Incident Detection via Commuter Cellular Phone Calls

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Abstract

Rapid and reliable incident detection is a critical component of a traffic management strategy. Traditional automatic incident detection methodologies rely on the interpretation of spot measurements of selected traffic characteristics (i.e. speed, volume, and occupancy). However, it is generally agreed that the current best algorithms still do not achieve the desired performance levels. Recent advances in wireless communication technologies have resulted in high levels of market penetration of wireless phones, providing the opportunity to detect incidents on the basis of commuter reports.

This paper examines the potential of driver-based incident detection. A methodology for quantitatively assessing the performance characteristics of driver-based incident detection is presented, and the data required to support this method are identified. Potential data sources within the Greater Toronto Area are identified and evaluated.

It is determined that existing data sources do not appear to be sufficient for directly determining the performance characteristics of driver-based incident detection within the Toronto Region. As a result, it is recommended that the use of traffic simulation modeling and statistical inference approaches be examined. Specifically, it is recommended that data needed to support the derivation of key driver behavior parameters be defined, and that the existing data sources be examined to determined if they could supply the required data.

1 Introduction

1.1 Background

Rapid and reliable incident detection is a critical component of a traffic management strategy. Since the early 1970's, automatic incident detection methodologies have relied on the interpretation of 20 or 30 second aggregated speed, volume, and occupancy data to detect the occurrence of an incident. Unfortunately, while much effort has been expended to improving these AID algorithms, it is generally agreed that the current best algorithms still do not achieve the desired performance levels.

Other forms of incident detection have also been developed, including video surveillance, which provides a reliable means of visually detecting and verifying incidents. However, this technology is costly, both in terms of capital costs and labour costs, preventing it from being deployed over more than just selected freeway sections.

The recent wide spread introduction of cellular telephones provides the opportunity for another method of incident detection. This approach relies on the commuting public to phone a central switchboard when they observe an incident. It has been suggested that transportation authorities can rely solely on motorists to detect and report incidents. While many media outlets and emergency response agencies have incorporated cellular phone calls from motorists as an additional means of obtaining incident data, the cost efficiency, reliability, and performance characteristics of relying on motorists for incident reporting has not been documented. Quantifying these performance measures is necessary before any decision can be made regarding the suitability of abdicating responsibility to motorists for the detection and reporting of incidents.

1.2 Objectives of Study

This paper examines the potential of using motorists' cellular phone reports as a source of data for input to an advanced traveller information system, and as a mechanism for detecting incidents. Trends in the use of wireless communications and levels of market penetration of these technologies into vehicles are examined. A framework for quantifying the efficiency, accuracy, and characteristics of driver-based incident reporting is proposed. The data requirements for this framework are identified. The availability of these data for the Toronto region is discussed.

1.3 Structure of Paper

Section 2 provides an overview of recent and expected future trends in wireless phone use by drivers. Section 3 provides a discussion on the relative similarities and differences between the use of driver-based cell phone reports for incident detection and the use of these reports for input to an advanced traveller information system. Section 4 provides a description of a framework that can be used to quantify the efficiency, reliability, and performance characteristics of using driver-based cell phone reports for incident detection. The data needed to carry out this analysis are identified. The data sources available for the greater Toronto region are listed, and comments are made on the sufficiency of these data. Finally, conclusions and recommendations are made.

2 Wireless Communications

Cellular telephones were introduced to the U.S. market place in 1983. These early devices consisted primarily of relatively large analogue cellular phones costing thousands of dollars (NHTSA, 1997). As a result of their high cost, these devices tended to be used primarily for business applications. During the past 15 years, continuing advances in wireless communication technologies have enabled wireless communication service providers to supply a much wider array of wireless communication options at lower cost to the consumer market. As illustrated in Table 1, these lower costs have resulted in a much greater level of market penetration in the general consumer market, with non-business use exceeding 50%.

