Abridgment

Control Emulation Method for Evaluating and Improving Traffic-Responsive Ramp Metering Strategies

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A method is developed for evaluating traffic-responsive ramp metering strategies and improving freeway performance in intelligent vehicle-highway systems operations. The method emulates real-time metering, as currently practiced in the United States and Canada, and traces the interactions between automatic rate-selection metering strategies and freeway performance through time. The method can facilitate traffic management by aiding in the design of new traffic-responsive ramp strategies, and in the evaluation of existing real-time control systems and selection of the best metering schemes. The method was tested successfully in emulating volume and occupancy thresholds, rate tables, and automatic rate-selection control strategies, and in assessing and selecting ramp strategies based on freeway performance measures (such as total volume and delay) on I-35W in Minneapolis.

The most advanced concept in freeway management and control includes a hierarchical traffic control structure; overall freeway control is decomposed into several components—demand prediction, network optimization and local control—in order to achieve computational and practical feasibility of optimal control strategies (*1*). However, the state of the art in freeway ramp metering has not reached the point at which comprehensive, networkwide control strategies are automatically generated and implemented through on-line optimization. As a result, most traffic-responsive metering systems still use automatic rate-selection procedures. These procedures select the most appropriate metering rates for a ramp by using predetermined thresholds and rate tables using the information received from loop detectors on the main freeway, upstream and downstream from the ramp. Although this method provides a degree of self-adjustment to prevailing traffic conditions, the lack of an efficient tool for updating the key components of the control system (i.e., thresholds, rate tables, and locations of the detector stations) significantly restricts the effectiveness of control.

Developing an efficient and cost-effective tool for evaluating "what if" control policies is an essential element in improving intelligent vehicle-highway system (IVHS) freeway traffic management. In this study, a method is developed that can simulate various traffic-responsive ramp metering strategies. The method emulates real-time metering systems based on a "mapping" of the control logic developed by experienced traffic engineers, at state departments of transportation, and by simulated freeway performance. The rest of this paper describes the structure of the method and an example application in the Minneapolis metering system.

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CONTROL EMULATION METHOD

The control emulation method developed in this study emulates real-time rate-selection metering using simulated freeway traffic performance when the freeway demand pattern and geometrics are known. Figure 1 illustrates the key components of the method (i.e., ramp control and freeway performance modules) interacting continuously through time. The ramp control module emulates the on-line automatic rate-selection process and determines metering rates using the traffic information provided by the freeway performance module. The key elements of the process include a set of

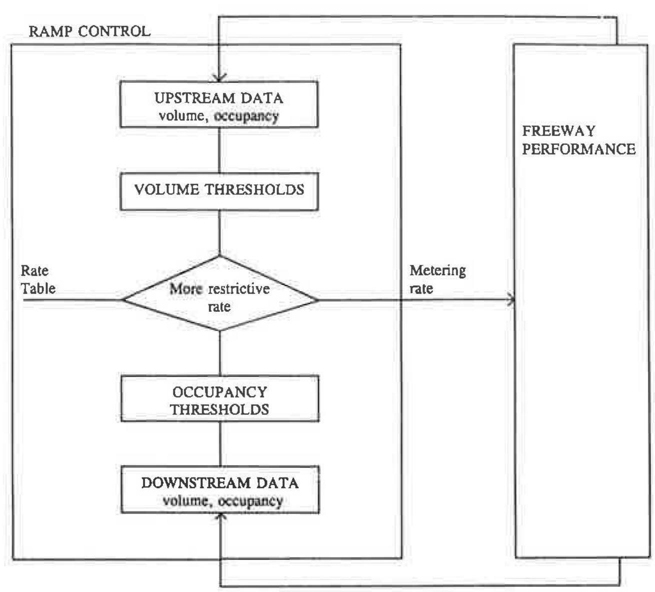

FIGURE 1 Automatic rate-selection process.

volume-occupancy thresholds, a rate table, and the locations of detector stations associated with each ramp. First, traffic volume and occupancy at predefined detector locations are determined by the freeway performance module, using dynamic simulation based on continuum modeling. Upstream volume and the highest downstream occupancy among a set of stations are compared with the predetermined volume-occupancy thresholds. Using the rate table, two rates are identified and the more restrictive rate is selected. Following a time delay, the freeway performance module uses that rate for determining the number of vehicles entering the freeway system. This rate-selection process is currently operating at the Minnesota Department of Transportation; variations of it are operating elsewhere in the United States and Canada.

