	0.006%	41%	9 min(a)
Difference In Speed	36.7%	0.012%	46%	10 min(a)
Standard Deviation	43.8%	0.008%	25%	8 min(a)
California(3)	NA	0.63%–0.74%	41%–56%	5.3–7.5 min(b)
AIDA	81%	NA	78%	NA
McMaster	87%–97%	NA	28%–35%	NA
High Occupancy(3)	NA	4%	94%	NA

(3) Ball Engineering; Incident Detection Issues Task A Report, Automatic Freeway Incident Detection, Draft Interim Report: October 1993
(a) With one mile spacing
(b) With l/2-mile detector spacing

Exhibit 23: Summary of Various Performance Measures

This information shows that the speed based algorithms perform very favorably when compared to other algorithms durrently in use. The speed based algorithms perform better than the other algorithms in terms of false alarm and operational false alarm rates. Based on the detection rate, the speed based algorithms are out performed by the other algorithms. However, each of the algorithms which have better detection rates also have significantly higher false alarm and operational false alarm rates. This trade-off between false alarms and incident detection is one faced by all algorithms and requires a delicate balance when setting up the algorithm thresholds. The California algorithms show a lower time-to-detect but that difference is more a result of the detector spacing that is used than the algorithms themselves.

5 RECOMMENDATIONS

While the field equipment and incident detection algorithms used on the Hartford Area ATMS show very favorable results they are not perfect, and there is room for improvement. Regarding the radar detectors, it is recommended that additional work be done with Whelen Engineering to determine if improved volume accuracy can be achieved. As previously mentioned, the Whelen detectors have shown themselves to be extremely accurate in other tests, and if so, similar results should be available to ConnDOT.

Of the three incident detection algorithms the Difference in Speed and Mean Speed algorithms showed similar results. While the Mean Speed algorithm had a lower FAR, the Difference in Speed algorithm had the highest detection rate. The Standard Deviation algorithm had the highest false alarm rate and the lowest detection rate. As discussed previously, the traffic conditions in the project area and the operation of the Standard Deviation algorithm are such that further fine tuning will probably not lead to improved results of this algorithm. While the false alarm rate could be minimized, this would be at the expense of the detection rate. Considering that the Mean Speed and Difference in Speed algorithms are present on the system, attention should be given to discontinuing the use of the Standard Deviation algorithm. Eliminating this algorithm will not have a sign&ant impact on the ability of the system to detect incidents, nor will it cause a degradation of detection time. The benefit of eliminating this algorithm would be a reduction in the number of total alarms. By reducing the number of alarms declared by the system, operator confidence in the system can be improved.

The false alarm rates attributed to the algorithms and the overall system can also be improved by adjusting the algorithm thresholds based on weather conditions. Adverse weather conditions. Adverse weather such as heavy rain and snow affect traffic conditions and result in motorists traveling at slower speeds. These slower travel speeds can result in alarms being declared even though there are no incidents present. The ATMS currently has only one set of algorithm thresholds that are used for all weather conditions. Due to the effect that weather has on traffic flow, the system should be modified to incorporate a second set of thresholds which can be used during inclement weather. These "weather thresholds" would utilize lower speeds than the current thresholds. The implementation of these lower thresholds could be implemented manually by the operators when inclement weather is present. It could also be possible to incorporate the "weather thresholds" automatically based on sensors installed in the field. This type of operation is being implemented as part of the I-95 Freeway Traffic Management System.

It should be noted that to have such a functionality as part of the ATMS would require major revisions to the field equipment including the addition of the precipitation detectors, modifying the communications equipment and revising the communications protocols.

The operations of the Hartford Area ATMS is such that each of the algorithms operates independently. During the course of this evaluation, results were also evaluated for the various algorithm combinations. This evaluation showed that using a combination of algorithms to declare incidents did not provide a significant improvement to system performance. Thus, revising the system to rely on multiple algorithms to declare an incident is not recommended.

The detection rate and time to detect of the algorithms can be improved by modifying the detector spacing. As discussed previously, the Hartford Area ATMS was an FHWA demonstration project which had limited funding. The design of the system and the placement of the detectors was based on a variety of factors including using existing overhead structures and trying to obtain the hugest area of coverage. The placement of the detectors was also affected by the presence of major roadway construction projects. A couple of locations which were recommended for detector stations were not constructed because major construction projects were underway in the area. These two criteria led to a system which has a detector spacing of approximately one mile. This detector spacing affects the detection rate and time-to-detect in the following manner:

- During light to medium traffic conditions, the queue resulting from an accident may not extend back to the upstream detector station. If the queue does not extend back to where traffic passing a detector station has to slow down, then the detectors cannot measure the reduced speeds and the accident will not be detected resulting in a lower detection rate.
- The increased spacing between the detectors results in more time being required for the queue to reach the upstream detector station (if it even extends back that far). As shown in Exhibit 22, the time to detect an accident can be reduced by approximately 4-6 minutes by using a l/2 mile detector spacing.

To improve the performance of the system, it is recommended that additional detectors be installed to achieve a l/2 mile detector spacing. While benefits can be achieved by providing this reduced spacing throughout the system, the following areas should be given the highest priority:

1. I-84 between High Street and Connecticut Boulevard - The preliminary design of the system included a detector station on I-84 at Main Street in Hartford. Due to the construction of a platform over I-84, this detector station could not be built. Now that the platform construction is complete, consideration should be given to installing a detector in this location. This area experiences severe levels of recurring congestion and a number of accidents. Placing a detector station at Main Street would also provide valuable information regarding traffic conditions under the platform which cannot be viewed by the system's CCTV cameras.

2. I-84 between Capital Avenue and High Street - This area has a number of entrance and exit ramps. The weaving activity that results in this area causes a number of accidents as well as reaming congestion, especially during the PM peak hour.

3. I-91 between I-84 and Jennings Road - This area also experiences recurring congestion that is the result of merging, weaving, and diverging activity associated with the interchange ramps between I-91 and I-84 and the Jennings Road ramps. During the AM peak hour, there is a difference in travel speeds on SB I-91 of over 20 miles per hour between Jennings Road and I-84. This large difference is speed illustrates the levels of congestion in this area.

4. I-91 between the Whitehead Highway and I-84 - During the PM peak hour, there is a difference in speed between these two sites of over 35 miles per hour. The congestion which occurs in this area is exacerbated by the presence of construction in this area which results in reduced lane widths and minimal ***acceleration*** lengths for a left hand on ramp. This area can be readily viewed from one of the CCTV cameras which provides valuable information to the system operators. Prior to installing a detector at this location, the Department may want to wait until the construction is complete to determine if a detector is truly necessary in this area.

Other areas such as I-91 south of Hartford should also be considered. While this area does not experience the congestion levels as the previous areas, it does have the largest spacing between detection zones, exceeding 7,900 feet in some instances. Adding detectors to reduce spacing to a l/2 to 3/4 mile will improve incident detection in this area.

Currently the setting of the thresholds requires personnel to review the speed data supplied by the system and then to manually adjust the threshold settings for the different algorithms at the individual detection zones. This is a very time consuming process, which needs to be performed approximately every three months. The three month value is based on previous work, where it was shown that travel speeds vary with the seasons, with lower travel speeds being present during the winter months. Construction activity in the project area also requires the refinement of thresholds as new long-term traffic patterns are established. The current operation of the system requires that when a threshold is changed from the default value, the operator has to change the value in a table for the specific fifteen minute interval for each day, even if the same value is going to be used for every day of the week It is recommended that the system be revised to modify the way that the various algorithm thresholds are set. One option for modifying the threshold settings include the use of a scheduler, where through the entry of angle command line, the operator can set a threshold level for a given time period. A second option would be to allow the system to automatically set thresholds based on historical data collected by the system. This latter method is being used by ConnDOT on their I-95 Freeway Traffic Management System The operation of the automatic threshold setting should be evaluated prior to its use on the Hartford Area ATMS.

APPENDIX A - Algorithm Flow Charts

APPENDIX A . INCIDENT DETECTION ALGORITHM FLOWCHARTS

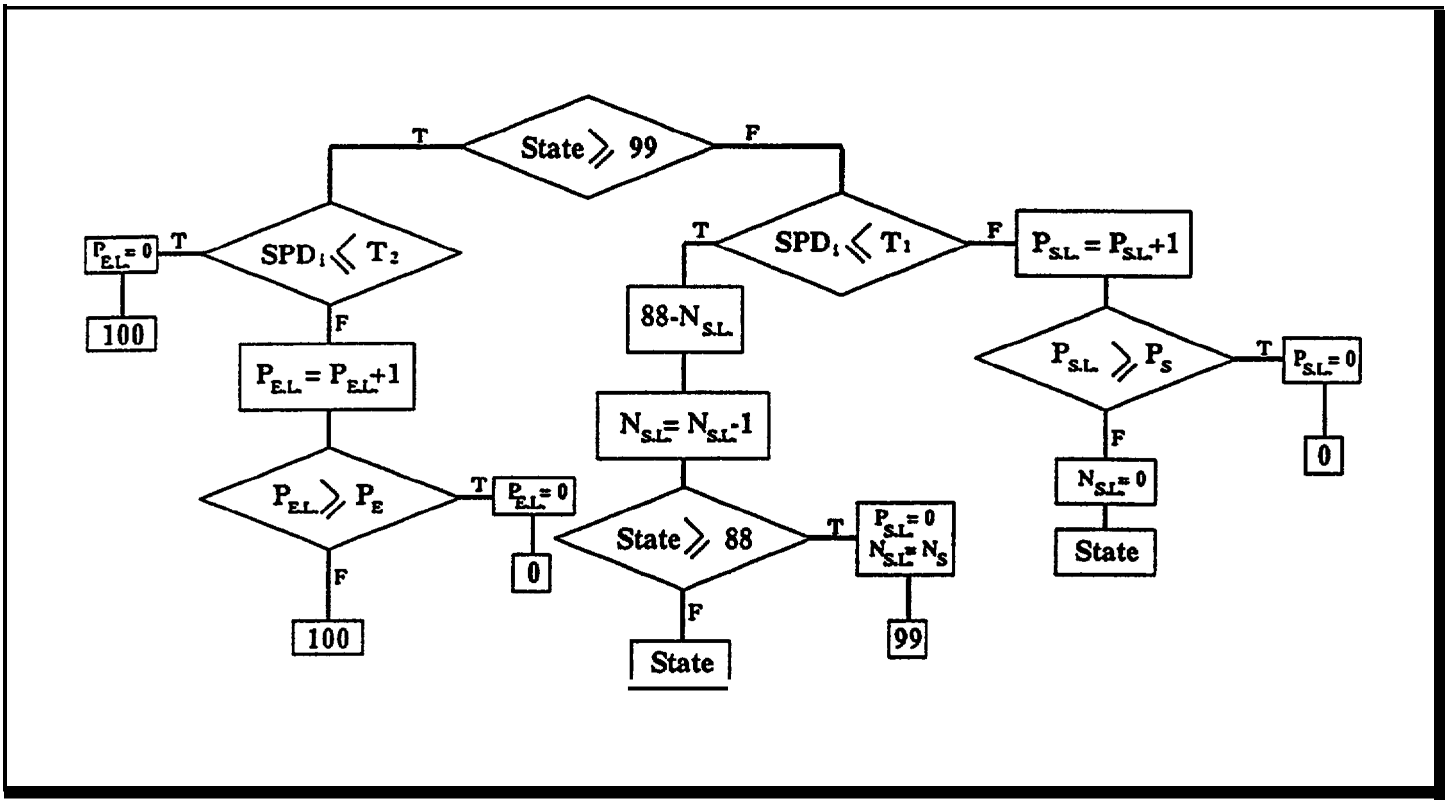
Included in this index are the flowcharts for the four individual incident detection algorithms used within CTATMS. Also included below is a list of definitions of variables and algorithm states used within the flowcharts.