Table 1: Primary phone use patterns (Source: Gallup, 1993)

Year	Business	Personal
1991	67%	33%
1993	54%	46%

The Cellular Telecommunications Industry Association (CTIA), the U.S. organization representing wireless service providers as well as equipment manufacturers, reports that there are currently more than 50 million cellular customers in the U.S. The current growth rate is approximately 40% per year. In Canada, the Canadian Wireless Telecommunications Association (CWTA) reports that there are currently 4 million cellular phone subscribers, with an annual growth rate of approximately 30% (CWTA, 1997). CWTA anticipates that 10 million Canadians, 40% of the population, will own wireless phones by the year 2005.

The high level of market penetration of cellular phones is not limited to a specific demographic segment of society. Table 2 provides data obtained from Bell Mobility, a Canadian wireless service provider, reflecting cellular phone use by age of subscriber in Ontario and Quebec in 1996. These data indicate that the greatest proportion of subscribers is in the 36-45 years old age category. However, cellular use, particularly for personal use, is reported for all age categories above 18 years old.

Table 2: Distribution of cellular phone subscribers
by age category (Source: Bell Mobility, 1996)

Age Category	Business	Personal	Total
18 - 25	2%	10%	7%
26- 35	21%	27%	25%
36 - 45	41%	30%	34%
46 - 55	27%	20%	22%
56 - 65	8%	8%	8%
66+	0%	4%	3%

These data support two significant trends:

- First, the number of existing cellular subscribers is substantial, and is expected to grow at a rate of 30 - 40% per year over the next several years. Thus, the levels of market penetration of cellular phones is likely to reach levels of 25 - 40% of the population within the next 5 - 10 years.
- Second, the low cost of cellular service subscription means the level of market penetration is not restricted to only business applications, or to only individuals with high income. Thus, the level of market penetration is broadly based, representing most socio-economic segments of society.

3 Driver use of Wireless Communication for Emergency Response and Traffic Management

The previous section has provided data describing the magnitude of the current and expected future level of market penetration of cellular phone subscription. These data indicate that the level of market penetration of cellular phone subscription in Canada and the U.S. is expected to reach or exceed 25% - 40% of the population within the next 5 to 10 years. Furthermore, this market penetration is across a broad spectrum of society in terms of socio-economic demographics. In this section, the use of cellular phones specifically for reporting traffic incidents is examined. The opportunity for using driver-reported traffic conditions as an input to an advanced traveller information system is also explored.

3.1 Emergency Reporting

In response to the increased availability of cellular phones, most existing emergency caller-response services, such as "911", have been adapted for access via wireless phone. As a result, in most urban centres in North America, motorists are able to contact police, fire, and/or ambulance services via cellular phone. Despite the recognition that many people subscribe to a wireless communication service primarily for safety benefits (e.g. ability to contact emergency service providers), little data have been collected that reflect aggregate trends in the use of emergency calls from wireless phones. Figure 1 illustrates the annual number in cellular "911" calls received by the California Highway Patrol between 1985 and 1995 (NHTSA, 1997). These data indicate that cellular calls increased almost 75 fold from 1985 to 1995. In California, these cellular calls, which represent only 30% of all emergency telephone calls, are directed to 24 regional communication centres. Thus, if the division of calls to all centres is equal, then on average, in 1995 each center would have received more than 10 cellular calls per hour, and almost 35 telephone (combined land line and wireless) calls per hour.

While emergency personnel are reported to be generally appreciative of the rapid notification permitted by cellular phone reporting, many emergency call response centres are overwhelmed by the number of calls received (NHTSA, 1997). Confounding the problem is that many calls are often received for the same incident, and many calls are of a non-critical emergency nature (e.g. reporting a disabled vehicle on the shoulder).

