

**FREQ Simulation and
Ramp Meter/HOV Bypass Optimization
for the
Northwest Study Area**

May 2008

By

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Abstract:

The I-290 / Illinois Route 53 corridor in the west and northwest suburban areas of Chicago suffers from heavy congestion throughout and beyond peak travel periods. Traffic management strategies, particularly ramp access strategies prioritizing high occupancy vehicle (HOV) travel, have been recommended as a means of mitigating and even reducing congestion in this corridor. The FREQ model developed by the University of California, in part assisted by the VISSIM modeling tool for bottleneck calibration, was used to determine the effect of implementing HOV priority strategies on entry ramps along the I-290 / IL 53 corridor.

FREQ model inputs were based on available historical and forecasted traffic data and network parameters. Several ramp meter and ramp HOV priority bypass scenarios were tested to determine potential year 2030 improvements in several performance measures from the forecasted 2030 base conditions.

Findings derived from application of these various scenarios indicated net *reductions* from 2030 base in: passenger-hours of travel (PHT) ranging from 2.0% to 15.4%, and tons of volatile organic compounds (VOCs) emitted from 2.4% to 13.5%. Vehicle-miles traveled (VMT) and gallons of fuel consumed remain relatively constant across scenarios.

In addition to the results of the FREQ analysis, present-day expressway and arterial highway design characteristics that adversely impact vehicle capacity and queue storage capability of ramps are identified and explained.

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I. Purpose and Need

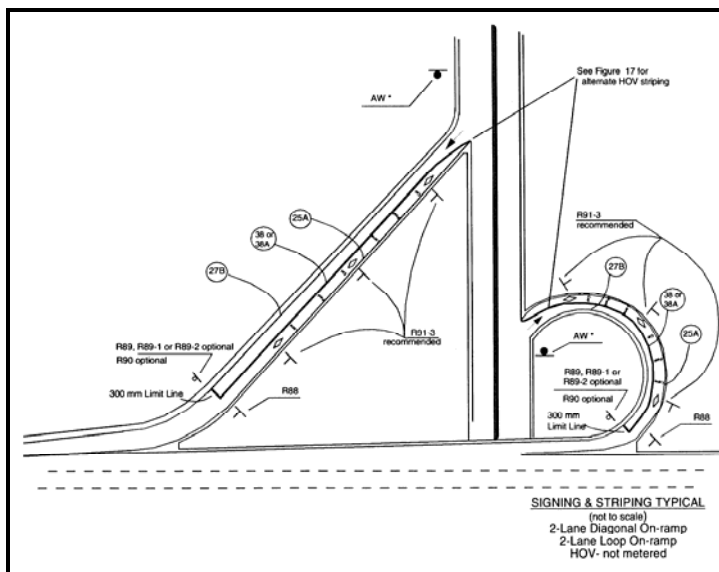
A report by American Highway Users Alliance, a non-profit transportation advocacy group based in Washington D.C. ranked the sections between Exit 17b (U.S. Route 45 or Mannheim Road) and Exit 23a (Illinois Route 50 or Cicero Avenue) of the I-290 Interstate Expressway as the 19th worst bottleneck in the nation (American Highway Users Alliance, 2004). The report also estimates that without any improvement, the delay¹ at the aforementioned bottleneck will increase from 14.4 minutes in 2002 to 19.2 minutes by 2025 (page 56). In regards to truck traffic, I-290 features two of the nation's 20 worst truck traffic bottlenecks – at the downtown I-90/94 “Spaghetti Bowl” junction (4th worst) and at the merge with I-355 in northeastern DuPage County (17th). The two bottlenecks combined for 6.94 million hours of travel delay in calendar year 2005 (FHWA Highway Interchange Bottlenecks National Study, 2005).

The overarching purpose of this study is to assess the effectiveness of implementing of ramp meters with and without HOV bypass lanes, for the I-290 corridor.

HOV Lane Concept Overview

HOV bypass lanes, or HOV priority entry (HOV PE) differs from the more commonly discussed expressway HOV Lane strategy. An HOV Lane is a through expressway lane dedicated to use solely by high occupancy (2+ or 3+ occupant) passenger vehicles, commuter vans or buses. In recent years, to maximize the vehicle carrying capacity of HOV lane facilities, several state and local transportation entities have made access to HOV lanes available to drive-alone (or SOV) vehicles paying a toll (High Occupancy Toll, or HOT, Lanes) or to low emission vehicles such as motorcycles or hybrids.

Figure 1 Design Diagram, Metered Freeway Ramps with HOV Priority Entry Lane (Left Lane)



Source: [FHWA, Ramp Management and Control Handbook](#)

¹ The difference in travel time between free-flow and congested conditions.

