

Impacts of TSM Improvements on Eastbound SR 520

NANCY L. NIHAN

In 1986, the Washington State Department of Transportation sponsored a project that analyzed and evaluated the impacts of ramp metering and a new ramp HOV lane on eastbound highway SR 520, which connects Seattle to the suburbs east of Lake Washington. The data analyzed included postcard origin-destination surveys, postcard surveys of perceived travel times and vehicle occupancies, manual vehicle occupancy counts, floating car travel times, queue length counts, electronic volume and lane occupancy counts, and bus travel times. The results indicated that the number of carpools and vanpools increased significantly on the ramp with the new HOV lane and that the overall level of service was improved for main-line SR 520. A significant number of trips were diverted from the local neighborhood to I-5. This result was expected and had the desired effect of diverting trips from the neighborhood and increasing HOV ridership.

In this paper, the assessment of transportation system management (TSM) improvements to two on-ramps on the highway SR 520 eastbound link connecting the city of Seattle, Washington, to suburbs east of Lake Washington is summarized. The on-ramps in question (at Montlake and Lake Washington Boulevard) are the last eastbound on-ramps before the SR 520 bridge across Lake Washington. Figure 1 shows the study location, including the SR 520 link. Figure 2 shows the locations of the two on-ramps. The two communities adjacent to these two ramps are the University of Washington (UW) to the north and the Montlake residential neighborhood to the south.

The TSM improvements at the study location consisted of the installment of ramp metering at both ramps and the construction of a high-occupancy vehicle (HOV) bypass lane at the Montlake on-ramp. The primary objective of the TSM improvements for the Montlake community was to divert through traffic from the neighborhood, whereas for the Washington State Department of Transportation (WSDOT) the objectives were to increase the percentage of HOV travel and to improve the main-line level of service.

The literature on TSM experiences in other cities (16) supports the findings of the SR 520 study. TSM strategies such as ramp metering and exclusive HOV lanes have been proved to increase main-line speeds and vehicle occupancies in Minneapolis, Sacramento, Portland, Miami, Houston, Boston, Los Angeles, Washington, D.C., Chicago, and other cities. These effects were the two prime WSDOT objectives for the SR 520

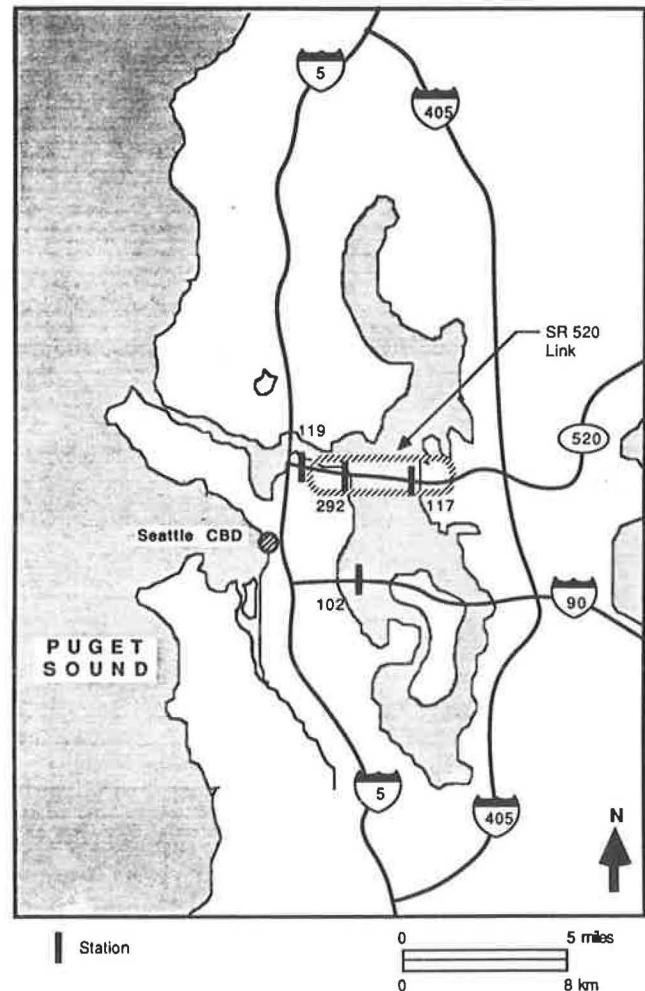


FIGURE 1 Study location.

project, and both were satisfactorily realized. The Montlake Community objective, diversion of trips through the neighborhood, was also realized.