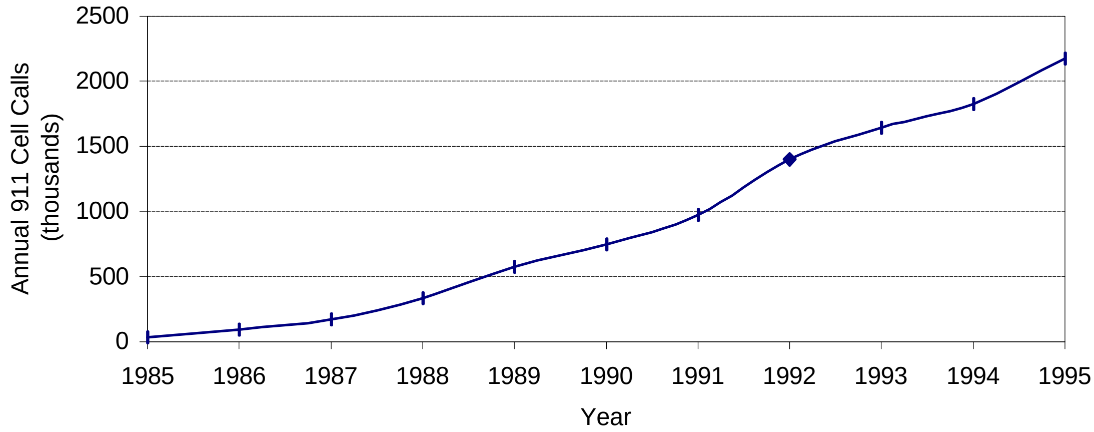

Figure 1: Total Annual 911 Emergency Calls Received in California from Cellular Phones (Adapted from: Table 2-6, NHTSA, 1997)

3.2 Information Source for ATIS

In addition to emergency reporting, the high levels of market penetration of wireless phones provides an opportunity to use driver reports as input to advanced traveller information systems. The previous section discussed the use of wireless phones for notifying emergency services of an event requiring a response. For these situations, once the emergency service has been notified, they are generally required to send a unit (e.g. police officer) to the scene to make an assessment. The officer on the scene then decides what course of action is to be followed. Thus, after the first notification, further calls from the public are not required (unless these subsequent calls provide relevant information not provided by previous callers), and simply consume valuable resources.

However, drivers can also provide information regarding traffic conditions that is important from a traffic management perspective. In this situation, drivers making reports via their cellular phones, act as probe vehicles, and provide a single sample of travel conditions at a point in time and a specific location in space. According to fundamental sampling theory, the level of reliability associated with the state of network conditions must be expected to increase as the number of reports also increases. Therefore, for acquiring network traffic condition data, multiple driver reports for a single event can be considered a benefit, rather than a dis-benefit.

Recognizing the value of the traffic network information that motorists can provide via cellular calls, many radio stations, and some departments of transportation, have instituted special cellular call numbers whereby motorists are encouraged to report traffic conditions. For example, in Toronto, the Bell Mobility network supports charge-free calls to at least 6 local radio stations (Q107, Energy 108, CKFM, CFRB, CHUM-FM, and CKEY) and one TV station (Global TV). The station receiving the calls then incorporate the network information into their traffic condition reports. Several limitations with this approach can be identified:

- There is no way to verify that the information received from the caller is correct.
- The number of cellular calls is divided among a number of different stations, each of which operates independent of each other.
- There does not appear to be a systematic approach to integrating cellular phone reports into other sources of traffic information.

4 Framework for Quantifying the Accuracy and Efficiency of Driver based Incident Reporting

4.1 Criteria

When considering the use of cellular reports for the purposes of emergency notification or for traffic condition reporting, it is important that the effectiveness and the efficiency of the approach be quantified and compared to other approaches.

Specifically, the effectiveness of using driver-based reports must be assessed in terms of the accuracy of the reports as compared to non driver-based approaches. Accuracy must be defined to include the correct identification or description of the event, the correct spatial location of the event, and the correct time at which the event occurred or was observed. Traditional automatic incident detection methods have defined several measures of effectiveness, including the mean time to detection (MTD), the detection rate (DR), and the false alarm rate (FAR).

