Testbed for Evaluating Automatic Incident Detection Algorithms

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ABSTRACT

Automatic Incident Detection (AID) algorithms are an integral component of incident management systems. Consequently, several incident management algorithms have been developed to respond to this need. However, none of these available AID algorithms has proven to be superior or dominant in all situations. Consequently, agencies that are contemplating to incorporate an AID algorithm as part of their Freeway Traffic Management System (FTMS) are faced with the difficult task of selecting the most appropriate algorithm for their situation.

The literature describes numerous off-line and on-line evaluation tests of current state-of-the-art AID algorithms. However, because these AID evaluation studies were conducted on different traffic network configurations for different incident scenarios and different traffic demands, a rigorous objective comparison of the various AID algorithms is very difficult. Consequently, there appears to be an urgent need for a standard testbed that can easily be utilised to evaluate and compare various AID algorithms.

This paper describes how a testbed that is composed of field and simulated data. The field data consists of 168 hours of 20-second data, including 26 incidents, while the simulated data consists of 60 hours of 20-second data including 75 incidents. The field data were measured along a 12-km section of Highway 401 in Toronto, Canada. The simulated data were generated by modelling the same section using the INTEGRATION microscopic model in order to complement the testbed to include a systematic set of incidents for different traffic flow regimes and locations. It is intended that this testbed serve as a step towards the development of a standard tool for the objective evaluation of AID algorithms.

I. INTRODUCTION

What is an Incident?

An incident was defined by Gall and Hall (1989) as a *random event that may disrupt the orderly flow of freeway traffic*. These incident events may include accidents, spilled truck loads, and stalled cars on the shoulder. The effect of an incident typically involves a change in the quantitative relationship of one or more of the macroscopic traffic variables (volume, density and speed) in the immediate neighbourhood of the causal event. An incident is, therefore, generally accompanied by the transition of a traffic stream from one traffic state to another. Such a transition is temporally and spatially limited by the shape of the shock waves, as illustrated in Figure 1.

Importance of Incident Detection Algorithms

Incident detection is an integral element of a comprehensive traffic control system. The importance of such an incident detection system is described in the following statistics provided by Busch (1991).

First, depending on the traffic conditions and the environmental situation, between 20 and 50 percent of all accidents on freeways are classified as secondary accidents, because they are caused by preceding (primary) accidents. Second, far more than 50 percent of these secondary accidents occur within 10 minutes

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of the first incident. Third, US studies in the Los Angeles conurbation have shown that more vehicle hours of delay result from extraordinary and accidentally occurring traffic disturbances (non-recurring) than from regularly occurring network overloading during typical daily peak hours (recurring).

Another study conducted by Robinson (1995) found that the impact of incidents on traffic congestion is a function of many factors, including; the severity, duration, location, prevailing traffic demand and pattern; and the timing of the incident with respect to the start of the peak period. This study concluded that these sensitivities of delay, to various incident attributes, suggest that there exists considerable scope for effective incident detection and management.

The ability to mitigate the impact of non-recurrent events, such as incidents, can potentially result in very substantial benefits in terms of a reduction in total system travel time, fuel consumption and vehicle emissions, and improvements in safety. Furthermore, the reduction of non-recurrent congestion may also increase total system throughput, thereby increasing the overall utilisation of the road network.

In order to facilitate and expedite the detection of incidents Automatic Incident Detection (AID) algorithms have been developed over the past two decades and continue to be developed. Several of these AID algorithms are currently in practice, including the California algorithms (Payne and Tignor, 1978; Levin et al., 1979; Arceneaux et al., 1989), the McMaster algorithm (Gall and Hall, 1989; Hall et al., 1993), APID (DelCan, 1987), and the Minnesota algorithm (Stephanedes et al., 1992; Stephanedes and Chassiakos, 1993). These AID algorithms attempt to infer the occurrence of an incident on the basis of field data that are typically measured using in-ground induction loop detectors.

Incident Detection Versus Congestion Detection

The existing AID algorithms differ in their detection criteria, that are the rules used to declare the occurrence of an incident. Despite these inherent differences, most AID algorithms share a common problem: they do not detect incidents as such; rather they detect congestion resulting from the incidents. AID algorithms must be able to distinguish between congestion caused by an incident (incident congestion) and recurrent bottleneck congestion (recurrent congestion). The fact that AID algorithms detect congestion rather than incidents results in the following problems:

a. Only incidents that cause congestion can be detected, resulting in what is termed in the literature as the *detection rate*.
b. AID algorithms can, erroneously, identify recurring congestion as incident congestion, resulting in what is termed in the literature as *false alarms*.
c. Congestion as a result of an incident requires some finite time to manifest itself, resulting in what is termed in the literature as the *mean time to detection*.

Paper Layout

This paper describes the development of a testbed of field and simulated data, that was generated and compiled at Queen's University, for MTO for the purpose of evaluating AID algorithms. This testbed was compiled for a 12 kilometre section along Highway 401 in Toronto, Canada.

The need for such a testbed is initially described in order to provide the context of this effort. Next, the study network that was utilised in compiling the AID testbed is described, prior to discussing the specifics of the testbed. Initially, the development of the field data component to the testbed is described in detail. This is followed by a description of the simulation component. The latter simulated dataset was required for two reasons. Firstly, it extends the field dataset by including more incidents. Secondly, it provides a controlled environment in which various incident scenarios and traffic conditions can be created by providing a wide variety of different but controlled incident and traffic conditions for the testing and evaluation of AID algorithms.

Subsequently, the use of the testbed is illustrated using one of the state-of-the-art AID algorithms, namely; the McMaster algorithm. The intent of this evaluation is threefold. Firstly, it serves to verify that the simulated data, that was synthesised as part of the testbed, is sufficiently similar to field data for the application of AID algorithms. Secondly, it demonstrates how the testbed can be utilised to evaluate and quantify the performance of AID algorithms. Thirdly, it serves as a benchmark for the evaluation of other AID algorithms.

The final section to this paper provides the reader with a summary to the paper in addition to providing the main conclusions of the paper.

II. Background

The literature provides the reader with numerous off-line and on-line evaluation tests of the current AID algorithms. These AID evaluation studies were usually conducted on different traffic network configurations for different incident scenarios and different traffic demands. The objective of this section is to demonstrate the difficulty to objectively compare results across studies and thus demonstrate the need for a standard testbed for the evaluation of AID algorithms.