Variable Name	Description
SPDi	Smoothed speed station i.
SPDi+l	Smoothed speed at station i+l, (the station adjacent and downstream of station i).
AV.SPD(i,t)	The average speed at station i for time period t.
AV.SPD(i+l, t-p)	The average speed at station i for the prior p periods.
SPDDF	SPDi+l - SPDi (Spatial difference in speed).
SPDRDF	SPDDF / SPDi+l (Relative Spatial difference in speed).
SPDCTD	$\frac{(AV.SPD(i+1,t-p)-AV.SPD(i+1,t))}{AV.SPD(i+1,t-p)}$ Relative temporal difference in speed downstream.
SDSPDi	Standard deviation of speed at station i.

Algorithm State Values

State	Indication
0	Incident Free.
1	Incident Terminated.
88-n to 88	Incident Tentative (see note below).
99	Incident Confirmed.
100	Incident Continuing.

Note: N represents the value of a number of operator modifiable persistence thresholds which specify the duration required from a Tentative to non-Tentative condition.



Mean Speed Algorithm

Tl- Speed Start Incident.

T2 - Speed-End Incident.

Ns - Intervals Start Incident.

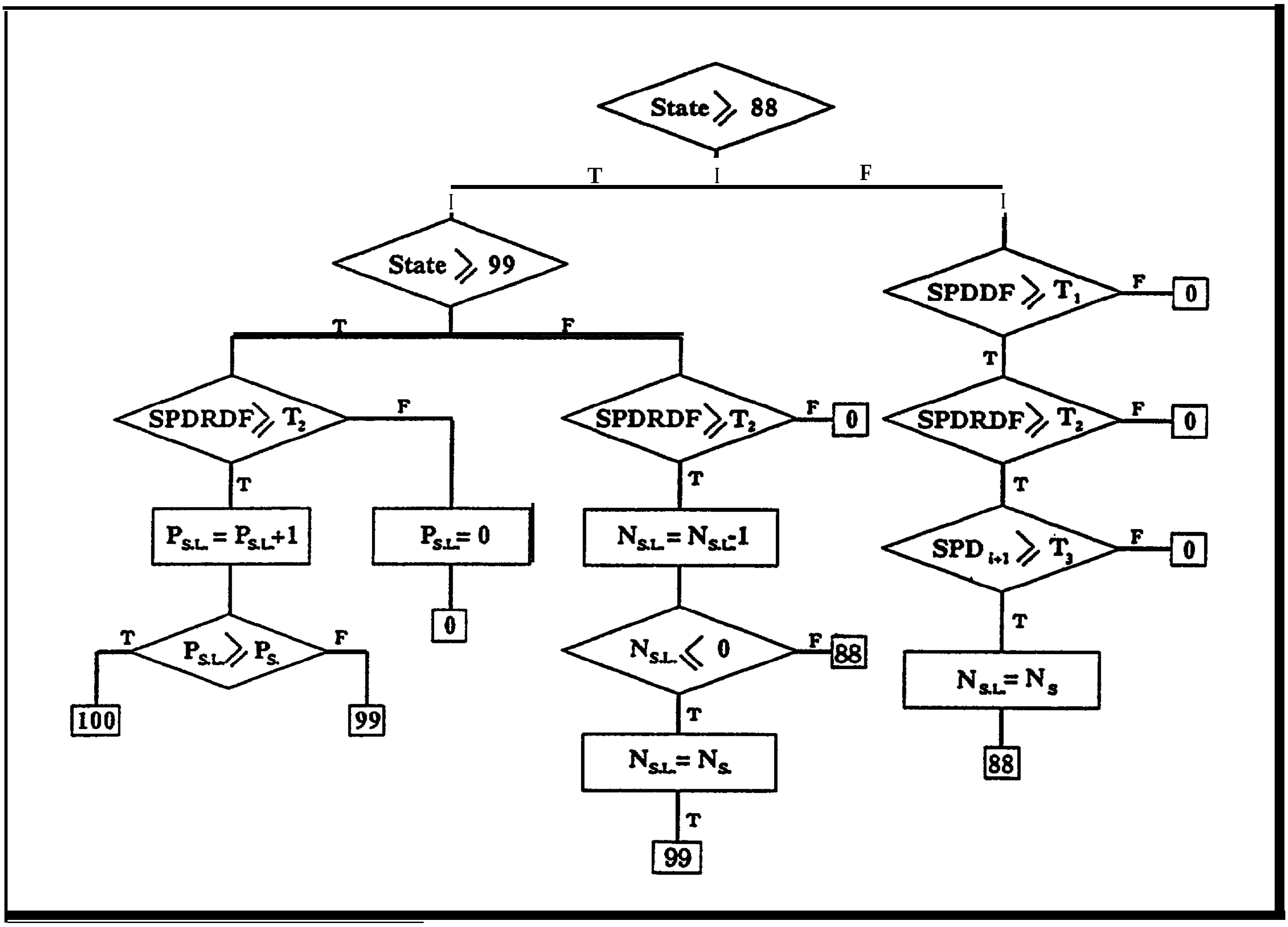
Nsl - Accumulator for number of consecutive intervals during which conditions required for incident detection were present.

Ps - Intervals End Tentative.

Psl - Accumulator for number of consecutive intervals during which conditions required for algorithm to leave Tentative state were present.

Pe - Intervals End Incident.

Pel - Accumulator for number of consecutive intervals during which conditions required for algorithm to leave Confirmed or Continuing state were present.



Difference in Speed With Persistence Check Algorithm

T1 – Spatial difference in speed.

T2 - Relative spatial difference.

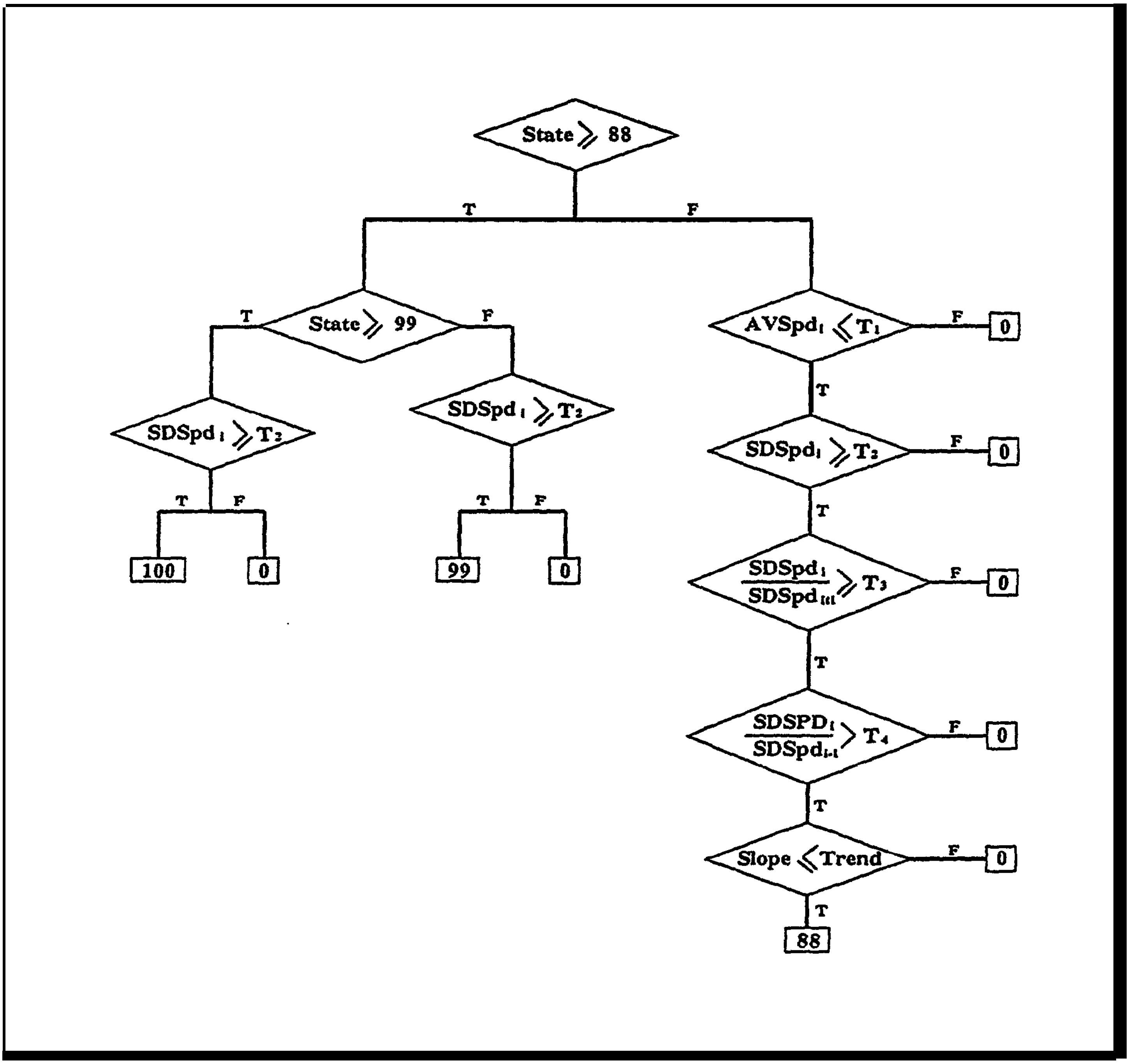
T3 - Downstream Speed.

Ns - Tentative Confirm

Nsl - Accumulator for number of consecutive intervals during which conditions required for algorithm to transition from a Tentative to a Confirmed state were present.

Ps - Confirm Continue.

