Abridgment

Performance Measurement for a Metered Freeway System

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Performance measures and data reduction techniques to quantify these measures from automatically collected data have been developed for the main-line freeway portions of the San Diego ramp metering system. These measures and techniques are primarily intended to allow detection of significant changes in the ongoing performance of the system. Performance indicators include speeds, volumes, flow rates, and occupancies for individual detector locations; throughputs, total travel times, and delays for freeway sections; and accident statistics. Current morning peak period conditions on the main-line freeway portions of the system were analyzed. Measures of freeway use, such as volumes and throughputs, display little variation from day to day. In contrast, measures of flow quality, such as travel time and delay, are highly variable. Most congestion appears to be the result of normal flow breakdown at fixed bottlenecks rather than incidents. Bottleneck capacities display considerable variation. There appears to be little relationship between daily use of the system, as represented by total morning peak period throughput in extended sections, and daily delay.

Ramp metering is a commonly used means of traffic control for freeways. Ramp metering systems often provide the potential for very flexible control, but to take full advantage of this potential, it must be possible to measure and evaluate the performance of the systems. The research described in this paper (*1*) was aimed at developing performance measures to be applied to the ramp metering system operated by the California Department of Transportation (Caltrans) in the San Diego area, as well as to similar systems elsewhere, and to use these to measure certain aspects of the performance of the San Diego system.

Most of the earlier evaluation studies on ramp metering have been before-and-after studies that compared conditions in the first few months after metering began with those on the uncontrolled freeway before metering (*2–4*). The most comprehensive and best-documented of these studies was that performed by the Texas Transportation Institute on the Gulf Freeway in Houston in the late 1960s (*2, 5, 6*). The current study was related to those cited in that it involved attempts to measure a variety of aspects of system performance. It differed from the earlier studies in that it was intended to evaluate the effects of relatively minor changes in an ongoing system.

Performance indicators chosen for the San Diego ramp metering system included spot speeds, flow rates, and occupancies at the controllers; travel time, delay, and throughput (or total travel, measured in vehicle miles) for sections; and accident statistics.

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In the case of all measures other than accident statistics, initial data reduction involved aggregating the raw data, which consisted of 30-sec counts for each freeway lane, to produce 6-min average values for all lanes at a particular location or for an entire section. Throughput, travel time, and delay were used mostly as indicators of overall daily performance for basic sections or more extended portions of the freeway and were thus further aggregated over the entire peak period.

These performance measures were used to analyze several aspects of current freeway performance for the San Diego ramp metering system. The aspects considered included normal variations in the various performance measures, sources of congestion in the system, performance of bottlenecks, and the relationship between daily levels of system use and delay.

VARIATIONS IN PERFORMANCE MEASURES

Total peak period volumes and throughputs were found to be quite stable. Volume counts for June and July 1986 were analyzed. For main-line detector locations, coefficients of variation (standard deviation divided by mean, expressed as a percentage) ranged from about 1 to 3 percent. For ramp counts, coefficients of variation tended to be somewhat larger. In most cases, the coefficients were less than 10 percent, but they were occasionally higher for lightly used ramps.

Travel times and delays, on the other hand, proved quite variable. These measures were aggregated for segments immediately upstream of the three major morning peak bottlenecks for April and May 1987. Standard deviations for travel time and delay were virtually identical (as would be expected) and amounted to about 20–30 percent of the mean travel time. Distributions of these measures proved to be extremely one sided.

SOURCES OF CONGESTION

Variations in travel time in the San Diego system are the result of both normal flow breakdown at the bottlenecks and incidents. In an effort to determine the relative frequency of these two sources of congestion, space-time displays of speeds and flows for June through October 1986 were analyzed. All episodes of congestion that involved speeds of 30 mph or less were identified. The overwhelming majority of the 403 episodes thus identified occurred in the vicinity of the major fixed bottlenecks and did not appear to have been the result of incidents. When incidents were involved, however, they usually contributed to the delay. In particular, recorded accidents appear to have contributed significantly to congestion only in rare instances.

BOTTLENECK PERFORMANCE

Because most congestion in the San Diego ramp metering system appears to be related to the performance of the major bottlenecks, a preliminary investigation of the capacities of these bottlenecks was undertaken. In this study, consideration was given to the question of how to identify capacity flows. The usual assumption is that the existence of a queue upstream of the bottleneck indicates capacity flow. On the other hand, a considerable body of literature contends that maximum discharge rates from queues are lower than maximum free flow rates (*7–12*).