STUDIES AND ANALYSIS

On March 10, 1986, ramp metering of both the Lake Washington Boulevard and Montlake on-ramps began, along with operation of the HOV lane at the Montlake ramp. To evaluate the impact of this TSM intervention, the following data collection procedures were employed:

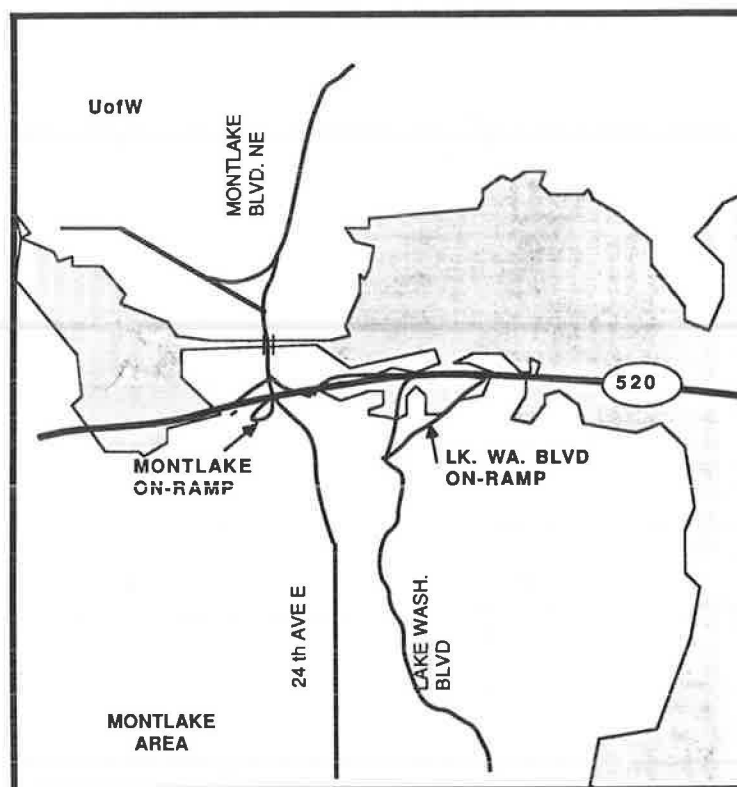


FIGURE 2 Eastbound on-ramps for SR 520 bridge link.

- Postcard surveys of origin and destination, travel time, and vehicle occupancy (February 25 and April 29, 1986);
- Manual vehicle occupancy counts (February 24 and 25, April 28 and 29, 1986);
- Bus arrival time counts (February 24 and 25, April 28 and 29, 1986);
- Manual counts of queue lengths on the ramps (February and April 1986);
- Floating car studies of travel time February through April 1986);
- Electronic volume and lane occupancy counts for main-line and ramps (February through April 1986); and
- Electronic bus passenger counts and travel time counts (February through April 1986).

A detailed description of the data collections and statistical analyses is given by Nihan (7). A summary of these findings follows.

Postcard Surveys

Origin-Destination (OD) Data

On February 25 and April 29, 1986, a postcard origin-destination (OD) survey was conducted at both the Montlake and Lake Washington Boulevard on-ramps during the 2-hr afternoon peak period. Some 1,000 postcards were handed out at each ramp at this time period during both the before and after data collections. The number of returned cards for the February and April counts were 627 and 531 for the Montlake ramp and 571 and 486 for the Lake Washington Boulevard ramp, respectively. The postcard questionnaires were duplicates of questionnaires that had been handed out in April 1982 as part of a

previous WSDOT study. This earlier survey yielded 407 responses for the Montlake ramp and 556 responses for the Lake Washington Boulevard ramp. With the results of this additional survey, there were two sets of before data (April 1982 and February 1986) and one set of after data (April 1986).