Psl - Accumulator for number of consecutive intervals during which conditions required for algorithm to transition from a Confirmed to a Continuing state were present.



Standard Deviation of Speed Algorithm

T1- Operating Speed.

T2- Standard Deviation Speed.

T3 - Spatial Standard Deviation Ratio.

APPENDIX B - Reports from Other Systems

Automatic Incident Detection through video image processing

by Panos G. Michalopoulos, *Department of Civil Engineering, University of Minnesota*
and by Richard D. Jacobson, Craig A. Anderson and Thomas B. DeBruycker, *Image Sensing Systems, Inc.*

Automatic Incident Detection is one of the major challenges in urban freeway operations. In spite of recent efforts worldwide, fast and reliable Automatic incident Detection has been elusive. To a large extent this can be attributed to the limitations of existing detection devices. To overcome this problem, a new wide-area video detection system called AUTOSCOPE was recently developed in Minnesota and was installed in the field for rigorous around-the-clock testing for over two years. As a result, AUTOSCOPE was substantially improved, weatherised and expanded *to* multiple camera units. Subsequently an incident detection system was developed, based on AUTOSCOPE measurements, installed at a site in Minneapolis and evaluated under continuous around-the-clock, real-time operation for over four months. In parallel to this, a39-camera, seven-mile, machine vision, live laboratory was designed on Interstate-394 for full deployment and validation of the incident detection system. In this paper the development and testing of the machine vision-based incident detection system is presented, along with the long-term AUTOSCOPE test results and plans for future improvements.

1. INTRODUCITON

Incident detection response and management is one of the major challenges in urban freeway operations requiring constant attention and considerable investment in manpower and equipment. While several methods are currently employed for detecting incidents. automatic techniques are becoming increasingly important for decreasing the detection time and increasing reliability. However, in spite of recent efforts worldwide, fast and reliable Automatic Incident Detection has been elusive. Conventional. automated techniques based on computerized algorithms are less effective than is desirable for operational use as they generate a high level of false alarms or missed incidents. Operator-assisted methods. on the other hand, minimize the false alarm risk, but also suffer from missed or delayed detections. are labour-intensive and restrict the potential benefits of Advanced Integrated Traffic Management as they require human attention for detecting incidents rather than only confirming, responding and managing them through computer-aided means.

Perhaps the *major* handicap of existing Automatic Incident Detection (AID) algorithms is that they are designed to operate with the limited data provided by existing vehicle detection devices. This information alone. typically volume and occupancy. has not been proven to be sufficient for effective and reliable incident detection. partly because volume is not a dynamic measurement and partly because occupancy is a surrogate father than a true measurement of a spatial traffic flow variable, namely density. Most importantly. the measurements upon which current detection algorithms must rely are essentially taken at a point rather than over space. Since traffic flaw dynamics are two-dimensional in nature (time and space) rather than one (time). it should be evident that any effort to monitor automatically a dynamic phenomenon (incident propagation) with conventional detection devices is bound to be met with limited success.

This observation leads to the conclusion that Automatic Incident Detection should be improved by extracting additional traffic flow parameters in both time and space. Based on this as well as the general need for wide-area detection. an advanced video detection system called AUTOSCOPE was recently developed at the University of Minnesota' with support from the U.S. Federal Highway Administration (FHWA) and the Minnesota Department of Transportation (Mn/DOT). This Device is also suitable for advanced traffic control as well as detailed traffic parameter extraction for modelling. simulation and studying traffic flow characteristics. Following extensive development and testing, AUTOSCOPE was installed in the field in 1989. and was improved both by manual testing and by continuous, around-the-clock comparison with loops for over two years at several freeway and intersection sites. As a result of this experience. AUTOSCOPE was commercialized by the private sector and field-deployed for Automatic incident Detection and intersection control*.

In this paper, long-term AUTOSCOPE test results during freeway operation are presented along with the development and field deployment of the entire incident detection system. called IDEAS (Incident Detection Evaluation throw AUTOSCOPE System). which is currently under way. In spite of the fact that IDEAS must. for the time being, rely only on single-camera input. preliminary test results over a continuous. around-the-clock. four-month period suggest an 80 per cent detection accuracy with a station alarm rate of 0.6 alarms/day They also indicate detection of incidents within almost two miles from the detection zone even when the incidents occur beyond the field-of-view of the camera as well as in adjacent freeways.

2. BACKGROUND

Vehicle detection has been the weakest link in advanced traffic applications and automatic surveillance. Although several options are available for replacing or supplementing loop detectors (the most widely used device), the use of video imaging has been widely accepted as the most viable alternative. However. in spite of major worldwide efforts *to* develop a machine vision system for traffic surveillance and control. a real-time. fieldable device having the capabilities and performance required for practical applications has been elusive. The major problems with other systems which were only recently resolved by the introduction of AUTOSCOPE are discussed in Reference 2.

Briefly, the system can detect traffic in multipie locations within the camera's field-of-view. These locations are specified by the user in a matter of minutes using interactive graphics and can be changed as often as desired. This flexible detection placement is achieved by placing detection lines. using a mouse, along or across the roadway lanes on a video monitor displaying the traffic scene. Since these detection lines exist only on the monitor and not in the pavement, they can easily be removed or adjusted following initial placement. Every time a car passes through these lines, a detection signal (presence and passage) is generated which is similar to the signal produced by loop detectors. Thus. the system can easily replace loops. In addition to the wireless detection. a single camera can replace many loops, thus providing true wide-area detection and becoming cost-effective. It should be noted that AUTOSCOPE does not have to be collocated with the camera: it can either be placed in the field along with the camera or at a central location where video input is received. Figure I depicts the system configuration.

Because of this design, AUTOSCOPE can be installed without disrupting traffic operations. Furthermore, if is not restricted to a particular detection configuration. but rather can be changed manually or dynamically as a function of traffic conditions. Finally. the wide-area view will enable the extraction of second-generation traffic parameters. such as queue lengths. delays. slops. density. etc., that cannot easily or economically be derived by conventional devices til' at all). Because of

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*A United Stores Patent bus been issued to *the University of Minnesota for the basic AUTOSCOPE technology and several foreign appli-*cations are pending . Image Sensing Systems.Inc. *hold a worldwide license to use the technology and have licensed Econolize Control Products. Inc. to manufacturer and distribute AUTOSCOPE* J *in North America*

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focused on increasing the detection accuracy, reducing the false alarm rate and developing a new speed detector that could track the position of individual vehicles in time and space.

The performance of AUTOSCOPE on the selected video-taped sequences was improved to greater than 96 per cent detection accuracy and less than 5 per cent false alarm rate. As a result, the AUTOSCOPE detection algorithms were ready for 24-hour extended on-line testing described in the next section.

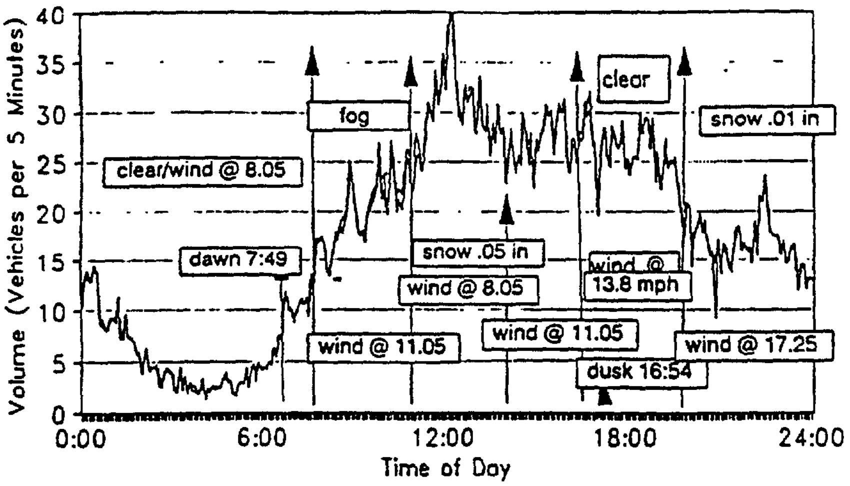
3.3. On-line testing

The objective of the on-line, long-term testing was to establish sustainable, continuous operation under real traffic and weather conditions and to ensure robustness and reliability. The tests ran continuously from April 1990 to September 1991 at both freeway test-sites described earlier using the ScopeServer. Automatic comparisons with loops were made of volume, occupancy and speed measurements on an individual vehicle-by-vehicle basis and also by 30-second intervals for 24 hours each day.

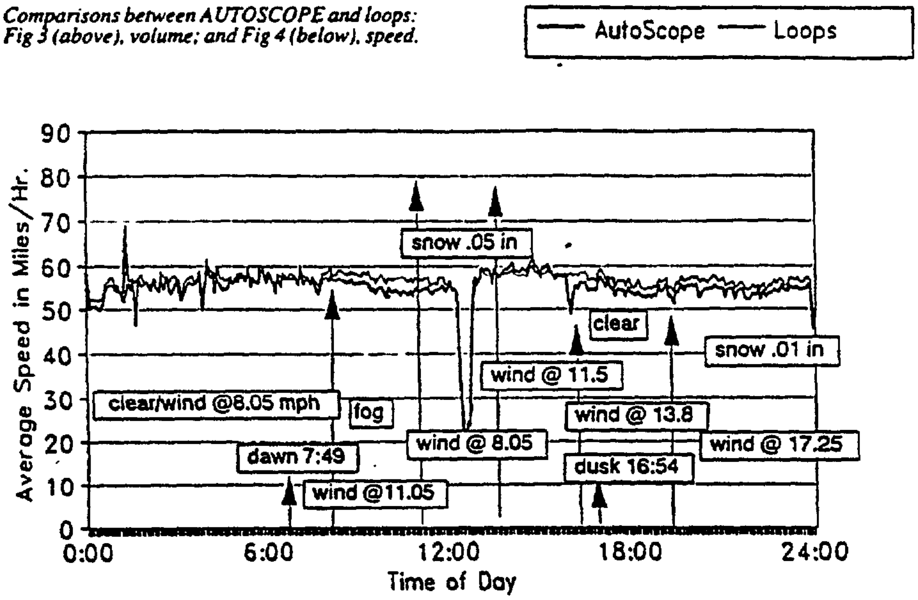
The 24-hour loop *versus* AUTOSCOPE data were used to identify recurring problems. When the disparity between the AUTOSCOPE and loop detection data became very large, the recorded video sequences were saved. The video tapes were then analysed using manual ground-truthing to identify the cause of the problems. During the tests several problems with loops were identified. The most significant involved their reliability. At random intervals loops would either stop working or they would produce totally inaccurate measurements for periods ranging from a few minutes to several hours. The other problems were relatively minor (i.e. volume error of 3 to 5 per cent during congested traffic flow conditions and speed errors of up to 15 per cent).

