Evaluating Benefits of Systemwide Adaptive Ramp-Metering Strategy in Portland, Oregon

Soyoung Ahn, Robert L. Bertini, Benjamin Auffray,
June H. Ross, and Oren Eshel

A systemwide adaptive ramp-metering (SWARM) system is being implemented in the Portland, Oregon, metropolitan area, replacing the previous pretimed ramp-metering system. SWARM has been deployed on six major corridors and operates during the morning and afternoon peak hours. This study entails a before and after evaluation of the benefit of the new SWARM system as compared with the pretimed system using the existing data, surveillance, and communications infrastructure. In particular, the objective of this study is to quantify the systemwide benefits in relation to savings in delay, emissions and fuel consumption, and safety improvements on and off the freeway due to the implementation of the SWARM system. A pilot study was conducted for 2 weeks on a 7-mi freeway corridor in an attempt to develop a strategic design for the future regional-level study. This paper discusses the selection process of the study corridor, the experimental design, and the results obtained from the pilot study.

Ramp meters were first implemented in the Portland metropolitan area by the Oregon Department of Transportation (DOT) in January 1981 along a 6-mi stretch of Interstate 5. Portland's original ramp-metering strategy employed a pretimed algorithm that determined the time that the meters were active as well as each ramp's metering rate based on historical patterns. As part of the original ramp-metering deployment, a surveillance system, including inductive loop detectors and closed circuit television (CCTV) systems, is in place. This original ramp-metering strategy was shown to be effective (*1*), and the ramp-metering system was expanded throughout Portland's freeway network. The freeway system in Portland currently consists of 138 metered on-ramps. In May 2005 a systemwide adaptive ramp-metering (SWARM) system began to be implemented in stages in the Portland metropolitan area and is currently operational on six major freeway corridors.

The objective of this research is to use the existing data, surveillance, and communications infrastructure to evaluate the new SWARM ramp-metering system in the Portland metropolitan area as it is being deployed. Although the SWARM system is designed to be more effective than the current ramp-metering strategy, the true benefits of the new system have not yet been quantified. Using an existing data stream and infrastructure, a true before-and-after evaluation of the benefits of the new SWARM system is ongoing. The findings from this study will aid in the optimal deployment of the current SWARM system and will be transferable to other regions in Oregon as their planned ramp-metering systems come online in the future.

This paper describes the experimental design of the pilot study that was conducted on a freeway corridor for 2 weeks in June 2006 and the results that were obtained. The SWARM system was shut off for 1 week and turned back on the following week. During the shutoff period, ramp meters operated at the pretimed rates that were deployed before the SWARM implementation. Data from loop detectors and video data from the CCTV cameras were collected to measure conditions on the freeway main line and the on-ramps.

In the following section, the SWARM algorithm and previous studies relevant to this study are described. The next section presents the experimental design of the pilot study, including the corridor selection process and the data collection efforts. Results from the corridor-level evaluations and the analysis of freeway queue dynamics are described following that. Future work and concluding remarks are provided in the final section.

BACKGROUND

Early ramp-metering systems in the United States were installed as pretimed (or fixed-rate) systems, whereby the activation and deactivation times of the ramp meters and the metering rates throughout the day were predetermined based on the analysis of historical data. This kind of metering strategy was designed to cope with "typical" traffic conditions and was not able to incorporate real-time freeway conditions. Consequently, the effectiveness of the fixed-time system deteriorated substantially with large variations in freeway conditions or when nonrecurrent conditions (e.g., incidents) occurred on freeways. With the enhancement of sensing and communication technology, this strategy has been replaced by more sophisticated algorithms that account for real-time traffic conditions, as is the case in Portland, Oregon.

Traffic-responsive ramp-metering algorithms were developed in an effort to cope with daily fluctuations and nonrecurrent freeway conditions. In these algorithms, metering rates and activation and deactivation times at individual ramps are determined proac-

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S. Ahn, Department of Civil and Environmental Engineering, Arizona State University, P.O. Box 875306, Tempe, AZ 85287-5306. R. L. Bertini, Department of Civil and Environmental Engineering, and O. Eshel, Portland State University, P.O. Box 751, Portland, OR 97207-0751. B. Auffray, L'école nationale des travaux publics d'Etat and Portland State University, P.O. Box 751, Portland, OR 97207-0751. J. H. Ross, Oregon Department of Transportation Research Unit, 200 Hawthorne Street Southeast, Suite B-240, Salem, OR 97301-5192. Corresponding author: S. Ahn, sue.ahn@asu.edu.

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tively in response to real-time freeway conditions along corridors. Many traffic-responsive ramp-metering algorithms have been developed, and some of them have been evaluated for their benefits via field testing [see, e.g., Cambridge Systematics (*2*), Hourdakis and Michalopoulos (*3*), and Levinson et al. (*4*)] or simulations [see, e.g., Zhang et al. (*5*)]. Various traffic-responsive ramp-metering strategies and their test results are described in numerous publications [e.g., Zhang et al. (*5*) and Bogenberger and May (*6*)].

The SWARM system was developed by the National Engineering Technology Corporation under a contract with the California Department of Transportation (Caltrans). The algorithm was first implemented in Orange County (District 12) and later in Los Angeles and Ventura Counties (District 7) in the late 1990s.

In the SWARM strategy (*7*), a freeway network is divided into contiguous freeway systems, whereby each freeway system is bounded by the location of two bottlenecks (identified by loop detectors) and contains multiple on-ramps and off-ramps in between. For each system, there are two "competing" modes of SWARM operation—global and local modes. Two metering rates are computed from the global and local modes, and the more restrictive rate is deployed in the field.