As mentioned previously, one concern of Montlake community residents was the percentage of travelers from downtown and other zones of origin. Most of these commuters should reasonably have selected the I-5 route to SR 520 but were instead using local streets and arterials to enter SR 520 at the Montlake or Lake Washington Boulevard ramps.

The before and after OD surveys indicated that before ramp metering, 40.3 percent of the trips using the two eastbound on-ramps had originated in these other zones. This was reduced to 33.3 percent after metering. Thus ramp metering had a diversionary effect on vehicles entering the two on-ramps, and a statistically significant percentage of those trips that had previously come from downtown and southern zones and passed through the Montlake neighborhood were diverted to other routes (most likely I-5). There were two reasons for these desired route diversions: (a) increased queues and travel times for drivers of single-occupant vehicles (SOVs) at both SR 520 on-ramps after metering and (b) improved level of service (LOS) for all vehicles on I-5 because of the improved LOS on main-line SR 520 after ramp metering.

Perceived Travel Times and Vehicle Occupancy

The postcard survey questionnaire also included questions about travel time and vehicle occupancy. For the 1986 before

and after surveys, a statistically significant increase in perceived travel time occurred on both ramps after the introduction of ramp metering. Average total travel time increased from 35.9 min to 38.4 min for the Montlake ramp ($p < .05$) and average total travel time increased from 35.7 min to 38.9 min for the Lake Washington Boulevard ramp ($p < .01$). It therefore appears that total perceived trip travel times increased slightly for both ramps due to the ramp metering. These results are further supported by actual travel time data collected by the floating car method and by the volume/lane occupancy data collected electronically. These increased travel times for SOV users of both ramps contributed to the desired route diversions mentioned previously.

The average vehicle occupancies for vehicles sampled in the 1986 postcard surveys were also statistically analyzed. These included single-occupant automobiles, carpools, and vanpools but did not include buses. The before and after postcard surveys of 1986 indicated that the TSM strategies caused no change in vehicle occupancy for the Lake Washington Boulevard ramp, but there was a significant increase in vehicle occupancy for the Montlake ramp. Average vehicle occupancy for the Montlake ramp increased from 1.30 people/vehicle to 1.49 people/vehicle ($p < .01$) after the introduction of the HOV lane and ramp metering. This result implied that a significant increase in the number of carpools and vanpools had been caused by the introduction of the HOV lane on the Montlake on-ramp and by the increased queue lengths that resulted from the metering on both ramps. This conclusion was further supported by data from manual counts.

Manual Vehicle Occupancy Counts

Vehicle occupancy counts were taken during the peak hours of February 24, 25 and April 28, 29, 1986, for the Montlake and Lake Washington Boulevard on-ramps and the two eastbound main-line SR 520 lanes. The vehicle occupancy data available for buses were not sufficient for analysis and will not be discussed here. The results indicated a significant decrease in the percentage of single-person automobiles and significant increases in percentages of carpools and vanpools on the Montlake ramp after introduction of the HOV lane. There was an increase in the percentage of single-person automobile trips and a corresponding decrease in carpool and vanpool trips observed on the Lake Washington Boulevard ramp, indicating a possible shift of carpool and vanpool trips to the Montlake HOV lane. Although the percentages of HOV changes at each ramp were similar (4 percent decrease in SOVs at Montlake and 4 percent increase in SOVs at Lake Washington), volumes on the two ramps (5,074 at Montlake versus 3,460 at Lake Washington Boulevard) indicated a larger absolute increase in HOVs at Montlake than would be explained totally by the shift from the Lake Washington Boulevard ramp. The main-line SR 520 lanes did not exhibit significant changes in vehicle occupancy.

With the exception of the possible shift in HOVs between ramps, the manual count results supported the postcard survey data and can be summarized as follows:

- HOV usage increased at the Montlake ramp. The postcard survey indicated an increase from 1.30 to 1.49 people/vehicle

on the Montlake on-ramp. The manual counts indicated a change from 1.23 to 1.32.