Efficiency must be assessed on the basis of the benefit obtained from the resources used. Thus efficiency could be quantified on the basis of benefit to cost ratio. The benefit might be determined from the measures of effectiveness, while the costs would those associated with providing the cellular call number service.

This paper focuses on establishing a framework for quantifying measures of effectiveness.

4.2 Proposed Framework

When assessing the effectiveness of emergency incident reporting, the initial metric to quantify is the accuracy of the driver report. Figure 2 illustrates the four possible outcomes, two of which result in correct responses, and two in incorrect responses. If

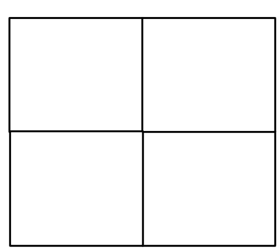

Figure 2: Possible outcomes for event reporting

an event has occurred, and a cellular call is received indicating the event has occurred, then the outcome is correct. Likewise, if an event has not occurred, and no call is received, this is also a correct outcome. However, if either an event has occurred and no call is received, or an event has not occurred, and a call is received, then the outcome is incorrect. The objective is to quantify the number of correct and incorrect outcomes that arise.

It is useful to examine more closely the conditions under which correct and incorrect outcomes may occur. A correctly identified event is one for which a call is received describing the correct spatial location of the event as well as the correct time at which the event occurred or was observed. In most cases it is likely practical to assume that the time at which the event was observed is equal to the time at which the cellular phone call was received, since notification that the caller was aware of the occurrence of the event some time prior to the cellular call (e.g. a caller indicates that they observed an incident 10 minutes ago), can not reduce the response time.

If an event is reported, but no event of that description occurred at the reported time and location, then the outcome is incorrect. Likewise, if an event occurs, but no report is received that matches the time and location of the event, then the outcome is incorrect.

These four possible outcomes are captured within the measures of false alarm rate and detection rate. Detection rate is the number of correctly identified events, divided by the total number of events that occurred. False alarm rate is the number of incorrect outcomes divided by the total number of outcomes.

Another important metric to quantify is the time required to make a correct identification of an event. This metric is typically captured by the mean time to detection (MTD).

The next section identifies the data required to compute the detection rate, false alarm rate, and mean time to detection for incidents reported by motorists.

4.3 Required Data

As illustrated in Figure 3, data are required describing two separate environments. Data are required that define reality, in terms of event occurrence, event description,

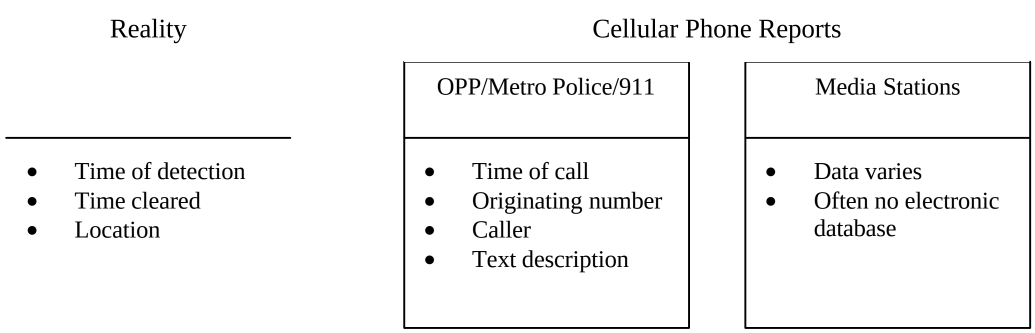

Figure 3: Potential data sources related to cellular phone reports

event location, and start and end time of event. Data are also required that define the set of cellular reports, including the number of calls received, the time at which the calls were received, and a description and the location of the event reported.

If these data are available, a relatively simple process could be undertaken to map the cellular reports to events in time and space. The number of occurrences of each of the four possible outcomes could be calculated, and the detection rate, false alarm rate, and mean time to detection could be readily computed.

