Developing Segmentwide Traffic-Responsive Freeway Entry Control

SUK JUNE KAHNG, CHAWN-YAW JENG, JAMES F. CAMPBELL, and ADOLF D. MAY

ABSTRACT

As part of a Highway Planning and Research project two types of segmentwide traffic-responsive freeway entry control strategies were developed: extended local traffic-responsive control and extended pretimed traffic-responsive control. These strategies were evaluated on a macroscopic dynamic freeway corridor simulation model by using 3 days of traffic data from the Santa Monica Freeway in Los Angeles. Extended local traffic-responsive control had a consistent advantage over extended pretimed traffic-responsive control. Based on the evaluation the extended local traffic-responsive control strategy has been selected for further evaluation and future field implementation on a segment of the Santa Monica Freeway. The development and evaluation of the segmentwide traffic-responsive control strategies are described. A brief description of implementation plans is also included.

Since its appearance in the early 1960s (1-6), freeway entry control, or ramp metering, has become a vital tool for transportation engineers to improve freeway operation. During the past two decades a number of different freeway entry control strategies have been developed and implemented (7-9). They may be classified into the following three categories: pretimed (10-15), local traffic-responsive control (16-21), and segmentwide traffic-responsive control (22-25).

Although much research and implementation has taken place in the first two categories, not as much experience has been acquired in the third. Recognition of this fact, coupled with anticipated advancements in computers and communication technology, identifies research needs with segmentwide traffic-responsive control.

Based on these observations, a freeway research study is being conducted at the Institute of Transportation Studies (ITS), University of California, Berkeley. Major objectives of the research include development of segmentwide traffic-responsive control strategies, field implementation and evaluation of the most promising strategy, and preparation of preliminary guidelines for segmentwide traffic-responsive control.

The purpose of this paper is to discuss current findings and results of the research (26), which are (a) development of the extended freeway corridor model FRECON2, (b) development of two types of segmentwide traffic-responsive control strategies, and (c) evaluation of these control strategies through simulation by using 3 days of traffic data from the Santa Monica Freeway in Los Angeles. A brief discussion of the field implementation plan is also included.

FREEWAY CORRIDOR SIMULATION MODEL: FRECON2

The iterative nature of control strategy development (i.e., strategy formulation, testing, evaluation, modification) requires a reliable freeway corridor simulation model. Desirable attributes of the model for this study include simulating the freeway dynamically, generating point-detector surveillance data, modeling priority entry control, modeling alternative surface streets, and modeling driver's spatial diversion phenomena.

Because no single existing freeway simulation model contains all the attributes required by this study, an existing simulation model was extended for the purpose of the study. The selected model (FRECON) is a macroscopic dynamic freeway simulation model developed by Babcock during a previous study at ITS (9). FRECON evolved from FREFLO, which was developed by Payne (27). Major features of FRECON that distinguish it from FREFLO include

1. An adaptive module that internally determines proper spatial and temporal step sizes to solve the model's discrete freeway state equations; this eliminates the deficiencies of FREFLO when it was applied to a lane-drop bottleneck (28); and
2. The ability to generate surveillance traffic data from emulated point detectors rather than using subsection average traffic performance for surveillance data as in FREFLO.

For the purpose of this study, the FRECON model was further extended into a freeway corridor model, FRECON2 (26). Three major areas of extension of the model include the modeling of priority entry control, alternative surface streets, and driver's spatial diversion. These additional features are briefly described in the following subsections.

Priority Entry Control

There exist three types of freeway entry control distinguished by the entry preference, based on passenger occupancy, given to vehicles at on-ramps (29): normal entry control (NEC), priority entry control (PEC), and no control (NC).

In NEC all the vehicles wishing to enter the freeway are metered by the signal at the on-ramp. In PEC a preset passenger occupancy cut-off value (PCV) is used to divide vehicles coming to the on-ramp into two groups: high-occupancy vehicles (HOVs) and non-HOVs. HOVs are permitted to enter the freeway without delay at the signal, whereas non-HOVs must wait at the signal. In NC all the vehicles are free to enter the freeway without delay, regardless of their passenger occupancies.

Based on these observations, FRECON2 uses a generalized priority entry control concept. NEC and NC are regarded as special cases of PEC. Suppose m is the highest passenger occupancy found among vehicles approaching an on-ramp. Then NEC is equivalent to PEC, with PCV = m + 1. NC is the same as PEC with PCV = 1, where all the vehicles are regarded as HOVs. With this generalized concept of PEC, FRECON2 can model a study section with mixed mode entry control (i.e., a study section with NEC, PEC, or NC).

