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16. Abstract

The detection of freeway incidents is an essential element of an area's traffic management system. Incidents need to be detected and handled as promptly as possible in order to minimize traffic delays. Various algorithms and detection technologies are examined to determine which combinations offer optimized detection performance.

This study represents an effort to compile, compare, and rank available incident detection strategies. Based on an extensive literature review, as well as on interviews with traffic management personnel, the California algorithm No. 8, McMaster algorithm, Minnesota (DELOS), and Texas algorithms were selected for testing. The performance of these algorithms was assessed using extensive incident and traffic data from San Antonio, Texas. For training purposes, the data were separated into subsets for calibration and testing. During calibration, algorithm parameters were optimized via a Monte Carlo estimation process. Trained algorithms were then tested and evaluated according to traffic data aggregation (smoothing) and incident type. Results verify the validity of the calibration process, though algorithm performance varied slightly between calibration and testing phases. Each algorithm performed differently under different situations. Based on this perception, a holistic data (algorithm) fusion and information fusion model was developed to exploit the advantages of different algorithms and incident detection resources. The fusion approaches were explored, and fusion results on the calibration data set were analyzed. Finally, recommendations were proposed and future work was identified.

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EVALUATION OF INCIDENT DETECTION METHODOLOGIES

by

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Evaluation of Incident Detection Methodologies

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DISCLAIMERS

Research performed in cooperation with TxDOT and the U.S. Department of Transportation, Federal Highway Administration.

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BIDDING, OR PERMIT PURPOSES

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IMPLEMENTATION RECOMMENDATIONS

The Texas algorithm, partially used for incident detection in some TxDOT districts, uses a single occupancy threshold that has a high false alarm rate — higher than that of other algorithms. The relatively simple logic of the Texas algorithm, or its relatively low data requirements, may be the cause of this higher false alarm rate. It is recommendedthat traffic management centers in Texas consider implementing some of the other algorithms identified in this report, if they intend to rely (at least in part) on automatic incident detection algorithms.

The accuracy of the algorithms is directly linked to the accuracy and dependability of the system level detectors. Inductive loop detectors have a reputation for producing intermittent errors. Efforts to reduce these errors will improve overall incident detection algorithm performance. Efforts to improve reporting accuracy (that is, with respect to time and location) will improve algorithm transferability from calibration to actual implementation.

A logical conclusion might be that better detection could be obtained by combining the sensor data as well as the indications given by different algorithms using the same data. This approach would exploit the strengths and weaknesses of different sensors and algorithms in varying conditions. Information integration and data fusion methods can improve the performance of an incident detection system beyond what any individual component or algorithm could achieve alone. The recommendation is that TxDOT consider adapting the algorithm fusion and information integration model. The steps required in applying the model are outlined below:

1. To reduce false alarms caused by inconsistent data collection times, set up the data collection devices to utilize the same time frames.
2. Select typical calibration data sets that are large enough to reflect the characteristics of the local traffic (and that have an accurate incident log).
3. Select and verify the threshold values carefully.
4. Obtain a priori algorithm fusion results with strict procedures and different traffic conditions for different priori results.
5. Collect field data from the highway patrol program and from cellular phone reports for use in information integration.
6. Verify the fusion performance in a small area before overall deployment.
7. Summarize the performance periodically and make improvements to the procedure as needed.

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ABSTRACT

This study represents an effort to compile, compare, and rank available incident detection strategies. Based on an extensive literature review process, as well as on interviews with traffic management personnel, the California algorithm No. 8, McMaster algorithm, Minnesota (DELOS), and Texas algorithms were selected for testing. The performance of these algorithms was assessed using extensive incident and traffic data obtained from San Antonio, Texas. For training purposes, the data were separated into subsets for calibration and testing. During calibration, algorithm parameters were optimized via a Monte Carlo estimation process. Trained algorithms were then tested and evaluated according to traffic data aggregation (smoothing) and incident type. Results verify the validity of the calibration process, though algorithm performance varied slightly between calibration and testing phases. Each algorithm performed differently under different situations. Based on this perception, a holistic data (algorithm) fusion and information fusion model was developed to exploit the advantages of different algorithms and incident detection resources. The fusion approaches were explored, and fusion results on the calibration data set were analyzed. Finally, recommendations are proposed and future work is identified.

PROJECT SUMMARY REPORT

This study represents an effort to compile, compare, and rank available incident detection strategies. Based on an extensive literature review process, as well as on interviews with traffic management personnel, the California algorithm No. 8, McMaster algorithm, Minnesota (DELOS), and Texas algorithms were selected for testing. The performance of these algorithms was assessed using extensive incident and traffic data obtained from San Antonio, Texas. For training purposes, the data were separated into subsets for calibration and testing. During calibration, algorithm parameters were optimized via a Monte Carlo estimation process. Trained algorithms were then tested and evaluated according to traffic data aggregation (smoothing) and incident type. Results verify the validity of the calibration process, though algorithm performance varied slightly between calibration and testing phases. Each algorithm performed differently under different situations. Based on this perception, a holistic data (algorithm) fusion and information fusion model was developed to exploit the advantages of different algorithms and incident detection resources. The fusion approaches were explored, and fusion results on the calibration data set were analyzed. Finally, recommendations are proposed and future work is identified.

