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Carbon Monoxide Impacts of Electronic Tolling Operations:
Two Conflicting Assessments of a Promising Intelligent Transportation Technology

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INTRODUCTION

On November 24, 1993, the US Environmental Protection Agency adopted the transportation conformity rule, pursuant to Section 176(c)(4) of the Clean Air Act. The conformity rule requires that transportation plans, programs, and projects funded or approved by the federal government or their agents under Title 23 (Highways) U.S.C. or the Federal Transit Act conform with state or Federal air quality implementation plans. Federal transportation planning regulations contain reciprocal language (40 CFR 450.312(d)), stipulating that the metropolitan planning organization shall not approve any plan or program that does not conform to the state implementation plan as determined in accordance with the conformity rule.

The final transportation/air quality conformity rule (23 CFR Part 450 and 49 CFR Part 613) constrains the development of transportation plans, improvement programs and projects and has increased pressure on statewide metropolitan transportation agencies to ensure that transportation and air quality plans are coordinated. Rigorous requirements for regional and local air quality modeling of transportation systems are included in the final conformity rule, and agencies are working diligently to meet these demands.

In response, transportation and air quality planners are looking for transportation strategies that will provide demonstrable air quality benefits. Emerging Intelligent Transportation Systems (ITS's) are being promoting by transportation planners as a means of reducing congestion delay, improving transportation safety, and also as a means of making vehicle travel "...more energy efficient and environmentally benign."[1] Previous research has identified electronic toll collection using automatic vehicle identification technologies as a promising ITS [2]. Unfortunately, the transportation-air quality community lacks the appropriate tools with which to predict the effects of microscopic changes to vehicular activity induced by ITS's. The currently used emissions models, EMFAC in California, and MOBILE in the remainder of the US, are unable to provide the resolution needed to quantify the effects of these changes. To make matters worse, the transportation activity models that are used to predict transportation activity do not provide the required level of detail to adequately predict emissions.

This research estimates the carbon monoxide (CO) emission impacts (running tailpipe emissions only) of electronic tolling operations in place of conventional toll plaza operations for a sample fleet of motor vehicles. A newly developed modal model, dubbed DITSEM, which takes into account important vehicular modal activity and vehicular attribute variables, is employed to estimate CO emissions. The results are then compared to CO emissions estimated by EMFAC7F, the emission inventory model used in California. The findings suggest that only by employing a true 'modal' model can we begin to identify environmentally beneficial ITS's, as current regional emission and transportation activity models are insufficient for this purpose. The findings are of critical importance to transportation and air quality planners, policy makers, and researchers. The results clearly demonstrate that the current regional emission modeling tools are insufficient and inadequate for assessing the emission impacts of transportation projects designed to smooth vehicular flows. Furthermore, current methods may yield erroneous results, leading to poor decisions and mis-allocation of transportation dollars.

This research is significantly different than previous research presented by the author[3] for several important reasons. First, a newly developed and significantly more robust emission model, DITSEM, is employed to estimate the emission impacts of electronic tolling. Second, the emission predictions are compared to the predictions offered by CARB's EMFAC7F model. Finally, the modeling comparison is performed in a manner consistent with a regional modeling emission analyses, as compared to a micro-scale or project-level analysis.

INTRODUCING THE DITSEM CO MODAL EMISSION MODEL

A newly developed modal emission model for predicting CO from motor vehicles is used to assess the CO emission impacts of electronic toll collection. The new model, dubbed DITSEM (Davis Institute of Transportation Studies Emission Model) actually consists of two statistical models: a weighted least squares regression model for prediction of 'high' emitters (1), and an ordinary least squares regression model for prediction of 'normal' emitting vehicles (2). The emission models take the form:

Model I - High Emitter Model (COPERCID* > 2.5)

$$\mathrm{LOG}_{10}[(\mathrm{CO/CID}) + 1] = 1.5720 - 0.5503(\mathrm{BAG}^2) + 0.1775(\mathrm{BAG2}^2) + 0.0128(\mathrm{MODYR}) + 0.0112(\%\mathrm{IDLE}) + 0.0104(\mathrm{AVGSPD}) \tag{1}$$

Model II - Normal Emitter Model (COPERCID* <= 2.5)

$$\mathrm{LOG}_{10}[(\mathrm{CO/CID}) + 1] = 2.2360 + 0.5132(\mathrm{BAG2}) + 0.0835(\mathrm{PKE{>}60}) - 0.0170(\mathrm{MODYR}) - 0.0067(\%\mathrm{IDLE}) + 0.04093(\mathrm{ACC{>}3}) \tag{2}$$

where;