Driver's Spatial Diversion

Inducing the proper amount of diversion without adversely affecting alternative routes is important for successful ramp metering. By using the diversion formula given in Equation 1, FRECON2 predicts the magnitude of diversion caused by freeway entry control. In the formula the two major factors that influence driver's diversion were chosen to be the percentage travel time difference between the freeway and alternative route (RATIO) and the driver's sensitivity (S):

$$FDIV = (1/2)\left(1 + \sin\left\{\pi[RATIO^s - (1/2)]\right\}\right) \quad (1)$$

where

- FDIV = fraction of queued vehicles at an on-ramp that divert to the available alternative routes (i.e., percentage diversion);
- RATIO = ratio of ΔT to FT + RD (i.e., percentage travel time difference);
- S = driver's sensitivity to the travel time difference between freeway and alternative routes;
- ΔT = FT + RD − AT; if $\Delta T < 0$, ΔT is set to 0;
- FT = freeway travel time;
- RD = delay at on-ramp; and
- AT = alternative route travel time.

Based on the diversion formula given in Equation 1, Figure 1 shows a sample relationship between percentage travel time difference (RATIO) and percentage diversion (FDIV) for varying values of driver's sensitivity (S).

Alternative Surface Streets

The major purpose of including an arterial model in FRECON2 is to evaluate (or predict) the potential impact of diverted vehicles on the alternative surface streets. This requires a surface street model that allows travel time to increase as traffic volume increases. The selected model is the Davidson model, which has been used in the FREQ series (29). In the Davidson model the travel time along a section of an arterial is estimated as a function of free flow travel time and flow/capacity ratios, as shown in Equation 2:

$$t = t_0 \cdot \left\{1 + J \cdot [(q/c)/(1 - q/c)\right\} \quad (2)$$

where

- t = section travel time,
- t_0 = section travel time at free flow speed,
- J = Davidson parameter,
- q = traffic flow (vehicles per hour), and
- c = arterial (or road) capacity (vehicles per hour).

Because of the inherent differences of the freeway model in FRECON and the Davidson arterial model (i.e., the former is a dynamic model whereas the latter is a static one), some consideration should be given to the use of different evaluation intervals for freeway and alternative routes. In FRECON2 the freeway evaluation interval is user supplied with almost no restriction. However, the arterial evaluation interval is internally determined to be the shortest possible interval that still gives enough time for the diverted vehicles to travel to their destination.

SEGMENTWIDE TRAFFIC-RESPONSIVE CONTROL STRATEGIES

To develop implementable (or feasible) segmentwide control strategies, in terms of available hardware and computing capability, the current study was directed toward the development of the following two types of control strategies (26): extended local traffic-responsive (ELT) control and extended pretimed traffic-responsive (EPT) control. These two strategies were then tested on the FRECON2 model by using 3 days of traffic data from the Santa Monica Freeway in Los Angeles. An overview of the strategies is given first, followed by the results of evaluation through simulation.

ELT Control Strategy

The ELT freeway entry control strategy has evolved from local traffic-responsive (LT) freeway entry control. The major difference between them is that the ELT control has an extended view of the freeway, so that each on-ramp controller is aware of, and reacts to, the changing traffic situation at its neighboring on-ramps.

Figure 2 shows an overview of the ELT control scheme. In the ELT control on-line traffic information is collected from detectors on both the freeway main line and the on-ramps and off-ramps. Micropro-

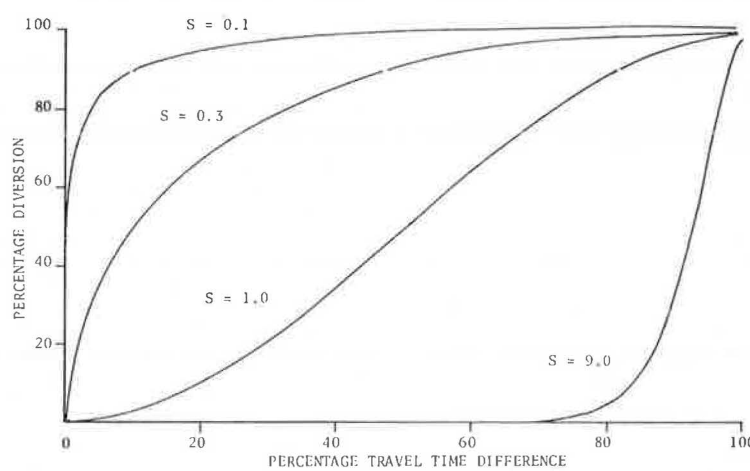


FIGURE 1 Relationship between percentage travel time difference (RATIO) and percentage diversion (FDIV) for different driver sensitivity values (S).

