Automatic Freeway Incident Detection using Travel Time Data from AVI Equipped Vehicles

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SUMMARY

The recent emergence of automatic vehicle identification (AVI) technology for use in electronic toll collection has provided an opportunity to develop automatic incident detection (AID) methods that rely on individual vehicle travel time data rather than loop detector data.

This paper examines the performance of two AVI based AID algorithms. Travel time data for testing the algorithms was obtained by simulating a 12-km section of the collector facility of Highway 401 in Toronto, Canada. The results from the two AVI based AID algorithms are compared to the performance of a leading loop detector based algorithm, which was also tested on simulated data. The AID performance results indicate that AVI based AID has the potential to improve on existing loop detector based AID methods.

INTRODUCTION

Most urban freeways throughout North America are heavily utilised and experience ever increasing congestion during the peak commuting periods. Recurrent congestion results from high traffic demands and limited roadway capacity. Non-recurring congestion results from the occurrence of unexpected events (incidents) such as accidents, stalled vehicles, or material spills. The U.S. Federal Highway Administration estimates that approximately 60% of travel time lost to congestion is due to incidents and the percentage is believed to be increasing (1).

The early detection of incident events minimises the delay experienced by drivers, wasted fuel, emissions, and lost productivity, while also reducing the likelihood of secondary accidents. The goal of automatic incident detection (AID) is to minimise the human requirements in the efficient and effective detection of incident events.

The emergence of automatic vehicle identification (AVI) technology has provided a new and previously unavailable form of real-time traffic data, namely individual vehicle travel times. This paper examines two freeway AID algorithms that rely on vehicle travel time data obtained from AVI equipped vehicles. The performance of these algorithms is compared to a leading conventional AID algorithm that relies on data obtained from in-road inductive loop detectors.

EXISTING AID ALGORITHMS

AID algorithms generally fall into three categories: time series, comparative, and artificial intelligence.

Time series AID algorithms employ statistical or time series models to estimate current conditions based on past traffic observations. The use of past traffic observations enables the algorithms to be dynamically responsive to traffic conditions and eliminate the necessity of estimating static thresholds. Examples of times series AID algorithms are the Standard Deviation algorithm (2) and the TRANSCOM System for Managing Incidents and Traffic (TRANSMIT) System (3). The AVI based AID algorithms examined in this paper are of the time series approach.

Comparative algorithms establish predefined incident patterns and attempt to identify these patterns by comparing loop detector output against predetermined thresholds. Two comparison algorithms that are in use are the California Algorithms (4) and the McMaster Algorithm (5,6).

Traffic flow presents a number of inhomogeneities that are difficult to distinguish from those driven by incident events. These inhomogeneities include traffic pulses, compression waves, and random traffic fluctuations. A number of techniques have been used to enhance AID algorithms in order to minimise the impact of these inhomogeneities. These techniques include the use of artificial intelligence, in the form of artificial neural network (7,8) and fuzzy logic (9), and the use of data smoothing (10).

PROPOSED AVI BASED ALGORITHMS

Two algorithms have been developed for examination in this paper, the *Confidence Limit Algorithm* and the *Speed and Confidence Limit Algorithm*. Both algorithms are based on travel time data from AVI equipped vehicles.

As an AVI equipped vehicle passes a roadside antenna the vehicle is uniquely identified through wireless communication between the vehicle's transponder and the antenna. Since an AVI equipped vehicle can be uniquely identified, its travel time between antennas can be calculated. If a vehicle is not equipped with a transponder, the roadside antenna can not communicate, and no data can be collected for the vehicle.

CONFIDENCE LIMIT ALGORITHM

The *Confidence Limit Algorithm* is based on the premise that vehicle travel times are the result of a temporally varying stochastic process with unknown properties. However, the process can be characterised on the basis of recently acquired travel time data as illustrated in Figure 1.

The algorithm is applied to each roadway segment at fixed intervals, in this case every 20 seconds. During the 20 second interval a number of individual vehicle travel times are measured from AVI equipped vehicles. All of the vehicle travel times received during each interval are aggregated to determine the mean interval travel time (MITT).