Several AUTOSCOPE problems were identified and corrected during the testing. One of the initial problems was caused by leading headlight reflections at night on wet pavement. There were specific regions of the camera field-of-view that reflected headlights directly into the camera from the road surface, resulting in the appearance of two distinct sets of headlights which led to the double-counting of cars. An attempt was made to reduce the reflected light using a polarised light filter, but very little improvement was observed. Ultimately, a set of night detection parameters was implemented which reduced the false detection rate from as high as 30 per cent to 7 per cent.

A second problem was that of distinguishing strong vehicle dynamic shadows from dark cars. Previous enhancements to AUTOSCOPE that dealt with shadows were a compromise between minimising false detections of shadows and detecting dark cars. This approach was effective at dealing with static shadows (such as tree shadows, pole shadows or dark cloud movements) and short, down-lane or cross-lane, dynamic vehicle shadows. Further testing revealed that during daylight transition periods (dawn and dusk) when the sun is low in the sky and very bright, the strong dynamic (vehicle) shadows cause false detections. An effective approach was implemented which reduced the false alarm rate from as high as 40 per cent to less than 10 per cent.



Comparisons between AUTOSCOPE and loops: Fig 3 (above), volume; and Fig 4 (below), speed.



A third problem that was identified and fixed was the difference between AUTOSCOPE and loop speed measurements. The difference was attributed to an incorrect calibration of the AUTOSCOPE speed detector size. The detector lengths were corrected and an accurate field-of-view calibration procedure was introduced. Resulting tests demonstrated that speeds averaged over 30 seconds were as reliable as loops over 24-hour periods for all weather, lighting and traffic congestion levels. Furthermore, individual vehicle speed calculations by AUTOSCOPE were within 2.5 mile/h from that of loops and within 5 per cent of actual speeds. The speed analysis was conducted at ranges of operation of 150 and 350 ft from the camera with only a very slight performance degradation at the longer range.

When these problems were resolved, the AUTOSCOPE performance was thoroughly re-evaluated. Figures 3 and 4 show the speed and volume detection performance as compared to loops during two artifact-rich days of operation. As can be seen from these figures, AUTOSCOPE closely tracks the loop measurements even when weather and lighting conditions vary substantially over 24 hours.

4. APPLICATION TO INCIDENT DETECTION

Automated incident detection was selected as the first application of the AUTOSCOPE technology to enable traffic managers to concentrate on more critical operations tasks and to reduce the number of monitors required for observing traffic conditions. For the purposes of this study an incident was defined as an unplanned occurrence on the freeway that impedes traffic flow.

A number of AID algorithms can be found in the literature. Their structure varies in the degree of sophistication, complexity and data requirements. Comparative performance evaluation of existing AID algorithms was presented in a recent paper where the need for more effective incident detection systems is identified. The most important include the *comparative* algorithms (California logic[5-7]), the type employing statistical forecasting of traffic behaviour (*time series* algorithms[8-10]) and the McMaster algorithms[11]. These algorithms operate on typical detector occupancy and volume outputs averaged over time intervals of 30 to 60 seconds. Another approach is employed by the HIOCC algorithms[12] that use one-second occupancy data to detect

5. INCIDENT DETECTION FIELD-TESTING

Prior to field implementation and real-time testing, the three incident detection algorithms — SPIES, McMaster and AIDA — were tested off-line using the incident database which was available as of September 1991. This testing revealed that the SPIES approach had problems caused by the significant signal noise due to traffic fluctuations during heavy congestion when vehicles accelerate and decelerate. Since it did not appear to be more promising than the other two incident detection algorithms, SPIES implementation was deferred until after the completion of the I-394 test site.

Following the off-line testing, the McMaster and AIDA algorithms were incorporated into the ScopeServer and have been running in parallel using real-time data from the 26th Street test site since December 1991. The results from the first four months (December 1991 to April 1992) of continuous around-the-clock operation are discussed next. The 26th Street test site is a very complex one as shown in Fig 6. It is just upstream of a point where I-35W splits into two freeways and a downstream exit ramp. The freeway that splits to the right has another exit ramp to a third freeway. The complexity provides an abundance of incidents, especially during the winter season.

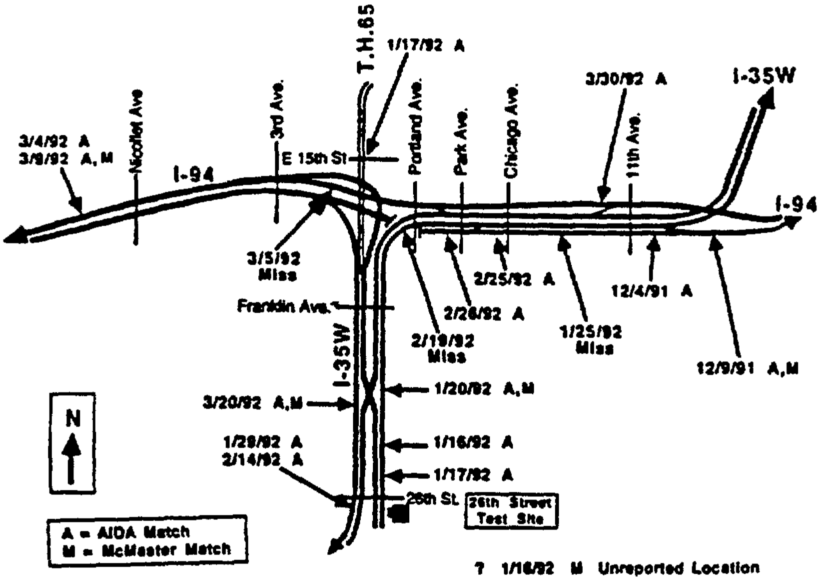


Fig 6. Incident occurrence and verification in the vicinity of the 26th Street installation.

Eighteen reported incidents judged relevant to the 26th Street location are indicated on the map in Fig 6 by dates and large arrows. All but one were taken from the TMC incident logs. An 'M' indicates a match by the McMaster algorithm and an 'A' indicates a match by the AIDA algorithm.

Overall performance summaries for the McMaster algorithm and the AIDA algorithm are given in Table I. For the four-month, 122-day period beginning 1 December 1991, the McMaster algorithm produced a total of 38 alarms resulting in a station alarm rate of 0.3 alarms per day. Five alarms matched confirmed incidents resulting in an incident detection accuracy of 28 per cent (5/18). An additional 24 per cent (9/38) of the alarms were designated likely incidents as judged by the severity of the measured traffic parameters as compared to the matched incidents. Typically, a very sharp drop in speed accompanied by a sharp rise in occupancy, characteristic of confirmed incidents, plus their occurrence during off-peak traffic hours, led to categorising these alarms as likely incidents. Some of these occurred after TMC operating hours and thus could not be confirmed, while others occurred during TMC operating hours but did not correspond to any incidents reported by TMC. Another 21 per cent (8/38) occurred during rush-hours. Finally, 42 per cent (16/38) of the alarms were confirmed to be false alarms. The majority were during late night or early morning periods, when the data were very noisy due to low traffic volumes.

The AIDA algorithm produced a total of 73 alarms during the four months of analysed data resulting in a station alarm rate of 0.6 alarms per day. Fourteen alarms matched confirmed incidents resulting in an incident detection accuracy of 78 per cent (14/18). Of the total of 73 alarms, 32 per cent (23/73) were judged to be likely incidents and another 47 per cent (34/73) occurred during rush-hours and would have required an operator to verify whether an incident had occurred. All likely incidents appeared serious enough to merit an operator's attention, whether they were caused by actual incidents or merely a heavily-congested freeway system . In either case an operator could take action to reduce traffic volumes entering the congested area via ramp metering changes. Finally, only 3 per cent (2/73) were confirmed as false alarms.

The AIDA incident alarm matches breakdown is as follows: Ten occurred during rush-hour — four accidents and two stalls during the morning rush-hour and three accidents and one spin-out during the evening rush-hour. Another four incidents were during off-peak hours — two accidents, one stall and one serious spill (bulldozer).

The AIDA alarm missed three accidents and one stall. The first accident missed occurred on 16 January 1992, at an unreported location during morning peak hours. This accident is believed to be upstream of the camera and would be more likely to be detected by an upstream station. The second accident missed occurred on I-94 eastbound on 25 January 1992 at noon and, as can be seen from Fig 6, would strictly cause a 'gawker slowdown' on I-35W. This accident would be more appropriately detected by a station on I-94. The third missed incident was a stall on the left shoulder of I-35W southbound near Portland Avenue, approximately 0.8 miles away, on 19 February 1992 at 16:15h, which only produced a 12 mile/h drop in smoothed 30-sec. interval speeds from 54 to 42 mile/h and a small increase in occupancy, 20 to 28 per cent, not enough to trigger an alarm.

Table I. McMaster and AIDA incident detection results

		McMaster					AIDA				
				Unknown cause		Confirmed			Unknown cause		Confirmed
Month	Number confirmed incidents	Total alarms	Match	Likely incident	Rush hour	false alarms	Total alarms	Match	Likely incident	Rush hour	false alarms
December	2	13	1	4	4	4	17	2	6	9	1
January	7	12	2	2	2	6	32	5	10	16	0
February	4	2	0	0	1	1	11	3	2	6	1
March	5	11	2	3	1	5	13	4	5	3	
Totals	18	38	5	9	8	16	73	14	23	34	2
Detection accuracy of confirmed incidents		28 per cent					78 per cent				
Station alarm rates (per day)		0.31					0.60				
Confirmed false alarms		42 per cent					3 per cent				
Unknown cause alarms		45 per cent					78 per cent				

vanced incident detection algorithms The McMaster incident detection algorithm[11] which was tested here is promising, but has some limitations. For instance, the characteristic curve on which the algorithm is based is subjective, time-dependent and not easy to obtain. Furthermore, the algorithm did not perform well in inclement weather, missed incidents close to the detection station and turned on some accident alarms very late (when clearing). On the other hand, it does not generate alarms very often on recurrent congestion, a desirable feature. The AIDA algorithm has a high incident detection accuracy, a low confirmed false report rate, short incident detection times and long detection range. AIDA is still a prototype that should improve in the deployment phase, especially when it will be able to combine data from adjacent cameras and utilise spatial traffic measurements such as density and speed profile that can be made available with some additional research and development.

6. CONCLUDING REMARKS

The field installation of AUTOSCOPE™ substantially improved the performance and reliability of the earlier version which, like other devices at this stage, suffered from problems that could only be overcome by the rigorous long-term tests described. As a result of these experiments and others at intersections, the system has evolved from a research and development prototype to a commercial product This required additional private funding to produce a fully weatherised, multiple-camera unit meeting cost-effective commercial standards. This process required Government-University-Industry co-operation.