The global mode operates on an entire system based on forecast densities at the system's bottleneck location. The densities around the bottleneck are forecast by performing a linear regression on a set of data collected from the immediate past and applying a Kalman filtering process to capture nonlinearity. A tunable parameter, T_{crit}, is the forecasting time span into the future (labeled in Figure 1), which is usually several minutes. The excess density (also labeled in Figure 1) is then the difference between the forecast density and a predetermined threshold density that represents the saturation level at the bottleneck. This excess density is converted to the (current) required density to avoid congestion in T_{crit}; that is,

$$\text{required density} = \text{current density} - \left(\text{excess density}/T_{\text{crit}}\right)$$

The corresponding volume reduction at each detector station is computed as

$$\text{volume reduction} = \left(\text{local density} - \text{required density}\right) * \left(\text{no. of lanes}\right) * \left(\text{distance to next station}\right)$$

The volume reduction (or excess if local density is smaller than the required density) is distributed to upstream on-ramps in the system according to distribution (or weighting) factors predetermined on the basis of demand, queue storage, and other relevant features of each on-ramp.

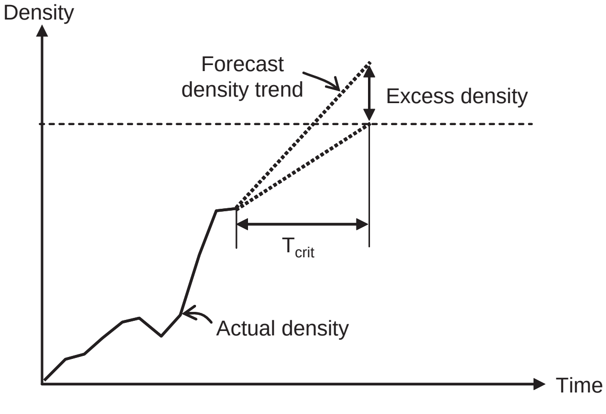


FIGURE 1 Forecasting theory of SWARM global mode.

The local mode operates with respect to (real-time) local traffic conditions near each ramp. The local metering system can be any existing local traffic-responsive algorithm.

SWARM has a built-in capability to clean the defective data in case of loop detector failures, which improves the robustness of the algorithm. With this feature and accurate prediction models, SWARM is able to accurately detect and avoid potential congestion in advance. However, if the prediction models are poor or if supporting loop detector data are not accurate, it can generate limited benefits (*5*).

SWARM was implemented in parts of southern California and is expected to be deployed on most of California's freeway network (*8*). The SWARM system implemented in Orange County could not be evaluated for a number of reasons. MacCarley et al. (*9*) noted that Caltrans did not receive proper training or documentation related to SWARM operations. Moreover, the algorithm itself did not appear to operate properly when tested in the field for 6 weeks.

The implementation and evaluation of SWARM was more successful in Los Angeles and Ventura Counties, California. There are more than 1,200 ramp meters in that network. Before implementation of the SWARM system, Caltrans District 7 operated pretimed and local traffic-responsive ramp metering throughout its freeway network in Los Angeles and Ventura Counties. The benefits of the new SWARM algorithm as compared with the previous ramp-metering operations were evaluated during the morning peak periods on a freeway corridor (westbound Route 210) that contains 20 controlled on-ramps [detailed descriptions of the evaluation methods and results are included in Pham et al. (*10*)]. Caltrans tested three operational strategies: global mode only, local mode only, and a combined strategy. Each strategy was evaluated for several days between September 2001 and January 2002.

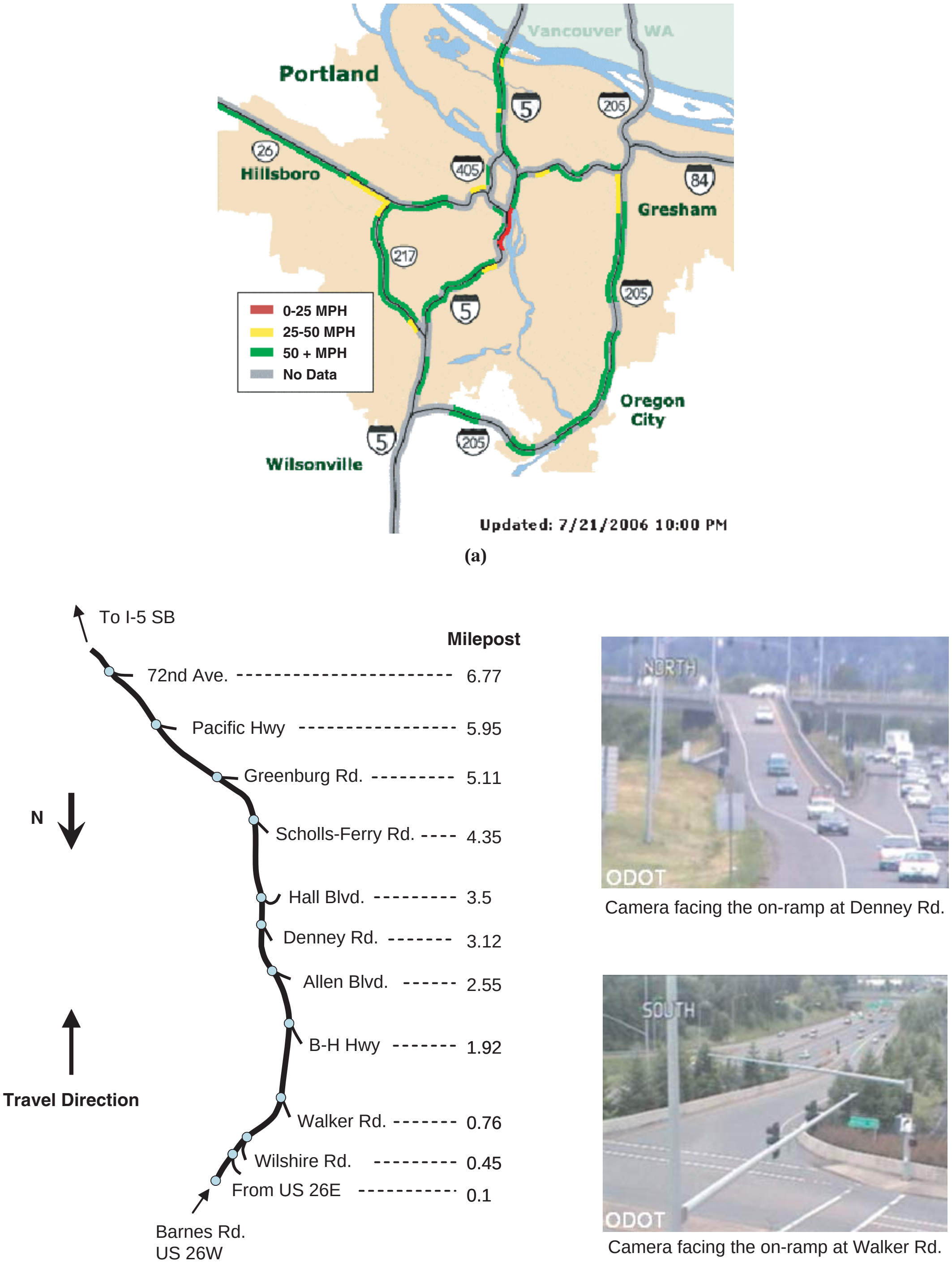
Caltrans found that the combined strategy generated the most benefits in regard to traffic conditions on the main-line freeway. In particular, it increased the main-line speed by 11% during the morning peak hour, decreased the travel time by 14%, and reduced the freeway delay by 17%. Furthermore, the queue lengths at the nine busiest on-ramps increased by more than 40%.

