HOV Lanes and Ramp Metering: Can They Work Together for Air Quality?

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The analysis process used to assess the air quality impacts of high-occupancy-vehicle (HOV) lane and ramp metering projects is discussed, and the degree to which these popular measures are effective and compatible when jointly applied to improve freeway operations is examined. It happens that there exist subtle and potentially perverse interrelationships between HOV lanes and ramp metering. Also, in an environment of worsening congestion, ramp metering has a limited life. Proper management of these respective systems can occur only when they are administered with full acknowledgment of their mutual interdependence and with a long-term view of their relative potential.

Transportation agencies in California currently find themselves having great difficulty proving air quality conformity with regulations stemming from the Clean Air Act for the favored traffic management measures of the moment: high-occupancy-vehicle (HOV) lanes and ramp metering projects. These two traffic management measures become intimately related when they coexist, in which case the analysis procedure for evaluating air quality impacts becomes quite involved.

Figure 1 is an effort to illustrate the process of analysis and decision making required in the San Francisco Bay Area to gain approval for HOV lane and ramp metering projects at the regional level. The point of the illustration is to emphasize the complexity of the process and the key role of analytical modeling in informing the eventual decision for or against a project.

The purpose of this paper is to provide a perspective on this analysis process and to examine in detail the degree to which these popular measures are effective and compatible when jointly applied to improve freeway operations. The adequacy of the methodologies used to analyze such projects is also addressed. It is argued that there exist subtle and potentially perverse interrelationships between HOV lanes and ramp metering. It is essential to address these interrelationships directly so that proper decisions can be made regarding the times and places to deploy either or both of these traffic management options.

RAMP METERING

Ramp metering projects attempt to hold traffic demand at freeway bottlenecks below their capacities, eliminating most mainline queue delays by imposing much smaller delays on vehicles temporarily held back on the ramps. Ramp metering also fills in naturally occurring gaps in the freeway traffic stream, resulting in smoother operation, greater flow rates, and less backup. Metering may also result in diversion of some very short trips from the freeways altogether.

Ramp metering is designed to reduce travel times and improve safety by eliminating stop-and-go driving conditions. The resulting higher speeds also reduce the carbon monoxide (CO) emissions along the freeway mainline. But, until recently, no one had thought much about the air quality consequences of the resulting on-ramp backups and the altered ramp acceleration behaviors.

The California Department of Transportation (Caltrans) recently performed air quality impact modeling to assess ramp metering projects along US-101 and Interstate 880 in the San Francisco Bay Area. Consideration was limited to the possibility of CO hotspots with no effort to determine areawide air quality impacts. In some instances, the modeled receptors next to proposed metered on ramps yielded CO excesses that rivaled those reduced excesses computed along the more smoothly operating freeway mainline.

Initial (as yet unpublished) investigations by consultants to the California Air Resources Board (CARB) and Caltrans revealed very high tailpipe emission rates when stop bars and meters are positioned near the on-ramp merge locations. The shortened acceleration distances seemed to result in increased acceleration rates for entering cars and higher emission. However, another recently completed study for CARB and Caltrans found no consistent differences in acceleration behavior from reduced acceleration distances per se except on heavily congested mainline freeways without auxiliary lanes (*1*).

In any case, moving the stop bar back along the ramp to lengthen acceleration distances reduces available storage for metered traffic, resulting in little flexibility for setting future metering rates. Queuing is required to stop short of the adjacent street intersection, because cities do not permit metered traffic to overflow onto city streets. The solution, if possible, is to rebuild ramps to provide greater lengths and widths for vehicle storage or auxiliary lanes to facilitate merging, or both; however, financial and land availability constraints often render such improvements infeasible.

HOV LANES

The theory behind the HOV lane program is that when mixed-flow traffic becomes sufficiently delayed, the time savings enjoyed by HOV lane users will promote carpool formation among the drivers of single-occupant vehicles (SOVs). There is some evidence that such a mode shift impact has occurred in some situations. For example, Pratt (*2*) reports reductions ranging from a few percent to over 20 percent in vehicles per person associated with vanpool and carpool increases on the Interstate-10 El Monte Busway, Shirley Highway, and the Houston transitways. However, significant mode shifts have not occurred to a marked degree at all installations.