The IDEAS incident detection system exceeded expectations not only in terms of performance, but also in terms of its capability to detect incidents based on single-camera, single-station measurements. For example, 14 of 18 confirmed incidents were detected during its first four months of operation, while only two confirmed false alarms were generated and the average daily station alarm rate was only 0.6 alarms.

Most importantly, incidents as far away as two miles were detected while the detection time ranged from −7 to +15 minutes from the reported time of the incident, depending on distance and freedom of vehicles to divert from the freeway prior to reaching the detection area. The above results are very encouraging given that the incident detection system is still experimental. Full deployment of IDEAS is currently underway at the I-394 site while plans for installation in several other freeways are being considered. The I-394 site will serve as a laboratory further to improve the IDEAS system. The I-394 installation should be completed in late 1993 and will enable fine-tuning of the alarm decision logic, use of adjacent camera information for confirming and localising alarms, development of an incident severity index, introduction of interactive learning for parameter calibration and prediction of incidents based on real-time measurements.

Video detection is not simply a replacement of loops, which will continue to serve their intended purpose for some time, but is a wide-area detection technology that can obtain more information including traffic parameters and measures of effectiveness (delays, stops, energy consumption, etc.) which have in the past been hard, labour-intensive, time-consuming and expensive to obtain. The deployment of video detection is a function of the specific application that the device is to accommodate which, in addition to incident detection, can include ramp control, large-scale database generation for IVHS applications (i.e. driver information systems and vehicle guidance), intersection control and a variety of enforcement applications. Deployment of the incident detection system developed here can use both loops and AUTOSCOPE which is important since many loops are already in place on freeways. Finally, the camera placement for incident detection is a function of the desired detection time. Since detection distances up to almost two miles have been demonstrated, AUTOSCOPE camera placement at the rate of one per mile is feasible. However, this assumes that vehicle diversion between cameras is insignificant so that the effects of incidents can reach the upstream camera within a reasonable time. To be sure, the exact placement of AUTOSCOPE depends on the geometry of the road and other existing instrumentation which will be determined in the preliminary engineering and design phase when the system is being deployed.

ACKNOWLEDGMENTS

Financial support for this research and fie equipment deployment was provided by the Minnesota Department of Transportation, the Federa Highway Administration, the Centre for Transportation Studies at the University of Minneso under the Exxon Oil Overcharge Fund, and private sources.

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**Authors' Note: The McMaster algorithm in th sense described in this paper refers to the logic a described in the literature and in Reference 1 rather than to the software recently produced b its developers.*

Ontario

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M3M IJ8

June 21, 1995

Mr. Jack L. Kay
President
JHK & Associates
2000 Powell Street, Suite 1090
Emeryville, CA 94608

Dear Me Kay

Re: Monthly System Performance Reports and ITS Privacy Issures

Attached, please final a copy of the monthly performance reports for our 3 Compass systems. I have also attached a copy of a discussion paper on ITS Privacy Issues which was prepared by our government's Information and Privacy Commissioner.

It was my pleasure to see many of you at the mid-year meeting in San Antonio. Best wishes for a safe and restful summer.

Sincerely,

P.R. Korpal
Manager (Acting)

Received

By.

HIGHWAY 401 COMPASS SYSTEM
RENFORTH DRIVE TO YONGE STREET
TRAFFIC DATA AND OPERATIONS REPORT
FOR MAY, 1995

	East Bound	West Bound	Total
*Monthly Average Daily Traffic (veh.)	180,768	184,704	365.472
*measured in the vicinity between Weston Road and Islington Ave			

	East Bound	West Bound
Monthly Average Peak Period Speed (km/h) AM (from 08:00 to 09:00)	75	59
Monthly Average Peak Period Speed (km/h) PM (from 17:00 to 18:00)	73	55

	East Bound	West Bound
Highest Hourly Per Lane Volume	2.292	2,416
Day of the Month	10	2
Time & Day	07:00 to 08:00	08:00 to 09:00
Station Description	W OF WESTON	W OF KENNEDY
Roadway Description	EXPRESS	COLLECTOR
Station Number	401DW0080DEE	401DE0270DWC

	*Total Monthly Vehicle-Hours of Delay
East Bound (veh-hrs)	92,390
West Bound (veh-hrs)	122,757
Highway 401 Total (veh-hrs)	215,156
* monthly accumulated total of additional travel time experienced by all vehicles that travel at less than 70km/h	

Between Yonge & Renforth	*Average Travel (min) At 08:00	*Average Travel (min) At 17:00
EastBound Collector	22	22
EastBound Express	20	20
WestBound Collector	23	24
WestBound Express	16	22
*Average travel time calculation is based on the Highway 401 COMPASS speed data		

CHANGEABLE MESSAGE SIGN UTILIZATION	
Number of Changeable Message Signs	13
Number of Non-Default Messages Displayed	11377
Non-Default Messages displayed per Sign per Day	28

CONFIRMED INCIDENT DATA BETWEEN YONGE STREET AND RENFORTH DRIVE CNCLUDING SHOULDER INCIDENTS		
Total Number of Confirmed Incidents		72
Percentage Detected by System		34.72%
Percentage Manually Detected		65.26%
Incident types	51.39%	Accidents
	15.28%	Disabled Vehicles
	30.56%	Road Work
	.00%	Debris
	2.78%	Other
Lane Blockage Types:	20.83%	Full closure
	65.28%	One Lane
	12.50%	Two Lanes
	.00%	Three Lanes
	.00%	Four Lanes
	.00%	Five Lanes
	.00%	Six Lanes
	1.39%	Other
Total Duration of the 72 Incidents: 5,658.92 min		
Ave Duration per incident: 78.60 min		
Percentage of False Alarms (false alarms divided by total alarms): 29.26%		
Percentage of Improper Classifications (congestion detected as incidents Divided by total alarms): 68.41%		

COUNTS OF PERATOR REACTION TIME TO CONFIRM INCIDENT DETECTION ALARMS FOR THE MONTH OF MAY		
	Counts	Percentage
Less than 3 Minutes	416	48.04%
3 To 6 Minutes	139	16.05%
6 To 15 Minutes	131	15.13%
Above 15 Minutes	180	20.79%
Total	866	100.00%

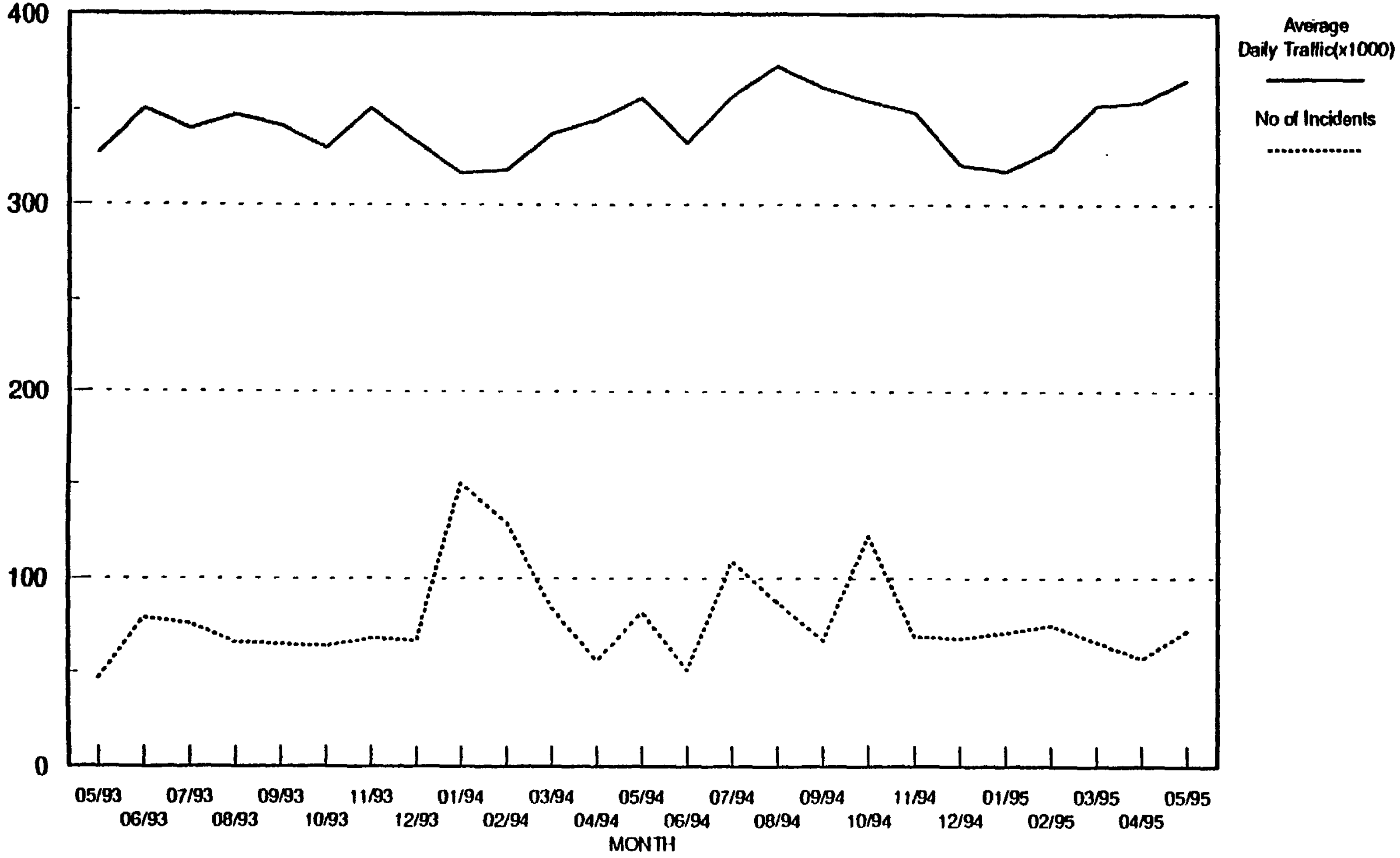
COMPASS Voice Logging Activities, MAY	
No. of Radio calls logged	N/A
No. of Phone calls logged	N/A
Total	N/A

MONTHLY FIELD EQUIPMENT OPERATING STATISTICS	
Potential No. of VDS Controller-Hours Available	90,768
Actual No. of VDS Controller-Hours Recorded	90,407
Percentage VDS Controller Availability	99.60%
Potential No. of CMS Controller-Hours Available	10,416
Actual No. of CMS Controller-Hours Recorded	10.322
Percentage CMS Controller Availability	99.10%

