CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

Transportation agencies often implement ramp metering and other traffic flow improvement projects with the intent of improving air quality and reducing congestion. The Clean Air Act Amendments of 1990 and the Transportation Equity Act for the 21st Century encourage the use of traffic flow improvements, such as ramp metering, as a means to improve air quality because they mitigate traffic congestion. However, emissions from motor vehicles do not necessarily decrease in proportion to reductions in traffic congestion and vehicle delay. Numerous factors influence the level of vehicle emissions. Under some conditions, a tradeoff between travel speed and emissions can exist. In addition, a tradeoff between different pollutants (e.g. NOx and HC) can also exist. Research has demonstrated that emissions are a function of both the changes in hours of vehicle operation (i.e. average speed) as well as changes in vehicle modal operation (associated with speed/acceleration profile). The current version of the US Environmental Protection Agency emission rate model (MOBILE5b), which only directly accounts for average speed effects, may not predict accurate emission rates in certain applications (Gertler et al., 1997; Pierson et al., 1990; NRC 1991). Hence, the emissions impacts that may result from a more widespread implementation of ramp meters in the Atlanta area are unclear.

To date, modeling techniques have not been capable of capturing off-cycle conditions and, in turn, have been unable to accurately analyze the air quality impacts of many traffic management strategies, including ramp metering. This research has attempted to add to the understanding of the systems impacts of transportation control measures (TCMs), especially those that influence onroad vehicle operating modes. This was accomplished through the application of current modeling techniques and a new modal emissions modeling tool (the MEASURE Aggregate Modal Model) in the analysis of the Atlanta ramp metering system as a case study.

The research team collected vehicle activity and operating mode data from the Atlanta metered system for 18 days. More than 26,000 laser gun traces of onroad speed/acceleration activity were collected during this study. The laser gun data comprise more than 480+ hours of onroad operating data, approximately 75% of which were collected at ramps and 25% collected on mainline sections. To supplement the remote sensing data, and obtain information on operating characteristics in areas that could not be monitored by laser gun, more than 200 instrumented vehicle runs were performed on mainline sections and more than 275 instrumented vehicle runs were performed on ramps. Ramp meters were not operated on 4 of the 18 data collection days. Hence, the research provided the opportunity to compare operations under metered versus non-metered conditions. Detailed data collection methods were discussed in Chapter 4 and results from the field assessments of vehicle activity were presented in Chapter 5. The study has assembled the largest operating mode profile database for a metered ramp system.

8.1 Observed Ramp Metering Effects

Researchers applied the MOBILE5a average speed emission rates and the MEASURE Aggregate Modal Model emission rates (discussed in Chapter 3) to the vehicle activity and operating mode conditions observed in the field. The assessment indicated that ramp meter operation on the I-75
study corridor had a potentially detrimental effect on vehicle emissions. Both the MOBILE5b and MEASURE Aggregate Modal Model results predicted an increase in NOx emissions under metered conditions. The MEASURE Aggregate Modal Model predicted larger emissions increases for all pollutants than did MOBILE5a.

Under volume-controlled conditions, predicted HC mass emissions estimates for all four onramps rose from 40 to 46% under metered conditions. The opposite trend at ramps was apparent for estimated NOx emissions. While the predicted Northside drive ramp emissions dropped by only a few percent under metered conditions, NOx reductions at the other ramps ranged from 12 to 22% under metered conditions.

While the onramp emissions estimates were important, the mainline emissions dominated the overall system evaluation. The estimated HC emissions analysis for the mainline section showed a 2% decrease in mass emissions under metered conditions. Total predicted system-wide HC emissions were lower by about 1% on a typical day when ramp meters were in operation, given the significant predicted increase in emissions at the ramps. Using measured vehicle activity and the MEASURE Aggregate Modal Model, researchers predicted 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 ramp emissions decreases were insignificant compared to the mainline emissions increase.