To account for the possibility of different free flow and forced flow capacities, 6-min average flow rates from detectors either immediately upstream or downstream of the bottlenecks were cross-classified with speeds just upstream of the bottlenecks on a monthly basis for the period June–November 1986. Table 1 presents an example of the distributions that resulted. Maximum flow rates were found to be similar for all upstream speeds greater than 30 mph. Because the cross-classifications indicated that maximum queue discharges were not significantly lower than maximum free flow rates, all 6-min flow rates coinciding with upstream speeds less than 50 mph were taken to be capacity flows for the conditions prevailing at the time that they occurred. It should be noted that this means that some low flows that were the results of incidents were included.

Distributions of these "capacity flows" were prepared from the cross-classification tables. Figure 1 shows a fairly typical histogram of one of the resulting monthly capacity flow distributions. Note that there appears to be considerable (and apparently random) variation in capacity flow. In all cases, the bulk of the distribution fell within an interval of about 20 percent of the average capacity. Table 2 summarizes means and coefficients of variation for the various capacity flow distributions. It should also be noted that the monthly mean capacities of all three bottlenecks are fairly high and that those at the College Avenue bottleneck on Interstate 8 are exceptionally high.

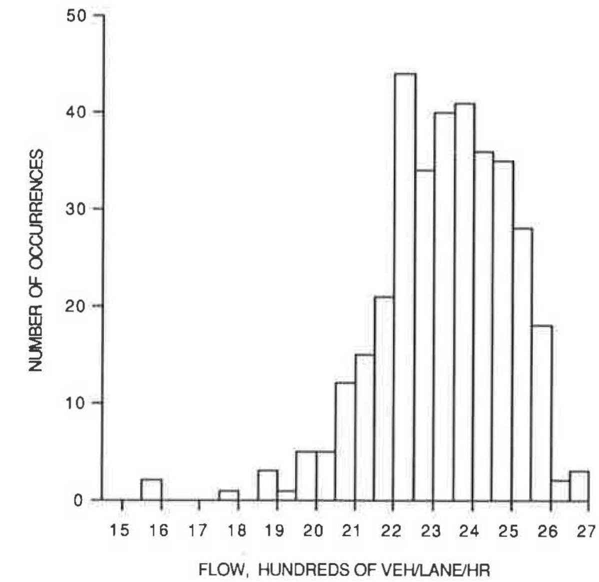

FIGURE 1 Histogram of 6-min flows through the College Avenue bottleneck on Interstate 8, with upstream speeds less than 50 mph, September 1986.

RELATIONSHIP BETWEEN DELAY AND THROUGHPUT

Relationships between throughput aggregated for the entire peak period and delay are not fully understood, although there has been some past discussion (*7, 13*). If bottleneck capacity remains constant and throughput in a section increases, delay should be expected to increase. If, on the other hand, variations in delay are primarily due to variations in bottleneck capacity—which they may be in this system (see the preceding section)—there should be little or no relationship between delay and throughput. The exception is that if drivers divert from the freeway when it is heavily congested, there may be a negative correlation.

Delays and throughputs aggregated over the entire morning peak period for the sections upstream of the major bottlenecks were plotted against one another for April and May 1987. Figure 2 shows an example of the resulting scatter plots. As can be observed, there is little correlation between throughput and delay. To the extent that there is a correlation, it is negative and appears to be due to diversion of traffic from the freeway system during the most severe delay-producing incidents.

TABLE 1 CROSS-CLASSIFICATION OF NUMBERS OF 6-MIN FLOW OCCURRENCES

Speed	Flow (hundreds of vehicles/lane/hr)									
(mph)	10–12	12–14	14–16	16–18	18–20	20–22	22–24	24–26	>26	Total
0–10	0	0	0	0	0	0	0	0	0	0
10–20	0	0	0	0	4	0	1	0	0	5
20–30	0	0	0	0	2	37	53	0	0	92
30–40	0	0	0	0	2	13	76	49	0	140
40–50	0	1	1	1	1	3	29	66	5	107
>50	0	5	16	33	72	58	54	43	2	283
Total	0	6	17	34	81	111	213	158	7	627

NOTE: Interstate 8 at Waring Road versus 6-min average speeds at College Avenue, September 1986.