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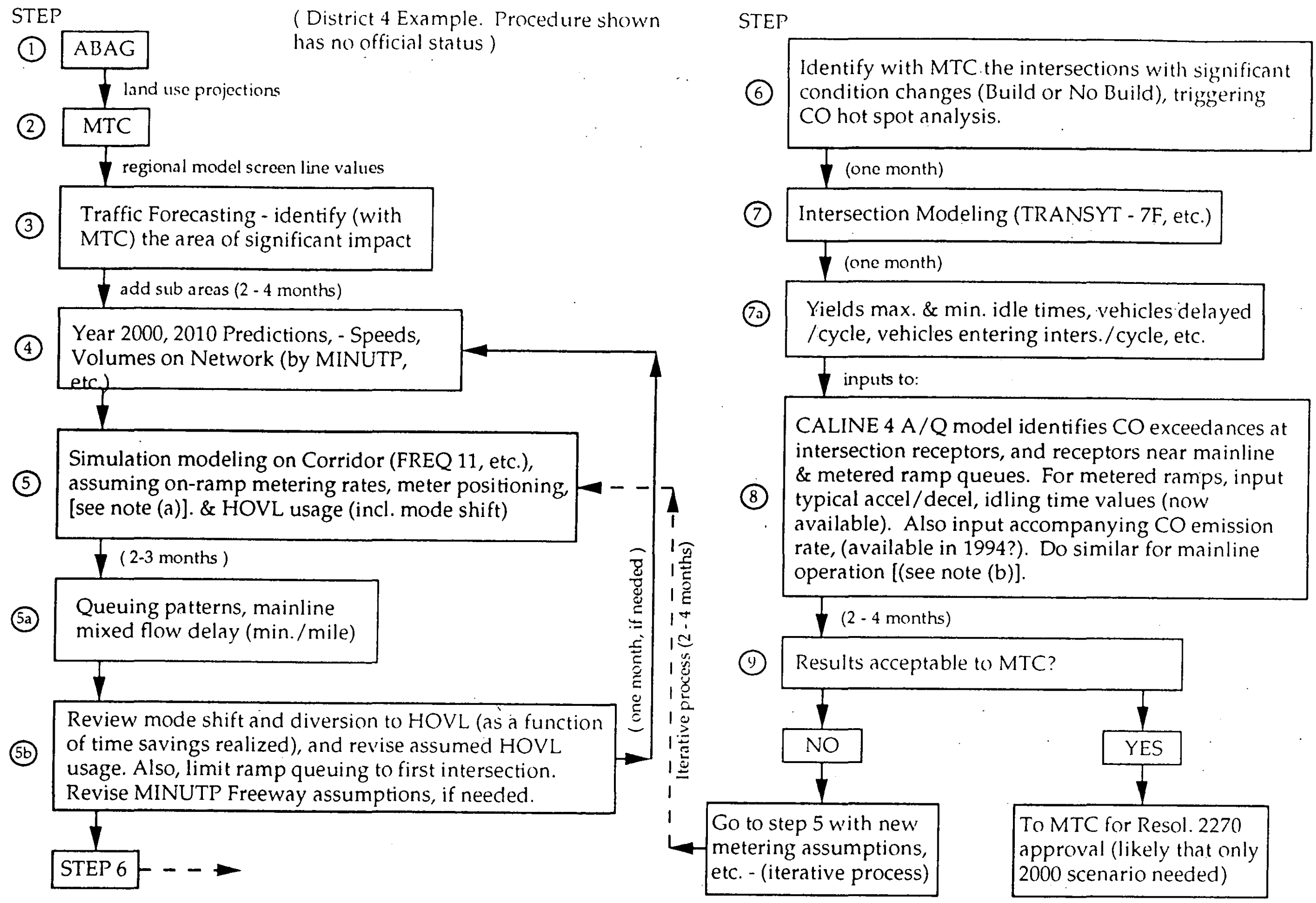

Footnotes

(a) Metering and stop bar positioning critical (e.g.) placing at on-ramp nose results in short acceleration distance. The high acceleration rate needed results in very high CO emission rates. But placing farther upstream lowers acceleration rates, but means reduced storage.