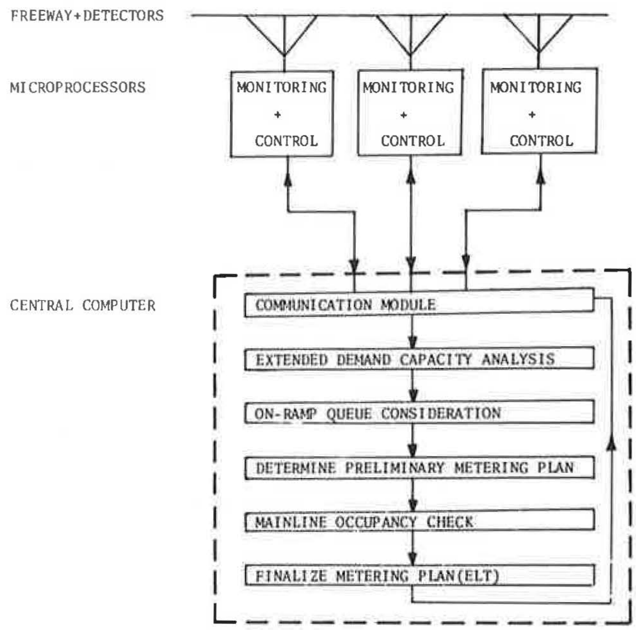


FIGURE 2 Overview of ELT control strategy.

cessor-based controllers (e.g., 170-type controller) located near the on-ramps transmit this information to the central computer.

Based on the real-time traffic data, ELT control determines the metering rates for each on-ramp to operate freeway bottlenecks at capacity while preventing main-line congestion and giving due consideration to on-ramp queues. To accomplish this purpose the ELT control uses the following five major steps: extended demand capacity analysis, on-ramp queue consideration, determination of preliminary metering plan, main-line occupancy check, and finalize metering plan.

Step 1: Extended Demand Capacity Analysis

For each control period t, once the central computer receives on-line traffic information from the microprocessor, extended demand capacity analysis estimates the effective downstream main-line capacity of each on-ramp i. The effective downstream main-line capacity of on-ramp i at time t, EDC(i,t), is defined as the minimum capacity available at time t between on-ramp i and the next downstream on-ramp i + 1 (including the section containing the on-ramp i + 1). This considers not only off-ramp flows between the on-ramps but also the minimum metering rate constraint of on-ramp i + 1.

The outcome of the first step is EDC(1,t), ..., EDC(n,t), where n is the number of on-ramps in the freeway segment.

Step 2: On-Ramp Queue Consideration

To balance out the queue length at each on-ramp, on-ramp i is allowed to ask for help from the upstream on-ramp i - 1 (i.e., on-ramp i can request on-ramp i - 1 to reduce its ramp metering rate). However, in the field the exact queue length at the on-ramp is not usually available to the controller once the queue grows beyond the queue detector. Thus the amount of help asked by on-ramp i from upstream on-ramp i - 1 is based on the following formula:

$$HELPQ(i,t) = A \cdot [ONVMAX(i) - ONVOLR(i,t)] + B \qquad (3)$$

where

A = user-supplied design parameter (currently, A = 0.9 is used),
B = user-supplied design parameter (currently, B = 300 is used for a single lane on-ramp),
ONVMAX(i) = maximum metering rate at on-ramp i,
ONVOLR(i,t) = metering rate at the on-ramp i during control period t, and
HELPQ(i,t) = reduction in the metering rate of upstream on-ramp i - 1 requested by on-ramp i at control period t.

The outcome of the second step is HELPQ(1,t), ..., HELPQ(n,t).

Step 3: Determination of Preliminary Metering Plan

Effective downstream main-line capacities of each on-ramp i, EDC(i,t), calculated in the first step are reduced by the amount of HELPQ(i + 1,t) requested by downstream on-ramp i + 1. Then the preliminary metering rate of on-ramp i for the next control period t + 1 is set as the difference between the reduced effective downstream capacity and the on-line measured main-line traffic flow upstream of on-ramp i:

$$PMR(i,t+1) = [EDC(i,t) - HELPQ(i+1,t)] - MF(i,t) \qquad (4)$$

where PMR(i,t + 1) is the preliminary metering rate for on-ramp i during the next control period t + 1, and MF(i,t) is the on-line measured main-line flow immediately upstream of on-ramp i during control period t.

The outcome of the third step is PMR(1,t + 1), ..., PMR(n,t + 1).