TABLE 2 MEANS AND COEFFICIENTS OF VARIATION OF 6-MIN FLOW DISTRIBUTIONS

	Bottleneck					
	Rte 15		College Ave.		Grossmont Summit	
Month	Mean[a]	Cov (%)	Mean[a]	Cov (%)	Mean[a]	Cov (%)
June	2,088	6.09	2,343	10.81	2,026	11.17
July	2,014	8.26	2,305	8.83	2,000	9.71
August	1,970	11.97	2,344	6.73	2,003	9.33
September	2,031	9.79	2,322	7.37	2,037	7.67
October	2,033	8.59	2,305	6.58	1,990	10.48
November	2,053	8.76	2,321	5.88	2,032	9.75

NOTE: For bottlenecks with upstream speeds less than 50 mph.
[a]Means in vehicles per lane per hour.

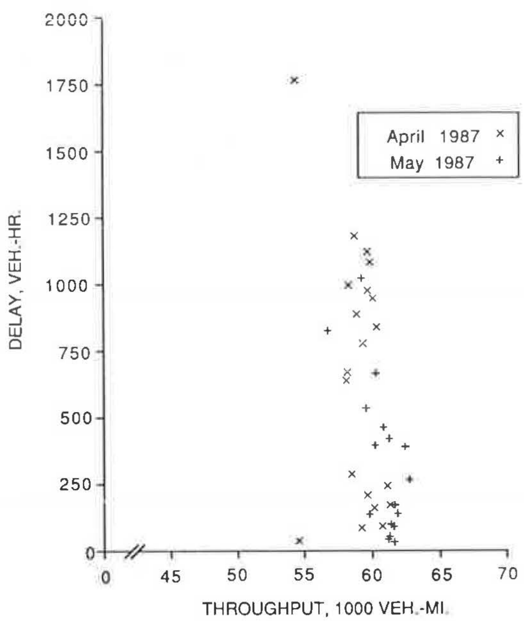

FIGURE 2 Scatter plot, morning peak period (6 a.m.–9 a.m.), delay versus throughput, Interstate 8, College Avenue–Spring Street, April–May 1987.

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REFERENCES

1. J. H. Banks. *Performance Measurement for Centrally-Controlled, Traffic-Responsive Ramp Metering Systems: Final Report.* Civil Engineering Report Series 87141. San Diego State University, San Diego, Calif., 1987.
2. C. Pinnell, D. R. Drew, W. R. McCasland, and J. A. Wattleworth. Evaluation of Entrance Ramp Control on a Six-Mile Freeway Section. In *Highway Research Record 157,* HRB, National Research Council, Washington, D.C., 1967, pp. 22–70.
3. L. Newman, A. M. Dunnet, and G. J. Meis. An Evaluation of Ramp Control on the Harbor Freeway in Los Angeles. In *Highway Research Record 303,* HRB, National Research Council, Washington, D.C., 1970, pp. 14–21.
4. N. L. Nihan and G. L. Davis. Estimating the Impacts of Ramp-Control Programs (abridgment). In *Transportation Research Record 957,* TRB, National Research Council, Washington, D.C., 1984, pp. 31–32.
5. J. A. Wattleworth and W. R. McCasland. Study Techniques for Planning Freeway Surveillance and Control. In *Highway Research Record 99,* HRB, National Research Council, Washington, D.C., 1965, pp. 200–223.
6. C. L. Dudek and W. R. McCasland. Cost-Effectiveness of Freeway Merging Control. In *Highway Research Record 363,* HRB, National Research Council, Washington, D.C., 1971, pp. 55–59.
7. *Traffic Control Systems Handbook.* FHWA, U.S. Department of Transportation, June 1976.
8. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.
9. P. J. Athol and A. G. R. Bullen. Multiple Ramp Control for a Freeway Bottleneck. In *Highway Research Record 456,* HRB, National Research Council, Washington, D.C., 1973, pp. 50–54.
10. J. Drake, J. Shofer, and A. May. A Statistical Analysis of Speed-Density Hypotheses. In *Highway Research Record 154,* HRB, National Research Council, Washington, D.C., 1967, pp. 53–87.
11. L. C. Edie. Car Following and Steady-State Theory for Non-Congested Traffic. *Operations Research,* Vol. 9, 1961, pp. 66–76.
12. H. J. Payne. Discontinuity in Equilibrium Traffic Flow. In *Transportation Research Record 971,* TRB, National Research Council, Washington, D.C., 1984, pp. 140–146.
13. V. F. Hurdle and D. Y. Solomon. Service Functions for Urban Freeways: An Empirical Study. *Transportation Science,* Vol. 20, 1986, pp. 153–163.