The desired outcome is a lower number of vehicles carrying a higher number of persons on the mainline expressway. Ramp metering, HOV PE in particular, is also expected to encourage carpooling or transit use in order to take advantage of the improved expressway facility. However, traffic volume and congestion of traffic flow on ramps and on crossing and parallel arterial roads may be increased through application of the ramp meters. The ability of the arterial system to accommodate diverted traffic flows depends on the capacity available for queued vehicles at ramp junction intersections.

Furthermore, ramp meters are known to reduce accidents. Minnesota DOT turned off 430 ramp meters along its expressway systems in the Twin Cities region for seven weeks in 2000. During this period travel times increased, crashes increased by 26% and volume on affected freeways decreased by 14%. Immediately subsequent, the ramp meters were returned to full operation. (Cambridge Systematics, 2001). Since delays caused by incidents account for 50% or more of total congestion in urban areas (Transportation Research Board, 2001), reducing accidents will lead to a decreased level of congestion.

While ramp metering is not the only option to improve the traffic flow along the I-290 corridor, its history of successes in other areas such as California, Minneapolis, Texas, and Milwaukee (USDOT, 1995, Cambridge Systematics, 2001), makes it a strong candidate that warrants an assessment of its applicability.

II. Background

This study of the I-290 corridor is comparable in format, simulation methodology, analysis and presentation of achieved benefit results to the extensive FREQ study of the South Study Area – Dan Ryan, Bishop Ford Freeway and I-57 – by CMAP staff in 2001 (Doenges, 2001). This study builds on the previous effort by CMAP staff that developed the FREQ simulation model for the I-290 corridor (Schermann, 2005).

This report documents additional work that has been performed by Kazuya Kawamura and Amir Samimi of the Urban Transportation Center at the University of Illinois, Chicago under the direction of Jose Rodriguez and Thomas Vick of CMAP². The work included:

- Data preparation and coding of the sections between Austin Avenue Interchange and Independence Boulevard Interchange
- Identification, data preparation, and coding of parallel arterials
- Data preparation and coding of VISSIM simulation for the I-88/I-294/I-290 Interchange
- Calibration, optimization, and simulation of existing conditions and future scenarios

² Vick retired from CMAP in November 2007, but provided input to the report.

diversion (called “spatial response”) possibilities that will be discussed later in this report. In FREQ, both types of spatial diversion assume that the trip origin is within the FREQ study area. Thus, FREQ does not simulate the route diversion for the trips that are merely passing through the corridor (i.e. both origin and destination outside the study area). One additional point worth mentioning is that FREQ does not simulate each of the individual surface streets separately as a potential diversion route. Rather, all the potential diversion routes are bundled together to form, in essence, a “parallel corridor”. Thus, the input for the parallel corridor must represent the aggregate characteristics of a combination of all the potential surface streets that are potential diversion routes.

With these assumptions in mind, a set of surface streets shown in Table 1 were chosen as potential parallel arterials. The basic criteria for selection were that the surface street:

- has sufficient capacity to accommodate diverted trips
- runs parallel to the I-290/IL53 for at least 3 miles
- is in the vicinity of the I-290/IL53 and is a known alternative route.

Table 1. List of Parallel Arterials

1. Meacham/Medinah (from Euclid Ave. to Lake)
2. Rohwling/Martingale (from Higgins Rd. to Lake St.)
3. Elmhurst Rd./York Rd. (from Lake-Cook to Cermak)
4. Arlington Heights Rd. (from Lake-Cook to Thorndale)
5. IL-83/Busse/Kingery (from Algonquin to Cerm)
6. Thorndale/Elgin-O’Hare (from Meacham to York)
7. Roosevelt (from Kingery Hwy to Eastern terminus)
8. Cermak (from Kingery Hwy to Eastern terminus)
9. US-20/Lake (from Medinah to Harlem)

Since the study corridor bends 90 degrees, combinations of north-south and east-west streets had to be considered as a potential diversion route.

Scope of the Study

The overarching goals of this study were to determine the traveler (passenger), system (VMT), and environmental (VOCs and gallons of fuel reduced) benefits achieved through an expressway corridor application of HOV ramp priority entry. Given the wider ranging impacts on the surrounding arterial system and the inclusion of an extensive alternate arterial network, a meso-scopic simulation model capable of integrating data elements from a larger area than a corridor was needed for this analysis. Meso-scopic simulation models are also less labor and data intensive than standard microscopic simulation models which require large volumes of custom prepared data focused on a single corridor.