The dynamic simulation developed in this study uses a finite difference scheme, which was specifically designed for one-dimensional, time-dependent, compressible flows containing strong shocks; the simulation has been applied to modeling traffic flow (*2,3*). The method determines traffic density, speed, and flow in each 100-ft segment of freeway every second, so that the effects of short-term (e.g., 6- to 30-sec) changes in metering rates on the traffic performance at the detector station locations can be assessed accurately. The detailed description of the modeling methodology for the performance module is reported elsewhere (*4*).

APPLICATION

The features of the control emulation method are illustrated through application to a freeway in the Minneapolis metropolitan area. In Minneapolis, metering rates at a ramp are determined from volume data from a mainline station upstream and occupancy data from five mainline stations downstream of that ramp. For each ramp, Minnesota Department of Transportation traffic engineers have used historical data to derive a set of volume-occupancy thresholds and a rate table consisting of six metering rates. In addition, rate selection every 30 sec is based on two measurements: the 1-min upstream volume and the highest 1-min occupancy among five downstream detector stations.

The preceding metering policy can be further described using the volume-occupancy (V-O) diagram. To illustrate, consider a typical volume-occupancy threshold policy described by curve *AA'* in Figure 2, where the whole space is subdivided into four regions, (i.e., no-control, occupancy-dominant, volume-dominant, and common volume-occupancy control regions). If a V-O measurement from the freeway falls into either the volume- or the occupancy-dominant region, the metering rate is determined by volume or occupancy respectively. In the common V-O control region the resulting metering rate is the same, whether it is determined by volume or occupancy. In Figure 2, the six metering rate levels are indicated by number, ranging from 1 to 6, where Rate 6 is the most restrictive. For instance, if upstream volume is 40 vehicles per minute and highest downstream occupancy is 30 percent per minute, control will be occupancy-based and Rate 5 will be activated at the ramp meter. If occupancy falls to 18 percent and volume remains the same, control will activate volume-based Rate 4, a less restrictive rate.

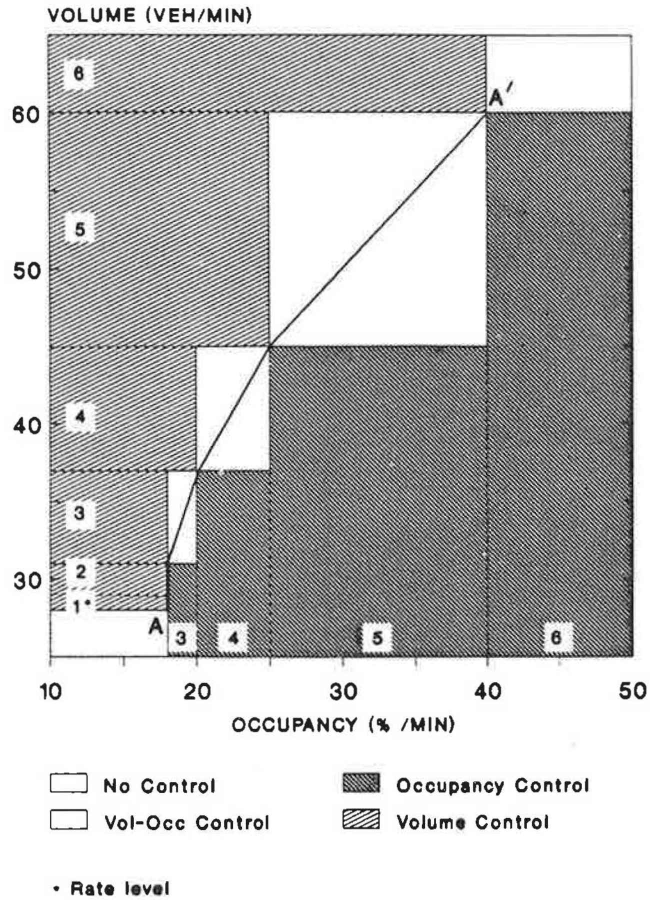

FIGURE 2 Typical volume-occupancy threshold policy.

Test Site and Model Testing

A 6-mi section of the I-35W freeway south of Minneapolis was selected as the test site (see Figure 3). This section contains 18 entrance-exit ramps and a variety of geometric types such as merging, diverging, and weaving. The test section also includes 13 mainline loop detector stations, at which volume and occupancy measurements can be obtained every minute.

