Innovative Evaluations of Traffic System Management Measures for Postearthquake Projects in Oakland, California

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On October 17, 1989, the upper deck of the I-880 elevated freeway structure between 18th and 34th streets in Oakland, California, collapsed because of the Loma Prieta earthquake. The collapse of this Cypress Viaduct severed the major artery, disrupting local and regional transportation. An interim replacement for the Cypress Viaduct could not be put in place because of community opposition, so the California Department of Transportation (Caltrans) had to develop interim traffic system management (TSM) measures to relieve severely congested freeways. The innovative network-based methodology used to analyze the interim TSM alternatives proposed by Caltrans is described, and the alternatives' projected effectiveness in relieving congestion on freeways and arterials in Oakland is examined. The analysis used performance-based ranking to select the alternatives that would qualify for FHWA emergency relief funding. The examination of results from various combinations of alternatives is included, and the phenomenon called synergistic effect is introduced as a measure of effectiveness to rank the combinations. The need for simultaneous improvement of arterials, ramp metering, and freeways to achieve optimum delay reduction and freeway congestion relief is also discussed. The synergistic effects of the combined alternatives are compared, and the projects approved by FHWA are listed.

On October 17, 1989, the upper deck of the I-880 elevated freeway structure between 18th and 34th streets in Oakland, California, collapsed because of the Loma Prieta earthquake. I-880 is the principal north-south freeway along the east shore of the San Francisco Bay, connecting I-80 in Oakland to I-280 in San Jose. The collapse of the freeway structure, commonly called the Cypress Viaduct, severed this major artery, disrupting local and regional transportation. In addition, a section of the San Francisco–Oakland Bay Bridge (I-80) upper-level deck also failed, causing the temporary closure of the Bay Bridge. The California Department of Transportation (Caltrans) quickly restored the Bay Bridge, but Caltrans has yet to install an interim replacement of the collapsed Cypress Viaduct. A permanent replacement is under development but will not be finished for 4 or 5 years. An at-grade expressway was proposed in this corridor to alleviate congestion until a permanent replacement facility could be built. This proposal met strong local public opposition. The public's concern was that the expressway would become permanent, disrupting the community and interfering with local traffic circulation. This created a need to quickly develop interim traffic system management (TSM) measures to relieve severely congested freeways until the permanent replacement freeway is completed. Figure 1 shows the location of the subject freeways.

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A network-based methology is described that was used to analyze interim TSM alternatives proposed by Caltrans and the projected effectiveness of the alternatives in relieving congestion on freeways and arterials in Oakland. The analysis ranked alternatives on the basis of their performance to select those that would qualify for FHWA emergency relief funds.

This paper also includes the examination of results from various combinations of alternatives and introduces the phenomenon called synergistic effect as a measure of effectiveness for ranking the combinations. The need for simultaneous improvement of arterials, ramp metering, and freeways to reduce delay and relieve freeway congestion is also discussed. The paper ends with the comparison of synergistic effects due to various combinations of arterial and freeway improvement projects, and it lists the projects that FHWA approved.

PRE-EARTHQUAKE CONDITIONS

Before the Loma Prieta earthquake, traffic flows were very congested on all routes leading to and from the Bay Bridge toll plaza in the peak periods. I-80 and I-580 regularly operated at capacity leading into the I-580 distribution structure and into the toll plaza. Eastbound I-80 traffic was heavily congested because of weaving constraints in the I-80/I-580 distribution structure. Delay during peak periods ranged from 15 min to 1 hr; it was highly variable. Figure 2 shows the estimated pre-earthquake average daily traffic (ADT) for 1988. The Cypress Viaduct was estimated to carry up to 165,000 vehicles, including 25,000 trucks, per day. An estimated 40 percent of northbound I-880 traffic traveled to and 20 percent of the southbound traffic traveled from the Bay Bridge during the morning peak hour.

Bay Area Rapid Transit (BART) transbay service parallels I-880 and the Bay Bridge. Before the earthquake, about 105,000 passengers used BART's transbay service every day. Arterial streets near the Cypress Viaduct, including West Grand Avenue and 14th Street leading into the industrial sections west of I-880, were used lightly. I-980, constructed in the early 1980s, was not heavily used as a peak-period bypass, although it provided convenient access to and from Route 24 and was the major route into and out of downtown Oakland. Truck volumes on I-880 were very high on the Cypress Viaduct, reaching 15 percent of daily traffic and 12 percent of peak-

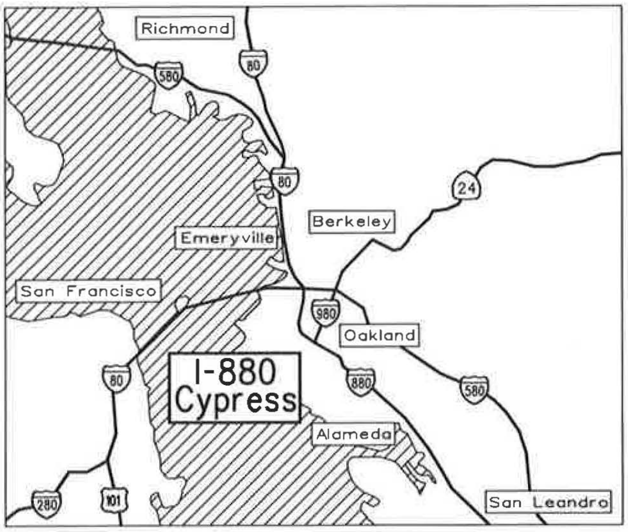

FIGURE 1 Project location.

hour traffic. This was because of the freeway's regional connections and the high concentration of major trucking centers along the I-880 corridor within Alameda County. In addition, the Cypress Viaduct was adjacent to the Port of Oakland, Army Supply Depot, U. S. Post Office Distribution Center, Naval Supply Center, and major distribution warehouses. Furthermore, the city of Oakland prohibited truck traffic on I-580 east of Grand Avenue, which forced more truck traffic onto I-880. The collapse of the Cypress Viaduct resulted in a severe deficiency in corridor capacity. As indicated in Figure 3, some of the vehicular demand was shifted to other modes and routes, but an estimated 90,000 vehicle equivalents per day was not accounted for in the transportation system.