(b) "Dynamic" modeling of the street network (i.e. simulation modeling similar to that already employed on the freeway by FREQ 11, etc.) will be available in two to five years. At present, only average link speeds are available. When queuing, accel/decel/idling profiles (including CO emission breakdowns) become available, the constant speed attributes of HOVL operation will become apparent in CO evaluations, - especially if an (area wide) burden analysis (i.e. total tailpipe emissions for the area) is run.

FIGURE 1 Typical freeway project adding HOV lanes and ramp metering.

The inconsistent results with regard to mode shift have a variety of explanations. Perhaps the major one is the necessity that, for fundamental mode shifts to occur, chronic congestion must exist with the prospect of only getting worse. Such congestion would not be alleviated, other than momentarily, by ramp metering or other operational improvements.

Figure 2 presents a summary of the varying success reported for a number of HOV facilities constructed across the country (*3–6*). The graph shows the first-year increases in carpooling related to the time savings per unit distance and the corresponding speed differences, assuming an HOV lane speed of 100 km/hr (60 mph). Unfortunately, the results for some installations are deceptive because the increase in HOV users often can be attributed to the migration of existing carpools from parallel arterials. In this regard, the only way to be sure of actual carpool formation is through a corridor-wide survey. This has been done in the case of the highly successful California State Route 55 operation in Orange County, thus ensuring that the more than doubling of HOV eligibles has indeed largely come from those who previously drove alone (*3,7*). In any case, shifting carpools from congested arterials to constant-speed HOV lanes offers air quality benefits, as will be explained.

A fact of life, however, is that the vacancies created by the migration of carpools to an HOV lane are typically back filled by SOVs, which may come from parallel arterials or from the mainline itself, having shifted from earlier or later periods. To the extent that back filling involves diversion from longer or more congested alternative routes, it may actually be beneficial for air quality, or the effect may be neutral if mostly time shifts are involved. However, if the new SOVs are composed of former transit riders, riders in newly generated trips, or former HOV riders from other periods, the incremental air quality consequences of back filling can be negative.