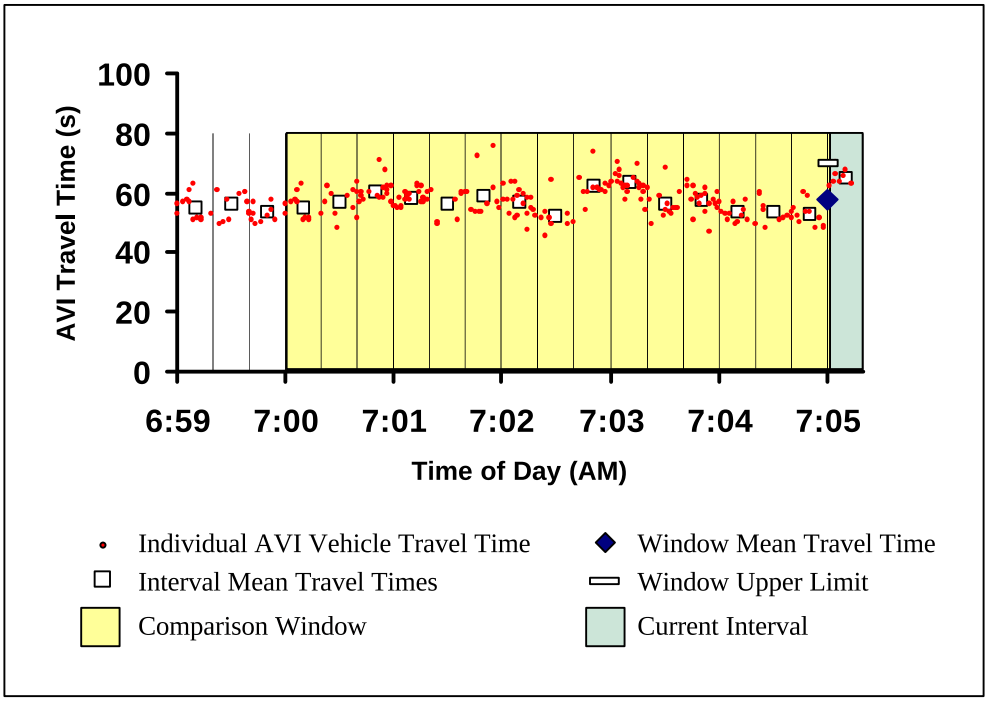

Figure 1 – Confidence Limit Process

A *comparison window* is defined, containing a number of intervals, from which the mean and variance of the MITT can be computed. Based on the assumption that MITT are log normally distributed, the log-normal mean and variance of a comparison window can be used to describe the expected mean travel time of the interval immediately following the comparison window. These log-normal statistics are used to establish an upper confidence limit for the mean segment travel time of the interval following the comparison window, as illustrated in Figure 1.

When performing AID in real-time, the mean segment travel time is calculated for the current interval and is compared to the upper confidence limit calculated for the corresponding previous comparison window. This process is illustrated in Figure 1.

It is assumed that changes in demand have a more gradual effect on traffic conditions than do incidents. Based on this assumption, if a mean interval travel time is greater than its corresponding upper limit, it can be stated with a specified level of confidence that the increase in travel time has resulted from a process other than that associated with ideal traffic conditions, namely from an incident.

A persistence check can be used so that an alarm is not called until a predefined number of consecutive intervals have mean segment travel times greater than their corresponding upper confidence limit. The use of a persistence check can decrease the effects of shock waves and other random traffic fluctuations.

SPEED AND CONFIDENCE LIMIT ALGORITHM

The *Speed and Confidence Limit Algorithm* requires the additional capability to capture vehicle speeds as they pass roadside antennas. The speed data does not have to be limited to the AVI equipped vehicles and can be collected by a variety of different sources. These sources include radar, wide area video detection, or even inductive loop detectors.

The *Speed and Confidence Limit Algorithm* is an extension of the *Confidence Limit Algorithm* and contains the same logic as described in the previous section. However, the *Speed and Confidence Limit Algorithm* performs an additional check based on vehicle speeds at the downstream roadside antenna. For this reason, the mean speed of vehicles equipped with AVI transponders is also calculated for each interval, as well as for the comparison window.