EXPERIMENTAL DESIGN

The freeway system in the Portland metropolitan region (see Figure 2*a*) consists of several Interstate and U.S. highways and state routes, serving local commuters, through traffic, as well as freight trucks from and to the Portland International Airport and the ports of Portland. A number of freeways exhibit recurrent congestion during the morning and afternoon peak periods, and the on-ramps on these major freeways are metered during the peak hours (e.g., 6–10 a.m. and 1–7 p.m.). There are seven major freeway corridors on which the Oregon DOT manages traffic congestion via ramp metering. The SWARM system has been implemented on six of these corridors in stages since May 2005.

Freeway Corridor Selection Criteria

The aim of the pilot study described here was to conduct a shutoff experiment of the SWARM operation for a short duration and develop a strategic design for a future regional-level evaluation. For that pur-



Camera facing the on-ramp at Denney Rd.

Camera facing the on-ramp at Walker Rd.

(b)

FIGURE 2 Portland metropolitan area: (*a*) freeway network and (*b*) schematic of OR-217 southbound with sample CCTV camera views.

pose, the following criteria were developed to select a corridor that can most likely achieve the current objective:

1. Level of congestion. Duration and spatial extent of congestion should be reasonably large (i.e., no localized queues). That allows for an assessment of SWARM performance while the global control interacts with the local controls at multiple on-ramps.

2. Spatial extent of queues. Queue(s) should be isolated within a corridor; that is, the location of a recurrent bottleneck (the head of a queue) and the tail of the resulting queue should reside in the same corridor. This ensures a comprehensive evaluation on a single freeway corridor without having to evaluate other intersecting freeways simultaneously. That facilitates more manageable allocation of resources and data collection efforts.

3. Loop detector spacing. The spacing between loop detectors should be reasonably small so that the data from loop detectors reflect actual conditions prevailing on the freeways as closely as possible.
4. Data quality. The pilot study involves shutting off the SWARM system for a short duration. During this period, it is imperative not to experience communication failures for extended periods between the loop detectors and the traffic management operations center (TMOC). In addition, the accuracy of evaluation results will depend on the accuracy of loop detector data received. The recent history of data quality at all corridors was taken into consideration.
5. Construction schedule. Construction on several corridors is ongoing or scheduled for the near future. The construction schedules were taken into consideration in selecting a corridor and scheduling the pilot study.
6. Stability of the SWARM system. The SWARM system implemented in the field should be stable; that is, all ramp meters should be working properly and the actual metering rates deployed should match the theoretical rates determined from the SWARM algorithm.
7. Corridor length and number of on-ramps. The length of freeway and the number of on-ramps were considered to make sure that the pilot study can be conducted in a manageable way in regard to time and resources. In general, a 5- to 10-mi corridor was considered to be manageable for the pilot study.

The feasibility of analyzing alternative routes was also considered to measure traffic diversion and its effect on alternative routes. However, this criterion was not incorporated at the final stage of selecting a corridor because (*a*) identifying all possible alternative routes would be difficult and (*b*) extensive data collection efforts will be required even for a small number of routes, which may not be feasible in regard to resources and cost allocation.

The existence of a high-occupancy-vehicle lane and transit service was also considered because the change in ramp-metering operation can affect their demand. However, it was believed that the change in demand in the short term would be negligible.

Study Corridor: Freeway

OR-217 southbound was determined to be most suitable for the pilot study in regard to congestion patterns, coverage of loop detectors, and data quality. OR-217 southbound is a 7-mi corridor that serves commuters during peak periods between downtown Portland and suburban areas in Beaverton, Tigard, and Lake Oswego, among others. It diverges from US-26; intersects with Highways 8 (Canyon Road), 10 (Beaverton–Hillsdale Highway), 210 (Scholls-Ferry Road), and 99W (Pacific Highway); and finally merges onto I-5 southbound (see Figure 2*b*).