FREQ was originally developed by the University of California at Berkeley’s Institute of Transportation Studies for use by the California Department of Transportation (Caltrans). The model was originally created in 1970 to be used as a tool to evaluate an improvement plan on a 140-mile segment of expressway in the San Francisco area. FREQ is currently

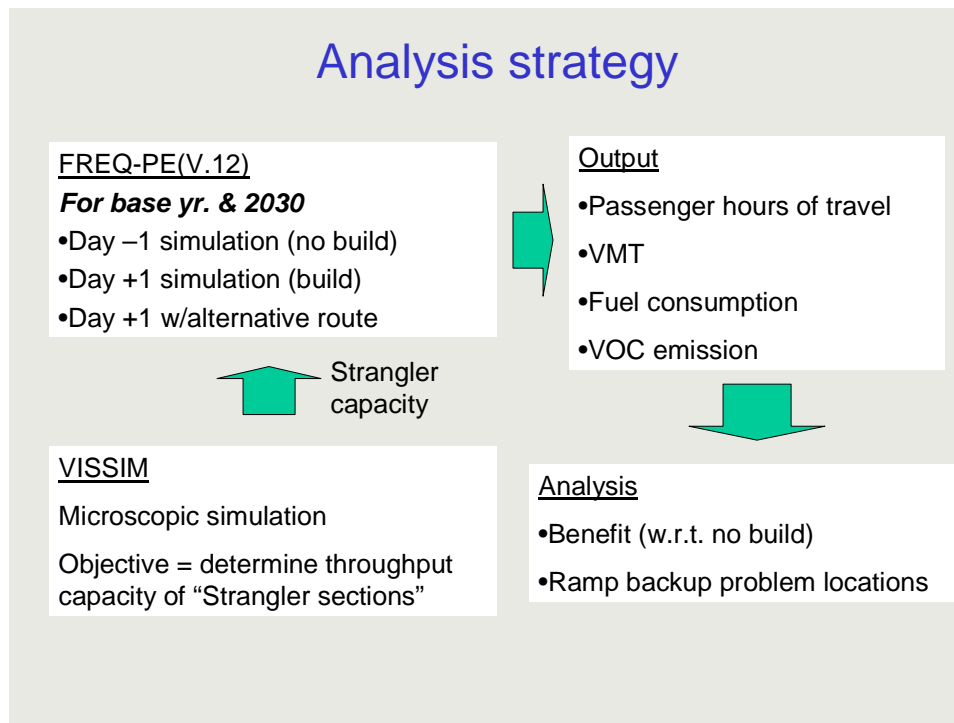
in its 12th version and has been improved to evaluate the effect of implementing HOV facilities on an expressway system. The FREQ model works on “pipeline” theory and generates synthetic origin-destination (O-D) trip tables based on traffic count data entered by the user into the model; the specific user inputs are explained below in Section III, Input Data. The FREQ model is capable of two types of general analyses: (1) priority lane (PL) to examine the effect of mainline HOV lanes or (2) priority entry (PE) to examine the effect of on-ramp HOV bypass lanes (Doenges, 2001). For the purpose of this study the FREQ PE model was used.

Preliminary work for FREQ modeling has been completed by the CMAP staff between 2001 and 2003. Detailed descriptions of the methodologies used to generate the input traffic volumes for both the mainline and ramps are included in the aforementioned CATS working paper (Schermann, 2005). One critical assumption that was inherited from Schermann’s work is the base year of simulation. As was for the Schermann’s work, March of 2002 was used as the base year for the traffic volumes. This is justified by the fact that traffic volumes for the I-290/IL53 corridor have been generally stable between 2002 and 2007.

Modeling Strategy

depicts the overall strategy for assessing the potential benefit of ramp metering strategies for the study corridor.

Figure 3 Overview of FREQ and VISSIM Modeling Strategy



VISSIM Simulation

One of the weaknesses of the FREQ program is its analysis of weaving sections. FREQ estimates the capacity of weaving sections using the method from the 1965 Highway Capacity Manual. As such it is not fully capable of analyzing complex weaving sections such as the I-290/I-88/I-294 interchange. To address this shortcoming, a micro-simulation model was developed for the I-290/I-88/I-294 interchange using the VISSIM software to obtain an accurate estimate of the capacity. VISSIM is a simulation tool that can be used to study the operation and behavior of complex roadway sections and also interrupted flow conditions. As the development of VISSIM simulation is an extremely labor and data intensive endeavor, only the I-290/I-294/I-88 Interchange was simulated.

Expanded Meso-Scopic Simulation

The FREQ analysis findings have additional importance as they may be used in estimating performance measures (or measures of effectiveness) data when ramp metering and HOV bypass strategies are considered by decision makers. Effects of ramp strategy implementation within FREQ can be inputted as appropriate algorithms in broader regional meso-scopie models used to evaluate effectiveness of ramp improvements made to links or series of links (e.g. corridors) in the regional travel network. Meso-scopie simulation models have the advantage of incorporating and utilizing actual O-D tables derived from aggregated regional traffic and demographic data. The adaptation of this report's FREQ findings on the I-290 corridor into meso-scopie simulation models for short-term and long-range strategy evaluation is envisioned as a next logical activity.