Note: VDS = Vehicle Detector Station
CMS = Changeable Message Sign

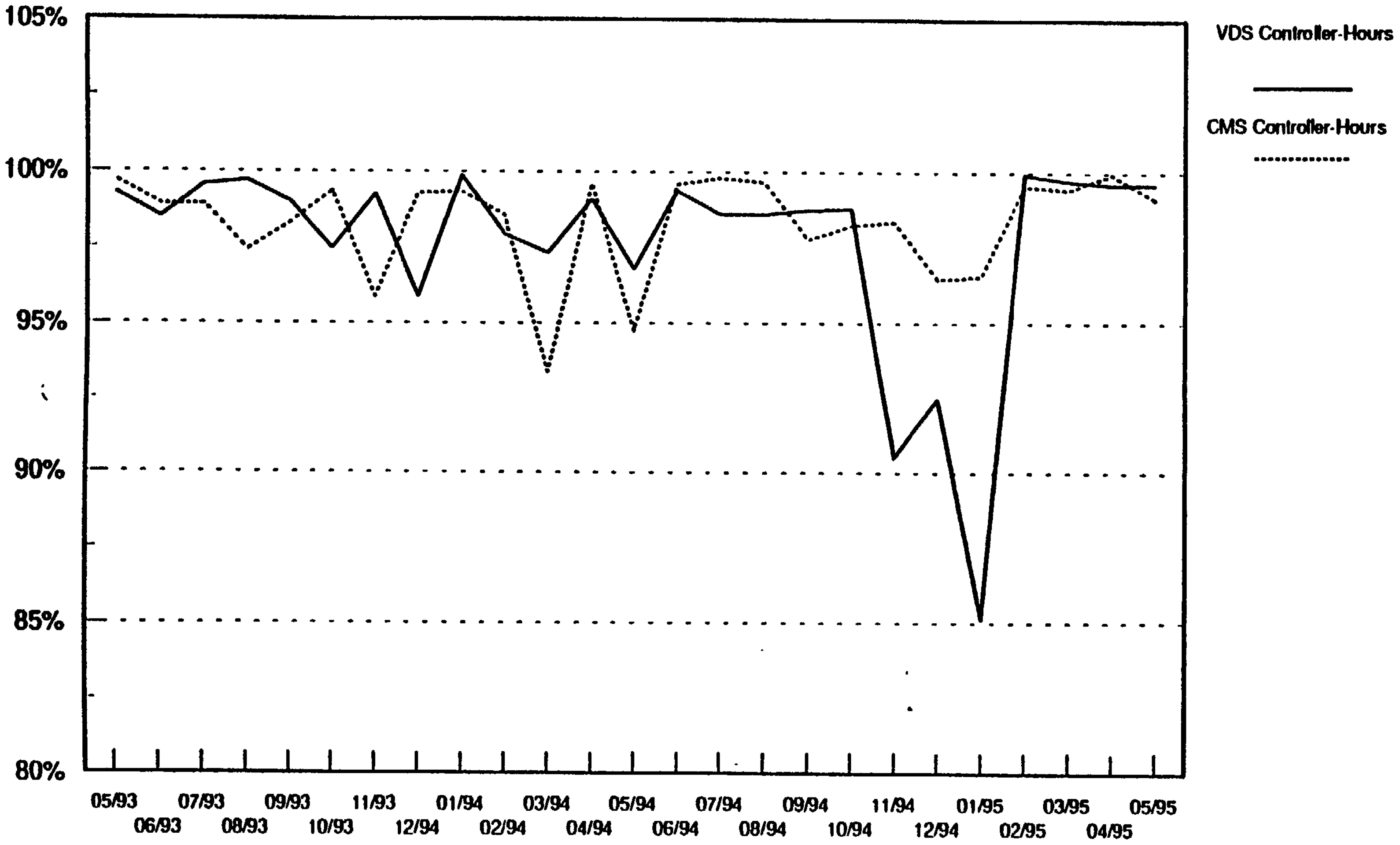
HIGHWAY 401 COMPASS SYSTEM

MONTHLY INCIDENTS/DAILY AVERAGE TRAFFIC
FROM MAY 1993 TO MAY 1995



HIGHWAY 401 COMPASS SYSTEM

MONTHLY EQUIPMENT AVAILABILITY
FROM MAY 1993 TO MAY 1995



Q.E.W. MISSISSAUGA COMPASS SYSTEM
ROYAL WINSOR DRIVE TO HIGHWAY 427
TRAFFIC DATA AND OPERATIONS REPORT
FOR MAY, 1995

	East Bound	West Bound	Total
*Monthly Average Daily Traffic (veh.)	84,094	77,160	161,254
*measured in the vicinity West of Highway 427			

	East Bound	West Bound
Monthly Average Peak Period Speed (km/h) AM (from 08:00 to 09:00)	60	79
Monthly Average Peak Period Speed (km/h) PM (from 17:00 to 18:00)	77	63

	East Bound	West Bound
Highest Hourly Per Lane Volume	2,264	2,359
Day of the Month	3	16
Time of the Month	07:00 to 08:00	17:00 to 18:00
Station Description	QEW EB, EAST OF ROYAL W.	QEW WB, E OF MISS. NB
Roadway Description	SINGLE	SINGLE
Station Member	1	41

	*Total Monthly Vehicle-Hours of Delay
East Bound (veh-hrs)	19,409
West Bound (veh-hrs)	05,583
Q.E.W. Total (veh-hrs)	24,992
* monthly accumulated total of additional travel time experienced by all vehicles that travel at less than 70km/h	

*AVERAGE TRAVEL TIME	Weekday Travel Time at: 08:00	Weekday Travel Time at: 17:00	Weekend Travel Time at: 10:00	Weekend Travel Time at: 17:00
Eastbound Royal Windsor Drive to Highway 427	29 min	11 min	11 min	11 min
Westbound Highway 427 to Ford Drive	10 min	12 min	10 min	11 min
*Average travel time calculation is based on the QEW Mississauga COMPASS speed/occupancy data				

Q.E.W. MISSAUGA COMPASS SYSTEM REPORT
FOR MAY, 1995

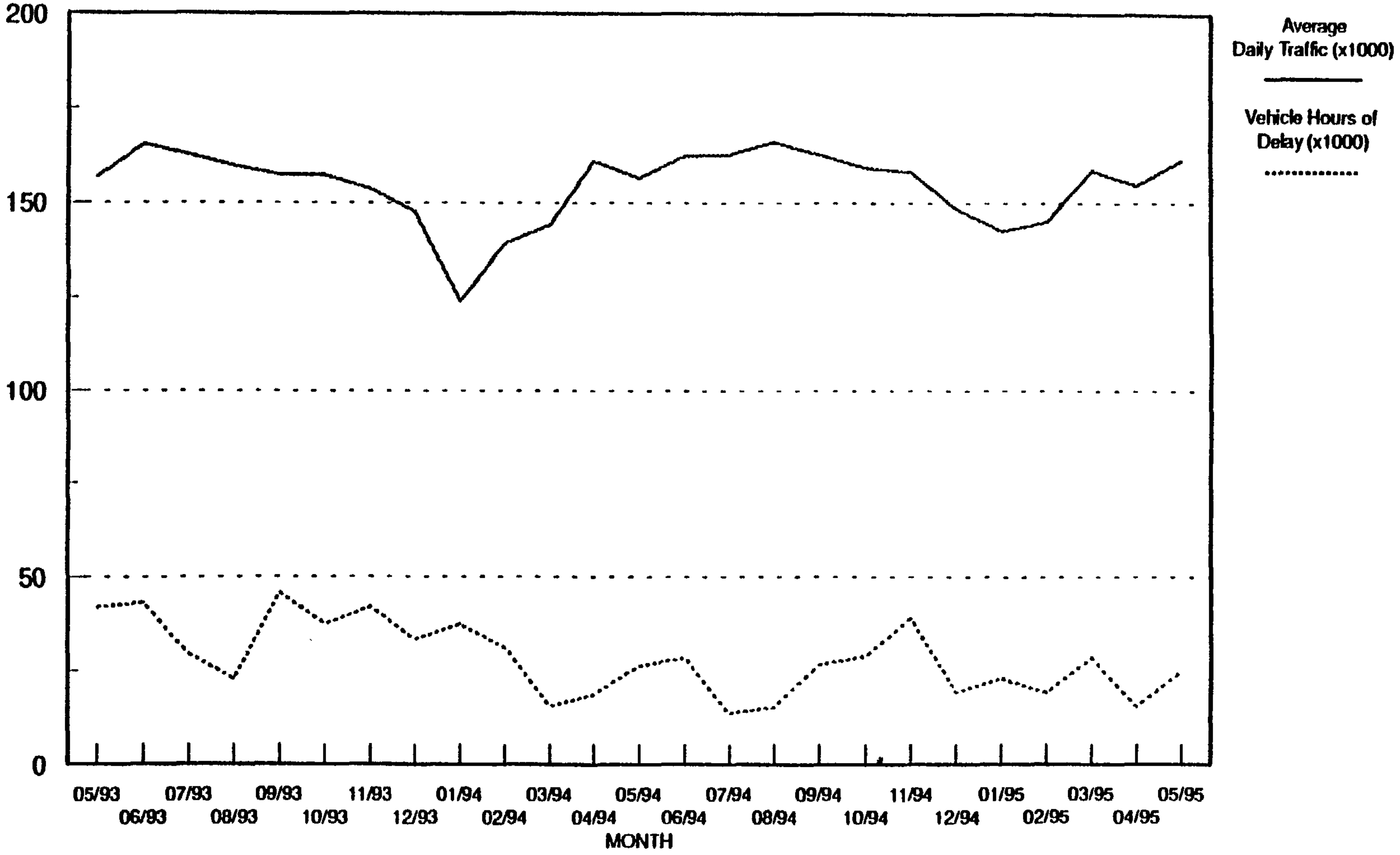
CHANGEABLE MESSAGE SIGN UTILIZATION	
Number of Changeable Message Signs	2
Number of Non-Default Messages Displayed	1484
Non-Default Messages Displayed per Sign Day	24

MONTHLY FIELD EQUIPMENT OPERATING STATISTICS	
Potential No. of VDS	25,296
Actual No. of VDS Controller-Hours Recorded	23,505
Percentage VDS Controller Availability	92.92%
Potential No. of CMS controller- Hours Available	3,720
Actual No. of CMS controller-Hours Recorded	3,713
Percentage CMS Controller Availability	99.81%
Note: VDS = Vehicle Detector Station CMS= changeable Message Sign	