Factors Influencing the Performance of AID Algorithms

Several factors impact the performance of AID algorithms. Some of these factors stem from the fact that AID algorithms attempt to detect congestion that results from incidents, rather than incidents per se. As a result, these AID algorithms can only detect incidents that impact the traffic flow characteristics. Furthermore, the propagation of congestion upstream of the incident is a function of numerous factors, such as the level of congestion prior and during the incident, the severity of the incident, and the duration of the incident. As the level of congestion and the incident severity increases, the speed of the backward forming shockwave increases allowing the AID algorithm to detect some incidents sooner. However, as the level of congestion increases, the number of false alarms also increases as the AID algorithm may mistakenly identify recurring congestion as non-recurring congestion.

Other factors that can impact the performance of AID algorithms include the spacing of detector stations and the technology of the surveillance system. Closely spaced detector stations can result in a quicker detection of the congestion resulting from the incident.

It can therefore be concluded, based on these factors, that the performance of an AID algorithm strongly depends on the specific characteristics of the testbed that is utilised in the evaluation process. For example, a testbed compiled for uncongested traffic conditions will most probably result in a lower false alarm rate and detection rate compared to a testbed compiled for congested traffic conditions.

Evaluation of AID Algorithms

Several studies have evaluated and compared different AID algorithms. However, most of these studies suffer from a number of drawbacks. Firstly, these studies do not share a common data base and, furthermore, the characteristics of the data base are not usually described in sufficient detail. Secondly, not all state-of-the-art AID algorithms are included in each evaluation study. Consequently algorithms need to be compared across studies. Thirdly, each evaluation study requires that the evaluators involve in the tedious effort of compiling a realistic evaluation testbed.

The most significant of evaluation studies of this type include the following:

1. Cook and Cleveland (1974) compared 19 algorithms including one of the Comparative algorithms.
2. Payne *et al*., (1976) compared 24 algorithms including the Comparative algorithms, again this study did not include the contemporary AID algorithms.
3. Levin and Krause (1979) and Levin *et al*. (1979) compared five algorithms including a number of the Comparative algorithms (algorithms 7, 8, and 10).
4. Busch and Fellendorf (1990) compared 12 algorithms including the Comparative algorithms and the HIOCC algorithm for varying traffic demands and detector spacing.
5. Stephanedes *et al*. (1992) and Stephanedes and Chassiakos (1993) compared five algorithms including the Comparative algorithm 7 and the Minnesota algorithm.

The first four evaluation studies did not include a number of the contemporary AID algorithms, like for example the McMaster algorithm, the Minnesota algorithm or AID algorithms that utilise Artificial Neural

Networks (ANN) or Fuzzy logic. The fifth study again did not include the McMaster algorithm, ANN and Fuzzy logic algorithms.

The Need for a Testbed

The literature demonstrates that there has not been a single evaluation study, up to this date, that has evaluated all existing AID algorithms, or at least all of the most promising AID algorithms. Furthermore, because these algorithms are continuously evolving and new AID algorithms are continuing to be developed, there appears to be an urgent need for a standard benchmark testbed that can be utilised to objectively evaluate existing and emerging AID algorithms.

A review by Busch (1991), together with a review of the state-of-the-art literature in AID algorithms, demonstrate that inductive loop detectors are still the primary source of measurement for virtually all existing systems. Thus, the existing evaluation studies appear to be consistent in terms of the detection technology. However, the traffic, incident and network configurations across the different literature sources vary considerably and thus it becomes extremely difficult to compare results across different studies. Consequently, there appears to be a need for a standard testbed to be utilised in evaluating and comparing different AID algorithms.

III. Study Network

The proposed study area is composed of eight interchanges along a 12-km freeway section on Highway 401 in Toronto, Canada. Highway 401 in Toronto experiences an average daily traffic flow of approximately 340,000 vehicles, making it one of the most heavily travelled freeways in North America. The section along Highway 401 that was utilised in this study extends from Allen Road in the east to Kipling Avenue in the west, as illustrated in Figure 2. This 12-km freeway section includes an express facility and a parallel collector facility, each of which typically consists of three lanes in each direction. The express and collector facilities are connected at some locations by transfer lanes. Changeable message signs are also located along this section, and are used to balance the demand, between the express and collector facilities.

The 12-km section of Highway 401, that is illustrated in Figure 2, was selected for the study for a number of reasons. Firstly, this section experiences major congestion during the AM and PM peak allowing the testbed to include field measurements during both uncongested and congested conditions. Secondly, as this section of the freeway is part of the COMPASS freeway traffic management system, it is well equipped with surveillance technology. Thirdly, there was no major construction along this section during the field data analysis period (October 1995) and thus most of the detectors were functioning during the analysis period.

As part of the Highway 401 COMPASS system, the study area encompasses a total of 131 detector stations that are spaced at approximately 600 metres. The detector spacing is consistent with a study Busch (1991) conducted which reviewed 21 European freeway surveillance systems, and found that the average spacing between detector stations was approximately 500 metres. The detector stations along the Highway 401 study network are located on the express, collector and transfer facilities in the eastbound and westbound directions. The detection technology along the study network, which is typical of most freeways in North America and Europe, consists of a combination of single and dual loop detectors (approximately 30 percent dual loops).

IV. Field Data Component

The 131 loop detectors, that are located along the study section, are polled every 20 seconds in order to measure the number of vehicles that cross the detector (volume), the percentage of time the detector is occupied (occupancy), and the average speed at which vehicles cross the detector (speed). These field measurements, are archived on the COMPASS system at the Ontario Ministry of Transportation (MTO), and were utilised to compose the field component of the dataset. In addition, the MTO archives incident statistics for incidents that occur within the COMPASS system. These statistics include: the estimated incident start and end times, the start and end times identified by the AID algorithm, and any further information regarding the incident.

Using these detector measurements, the typical spatial and temporal variation in flow, occupancy and speed along the study area were generated. The spatial and temporal variation in occupancy demonstrates congestion during the AM and PM peaks at the west end of the eastbound express and collector facilities as illustrated in Figure 3 and Figure 4, respectively. Alternatively, the westbound express and collector facilities experience congestion along the entire section during the AM and PM peaks as illustrated in Figure 5 and Figure 6, respectively.

