Benefits of Central Computer Control for Denver Ramp-Metering System

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An evaluation was made to determine the effects of providing central computer coordination on the Denver ramp-metering system. Information from the system was collected with the coordination algorithm operational and with it disabled. The data suggest that, when local demand-responsive ramp-metering control is unable to maintain freeway speeds at or near the posted limit of 55 mph, central coordination can be useful in reducing main-line delays. However, when speeds are near 55 mph with local ramp metering in operation, central coordination of the type used in the Denver system may be of little benefit.

In the 1970s the Denver metropolitan area experienced unprecedented growth in population and employment. For the motoring public, this growth resulted in increased congestion, delay, vehicle emissions, fuel usage, and frustration. Two studies, one conducted by the Denver Regional Council of Governments (*1*) and the other by the Colorado Department of Highways (*2*), recommended the implementation of ramp metering on selected portions of the freeway system to improve traffic flow and safety.

These studies led the Colorado Department of Highways to install ramp metering as a demonstration project on one of the most congested portions of the Denver freeway system. Metering began on March 3, 1981, during the morning peak period on five ramps of northbound I-25 from Hampden Avenue to Colorado Boulevard. Bus bypasses were built at two of these ramps to accommodate existing bus routes and to give preference to transit riders.

The initial system used stand-alone, demand-responsive controllers at each ramp metering location. Geometric improvements were made to bring acceleration lanes to standard lengths and to improve interchange designs. The demonstration project was an immediate technical and public relations success because it eliminated most stop-and-go traffic on this section of freeway. The project resulted in a 58 percent increase in freeway speed and a 37 percent reduction in vehicle-hours of travel (VHT) during the morning peak period (*3*).

Due to the success of the initial project, ramp metering was sanctioned as a transportation systems management strategy in the Denver area. The system was expanded in 1984 and in subsequent years to include a central computer with system coordination as well as additional meters on I-25, I-225, US-6, and I-270. In 1988, 24 ramps were under metered control with 22 operating during the morning peak period and 15 during the evening peak period (see Figure 1).

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SYSTEM DESCRIPTION

The system is divided into six groups, with one to seven ramps per group (see Figure 1). Most ramps are striped for two lanes of vehicle storage. I-25, which includes Groups 1 and 2, is a six-lane facility in this part of the metropolitan area. Ramp control is operational for northbound traffic from County Line Road on the south to Colorado Boulevard on the north. Group 1 is separated from Group 2 by the I-225 interchange.

I-225 has four lanes north of the Parker Road interchange and six lanes between Parker Road and the junction of I-25. Group 3 includes all the southbound ramps, and Group 4 controls traffic on the northbound ramps. The northbound Yosemite Street onramp is the only nonmetered location on I-225. The two-lane I-225 and Parker Road southbound entrance ramp is unique within the system in that it allows two vehicles in each lane to enter the freeway during each metering cycle. This ramp also includes a high-occupancy vehicle (HOV) bypass lane with bus-only access to a park-and-ride lot.

Groups 5 and 6 are single-ramp systems on US-6 and I-270, respectively. These two groups were not included in the evaluation. Additional metering locations are planned for I-25 southbound and I-70 westbound between I-225 and I-270. Communications between the local ramp controllers and the central computer are handled by a combination of leased telephone lines and state-owned cable.

RAMP CONTROL STRATEGIES

The ramp controllers are programmed to operate only during weekdays for one or both of the peak periods. During metering periods, each ramp meter selects one of six metering rates on the basis of local traffic conditions (see Figure 2). Main-line primary and secondary detectors are used to determine the volume, occupancies, and speeds in each lane. The secondary detectors function as a backup for the primary detectors. The ramp presence and passage detectors inform the controller when a vehicle is waiting to be metered and when it has passed the metering signal. A 2-sec delay is programmed into the controller to prevent a vehicle from receiving an immediate green indication. Rate selections are made every 20 sec according to the information provided by the main-line detectors. An exponential smoothing function is included in the algorithm to prevent rapid switching between rates.

Queue detectors are installed near the entrance of the ramp to sense when vehicles are backing toward the cross street.