Step 4: Main-Line Occupancy Check

The main-line occupancy check is used as a feedback mechanism in the ELT control. This operates on two levels. The first level compares each on-ramp's upstream main-line occupancy against the preset critical occupancy value. If this comparison indicates that the detector occupancy upstream of on-ramp i is greater than the critical occupancy associated with the location, the PMR(i,t) is reduced to the minimum metering rate for on-ramp i. Otherwise the PMR(i,t) remains unchanged. The second level of occupancy checking allows on-ramp i to request help from upstream on-ramp i - 1, in terms of a reduction in the metering rate of on-ramp i - 1, if the main-line occupancy problems at on-ramp i persist for more than a user-specified number of control periods. Then the PMR(i - 1, t + 1) is reduced to the minimum metering rate for on-ramp i - 1.

The outcome of the fourth step is revised PMR(1,t + 1), ..., PMR(n,t + 1), if necessary.

Step 5: Finalize Metering Plan

The revised preliminary metering rates that result from the foregoing analyses are checked against minimum and maximum metering rate constraints to be finalized. Then the finalized metering rates [MR(i,t + 1)] are sent to the microprocessors at the on-ramps to be implemented.

The outcome of the fifth step is finalized metering rates, MR(1,t + 1), ..., MR(n,t + 1).

This procedure is repeated in the ELT controller for each control period. Currently, a 1-min control period is used in the ELT control.

EPT Control Strategy

The EPT control strategy has evolved from linear programming (LP) based pretimed control strategies (29-31). The major difference is that the EPT control determines the metering rate based on on-line traffic information and historical traffic data rather than based solely on historical data, so the EPT control can respond to changing traffic situations.

Figure 3 shows an overview of the EPT control scheme. In EPT control the only real-time traffic data are traffic flow data from the first main-line section of the freeway. Other traffic flow data needed for the EPT control, which are on-ramp and off-ramp flows, will be historical. Based on these real-time and historical traffic data, EPT control determines metering rates to maximize the sum of input flows while preventing main-line congestion. In order to do this EPT control uses the following three major steps: combining on-line and historical data, demand prediction, and LP optimization.

Step 1: Combining On-Line and Historical Data

For each control period, the central computer receives on-line measured traffic flow of the first main-line section and combines this information with the historical traffic demand stored in the central computer memory for on-ramps and off-ramps, O(i,t + 1) and D(i,t + 1). This step generates a preliminary traffic demand set for the first main line and all on-ramps and off-ramps in the freeway segment.

The outcome of the first step is O(1,t), O(2,t + 1), ..., O(n,t + 1), ..., D(1,t + 1), ..., D(n,t + 1).

Step 2: Demand Prediction

Because of the static nature of the LP technique used in the EPT control, the length of each control interval should be comparable to the time required for vehicles to travel through the control section. In the case of a long control interval, actual traffic flow from the first main line in the next control period, O(1,t + 1), might be substantially different from that of the current control period, O(1,t). Then it is desirable to predict O(1,t + 1) based on O(1,t) and use the best estimate of O(1,t + 1), O'(1,t + 1). For this purpose, several prediction algorithms were tested, including a simplistic approach, a historical factor approach, a moving average approach, and an autoregressive approach (26).

The historical factor approach proved superior. The EPT control uses this historical factor approach (as shown in Equation 5) to predict the first sec-

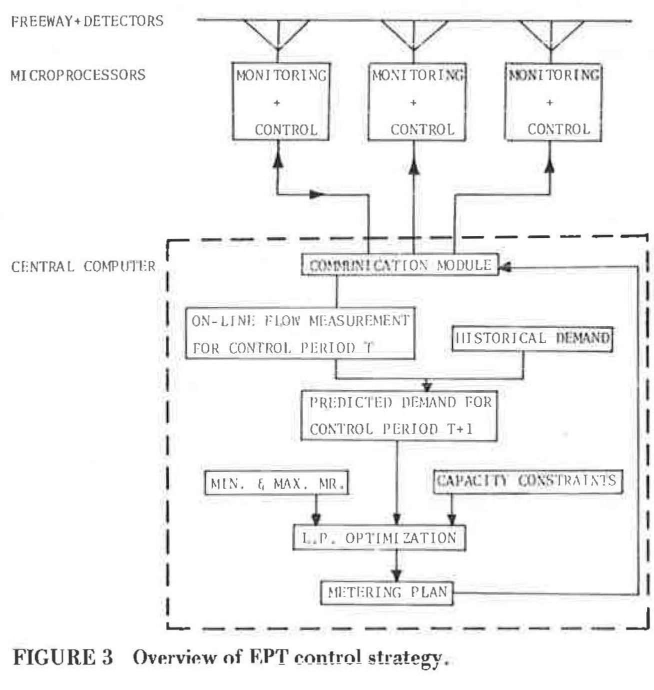


FIGURE 3 Overview of EPT control strategy.

tion's main-line traffic demand for the next control period:

$$O'(1,t+1) = O(1,t) \cdot K(t+1) \quad (5)$$

where

$O'(1,t+1)$ = predicted traffic flow on the first main-line section for control period t + 1,
$O(1,t)$ = on-line measured traffic flow on the first main-line section during control period t, and
$K(t+1)$ = historical factor for control period t + 1.