POSTEARTHQUAKE CONDITIONS

Immediately after the earthquake, most streets and highways within the I-880/Cypress area were closed because of unstable structures, demolitions, or reconstruction activities. When the Bay Bridge reopened, only the I-580 and I-80 approaches to the bridge could carry its 240,000 daily vehicles. Because of the loss of the I-880 Cypress Viaduct capacity, Caltrans has pursued up to 15 alternative configurations for the interim replacement of the Cypress Viaduct. None of these was acceptable to the city of Oakland or the West Oakland neighborhood. Cypress Street is now only partially open to traffic, and its ramp connections to freeways are incomplete.

IMPACTS ON THE NETWORK

Corridor Travel

Vehicle queues now regularly cause much congestion within the I-580/I-980/Route 24 distribution structure, thus affecting all freeway routes. Vehicle queues also back up on northbound I-880 to the south for traffic using I-980 and on southbound Route 24 for traffic using I-580. Traffic congestion along I-80 east of the I-580 interchange has significantly worsened because of limited ramp capacities. Weekend travel along this route is equally congested.

Trucking Impacts

Many of the 25,000 trucks per day (15 percent of ADT) that had used the Cypress Viaduct now use I-980 and I-580, resulting in up to 12 percent truck traffic mix on these freeways during peak hours. Local morning and afternoon deliveries have been delayed during peak periods, requiring that they be rescheduled to different time periods. Off-peak truck travel now significantly affects the level of service of freeway connectors on I-880, I-980, I-580, and I-80.

Impacts On Oakland

The absence of an interim Cypress replacement has reduced accessibility and mobility within Oakland and throughout the region. Traffic has sought alternative routes. Because substantial replacement highway capacity has not been provided in the Cypress Street corridor, traffic has attempted to filter into the local street system, especially into residential neighborhoods. Figure 4 shows recent changes in traffic volume on local streets. Poor signal progression and low operating speeds have limited the amount of traffic diversion to neighborhood streets. Caltrans thus proposed interim TSM projects to provide additional arterial corridor capacity until a permanent replacement can be built.

INTRODUCTION TO METHODOLOGY

The objectives of the proposed interim TSM alternatives were specifically to reduce freeway congestion caused by the loss of I-880 on the corridors adjacent to the Bay Bridge and to improve mobility within the city of Oakland. These alternatives were classified as interim measures because they were designed to relieve congestion temporarily until the replacement facility can be completed. The permanent facility is planned to be open to traffic within 5 years, and it will eventually divert excess traffic off the freeways that are now congested.

Because the prime objective of the interim TSM measures was to reduce congestion on the freeways, the principal measure of effectiveness used to screen alternatives was reduction in vehicle hours traveled (VHT). Another measure used effectively was the cost-effectiveness of the alternatives, represented as the VHT reduced per $1,000 of implementation cost. As the analysis proceeded, a measure called synergistic effect was also introduced to compare various combinations of TSM alternatives. The measures of effectiveness for each alternative were estimated on the basis of output by a computer travel-forecasting model. The model produced raw output such as vehicle miles traveled (VMT) and VHT by facility types for the area under study. This output was then refined to produce effectiveness ratings.

The evaluation of TSM measures was unique for several reasons. First, the main goal was to reduce congestion spe-