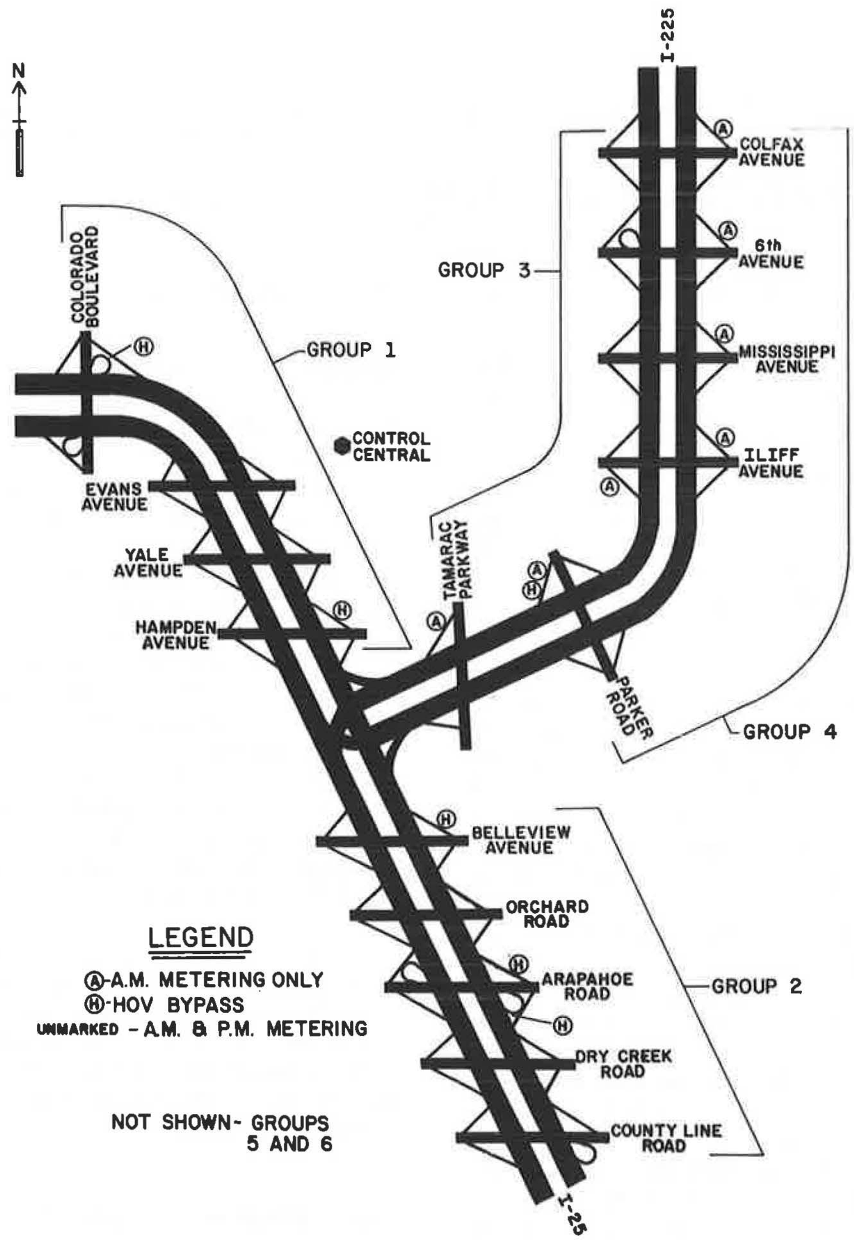

FIGURE 1 Denver area ramp-metering system.

When the occupancies of the queue detectors exceed an established threshold, the controller overrides the normally selected metering rate. The controller then initiates less restrictive rates until the backup is reduced to an acceptable level. The HOV detector, when actuated, extends the red signal time by a preset amount to help avoid conflicts in the merge area.

CENTRAL CONTROL STRATEGIES

Every 20 sec the central computer collects detector and metering rate data from each ramp. If a ramp is in the most restricted rate (freeway congested) or in queue override (ramp congested), the ramp is defined as critical. A system coordination plan is then put into effect. This plan calculates the travel time between ramps and, after that time, forces a more restrictive metering rate on the next upstream ramp.

If the ramp remains in a critical condition during the next sampling period, the rates of the next two upstream ramps are forced one rate more restrictive. The system continues to add ramps to the coordination plan during each sampling cycle until all ramps in the group are under central control. If more than one ramp becomes critical, multiple plans are put into effect.

When the last ramp in a group is put under the system coordination plan (see Figure 1), the central computer begins implementing coordination in the first ramp of the next upstream group that feeds the critical ramp. The system coordination plan continues until the ramps return to a noncritical condition. The plan returns the local controllers to normal operation one rate at a time at the 20-sec sampling intervals.

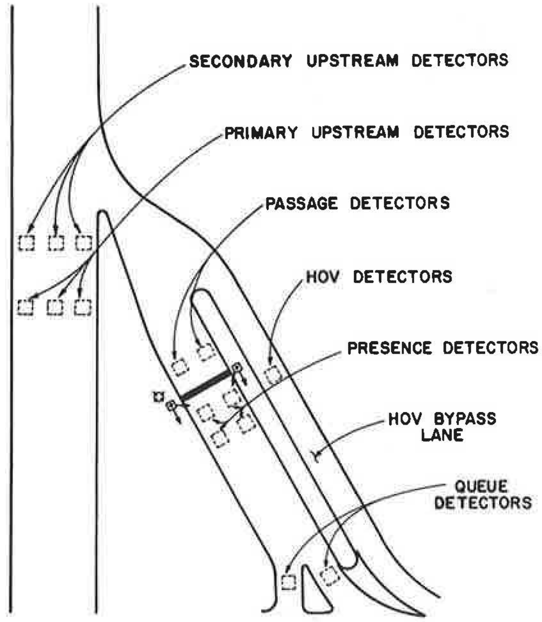

FIGURE 2 Typical metered freeway ramp.