- Some carpools and vanpools may have shifted from the Lake Washington Boulevard on-ramp to the Montlake on-ramp. The manual counts indicated a change from 1.26 to 1.20 people/vehicles. This was contradicted by the OD survey data, which indicated no significant change in vehicle occupancy at the Lake Washington Boulevard on-ramp.

- Vehicle occupancy on main-line SR 520 remained stable.

Although both the postcard surveys and the manual counts indicated a significant increase in vehicle occupancies at the Montlake on-ramp, the observed occupancy levels were lower for the manual counts than for the surveys. This difference may have been caused by a sample bias in the postcard returns that favored non-SOV drivers or a simple difference in the manual counts, which included counts for two extra days (Monday, in each case). Because Tuesday is a more representative day, the postcard survey data may be favored here. In any case, both data sets indicated an increase in HOV travel at the Montlake on-ramp.

Bus Arrival Times

Bus arrival times for February 24, 25 and April 28, 29, 1986, were collected at the Evergreen Point Freeway station on the east side of Lake Washington (east end of the SR 520 link) between 3:30 p.m. and 6:00 p.m. These data did not display significant differences in late and early times when they were compared with the actual schedules for these days. A parallel electronic data collection was conducted by Metro, the local transit authority, using specially equipped buses. However, this sample, which provided only 11 travel time values for all before-and-after periods and all bus routes, was inadequate for serious study.

A better indication of the effect of the ramp metering on bus service was Metro's determination over several months that buses were arriving at the Montlake and Evergreen Point Freeway flyer stations earlier after installation of the ramp controls and HOV lane. Metro therefore revised its fall 1986 schedules to reflect these time savings. Schedules for buses coming from downtown on I-5 to SR 520 were revised to reflect a savings of 3 minutes; schedules for buses using the Montlake ramp to SR 520 were revised to reflect a savings of 4 minutes. These facts, coupled with the time savings realized by the HOV lane on the Montlake ramp and the faster speeds on main-line SR 520 due to the metering, suggested that all bus service benefited from the TSM improvement. (It should be noted that there was no bus service using the Lake Washington Boulevard ramp either before or after the improvements.) Subsequent Metro ridership increases supported these conclusions (9).

Manual Ramp Queue Counts

Data on queue lengths were also collected manually. Queue lengths were measured every 15 min from 2:30 p.m. to 5:45 p.m. at both on-ramps. The 10 weekdays between February 17 and 28, 1986, provided the before data, and the 10 weekdays between April 14 and 28, 1986, provided the after data. Queue

lengths were expressed in vehicles and were displayed graphically for day and time of day in three-dimensional plots. The total of before data for each station was also aggregated, as was the total after data. These totals were compared by using before-and-after histograms and the Mann-Whitney U statistic. It was found that the queue lengths were significantly longer at both ramps after the ramp controls were in effect. The average queue length for the Montlake ramp increased from 60 to 113 vehicles ($p < .01$), whereas the average for the Lake Washington Boulevard ramp increased from 14 to 80 vehicles ($p < .01$). This had the desired deterrent effect on SOVs and non-neighborhood traffic.

Figure 3 shows the queue length data for the Lake Washington Boulevard on-ramp for 8 days before the ramp metering and 10 days after the ramp metering. The before days included January 18–February 21, 1986, and February 24–28, 1986, and the after days included April 21–25, 28–30, and May 12, 1986. The plots show queue length in vehicles by date and time of day between 2:30 p.m. and 5:45 p.m. A similar plot was obtained for the Montlake on-ramp. Both plots indicated an increase in queue length for the on-ramps after the ramp metering intervention. This increase in queue length was most pronounced for the Lake Washington Boulevard on-ramp.

Floating Car Studies

Floating car studies of travel times were performed for February and April. From the collected data, 10 before runs and 10 after runs from the Montlake parking lot at UW to Evergreen Point (the end of the bridge), all made between 4:30 p.m. and 5:30 p.m. and using the Montlake on-ramp, were available. For each of these runs the time to reach the Montlake ramp from the parking lot (t_a), the time on the Montlake on-ramp (t_b), main-line time across the bridge (t_c), time to reach main line ($t_a + t_b$), and total travel time ($t_a + t_b + t_c$) were computed.