ACC>3 = percent of cycle spent with acceleration rate greater than 3 mph/sec,
AVGSPD = average speed of cycle in miles per hour
BAG2 = LOG_{10}(B2PERCID + 1),
B2PERCID = carbon monoxide emissions in micro-grams per cubic inch displacement per second on the Federal Test Procedure, Bag 2,
CO = micro-grams per second of carbon monoxide emissions,
CID = cubic inches of engine displacement,
MODYR = last 2 digits of model year of vehicle,
%IDLE = percent of test cycle time spent at idle,
COPERCID* = $\mathrm{LOG}_{10}[(\mathrm{CO/CID}) + 1]$
PKE>60 = percent of cycle spent with positive kinetic energy (velocity x acceleration) greater than 60 mph^2/sec.

The linear model predicts micrograms of CO per cubic inch of engine displacement emitted from an automobile with known attributes. The automobile's attributes, defined by its model year (last two digits) and its Federal Test Procedure Bag2 Test result, must be known in order to estimate hot stabilized CO tailpipe emissions. Modal activity of the driving 'cycle' or schedule driven by the vehicle must also be known in order to estimate CO emission with DITSEM. These modal activity parameters include the time based percent of the cycle spent with instantaneous acceleration rates greater than 3 mph per second, time based percent of cycle spent with acceleration-speed product greater 60 mph^2 per second, and average cycle speed[4].

Essentially, DITSEM is an approximation for the true population model:

$$CO_{ij} = f(\text{vehicle i attributes, cycle j attributes, } \Phi) \quad (3)$$

where;

Co_{ij} = carbon monoxide emissions for vehicle i on cycle j,

f = a function linear in parameters,

Φ = unexplained random error in observed emissions.

Statistical goodness of fit (gof) tests were employed to quantify the statistical fit of CO emission predictions by DITSEM with observed CO emissions on vehicle tests. The same gof tests were employed to quantify the predictive ability of CO emission prediction algorithms embedded in two other emission models, CARB's EMFAC7F [5 6 7] and Caltran's CALINE4[8]. These tests included mean squared prediction error, mean absolute prediction error, Theil's U Statistic, and the linear correlation coefficient.

DITSEM clearly outperformed competing model emission prediction algorithms in its ability to accurately predict CO emissions. In addition, DITSEM was able to predict emissions consistently and accurately across cycles with distinctly different modal profiles [9]. This 'new' ability to adequately predict differences in modal activity contributions from CO emissions allows for the assessment of 'flow smoothing' operations offered by some intelligent transportation technologies (ITS's). This practical application of DITSEM illustrates the value and importance of having a modal model, and demonstrates its considerable power for forecasting the CO emissions impacts of ITS's.

APPLICATION OF DITSEM TO ELECTRONIC TOLL COLLECTION

Previous research identified Advanced Traffic Management Systems (ATMS) as one of the most likely ITS bundles to offer air quality benefits [10]. As the name implies, ATMS employ computer control technologies to 'optimize' or smooth traffic flows on a transportation network. Examples of ATMS technologies are real-time traffic signal network optimization, real-time ramp metering, and electronic vehicle toll collection via automatic vehicle identification technologies (AVI). These computer controlled systems are designed to reduce congestion levels, minimize system-wide delay levels, and generally smooth vehicular flows. ATMS technology bundles also include various signal actuation bundles, incident detection, rapid accident response, and integrated traffic management.

This paper examines the CO emission impacts of one such applied ATMS, namely Automatic Vehicle Identification (AVI) used to implement electronic toll collection (ETC). By allowing vehicle tolls to be collected either through a windshield displayed bar-coded debit card, or by some other mechanism, vehicles can forgo the deceleration, stop-delay, and ensuing acceleration that results from an encounter with a conventional toll plaza.

Electronic tolling employs advanced communications technologies between roadways and vehicles. If conventional tolling operations performed on bridges or tolled turnpikes are replaced with automatic and transparent vehicle identification and debiting, for example, then toll plaza induced delays experienced by motorists may be eliminated. In the Orlando, Florida region for example, motorists pass through ETC stations at ordinary freeway speeds of 55 mph and greater. The elimination of the 'modal' activities associated with conventional toll plazas will result in fewer accelerations and decelerations, and less idling experienced under conventional toll plaza operations.