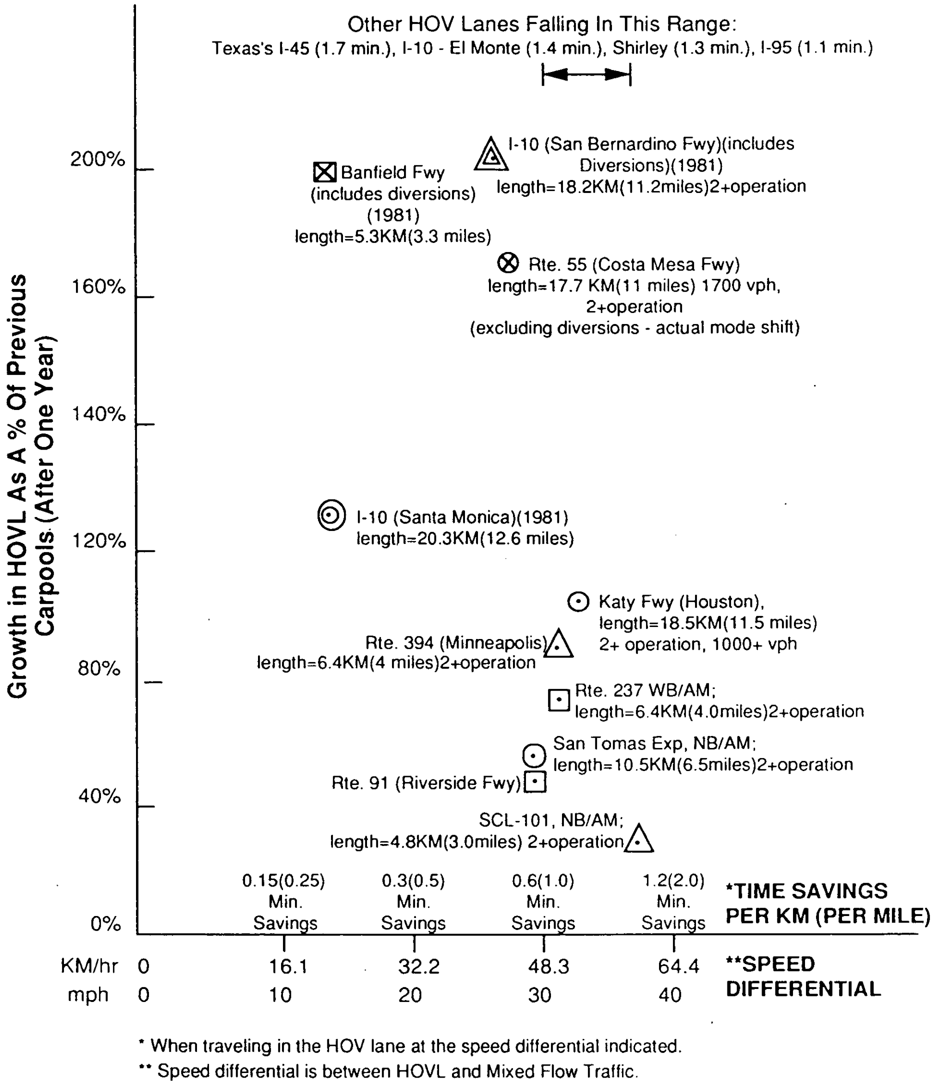

FIGURE 2 HOV lane growth versus time savings for various facilities.

Proving the air quality benefits of HOV lanes is problematic because the methodology developed thus far is largely inadequate for the task. Although traffic modeling for the freeway systems has achieved some success, modeling of the surrounding street network is still fairly primitive, viewed from the perspective of air quality impact determination.

What is needed, among other things, is an accurate assessment of the comparative traffic conditions to be experienced on the various routings from home to work. Planning models assign trips to these routings on the basis of the shortest travel times or costs. As a general rule, the higher the route speed, the lower the CO emission. For the moment the impact of CO emissions is the major hurdle in gaining project approval.

WHAT IS THE PROBLEM?

In looking at tailpipe emissions, it is important to recognize that the emissions are not simply a function of the average speed on a journey from home to work. In reality, driving in congested areas means a great deal of speeding up, slowing down, lane changing, and idling. All of these operational modes have vastly differing instantaneous emission rates. It is only when these actual driving profiles under typical urban travel conditions are understood that a true picture of the air quality consequences of typical arterial and freeway congestion and of congestion mitigation measures becomes apparent.

Most planning models depict travel in terms of constant average speeds between major intersections. The fallacy here is that congested operations with accelerations, decelerations, and idle times can produce CO emissions that are much different from those that the average speeds imply. Unfortunately, most past empirical research to develop emission factors has focused on the average vehicle emissions produced throughout a complete driving cycle rather than on the disaggregate emissions associated with the individual modes of operation. In ongoing research, CARB and others are working to gain insight into the emission impacts of various driving modes experienced on arterials, freeways, and metered on ramps.

The magnitude of the problem of estimating disaggregate mode-specific emission factors should not be underestimated. The task is made considerably more difficult because of the need to cope with the varying emissions characteristics of the composite fleet on the road. Emissions characteristics vary with model, vehicle age, and factors such as the deteriorating efficiency over time of catalytic converters. The emission differences among various vehicles become amplified when the averaging effects of driving cycles are eliminated. Therefore, it may be years before the requisite disaggregate profiles of vehicle operation and emission rates have been agreed on and made available.

Meanwhile, there are continuing efforts to reduce, and perhaps some day eliminate, vehicle pollution emissions. Although solving the motor vehicle air pollution problem would simplify the analysis, the need for careful evaluation of the effectiveness and synergetic relationships of HOV lane and ramp metering projects would remain, with attention more focused on user benefits and other mobility impacts.