In compiling the field data, two potential approaches could have been undertaken. In the first approach, field data obtained just prior, during and just after the occurrence of an incident could be compiled and spliced with other incidents in order to form a concentrated bank of incidents. In the second approach, continuous field data obtained over a selected time frame (e.g. one week) would be compiled. These data would contain field data for incidents that were either detected or not detected, in addition to any false alarms that occurred on the study section during the analysis time frame. The advantage of the first approach is that the testbed includes a large number of incidents, while still reducing the data storage requirements. However, this approach also suffers from two major drawbacks, namely: the field data can be distorted by the splicing process, and the dataset may not provide enough opportunities for the AID algorithms to encounter false alarms. Consequently, in generating the AID testbed for this study, it was elected to utilise the second approach to compile the field data component in a continuous fashion and to supplement this dataset with continuous simulated data. The simulated data would add more incidents to the testbed, where these incidents could be configured under “laboratory” conditions, allowing for the testing of AID algorithms under different pre-selected incident and traffic conditions.

Field data were collected for an entire week in October 1995 (October 9 to 15 inclusive). During the week under consideration, a total of 26 incidents occurred along the 12-km highway section, as summarised in Table 1. Each day’s dataset requires approximately 80 Mbytes of disk space, permitting the data for all 7 days to be stored on a single CD (the field data CD). The format that was utilised in compiling the data is demonstrated in Table 2 and described in Table 3.

V. SIMULATED DATA COMPONENT

The generation of synthetic data provides several opportunities to examine features that are not available in field data, including the ability to control the incident characteristics, and location as well as the traffic flow conditions prior, during and after the time when the incident is cleared. This level of control permits systematic assessment of AID algorithms for different flow regimes, incident types, and surveillance levels.

Prior to utilising synthetic data as part of the testbed, it was critical that these synthetic data be tested for consistency with field data. Consequently, a study was conducted in order to verify that the characteristics of the synthetic data generated from the INTEGRATION model were similar to the characteristics of the field data for a subsection of the study section illustrated in Figure 2 (Hellinga *et al*., 1997). On the basis of these verification comparisons, the study conducted by Hellinga *et al*. (1997) concluded that the simulated data exhibited similar trends to the field data allowing the simulated data to be used as part of the AID testbed.

The next step in the generation of synthetic data was to code the same 12-km section along Highway 401 for use with the INTEGRATION model. A brief description of the coding process and the experimental design that was utilised to create the bank of incidents are described in this section.

Coding of Study Network

The same 12-km network, that was described earlier in this paper, was coded for the INTEGRATION model. This coding entailed generating the five basic INTEGRATION input files, namely: the node file, the link file, the signal timing file, the Origin-Destination (O-D) demand file, and the incident file. The node and link files were created using detailed maps of the study area while the basic link traffic flow parameters were calibrated to field loop detector data using a generalised Greenshields’ model (Van Aerde and Rakha, 1995). The coded network, that is illustrated in Figure 2, is composed of 478 nodes, 30 origin-destination zones, and 597 links. Coding of ramp meter signals was not required as the Highway 401 is currently not ramp metered. Time varying 15-minute O-D demands were generated synthetically using 15-minute link flow counts that were generated from loop detector measurements (Van Aerde *et al*., 1991). The O-D demand was constructed to replicate the build up of the AM peak from 5:00 AM to 11:00 AM.

Loop detectors were coded to replicate the location of field loop detectors. The intent was to replicate as much as possible the traffic and network conditions that were present in the field.

Creation of Synthetic Loop Detector Data

The synthetic data component of the testbed, that was generated using the INTEGRATION model, includes a total of 75 incidents. Several factors were varied in order to generate a diversity of incident and background traffic scenarios as demonstrated in Table 4. These factors include the level of congestion during the incident, the incident severity, the incident longitudinal location, the lateral location of the incident indicating which lane(s) were blocked, the incident duration, and the section geometry at the incident location. In order to generate these 75 incident scenarios a total of 10 simulation runs were conducted on the 12-kilometre freeway section as demonstrated in Table 5. Appendix (A) presents the incident files that were utilised to generate the synthetic testbed component.

VI. EXECUTION OF MCMASTER ALGORITHM ON AID TESTBED

The AID testbed that was compiled at Queen's University includes a total of 101 incidents over 228 hours. These data comprise 168 hours of field data including a total of 26 incidents and 60 hours of simulated data including a total of 75 incidents.

The testbed that was compiled at Queen's University offers several advantages over other testbeds that have been utilised to evaluate AID algorithms. Firstly, the size of this testbed is relatively large compared to other testbeds. Specifically, a total of 140 hours of traffic data including 27 incidents was utilised to evaluate the Minnesota algorithm (Stephanedes and Athanasios, 1993), while a testbed of 64 normal weekdays including 28 incidents was utilised to evaluate the McMaster algorithm (Hall *et al*., 1993). Secondly, in this testbed, the majority of incidents are simulated allowing precise information regarding these incidents to be available, including the exact time at which each incident occurred, the exact duration of each incident, the exact longitude location of each incident, the exact latitude location of each incident, and the spatial length of each incident. These information are rarely available in the field. Thirdly, the simulated data provides a controlled environment for generating incidents for the evaluation of AID algorithms for different traffic and incident characteristics.

The McMaster algorithm was coded based on information provided in the literature (Gall and Hall, 1989; Hall *et al*., 1993) which does not necessarily coincide with the proprietary McMaster logic that was running in the field at the time of the study. The McMaster algorithm was executed on the AID testbed for a number of reasons. Firstly, because the McMaster algorithm operates in the field, it was essential that the coded logic be verified by comparing its results to the results of the McMaster algorithm that operated in the field at the time of the analysis. Secondly, the coded McMaster algorithm was executed on the simulated data in order to determine if the characteristics of the simulated data, in terms of incident detection, were consistent with the characteristics of the field data. Thirdly, it was important to generate some performance statistics for a typical AID algorithm in order to set the stage for the evaluation of other AID algorithms. This section describes the results of the execution of the McMaster algorithm on the AID testbed that was compiled for MTO at Queen's University.