This freeway corridor contains 12 on-ramps, 10 of which are controlled by ramp meters. The ramp-metering system on this freeway is supported by 36 loop detectors and nine CCTV cameras. Loop detectors are located 0.75 mi apart, on average (minimum of 0.31 mi and maximum of 1.23 mi). SWARM was implemented on this corridor in early November 2005.

Figures 3*a* and 3*b* show two speed contour plots that were constructed from the average readings taken for 1 month before the SWARM implementation and 1 month after the implementation. The vertical axis in each figure represents distance along the freeway as marked by a milepost, and the horizontal axis corresponds to time of day. The gray scale represents average speeds over 5 min as estimated from loop detector readings, and the ranges of speeds and the corresponding colors are provided on the right side of each figure. The extent of congestion is illustrated by the dark time–space region corresponding to low average speeds.

Typically, queues form on this corridor during each morning and afternoon peak period. In the morning peak period, a recurrent bottleneck is located between Scholls-Ferry Road and Greenburg Road, and the resulting queue propagates over 4–5 mi upstream. The bottleneck activates as a result of a large inflow from the on-ramp at Scholls-Ferry Road and remains active for several hours (7 a.m.–9 a.m.). During this period, traffic speeds can drop as low as 20–30 mph along some portions of the freeway (e.g., near Beaverton–Hillsdale Highway).

During the afternoon peak, a queue forms between Denney Road and Allen Boulevard and propagates several miles upstream (often to Barnes Road). However, a queue from this active bottleneck is often overridden by another queue that forms on I-5 southbound and spills over to OR-217 southbound. Typically, the duration of congestion is longer in the afternoon, and the condition can become severe (especially when the queue from I-5 southbound reaches this corridor), such that traffic speeds can fall below 20 mph for extended periods.

On the basis of the observed congestion patterns, data collection and analysis were focused on the morning peak periods, in which a systemwide evaluation is possible in the corridor.

Study Corridor: On-Ramps

On the study corridor, there are 12 on-ramps serving traffic from the local areas and from other highways (Highways 10, 8, 210, and 99W). For each of these on-ramps, volumes during the peak hours and the queue storage space (in feet) were measured to assess whether on-ramp traffic is adequately accommodated without causing additional delays to local traffic during the peak period. In particular, the average hourly volume during each peak was computed on the basis of the total peak-hour volume. The queue storage space was provided by the Oregon DOT. The number of lanes on the ramp was taken into consideration in estimating the storage space.

The bar chart in Figure 4 corresponds to average hourly volumes during the morning peak (6–9 a.m.), and the line chart shows storage spaces. The average hourly volumes were measured from the data taken from April 3 to April 7, 2006, which were the most recent weekdays at the time of analysis. The traffic conditions on these days were typical for this corridor. (There are 10 on-ramps in this plot; the freeway connector from US-26E to OR-217 and the on-ramp at Barnes Road are not depicted. The data for the freeway-to-freeway connector were not available because the ramp is not controlled. Data at the Barnes Road on-ramp are available but were omitted in this analysis because the ramp is located where the freeway begins and is regarded more as part of the main line.)

The figure shows that the on-ramps at Beaverton–Hillsdale Highway and Scholls-Ferry Road carried more than 700 vehicles per hour (vph), on average, from 6–9 a.m. The volume at these two ramps was nearly twice the volume at the other on-ramps. The figure also illustrates which on-ramps are at risk of queue spillover to local streets during the peak hours. It appears that the on-ramp at Allen Boulevard is at the highest risk compared with the other on-ramps. (72nd Avenue is located downstream from the recurrent bottleneck and, hence, is unlikely to experience a queue spillover.) On the basis of these preliminary observations, the on-ramps at Beaverton–Hillsdale Highway, Scholls-Ferry Road, and Allen Boulevard were given prior-

