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16. Abstract
Many metropolitan areas use ramp meters as an effective means to reduce freeway congestion. Smoothing the entry of vehicles onto the freeway reduces the potential for traffic flow breakdown and prevents, or delays, the onset of low-speed congested flow conditions. Only five ramp meters have been installed to date in the Atlanta region. Given the limited deployment of ramp meters in Atlanta, GDOT is currently examining the potential benefits of expanding the use of ramp meters in the region to increase system efficiency. However, Atlanta is a non-attainment area for ozone and the air quality impacts of ramp meter operation are uncertain. Previous emissions analyses on metering impacts have been limited by poor quality vehicle activity data and emission rate models that were never designed to examine the impacts of changes in vehicle operating characteristics on emissions. The objectives of this research effort were 1) analyze the congestion benefits of the existing ramp meter system, 2) quantify the emissions impacts of ramp operations along the current metered corridor using a traditional emission rate model and an advanced modal emission rate model, 3) simulate the potential impacts of metering on the corridor under conditions not observed in the field, 4) assess the potential emissions impacts from the simulations, and 5) provide recommendations on the applicability of the research results to future ramp metering strategies that may be proposed in Atlanta.

The research team concluded that transportation planners and engineers should be cautious in the implementation of ramp metering from an air quality perspective. For the corridor-specific scenarios examined in this research, NOx emissions tended to increase under metered conditions. Congestion benefits from metering were predicted to be significant on this corridor for high volume and lane-closure conditions, increasing the potential congestion benefits of metering. Yet, NOx emissions for these scenarios were also projected to increase over non-metered conditions. Given the low congestion levels on the study corridor, and the poor performance of the simulation model under some modeled scenarios, the modeling results for the study corridor are not directly transferable to many other freeway corridors in Atlanta. Hence, despite the findings for this corridor, the research team believes that ramp metering implementation can provide emissions benefits on some of Atlanta's most congested freeway corridors, where flow breakdown is significant. Additional simulation model improvements will be required in order to make this demonstration in future research.

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ABSTRACT

Many metropolitan areas use ramp meters as an effective means to reduce freeway congestion. Smoothing the entry of vehicles onto the freeway reduces the potential for traffic flow breakdown and prevents, or delays, the onset of low-speed congested flow conditions. Only five ramp meters have been installed to date in the Atlanta region. Given the limited deployment of ramp meters in Atlanta, GDOT is currently examining the potential benefits of expanding the use of ramp meters in the region to increase system efficiency. However, Atlanta is a non-attainment area for ozone and the air quality impacts of ramp meter operation are uncertain. Previous emissions analyses on metering impacts have been limited by poor quality vehicle activity data and emission rate models that were never designed to examine the impacts of changes in vehicle operating characteristics on emissions. The objectives of this research effort were to: 1) analyze the congestion benefits of the existing ramp meter system, 2) quantify the emissions impacts of ramp operations along the current metered corridor using a traditional emission rate model and an advanced modal emission rate model, 3) use CORSIM to simulate the potential impacts of metering on the corridor under conditions not observed in the field, 4) assess the potential emissions impacts from the simulations, and 5) provide recommendations on the applicability of the research results to future ramp metering strategies that may be proposed in Atlanta.

The research team concluded that transportation planners and engineers should be cautious in the implementation of ramp metering from an air quality perspective. For the corridor-specific scenarios examined in this research, NOx emissions tended to increase under metered conditions. Congestion benefits from metering were predicted to be significant on this corridor for high volume and lane-closure conditions, increasing the potential congestion benefits of metering. Yet, NOx emissions for these scenarios were also projected to increase over non-metered conditions. Given the low congestion levels on the study corridor, and the poor performance of the simulation model under some modeled scenarios, the modeling results for the study corridor are not directly transferable to many other freeway corridors in Atlanta. Hence, despite the findings for this corridor, the research team believes that ramp metering implementation can provide emissions benefits on some of Atlanta's most congested freeway corridors, where flow breakdown is significant. Additional simulation model improvements will be required in order to make this demonstration in future research.
EXECUTIVE SUMMARY