The coded McMaster algorithm was tested on the field data component of the testbed in order to verify that the performance of the coded McMaster algorithm was consistent with the performance of the McMaster algorithm that operated in the field at the time of the analysis (October 1995). The McMaster parameters that were utilised in the evaluation were the parameters that were used by MTO at the time of the analysis. The field data consisted of a total of 26 incidents that were recorded in the incident log that was compiled as part of the COMPASS system. Of these 26 incidents, the McMaster algorithm in the field detected 11 incidents while the coded McMaster algorithm detected 10 incidents of which 7 were common as demonstrated in Table 6.

The results that are presented in Table 7 demonstrate that the version of the McMaster algorithm that was coded at Queen's University performed very similar to the McMaster algorithm that was running in the field at the time of the study. Specifically, the Detection Rate (DR) was within 3 percent and the on-line False Alarm Rate was within 1 percent.

The next step was to verify that the simulated data produced similar results, in terms of automatic incident detection, as did the field data. Consequently, the coded McMaster algorithm was executed on the simulated data to detect 28 incidents of the 75 incidents as demonstrated in Table 8. Again, the parameters that were utilised in the analysis were identical to those derived at by MTO during the time of the analysis. Table 8 also lists the characteristics of each of the simulated incidents in terms of the exact duration and severity of the incident. Some of these incident statistics that are provided as part of the simulated data can not be obtained from field data such as, for example, the exact duration of the incident because of the typical lag in identifying incidents in the field. Because the simulated data provides a controlled environment for which precise incident information is available, it was paramount to include simulated data as part of the incident detection testbed.

The results that are presented in Table 9 demonstrate that the performance of the McMaster algorithm was very similar for both the field and simulated data. Specifically, the Detection Rate (DR) was within 1 percent and the on-line False Alarm Rate (FAR) was within 2 percent. However, the off-line FAR was much higher for the simulated data versus the field data (approximately 6 folds higher). The precise reason for the large discrepancy in the off-line FAR's is speculated to have resulted because the simulated data, although it included a smaller amount of data (60 hours versus 168 hours), was composed of a larger number of incidents (75 versus 26 incidents). The smaller amount of data resulted in a smaller denominator in computing the off-line FAR for the simulated versus the field data. While the larger number of incidents resulted in more alarms as a result of the shockwaves that are generated by the incidents and thus a higher numerator in computing the off-line FAR for the simulated versus field data. Consequently, the higher off-line FAR for the simulated versus field data.

Based on the results presented in Table 9 it was concluded that the simulated data was reasonably consistent with the field data in terms of incident detection logic. Consequently, the results that are presented in Table 9 serve as a benchmark for the evaluation of other AID algorithms that may be evaluated using the testbed that was compiled at Queen's University.

VII. Conclusions and Recommendations

This paper describes how a testbed that is composed of field data and simulated data was compiled at Queen's University. The field data is composed of a total of 168 hours of 20-second data measurements including a total of 26 incidents, while the simulated data is composed of 60 hours of 20-second detector data including a total of 75 incidents.

The conclusions of the study are:

a. The application of the McMaster AID algorithm to simulated data generated by INTEGRATION and observed field data resulted in a detection rate and an on-line false alarm rate within 2 percent.
b. On the basis of these results, it can be concluded that loop detector data generated from the INTEGRATION model can be utilised to evaluate AID algorithms.
c. The AID testbed that was compiled at Queen's University includes a variety of controlled incident scenarios, namely: off-peak versus peak conditions, different incident severities, different longitudinal locations relative to detector stations, different lane blockages, different incident durations, and different locations relative to off- and on-ramps.

It is recommended that this testbed serve as a standard evaluation tool for the evaluation of AID algorithms.

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Table 1: Incident summary for field data

Incident number (Seq.)	Date	Time	Station ID
1	October 9, 1995	14:22:18	DW 0040 DWC
2	October 9, 1995	19:15:17	DW 0080 DEE
3	October 10, 1995	09:25:21	DW 0040 DWE
4	October 10, 1995	09:26:47	DE 0060 DWC
5	October 10, 1995	12:23:31	DE 0030 DWC
6	October 10, 1995	12:39:31	DE 0020 DWC
7	October 10, 1995	15:08:09	DW 0010 DWE
8	October 10, 1995	15:33:26	DE 0070 DWC
9	October 11, 1995	09:44:20	DE 0060 DWC
10	October 11, 1995	09:45:44	DE 0080 DWC
11	October 11, 1995	13:40:40	DE 0090 DEC
12	October 11, 1995	17:44:11	DW 0040 DWS
13	October 11, 1995	18:00:07	DE 0060 DWE
14	October 11, 1995	19:00:11	DW 0060 DEC
15	October 12, 1995	09:31:51	DW 0020 DWE
16	October 12, 1995	09:54:00	DE 0080 DWE
17	October 12, 1995	09:59:38	DW 0020 DWT
18	October 12, 1995	15:14:22	DW 0030 DEC
19	October 12, 1995	16:38:31	DW 0060 DEE
20	October 13, 1995	09:45:05	DE 0070 DWE
21	October 13, 1995	17:14:55	DW 0030 DWE
22	October 13, 1995	22:47:27	DW 0080 DEE
23	October 13, 1995	22:55:47	DW 0070 DEC
24	October 14, 1995	00:19:53	DW 0040 DEE
25	October 14, 1995	00:57:48	DW 0040 DEC
26	October 15, 1995	12:50:11	DE 0070 DEC

Table 2: Example illustration of loop detector file

Line #	**Description**							
1	Detector output for day 1							
2	20	16	10	1	540	112	30	401DW0010DES
3	20	16	10	2	720	120	35	401DW0010DES
4	20	16	10	3	1080	103	65	401DW0010DES

Table 3: Description of fields in the loop detector file

Line #	Field	Description
1	1	File title (up to 40 characters)
2+	1	Time (seconds) at end of interval [integer]
	2	Detector station identification number [integer]
	3	Detector station type
	4	Lane number - lanes are numbered consequtively from 1 in the median lane, increasing to the shoulder lane
	5	Lane volume measured during previous polling interval (veh/h/lane)
	6	Lane speed measured during previous polling interval (km/h)
	7	Lane occupancy measured during the previous polling interval (percent)

Table 4: Factors considered in experimental design

Factor	Number	Values
A. Level of Congestion	2	off-peak and peak conditions
B. Incident severity	2	1 and 2 lane blockage
C. Incident longitudinal location	5	50, 100, 200, 300, and 500 metres upstream detector station
D. Incident lateral location	3	median, centre, and shoulder
E. Incident duration	5	1, 5, 10, 20, and 30 minutes
D. Location geometry	5	upstream of on-ramp, downstream of on-ramp, upstream of off-ramp, downstream of off-ramp, and basic section