Using DITSEM to model the relative contributions of CO emissions from acceleration, deceleration, cruise, and idle events, we assess the impacts of electronic tolling using AVI. The goal is to quantify the expected CO emission differences between a toll-plaza and the no toll-plaza, or AVI scenario. In addition, the predictions provided by EMFAC7F are also computed and presented, in order to demonstrate the differences between the two CO emission prediction algorithms and to demonstrate the inability of conventional regional emission models to adequately predict CO emission benefits of flow-smoothing transportation projects.

Experimental Design

Before describing the hypothetical 'experiment', the analysis framework is described. DITSEM and the CO emission prediction algorithms embedded in the EMFAC7F model are compared in this section. Recall that the goal of this paper is to demonstrate that regional analysis will yield erroneous emission impact results for several transportation plans, programs, and projects. EMFAC7F, the regional emission model in California, is used as the computational basis in the following analysis. The proposed electronic toll-plaza, then, is 'modeled' as part of a network analysis, as opposed to a micro-scale or local impact analysis.

The toll plaza is hypothetically set up as a small segment of a much larger transportation network. In keeping with a network analysis, we assess the toll plaza's impact on the transportation link of which it is a part. The point here is that the local impacts of the toll plaza are not assessed, but rather the impacts to the network link as a whole are assessed. For example, the average speed of vehicles passing through a toll plaza drops considerably if you only consider the impact on traffic, say a half mile upstream and downstream of the toll plaza. These boundaries may be appropriate for a micro-scale 'hot spot' analysis, but are too small for a regional analysis. An effort is made in the following analyses to 'mimic' the regional analysis process, since EMFAC7F is a regional model. Points where the analysis pays particular attention to regional modeling processes are pointed out during setup of this hypothetical scenario. In no way, however, can this analysis cover the complexity of issues involved with a regional analysis of a toll plaza, and only rough assessments of what a true regional analysis would predict are made.

In the following analyses, both DITSEM and EMFAC7F are employed to estimate the difference in CO emissions between a fleet of vehicles encountering a conventional toll plaza, and the same fleet of vehicles experiencing uninterrupted flow with electronic toll collection operations. To perform these comparisons, a toll plaza is first simulated on a transportation link. The link is assumed to be bridge with toll collection operations, such as San Francisco's Golden Gate Bridge. To be consistent with regional modeling practice, this transportation network 'link' is modeled as a 10 mile link. The analysis estimates the impact of three important emission related variables. First, two toll-plaza levels of service (LOS) D and F [11], are considered, as these are the most likely factors that might lead to implementation of electronic toll collection. Then, under each LOS category, 10 various 'penetration rates' of aggressive driving behavior, i.e., hard accelerations, decelerations, and high top speeds are considered. Finally, two average operating mainline average speed scenarios are considered, 45 and 55 mph.

Level of service effects are assumed to exist only at the toll plaza. That is, congestion is assumed not to exist on the mainline link, as evidenced by the use of 45 and 55 mph average mainline speeds. The complex effects that result from mainline congestion require the use of sophisticated modeling programs that are not currently compatible with DITSEM required inputs, and are currently beyond the scope of this research effort. Table 1 shows toll plaza level of service as a function of queue length and time spent in the queue [12]. These queue length times are used to develop speed-time profiles for vehicle fleets under different scenarios. As stated previously, toll plaza LOS D and F are considered in these analyses. The average vehicular delay assumed for the two LOS scenarios is 50 seconds under LOS D, and 85 seconds under LOS F. As these level of service categories were developed for determining when conventional toll plazas should undergo capacity expansion, they are by no means meant to be representative of delays experienced on current facilities. There are likely to be many existing conventional toll facilities that experience upwards of 30 minute to 45 minute delays at times.

The analysis also accounts for differences in 'modal' activities, which are known to be important in the calculus of emissions. DITSEM is able to account for differences in modal activity, while EMFAC7F's only measure of vehicle activity is average speed. In developing speed-time profiles for different LOS categories D and F, 10 different levels of driver aggressiveness penetration rates are assumed. Aggressive driving behavior includes high top speeds, high acceleration rates, and high deceleration rates. Aggressive acceleration rates from about 5 mph per second to 10 mph per second are possible with many modern technology vehicles, with deceleration rates about the same. More mild or normal acceleration rates are found to be between 2 and 4 mph per second [13]. Two different speed time profiles are constructed for each LOS category, one for aggressive driving behavior and one for normal driving behavior. Then, 10 varying levels of aggressive driving behavior 'penetration rates' are assumed, from 0% aggressive driving behavior to 100% driving behavior. For the analysis presented here, aggressively driven vehicles are selected randomly, so high-emitters have as high a chance of being driven aggressively as do normal emitting vehicles. In reality, however, we might expect aggressive drivers to be more likely to tamper with their vehicles to achieve gains in performance. If this were the case, then high emitting vehicles would be more likely to be driven aggressively.