III. Simulation and Calibration

This section describes the methodology and assumptions used to carry out the development of the FREQ simulation.

Input data

The FREQ simulations were conducted for the following four time periods, each covering 8 hours.

- Inbound AM travel period (4:00AM – 12:00 Noon)
- Inbound PM travel period (12:00 Noon – 8:00 PM)
- Outbound AM travel period (4:00AM – 12:00 Noon)
- Outbound PM travel period (12:00 Noon – 8:00 PM)

It should be noted that AM and PM simulations were conducted independently. Thus, the traffic condition at the end of the AM simulation does not necessarily match the starting condition of the PM simulation.

The input data for FREQ consist of:

- Characteristics of each ramp and mainline segment including: length, number of lanes, grade, capacity, and free-flow speed
- Traffic volume and truck percentages for each mainline segment
- Characteristics of each parallel arterial segment including: capacity, grade, free-flow speed, and signal progression, and

- Average vehicle occupancy, occupancy distribution (single person, two persons, three or more persons, and bus), and percent of trucks with a diesel engine.

The physical characteristics of the ramp and expressway sections were taken from the base FREQ input file developed by CATS staff (Schermann, 2005). The configurations of the I-290/I-294/I-88 interchange and the Dundee Road interchange were modified to reflect the improvements made at those locations. The free-flow speed and the capacity for the all the arterials and also the mainline sections between Austin Avenue and Independence Boulevard were obtained from the CMAP's travel demand model. The free-flow speed and capacity for the parallel arterials are included in the Appendix.

For all the sections, with the exception of between Austin Avenue and Independence Boulevard, traffic volumes and truck percentages derived by Schermann (2005) were used. The ramp volumes for the sections between Austin Avenue and Independence Boulevard interchanges were derived from the average weekday traffic volumes recorded during the week of March 1 and 8, 2004. Although the volumes for other sections were derived based on the traffic counts from March 2002, the same data were not available for the sections between Austin Avenue and Independence Boulevard interchanges until 2004.

There are two "splits" of traffic volumes that had to be estimated from the field data. They are: the share of the traffic that splits between I-290 and the Frontage Road at Section 52, and the split between I-290 and Frontage Road for the traffic entering from I-88/I-294 (to determine the volume entering from I-88 at Section 53). The splits were estimated based on the traffic counts from 2004. The splits were then applied to the original FREQ input to derive the revised FREQ input time slice counts for Frontage Road off/on (Sections 53 and 58) for the inbound simulations.

It should be noted that for the base year simulation, the capacity and free-flow speed for the parallel routes reflect the 2007 condition while the figures were revised for the 2030 simulations to include major capital projects planned or programmed for any of the arterials listed in Table 1.

For both the mainline and the arterials, vehicle occupancy distribution was assumed to be 90% SOV, 7% 2 persons per vehicle, and 3% 3+ persons per vehicle. It was also assumed that the average occupancy for the 3+ vehicles was 3.2 persons.

Calibration

The calibration of a FREQ model involves observing the similarities and differences between simulated and observed conditions and making adjustments to the model parameters. The speed profile of each segment and the location and duration of the queues are two most important indicators of model's performance. It is imperative that the model closely replicates the observed conditions in terms of those two indicators.

Observed conditions were derived from the IDOT detector report during the November and December of 2003. The speed data from Tuesdays and Thursdays were screened first

for the signs of incidents. Then, the average speed was calculated for each time period for each segment. Speed data can also be used to identify the location and duration of the queues. The final speed profiles for both inbound (East bound) and outbound (West bound) are included in the Appendix. While it would have been desirable to use the speed profiles from March 2002, the time period for which the traffic volume data were derived, complete detector reports were not available since some of the detectors along the study segment were not functional until November of 2003.

There are two general types of parameters to be adjusted during the calibration process. The first type is the global settings such as occupancy distributions and the shape of the speed-volume curve. Although FREQ allows these parameters to be adjusted for each section, the absence of field data precludes such local adjustments in most cases. The second type is section-specific characteristics that include: capacity, free-flow speed, and the method of capacity estimation (for merging and weaving sections).

In general, once the integrity of the input data (e.g. traffic volume) is verified, the segment-by-segment adjustment of capacity is the most important process in the calibration of a FREQ model, and this study was no exception. Below, the key assumptions and adjustments made during the calibration are summarized.