Table 5: Experimental design for simulated data

Batch	Factor						Total
	A	B	C	D	E	F	
A-1	2	2	uncontrolled	shoulder	1 and 20 min	uncontrolled	8
A-2	2	2	uncontrolled	shoulder	5 and 10 min	uncontrolled	8
A-3	2	2	uncontrolled	shoulder	30 min	uncontrolled	4
B	peak	2	uncontrolled	shoulder	5 min	5	10
C-1	peak	1 lane	5	shoulder	5 min	basic	5
C-2	peak	1 lane	5	shoulder	1 min	basic	5
C-3	off-peak	1 lane	5	shoulder	5 min	basic	5
D-1	2	1 lane	uncontrolled	shoulder	5	uncontrolled	10
D-2	2	1 lane	uncontrolled	centre	5	uncontrolled	10
D-3	2	1 lane	uncontrolled	median	5	uncontrolled	10
Total							75

where: uncontrolled means that the factor is not controlled and can take different values

Table 6: Description of incidents in field dataset

Incident	Detected by algorithm in field	Detected by coded algorithm	Incident description
1		Yes	Partial blockage
2			Partial blockage
3	Yes	Yes	Partial blockage
4			Partial blockage
5	Yes	Yes	Partial blockage
6			Partial blockage
7			Partial blockage
8	Yes	Yes	Partial blockage
9			Partial blockage
10			Partial blockage
11			Partial blockage
12	Yes		Partial blockage
13		Yes	Partial blockage
14	Yes	Yes	Partial blockage
15	Yes		Partial blockage
16		Yes	Partial blockage
17			Total blockage of transfer lane
18			Partial blockage
19	Yes	Yes	Partial blockage
20	Yes	Yes	Partial blockage
21			Partial blockage
22	Yes	Yes	Partial blockage
23			Partial blockage
24	Yes		Partial blockage
25			Partial blockage
26	Yes		Partial blockage

Table 7: Comparison of field and coded McMaster algorithm results for field data component of testbed

Parameter		**Field**	**Coded McMaster algorithm**
Total number of incidents	A	26	26
Total number of incidents detected	B	11	10
Total number of false alarms	C	255	287
Detection rate (B/A)	D	42.3	38.5 %
Total number of tests (1 per 20 sec)	E	6,259,680[1]	6,259,680[1]
Off-line false alarm rate (C/E × 100%)	F	0.00407 %	0.00458 %
On-line false alarm rate (100% × C/(B+C))	G	95.9 %	96.6 %

[1] 7 days × 24 hours/day × 60 minutes/hour × 3 tests/minute × 207 detectors = 6,259,680

Table 8: Description of incidents in synthetic dataset

Incident #	Direction	Facility	Start Time (hours)	Duration (minutes)	Severity (lanes blocked)	Lanes in Section	Batch	Detected?
1	EB	C	5:30 AM	20	2	4	Batch a-1	
2	EB	C	7:30 AM	20	1	5	Batch a-1	Yes
3	EB	E	5:45 AM	1	2	3	Batch a-1	
4	WB	E	5:45 AM	20	1	3	Batch a-1	
5	WB	C	6:00 AM	1	1	4	Batch a-1	
6	WB	E	8:15 AM	1	1	3	Batch a-1	
7	WB	S	8:30 AM	20	2	5	Batch a-1	
8	WB	C	8:00 AM	1	2	4	Batch a-1	
9	EB	C	5:30 AM	10	2	4	Batch a-2	
10	EB	C	7:30 AM	10	1	5	Batch a-2	Yes
11	EB	E	5:45 AM	5	2	3	Batch a-2	
12	WB	E	5:45 AM	10	1	3	Batch a-2	
13	WB	C	6:00 AM	5	1	4	Batch a-2	
14	WB	E	8:15 AM	5	1	3	Batch a-2	
15	WB	S	8:30 AM	10	2	5	Batch a-2	
16	WB	C	8:00 AM	5	2	4	Batch a-2	
17	EB	C	5:30 AM	30	1	4	Batch a-3	
18	EB	C	5:45 AM	30	2	3	Batch a-3	Yes
19	EB	E	8:30 AM	30	2	5	Batch a-3	
20	WB	E	7:30 AM	30	1	4	Batch a-3	
21	EB	E	7:00 AM	5	1	3	Batch b	Yes
22	EB	E	8:00 AM	5	1	3	Batch b	
23	WB	E	7:30 AM	5	2	3	Batch b	Yes
24	WB	C	8:15 AM	5	1	3	Batch b	
25	EB	C	7:00 AM	5	1	3	Batch b	
26	EB	E	8:00 AM	5	2	3	Batch b	Yes
27	WB	C	7:15 AM	5	2	3	Batch b	Yes
28	EB	E	7:30 AM	5	1	3	Batch b	Yes
29	WB	E	7:00 AM	5	2	3	Batch b	Yes
30	WB	C	7:45 AM	5	1	3	Batch b	
31	EB	E	7:00 AM	5	1	3	Batch c-1	Yes
32	WB	E	7:00 AM	5	1	3	Batch c-1	
33	EB	E	8:00 AM	5	1	3	Batch c-1	
34	WB	E	7:45 AM	5	1	3	Batch c-1	Yes
35	EB	E	8:30 AM	5	1	3	Batch c-1	Yes
36	EB	E	7:00 AM	1	1	3	Batch c-2	
37	WB	E	7:00 AM	1	1	3	Batch c-2	
38	EB	E	8:00 AM	1	1	3	Batch c-2	
39	WB	E	7:45 AM	1	1	3	Batch c-2	
40	EB	E	8:30 AM	1	1	3	Batch c-2	
41	EB	E	6:00 AM	5	1	3	Batch c-3	
42	WB	E	6:00 AM	5	1	3	Batch c-3	
43	EB	E	5:45 AM	5	1	3	Batch c-3	
44	WB	E	5:30 AM	5	1	3	Batch c-3	
45	EB	E	10:30 AM	5	1	3	Batch c-3	Yes
46	EB	C	6:30 AM	10	1	3	Batch d-1	Yes
47	EB	E	6:15 AM	5	1	3	Batch d-1	
48	EB	C	10:00 AM	30	1	3	Batch d-1	Yes
49	WB	E	6:09 AM	20	1	3	Batch d-1	
50	WB	C	10:19 AM	1	1	3	Batch d-1	
51	WB	E	8:15 AM	10	1	3	Batch d-1	Yes
52	WB	C	7:39 AM	10	1	3	Batch d-1	
53	WB	C	8:00 AM	1	1	3	Batch d-1	
54	EB	E	8:00 AM	30	1	3	Batch d-1	Yes
55	EB	E	7:39 AM	20	1	3	Batch d-1	Yes
56	EB	C	6:30 AM	10	1	3	Batch d-2	Yes
57	EB	E	6:15 AM	5	1	3	Batch d-2	
58	EB	C	10:00 AM	30	1	3	Batch d-2	Yes
59	WB	E	6:09 AM	20	1	3	Batch d-2	
60	WB	C	10:19 AM	1	1	3	Batch d-2	
61	WB	E	8:15 AM	10	1	3	Batch d-2	Yes
62	WB	C	7:39 AM	10	1	3	Batch d-2	
63	WB	C	8:00 AM	1	1	3	Batch d-2	
64	EB	E	8:00 AM	30	1	3	Batch d-2	Yes
65	EB	E	7:39 AM	20	1	3	Batch d-2	Yes