Unfortunately, in practice, several critical components of these required data are likely to be unavailable, or in a format that does not readily permit automated mapping of reports to events.

Reliable data must exist that can be considered to define reality. Obviously, some form of continuous (in both time and space) surveillance must be operational on the roadway network under consideration. Typically, this would be in the form of loop detector and visual (close circuit television camera) surveillance. While arguments can be made that even the best of surveillance systems cannot record the exact location or the precise start and end times of an event, data from these systems are used to evaluate traditional forms of automatic incident detection.

The remaining data item that is particularly difficult to obtain is the event description, including location. Unlike the time of the call, which is automatically recorded for billing purposes, etc., this information is solely contained within the verbal dialogue, and cannot be automatically extracted. Availability depends on whether or not the operator receiving the call, records this information into a permanent database. Thus, availability depends on the specific system being examined.

The next section examines the data sources available within the Toronto region in an attempt to determine if sufficient data are available to permit a quantitative assessment to be made of the effectiveness of incident detection on the basis of cellular phone reports.

4.4 Data Available in the Toronto Region

The primary road transportation network within Toronto is divided between two separate jurisdictions, namely the Ministry of Transportation of Ontario (MTO), which is responsible for provincial highways, and the City of Toronto, which is responsible for all local roads. Each jurisdiction operates and maintains its own traffic management and control centers.

Highway 401 in Toronto is a major freeway corridor providing primary east-west intra- and inter-city movement. The MTO operates COMPASS, a freeway traffic management system, on a 55-km long section of Highway 401 in Toronto. Traffic surveillance within COMPASS consists of near-full spatial coverage of the facility via closed circuit TV cameras (spaced approximately every 1-km), as well in-road induction loop detectors linked to a central control room via fibre-optic cable.

The McMaster automatic incident detection algorithm is executed continuously, using the loop detector data as input (Hall, *et al*., 1993). In addition, operators in the control room continually monitor the CCTV camera views, to identify and/or confirm the occurrence, location, and/or type of incident. An electronic database of detected and confirmed incidents is maintained as part of the COMPASS system. Operator confirmed incidents can be used to reflect reality. These incident logs identify the time at which the incident was identified, the location of the incident, and the time the incident was cleared. COMPASS also contains a database of congestion information, as represented by measured spot speeds at the loop detectors. Thus, COMPASS provides data reflecting reality in terms of both incidents and network traffic conditions for Highway 401.

The City of Toronto is responsible for non-provincial highways, including the Don Valley Parkway, and Gardiner-Lakeshore system. These traffic management and control activities comprise a system called RESCU, which receives field data from loop detectors, CCTV cameras, service vehicles, and emergency response services. In turn, RESCU provides information to media stations, police and other emergency services, and to City of Toronto service vehicles. The electronic data stored by RESCU can also be used to reflect reality, both in terms of incidents and traffic conditions.

Data reflecting cellular phone reports are less well defined. Several potential sources exist, including the 911 emergency service, Ontario Provincial Police (OPP), Metropolitan Toronto Police, media stations having cellular phone-in lines, and cellular service providers.

Discussions with the OPP and Metro Toronto Police indicate that electronic databases are maintained for calls received at their phone reporting centres. Operators enter information into the database while receiving the call. The time of the call, caller name, originating phone number, and a text field description of the event are recorded. No explicit distinction is made between calls made from a cellular phone and calls made from a conventional phone.

There does not appear to be any automatic method of distinguishing cell calls from land-line calls. Even if cell phone numbers could be distinguished from land-line phone numbers (e.g. by comparing the caller's phone number to a database of existing phone numbers), spurious matches would occur, as the provision of phone number tracing for 911 calls is not mandatory. While many of the largest Canadian phone companies (e.g. Bell Canada) do provide phone number tracing, deregulation in the phone service industry (particularly the long distance service industry), has given rise to many new service providers, some of whom do not provide phone number tracing. Furthermore, many flat rate long distance service providers lease land lines from other companies, through which they route their customers calls. The call number trace-back service provides only the number of the leased line, not the number of the originating call. Thus even for land-line calls, call number tracing is not always possible.