The data in Table 1 give the test results of the historical factor approach that used 3 days of traffic data from the Santa Monica Freeway.

The outcome of the second step is $O'(1,t+1)$.

Step 3: LP Optimization

By using the predicted first section's main-line traffic demand and the historical data for on-ramps and off-ramps, LP is used to generate optimal metering rates that maximize the sum of input flows within constraints of section capacities. Equations 6-10 give the formulation used in the EPT control. Maximum and minimum metering rate constraints are also considered in this stage.

$$\text{Maximize} \sum_{i=1}^{n} x_i \quad (6)$$

TABLE 1 Test Results of Historical Factor Approach

	Mean	Standard Deviation	Correlation Coefficient	t Value	F Value
Day 1			0.801	-0.11	1.100
R	7,150	551			
H	7,157	579			
Day 2			0.842	-0.08	1.095
R	7,033	713			
H	7,038	745			
Day 4			0.741	0.22	1.695
R	6,631	481			
H	6,617	625			

Note: R = real data [0(1,t)] in vehicles per hour, and H = data predicted by the historical factor approach [0′(1,t)] in vehicles per hour.

$$\text{Subject to} \sum_{i=1}^{n} A_{ij}x_i \leq C_j \quad \text{for } j = 1, 2, \ldots, m \quad (7)$$

$$x_i \leq ONVMAX(i) \quad \text{for } i = 1, 2, \ldots, n \quad (8)$$

$$x_i \geq ONVMIN(i) \quad \text{for } i = 1, 2, \ldots, n \quad (9)$$

$$x_i \geq 0 \quad \text{for } i = 1, 2, \ldots, n \quad (10)$$

where

x_i = input flow rate from on-ramp i (i.e., the finalized metering rate for on-ramp i),
n = number of on-ramps,
m = number of freeway sections,
A_{ij} = fraction of vehicles from on-ramp i that travel through section j,
C_j = capacity of section j,
ONVMAX(i) = maximum metering rate for on-ramp i, and
ONVMIN(i) = minimum metering rate for on-ramp i.

The outcome of the third step is finalized metering rates MR(1,t + 1), ..., MR(n,t + 1).

The finalized metering rates are sent to microprocessors in the field to be implemented. This procedure (steps 1-3) is repeated in the EPT control for each control period. Currently, a 5- to 10-min control period is used in the EPT control.

Preliminary Evaluation of Extended Control Strategies

The ELT and EPT control strategies were tested with the FRECON2 model. Because the major purpose of the testing was to select one strategy for more comprehensive evaluation and field implementation, the scope of the evaluation was limited to the expected performance of the strategies on the first day of implementation without diversion. Thus new features of the FRECON2 model (i.e., priority treatment, diversion, surface street modeling) were not engaged in the testing.

Figure 4 shows a schematic diagram of the modeled study section, which is approximately 7.8 miles long. The simulation time period is from 15:00 to 18:00. From the 5 days of traffic data for the Santa Monica Freeway obtained from the California Department of Transportation (Caltrans) during a previous study at ITS (9), 3 days of data (days 1,