Outbound (AM and PM)

- The capacity for each segment must be the same for AM and PM simulations.
- The calibration process started with the PM simulation since congestion is greater, and thus more bottleneck conditions could be observed.
- For segments without any plausible reason for capacity reduction, such as substandard configuration, 2100 vehicles per hour per lane (vphpl) was used
- The key bottlenecks for the outbound direction are: the lane drop at the Austin Avenue exit, the segments between the Harlem Avenue entrance and the 25th Avenue interchange, and the segments between the York Road entrance (Section 38) and the I-355 exit.
- While the lane reduction at the Austin exit presents a significant decrease in the capacity, another bottleneck exists between the Harlem Avenue entrance and the Des Plaines entrance. The estimated capacity for Section 12 is 5850 vehicles per hour (vph), which is equivalent of approximately 1615 vphpl, an unusually low figure for a regular expressway segment. There are several plausible explanations for this. Firstly, the left-side entrance (at Harlem Avenue) followed by the right-side entrance (at Des Plaines Avenue) leaves only the center lane without disturbance in the traffic flow. Secondly, the merging at the Harlem entrance is made difficult by the fact that due to the difference in the elevations, neither the mainline vehicles nor entering vehicles can visually recognize each other until the last moment. And finally, overpasses may present visual distraction for the drivers, especially during the merging. For other sections, congestion is caused simply by the gradual buildup of mainline volumes due to the constant stream of entering vehicles at the interchanges at Des Plaines Avenue, 1st Avenue, 17th Avenue and 25th Avenue.
- For the segments between York Road entrance and I-355 exit, a prolonged congestion, both temporary and spatially, is not caused by a single segment. Rather, a series of weaving and merging, occurring in a relatively short distance, creates a complex pattern

of disturbance. As a result, those sections operate at or near capacity for a long period of time, a condition that easily leads to congestion.

Inbound (AM and PM)

- The capacity for each segment must be the same for AM and PM simulations.
- The calibration process started with the PM simulation since congestion is greater, and thus more bottleneck conditions could be observed.
- For segments without any plausible reason for capacity reduction, such as substandard configuration, 2100 vehicles per hour per lane (vphpl) was used.
- For the inbound simulations, the default lower limb speed (the part of the speed-flow curve that represents over-saturated condition) was changed from 30 mph to 35 mph for the entire study area since the speed within the queue seem to be more accurate with the latter especially for the Dundee Road entrance to the Kirchoff Road entrance for the PM simulation.
- The key bottlenecks for the inbound direction are: Euclid Avenue entrance, Southbound I-294 connector, multiple segments between the Frontage Road merge to Austin Avenue entrance. In addition, a light speed drop is observed for the fly-over bridge at the I-290/I-355 Interchange
- The two-lane section of I-290 at the I-355 interchange is a fly-over bridge with a tight horizontal curve and a limited line of sight. Thus, the capacity and speed were decreased to 3300 vph and 50 mph, and also the highest upgrade (4%) allowed by FREQ was used.
- The effect of the queue spillover from the southbound I-294 connector was simulated by reducing the capacity of the mainline to 4000 vph⁴. This figure is extremely low for a 3-lane expressway section. During the peak periods, I-290 inbound between St. Charles Road and the southbound I-294 exit operates essentially as a two-lane segment since the outermost lane is occupied by the queued vehicles that are exiting to I-294.
- The congestion that is observed between the I-290/I-294/I-88 interchange and Austin Avenue interchange seems to be caused by the combined effect of a series of segments that are operating at or near capacity for a prolonged period of time each day. Calibrated capacities for these segments are well below 2000 vphpl, indicating a presence of factors that causes driver distraction, as discussed earlier for the outbound simulation. In addition to the overpasses and left-side entrance/exit that were mentioned as the possible factors in the previous section, the left-shoulder clearance is substandard for a short distance between the 1st Avenue and Des Plaines Avenue interchanges. Furthermore, the results indicate that the weaving sections are operating well below the expected capacity. For example, even with the auxiliary lane, the estimated capacity at the 25th Avenue interchange is only 5800 vph for a four-lane section.
- VISSIM-estimated capacity was used for the section from the Mannheim Road frontage Road entrance to the southbound 25th Avenue exit⁵.

⁴ It should be noted that congestion already exists at 12 noon, thus it is impossible to replicate the measured speed in the PM simulation. Thus, for section 50, AM run is used to estimate the capacity.

⁵ Research have shown that weaving section capacity can be significantly lower than the HCM method suggest, and the result of the VISSIM simulation confirmed it.

- The capacity for the last segment was reduced to replicate the congestion that originates around Western Avenue, which is outside of the study area.

IV. Alternate Scenarios

Using the FREQ models that were calibrated for the 2002 conditions, following alternatives for 2030 were analyzed.