Before versus after values were compared by using the Mann-Whitney U statistic. These results indicated an increased time to reach the main line, an increased total travel time, and a slight decrease in main-line travel time. When the results were analyzed separately, they indicated no statistically significant changes in the times to get to the on-ramp and the times on the on-ramp. However, the times were increased marginally in both cases. When the results were combined ($t_a + t_b$), there was a

statistically significant increase in the total time to reach the ramp-merging point. This median increase was 243.5 s. The results also indicated an insignificant decrease in main-line travel time but a significant increase in the total travel time from point of origin to point of destination. The median increase in total travel time was 238.5 s.

The mean differences in total travel time ($t_a + t_b + t_c$) and time to the ramp merge ($t_a + t_b$) were 281 s and 301 s, respectively. The travel time results therefore indicated that a net total increase in travel time was experienced by travelers from UW to the east side. This increase was entirely due to a larger increase in the time it took to go from the point of trip origin to the ramp merge with SR 520 and was offset slightly by improved travel time on the main-line link. These results and the volume/lane occupancy results indicated that travelers already on the main line experienced a slightly improved travel time. The average increase in time spent on the Montlake on-ramp was 5 min. Thus, because the HOV bypass did not experience this increase, there was roughly a 5-min difference in trip time between SOVs and HOVs using the Montlake on-ramp.

Volume/Lane-Occupancy Counts

A special technique known as time series intervention analysis was used to analyze the electronic volume/lane occupancy data for the intervention effects of the ramp control program. This technique, described by Davis and Nihan (8) and Nihan and Davis (9), is related to other work (10, 11). At its simplest (linear models with residuals that are not serially correlated), this technique is just linear regression analysis performed on time series data with an intervention variable included as one of the independent variables. The intervention variable has values of 0 for time periods occurring before the intervention of interest and values of 1 for time periods following the intervention. Simple regressions are run for the performance variable of interest (e.g., volume on eastbound SR 520), using both a covariable to control for trends (e.g., volume on east I-90) and the intervention variable representing the time that the ramp controls were put into effect as independent variables. The resulting coefficient of the intervention variable for the above example gives the amount of increase or decrease in SR 520 volume due to the ramp controls. When correlated residuals are

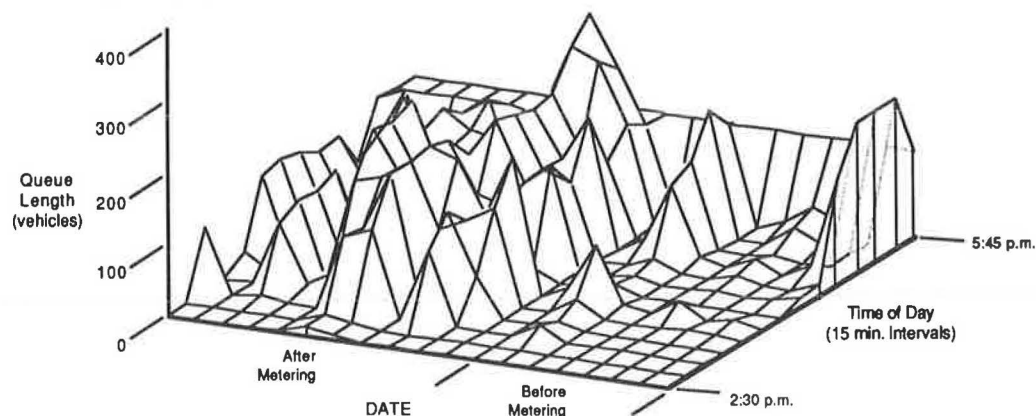


FIGURE 3 Queue length data for Lake Washington Boulevard on-ramp.

present, the time series data cannot be modeled with simple linear regression techniques, and more complicated time series models known as ARIMA intervention models may be required. Such model forms were not required for the SR 520 analysis but are discussed elsewhere (8).

During the study, electronic data for main-line and ramp volumes and for lane occupancy was continually being transferred to a UW data base through a telecommunication link between the WSDOT Traffic Systems Management Center (TSMC) in Seattle and UW. These data were in the form of 5-min volume/lane occupancy values for each lane from numerous presence detector stations throughout the Seattle area. The 5-min lane and ramp data could be summarized by time interval and by station.