Finally, for each LOS category and each aggressive driving behavior penetration rate, we consider two average uncongested mainline operating approach speeds, 45 and 55 mph. Of course, speed-time profiles are developed for both toll-plaza and electronic toll collection (ETC) scenarios.

Table 2 displays the modal variables and summary statistics of the assumed speed-time profiles for the various scenarios. All vehicle speed time profiles begin and end their speed-time trajectory at a constant speed, either 45 mph or 55 mph. The table shows cycle attributes such as time proportion of cycle at acceleration rates greater than 3 mph per second and average cycle speed. Recall that all cycles are 10 miles in length, the assumed length of the modeled transportation network link.

A BASIC computer program was written, debugged, and compiled to estimate emissions from DITSEM and EMFAC7F for these analyses [14]. Through each iteration of the program, vehicles are selected at random to be driven aggressively. For example, when aggressive penetration rates of 10% are assumed, the program randomly selects that 10% of the vehicles. The program sums and compares predicted emissions using both EMFAC7F and DITSEM under both AVI and toll plaza scenarios. The program also computes emission estimates under both LOS D and LOS F toll plaza conditions.

A subset of 4431 vehicle-tests contained in the current Speed Correction Factor (SCF) Data Base was selected to estimate CO emissions from a 'fleet' of vehicles passing through the toll plaza and ETC scenarios. This sample size resulted from the selection of all vehicles in the SCF data set that contain all variable information (i.e. no missing values) necessary to make estimations from both the EMFAC7F and DITSEM models.

Since the DITSEM modal model can predict the marginal contributions to CO emissions from acceleration, idle, and positive kinetic energy attributes, the resulting emissions predictions reflect the effect of microscopic traffic flow adjustments under the two different scenarios. The results of the modeling runs can be seen in Table 3. The results presented represent a summary of the detailed output provided by the BASIC program, and only show selected program runs. The modeling results illustrate many important differences between the two CO emission prediction models, EMFAC7F and DITSEM.

First, the table shows that DITSEM is sensitive to changes in driving behavior differences, in comparison to EMFAC7F predictions, which remain relatively constant across varying levels of driver aggressiveness (prediction differences are caused by different cycle duration only). In each LOS category, for both 45 and 55 mph analyses, benefits predicted by DITSEM accrue with increasing penetration of aggressive driving behavior. For example, with LOS F conditions at the toll plaza, and 55 mph mainline free flow speeds on the 10 mile 'study' link, DITSEM predicts that CO emission reductions will increase from 17.6 grams per vehicle to 19.7 grams per vehicle as aggressive driver penetration rate increases from 0 to 100%. In every similar case for the EMFAC7F model, emission reductions are constant with respect to driver aggressiveness penetration rates. DITSEM model predictions agree with current field observations and research findings; emissions increase with increasing modal activities of accelerations, high speeds, and decelerations. EMFAC7F model predictions confirm our current modeling inadequacies; they cannot predict the emission impacts of 'flow smoothing' transportation programs such as Intelligent Transportation Technologies.

The table illustrates another shortcoming of the EMFAC7F model. Under both LOS D and LOS F conditions for freeway mainline speeds of 55 mph, EMFAC7F predicts that CO emissions will actually increase with the application of electronic toll collection. This aberration is due to EMFAC7F's speed correction factor methodology, which in its calculus of average speeds determines that 55 mph average speeds lead to higher CO emissions than do 48 mph average speeds. This anomaly, therefore, incorrectly predicts the magnitude and sign of emission reductions.

To provide perspective on this result, if a regional analysis were performed to determine whether to install electronic tolling in place of conventional toll plazas on a 55 mph freeway mainline, EMFAC7F would indicate that this will increase the CO emission inventory, and therefore should not be installed. DITSEM, on the other hand, demonstrates the benefits of ETC under all operating speeds.