The Georgia Department of Transportation (GDOT) is currently examining the potential benefits of expanding the use of ramp meters in the Atlanta region as a means to improve system efficiency. However, because Atlanta is a non-attainment area for ozone, GDOT desired to evaluate the potential emissions impacts of ramp meter operations. The Georgia Institute of Technology research team proposed to conduct an analysis of the emissions impacts of ramp metering along the existing metered I-75 corridor. The objectives of this research effort were to: 1) analyze the congestion benefits of the existing ramp meter system, 2) quantify the emissions impacts of ramp operation along the current metered corridor using a traditional emission rate model and an advanced modal emission rate model, 3) simulate the potential impacts of metering on the corridor for conditions not observed in the field, 4) assess the potential emissions impacts of the simulations scenarios, and 5) provide recommendations on the applicability of the research results to future ramp metering strategies that may be proposed in Atlanta. The research team collected eighteen days of vehicle activity data along the I-75 five-ramp system just north of the downtown. Researchers collected traffic volumes and speed/acceleration data using laser guns, video cameras, and probe vehicles during the evening peak period when ramps are normally in operation on the corridor. Meters were turned off on four of the eighteen days, allowing the research team to observe the impacts of metering. Researchers used the MOBILE5b and MEASURE Aggregate Modal Model to predict the emission rates from light-duty vehicle activity under the operating mode conditions observed in the field. These emission rates were applied to observed and simulated vehicle activity estimates to predict mass emissions and provide a basis for scenario comparison.

Field observations indicated that the operation of the ramp meters on this corridor provided only a very small decrease in mainline freeway travel time. Given the current low levels of congestion on the study corridor, due to an upstream bottleneck, the operation of the meters did not provide significant congestion reduction benefits. However, the changes in vehicle operations on the ramps and the mainline segments did impact predicted emissions. The predicted changes in onramp hydrocarbon emissions, associated with hard acceleration activity, were significant. Yet, the changes in mass emissions on the ramps were small compared to the predicted emissions changes on the mainline. Total predicted system-wide HC emissions were lower by about 1% on a typical day when the ramp meters were in operation (the combined effect of the 30% to 46% increase in ramp emissions and 2% decrease in mainline emissions). However, the emissions estimates showed an increase in mainline NOx emissions of approximately 4% under metered conditions. System wide NOx emissions were also predicted to increase by approximately 4% because the decrease in NOx emissions at each ramp was insignificant compared to the mainline emissions increase.

Using the field data, the researchers developed and calibrated a CORSIM simulation model application for the metered corridor. The model was used to simulate the effect of ramp metering under various operating conditions. The research team first simulated the observed conditions and then simulated conditions that were never observed on the metered system to examine: 1) the potential effects of high traffic flow conditions as might occur just prior to forced flow breakdown, and 2) the potential effects of a lane-closure where simulated forced
flow conditions are achieved. Performing these analyses allowed the team to assess the metered system under a wider range of traffic conditions, providing a better understanding of potential emissions impacts. Simulation model results confirmed the results of other research reported in the research literature; metering can significantly reduce mainline freeway travel times by inducing a slight delay on the ramps and smoothing the entry of traffic onto the freeway. However, under metered conditions on this study corridor, the mainline gram/second emission rates increased at a faster rate than the rate of travel times declined. Thus, high volume simulations lead to potentially higher mainline freeway emissions after metering was introduced. Similarly, metering under peak-hour lane-closure conditions was predicted to increase HC by 4% and NOx by 6% over non-metered lane-closure conditions. It is important to note, however, that the emissions baseline, against which meter-induced emissions changes are compared, is a planning/policy decision. The simulation model predicted that metering under peak-hour lane-closure conditions would increase NOx emissions from approximately 76,600 grams to 81,600 grams. However, the final emissions level remains lower than the peak-hour emissions levels had a lane closure not occurred (87,900 grams). Hence, one can argue that ramp metering under incident and extreme non-recurrent congestion conditions does not constitute an emissions increase from a planning perspective, because the facility emissions remain below those of normal operating levels.

Predicted emissions differences for HC or NOx under metered versus non-metered conditions must be evaluated within a regional context. The daily NOx emissions budget for the Atlanta Region is approximately 245 tons per day (ARC, 1999). The estimated emissions increase due to ramp metering on this study corridor accounts for less than 0.005 to 0.01 percent of the daily regional budget. Even an extensive ramp metering system is not likely to result in large emissions changes relative to the total regional budget.

Predicted changes in speed and acceleration conditions serve as inputs to modal emissions models, which predict emissions as a function of vehicle operating mode. The results of the simulation studies indicated that calibrated CORSIM simulation models require significant improvement before they will accurately simulate the changes in onramp activity profiles. In addition, the CORSIM routines typically underestimated high-speed operations in the downtown corridor. Additional research designed to improve lane change algorithms, car following algorithms, and the interface between the arterial and freeway models should be conducted. Without CORSIM improvement, simulation applications are likely to underestimate emissions under metered and non-metered conditions and may overestimate the percentage increase in emissions likely to result from metering. Notwithstanding the shortcomings of CORSIM speed/acceleration predictions, the high-flow simulation exercises did corroborate research efforts historically demonstrating that ramp metering has a potentially significant impact on mainline average freeway speeds under heavy flow conditions. The lane-closure simulations also supported other research efforts demonstrating that ramp metering has a potentially significant impact on mainline average freeway speeds.