It is important to consider that these conclusions apply only to the study corridor under the conditions normally observed during the field study. Extrapolation of these findings to other areas should only be performed within the context of this study. The research indicated that ramp metering in the study corridor is not recommended, due to the fact that little travel time benefit is realized (a 2mph increase in average speed) and there is a modeled NOx emissions increase. This is not to say that the same conclusions would be reached for every potential ramp-metered corridor. Indeed, under certain congested traffic conditions, ramp metering can delay the onset of forced flow conditions and greatly improve travel time on a metered corridor. Because the study area never entered forced flow conditions, researchers undertook a series of CORSIM simulation analyses to provide insight into how the metering system would affect emissions under conditions that were never observed in the field.

8.2 Simulated Ramp Metering Effects

Analyzing the impacts of potential forced flow conditions was accomplished with the field dataset through the application of CORSIM simulation modeling tools. The data collected as part of this research was used to calibrate a CORSIM traffic simulation model, for use in simulating the effect of ramp metering on increased traffic volumes. The outputs from simulation runs were then used to assess the potential changes in modal activity and emissions under traffic conditions not observed during the data collection process. First, the research team simulated the existing corridor under observed conditions. The research team then examined: 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 were achieved. Performing these analyses allowed for the assessment of the ramp
metering system under a wider range of traffic conditions and provided a more complete understanding of the air quality impacts of ramp metering on the corridor.

8.2.1 Simulation of Observed Conditions

Emissions predictions from field data indicated between a 30 and 46% increase in ramp HC emissions, versus simulation run predictions of a net average increase in ramp HC emissions of 50%. Emissions predictions from field data indicated between a 2% to 22% decrease in ramp NOx emissions, depending on the onramp in question, versus simulation predictions of a net average increase in NOx ramp emissions of 21%. The research team noted significant differences between observed and simulated average speed conditions on metered and non-metered ramps. In the simulation, ramp speeds were predicted to drop from 44 mph to 8 mph under metered conditions. However, observed ramp speeds only dropped from 41 mph to 32 mph. Acceleration distributions also differed significantly as illustrated in the speed/acceleration plots. As discussed in Chapter 6, the research team believes that the discrepancy results from the simulation model's treatment of vehicles transferring between the arterial network and freeway network modules (at interface nodes) under congested conditions. Given the field findings, simulation model performance for ramps requires significant improvement.

Field observations yielded a predicted 2% decrease in mainline freeway HC emissions and an estimated 4% increase in mainline freeway NOx emissions. However, simulation results predicted much larger percentage increase in both HC and NOx mainline freeway emissions. Simulations indicated that a nearly 7% increase would result in both HC and NOx emissions for the freeway mainlines. Field observations recorded higher speed activity and more hard acceleration conditions under all ranges of speeds that lead to higher emissions in the MEASURE Aggregate Modal Model regime. The difference between emissions estimates arise predominantly from the difference in predicted starting points and changes in average speeds, and to some extent from differences in percentage of operations under higher power demand conditions (inertial power surrogate values). Again, the simulation models require improvement for predicting the high-speed activities that were observed on the freeway under current traffic conditions.

8.2.2 Simulation of High-Flow Conditions

The high-flow simulation exercises corroborated independent research efforts that have historically demonstrated that ramp metering has a potentially significant impact on mainline average freeway speeds under heavy flow conditions (roughly 10mph in this case). With ramp metering, mainline freeway hours of vehicle activity dropped by nearly 20% under high-flow conditions, compared to a drop of only 8% under observed flow conditions. This occurred while ramp delay and arterial congestion contributions remained constant. Hence, as expected, ramp metering provides greater mainline freeway time savings under heavier traffic flow conditions. The basic problem is that under metered conditions gram/second emission rates increased at a greater rate than the rate of travel times decline. Thus, high volume conditions lead to potentially higher mass emissions for the metered scenarios than observed flow conditions. In this case, the net emissions increase from metering rose from 33% to 45% for NOx and from
37\% to 39\% for HC when moving to higher flow conditions. Hence, emissions impacts were even worse under high-flow conditions than under observed conditions.