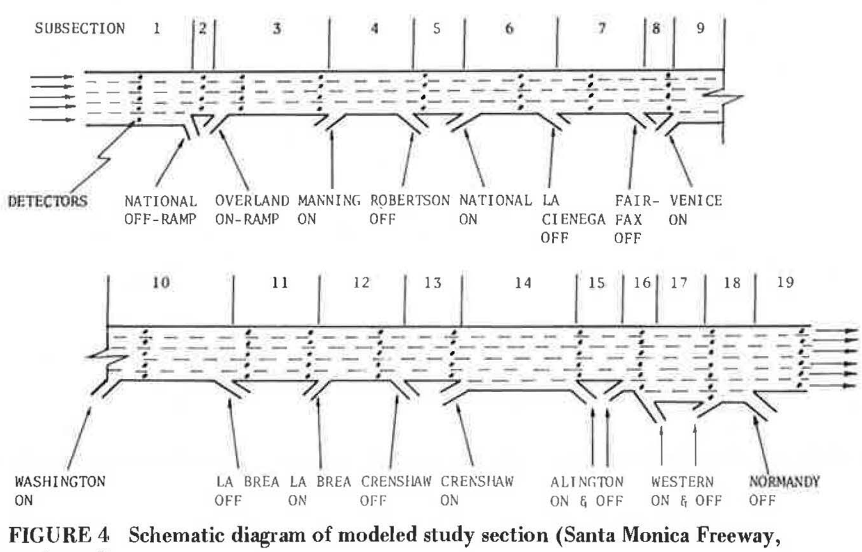


FIGURE 4 Schematic diagram of modeled study section (Santa Monica Freeway, eastbound).

2, and 4) with differing degrees of traffic demand (i.e., heavy, medium, and light) were selected for this test. The control parameters in the control strategies were calibrated for day 1. Then the control strategies were applied to days 2 and 4.

There exist a number of criteria that can be used in evaluating freeway entry control strategies. These include traffic performance measures, congestion elimination, bottleneck utilization, on-ramp queues, reliability (or consistency), data requirements, on-line computing time and memory requirements, and theoretical soundness.

Comparison of Traffic Performance Measures

The data in Table 2 compare traffic performance measures that result from the ELT and EPT controls. Both controls produced almost identical total travel service (i.e., total traveled distance in terms of vehicle miles) for all 3 days.

TABLE 2 Comparison of Traffic Performance Measures

Day	Measure	ELT Control	EPT Control	Difference[a] (%)
1	TTD	173,917	173,844	0.0
	FTT	3,537	3,554	-0.5
	OWT	777	849	-8.5
	TTT	4,314	4,403	-2.0
2	TTD	174,808	174,803	0.0
	FTT	3,624	3,771	-3.9
	OWT	1,031	904	14.0
	TTT	4,655	4,675	-0.4
4	TTD	163,168	163,164	0.0
	FTT	3,232	3,219	0.4
	OWT	92	372	-75.0
	TTT	3,323	3,591	-7.5

Note: TTD = total traveled distance (vehicle miles), FTT = freeway travel time (vehicle hours), OWT = on-ramp wait time (vehicle hours), and TTT = total travel time (vehicle hours).

[a]Difference = (ELT − EPT) · 100/EPT.

However, total travel times, which indicate the effectiveness of the control, were different for the two controllers. For all 3 days the ELT control resulted in shorter total travel times (approximately 0 to 7 percent less) compared with those from the EPT control.

For days 1 and 4 the EPT control caused unnecessary excess delay at on-ramps, which resulted in the longer total travel time compared with that from the ELT control. Although the EPT control gave a shorter on-ramp wait time on day 2, this was offset by the substantial increase in the freeway travel time (FTT).

Comparison of Freeway Congestion Elimination

Figure 5 shows traffic density maps (i.e., number of vehicles per lane per mile) for the two control strategies as an indication of the degree of main-line congestion remaining on the freeway. Among the 19 sections in the study site, the density map of only the first 13 sections (1-13) for time period 15:00 to 17:40 is shown in Figure 5 because no congestion occurred downstream of section 13 or after 17:40. Identified bottlenecks in the study site are sections 4, 6, and 11. In the density map, sections with densities greater than 60 vehicles per lane per section are defined as congested sections. The only exception is the bottleneck section 11, which tends to show densities slightly higher than 60 when operating at capacity.

As can be seen in Figure 5, the ELT control was able to eliminate the main-line congestion upstream of all three bottlenecks for all 3 days. However, the EPT control failed to eliminate the congestion for both day 1 and day 2. Although the EPT prevented congestion on day 4, the excessive on-ramp delay, as already given in the data in Table 2, indicates that the EPT overcontrolled the freeway, thus resulting in longer total travel time.

The data in the following table compare the remaining congestion for both controllers in terms of (minute•miles) of congested region remaining:

	Congestion Remaining (minute•miles)	
Day	ELT Control	EPT Control
1	0.0	7.1
2	0.0	40.4
4	0.0	0.0

Again, the EPT control left congestion on the freeway on both day 1 and day 2, whereas the ELT control eliminated the congested region completely for all 3 days.

Comparison of Freeway Bottleneck Utilization

Traffic volume through a bottleneck section downstream of queued on-ramps indicates whether the controller uses the bottleneck effectively. The data in Table 3 give the duration of traffic flow through the bottleneck at a level greater than or equal to 99 percent of the capacity of the bottleneck (i.e., operating near or at capacity).