When an incident occurs, the capacity at that location decreases. The decreased capacity at an incident is likely to create congestion upstream of the incident and reduce the flow downstream of the incident. The decrease in flow downstream is in turn likely to allow an increase in speed downstream. Therefore, if an incident occurs on a segment it is likely that the speed of the vehicles exiting the segment will increase.

The *Speed and Confidence Limit Algorithm* first determines whether a mean interval travel time indicates that there may be an incident before considering the speed of vehicles exiting the segment. If the mean interval travel time exceeds the confidence limit, then an alarm is called only if the speed of vehicles as they exit the segment has also increased.

TESTING THE AVI BASED AID ALGORITHMS

This section describes the simulated data and the different parameter values used to test and calibrate the two AVI based AID algorithms. The data for testing the algorithms was generated using a simulation model because no AVI field data were available.

Network Description

The network used in this study is modeled after eight interchanges along a 12-km freeway section of Highway 401 in Toronto, Canada. This facility experiences an average daily traffic flow of approximately 340,000 vehicles, making it one of the most heavily traveled freeways in North America. This freeway section includes an express facility and parallel collector facility, however, only the collector facility was modeled for this study. As illustrated in Figure 2, the eastbound and westbound freeway directions are both divided into 10 segments approximately 1.2 km in length with AVI roadside antennas at both ends of each segment.

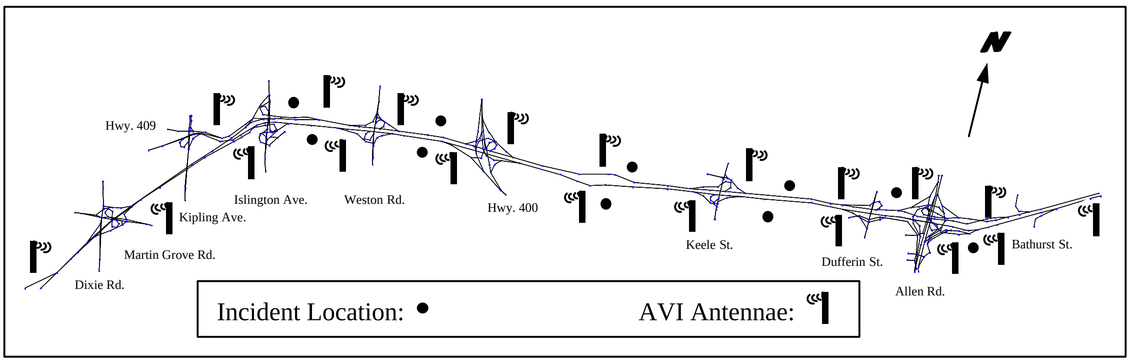

Figure 2 – Simulation Network

The network was simulated using the Integration traffic simulation model (11). The origin-destination traffic demand was constructed to replicate the build up of the AM peak from 5:30 AM to 10:30 AM. A total of 101,142 vehicle trips were simulated during this 5 hour time period. At several locations, the network experiences severe recurring congestion during the simulation. This permits the testing of AID during both uncongested and congested conditions.

Incident Data

Twenty-four separate scenarios were simulated, resulting in a total of 120 hours of simulated traffic conditions. All the scenarios used the same network and O-D demand characteristics. However, each scenario included the modelling of 5 unique incidents, for a total of 120 simulated incidents. These 120 incidents had varied location (20 locations as illustrated in Figure 2), duration (5, 10, 20, and 30 minutes), time of day (60 during peak and 60 during off-peak), severity (100 single lane closures and 20 two-lane closures on three-lane sections), and traffic conditions.

Parameters Varied in Testing the Algorithms

The level of market penetration (LMP) of AVI equipped vehicles on a facility can vary significantly. Therefore, the algorithms were tested at 6 different LMP (1%, 5%, 10%, 25%, 50% and 100%). For each LMP the duration of the comparison window, the confidence level and the number of degree of persistence checks were also varied. The initial testing of the algorithms was performed for a total of 27 different parameter combinations for each LMP. Based on the results from these initial tests, a second set of 27 parameter combinations was tested for each LMP.