Care must be taken in extrapolating findings from the study corridor simulation modeling results to other freeway corridors. There are no field observations under high-flow or lane-closure simulation conditions to which researchers can compare the simulation results. Given the noted differences between simulated and observed traffic conditions under normal operating conditions, the researchers believe that the simulated flows for high-flow conditions are also
likely to underestimate the maximum speeds and acceleration rates on the mainline. Hence, real world emissions under metered conditions for heavy congestion and lane-closures may be higher than predicted by the simulation outputs. Thus, although the percentage emissions increases that result from metering may be somewhat lower than simulated, the net magnitude of the predicted change may be higher.

During the collection of vehicle activity data, the Georgia Tech Air Quality Laboratory performed a concurrent emissions verification study. The Laboratory conducted remote sensing studies, instantaneous infrared measurements across vehicle exhaust plumes to assess the level of emissions from the vehicles, to assess the relative emissions distributions and fraction of high emitting vehicles in the monitored fleet. Researchers also conducted vertical flux experiments to measure vertical movement of pollutants from the roadway. Estimates of vertical pollutant transport were linked back to vehicle activity to quantify the emissions effect of the fleet as a function of onroad vehicle operating conditions. The study concluded that measured emissions above the roadway are highly variable, and highly influenced by the presence of heavy-duty trucks. The impact of trucks on monitored emissions is so significant that pollutant concentration spikes observed in the field link back to specific video images of trucks passing through the observation site. Researchers also observed significant variation in emissions as a function of the onroad fleet composition, which varied by time of day (especially on ramps).

Based upon emissions flux measurements, the research team determined that emissions under observed congested conditions were lower than under observed free flow conditions. That is, as traffic volumes decline and vehicle speeds increase significantly, air samples collected above the facility demonstrated that emissions from the monitored facility increased. Because emissions are the product of activity and emission rates, field observations support the prediction that emission rates are increasing at a much more rapid rate than traffic volumes are decreasing. Hence, high-speed emissions on freeway are cause for significant emissions concern.

The emissions experiments, however, did not observe a statistically significant difference in emissions under metered and non-metered conditions. In part, this is because predictions were only prepared for light-duty vehicles. The absence of a statistically significant measurable difference for metering is also not surprising because the predicted changes are too small to fall outside of the boundaries of experimental sampling and analysis error (within ±10%). The predicted emission increase for light-duty vehicle HC was only 1% and the predicted increase for light-duty vehicle NOx was only 4% for the mainline sections near the sampling locations. Hence, the sampling effort could neither support nor refute the predicted emissions increase from ramp metering on this system.

As freeway conditions approach breakdown, regions need to decide whether trading an emissions increase for a significant reduction in travel time warrants the implementation of metering strategies. If so, the region will likely need to identify alternative means of reducing the emissions resulting from improved traffic flow on the freeway corridor. Given the small relative contribution of potential metered corridors to the overall regional emissions inventory, and the potential travel time savings of highway users, it seems reasonable to pursue alternatives that compensate for the metered system emissions increase. Simulation modeling tools and modal emissions models can help with these decisions.
The researchers acknowledge that there is a great deal of uncertainty in both the simulation modeling runs and the emission rate model outputs used in the analyses. However, the results of the field and simulation studies indicate that additional research on the emissions impacts of ramp metering is warranted. First, while ramp metering on the I-75 study corridor may never yield emissions benefits, ramp metering in other significantly congested areas may still benefit from metering. The research team recommends similar studies be conducted on the I-75/I-85 connector (to I-20) and on one of the most congested segments of the I-285. These corridors achieve such high levels of congestion that emissions may decline when metering smoothes traffic flow. Any simulation analyses should employ simulated traffic volumes coupled with appropriate speed/acceleration profiles measured from existing systems (until researchers improve the simulation models to provide better estimates of speed/acceleration profiles). Second, MOBILE6 and more advanced second-by-second modal emission rate models will soon replace the models employed in this study. Once the new emission rate models become available, the research team recommends repeating the analyses reported in this study using the observed activity data and the new emission rates.

Ramp metering has been and will likely continue to be a popular cost-effective traffic management tool with a high potential for improving freeway traffic flow. Ultimately the decisions to implement a ramp metering system will be a function of the specific traffic operations and air quality issues associated with the area under consideration. Given the projected emissions increases, optimizing the tradeoff between time savings and increased emissions will likely be next order of business in modeling the detailed impacts of ramp meters.