Except at bottleneck section 4 in day 2, the ELT control kept all three bottlenecks operating near capacity at least as long as the EPT control.

Comparison of On-Ramp Queue Conditions

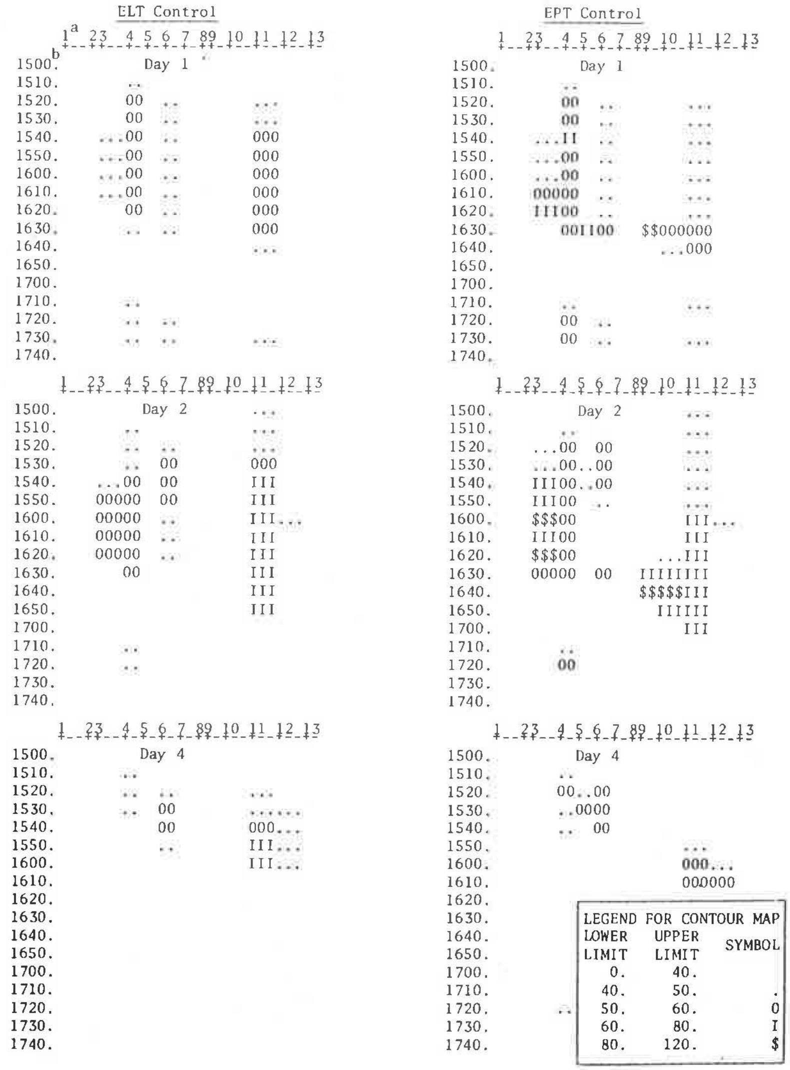
One of the major concerns of practicing traffic engineers when they plan to implement a new control strategy is the on-ramp queue lengths and the consequential impact on the surrounding surface streets. In the simulation tests the ELT control was able to balance out on-ramp queues while eliminating congestion on the freeway. In the EPT control, however, considerable difficulties were experienced in controlling on-ramp queue lengths because of the long control interval required by the static nature of LP in the EPT and the absence of on-line traffic data for on-ramp and off-ramp flows.

The ELT control, compared with the EPT control, requires more observations of traffic on the freeway. Although this might be an additional burden in terms of hardware, this analysis indicated that this frequent on-line observation is necessary for the control to operate effectively and reliably.

In terms of computing time and memory requirements, the EPT control requires more computing time for solving LP and more memory space for storing historical traffic demand.

In addition to the static nature of LP, the absence of both a feedback mechanism and real-time traffic information in the EPT control was identified as a major problem in terms of reliability and effectiveness, especially for different days with varying traffic demand. On the other hand, the ELT control, which has a feedback mechanism and uses a short control interval, resulted in more reliable performance for all 3 days compared with the EPT control.

Throughout this analysis the ELT control had a consistent advantage over the EPT control in the areas of traffic performance, congestion elimina-



[a]Freeway subsection number.
[b]Simulation time period.

FIGURE 5 Comparison of freeway congestion elimination.