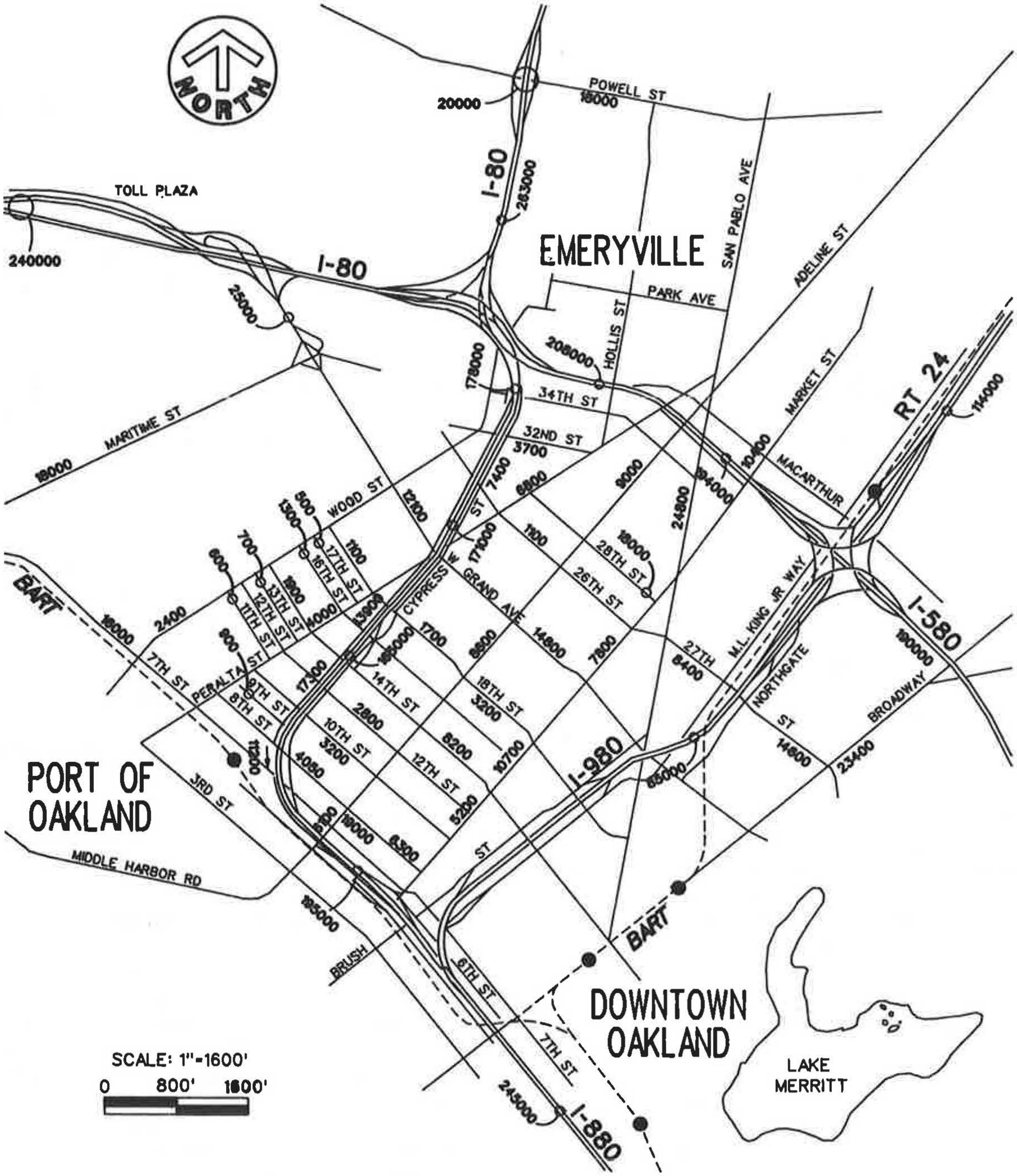

FIGURE 2 Estimate of pre-earthquake ADT.

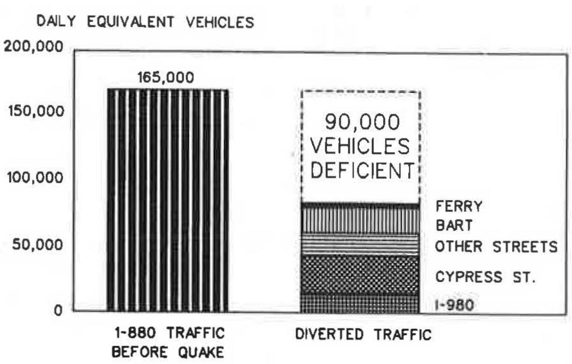

FIGURE 3 Deficient corridor capacity: where has I-880 traffic gone?

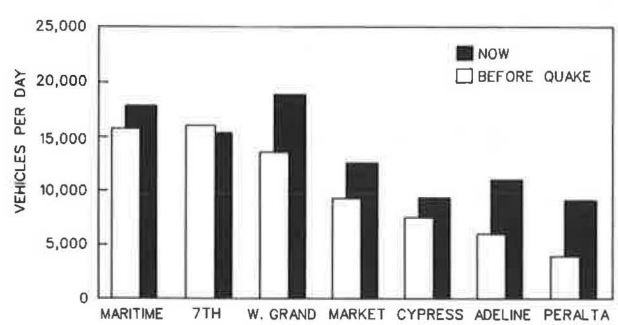

FIGURE 4 Postearthquake traffic volume changes on selected Oakland streets.

cifically on freeways rather than on arterials. Second, project alternatives needed to be operational by April 1991 in order to meet the early implementation requirements of FHWA. Third, low-cost and high-cost alternatives were considered together, low-cost alternatives being arterial improvements and high-cost alternatives being improvements to freeway connectors and mainlines. Fourth, measures of effectiveness included only VHT reduction, cost-effectiveness, and synergistic effects. Other measures commonly used in low-cost TSM studies, such as user costs, energy use, and parking, were not considered because they were not related to critical project issues, and a full-scale benefit-cost analysis was not prepared. Finally, time constraints required shortcut methods to evaluate projects quickly.

Transit measures were evaluated by other agencies. Many transit measures were implemented as emergency measures just after the earthquake to cope with the loss of the Cypress facility and the collapse of part of the Bay Bridge. Transit measures included introducing ferry service between the East Bay and San Francisco, increasing capacity on BART and Alameda–Contra Costa Transit, adding park-and-ride lots, and using carpool services. Some of the measures initially implemented have caused some permanent diversion from automobile trips to transit trips.

Caltrans proposed other options, such as traffic surveillance and motorist information systems, changeable message signs at weigh stations, and additional park-and-ride facilities. But because these options were not part of the freeway or arterial construction projects, they were excluded from this analysis. Caltrans, however, assessed these options independently and forwarded their recommendations to FHWA.

Travel Forecasting Methodology

At the time of the earthquake, a travel demand forecast model was being developed for Alameda County by Barton-Aschman Associates, Inc., of San Jose, California. Its principal purpose was to evaluate future transportation and land use alternatives as part of a countywide transportation plan. Fortunately, the highway network and corresponding traffic zone system were already developed at a level of detail sufficient for analyzing link-level traffic volumes on the freeways, expressways, major arterials, and selected minor arterials in the Oakland area. In order to simulate current travel patterns for the analysis of alternative interim TSM measures, the 1987 Metropolitan Transportation Commission (MTC) Bay Area person-trip tables (home-based work, home-based shop/other, home-based social/recreational, and nonhome based) were converted and applied to the Alameda County zone structure. County-to-county specific adjustment factors were applied to each of the person-trip tables to account for intercounty transit use and county-to-county specific vehicle occupancy rates. MTC's regional morning peak-hour factors for each trip purpose were applied and adjusted to create a morning peak-hour vehicle trip table.

At the time this study was conducted, the development of the Alameda County modeling procedure was not at a stage that allowed carpooling to be addressed. Alternatively, MTC's high-occupancy vehicle (HOV) travel demand estimates were used to account for carpool traffic. Existing HOV travel is reported to make up approximately 12 percent of the morning peak-hour vehicle trips on the Bay Bridge and much less elsewhere.

After the morning peak-hour trip table was assigned to the highway network, a validation procedure was used to measure the accuracy of the assignment results against observed travel patterns and volumes. Pre-earthquake ground-count data on freeway sections (Bay Bridge, I-80 at University, I-880 at 66th, I-980 at 18th, I-580 at 35th and Kellar and at the Caldecott Tunnel) and several arterial streets (Cypress Street, Peralta Avenue, and Grand Avenue) were compared with the model results. Minor modifications were made to the network and to transbay volumes so that the model represented vehicle trips on the network. The adjustments ultimately allowed the model to estimate pre-earthquake link volumes to within approximately 10 percent of the observed counts. An evening trip table was quickly developed by inverting the morning trip table and adjusting external stations, such as the Bay Bridge and the Caldecott Tunnel.