The telecom data were used to analyze the change in LOS along the SR 520 section affected by the ramp controls. Three stations were chosen for these regression analyses (see Figure 1). These included station 292 (between Montlake and Lake Washington Boulevard on-ramps), station 117 (Evergreen Point Bridge toll plaza), and station 102 (I-9 bridge toll plaza). Stations 292 and 117 were chosen to assess the impact of the ramp controls on SR 520 main-line LOS, whereas station 102 provided covariable information used to control for trend effects. For each half-hour period between 3:00 p.m. and 6:00 p.m., for each station, and for each week day between February 10 and April 30, 1986, the total volume and average lane occupancy were computed from presence detector data.

Separate time series analyses on the lane occupancy data and on the volume data were performed to assess the true increases or decreases due to ramp metering at stations 292 and 117. The lane occupancy regressions indicated significant decreases in average occupancy for station 292 due to the controls and small but significant increases in average volumes. Thus the regression results indicated an improved LOS at station 292 that was probably caused by reduction of merging conflicts due to the ramp metering at the Montlake on-ramp. The results for station 292 were taken as the best LOS measures for the main line. It should be noted, however, that later investigation indicated that the loop detectors at station 117 were consistently overestimating volumes. Therefore the results for this station were largely ignored, although relative results supported the results obtained for station 292.

As analysis of the volume/lane occupancy data continued, the effective vehicle length suggested by TSMC (22 ft) was assumed, and it was also assumed that this effective length remained stable during the entire study period. A longer effective length would give similar relative results but would cause slightly lower before and after speeds. Main-line

speeds were then calculated from the before and after volume/lane occupancy data. Table 1 presents these calculations for station 292. Speeds at station 292 were significantly increased for all time periods, representing significant improvements in main-line LOS at that point.

In addition to the regression analyses, several days' worth of volume/lane occupancy data were plotted to produce graphical displays of the impacts of ramp metering on the SR 520 main line. Three sets of volume/lane occupancy plots were made for stations 292, 117, and 119. The plots displayed 5-min volume/lane occupancy values for the period 6:00 a.m.–6:00 p.m. for 3 days before the ramp control intervention (February 26–28, 1986) and 3 days after ramp controls were in effect (March 11–13, 1986). Although the ramp controls were in effect only during the afternoon peak period, full-day data sets were used to observe the complete volume and occupancy curves and therefore to assess the general capacity limitations and LOS ranges. As before, station 292 represented the location between the Montlake ramp merge and the Lake Washington Boulevard merge, and station 117 represented the former location of the Evergreen Point toll plaza. Station 119, located at the beginning of the eastbound SR 520 lanes just after the junction of I-5 and SR 520, represented flow upstream from the ramp merges.

Figure 4 presents the volume/lane occupancy plots for station 292. The solid circles represent points of volume/lane occupancy for days before the ramp controls were in effect, and the open circles represent the points on the volume/lane occupancy curve for days after the ramp control improvement.