The databases from the emergency services often do not provide a record of all calls received. If calls are received for an event that the service is already aware of, the operator often does not create an additional record in the database. Thus, these databases can not be used with a level of confidence to determine the number of calls associated with any single event.

There also does not appear to be any reliable means of automatically determining the accuracy of the caller's report. While the operator does enter a text description of the event on the basis of the caller's report, this description is usually very brief. Even if the report from the officer assigned to the scene provides sufficient detail, an evaluation of the accuracy of the caller's report may not be possible.

In conclusion, the limitations identified in the available data appear to preclude the direct evaluation of the performance characteristics of incident reporting on the basis of driver-based cellular reports.

4.5 Other Approaches

Given the limitations in the available data, it is desirable to assess other approaches for evaluating the potential of using driver-based incident reporting. One such approach is the use of simulation modelling. Mussa (1997) presents an evaluation of driver-based freeway incident detection, in which the FRESIM model is used to simulate a section of freeway under various traffic demand and incident conditions. Assumptions are made about the proportion of drivers with cellular phones, the likelihood that drivers with phones will report an incident if they are aware of one, and the conditions under which drivers are aware of an incident. These assumptions are used within a binomial probability distribution to estimate the likelihood of detection as a function of detection time. The results of this analysis indicate that driver-based incident detection is far superior to traditional traffic data based incident detection. However, the assumptions made in the analysis, particularly with respect to the propensity of drivers to report incidents (assumed to be 100%) are not based on field data and do not appear to be realistic. Furthermore, while the study evaluation included detection rate and mean time to detection as measures of performance, false alarm rate was not addressed.

Despite the limitations of the study by Mussa, the study does serve to illustrate that a methodology based on simulation, in which the necessary probability functions (e.g. proportion of drivers with cellular phone; propensity to report incidents; conditions under which drivers report incidents) are developed on the basis of field data, may provide an accurate means of evaluating driver-based incident reporting

5 Conclusions and Recommendations

Incident detection is one of the key components of most traffic management systems. However, traditional approaches to automatic incident detection do not provide the levels of performance desired by traffic management system operators. The wide-spread use of wireless communication devices, made possible by the tremendous advances in wireless communication technologies during the past decade, provides the opportunity to rely on driver-based incident detection.

Driver-based incident detection appears to provide several benefits over traditional incident detection, including little to no field infrastructure requirements (except a communication center with operators available to receive calls) and the potential to obtain detailed information regarding the event.

While many transportation authorities and emergency services use information from cellular based calls, driver-based incident detection does not appear to have been objectively evaluated in terms of accepted incident detection measures of performance (e.g. mean time to detection, false alarm rate, and detection rate).

Several data sources are available in the Greater Toronto Region, including traffic data and incident logs from the Ministry of Transportation of Ontario (COMPASS System) and the City of Toronto (RESCU); and incident data from emergency services including OPP, Metro Toronto Police Services, and 911.

An examination of these data sources indicates that these data sources do not appear to be sufficiently detailed to permit the direct determination of the performance characteristics of driver-based incident detection within the Toronto Region.

In the absence of sufficient data sources to support the direct determination of the characteristics of driver-based incident detection, the use of traffic simulation modelling may provide a mechanism for estimating these characteristics. The application of simulation models requires the derivation of probability distributions for select driver behavior parameters, such as the proportion of drivers with wireless phones, the propensity of drivers to report incidents, and the conditions under which drivers report incidents.

It is recommended that data needed to support the derivation of these key driver behaviour parameters be defined, and that the existing data sources be examined to determined if they could supply the required data.

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Acknowledgements

The author gratefully acknowledges the financial support of the Natural Sciences and Engineering Research Council of Canada.

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