- 2030 without ramp metering (base condition)
- 2030 with ramp metering
- 2030 with ramp metering with spatial shift
- 2030 with ramp metering with HOV priority entry lane (PE)
- 2030 with ramp metering with HOV priority entry lane (PE) and spatial shift
- 2030 with ramp metering with HOV priority entry lane (PE) and spatial and modal shifts
- 2030 with ramp metering with HOV priority entry lane (PE) with Bus Service
- 2030 with ramp metering with HOV priority entry lane (PE) and spatial shift with Bus Service
- 2030 with ramp metering with HOV priority entry lane (PE) and spatial and modal shifts with Bus Service

This section discusses the approach used for the simulation and analysis of these scenarios.

Growth rates

The growth rates for individual ramps were developed based on the 24-hour volumes from the CMAP 2030 demand forecasting model. Since some sections of parallel arterial are already over the specified capacity for the 2002 base case, FREQ does not allow growth factors to be applied to the arterial volume if the demand for the arterial is already at the capacity. However, some of the growth rates projected by the CMAP model were extremely large or small. Thus, the minimum and maximum growth rates of 0.8 and 2.0, respectively, were used to limit the growth rate inputs to FREQ to levels consistent with CMAP 2030 model or VISSIM-determined capacity.

Spatial shift

As mentioned earlier, FREQ simulate two types of route diversion behavior. The first type is termed “short trip response” that represents the route diversion for the travelers whose trip destination is within the study area. FREQ assumes that for those short trips, the travelers who divert to surface streets due to the on-ramp delay complete the trip on the surface streets. On the other hand, “long trip response” assumes that the destination of the trip is outside (i.e. downstream of) the study area. For the long trips, it is assumed that the travelers who diverts due to on-ramp delay will divert to the next on-ramp

downstream only if such a diversion would result in a travel time saving. Unfortunately, this simple diversion mechanism tends to create unreasonably long queues at the ramps that are immediately downstream of the freeway bottleneck segments. For this reason, long trip response was excluded from the simulation for this study.

Modal shift

FREQ can be used to simulate the modal shift among SOV, HOV, and buses. FREQ does not simulate the mode shift involving rail transit. FREQ uses logit model to estimate the mode shift with in response to the changes in the relative attractiveness of each mode. Although users can define the parameters of the logit model, the default value was used for this study due to the absence of information. Although CMAP's demand forecasting model also uses logit model, parameters are not transferable since the choice sets are different. In particular, the zonal socioeconomic factors that may affect mode choice within the CMAP model are not transferable.

FREQ allows short-trip diversion, long-trip diversion, and modal shift to be simulated in all possible combinations of order. From behavioral perspective, as is done in the travel demand forecasting, it is natural to assume that the possibility of spatial diversion is considered first by the travelers because mode shift often require greater adjustments to travel habits. Thus, the sequence of simulation was to the short-trip spatial shift followed by the modal shift.

Optimization of ramp metering rates

FREQ allows users to choose four different objectives when optimizing the metering rates. They are: "maximize vehicle input to freeway", "maximize vehicle-miles of freeway travel", "maximize passenger input to freeway", and "maximize passenger-miles of freeway travel". However, when performing a simulation without HOV priority entry (PE) lanes, only the first two types of objectives are available. This creates a problem since in order to minimize the passenger travel time, the third objective, maximize passenger input to freeway" is the most effective approach. Choosing the first two objectives tend to increase the passenger travel time. Therefore, the results from the simulations with and without PE lanes are not directly comparable. In fact, they tend to produce vastly different results. Furthermore, mode shift can be engaged only when HOV priority entry lanes are simulated.

For each scenario, metering rate and queue limit at each on-ramp were adjusted to find the optimum combination that minimized the passenger travel time. Since the adjustments relied on try-and-error process, the results are not likely to be the true mathematical optimum. However, the results presented here should be sufficiently close to the true optimum for the purpose of the study.

Simulation Parameters

Following are parameters used for the simulations of 2030 conditions.

- Cutoff level for priority entry = 2 passengers per car

- Optimization criteria for the ramp metering rates = “maximize passenger input to freeway” for the PE scenarios, “maximize vehicle input to freeway” for others
- In most cases, not engaging the ramp queue length limits produces significant saving in the total passenger travel time. However, it is unrealistic to assume that a large number of vehicles, sometimes exceeding 1000 vehicles, can be stored at a ramp. Even if it were physically possible, such a long queue would prompt a large portion of the drivers to violate the ramp meters or would be politically unviable as an invitation to use arterials and collector streets for regional travel. Therefore, queue length limits varying between approximately 80 and 200 vehicles were applied to the ramps. While detailed analysis was not conducted, the limits at individual ramps generally reflect the surrounding land use and the layout of the surface streets.
- Ramp metering was not applied to expressway-to-expressway connections and the Frontage Road on-ramp.
- Minimum time savings for spatial response to occur = 5 minutes

V. Findings

This section summarizes the key findings from the FREQ analysis of the 2030 alternates.