66	EB	C	6:30 AM	10	1	3	Batch d-3	Yes
67	EB	E	6:15 AM	5	1	3	Batch d-3	
68	EB	C	10:00 AM	30	1	3	Batch d-3	Yes
69	WB	E	6:09 AM	20	1	3	Batch d-3	
70	WB	C	10:19 AM	1	1	3	Batch d-3	
71	WB	E	8:15 AM	10	1	3	Batch d-3	Yes
72	WB	C	7:39 AM	10	1	3	Batch d-3	
73	WB	C	8:00 AM	1	1	3	Batch d-3	
74	EB	E	8:00 AM	30	1	3	Batch d-3	Yes
75	EB	E	7:39 AM	20	1	3	Batch d-3	Yes

Table 9: Comparison of McMaster algorithm results for field and synthetic data

Parameter		Field Data	Simulated Data
Total number of incidents	A	26	75
Total number of incidents detected	B	10	28
Total number of false alarms	C	287	473
Detection rate (B/A)	D	38.5 %	37.3 %
Total number of tests (1 per 20 sec)	E	6,259,680[1]	2,235,600[2]
Off-line false alarm rate (C/E × 100%)	F	0.00458 %	0.0212 %
On-line false alarm rate (100% × C/(B+C))	G	96.6 %	94.4 %

[1] 7 days × 24 hours/day × 60 minutes/hour × 3 tests/minute × 207 detectors = 6,259,680

[2] 10 runs × 6 hours/run × 60 minutes/hour × 3 tests/minute × 207 detectors = 2,235,600

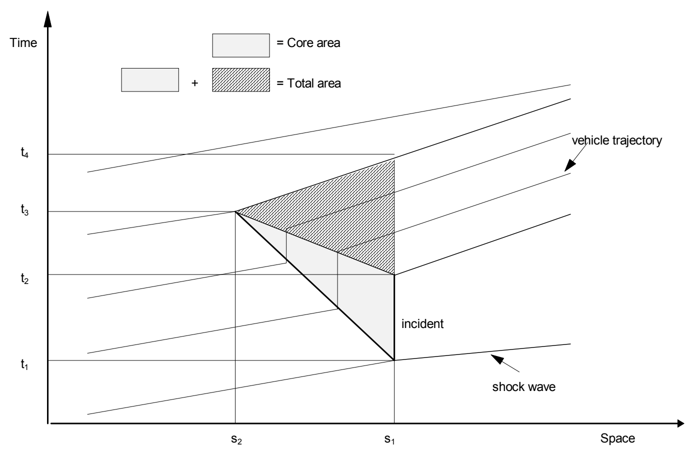

Figure 1: Representation of the impact of an incident on vehicle space-time trajectories

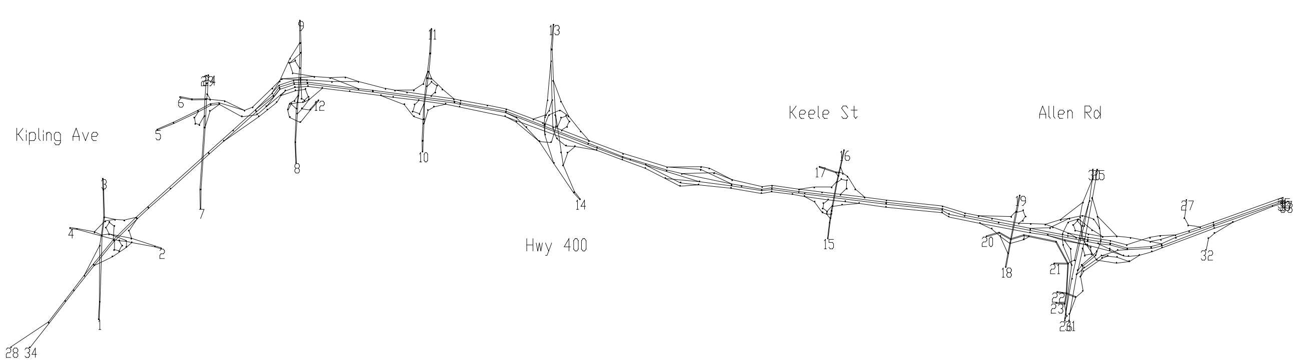

Figure 2: Study network configuration (Hwy 401, Toronto, Canada)