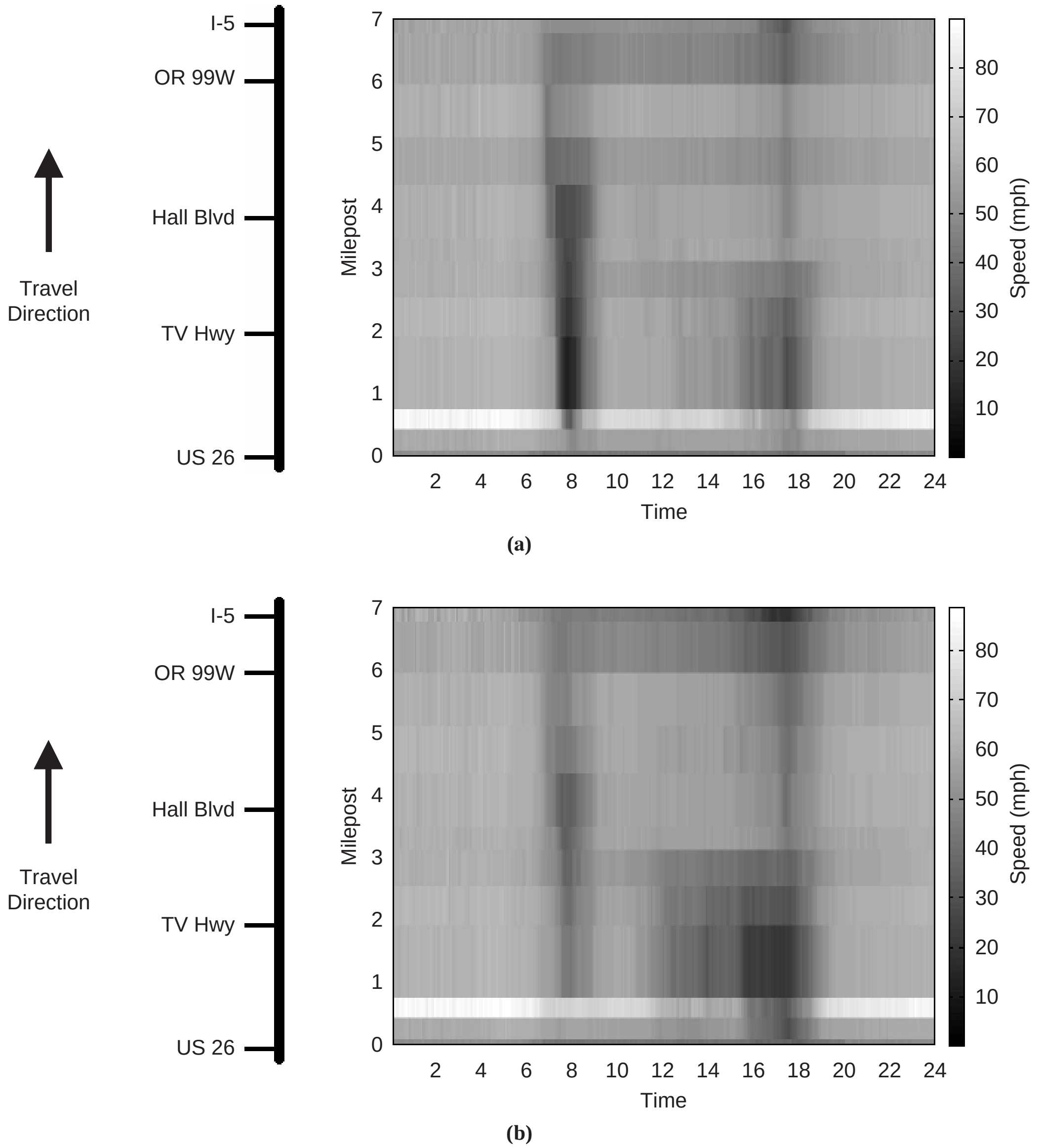


FIGURE 3 **Speed contour for (*a*) OR-217 southbound, pretimed, weekdays in October 2005 and (*b*) OR-217 southbound, SWARM, weekdays in December 2005.**

ity in the video data collection plan so that delays on these on-ramps as well as queue length can be analyzed adequately.

Data Collection Efforts

Data collection for the pilot study was conducted for 2 weeks in June 2006. The SWARM system was turned off from June 19 to June 23 to obtain necessary before data, and the ramp meters were operated on the basis of the historical pretimed rates instead. SWARM was back in operation on June 26, and after data were collected during the same week (from June 26 to June 30).

Changes in freeway conditions were measured in regard to flow, speed, travel time, delay, vehicle miles traveled (VMT), and vehicle hours traveled (VHT). All these measures were obtained directly or estimated from the data acquired from the loop detectors. On OR-217 southbound, there are 36 loop detectors including the ones at the metered on-ramps. These detectors are maintained by Oregon DOT and produce vehicle count, occupancy, and estimated speed at a sampling interval of 20 s. (The detectors at the on-ramps produce vehicle counts only.)

These 20-s data are archived in the Portland Oregon Regional Transportation Archive Listing (PORTAL, portal.its.pdx.edu) along with other types of data (e.g., weather data). In addition to SWARM's built-in data quality control process, a sample of loop detector data was further tested for accuracy in March 2006. The aim was to assess the performance of loop detectors on OR-217 southbound and make recommendations on which loop detectors need immediate attention for repair, adjustment, and so on. Individual 20-s readings from loop detectors were flagged if they failed any of the tests listed below:

- Volume > 17 (≈3,060 vph),
- Occupancy > 95%,
- Speed > 100 mph,

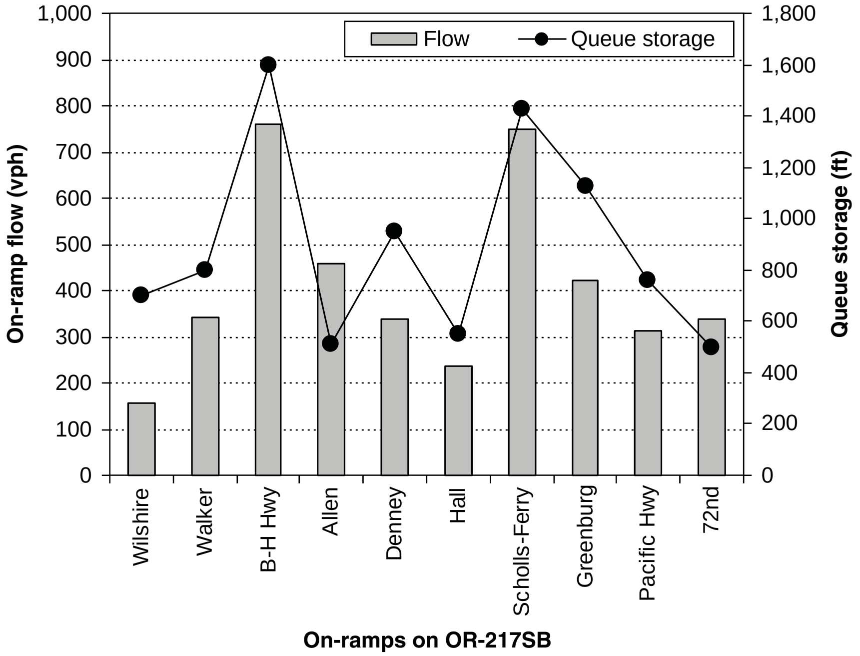


FIGURE 4 Average hourly volumes versus on-ramp queue storage (6–9 a.m.).