The postearthquake roadway conditions ("no-build" alternative) defined and coded in the network included some freeway improvements implemented by Caltrans soon after the earthquake. The existing ground-level Cypress Street between 8th and 34th streets (formerly under the Cypress Viaduct) that was partially reopened was also included in the network.

Model Representation of Interim TSM Measures

The TSM alternatives proposed for the interim included improving signal coordination on major arterials parallel to congested freeways, adding arterial lanes by removing onstreet parking and restriping, and improving some intersections on selected arterials. Alternatives on freeways included upgrading connectors at major interchanges and adding lanes in congested sections. Connector upgrades at some locations involved physically widening structures and at other locations, just restriping and reducing shoulder widths. Freeway upgrades included restriping and widening roadways.

To estimate the VHT reduction for each TSM measure, the network description of each alternative was coded into the travel forecasting model as closely as possible. The model then provided regional travel assignments on all roadway facilities represented in the network, from minor arterials to freeways. Some innovative techniques were developed to represent improved arterial signal progression and freeway on-ramp metering. Improvements to signal progression on arterials were represented in the model as increased arterial operating speed. Input operating speeds on all segments of arterial streets with improved signal progression were increased by 10 mph, the maximum improvement practicably attainable. This increase shortened running time in the model, which equated to the improved progression in the field. Widened, added, and restriped lanes were represented as increased capacity for given segments.

To test systemwide ramp metering, metered freeway ramps were coded with reduced capacity. A single-lane ramp with a typical capacity of 1,500 vehicles per hour was reduced 40 percent to 900 vehicles per hour (*1*). This resulted in significantly fewer vehicles' entering the freeway system and diverted traffic from the on-ramps to the arterial system. It was understood that optimum metering rates could not be developed by this method, but the order-of-magnitude effectiveness rating was reasonable.

Another useful output from the travel forecast model was the volume-difference plots of the network. Volume plots were prepared to show the differences in peak-hour volumes for each link of the network between a specific TSM alternative and the no-build scenario. The plots were prepared in color: green showed decreases in volumes and red showed increases. Each plot provided a networkwide comparison of individual TSM measures with the no-build scenario, so the effects of the proposed TSM measures could be identified by just looking at the plot. The new traffic circulation patterns caused by the improvements were also observed and analyzed from the plots. Analyses of traffic patterns revealed that almost every TSM alternative considerably affected the freeways.

Other output from the travel forecast model included VHT differences between alternatives. It appeared that the VHT values reasonably reflected the TSM measures and were sensitive to minor modifications. Furthermore, the model provided VHT by facility type and level of service. This allowed the examination of VHT reductions on freeways and major and minor arterials by level of service. All of these measures were obtained from the model for morning and evening peak hours.

INTERIM TSM ALTERNATIVES CONSIDERED

This section describes the alternatives analyzed in this project, which are also summarized in Table 1. Several of these were dropped from further consideration because of opposition from public groups.

1. *Improvements along Adeline, Market, West Grand, Castro, and Brush streets.* This project would replace signal controllers along West Grand Avenue and Adeline, Market, Brush, and Castro streets. It would allow time-based coordination of signals along routes that could serve as alternatives to congested freeways. Some striping and parking controls during

TABLE 1 SUMMARY DESCRIPTION OF INTERIM TSM MEASURES

ALT.	JURISDICTION	PROJECT DESCRIPTION	COST ESTIMATE	TIME TO IMPLEMENT
1	Caltrans/Cities of Oakland and Emeryville	Installation and coordination of signal controllers on local city streets (W. Grand, Adeline, Market, Brush, Castro	$170,000	4-6 months
2	Caltrans and City of Oakland	Replacement of exsisting signal controllers along W. Grand Ave. with new TCT type controllers	$40,000	2-4 months
3	Caltrans/Cities of Oakland,Emeryville and Berkeley	Upgrade San Pablo Ave with new signals, new controllers, left turn lanes and signals	$2.1 million	3-12 months
4	Caltrans and City of Emeryville	Upgrade existing signal equipment and install new signal on Hollis St.	$370,000	9 months
5	Caltran and City of Oakland	Restripe W Grand Ave. to provide a bus and vanpool lane only	$80,000	3-4 months
6	Caltrans/Cities of Emerville and Oakland	Extend West MacArthur Blvd., Shellmound and Ettie St. ramps	5 million	24-36 months
7	Caltrans	Widen eastbound mainline I-580 and modify I-580/980 and I-580/80 connectors	$10 million	24 months
8	Caltrans	Widen west bound I-980 between I-580 and I-880 by striping and restriping of I-980 to I-880 connectors	$300,000	16 to 18 months
9	Caltrans and City of Berkeley	Improvements to westbound I-80 Powell St. ramps plus auxiliary lane	$9.8 million	24 months
10	Caltrans	Widen EB on-ramp of Powell St. Interchange	$150,000	6 months
11	Caltrans	Ramp Metering along Ala-24/80/880/980	$5.25 million	9-18 months

peak periods were proposed for Market Street. The estimated costs for improvements along each route would be as follows: Adeline, $35,000; Market, $60,000; and Castro and Brush, $75,000. Implementation was estimated to take between 4 and 6 months.

2. *Signal improvements to West Grand and Northgate avenues.* This project would replace signal controllers along West Grand and Northgate avenues. It would allow time-based coordination of signals along routes that could serve as alternatives to congested freeways. This project was estimated to cost $40,000 and take 2 to 4 months for implementation.

3. *Signal Improvements along San Pablo Avenue.* This project would upgrade signal equipment, install left-turn phasing, and add left-turn bays on San Pablo Avenue between Ashby Street and the I-580 and I-980 freeways. The cost was estimated to be $2.1 million, and the time to implement was estimated to be 3 months to 1 year. Proposed improvements to San Pablo Avenue from Ashby Street to the I-580 and I-980 freeways were originally developed as part of the transportation management plans for reconstructing I-80 east of I-580.

4. *Signal improvements on Hollis Street.* This project would upgrade signal equipment and install new signals on Hollis Street between Ashby Avenue and Yerba Buena Street. The cost was estimated to be $370,000. Time to implement was estimated to be 9 months.