PERCENTAGE OF QEW RAMP METERING RATE UTILIZATION					
ON RAMP LOCATION	RATE IN SECONDS				
	5.0	6.0	7.5	10.0	15.0
Ford Drive	46.30%	13.48%	20.53%	19.59%	0.11%
Winston Churchill NB	45.15%	13.74%	18.27%	22.84%	10.00%
Winston Churchill SB	45.13%	13.85%	18.18%	22.85%	0.00%
Erin Mills/Southdown	39.32%	18.72%	21.23%	20.73%	0.00%
Missssauga Road SB	16.66%	10.39%	38.70%	34.15%	0.10%
Mississauga Road NB	16.86%	9.29%	38.43%	35.38%	0.08%
Highway 10 NB	22.86%	25.54%	35.20%	16.40%	0.00%
Highway 10 SB	22.01%	25.22%	36.00%	16.77%	0.00%
Cawthra Road NB	37.43%	32.72%	25.33%	4.52%	0.00%
Cawthra Road SB	37.57%	32.64%	25.26%	4.53%	0.00%
Overall Averages	32.28%	20.15%	28.21%	19.34%	0.03%

QEW MISSISSAUGA COMPASS

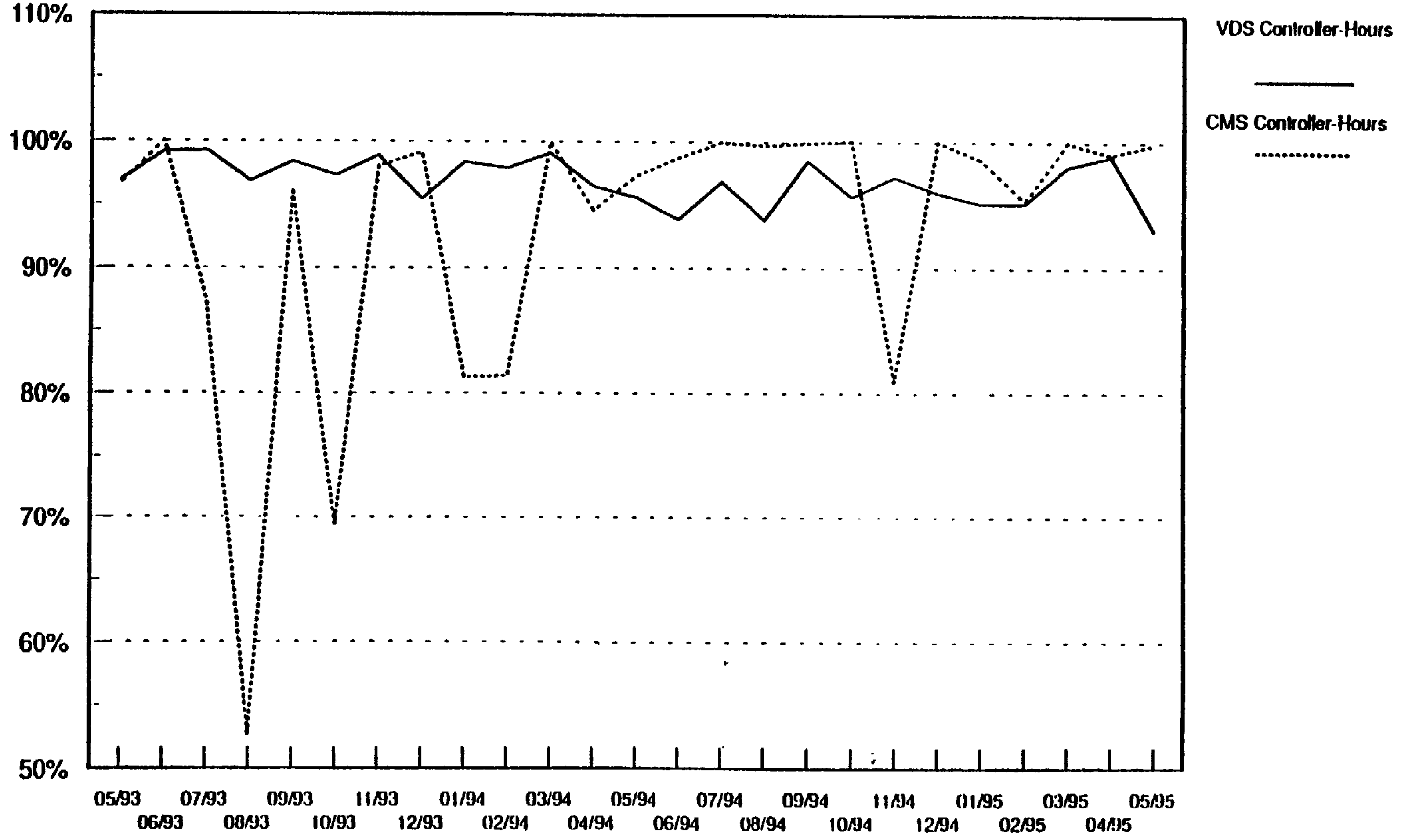
DAILY AVERAGE TRAFFIC/VEHICLE HOURS OF DELAY
FROM MAY 1993 TO MAY 1995



QEW MISSISSAUGA COMPASS

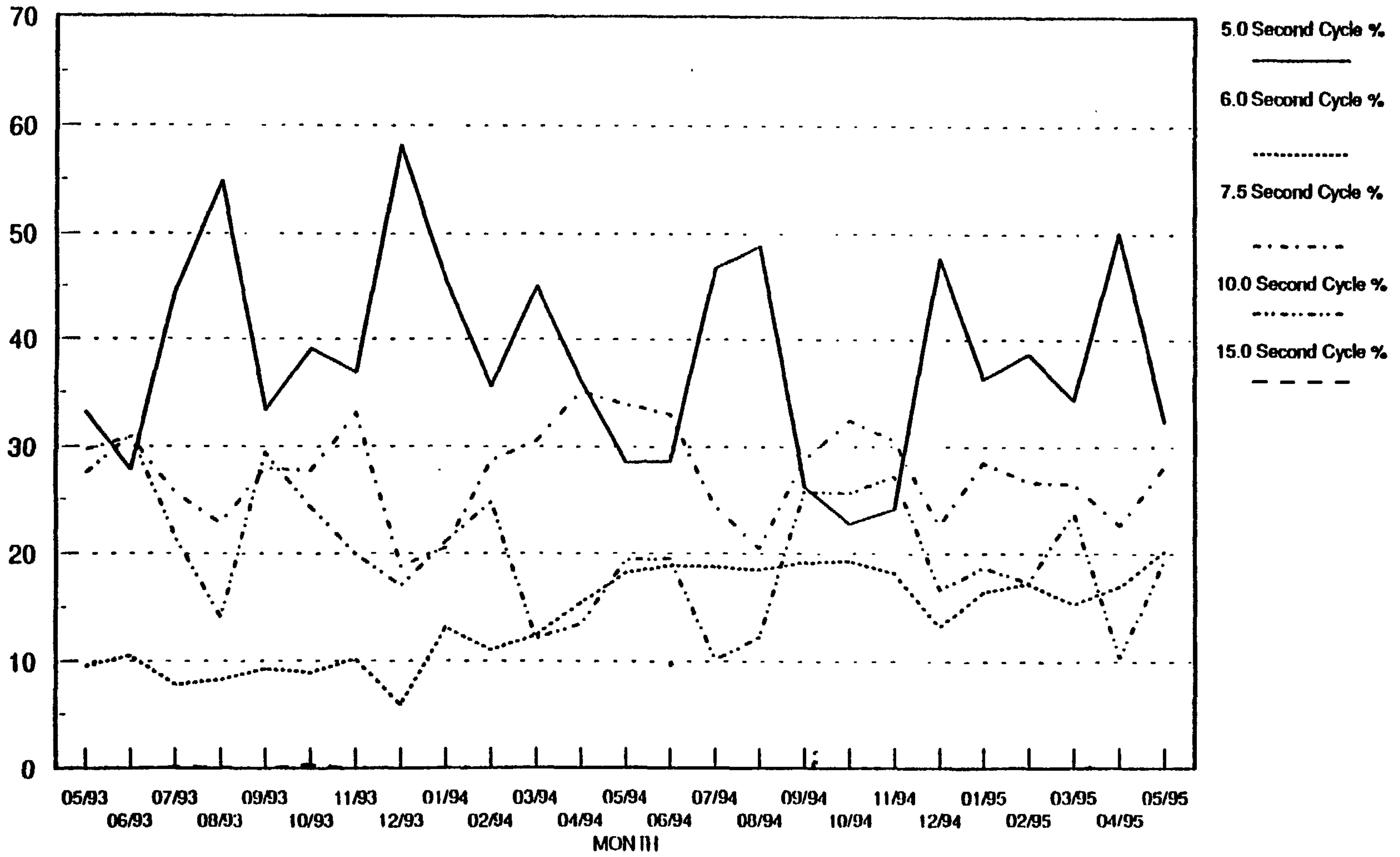
MONTHLY EQUIPMENT AVAILABILITY

FROM MAY 1993 TO MAY 1995



QEW MISSISSAUGA COMPASS

PERCENTAGE OF RAMP METERING RATE UTILIZATION
FROM MAY 1993 to MAY 1995



Q.E.W. BURLINGTON COMPASS SYSTEM
BURLINGTON ST. TO FAIRVIEW ST.
TRAFFIC DATA AND OPERATIONS REPORT
FOR MAY, 1995

	Toronto Bound	Niagara Bound	Total
*Monthly Average Daily Traffic (vehicles)	46.075	53.201	99.276
*measured at top of Skyway			

	Toronto Bound	Niagara Bound
Monthly Average Peak Period Speed (km/h) AM (from 08:00 to 09:00)	85	76
Monthly Average Peak Period Speed (km/h) PM (from 17:00 to 18:00)	86	84

	Toronto Bound	Niagara Bound
Highest Hourly Per Lane Volume	1,443	1.551
Day of the Month	1	19
Time of the Month	08:00 to 09:00	17:00 to 18:00
Station Description	EASTPORT DR NB	SOUTH OF WOODWARD SB
Roadway Description	STANDARD	STANDARD
Station Number	QEWDS0040DNS	QEWDS0090DSS

	*Total Monthly Vehicle-Hours of Delay
Toronto Bound (veh-hrs)	00.012
Niagara Bound (veh-hrs)	00.176
Q.E.W. Burlington Total (veh-hrs)	00.188
* monthly accumulated total of additional travel time experienced by all vehicles that travel at less than 70km/h	

Between Burlington & Fairview	*Average Travel for Weekday		*Average Travel for Weekend	
	08:00	17:00	10:00	17:00
Niagara Bound	4	4	4	4
Toronto Bound	4	4	4	4
*Average travel time calculation is based on the QEW Burlington COMPASS speed/occupancy data				

CHANGEABLE MESSAGE SIGN UTILIZATION	
Number of Changeable Message Signs	**8**
Number of Non-Default Messages Displayed	**600**
Non-Default Messages Displayed per Sign per Day	**3**

CONFIRMED INCIDENT DATA BETWEEN

BURLINGTON STREET AND FAIRVIEW STREET (INCLUDING SHOULDER INCIDENTS)