- Speed < 5 mph,
- Speed = 0 when volume > 0,
- Speed > 0 when volume = 0, and
- Occupancy > 0 when volume = 0.

These tests detect physically invalid readings (e.g., volume = 0 and speed > 0) or readings that correspond to unlikely events (speed > 100 mph in 20 s).

The percentage of readings that failed each listed test category was determined. The majority of the loop detectors on OR-217 southbound (of 36 loop detectors) showed a low percentage (less than 5%) of failed readings except for (*a*) the left lane at Walker Road, where 18% of the speed readings exceeded 100 mph, and (*b*) the left and center lanes at 72nd Avenue, where 10% and 7% of the speed readings were less than 5 mph, respectively. Although these speed readings are physically valid, it is highly unlikely that such large percentages of readings would display those extreme values. Defective 20-s readings and missing readings were replaced with the values that were interpolated using the closest neighboring readings in time.

For the on-ramps, suitable data collection tools were allocated to measure the metering rates and demand at each on-ramp. The merge loop detectors at the on-ramps provide necessary data to measure the metering rates under two different operations. However, the demands were measured from road tubes and CCTV cameras because the current queue loops at the entrances to the ramps are not currently configured to transmit their data (count, occupancy, and speed) to TMOC.

RESULTS

During the data collection period for the pilot study, there were no adverse weather conditions that could potentially affect driving behavior. However, there were significant incidents on June 21 and June 30 during the morning peak hours, which resulted in unusual traffic patterns. The data from these 2 days were excluded in the comparative analysis. Thus, the data from 8 days (4 days each under the pretimed and the SWARM operations) were analyzed to make recommendations for the future regional-level study and to report some preliminary findings.

This section presents results of the evaluation of freeway conditions before and after the SWARM implementation. As a first step, the quality of the loop detector data was investigated to ensure that there was no significant change in quality during the study period. Then, some basic performance measures such as VMT, VHT, and total delay were computed and compared.

One of the major concerns with implementing the SWARM system (or any sophisticated traffic-responsive systems) is communication failures between loop detector stations and the traffic management center, because the performance of SWARM depends largely on the availability of accurate data. To compute metering rates in response to real-time traffic conditions, the SWARM algorithm requires a great deal of data from multiple freeway locations and on-ramps. A large number of (simultaneous) data streams can cause communication failures and loss of data if the communication network is not established to accommodate them.

Figure 5 was constructed by computing the percentage of 20-s readings that corresponded to communication failures during the morning peak hours (6–9 a.m.) under the pretimed ramp metering (white bars) and the SWARM operations (shaded bars). The figure shows that the percentage of communication failures was below 2% at most locations with the pretimed strategy, whereas the percentages under SWARM were much larger. At some freeway locations, such as near Walker Road and B-H Highway, the communication failures exceeded 10%. [At 72nd Avenue the percentage of communication failures was larger than 60% (64% for pretimed and 69% for SWARM); this indicates that other factors might be causing the communication failures at the location.] The missing data due to communication failures were replaced with interpolated values for further analysis.

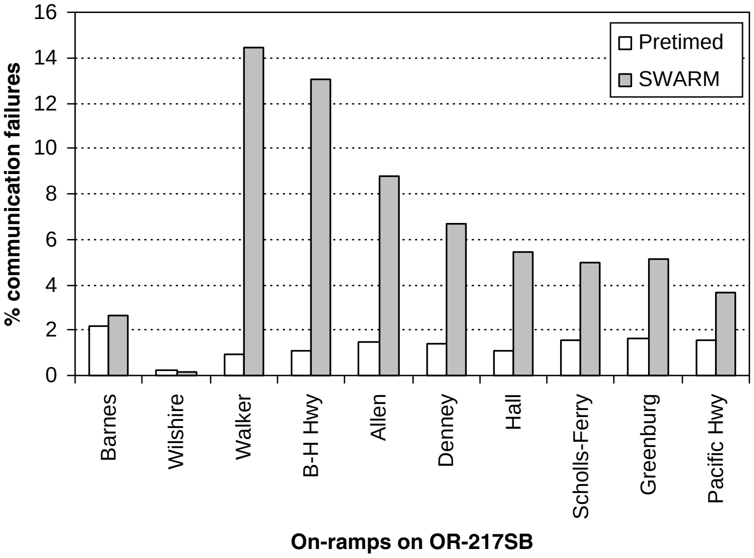


FIGURE 5 Percent communication failures under SWARM versus pretimed.

Table 1 summarizes the basic measures computed from the loop detector data from 6 to 9 a.m. This time window was just large enough to capture the morning congestion during the 2 study weeks. It shows that the VMT increased marginally (0.8%) under the SWARM operation; the increase indicates that the morning demand for this freeway corridor remained nearly independent of the ramp-metering control deployed in the field (at least for the short term). However, surprisingly, the VHT and the average travel time increased by 6.0% and 5.1%, respectively, under SWARM, corresponding to a significant increase of 34.7% in total freeway delay.

In an attempt to understand the reason for this increase, the temporal and spatial changes in freeway delay were plotted as shown in Figure 6. The darker time–space regions correspond to the increases in delay under SWARM, as indicated by the gray scale on the right side of the figure. The figure illustrates that most increases were observed between 6:30 and 8:30 a.m.