5. *HOV lanes on westbound West Grand Avenue.* This project would provide an HOV lane on West Grand Avenue from Campbell Street to the San Francisco–Oakland Bay Bridge toll plaza. Project cost was estimated to be $80,000. Implementation time was estimated to be 3 to 4 months. This HOV lane would replace one of the current mixed-flow lanes during peak periods. The right lane on the West Grand Avenue viaduct, beginning at Campbell Street, would be restricted to buses and vanpools.

6. *MacArthur Boulevard extension and Ettie Street ramps.* This project would extend Ettie Street underneath I-580, extend MacArthur Boulevard to join Ettie Street, and construct on- and off-ramps to provide local traffic access to and from the Bay Bridge. The cost was estimated to be $6 million, and the project could be implemented in 2 to 3 years. Currently, the MacArthur Boulevard on-ramp to westbound I-580 is closed because of operational problems on I-580. The MacArthur Boulevard off-ramp from eastbound I-580 was a left-hand off-ramp, so it was proposed to close this ramp as well as the 32nd Street on- and off-ramps to the Cypress corridor.

7. *Widen eastbound mainline I-580 and modify I-580/I-980 and I-580/I-80 connectors.* This project would widen eastbound mainline I-580 between the distribution structure and Hollis Street, widen the I-580 eastbound branch connector to westbound I-980 from two lanes to three by restriping and additional paving, and restripe the connector from westbound I-580 to westbound I-980 from two lanes to one. It would involve major construction work and would cost approximately $10 million. It was estimated that these projects could be implemented in 2 years. When implemented, they would provide increased capacity within the existing I-580 and I-980 corridor.

8. *Widen westbound I-980 between I-580 and I-80.* This project would widen the mainline westbound I-980 and the direct connector from westbound I-980 to southbound I-880 to provide three 12-ft lanes. The estimated cost would be $300,000 and the estimated implementation time, 16 to 18 months.

9. *Improvements to westbound I-80/Powell Street ramps.* Currently, a project to reconstruct the Powell Street interchange on I-80 is in the design phase. It involves the construction of two hook ramps and a new lane from the on-ramp to the distribution structure. The cost estimate was $9.8 million and the time to fully implement this project was estimated at 2 years. This project would provide operational improvements at the Powell Street interchange on the west side of the freeway only.

10. *Widen eastbound I-80/Powell Street on-ramp.* This project would widen the eastbound on-ramp to I-80 from Powell Street and provide a free right turn from westbound Powell Street onto the ramp. The cost was estimated to be $150,000 and the implementation time, 6 months.

11. *Ramp metering along Route 24 and Interstates 80, 580, 880, and 980.* Ramp metering was proposed as part of an overall traffic operations system aimed at improving the operation of the area freeway system. For this project, it was proposed that 35 on-ramps be metered on I-880 south of I-980/I-880, on I-80 east of the distribution structure, on Route 24 east of the Route 24/I-580 interchange, I-980, and I-580 in Oakland. About 35 of the metered ramps would be located within the core of the study area, and the rest distributed within a few miles on I-880, I-80, Route 24, and I-580. Ramp metering would require geometric modification at many ramps to provide storage for ramp queues, additional lanes to accommodate high volumes, HOV bypass lanes, and enforcement areas. Caltrans estimated the cost of metering each ramp at $150,000, including geometric modifications.

EVALUATION OF INDIVIDUAL ALTERNATIVES

The results of the alternatives analysis are summarized in Tables 2–4. Table 2 shows the VHT differences of TSM alternatives from no-build by facility type. Alternatives 1–11 are the individual TSM measures as proposed by Caltrans. Various combinations of individual measures are referred to as Combinations 1–7.

1. *Improvements along Adeline, Market, West Grand, Castro, and Brush streets.* Increased speed and capacity on Brush and Castro streets would provide easier access to West Grand Avenue for vehicles on I-980 and I-880 during peak-period congestion. Table 2 indicates that this alternative would reduce 865 VHT per day on freeways. VHT would increase on the arterials, however, because of increased congestion. This delay due to increased congestion on arterials would override the benefits gained on freeways and thus increase VHT by 1,260 on the network. This alternative would achieve the objective of reducing congestion on freeways, but it would have negative impacts on the arterials. Table 4 shows that this alternative would perform fairly well, in terms of cost-effectiveness, in comparison with others.

2. *Signal improvements to West Grand and Northgate avenues.* Merely enhancing signalization on West Grand Avenue would increase westbound traffic flow anywhere from 80 to 1,100 vehicles per hour during both peak periods. The largest increase, 1,100 vehicles per hour, would occur between I-980

TABLE 2 1990 VHT DIFFERENCES OF TSM ALTERNATIVES FROM NO-BUILD BY FACILITY TYPE

ALTERNATIVE DESCRIPTION	ALTERNATIVE	DAILY VHT DIFFERENCES		
		FREEWAYS	MAJOR	MINOR
W. Grand, Market, Adeline, Brush, Castro	1	- 865	1590	535
W. Grand & Northgate	2	- 1240	135	- 50
San Pablo Avenue	3	- 520	195	- 1560
Hollis Street	4	- 420	- 395	485
HOV Lane on WB Grand	5	- 445	- 300	- 25
MacArthur, Ettie Street Extension	6	- 435	- 75	- 5
Widen EB I-580	7	305	250	830
Widen WB I-980	8	95	- 295	50
Improvments to WB I-80 Powell	9	255	1110	980
Widen EB I-80 Powell	10	0	0	0
Ramp Metering	11	- 2260	3970	2700

NOTE: EB = eastbound, WB = westbound.