Finally, Table 3 shows another effect of the average speed versus modal modeling regime. Although EMFAC7F correctly predicts that emission reductions will occur for 45 mph mainline speeds, it underestimates the magnitude of benefits. This occurs since EMFAC7F drastically under-predicts toll plaza emissions (no modal component reflected), and therefore under-predicts the CO emission reductions associated when toll plaza induced modal activity is removed from the road. This again reiterates EMFAC7F's inability to account for 'modal' activity, and therefore leads to inaccurate assessment of ETC. These findings also suggest that the current modeling methodology has potential to seriously under-predict CO emissions for 'congested' transportation networks.

Discussion of Electronic Tolling Collection Analyses Results

The DITSEM model predictions suggest that reductions in CO emissions can be realized through the application of a particular Intelligent Transportation Technology (ITS). But how do we know that DITSEM is making good predictions, and for that matter, making better predictions than EMFAC7F? There is a three part answer to this question: 1) the model predictions agree with anecdotal evidence and research about modal activity; 2) DITSEM explicitly accounts for modal changes that take place between the two hypothetical scenarios, and 3) the findings agree with a field test of ETC performed by a field study that measured emission reductions under implementation of various ETC scenarios [15].

It is interesting to ask what kind of emission reductions could be expected given the predictions illustrated in Table 3. For example, how do reported grams per vehicle emission reductions translate to metric tons of CO reduction per year? Table 4 provides the answer to this question. The table shows the annual expected metric tons per lane of CO emissions reduction from implementing ETC on a conventionally tolled roadway. The table shows the estimates for average daily traffic volumes from 2500 to 25,000 vehicles per day per lane. For example, if there are 3 tolled lanes (conventional toll plaza with LOS = D) to be replaced with ETC on a mainline with average speeds of 55 mph, with average daily traffic volumes of 20,000 vehicles per lane, we would expect to get 3 x 83 = 249 metric tons per year reduction in CO emissions from application of this measure. Remember that we must assume no mainline congestion, and must ignore any travel behavior changes that might be brought about by ETC. Of course, the magnitude and relative importance of this reduction is region specific, and would need to be 'weighed' against other emission reduction strategies to compare costs and benefits.

The results here indicate that the application of electronic toll collection in lieu of traditional toll plazas can bring about reductions in CO emissions from motor vehicles. The reductions however, are dependent upon driving behavior, approach speeds, traffic volumes, and the aggressive driving behavior penetration of the vehicle fleet. In addition, transportation modeling uncertainty will likely increase the range of uncertainty brought about by the previously mentioned factors.

In the analyses presented here, congestion is assumed not to exist (outside of the toll-booth induced congestion), but practical experience shows that tolled links can operate in the congested flow regime, and we need to consider these congestion effects on emission estimates. This can be approached by expanding this analyses to include micro-simulations of traffic flow on a series of links.

We also need to address the behavioral changes that might be induced by application of ITS's. For example, previous peak-period congestion induced by toll-plazas, now eliminated by application of electronic tolling using AVI, might make the travel route more attractive to motorists. If this short-term increase in peak period level of service attracts 'new' motorists to the facility, then the projected emissions reductions may be partially or fully offset by increased traffic and congestion. These questions can be partially addressed through field studies of electronic toll collection pilot projects, and perhaps through the use of advanced network simulation modeling.

The potential benefit of ETC to any non-attainment region would depend on many factors. Of course, a cost analysis of ETC would help to determine the expected CO reduction per unit cost of capital investment and maintenance. Electronic toll collection may be desirable for reasons other than air-quality, such as congestion relief. Under these circumstances, the relative amount of emission reduction may be of secondary importance--but the fact that it can be demonstrated to be beneficial to air quality is critical for the regional transportation plan.

We have ignored to this point emissions of hydrocarbons (HC), oxides of nitrogen (NOx), and particulate matter (PM). Since HC emissions are sensitive to some of the same parameters as are CO emissions, such as fuel enrichment, we expect HC emissions to behave similarly to modal activity as do CO emissions, but with smaller magnitudes. NOx and PM, on the other hand, are less sensitive to 'modal' activities and are less likely to be significantly affected in such an analysis.

The most evident and perhaps important finding of this research is that there are likely many transportation programs and projects that may improve air quality. However, they will not be implemented because the current regional modeling chain is insufficient for accurate analysis of such projects. Other potentially beneficial programs might include roving emergency vehicle services, advance warning message systems, signal optimization strategies, and any other systems that 'smooth' flows on the transportation system. On the other hand, there are likely projects that will worsen air quality, but suffer equally from the inadequate models and will be modeled to show air quality benefits.

