Application of Time-Series Analysis Techniques to Freeway Incident Detection

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An approach for the automatic detection of freeway capacity-reducing incidents based on the time-series analysis techniques formulated by Box and Jenkins is suggested. An autoregressive integrated moving average model of the form ARIMA(0,1,3) has been recently developed to describe the dynamic and stochastic character of freeway traffic variables. This model is used to provide short-term forecasts of traffic occupancies and the associated 95 percent confidence limits. An incident is detected if the observed occupancy value lies outside the confidence limits of the corresponding point forecast. A total of 1692 min of occupancy observations associated with 50 traffic incidents that took place on the Lodge Freeway in Detroit are used in evaluating the algorithm performance. The algorithm detected all 50 incidents. The resulting false-alarm rate is 2.6 percent when constant parameters of the ARIMA model are used and it decreases to 1.4 percent with variable-parameter estimates. Furthermore, the average time lag to detection when constant- and variable-parameter estimates are used is 0.58 min and 0.39 min, respectively.

In a companion paper (1), we noted that there is growing interest in the development of computer-based systems for the surveillance and control of urban freeway traffic. It has also been explained that these systems require short-term forecasts of real-time traffic variables (occupancies and flows) to allow for the operational changes that usually take place after implementing the control decisions. Furthermore, it has been mentioned that when the forecasted value of a key traffic variable is compared with the next observation it can signal a possible change in traffic stream behavior and can suggest a suitable control response. Finally, the stochastic and dynamic character of freeway traffic variables has been modeled by an autoregressive integrated moving average model of the form ARIMA (0,1,3) which follows the analysis techniques described by Box and Jenkins (2).

In this paper, we present a methodology for the automatic detection of freeway capacity-reducing incidents (accidents, stalled vehicles, instances of debris, etc.), based on the developed ARIMA (0,1,3) model. The problem of accurately detecting freeway incidents both in time and space is an integral part of any effective computer-based control and surveillance system. Information that concerns the magnitude of capacity reduction is obviously needed to balance the demand with available capacity by means of route-diversion messages and ramp-metering control. In addition, knowledge of the nature and location of an incident is required to effectively dispatch emergency services and to determine the appropriate kind of help needed at the incident scene.

Several techniques for freeway incident detection have been tried, albeit with mixed success. Of these techniques, computer-based incident detection seems to be the only technique able to detect all incidents and to provide a numerical scaling of the magnitude of capacity reduction--information that could only be guessed at by a human operator. Computer-based incident detection, however, has some inherent limitations. False alarms represent a major operational problem, especially if emergency services are dispatched every time. Another limitation of computer-based incident detection is that it is a blind system, in the sense that it cannot determine the nature of the detected incident (3). Closed-circuit television surveillance, therefore, can be successfully used to supplement computer-based incident detection by providing a human operator with some form of visual validation and assessment of incidents. This can be achieved in a manner similar to that described by Saridis and Lee (4) in their discussion of hierarchically intelligent control and management of traffic systems. In addition, control measures (ramp metering, advisory messages, etc.) can be undertaken immediately without the inevitable time lag where human interpretation--other than confirming the incident--is involved.

ALGORITHM DEVELOPMENT AND EVALUATION

Several algorithms have been proposed for the automatic detection of freeway capacity-reducing incidents and some of them have been in operation for more than two decades. In general, these algorithms can be categorized as pattern-recognition algorithms (5-10) and smoothing algorithms (11-13). The first category of algorithms uses one or more traffic variables to distinguish between incident and incident-free situations. The second category makes use of short-term forecasts of traffic variables to detect the sudden changes in traffic stream behavior associated with incidents. The appealing characteristic of smoothing algorithms is that past trends of traffic variables can predict recurrent congestion while nonrecurrent congestion due to incidents is unpredictable. All of these previously developed algorithms, however, have two major problems: high false-alarm rates and threshold calibration requirements. In fact, the two problems are strongly related because the threshold levels for detection cannot allow for all of the factors that cause variations in traffic flow (time of day, geometrics, pavement and environmental conditions, etc.). Intuitively, the use of real-time estimates that capture the variability in traffic variables as detection thresholds should lessen the false-alarm problem and should improve the overall performance of the detection algorithm.