TABLE 3 SYNERGISTIC EFFECT OF COMBINATION ALTERNATIVES FOR INTERIM CYPRESS REPLACEMENT

COMBINATIONS	ALTERNATIVE	MAJOR ARTERIALS			MINOR ARTERIALS			FREEWAYS			ALL FACILITIES		
		VHT			VHT			VHT			VHT		
		COMB	SUM OF INDIV ALTS	SYN	COMB	SUM OF INDIV ALTS	SYN	COMB	SUM OF INDIV ALTS	SYN	COMB	SUM OF INDIV ALTS	SYN
Alts. 1, 2, 4, & 5	Comb 1	- 710	1030	- 1740	- 730	945	- 1675	- 1335	- 2970	1635	- 2775	- 995	- 1780
Alts. 1, 2, 3, 4, & 5	Comb 2	1365	1225	140	- 2780	- 615	- 2165	- 815	- 3490	2675	- 2230	- 2880	650
Alts. 1 & 2	Comb 3	705	1725	- 1020	310	485	- 175	- 1255	- 2105	850	- 240	105	- 345
Alts. 7, 8, & 9	Comb 4	- 1935	1065	- 3000	- 1095	1860	- 2955	1445	655	790	- 1585	3580	- 5165
Alts. 1, 2, 3, 4, 5, 6, & 11	Comb 5	2845	5120	- 2275	- 1625	2080	- 3705	- 4880	- 6185	1305	- 3660	1015	- 4675
Alts. 7, 8, 9, & 11	Comb 6	3640	5035	- 1395	425	4560	- 4135	- 1825	- 1605	- 220	2240	7990	- 5750
Alts. 1 to 11	Comb 7	2005	6185	- 4180	- 6460	3940	- 10400	- 3335	- 5530	2195	- 7790	4595	- 12385

SYN = Synergy Effect

TABLE 4 SUMMARY OF ALTERNATIVE RANKINGS AND FHWA APPROVAL

Alternative	Daily Systemwide Delay Reduction (VHT/Day)	Daily Freeway Delay Reduction (VHT/Day)	Daily Systemwide Synergy Effect (VHT/Day)	Cost Per Yearly VHT Reduced ($/VHT per Yr)	FHWA Approval
1	0	865	n/a	0.75	Yes
2	1155	1240	n/a	0.12	Yes
3	1885	520	n/a	4.29	Yes
4	330	420	n/a	3.39	Yes
5	770	445	n/a	0.39	Yes
6	515	435	n/a	45.45	No
7	0	0	n/a	n/a	No
8	150	0	n/a	7.69	Yes
9	0	0	n/a	n/a	No
10	0	0	n/a	n/a	Yes*
11	0	2260	n/a	8.93	Yes
Comb 1	2775	1335	1780	0.88	Yes
Comb 2	2230	815	0	1.74	Yes
Comb 3	240	1255	345	0.58	Yes
Comb 4	1585	0	5165	47.62	No
Comb 5	3660	4880	4675	9.71	Yes w/o Alt 6
Comb 6	0	1825	5750	52.63	No**
Comb 7	7790	3335	12385	59.17	No**

* This alternative was approved to alleviate local ramp congestion

** Some alternatives in these combinations were approved, but they were low cost compared to the high cost ones which were not approved and thus the high "cost per yearly VHT reduced."

and Cypress in both directions along West Grand Avenue. The West Grand Avenue segment between Cypress Street and I-80 would experience an increase of about 580 vehicles per hour in both directions. Even larger increases would occur during the evening peak period. The increase in traffic flow on West Grand Avenue and Northgate would be primarily due to diversion of traffic from I-580, I-980, and other adjacent minor arterials.

Overall, this alternative would reduce 1,155 VHT daily, of which 1,240 VHT would be from freeways. On the basis of this measure, this alternative ranked second among all TSM alternatives. However, it would rank first in cost-effectiveness, costing 12 cents per VHT reduced, as shown in Table 4. Although this would be the most cost-effective individual TSM alternative of those considered, it would cause a minor increase in congestion on major arterials.

3. *Signal improvements along San Pablo Avenue.* San Pablo Avenue signal improvements would cause a systemwide reduction of 1,885 daily VHT. This made it the best alternative in terms of systemwide VHT reduction, but it ranked fourth for freeway improvement. Increases of traffic on San Pablo, West Grand, Powell, Brush, and Castro would apparently be due to diversion of traffic from adjacent major and minor arterials and from freeways such as I-980, I-580, and I-80.

Unfortunately, when cost was taken into account, the cost per yearly VHT reduced would be $4.29, among the lowest as shown in Table 4. However, improvements on San Pablo Avenue would contribute to significant reductions in freeway traffic volumes across several freeways. As shown later, this alternative would greatly help to reduce congestion if it were implemented in combination with other TSM measures.

4. *Signal improvements on Hollis Street.* Improvements along Hollis Street would have some effect on arterial traffic paralleling I-880 without major changes in freeway ramp movements on I-580, I-880, and I-980. Hollis Street could be a truck route for port-related traffic. Any reduction of truck traffic on Interstates 880, 580, and 980 would increase operating capacity for passenger cars on these freeways.

This alternative would rank fourth in terms of systemwide cost-effectiveness, costing $3.39 per yearly VHT reduced. Improvements on Hollis Street thus would provide easier, less-congested access to the north of the distribution structure for trucks and other vehicles from Peralta Street instead of via Cypress Street and I-80 eastbound, which were already congested during morning and evening peak periods. The effectiveness of this alternative would be limited to areas adjacent to Peralta Street, Hollis Street, and some of San Pablo Avenue. Some reduction in traffic on freeways would be noted on I-980, Route 24, I-880, and I-580. This alternative would rank similarly to improvements to San Pablo Avenue in terms of systemwide cost-effectiveness but better in terms of freeway cost-effectiveness. Furthermore, it could be used effectively in combination with other TSM measures.

5. *HOV lanes on westbound West Grand Avenue.* This proposal to provide an HOV lane on westbound Grand Avenue from Campbell Street to the San Francisco–Oakland Bay Bridge toll plaza would reduce daily systemwide VHT by 770. Table 2 indicates that the majority of reduction would be on freeways. This systemwide and freeway cost-effectiveness of this alternative given in Table 4 would put it second behind improvements to West Grand and Northgate. The introduction of an HOV lane on West Grand Avenue would be most successful in combination with other TSM measures.

6. *MacArthur Boulevard extension and Ettie Street ramps.* Although this alternative would involve extensive construction, the VHT reduced systemwide would not be as substantial as Alternatives 2, 3, and 5. However, travel on freeways would be reduced. This alternative would also cause minor VHT reductions on major and minor arterials. Systemwide and freeway cost-effectiveness would be low because of the high cost of implementation. This alternative would rank sixth in cost-effectiveness and in VHT reduction on freeways.