Fortunately, researchers are currently developing both improved emission models and transportation activity models. It is critical during this development process that clean air legislation and policies keep pace with model developments. We are already in a position where transportation projects that have potential to improve air quality cannot be modeled to show the benefits. This problem has the potential to seriously hinder meeting the objectives of clean air legislation--to improve air quality.

Table 1 - Toll plaza level of service guidelines.

Level of Service (LOS)	Average Vehicular Time Spent in Queue, t (seconds)	Average Queue Length, L (Vehicles)
A	≤ 15	≤ 1
B	$15 < t \leq 30$	$1 < L \leq 2$
C	$30 < t \leq 45$	$2 < L \leq 3$
D	$45 < t \leq 60$	$3 < L \leq 6$
E	$60 < t \leq 80$	$6 < L \leq 10$
F	> 80	> 10

Table 2 - Characteristics of assumed vehicle speed-time profiles for toll-plaza and electronic toll collection scenarios.

Level Of Service And Driving Behavior	Scenario	Speed (Mph)	Acc>3* (%)	PKE>60 ** (%)	%Idle (%)	Cycle Duration (Seconds)	Average Speed (Mph)
LOS D 'Normal Driving'	ETC	45	0	0	0	800	45.00
		55	0	0	0	654	55.04
	Toll Plaza	45	0.3	0.9	5.8	863	41.70
		55	0	1.9	6.9	722	49.87
LOS D 'Aggressive Driving'	ETC	45	0	1.9	0	803	44.85
		55	0	4.4	0	654	55.04
	Toll Plaza	45	1.0	3.0	5.8	863	41.71
		55	1.3	5.3	7.0	717	50.21
LOS F 'Normal Driving'	ETC	45	0	0	0	800	45
		55	0	0	0	654	55.04
	Toll Plaza	45	0.3	0.9	9.0	898	40.08
		55	0	1.8	10.5	757	47.56
LOS F 'Aggressive Driving'	ETC	45	0	1.9	0	803	44.85
		55	0	4.4	0	654	55.04
	Toll Plaza	45	1.0	1.8	9.5	898	40.08
		55	1.2	5.1	11.3	752	47.87

* Percent of cycle time spent with acceleration rates greater than 3.0 mph/sec

** Percent of cycle time spent with positive kinetic energy (speed x accel) greater than 60 mph^2/sec

Table 3 - Estimated carbon monoxide emission reductions of electronic toll collection in place of conventional toll plaza - EMFAC7F versus ditsem model predictions.

Assumed Penetration Rate of Aggressive Driving Behavior (%)	DITSEM Predicted CO Reduction (grams / vehicle)	EMFAC7F Predicted CO Reduction (grams / vehicle)	DITSEM Predicted CO Reduction (grams / vehicle)	EMFAC7F Predicted CO Reduction (grams / vehicle)
LOS D Analysis Results (50 Second Stop Delay)	45 mph Average Mainline Speed	45 mph Average Mainline Speed	55 mph Average Mainline Speed	55 mph Average Mainline Speed
0	10.0	3.8	11.1	-10.9
20	10.1	3.8	11.4	-10.9
40	10.3	3.7	11.5	-10.8
60	10.4	3.7	11.8	-10.8
80	10.5	3.8	11.9	-10.7
100	10.6	3.7	12.0	-10.7
LOS F Analysis Results (85 Second Stop Delay)				
0	16.8	6.3	17.6	-11.5
20	17.1	6.3	18.1	-11.5
40	17.3	6.3	18.4	-11.5
60	17.6	6.3	18.9	-11.5
80	17.8	6.2	19.3	-11.5
100	18.0	6.2	19.7	-11.5

Table 4 - DITSEM predicted co reductions in metric tons per lane per year electronic toll collection in place of conventional toll plazas.

Level of Service D: 20% Assumed Aggressive Driver Penetration

Daily Traffic Volume Per Lane (vehicles)	45 mph Average Mainline Speed	55 mph Average Mainline Speed
25,000	92	104
20,000	74	83
15,000	55	62
10,000	37	42
5000	18	21
2500	9	10

Level of Service F: 20% Assumed Aggressive Driver Penetration

Daily Traffic Volume Per Lane (vehicles)	45 mph Average Mainline Speed	55 mph Average Mainline Speed
25,000	156	165
20,000	125	132
15,000	93	99
10,000	62	66
5000	31	33
2500	16	17

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