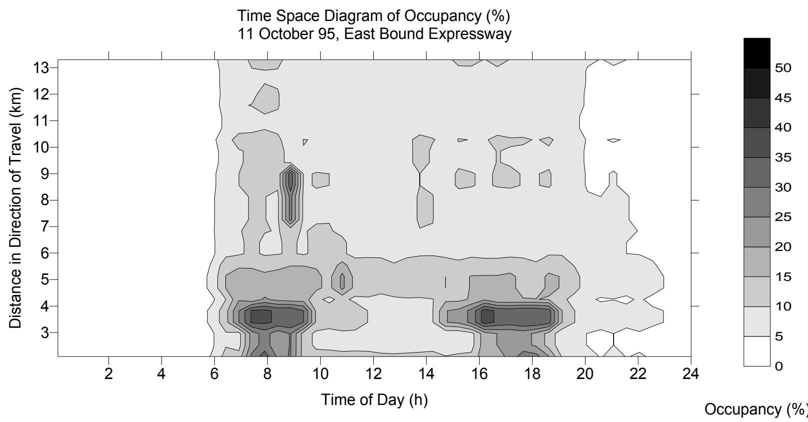

Figure 3: Typical spatial and temporal variation in occupancy on study network along eastbound expressway

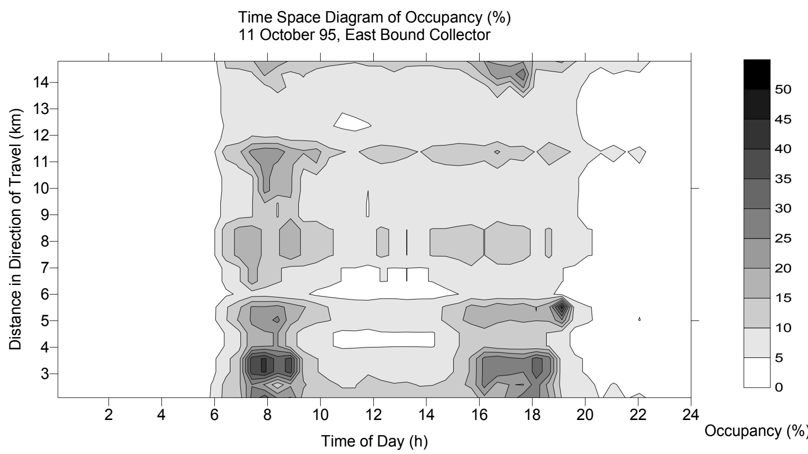

Figure 4: Typical spatial and temporal variation in occupancy on study network along eastbound collector

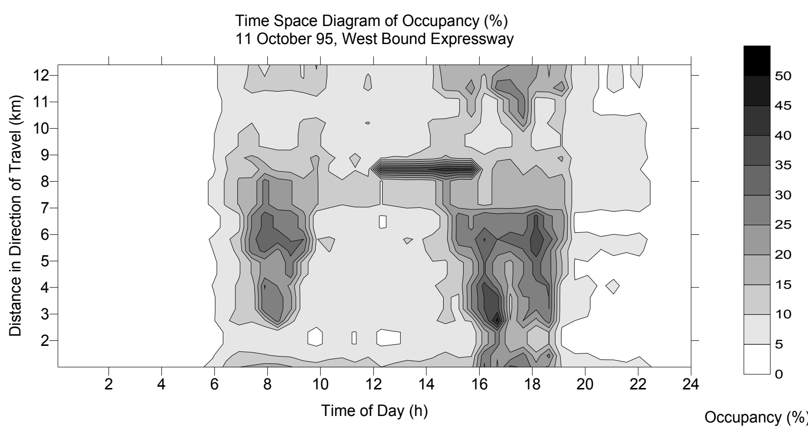

Figure 5: Typical spatial and temporal variation in occupancy on study network along westbound expressway

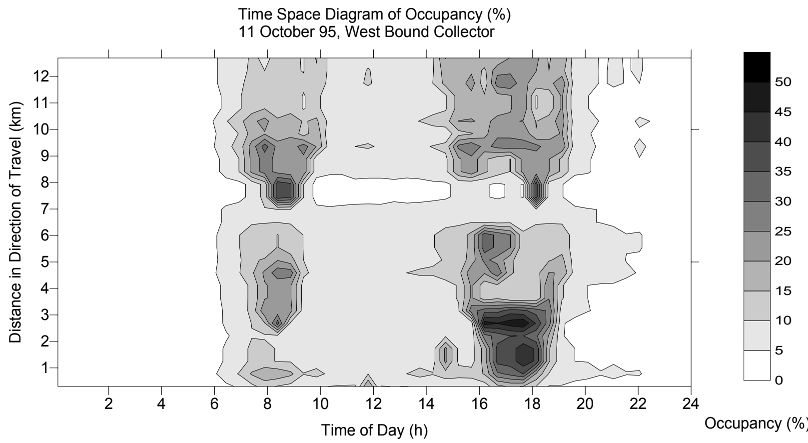

Figure 6: Typical spatial and temporal variation in occupancy on study network along westbound collector

APPENDIX (A)

TABLE A.1: INCIDENT FILE FOR BATCH A-1

```
hwy 401 - 8 interchange network: Batch A1
-8                                                                u/s detector
1  160    0.120  0.220   1800   3000  0011      Inc. A - 5:30-5:50 2 lanes   39
2  167    0.225  0.325   9000 10200 00001      Inc. B - 7:30-7:50 1 lane    71
3  344    0.240  0.340   2700   2760   011      Inc. C - 5:45-5:46 2 lanes  149
4  448    0.260  0.360   2700   3900   001      Inc. D - 5:45-6:05 1 lane   107
5  280    0.205  0.305   3600   3660  0001      Inc. E - 6:00-6:01 1 lane    83
6  458    0.200  0.300  11700 11760   001      Inc. F - 8:15-8:16 1 lane    69
7  305    0.100  0.200  12600 13800 00011      Inc. G - 8:30-8:50 2 lanes    4
8  286    0.100  0.200  10800 10860  0011      Inc. H - 8:00-8:01 2 lanes   54
```

TABLE A.2: INCIDENT FILE FOR BATCH A-2

```
hwy 401 - 8 interchange network: Batch A2
-8
1  160    0.120  0.220   1800   2400  0011      Inc. A - 5:30-5:40 2 lanes   39
2  167    0.225  0.325   9000   9600 00001      Inc. B - 7:30-7:40 1 lane    71
3  344    0.240  0.340   2700   3000   011      Inc. C - 5:45-5:50 2 lanes  149
4  448    0.260  0.360   2700   3300   001      Inc. D - 5:45-5:55 1 lane   107
5  280    0.205  0.305   3600   3900  0001      Inc. E - 6:00-6:05 1 lane    83
6  458    0.200  0.300  11700 12000   001      Inc. F - 8:15-8:20 1 lane    69
7  305    0.100  0.200  12600 13200 00011      Inc. G - 8:30-8:40 2 lanes    4
8  286    0.100  0.200  10800 11100  0011      Inc. H - 8:00-8:05 2 lanes   54
```