Motivated by the preceding remarks, the ARIMA algorithm outlined here has been structured so that it includes real-time estimates of the variability in traffic variables. Traffic occupancy has been chosen as the key state variable and an incident is detected if the observed occupancy value lies outside the confidence limits constructed two standard deviations away from the corresponding point forecasts. These confidence limits are given by

$$\hat{X}_{t+1}(\pm) = \hat{X}_t(1) \pm 2\hat{\sigma}_a \quad (1)$$

and

$$\hat{X}_t(1) = X_t - \theta_1 e_{t-1}(1) - \theta_2 e_{t-2}(1) - \theta_3 e_{t-3}(1) \quad (2)$$

where

X_{t+1} = traffic occupancy observed at time (t+1),
$\hat{X}_{t+1}(\pm)$ = approximate 95 percent confidence limits for X_{t+1},
$\hat{X}_t(1)$ = point forecast made at time t,
$e_{t-1}(1)$ = forecast error made at time (t-1),
$\theta_1, \theta_2, \theta_3$ = parameters of a moving average operator of order 3, and
$\hat{\sigma}_a$ = estimate of the standard error of the white-noise variables.

Figure 1. Performance of ARIMA occupancy algorithm during an incident.

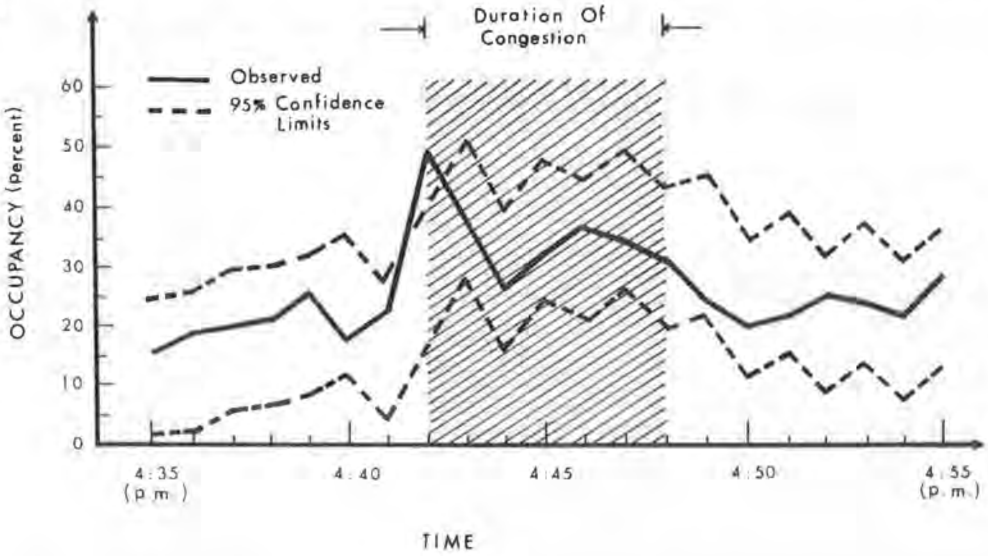
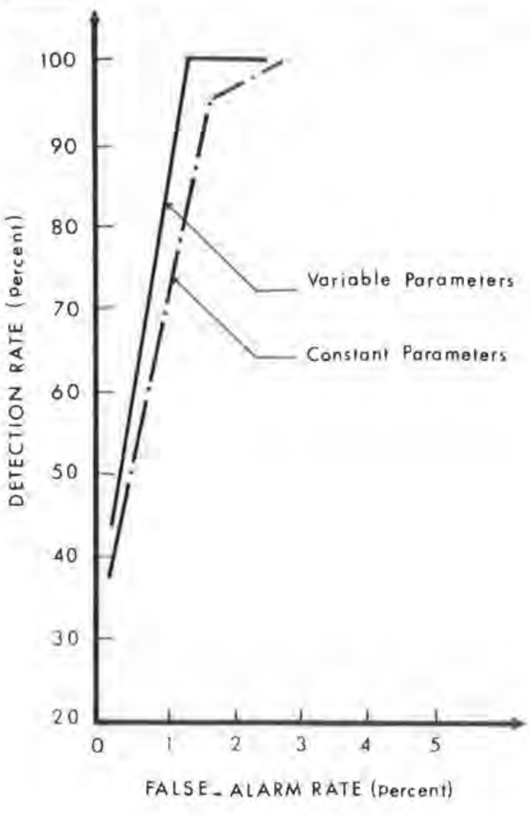


Figure 2. Operating characteristic curves for ARIMA incident-detection algorithm.



To help illustrate, the solid line in Figure 1 represents occupancy observations upstream of a traffic incident that involved a disabled vehicle on the Lodge Freeway in Detroit. The broken lines are the 95 percent confidence limits of the point forecasts. For this particular incident, the algorithm response is indicated by the deviation of the observed occupancy value from the corresponding confidence limits at the onset of congestion development.