RESULTS

Two primary measures of performance, namely detection rate and false alarm rate, are used to evaluate AID algorithms. The detection rate (DR) is defined as the number of incidents correctly detected by the AID algorithm divided by the total number of incidents known to have occurred during the observation period. The off-line FAR is calculated by dividing the number of false alarms by the total number of alarm tests during the observation period.

Table 1 summaries the results for the parameter combinations that provided the highest detection rate (DR), while providing an off-line FAR of less than 0.2%, for each LMP, for both algorithms. The last row of Table 1 provides performance results for the McMaster Algorithm, a leading conventional AID algorithm that relies on loop detector data. These results were obtained for the same section of Highway 401 on the basis of simulated detector data (12) and are provided as a point of comparison for the results obtained for the proposed AVI algorithms.

As illustrated in Table 1, the off-line FAR for the McMaster AID is almost an order of magnitude smaller than the results obtained in this study. However, the McMaster off-line FAR value is based on a greater number of alarm checks since the spacing of the inductive loop detectors is less than the spacing of the AVI roadside antennae modelled for testing the AVI based AID algorithms. In order to reasonably compare the results, this off-line FAR is converted to a value of false alarms (FA) per km, per hour (FA/km/hr). The network modelled for the coded McMaster algorithm was composed of approximately 12 km of express facilities and 8 km of collector facilities, for a total network length of 20 km in each direction. The testing of the coded McMaster algorithm on this network resulted in 473 FA during the 60 hours of simulation. This results in an off-line FAR of approximately 0.20 FA/km/h at a DR of 37.3%.

The off-line FAR results of the AVI based AID algorithms presented in Table 1 have been similarly converted, based on a total network length of 12 km in each direction and 120 hours of simulated data.

Table 1 – AID Results as a Function of the Level of Market Penetration

	LMP	DR	Off-line FAR	
	(%)	(%)	(%)	(FA/km/h)
Confidence Limit Algorithm	1	20	0.16	0.23
	5	28	0.13	0.19
	10	30	0.13	0.19
	25	24	0.15	0.22
	50	28	0.17	0.25
	100	29	0.19	0.28
Speed and Confidence Limit Algorithm	1	43	0.18	0.26
	5	43	0.15	0.22
	10	51	0.18	0.26
	25	51	0.19	0.28
	50	48	0.20	0.29
	100	41	0.17	0.25
McMaster Algorithm	N/A	37.3 [a]	0.02 [b]	0.20 [b]

[a] as reported by Rahka and Van Aerde (12)
[b] calculated based on data from Rahka and Van Aerde (12)

Table 1 indicates that the detection rates of the *Confidence Limit Algorithm*, at all levels of market penetration, are lower than those of the McMaster algorithm, while the off-line FAR is higher for two-thirds of the LMP cases. The *Speed and Confidence Limit Algorithm* also has off-line false alarm rates that are higher than the McMaster algorithm. However, the detection rates are higher at all levels of market penetration for the *Speed and Confidence Limit Algorithm* when compared to both the McMaster algorithm and the *Confidence Limit Algorithm*. These results indicate that the addition of a vehicle speed check to the base *Confidence Limit Algorithm* provides substantially better AID performance (almost twice the DR).

A further advance of the AVI based AID algorithms is that the surveillance infrastructure can be maintained without lane closures and is not affected by pavement resurfacing, unlike loop detectors which generally required replacement after pavement rehabilitation.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that AVI based AID has the potential to provide improvements over leading loop detector based AID algorithms. Specifically, the AVI based AID algorithms examined in this study provided up to 36% improvement in DR with only an increase in the FAR from 0.20 FA/km/h to 0.26 FA/km/h, when compared to a coded McMaster algorithm, that was also tested using simulated data. The inclusion of vehicle spot speed data along with AVI vehicle travel time data resulted in up to 108% increase in DR with only an 18% increase in FAR (in FA/km/h), when compared to using only vehicle travel time data.

It is recommended that once available, field data be used to test and further develop AVI based AID and that the impact of factors such as antennae placement be quantified.

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