The increase in freeway delay with the SWARM operation is attributable to either higher metering rates at the on-ramps or diminished flow through the bottleneck (i.e., bottleneck discharge rate). Unfortunately, the latter could not be verified because the bottleneck discharge rate cannot be estimated solely from the current configuration of the loop detectors. However, higher metering rates appear to play a role in the increase in the freeway delay, as illustrated in Figure 7. The figure shows the cumulative vehicle counts at all on-ramps, *N,* plotted on an oblique time axis. In other words, the curves shown in the figure correspond to the quantities, $N - q_0 * (t - t_0)$, where q_0 is a background flow (3,600 vph in this case), t is time, and t_0 is the start time (6:30 a.m. in this case). This data processing technique was used to better reveal the changes in traffic states (i.e., flows) over time, as described in detail in numerous references [e.g., Cassidy and Windover (*11*) and Munoz and Daganzo (*12*)]. Figure 7 shows that the cumulative curve for SWARM (squares) lies above that for the pretimed (shaded circles) strategy, and the vertical separation between the two curves increases over time. This indicates that the SWARM strategy consistently admitted higher flows to the freeway throughout the 2-h morning peak period.

Figure 8 displays the on-ramp flows at the meters between 6:30 and 8:30 a.m. under the pretimed (white bars) and SWARM (shaded bars) operation. It shows that the flows were slightly larger at most on-ramps when SWARM was in operation. The increases in flow (except at Hall Boulevard) ranged between 3% and 9%. These moderate increases in flow resulted in decreases in travel time on the ramps, as indicated in Figures 9*a* and 9*b.* For these figures, vehicle travel times were sampled once every 5 min at Beaverton–Hillsdale Highway and Scholls-Ferry Road on-ramps. Both of these figures show that travel times on the on-ramps were lower in general with SWARM. Assuming that each travel time is a good representative of travel times during the preceding 5-min period, the overall decreases in travel time were 23% at the Beaverton–Hillsdale Highway on-ramp and 37% at the Scholls-Ferry Road on-ramp (large percent decreases in travel time are not surprising because travel times on these two on-ramps are less than 2 min).

TABLE 1 Summary of Evaluation Results of Main-Line Freeway

	VMT	VHT	Travel Time	Delay (vehicle hours)
Pretimed	65,871	1,337	8.8	210
SWARM	66,426	1,416	9.2	283
% Change	0.8	6.0	5.1	34.7

CONCLUSION

This paper described the experimental design to evaluate the benefit of the SWARM strategy compared with the pretimed metering strategies. In designing the study, the freeway corridor for the pilot study was carefully selected on the basis of a number of criteria that were developed, taking into consideration the congestion patterns and the feasibility in regard to resource allocation. For the selected corridor, data quality and on-ramp conditions were further investigated to determine a data collection plan that conformed to the objective, given the resources available.

The pilot study was conducted for 2 weeks, and the changes in freeway conditions were reported. It was found that the VMT exhibited a

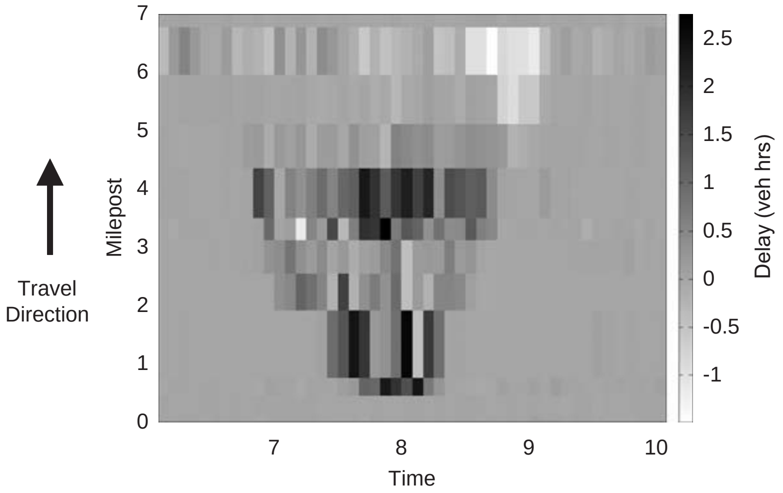


FIGURE 6 Changes in delay under SWARM in time–space plane.

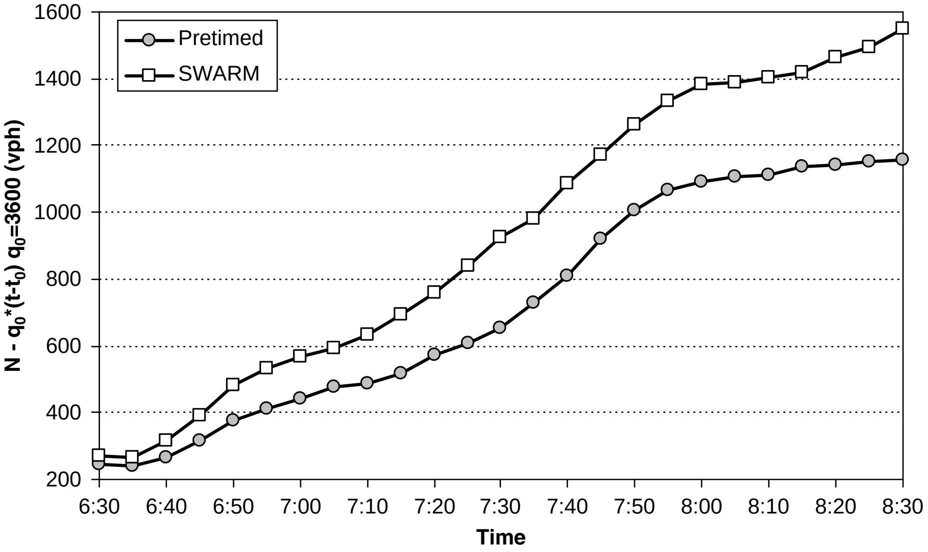


FIGURE 7 Cumulative on-ramp vehicle counts.