EXPERIMENT SUMMARY

Based on an extensive literature review and on interviews with traffic management personnel from various agencies, four incident detection algorithms were selected for testing. One of the best-known and extensively tested algorithms is the California algorithm developed by Payne et al. (1976). The California algorithm No. 8, written with logic to detect compression waves, was selected for testing in this experiment. Also selected was another widely tested algorithm developed by Hall et al. (1993), known as the McMaster algorithm. Stephanedes and Chassiakos (1993) developed the DELOS 3.3 algorithm, also known as the Minnesota algorithm. This algorithm, which incorporates an exponential smoothing function in its detection logic, was also selected for testing based on favorable performance reported in the literature. Finally, a procedure currently in use in several TxDOT districts, referred to as the "Texas algorithm," was also included for comparison purposes.

For calibration and testing, data were obtained from the TransGuide traffic management center in San Antonio, Texas. The data were generated from loop detectors on San Antonio freeways that report speed, volume and occupancy in 20-second intervals. Errors in the traffic data were corrected using data filtering algorithms.

Each algorithm was calibrated via a Monte Carlo technique in which thresholds were randomly generated from a uniform distribution (between bounds obtained from the literature). For each threshold set, performance was ascertained according to detection rate, false alarm rate, and detection time. For each situation, an algorithm's "efficient frontier" was identified by selected threshold sets that exhibited pareto-optimal performance. Algorithms were then compared based on their respective efficient frontiers.

This process was followed to determine algorithm performance under several situations, which differed according to the type of input data and the type of incident being considered. Data were smoothed via an arithmetic average, statistical median, and single exponential smoothing over 1-minute and 2-minute windows, updated every 20 seconds. In addition, incidents were separated into three groups. The first group included accidents, stalls, and incidents labeled as "congestion." The second group included accidents and stalls only, while the third included only accidents.

The calibration and test performance of the California algorithm No. 8, DELOS algorithm, and McMaster algorithm provide encouraging results. However, the detection mean time may still be too long under some situations for an efficient detection system; moreover, the false alarm rate is high. To improve incident detection performance, several researchers in the traffic management field have explored and developed innovative detection systems and logic. The recent technical developments in data collection at the system level include the use of video image processors (VIP) and automatic vehicle identification systems (AVI). Minnesota/DELOS algorithm and artificial neural network (ANN) algorithms are examples of recent advances in detection logic.

At the present time, no system and logic are clearly superior to the others. In an effort to improve overall algorithm detection, an algorithm fusion and information integration model was developed. The model was based on close observations of traffic fluctuation and on the responses of the individual algorithms. The data fusion approach, combining as it does existing algorithms, achieves a more efficient system by utilizing the strengths of each individual algorithm. The data fusion strategy recognizes that relative detection algorithms were developed from one perspective of the dynamic traffic flow and, thus, have superior performance in specific situations. For example, while the comparative algorithms perform well in moderate-to-heavy traffic, time-series algorithms are preferred in light-to-moderate traffic. Information integration and data fusion techniques can improve the performance of the incident detection system beyond what any of the components could achieve alone. Reengineering existing incident detection systems is not necessary, as the subcomponents or algorithms remain intact. The overall system can take advantage of growing computer power more efficiently. The two-step algorithm fusion model is illustrated using TransGuide loop data, while information integration is presented using I-880 incident data from California.

Step one of the two-step algorithm fusion model determines the ranges of the false alarm and the detection rates. Groups of precalibrated threshold values for each algorithm are used to determine such ranges based on values obtained at predefined false alarm levels from each calibrated algorithm. The fusion algorithm is able to distinguish the specific false alarm and detection level for that incident, when a particular algorithm triggers an incident. The system indicates the associated false alarm and detection rates until another algorithm reports the same incident. Yet while step-one fusion improves the detection rate, the false alarm rate is high. After a second algorithm identifies the same incident, the system will then perform the step-two fusion. Step-two fusion combines the two incident signals to reduce the false alarm level (or uncertainty). And because the system uses redundant information, its performance exceeds that associated with the use of a single algorithm.

The preselected threshold values are obtained by analyzing the enveloping curve of algorithm calibration results. After running the algorithm with randomly generated threshold value combinations, the detection rate and false alarm rates can be plotted. An optimum enveloping trade-off curve is obtained, allowing for the selection of groups of threshold values at predefined false alarm levels. The points on the curve express the optimum performance of the algorithm. The threshold values that are obtained can be used for testing larger data sets and algorithm fusion techniques.