Work is proceeding to improve the dynamic modeling of traffic performance in mixed arterial and freeway networks, which will become increasingly relevant to the evaluation of HOV and ramp metering projects. The goal is to be able to realistically model the actual performance of traffic flowing through a network, including the accelerations, decelerations, and cruise and idle periods resulting from both traffic congestion and the various traffic control devices that operate throughout the network.

Fortunately, a great deal of progress has been made in traffic modeling over the past several years. A number of microscopic models now exist that can track individual vehicles through fairly large mixed freeway-arterial networks and provide quite realistic representation of the development, propagation, and eventual shrinkage of queues, along with plausible traveler diversion behavior in the face of recurring and nonrecurring congestion (*8–12*). Although not trivial, the goal of extending such traffic models to provide location-specific vehicle operational mode data for use as input to disaggregate mode-specific emission models as well as other impact models is within reach. Once these traffic models have been extended and the necessary mode-specific emission factors are made available for all the relevant pollutant species, the evaluation of HOV lanes and ramp metering projects and their systemwide air quality impacts on urban corridors will become a reality.

DO RAMP METERING AND HOV LANES WORK TOGETHER?

With traffic operations centers utilizing camera and loop detector surveillance, one regularly seeks to optimize freeway operating conditions by varying metering rates at on ramps. This sounds sensible enough until it is realized that the HOV lanes can be part of the equation.

HOV lanes succeed in promoting mode shift only when they realize a significant time saving, on the order of a 0.5 min/km (1 min/mi). This value corresponds to mixed-flow traffic moving no faster than an average of 50 to 65 km/hr (30 to 40 mph). This seems to place the metering program goals at loggerheads with those of the HOV lane program, and it may be some time before there is a meeting of the minds on the proper roles of these two strategies.

On the other hand, if ramp metering can be tuned carefully so that the mainline freeway operates consistently in the range of 50 to 65 km/hr (30 to 40 mph), and if the extent of HOV systems is sufficient to provide the long journey lengths needed to produce significant cumulative travel time savings for HOV users, the promise of both of these traffic management strategies could theoretically be achieved together. Speeds in the range of 50 to 65 km/hr (30 to 40 mph) largely correspond to the upper end of freeway conditions at Level of Service E. This is exactly the range that yields the greatest traffic throughput on the mixed-flow lanes, assuming that traffic flow stability can be maintained and at the same time provides sufficient long-term incentives toward greater HOV participation.

Of course, the assumption that traffic flow stability can be maintained is a significant one. Under today's operating conditions, consistently maintaining stable flow near capacity is difficult. However, some of the new vehicle control technologies now being developed through the national Intelligent Vehicle-Highway System (IVHS) initiative may result in basic operational improvements that can make this requirement easier to achieve.

Bearing on this picture is the realization that in an atmosphere of worsening congestion, ramp metering has a limited life. Perhaps a fourth of the meters in Los Angeles already have become useless during the most congested periods of the day. This typically occurs when on-ramp queues start overflowing onto city streets and the meters have to be turned off.

With the support of FHWA and, thus far, with the support of the air quality monitoring agencies, both ramp metering and HOV lane programs have achieved considerable momentum. However, both programs are increasingly under attack, in part because of the inability to demonstrate convincingly that when properly designed and coordinated, these facilities represent the best practical strategy available for achieving improved air quality as well as increased user benefits. This situation may change after the needed planning tools discussed earlier are developed, which will enable a more scientific evaluation of the impacts of these programs and whatever synergetic relationships they may prove to have.

The short-run view perhaps should be that ramp metering with centralized monitoring (and HOV lane bypass of the meters) offers the greatest promise. As congestion worsens, however, and many meter locations become less effective because of excessive queue lengths, HOV lanes will become increasingly attractive as their trip time savings accrue.

Meanwhile, proper management of these respective systems can occur only when they are administered with full acknowledgment of their mutual interdependence and with a long-term view of their relative potential. An enormous investment is being made in both programs. It is important that their respective roles not be compromised. State and federal leadership in this regard is essential to establishing the necessary perspective. Otherwise, the situation could easily become competitive and counterproductive, resulting in a deterioration of public confidence and cooperation with either program.

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