TABLE 3 Duration of Near-Capacity Flow Operation at Bottlenecks

		Duration (min)		
Day	Section	ELT Control	EPT Control	Difference[a] (%)
1	4	90	85	5.8
	6	80	75	6.7
	11	80	80	0.0
2	4	70	75	-6.7
	6	55	35	57.1
	11	120	105	14.3
4	4	25	20	25.0
	6	30	20	50.0
	11	40	5	700.0

[a]Difference = (ELT − EPT) · 100/EPT.

tion, bottleneck utilization, on-ramp queue management, and computing time and memory requirement. Based on this analysis the ELT control strategy was selected for further evaluation and future field implementation in a segment of the Santa Monica Freeway. Although the ELT control balanced on-ramp queue lengths for 3 different days, the overall increased queue lengths at on-ramps cause major concerns from the viewpoint of field implementation.

Because the evaluation test was limited to expected queue length on the first day of implementation with no diversion, it is premature to draw any conclusions from those queue lengths. An extensive simulation evaluation of the selected control strategy (ELT) for a wide variety of operating environments is planned before actual field implementation. Major factors to be considered include daily traffic demand variation, on-ramp queue constraints, driver's diversion, alternate routes condition, and so forth. New features of the FRECON2 model will play an important role in this evaluation. Depending on the results of this evaluation, some modifications in the ELT control strategy might be necessary, especially in handling on-ramp queues.

FIELD IMPLEMENTATION PLAN

Field implementation of the ELT control strategy is one important and difficult phase of the project. Based on a field study conducted from May 17 through May 19, 1983, the boundaries of the study section in space and time have been modified. The modified study site boundary chosen for future field implementation is a 6.4-mile section of the eastbound Santa Monica Freeway in Los Angeles that contains eight on-ramps and eight off-ramps. Because there is no congestion downstream of section 13, the study site was shortened to 6.4 miles (from 7.8 miles). However, because of growth in the traffic demand, the time period has been extended to cover 13:30 to 19:00 (from 15:00 to 18:00). Implementation is expected to be conducted as required hardware and communication systems become available in the study site.

The basic hardware necessary is main-line and ramp detectors, a California Type 170 Controller (32) at each on-ramp, a central computer, and communication lines between each 170 Controller and the central computer. The major problem from the implementation perspective is developing software for the 170 Controller and the central computer based on the ELT control strategy. The study site is currently controlled by a combination of local main-line-responsive (LMR) and time of day (TOD) metering that uses software resident in the 170's developed by Caltrans (33). This software also transmits volumes, occupancies, and error alarms from up to six detectors to the central computer. The central computer is currently used mainly to acquire and manage data from the 170's (34). New software is being developed in assembly language for the microprocessor-based 170's and in FORTRAN for the central computer.

New software for the 170 Controller includes routines to transmit a queue length alarm to the central computer and to check the metering rate received from the central computer. If a metering rate is received by the 170 (i.e., sent from the central computer), that value will be used instead of the value calculated in the existing LMR metering algorithm. If a metering rate is not received because of an error of the central computer or a communication failure, then the LMR metering rate is used.

New software for the central computer includes routines to receive, identify, error check, and store data transmitted from the 170's and to execute the ELT control algorithm to calculate a metering rate. Major tasks in writing the central computer software are the routines to interpret and error check the data received from the 170's. For any responsive control strategy, it is crucial to identify and compensate for errors in the detector data. Extensive testing of the new software must be conducted to ensure the proper and safe operation of the ELT control before actual implementation.

To evaluate the benefits of ELT control a comprehensive traffic study will be conducted before and after implementation. Data to be collected includes main-line and ramp demands, on-ramp delay, on-ramp queue lengths, and traffic volume and travel time along the freeway and alternative surface streets. Two weeks of data collection immediately before implementation form the before study. The after study period consists of the first week of operation of ELT control and another 5 days from the third and fifth weeks of operation.

SUMMARY

Two types of implementable (in terms of available hardware and computing capability) segmentwide control strategies were developed: ELT control and EPT control. To evaluate the extended control strategies an existing macroscopic dynamic freeway simulation model (FRECON) was extended to a freeway corridor model, FRECON2. New features of FRECON2 include the modeling of alternative surface streets, priority entry control, and driver's spatial diversion.

Preliminary evaluation of the ELT and EPT control strategies was conducted on the FRECON2 model by using 3 days of traffic data from the Santa Monica Freeway. Throughout the evaluation the ELT control demonstrated a consistent advantage over the EPT control in decreasing total travel time, eliminating freeway congestion, using the bottlenecks efficiently, and balancing on-ramp queues. Based on the evaluation, the ELT control has been selected for further evaluation through simulation and future field implementation on the Santa Monica Freeway.

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