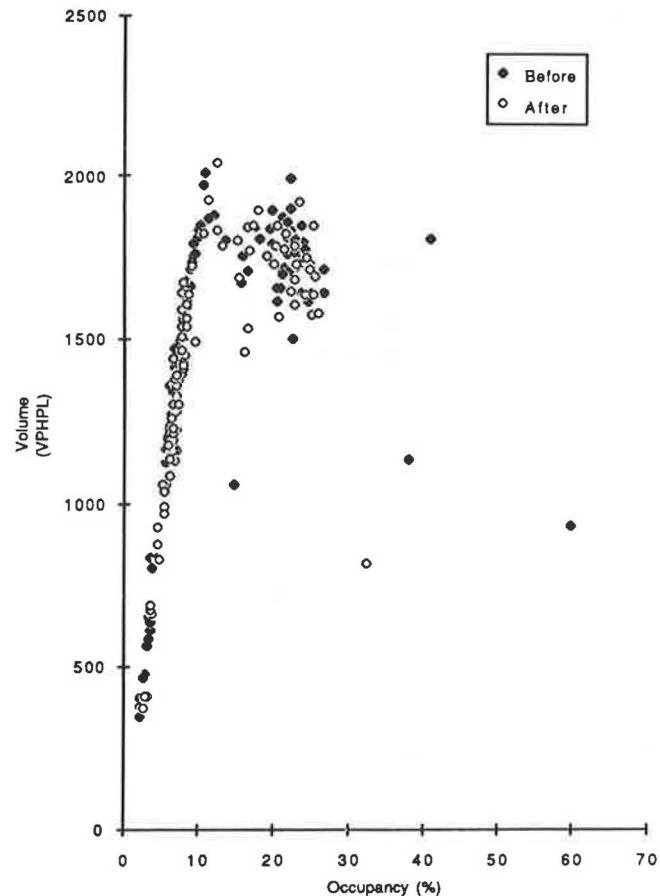


FIGURE 4 Volume versus lane occupancy (Station 292).

TABLE 1 INTERVENTION CHANGES AT STATION 292

Period	Before Speed (mph)	Change (mph)	Significance
3:00–3:30	25.1	+10.4	$p < .05$
3:30–4:00	24.4	+9.7	$p < .05$
4:00–4:30	23.9	+10.5	$p < .01$
4:30–5:00	26.7	+7.9	$p < .05$
5:00–5:30	27.1	+5.6	$p < .10$
5:30–6:00	25.2	+4.8	$p < .05$

The graph illustrates a shift in points away from the LOS F range after the ramp control intervention. Note the scatter of solid circles to the right of each plot indicating level of service F. The open circles corresponding to the same time periods are less scattered and move to the left and vertically, indicating an improvement in LOS for these periods. Similar plots were obtained for stations 117 and 119. Both plots reflected improvements in main-line SR 520 LOS due to the ramp controls.

CONCLUSIONS

Postcard Surveys

Ramp metering appears to have had a diversionary effect on vehicles entering the Lake Washington Boulevard on-ramp so that a significant percentage of those who had previously come from the downtown and southern zones and then passed through the Montlake neighborhood were diverted to other routes (most likely I-5). This was one of the desired outcomes of the TSM strategy.

Total perceived trip travel times increased slightly on both ramps due to the ramp metering. This result was further supported by actual travel times obtained from floating car studies. The before-and-after postcard surveys indicated a significant increase in vehicle occupancies for the Montlake ramp but no change for the Lake Washington Boulevard ramp. Thus the postcard surveys, which were limited to automobiles and vans, implied a significant increase in the numbers of carpools and vanpools caused by the introduction of the HOV lane on the Montlake on-ramp. This conclusion was supported by manual vehicle occupancy counts.

Manual Vehicle Occupancy Counts

The data obtained for buses in these counts were not sufficient for analysis. The remaining data indicated a significant decrease in the number of SOVs and significant increases in the number of carpools and vanpools on the Montlake ramp due to the introduction of the HOV lane. The manual counts indicated a slight increase in single-person automobile trips and a corresponding decrease in carpool and vanpool trips on the Lake Washington Boulevard on-ramp, indicating a possible shift in carpool and vanpool trips to the Montlake HOV lane. The main-line SR 520 lanes did not exhibit significant changes in vehicle occupancy.

Volume/Lane Occupancy Results

The time series intervention analyses of volume/lane occupancy data indicated statistically significant improvements in level of service on main-line SR 520 after the ramp controls were introduced. Plots of volume and occupancy for several days' data supported these time series regression results. If a stable effective vehicle length for the before-and-after traffic streams is assumed, the electronic data showed significant improvements in main-line SR 520 speeds.

Travel Time: Floating Car Method

The statistical analysis of several days' travel time data indicated that a net total increase in travel time was experienced by

travelers from UW to the east side (an average of 4.7 min). The average increase in travel time from the point of origin to the ramp merge with the main-line link was 5.0 min. These results and the volume/lane occupancy results indicated that travelers already on the main line experienced a slightly improved travel time, whereas travelers using the ramps were dissuaded from SOV travel and through travel on neighborhood arterials. Travelers using the new HOV lane on the Montlake ramp had a 5-min travel time advantage over SOV travelers.