Furthermore, it was explained in the companion paper (1) that the moving average parameters of the ARIMA(0,1,3) model vary over time and that it may be desirable to update these parameters occasionally. To explore the effect of this variation on the performance of the ARIMA incident-detection algorithm, a total of 1692 min of occupancy observations associated with 50 freeway traffic incidents were used in the analysis. These incidents took place on a 3.2-km (2-mile) section of the Lodge Freeway and are described in Cook and Cleveland (11).

The confidence limits given by Equations 1 and 2 were computed once by using constant-parameter values estimated from representative incident-free data, and second by using parameters estimated from the observations that cover the incident in hand. The performance results are shown in Figure 2 as operating characteristic curves that relate the detection rate to the false-alarm rate. As noted, the ARIMA algorithm detected all 50 incidents. The resulting false-alarm rate is 2.6 percent when constant-parameter estimates are used and it decreases to 1.4 percent with variable-parameter estimates. Importantly, these are on-line false-alarm rates since they have been computed by using occupancy observations closely associated with traffic incidents. An on-line false-alarm rate is the percentage of false-incident messages out of the total incident messages generated by the algorithm (7).

In addition to detection rate and false-alarm rate, a third important measure of performance is the average time lag to detection. Switching from constant- to variable-parameter estimates reduces the average time lag from 0.58 min to 0.39 min, respectively. Although the detection performance of the ARIMA algorithm improves when the parameter estimates are updated, the question of whether or not to update them must be answered by the operating authority. A trade-off between the benefits gained from improving the algorithm performance and the computational requirements for updating the parameters has to be made.

CONCLUSIONS

The ARIMA incident-detection algorithm described in this paper has shown promising results; however, some further remarks need to be addressed. First, the performance of the algorithm has been evaluated only under heavy and moderate traffic-flow conditions (1200-2000 vehicles/h per lane). More evaluation is required by using incident data recorded during light traffic where the effect of the incident is not remarkably noticeable in the traffic data. Second, work is needed in studying the effect of the data aggregation interval (20, 30, or 60 s) on the detection performance of the algorithm. It is believed that data aggregation induces a masking effect on the actual 0-1 pulses obtained each 0.01-0.25 s from point detectors. Finally, the computational requirements for implementing the ARIMA algorithm by using microprocessors must be examined. As of this writing, the above remarks are being explored.

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Effects of Rail-Highway Grade Crossings on Highway Users

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Basic research into effects of rail-highway grade crossings on highway users was conducted. The overall objective was to investigate improved techniques for estimating nonaccident effects, such as excess delay, user costs, direct energy consumption, and pollutant emissions. Numerical results also were desired. A microsimulation model is developed for analyzing delays due to train blockages at grade crossings not affected by other highway system bottlenecks. An analytic model is then developed to estimate effects of a vehicle slowing at grade crossings with no train present due to rough surface conditions. These models are validated to the extent possible based on field studies. A sensitivity analysis reveals that for most practical applications, train blockages can be analyzed more easily by using simple equations. A sample application of the method is presented in which 385 grade crossings are evaluated from which design options have been selected. The model developed for analyzing effects of a vehicle slowing with no train present is recommended for further applications, although more extensive validation studies are desirable. Numerical results indicate that nonaccident costs of grade crossings dominate accident costs in the ratio of about 3.5:1. The effects of a vehicle slowing with no train present dominate effects of train blockages in the ratio of about 2:1. The methods developed are felt to represent a significant improvement over earlier techniques for estimating highway-user effects. The methods can be applied to evaluation of alternatives such as rail relocations, construction of grade-separation structures, and crossing-surface improvements. Areas of further research are also identified.

The majority of research on rail-highway grade crossings has been devoted to accident aspects. That such research has been justified is seen in a steady decline in crossing fatalities over time (1). Safety investigators have delved into various areas, which include design, driver behavior, conspicuity, and predictive accident equations, among others.

In contrast, nonaccident aspects of grade crossings have been studied in much less detail. Although major nonaccident aspects have been identified (2, Chapter 3), the research is not well developed. These nonaccident aspects fall into the following categories: delay and increased operating costs for highway users, community barriers (physical and psychological), environmental degradation, incompatible or inappropriate land uses, and increasing operating costs to railroads. The categories are not necessarily separate from one another.

The most important nonaccident aspects, or at least the most readily quantified, are those associated with highway users, such as excess delay, cost, energy consumption, and vehicle emissions attributable to grade crossings. Generally, it is required that some or all of these effects be explicitly considered in plans to alter crossing conditions. Such plans might include schemes for rail relocation, grade separation, or crossing-surface improvement. For proper evaluation, it is desirable to have readily applied techniques for quantifying all or some of these highway-user effects.