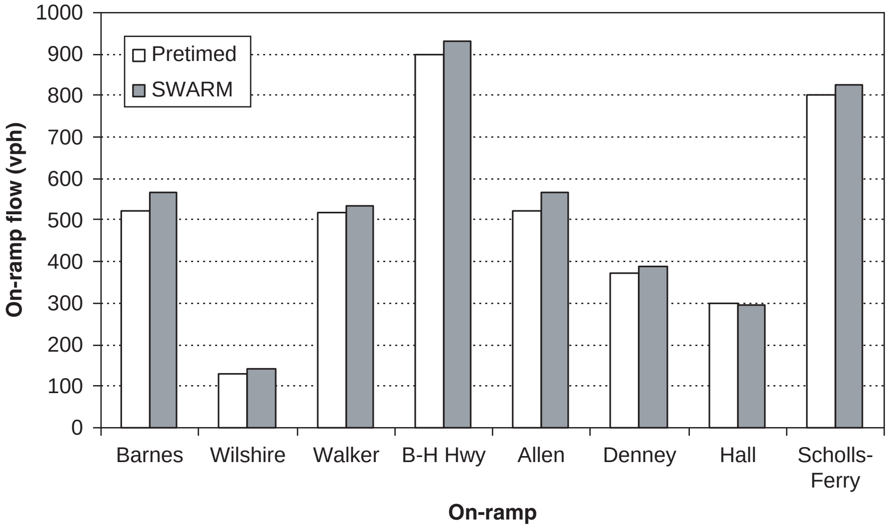


FIGURE 8 On-ramp volumes between 6:30 a.m. and 8:30 a.m.

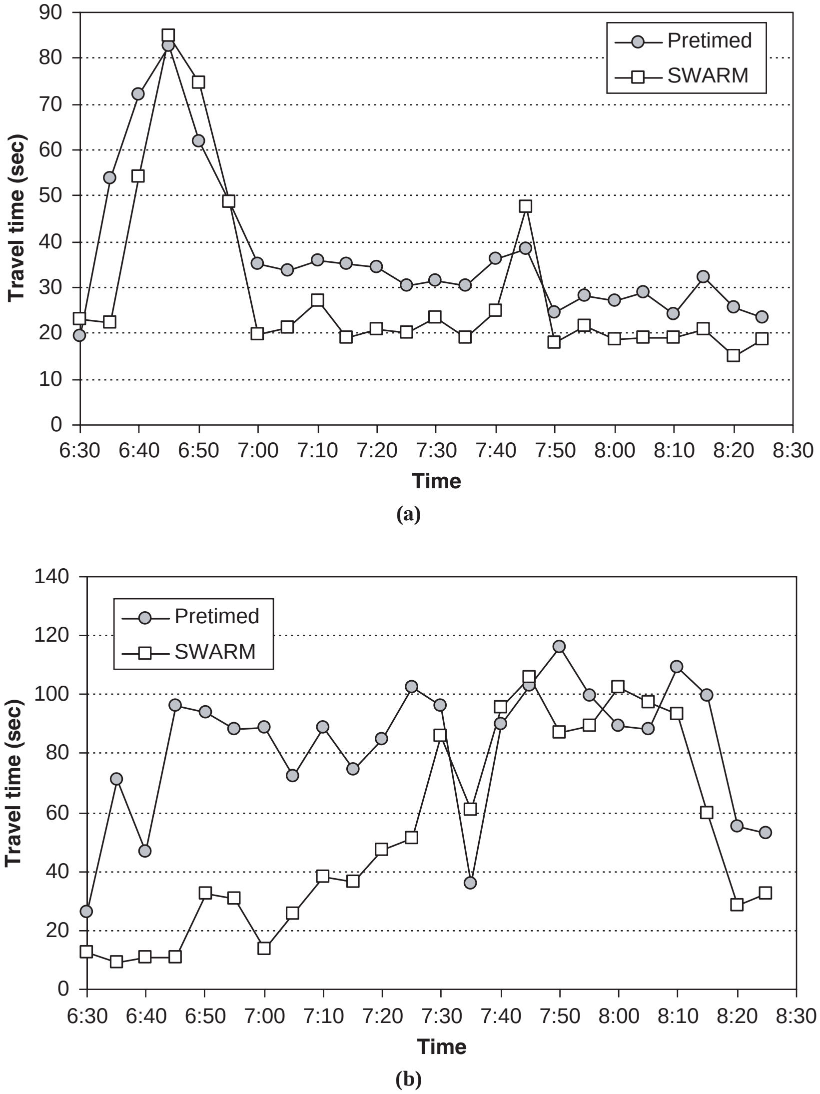


FIGURE 9 Travel time on (*a*) Beaverton–Hillsdale Highway on-ramp and (*b*) Scholls-Ferry Road on-ramp.

marginal increase under the SWARM operation. However, the total delay on the freeway increased with SWARM, and empirical evidence suggests that this increase resulted from higher metering rates at most of the on-ramps. These higher metering rates under SWARM resulted in lower travel times on several major on-ramps, which indicates that the increase in freeway delay was traded for lower on-ramp delays. However, whether the increase in the total freeway delay was caused solely by the higher merging rates remains an open question because the bottleneck discharge rate could not be measured from the data. Moreover, delays could not be quantified at all on-ramps because of the limitations on data collection efforts, and hence it was not feasible to analyze the systemwide trade-offs between the freeway and on-ramp delays.

The lessons learned from the pilot study are being incorporated in designing the regional-level study, and the results of this research will help Oregon DOT fine-tune the deployment of the SWARM system and in reporting its benefits to decision makers and the public. These results will be transferable to other regions, states, and countries in the future.

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