7. *Widen eastbound mainline I-580 and modify I-580/I-980 and I-580/I-80 connectors.* This alternative would cause similar changes in travel patterns for morning and evening peak periods. This was also one of the alternatives that would not cause any reduction in VHT on freeways or on minor and major arterials. Furthermore, it would divert traffic from West Grand Avenue to I-580 and I-980 and thus contradict the objective of the TSM measures. This was not desirable, although the alternative could be used in combination with other TSM measures to produce more desirable results.

8. *Widen westbound I-980 between I-580 and I-80.* This alternative would have little effect by itself. The introduction of capacity to the connectors and to I-980 would allow more traffic into the freeway system, increasing congestion on bottleneck sections of I-980. Because of the low systemwide VHT reduction, the cost-effectiveness would not be significant. It would cost only $300,000 to implement this alternative, so it still may be combined with other TSM measures to produce better results.

9. *Improvements to westbound I-80/Powell Street ramps.* This proposal would construct two buttonhook ramps and a new lane from the Powell Street on-ramp to the distribution structure in the westbound direction of I-80. It would cause a significant increase in daily VHT, 10 percent of which would be due to an increase on freeways. Because the I-80 freeway segment between Powell Street and the distribution structure were already severely congested, the introduction of an extra lane and the reconstruction of hook ramps to provide longer weaving distance would only allow more traffic to get into the freeway system and be delayed at bottleneck points. Thus, the cost-effectiveness would be zero because of the high cost of implementation and no VHT reduction systemwide. This alternative would not meet the TSM objectives.

10. *Widen eastbound I-80/Powell Street on-ramp.* This proposal would widen the eastbound on-ramp to I-80 from Powell Street and provide a free right turn from westbound Powell Street onto the ramp. No changes in freeway volumes or daily VHT were predicted. It can be concluded that this improvement would be insignificant in affecting the network.

11. *Ramp metering along Route 24 and Interstates 80, 580, 880, and 980.* This alternative would achieve desirable results in terms of reducing freeway traffic volumes on I-980, I-580, and I-80. It would reduce daily VHT on freeways by almost 2,260, but it would increase VHT on surface streets by an equivalent amount. This was the alternative that would offer the highest reduction in VHT on freeways.

It appears that this alternative would also reduce traffic congestion on the distribution structure, especially during the evening peak and some during the morning peak, and thus reduce VHT on freeways and for the whole system. During the evening peak period, this alternative would have a more widespread effect on arterials such as San Pablo, Seventh, MacArthur, Northgate, and Broadway. All would experience an increase in traffic volumes that were diverted from freeways by ramp metering.

With the cost of each ramp meter estimated at $150,000, the total cost for this alternative was estimated to be $5.25 million. This measure would rank among the lowest in cost-effectiveness, but it would achieve the overall objective of reducing traffic on the freeway system and reducing VHT.

ANALYSIS OF COMBINATION ALTERNATIVES

In reviewing the volume-difference plots for each alternative, it was theorized that certain characteristics of each alternative could be combined to achieve better results. The interim TSM alternatives analyzed were thus categorized into three main sets. The first set included Alternatives 1–6, which primarily involved improvements to arterials and signal progression. The second set included Alternatives 7–10, which were mainly capacity increases to selected freeway segments and ramp connectors. Alternative 11, the freeway ramp metering alternative, was the only additional alternative in the third set.

Developing combined TSM alternatives involved consideration of freeway congestion relief in selected directions. The results of combining freeway measures with arterial improvements produced remarkable results. These combinations displayed a synergistic effect, in which the coordinated benefits from a combination of alternatives were greater than the sum of benefits from the individual alternatives—the whole was greater than the sum of its parts.

Synergistic Effect of Combination Alternatives

Combinations 1–7 were various combinations of Alternatives 1–11. Various combinations of street improvements were incorporated in Combinations 1–3. Combination 4 was a combination of freeway improvements. Ramp metering was combined with arterial projects in Combination 5 and with freeway projects in Combination 6. Combination 7 was the "chef's special": it included all street and freeway improvements, including ramp metering.

Table 3 compares the benefits of various combinations in terms of VHT reduction by facility type and includes benefits of each combination and the sum of benefits from individual measures in that combination. The increase in combined benefits compared with the sum of benefits gained by individual alternatives is the synergistic effect.

Synergistic effects reducing up to 12,835 VHT were reached in this evaluation, and in some cases no effect was shown on certain facility types (which indicates incompatibility). Overall, all the combinations would have synergistic effects except Combination 2. Combining street improvements and ramp metering would have systemwide synergy for reducing 4,675 VHT, four to five times more combined VHT reduced than the sum of the VHT reduced by individual alternatives.

Synergistic Effect of Arterial Combinations

All the TSM measures that included improvements to arterials would relieve congestion on freeways. Most of them would also reduce delay on minor arterials and throughout the system. Because of their low costs of implementation, these alternatives would perform better than freeway improvements in terms of cost-effectiveness. The performances of these individual alternatives would be, however, restricted by low-level improvements on selected arterials. These selected improvements would create some bottlenecks and increased congestion where projects ended. Thus, these alternatives would not produce optimum networkwide benefits, as had been anticipated. Under such circumstances, a need was identified to combine some alternatives to prevent bottlenecks and harness the favorable synergistic effects.

Combination 1, which included Alternatives 1, 2, 4, and 5, is a good example of the synergistic effect. Alternatives 1, 2, and 4 individually would cause increased delay on major and minor arterials combined, minimizing systemwide benefits. Alternative 5, however, would cause significant delay reduction on all facility types, so the net benefit produced by the combination of these alternatives would be a significant systemwide synergistic effect, as shown in Table 4.

Combination 2 includes Alternatives 1–5. This combination would significantly reduce congestion on minor arterials but the increased congestion on San Pablo Avenue would be more significant than the gains made by combining the alternatives. This is the only combination among the seven considered that would not produce a systemwide synergistic effect. One solution would be to include some geometric improvements at intersections in addition to signal coordination and to extend the limits of improvements at both ends of the project.