Ramp metering without HOV priority entrance (PE)

Error! Reference source not found.2 summarizes the results of the simulations with ramp metering without PE. As shown, without the PE, the benefit of ramp metering is modest. Although the congestion on the mainline can be reduced significantly with ramp metering as depicted in the example for the inbound AM simulation, a massive increase in the delay at the ramps offsets the benefit.

Table 2. Simulation Results - 2030 Ramp Metering without Priority Entrance

Scenario	2002 base				% change	
		1	2	3	3-1	2-1
Mainline, Ramp & arterial		2030 base	2030 ramp meter only	2030 ramp meter and spatial shift		
Passenger hours	305,181	411,692	421,618	403,560	-2.0%	2.4%
Total Vehicle miles traveled	7,822,471	7,932,117	7,944,586	7,952,905	0.3%	0.2%
Total Gas consumption (gallons)	2,005,356	1,751,407	1,749,918	1,761,107	0.6%	-0.1%
Total VOC (tons)	2,303	3,239	3,296	3,162	-2.4%	1.8%

When the queue at a ramp reaches the pre-specified limit, the FREQ program increases the metering rate (i.e. flow is increased). This situation, which is relatively common, limits the effectiveness of ramp metering. As a result, ramp metering was not able to reduce the congestion at some of the major bottlenecks including: Euclid Avenue and the

entrances at Austin Avenue and Harlem Avenue in the outbound direction. At these locations, there are not enough ramps in the upstream to curtail the traffic volume to the point where congestion is reduced while keeping the queue length below the limit.

When ramp meters are not able to decrease the downstream congestion, it is often detrimental to operate the meters since it generates queuing delay at the ramps without significant reduction in the mainline travel time. For those situations, some of the ramp meters must to be tuned off to reduce the ramp delay and the overall travel time. In the inbound direction, the queue length limits were set at 10 vehicles for the ramps between the beginning of the corridor at Lake-Cook Road and Kirchoff Road. For the outbound direction, the same queue limit was applied for the ramps between the beginning of the study corridor at the Independence Avenue entrance and the 1st Avenue entrance.

The analysis showed that ramp metering was able to dissolve congestions at near Austin and St. Charles Road interchanges. However, the increase in delay at the ramps and arterials, and the persistent congestion near the Euclid interchange lead to only a modest decrease in the overall passenger travel hours (2.4%). The outbound PM simulations indicate similar situations. For the outbound, the location of the most serious bottleneck is near the beginning of the study section. Combined with the lack of storage space at the ramps in the Chicago and inner suburban communities, ramp metering has failed to reduce congestion in any noticeable manner. As a result, the overall reduction in PHT is merely 1.39%.

Ramp metering with HOV priority entrance

As shown in **Error! Reference source not found.** when HOV priority entrance lanes are combined with mode and spatial shifts, ramp metering can achieve considerable reduction in travel time. Although the scenarios without mode shift seem to worsen the traffic conditions, it is mainly due to the fact that the metering strategies were optimized to produce the greatest benefit under the Scenario 4. If the metering rates were optimized for the Scenarios 2 or 3, the results would have been similar to those reported for the ramp metering without PE. It should be noted that bus services were not considered in the analysis. Therefore, only the shift between SOV and HOV modes are simulated. When PE is engaged, it is possible to use aggressive metering strategies without violating the queue limit constraint since more travelers shift to HOV as the ramp delay increases and, as a result, ramp metering dissolves all the congestion along the inbound corridor.

Table 3. Simulation Results - 2030 Ramp Metering with Priority Entrance

Scenario						% change		
	2002 base	2030 base	2030 ramp meter only	2030 ramp meter and spatial shift	2030 ramp meter, spatial and modal shift	4-1	3-1	2-1
Mainline & Ramp								
Passenger hours	125,955	272,059	304,818	290,070	229,164	-15.8%	6.6%	12.0%
Total Vehicle miles traveled	4,930,839	5,040,485	5,058,316	5,027,556	4,992,509	-1.0%	-0.3%	0.4%
Total Gas consumption (gallons)	292,276	354,367	367,654	360,248	332,169	-6.3%	1.7%	3.7%
Total VOC (tons)	1,478	2,508	2,726	2,612	2,132	-15.0%	4.1%	8.7%

In contrast to the inbound simulations, ramp meters, even with PE, were not able to improve the severe congestion outbound between the Independence Avenue and 25th Avenue Interchange. This is mainly because of the lane imbalance – reduction from 4 lanes to 3- occurring west of Austin Ave and also because, as discussed earlier, there are not enough ramps in the upstream of the bottleneck at Harlem Avenue to be metered. Conversely, if the study area were to be expanded eastward and include more ramps, it may be possible to demonstrate additional congestion reduction more effectively.