RESULT SUMMARY

During the calibration process, all algorithms produced false alarm rates between 0% and 2.5%, with a corresponding detection rate between 20% and 100%. Detection times are available only as relative measures of performance, to compare one algorithm to another. Because the incident reports do not list the actual time of the incident, correct time-to-detect values are not available.

The California algorithm No. 8 was able to detect more incidents than the other algorithms, regardless of the incident type. However, when the incident type was limited to not include "congestion" incidents, the DELOS algorithm exhibited the best performance. When detecting only accidents and stalls, the DELOS algorithm detected 92% of the incidents, with a relatively low 0.6% false alarm rate. When used to detect accidents only, the algorithm detected 93% of the incidents, with a false alarm rate of 0.4%. These false alarm rates are relatively low compared to the other algorithms, which achieved similar detection rates at nearly twice the false alarm rate. A false alarm rate of 0.6% corresponds to three false alarms every 20 seconds, or over 500 per hour for a freeway network with 500 detector stations (the approximate size of the San Antonio network) reporting data every 20 seconds. For the two 3-hour peak periods considered in the study, a 0.6% false alarm rate corresponds to over 3,000 false alarms. This alarming number of false alarms causes extreme difficulty for the traffic management personnel responsible for incident response. While algorithm developers strive to reduce the false alarm rate, traffic management personnel have the option of implementing procedures to produce fewer false alarms, though the trade off is detecting fewer incidents. For example, the DELOS algorithm was able to detect nearly 60% of accidents and stalls at a false alarm rate of 0.1%, or 90 false alarms per hour.

Implementation of the algorithms on a separate subset of data produced different results. The California algorithm and McMaster algorithm exhibited superior performance relative to their calibration results. The DELOS algorithm did not perform as well as with the previous test data. All algorithms detected up to 97% of the incidents, with false alarm rates less than or equal to 3%.

In part, the performance difference (between calibration and testing) may be due to the relatively small size of the data set used for calibration. In this research, every effort was made to select a calibration data set having characteristics similar to those of the data set reserved for testing, in terms of the relative incident frequency and type. Use of a larger subset of data for calibration might improve the predictability of the performance when applied to a different data set.

The calibration process implemented in this research succeeded in obtaining threshold combinations that produced pareto-optimal algorithm performance. In addition, the Monte Carlo approach allowed for a relatively quick calibration of the algorithms. A more extensive calibration procedure might involve shrinking the boundaries of the random thresholds generated in order to “zero in” on an optimum threshold. Another method might use an automated search technique such as minimum least squares, or alternatively, one might use a search heuristic such as a Tabu Search (see Bach et al., 1998) or simulated annealing (Cohen, 1994) to seek optima for each threshold. The task of investigating optimal parameters may also be suited to genetic algorithms (see Goldberg, 1989).

The performance evaluation of current incident detection methodologies identified a certain degree of inefficiency, a result of a lack of integration among various detection systems and of the unsatisfactory performance of any one algorithm. Most correct detection systems are based on a particular logic that tends to operate well in certain situations but not in others.

In an effort to address the lack of efficiency in current incident detection procedures, the project developed an integrated incident detection method. To conduct the data fusion, a simple voting approach is used. Three of the algorithms (California No. 8, DELOS, and McMaster) were selected to test the methodology using data fusion (TransGuide in San Antonio). The method provides traffic management center (TMC) operators with a continuously updated incident probability as data is received from various sources. Algorithm fusion potentially enhance the utilization of existing sources, reduce detection delays, and improve overall incident detection performance with the aid of historical incident databases and experienced TMC operator input.

Algorithm fusion uses a two-step approach: First, the detection performance of individual algorithms are combined to ensure a higher detection rate; second, multiple algorithm fusion is conducted to reduce the false alarm rate. Using the TransGuide peak hour data, it was found that the algorithm fusion increased the detection rate by 20%. The false alarm rate was reduced compared to the best performance of all three algorithms, with little detection delay.

Information integration combines current primary detection sources, including conventional police patrol, camera surveillance, automatic incident detection (AID) systems, and, recently, motorist cellular phone reporting. The information integration methodology is an effort to fully utilize redundant, complementary, and cooperative information to improve the reliability of current incident detection systems. The cross verification of AID results can significantly reduce the false alarm rate of cellular phone reports. For example, overall detection performance could be as high as 90%, with a false alarm rate of 0.5% within 2 minutes on the I-880 experiment section in California (Skabardonis et al., 1998). The detection performance using the information integration method is superior to that of the previously reported methodologies and technologies.

RECOMMENDATIONS

The Texas algorithm, partially used for incident detection in some TxDOT districts, uses a single occupancy threshold that has a high false alarm rate, higher than that of the other algorithms. The relatively simple logic of the Texas algorithm, or the relatively low data requirements, may be the cause of this higher false alarm rate. It is recommended that traffic management centers in Texas consider implementing some of the other algorithms identified in this report, if they intend to rely (at least in part) on automatic incident detection algorithms.

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