Total Number of Confirmed Incidents	**60**
Percentage Detected by System	**5.00%**
Percentage Manually Detected	**95.00%**

Incident types:	8.33%	Accidents
	10.00%	Disabled Vehicles
	60.00%	Road Work
	.00%	Debris
	31.67%	Other
Lane Blockage Types:	.00%	Full Closure
	31.67%	One Lane
	6.67%	Two Lanes
	.00%	three Lanes
	.00%	Four Lanes
	.00%	Five Lanes
	61.67%	Other

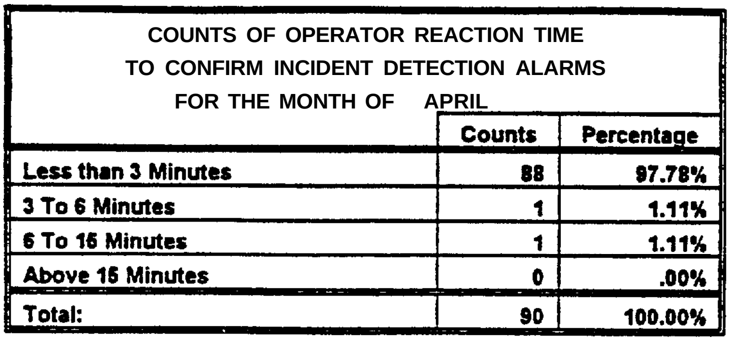
Total Duration of the 60 Incidents: 4,095.57 min

Average Duration per Incident: 68.26 min

Percentage of False Alarms (false alarms divided by total alarms): 96.88%

MONTHLY FIELD EQUIPMENT OPERATING STATISTICS	
Potential No. of VDS Controller-Hours Available	**21,600**
Actual No. of VDS Controller-Hours Recorded	**16,607**
Percentage VDS Controller Availability	**76.88%**
Potential No. of CMS Controller-Hours Available	**5,760**
Actual No. of CMS Controller-Hours Recorded	**4,438**
Percentage CMS Controller Availability	**77.06%**

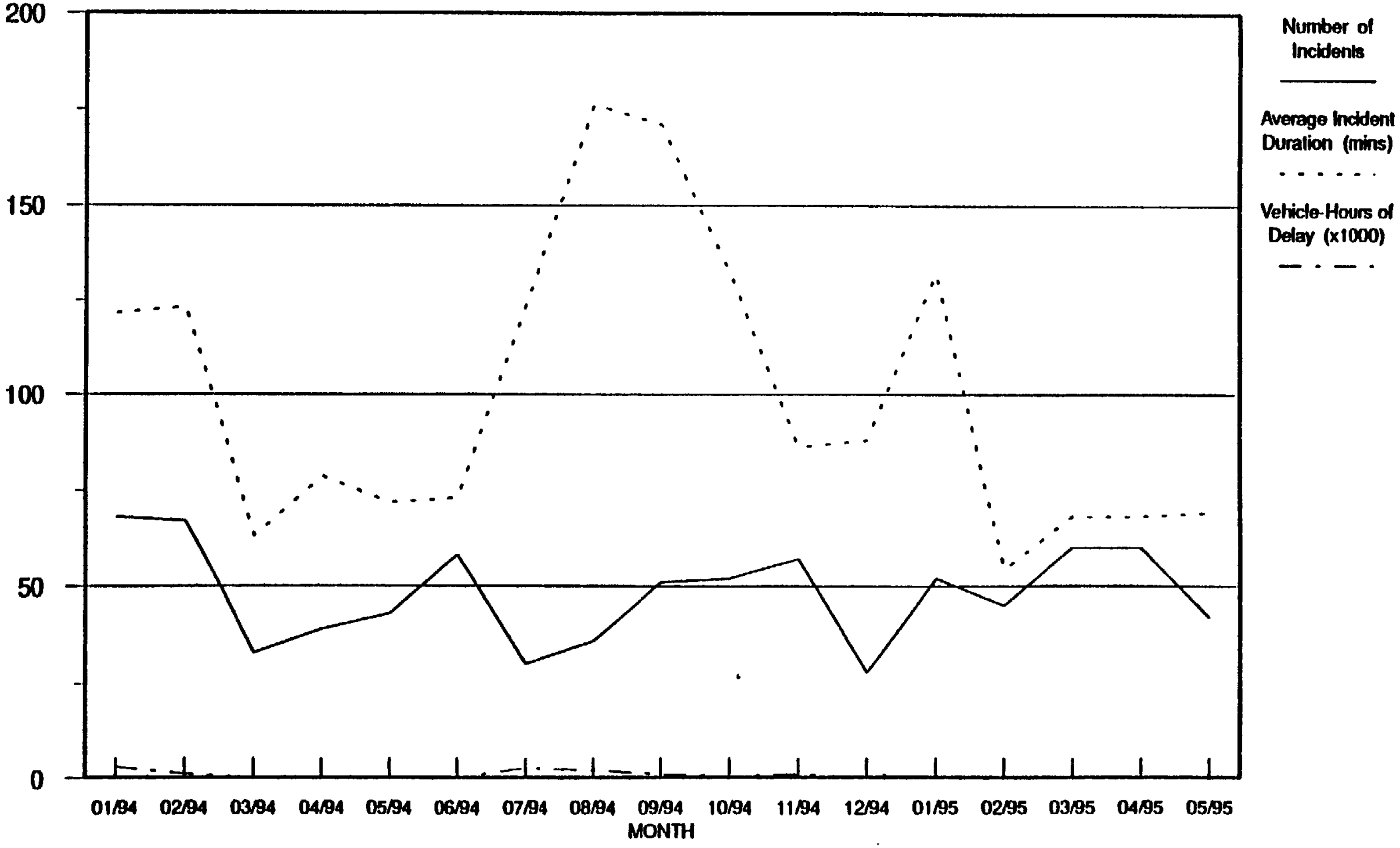
Note: VDS = Vehicle Detector Station
CMS = Changeable Message Sign



COUNTS OF OPERATOR REACTION TIME
TO CONFIRM INCIDENT DETECTION ALARMS
FOR THE MONTH OF APRIL

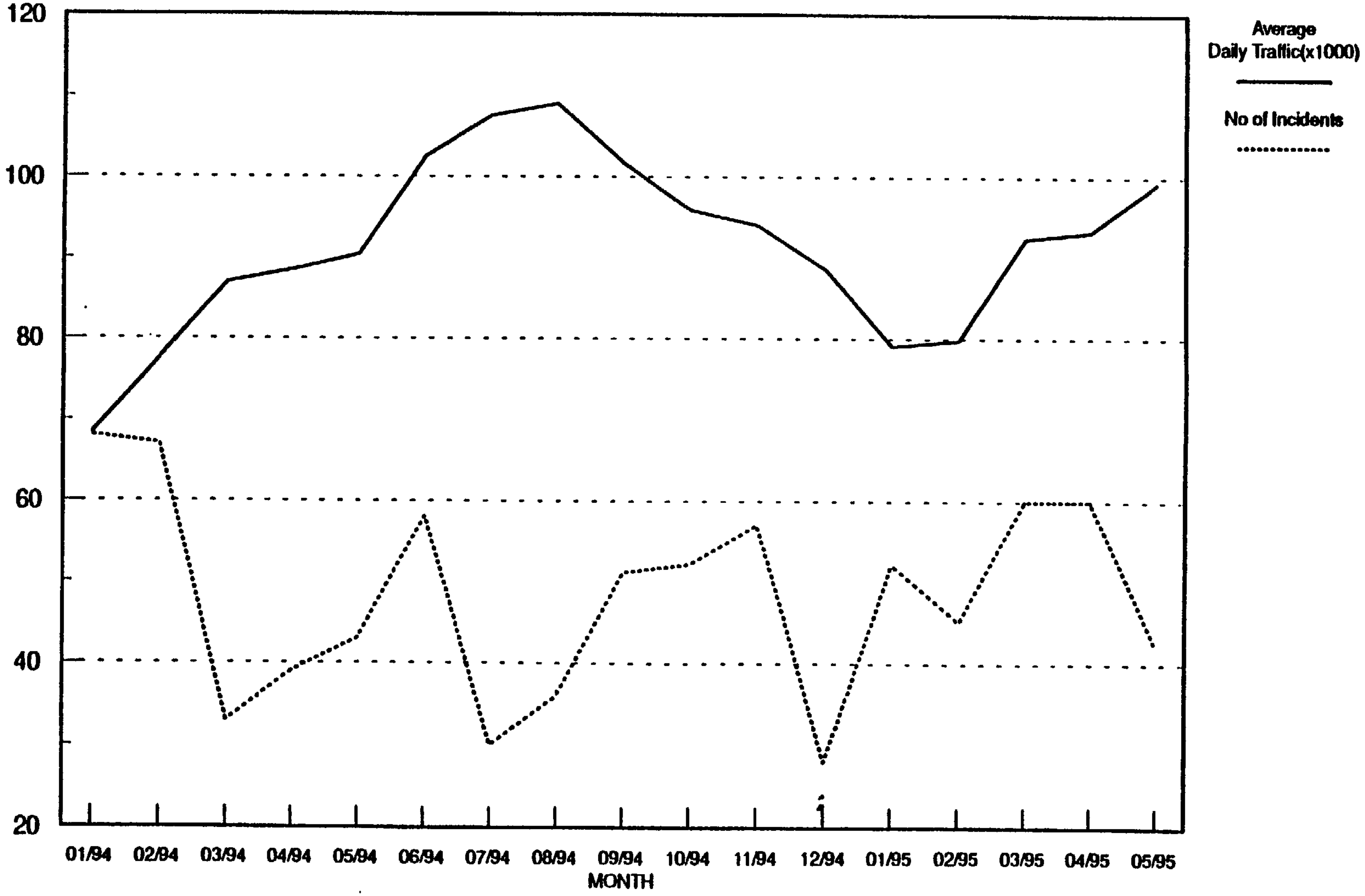
	Counts	Percentage
Less than 3 Minutes	88	97.78%
3 To 6 Minutes	1	1.11%
6 To 15 Minutes	1	1.11%
Above 15 Minutes	0	.00%
Total:	90	100.00%

Q.E.W. BURLINGTON COMPASS
MONTHLY INCIDENTS/VEHICLE-HOURS OF DELAY
FROM JANUARY 1994 TO MARCH 1995



Vehicle - Hours of Delay Calculation is based on the
Highway 401 Compass occupancy versus speed curve

Q.E.W. BURLINGTON COMPASS
MONTHLY INCIDENTS/DAILY AVERAGE TRAFFIC
FROM JANUARY 1994 TO MAY 1995



Q.E.W. BURLINGTON COMPASS
MONTHLY EQUIPMENT AVAILABILITY
FROM JANUARY 1994 TO MAY 1995