Overall, the reductions in PHT, VMT, gallons of fuel consumed, and VOCs emitted from the managed mainline and ramp traffic flow should be compared along slight (<10%) increases in these same performance measures experienced by the arterial system. Even with the arterial system included in the comparison, the greater I-290/IL 53 corridor still enjoys significant reductions in PHT and VOCs emitted. VMT remains reduced but at a lower magnitude, whereas gallons of fuel consumed would rise by 5.3%.

Table 4. Simulation Results for Arterial and for combined Mainline, Ramp & Arterial, 2030 Ramp Metering with Priority Entrance

Scenario	1		2	3	4	% change		
Arterial	2002 base	2030 base	2030 ramp meter only	2030 ramp meter and spatial shift	2030 ramp meter, spatial and modal shift	4-1	3-1	2-1
Passenger hours	179,226	139,633	139,633	145,218	145,218	4.0%	4.0%	0.0%
Total Vehicle miles traveled	2,891,632	2,891,632	2,891,632	2,924,669	2,924,669	1.1%	1.1%	0.0%
Total Gas consumption (gallons)	1,713,080	1,397,040	1,397,040	1,512,238	1,512,238	8.2%	8.2%	0.0%
Total VOC (tons)	825	731	731	748	748	2.3%	2.3%	0.0%

Scenario	1		2	3	4	% change		
Mainline, Ramp & arterial	2002 base	2030 base	2030 ramp meter only	2030 ramp meter and spatial shift	2030 ramp meter, spatial and modal shift	4-1	3-1	2-1
Passenger hours	305,181	411,692	444,451	435,288	374,382	-9.1%	5.7%	8.0%
Total Vehicle miles traveled	7,822,471	7,932,117	7,949,948	7,952,225	7,917,178	-0.2%	0.3%	0.2%
Total Gas consumption (gallons)	2,005,356	1,751,407	1,764,694	1,872,486	1,844,407	5.3%	6.9%	0.8%
Total VOC (tons)	2,303	3,239	3,457	3,360	2,880	-11.1%	3.7%	6.7%

Ramp metering with HOV priority entrance with bus service

FREQ is capable of simulating the effect of bus services that provide alternative means to travel on the expressway. It should be noted that FREQ only simulates the effect of bus services that travel on the expressways (with a priority entry when it is engaged). Thus, analysis does not reflect the effect of local buses that use arterials in the modal shift.

Bus service was simulated for the 2030 conditions. To engage bus transit, the default occupancy (i.e. mode share) was set to bus = 0.005, SOV = 0.895, 2OV = 0.07, 3OV = 0.03. An Average occupancy of 20 passengers per bus and the "Medium" level of bus service were assumed. Also, the default modal shift parameters of the program were used.

Table 5 shows the results of the FREQ runs with bus services. The numbers show that the hypothetical bus service will significantly increase the benefit of the ramp metering with PE by converting drivers to buses. It needs to be stressed that FREQ only provides sketch-level capabilities for analyzing the effect of the bus service. Thus, a more detailed analysis using a travel demand forecasting model or similar tools need to be conducted to accurately estimate the benefit of the bus service on I-290/IL53.

Table 5. Simulation Results- 2030 Ramp Metering with Priority Entrance and Bus Service

Scenario		1	2	3	4	% change		
Mainline & Ramp	2002 base	2030 base	2030 ramp meter only	2030 ramp meter and spatial shift	2030 ramp meter, spatial and modal shift	4-1	3-1	2-1
Passenger hours	125,955	294,810	330,381	314,399	222,293	-24.6%	6.6%	12.1%
Total Vehicle miles traveled	4,930,839	5,040,485	5,058,348	5,028,746	4,976,171	-1.3%	-0.2%	0.4%
Total Gas consumption (gallons)	292,276	354,368	367,669	360,297	327,035	-7.7%	1.7%	3.8%
Total VOC (tons)	1,478	2,508	2,726	2,613	2,053	-18.1%	4.2%	8.7%

VI. Conclusion

This study investigated the potential application of ramp metering with and without HOV priority entry (PE) lanes for the I-290 corridor. The analyses using FREQ and VISSIM programs estimated that ramp metering without HOV PE lanes will not improve the overall travel condition along the corridor significantly. With HOV PE lanes, however, ramp metering is expected to reduce total passenger travel time by 15.8 % for the 2030 condition along the mainline expressway and ramps. Vehicle miles traveled, fuel consumption, and total emission of volatile organic compound (VOC) are projected to decrease by 1.0%, 6.3%, and 15.0%, respectively. Additional analysis revealed that providing bus services on I-290/IL53 with PE will increase the benefit although more rigorous analysis will be needed to accurately estimate the quantity.

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