The control emulation method was first tested by simulating the test site with the current metering strategy and the real volume data collected from the upstream boundary and each ramp of the test section. The simulated volume was compared with the real data collected from the mainline loop detectors. Results from the volume comparison indicated an error ranging from 5 to 12 percent. Performance could improve with improvements in modeling, an issue currently being addressed by the authors.

Evaluation of Occupancy Thresholds

As an example, the control emulation method was applied to determine the effects of occupancy threshold changes on traffic performance in a sample freeway section. Four alternative threshold policies were formulated by increasing or decreasing occupancy thresholds by 2 and 4 percentage points above or below their current values, respectively, while keeping vol-

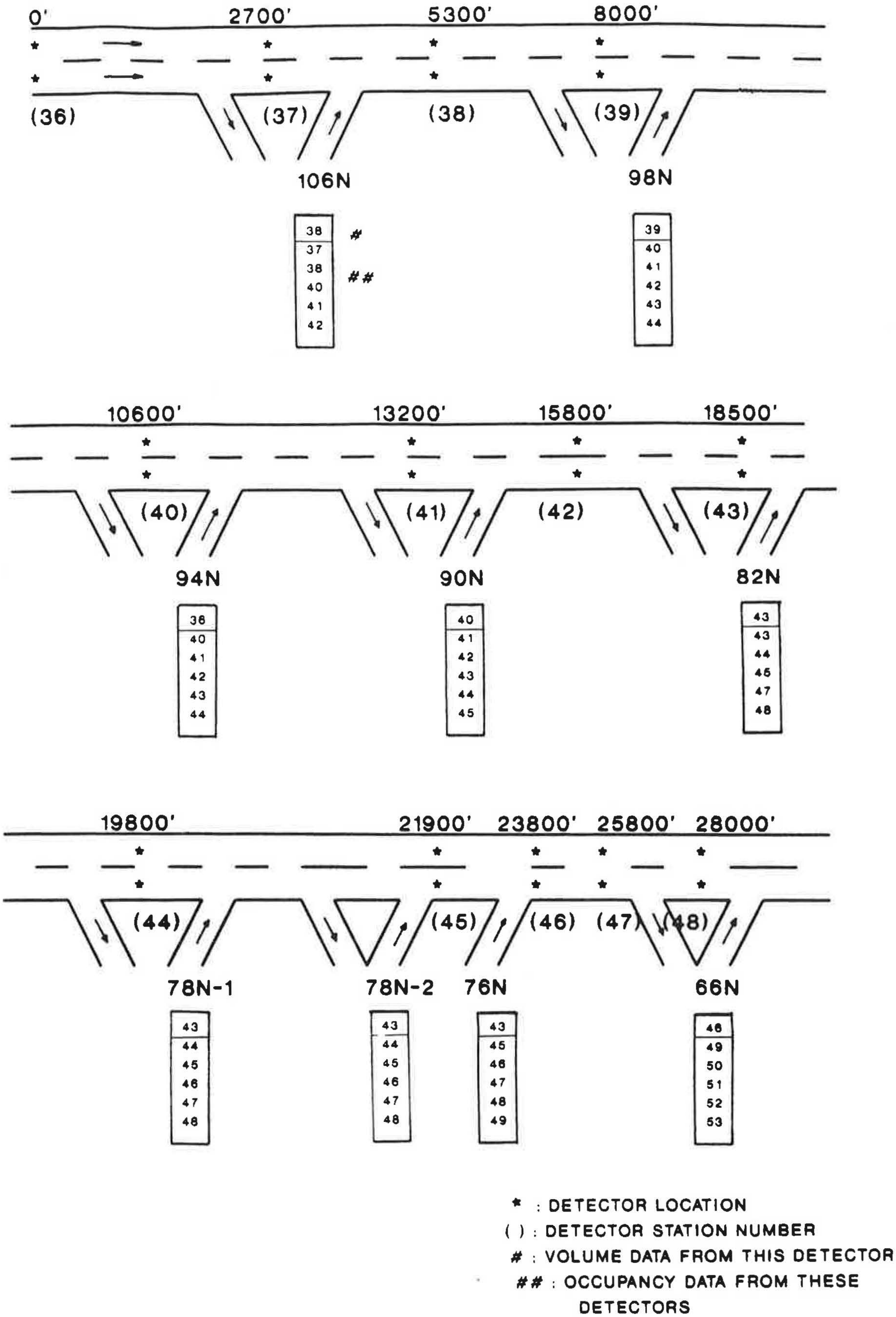

FIGURE 3 Freeway test section, I-35W, Minneapolis.