Analysis of the results from Combination 4 and a comparison with the results from Alternative 11 produced an important conclusion about ramp metering. Alternative 11 indicated that ramp metering would reduce congestion on freeways but cause significant diversion to major and minor arterials, resulting in no systemwide benefit. Because no improvements would be made to the arterial system in conjunction with the ramp metering in this combination, the level of service of the arterials would decrease because of increases in traffic.

A solution proposed to reduce arterial congestion included improvement of local arterials along with ramp metering. Combination 4 would accomplish this with considerable benefits to freeways, minor arterials, and all facilities. Major arterials, however, would require further improvements, such as extending the project limits and geometric modifications at intersections. The systemwide benefit of 4,675 VHT in delay reduction in Combination 5 would be the highest among the combination alternatives. This indicates that ramp metering should be accompanied by simultaneous improvements to the local arterial system to relieve systemwide congestion.

Synergistic Effect of Freeway Combinations

The second set of TSM alternatives analyzed were the freeway improvement alternatives, including Alternatives 7–10. Surprisingly, these improvements would increase congestion on all types of facilities in the network. The main reason for the poor showings is apparently that the increase in capacity on the freeways would cause some diversion of traffic from the arterial system to the freeway system. The improvements would also create capacity for through traffic that previously used alternative freeway routes. The freeway improvements would not relieve congestion on the arterial system.

The synergistic effect of Combination 4 (Alternatives 7–9), however, is encouraging. Combination 4 shows a synergistic effect of 5,165 VHT reduced on all facilities combined. The freeways do not show any synergistic effect, though, which means that the combination would not help to relieve congestion on freeways. It can be concluded at this stage that individual freeway improvements would help the arterial system but hurt the freeways. However, arterial benefits could be realized only by combining the various freeway improvements, not individually. It is then concluded that the arterial improvements would be more effective than freeway alternatives in relieving freeway congestion. As for a synergistic effect, a combination of freeway and arterial improvements would be worth exploring.

The combinations of freeway improvements with ramp metering is shown on Combination 5. This combination displays similar characteristics to Alternative 11, which is freeway ramp metering without arterial improvements. This combination would also produce results that are directly opposite of those that would be produced by Combination 3 (freeway improvements combination without ramp metering). In Combination 3, congestion would be relieved on the freeways but worsened on the arterial system. Synergistic effect on this combination would be negligible.

Synergistic Effect of Freeway and Arterial Combinations

Maximum systemwide benefit in congestion relief would be obtained in Combination 7, which includes all arterial and freeway improvements and ramp metering. This combination would have an additional systemwide synergistic effect of more than 12,300 VHT reduced.

FHWA REVIEW OF ALTERNATIVES

Caltrans submitted an interim traffic relief plan to FHWA to qualify for emergency relief funding. The plan included the alternatives in this paper and others proposed by transit agencies. The freeway and arterial alternatives in the package included information presented in this paper. FHWA responded to the package within weeks, and its responses to freeway and arterial improvements are summarized in this section.

FHWA reviewed each freeway and arterial improvement project for cost-effectiveness, as well as for the probability that each project would be fully operational by the target date. FHWA approved local city street improvements such as West Grand, Adeline, Market, Brush, Castro, Northgate, San Pablo, and Hollis. These streets were approved as Alternatives 1–4.

Alternative 5 was first conditionally approved but later dropped because of feasibility reasons. Alternative 6 was not approved as proposed because the implementation time would be too long and the project would conflict with using the 32nd Street on-ramp as an HOV entrance. However, a lesser project of extending MacArthur to Hollis was to be considered if it could be implemented within the established time limit.

Alternative 7 was partially approved. The ramp connector modifications were approved as an excellent example of a low-cost operational improvement. However, the mainline I-580 widening was conditionally approved: it must be split-funded using system and emergency relief funds. The use of emergency relief funds is considered necessary to expedite the design and construction of the project. The ramp connector from westbound I-580 to eastbound I-80 was not approved at this time because of the implementation time and staging requirements for building the distribution structure.

Alternative 8 was approved and considered another good example of a low-cost operational and capacity improvement. Alternative 9 was not approved because the interchange would not serve the I-880/Cypress traffic and the project would take too long. Alternative 10 was approved as long as signing is provided at Hollis Street and San Pablo Avenue to advise eastbound I-80 travelers of its availability.

FHWA supported Alternative 11. The ramp meters at critical ramps that can be implemented by the set deadline were approved. Because ramp metering is a new concept in this area, Caltrans must take appropriate marketing measures as part of the implementation process.

CONCLUSIONS

Several conclusions can be based on the results of this analysis. First, low-cost improvements on arterials paralleling the congested Oakland freeways would be more effective in relieving freeway congestion than selected low-cost improvements to the freeways themselves. This is because minor freeway improvements attract traffic to the freeways whereas arterial improvements divert traffic from the freeways. Second, metering freeway on-ramps without improving adjacent arterials would worsen congestion on the arterial system much more than it would lessen congestion on freeways. Third, the most effective TSM alternative to relieve congestion on freeways would include minor freeway improvements with arterial signal coordination, along with freeway ramp metering at bottleneck locations. The final recommendation is that the synergistic effect of project combinations be included as one of the measures of effectiveness to rank low-cost TSM alternatives. Table 4 summarizes the benefits, cost-effectiveness, and FHWA response for all the alternatives studied. FHWA clearly approved alternatives with low implementation costs and significant contribution reducing freeway delay. Synergistic effect was also high for combination of approved alternatives.

Although the methodology described in this paper was applied to projects resulting from the Loma Prieta earthquake in order to qualify for the FHWA emergency relief funds, the computer travel forecast model and measures of effectiveness employed are typical analysis tools used for most urban transportation projects. The process used in the methodology was independent of the cause that initiated the work. Furthermore, every effort was made for the methodology and measures of effectiveness to adhere to FHWA and Caltrans guidelines on project evaluation, and the results were accepted by both agencies. The results presented in this paper have tremendous applications for TSM studies nationwide that evaluate arterial improvements, freeway improvements, and ramp metering.

REFERENCE

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