Ramp Queue Lengths

Plots and statistical tests indicated an increase in queue lengths for the on-ramps after the ramp metering intervention. The increase in queue length was most pronounced for the Lake Washington on-ramp. These queue length increases for SOVs resulted in the desired shifts in route and mode choice. The 5 min saved by HOVs on the Montlake Ramp resulted in a change in the automobile occupancy from 1.3 people/vehicle to 1.5 people/vehicle. This change applied to vans and automobiles only and did not reflect the suspected additional increase in bus occupancy, which was not measurable.

Bus Arrival Times and Electronic Travel Times

The manually collected bus arrival time data did not give conclusive results. Also, the travel time data sample collected electronically by Metro was too small for adequate analysis. However, the observed main-line speed improvements, the 5-min HOV lane time advantage, and the changes that Metro made in the fall 1986 bus schedules to reflect improved travel times (an average of 3 min saved for buses coming from downtown on I-5 and 4 min for buses using the Montlake on-ramp) led to the conclusion that bus travel times were significantly improved due to the ramp metering and the introduction of the HOV lane.

RECOMMENDATIONS

The conclusions just discussed led to the overall final determination that the ramp metering and HOV lane have had the desired results. That is, these TSM techniques have

- improved main-line travel,
- increased the attractiveness of carpools, vanpools, and buses, and
- diverted unwanted traffic coming from other parts of the city into and through the neighborhood.

It is recommended that this type of TSM strategy be used in situations such as the SR 520 case, where main-line volumes are already at or near capacity during the peak hours and where even small volume diversions and volume controls can have a significant impact on main-line LOS.

ACKNOWLEDGMENTS

The research described in this paper was sponsored by the Washington State Department of Transportation. Special thanks

are due to Mark Hallenbeck and Gary Davis, who assisted with the data collections. Davis also assisted with the computer runs.

REFERENCES

1. *Special Report 172: Transportation System Management*. TRB, National Research Council, Washington, D.C., 1977.
2. *Special Report 190: Transportation System Management in 1980—State of the Art and Future Directions*. TRB, National Research Council, Washington, D.C., 1977.
3. *NCHRP Report 81: Experiences in Transportation System Management*. TRB, National Research Council, Washington, D.C., 1981.
4. ITE Technical Council Committee 6A-37. A Summary Report: The Effectiveness of High-Occupancy Vehicle Facilities. *ITE Journal*, Feb. 1988, pp. 17–18.
5. S. A. Ahmed. Urban Freeway Traffic Management Technology. *ASCE Journal of Transportation Engineering*, Volume 112, No. 4, July 1986, pp. 369–379.
6. C. A. Rogers. Effects of Ramp Metering with HOV By-Pass Lanes on Vehicle Occupancy. In *Transportation Research Record 1021*, TRB, National Research Council, Washington, D.C., 1985, pp. 10–15.
7. N. L. Nihan. *Eastbound SR 520: Impacts of Freeway Surveillance and Control*. WSDOT Report WA-RD 99.1, Washington State Department of Transportation, Seattle, 1987.
8. G. A. Davis and N. L. Nihan. Use of Time-Series Designs to Estimate Changes in Freeway Level of Service Despite Missing Data. *Transportation Research*, Vol. 18A, No. 5/6, 1984, pp. 431–438.
9. N. L. Nihan and G. A. Davis. Estimating the Impact of Ramp Control Programs (abridgment). In *Transportation Research Record 957*, TRB, National Research Council, Washington, D.C., 1984, p. 31.
10. N. Levin and Y. Tsao. Forecasting Freeway Occupancies and Volumes (abridgment). In *Transportation Research Record 773*, TRB, National Research Council, Washington, D.C., 1980, pp. 47–49.
11. S. J. Ahmed and A. R. Cook. Application of Time-Series Analysis Techniques to Freeway Incident Detection. In *Transportation Research Record 841*, TRB, National Research Council, Washington, D.C., 1982, pp. 19–21.
12. *Evaluation of the Eastbound SR-520 Traffic Management System*. Summary report. Traffic Systems Management Center, Washington State Department of Transportation, Seattle, 1987.