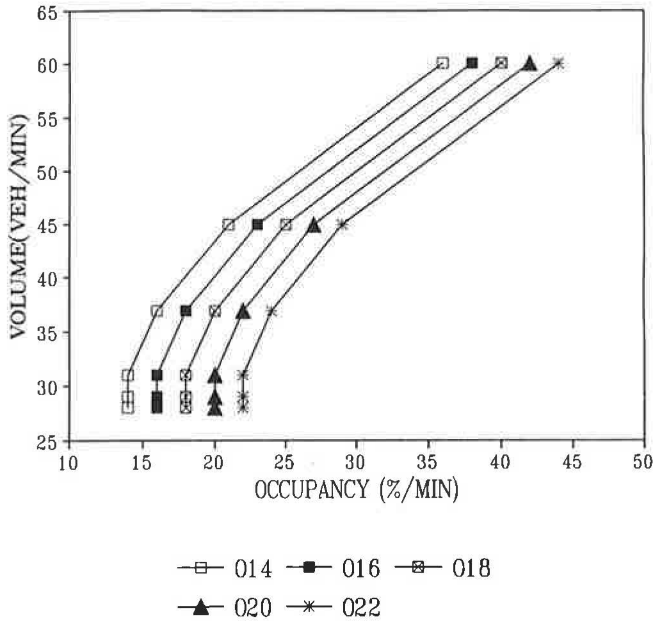

FIGURE 4 Occupancy threshold strategies.

ume thresholds unchanged. The four policies and the current one are presented in Figure 4. The demand, consisting of 5-min measurements of traffic volume entering and exiting each ramp and traffic volume arriving at the upstream boundary, was the average Thursday demand measured in November 1990. Two performance indexes were selected and their values assessed.

- Total volume entering the freeway during the simulation period, and
- Total delay, defined as the total travel time of all vehicles at a speed less than 45 mph.

Higher-occupancy thresholds resulted in higher 3-hr volume and delay on the freeway as expected (see Figure 5). The results also suggest that volume is more sensitive to occupancy threshold decreases below the current value than to threshold

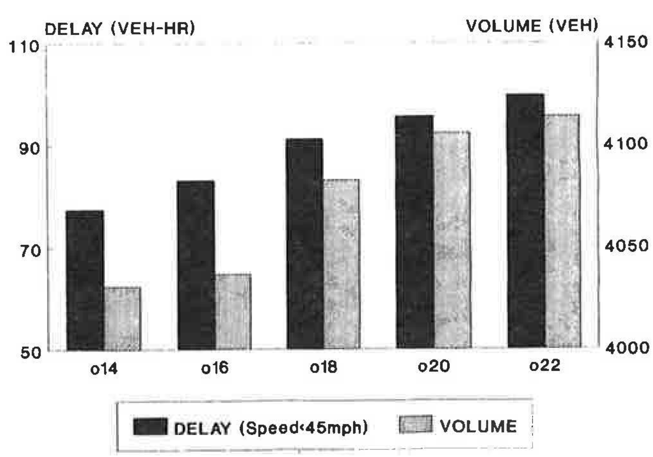

FIGURE 5 Performance of occupancy threshold strategies: existing demand.

increases. For example, with existing demand, increasing the current 18 percent threshold by 2 percentage points results in a 0.6 percent increase of freeway volume and a 4.8 percent increase of total delay. However, shifting down the current threshold by 2 percentage points results in a 1.1 percent volume decrease and a 8.9 percent delay reduction. By considering the trade-offs between volume increase and delay reduction, a desirable threshold policy can be determined for a freeway section.

CONCLUDING REMARKS

The proposed control-emulation method can be a practical traffic management tool by aiding in the design of new traffic-responsive ramp strategies as well as in the evaluation of existing control systems and selection of the best metering schemes. Using this tool for consideration of trade-offs between performance indicators, such as volume increase and delay reduction, a desirable threshold policy can be determined for a freeway section before implementation. Although the new method improves on the performance of conventional systems, it is still restricted by modeling and hardware limitations. In order to achieve an adaptive metering performance in real-time, large IVHS freeway networks, the authors are researching the need for improved traffic prediction, data collection, and parallelization of large-scale computations. Research also continues for automating the selection of optimal strategies in arterials. It is anticipated that the two branches of work will lead to improved selection of demand responsive control strategies in urban networks.

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