The central computer also monitors the traffic just before and after the peak periods to determine if metering should occur earlier or later than the core metering times. If conditions are favorable for ramp control, the central computer allows the local controllers to begin metering up to 20 min before and to remain on 30 min after the mandatory metering times.

DATA COLLECTION

Data on the effects of the system coordination algorithm were collected during September, October, and November of 1988. This time of the year was selected because of the stability of the daily traffic patterns. For similar reasons, only information from the morning peak period on Tuesdays, Wednesdays, and Thursdays was used to evaluate the benefits of coordination.

A microcomputer was used to collect and summarize data from the ramp-metering central computer. The microcomputer was connected to the central computer using a readily available communications software package. Volume and speed data for each ramp in the four groups were obtained for the hours of 7:00, 8:00, and 9:00 a.m. This information was transferred to a spreadsheet program that contained distances between the ramps. VHT and vehicle-miles of travel (VMT) were calculated for each group by adding VMT and VHT between each ramp. Data from each day were examined for indications of inclement weather, accidents, or equipment malfunctions, and any suspect information was rejected.

Six days' worth of acceptable data was collected between September 28 and October 13 with the system in normal operation (coordination on). On October 18 the system coordination algorithm was disabled, and 8 days' worth of information was gathered (coordination off). Data for an additional 2 days of normal operation were obtained on November 8 and 10.

EVALUATION

A summary of the data is presented in Tables 1 and 2. For all groups there was a slight reduction in VMT for the coordinated condition compared with the noncoordinated condition. VHT reductions were 13.1 and 3.9 percent for Groups 1 and 4, respectively, with only slight reductions indicated for Groups 2 and 3.

A statistical test was performed to determine if the differences between the two conditions were significant given the sample size and the magnitude of the differences. The criterion used was the t distribution. The required t values for several levels of significance are as follows:

Minimum t Value	*Level of Significance*
1.34	0.2
1.76	0.1
2.14	0.05
2.62	0.02
2.98	0.01

Calculated t values for the ramp metering data are as follows:

Group	*VMT*	*VHT*
1	0.37	3.62
2	0.82	0.18
3	1.79	0.29
4	0.91	1.50

From this information, it appears that three values are significant: (a) the difference in Group 1 VHT is significant at the 0.01 level; (b) the difference in Group 3 VMT is significant at the 0.1 level; and (c) the difference in Group 4 VHT is significant at the 0.2 level. The rest of the data indicates no statistically significant change between the two conditions.

Because only minor benefits were found during coordination (with the exception of Group 1 VHT), further examination of the data was performed. Traffic volumes and speeds at the ramps closest to the bottleneck locations and average group speeds were reviewed (see Tables 3–5). For Groups 2, 3, and 4, the ramp and average group speeds were near or at the posted speed limit of 55 mph. For Group 4, the speed at Colfax and I-225 increased by 2 mph under coordination.

TABLE 1 VEHICLE-MILES OF TRAVEL

GROUP	WITHOUT COORD.	WITH COORD.	% DIFF.
1	21498	21360	-0.6
2	32857	32503	-1.1
3	33906	33451	-1.3
4	31862	31514	-1.1

TABLE 2 VEHICLE-HOURS OF TRAVEL

GROUP	WITHOUT COORD.	WITH COORD.	% DIFF.
1	603	524	-13.1
2	570	567	-0.5
3	604	601	-0.5
4	564	542	-3.9

TABLE 3 TRAFFIC VOLUMES AT RAMPS CLOSEST TO BOTTLENECK

GROUP	LOCATION	VOLUMES WITHOUT COORD.	VOLUMES WITH COORD.	% DIFF
1	I-25 AND COLORADO	7267	7199	-0.9
2	I-25 AND BELLEVIEW	7010	6881	-1.8
3	I-225 AND TAMARAC	5246	5185	-1.2
4	I-225 AND COLFAX	4166	4108	-1.4

TABLE 4 TRAFFIC SPEEDS AT RAMPS CLOSEST TO BOTTLENECK

GROUP	LOCATION	SPEEDS WITHOUT COORD.	SPEEDS WITH COORD.	% DIFF
1	I-25 AND COLORADO	31	42	+35.5
2	I-25 AND BELLEVIEW	57	56	-1.8
3	I-225 AND TAMARAC	55	55	0.0
4	I-225 AND COLFAX	54	56	+3.7

TABLE 5 AVERAGE GROUP SPEEDS

GROUP	SPEEDS WITHOUT COORD.	SPEEDS WITH COORD.	% DIFF.
1	37	42	+13.5
2	58	57	-1.7
3	56	55	-1.8
4	57	58	-1.8

The other ramp and group speeds either did not change or decreased by 1 mph during coordination.

CONCLUSIONS

The data suggest that, when local demand-responsive ramp metering control is unable to maintain freeway speeds near the posted limit of 55 mph, central coordination can be useful in reducing main-line delays. However, when speeds are near 55 mph with local ramp metering in operation, central coordination of the type used in the Denver system may be of little benefit.

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2. *I-25 TSM Study, Ramp Metering Feasibility Analysis*. Colorado Department of Highways, Denver, Aug. 1979.
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