TABLE A.3: INCIDENT FILE FOR BATCH A-3

```
hwy 401 - 8 interchange network: Batch A3
-4
1  160    0.120  0.220   1800   3600  0001      Incident A -  5:30-6:00   39
2  344    0.240  0.340   2700   4500   011      Incident C -  5:45-6:15  149
3  305    0.100  0.200  12600 14400 00011      Incident G -  8:30-9:00    4
4  455    0.200  0.300   9000 10800  0001      Incident I -  7:30-8:00   84
```

TABLE A.4: INCIDENT FILE FOR BATCH B

```
highway 401 - June/96 Batch B
     -10
       1     345   0.374   0.424    7200    7500    001  155
       2     317   0.088   0.138   10800   11100    001   17
       3     446  0.1615  0.2115    9000    9300    011  113
       4     284  0.1275  0.1775   11700   12000    001   68
       5     165  0.2245  0.2745    7200    7500    001   53
       6     328   0.271   0.321   10800   11100    011   74
       7     279   0.159   0.209    8100    8400    011   83
       8     334    0.28    0.33    9000    9300    001  104
       9     300   0.371   0.421    7200    7500    011   13
      10     292   0.119   0.169    9900   10200    001   41
```

TABLE A.5: INCIDENT FILE FOR BATCH C-1

```
highway 401 - 8 interchange network : Batch C-1
      -5
       1     344   0.375   0.425    7200    7500 001            7:00:00 200m   149
       2     448    0.48    0.53    7200    7500 001            7:00:00 300m   107
       3     333   0.515   0.565   10800   11100 001            8:00:00 500m    93
       4     457    0.33    0.38    9900   10200 001            7:45:00 100m    69
       5     321    0.12    0.17   12600   12900 001            8:30:00  50m    31
```

TABLE A.6: INCIDENT FILE FOR BATCH C-2

```
highway 401 - 8 interchange network : Batch C-2
      -5
       1     344   0.375   0.425    7200    7260 001            7:00:00 200m   149
       2     448    0.48    0.53    7200    7260 001            7:00:00 300m   107
       3     333   0.515   0.565   10800   10860 001            8:00:00 500m    93
       4     457    0.33    0.38    9900    9960 001            7:45:00 100m    69
       5     321    0.12    0.17   12600   12660 001            8:30:00  50m    31
```

TABLE A.7: INCIDENT FILE FOR BATCH C-3

```
highway 401 - 8 interchange network : Batch C-3
      -5
       1     344   0.375   0.425    3600    3900 001            6:00:00 200m   149
       2     448    0.48    0.53    3600    3900 001            6:00:00 300m   107
       3     333   0.515   0.565    2700    3000 001            5:45:00 500m    93
       4     457    0.33    0.38    1800    2100 001            5:30:00 100m    69
       5     321    0.12    0.17   19800   20100 001           10:30:00  50m    31
```

TABLE A.8: INCIDENT FILE FOR BATCH D-1

```
hwy 401 - 8 interchange network: Batch D-1
-10
1  158   0.025  0.125   5400  6000   001      Inc. A - 6:30- 6:40    26
2  322   0.400  0.500   4500  4800   001      Inc. B - 6:15- 6:20    38
3  180   0.250  0.350  18000 19800   001      Inc. C -10:00-10:30   105
4  458   0.200  0.300   4200  5400   001      Inc. D - 6:10- 6:30    69
5  444   0.150  0.250  19200 19260   001      Inc. E -10:20-10:21   136
6  448   0.255  0.355  11700 12300   001      Inc. F - 8:15- 8:25   107
7  282   0.100  0.200   9600 10200   001      Inc. G - 7:40- 7:50    76
8  297   0.060  0.160  10800 10860   001      Inc. H - 8:00- 8:01    24
9  328   0.250  0.350  10800 12600   001      Inc. I - 8:00- 8:30    74
10 438   0.080  0.180   9600 10800   001      Inc. J - 7:40- 8:00   148
```

TABLE A.9: INCIDENT FILE FOR BATCH D-2

```
hwy 401 - 8 interchange network: Batch D-2
-10
1  158   0.025  0.125   5400  6000   010      Inc. A - 6:30- 6:40    26
2  322   0.400  0.500   4500  4800   010      Inc. B - 6:15- 6:20    38
3  180   0.250  0.350  18000 19800   010      Inc. C -10:00-10:30   105
4  458   0.200  0.300   4200  5400   010      Inc. D - 6:10- 6:30    69
5  444   0.150  0.250  19200 19260   010      Inc. E -10:20-10:21   136
6  448   0.255  0.355  11700 12300   010      Inc. F - 8:15- 8:25   107
7  282   0.100  0.200   9600 10200   010      Inc. G - 7:40- 7:50    76
8  297   0.060  0.160  10800 10860   010      Inc. H - 8:00- 8:01    24
9  328   0.250  0.350  10800 12600   010      Inc. I - 8:00- 8:30    74
10 438   0.080  0.180   9600 10800   010      Inc. J - 7:40- 8:00   148
```

TABLE A.10: INCIDENT FILE FOR BATCH D-3

```
hwy 401 - 8 interchange network: Batch D-3
-10
1  158   0.025  0.125   5400  6000   100      Inc. A - 6:30- 6:40    26
2  322   0.400  0.500   4500  4800   100      Inc. B - 6:15- 6:20    38
3  180   0.250  0.350  18000 19800   100      Inc. C -10:00-10:30   105
4  458   0.200  0.300   4200  5400   100      Inc. D - 6:10- 6:30    69
5  444   0.150  0.250  19200 19260   100      Inc. E -10:20-10:21   136
6  448   0.255  0.355  11700 12300   100      Inc. F - 8:15- 8:25   107
7  282   0.100  0.200   9600 10200   100      Inc. G - 7:40- 7:50    76
8  297   0.060  0.160  10800 10860   100      Inc. H - 8:00- 8:01    24
9  328   0.250  0.350  10800 12600   100      Inc. I - 8:00- 8:30    74
10 438   0.080  0.180   9600 10800   100      Inc. J - 7:40- 8:00   148
```