8.2.3 Simulation of Lane-Closure Conditions

The lane-closure simulations also supported previous research efforts demonstrating that ramp metering has a potentially significant impact on mainline average freeway speeds. Simulations of observed peak-hour flows indicated that metering would yield a small increase in average freeway speeds; from 53 mph to 55 mph. However, under the lane-closure simulations, metering was predicted to increase average freeway speeds from 39 mph to 45 mph. Ramp metering was predicted to reduce mainline freeway travel times by 6\% for non-lane-closure conditions and by 13\% under lane-closure conditions, indicating that ramp metering is even more effective at reducing travel delay under incident conditions.

As with the previous simulations for observed flow and high volume flow conditions, metering under peak-hour and peak-hour lane-closure conditions are predicted to lead to higher emissions. Metering under peak-hour conditions lead to a predicted 4\% increase in HC and NOx emissions. These increases come with a relatively small increase in average speeds (less than 3 mph). Metering under peak-hour lane-closure conditions was predicted to increase HC by 4\% and NOx by 6\% compared to non-metered lane-closure conditions. The smaller predicted increase in mainline and ramp emissions under lane-closure conditions comes with much larger mainline freeway travel time savings (nearly 50 seconds per vehicle).

The simulation scenarios indicated that the system would experience very large increases in travel times and emissions on local roads under lane closure conditions. The increases in arterial travel times may be more than enough to offset travel time benefits gained on mainline freeway segments. The impact of ramp metering on the local arterial segments appears from simulation results to be a critical factor in ramp metering system evaluation. In designing ramp meter solutions, engineers and planners should ensure that ramp queues do not spill back onto arterials.

As outlined in Chapter 6, there is a great deal of uncertainty associated with the simulation predictions on ramp speeds and mainline high-speed operations. The differences between simulated and observed traffic data under normal operating conditions indicate that simulated flows for high-flow conditions are 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 in the real world than were simulated, the net magnitude of the predicted change may be higher. Nevertheless, great care must be taken in attempting to extrapolate these simulation results to other corridors and operating conditions. There are no field observations under high-flow or lane-closure simulation conditions to which researchers can compare the simulation results. Moreover, the simulation models require improvement.
8.3 Results from Field Emissions Measurement

The peak-period and off-peak vehicle fleet observed in the study corridor changed significantly as a function of time of day. The fleet was slightly older, and more trucks and sport-utility vehicles were observed in off-peak periods. Based upon vehicle registration data, the evening peak period fleet appears to be composed primarily of commuters that are local residents (based upon the census block group of vehicle registration). In performing all work, the field emissions measurement team was required to explicitly account for the changes in vehicle subfleet characteristics as a function of time of day (normalizing for fleet composition) in drawing comparative emissions conclusions.

The remote sensing studies indicated that metered ramps yielded higher emission rates near the stopline under metered conditions for CO at 4 of 5 locations, for NOx at 3 of 5 locations, and for HC at 4 of 5 locations. This is not terribly surprising, as the instantaneous load on the engines under the hard acceleration conditions can lead to large increases in localized emissions. However, the measured results do not infer that emissions are higher for the entire ramp trip under metered conditions (emissions were measured near the point of maximum acceleration). Interestingly, the onramp location that consistently did not result in an emissions increase near the stopline was Northside Drive, a cloverleaf entrance ramp. The conditions under metered and non-metered conditions simply did not differ as greatly at this location because the tight cloverleaf requires significantly slower operating speeds under non-metered conditions (which are closer in form to metered conditions that at other ramps).

The Air Quality Laboratory field team installed sampling equipment above the roadway at two locations along the study corridor (one northbound and one southbound location). Given the physical nature of the traffic corridor, the vertical flux study examined the vertical migration of vehicle emissions moving from the roadway. The study concluded that measured emissions above the roadway are highly variable, and are heavily influenced by the presence of heavy-duty trucks. The impact of trucks on emissions is so pronounced that the pollutant concentration spikes can be observed directly in the data and linked to the video image of the truck’s passage. Unfortunately, the field study could not determine a statistically significant difference in emissions flux on the corridor under metered and non-metered conditions. The modeled emission increase for HC was only 1% and for NOx was only 4%, both of which are well within the confidence bounds of the emissions measurements. Hence, no conclusions could be drawn regarding a measured emissions impact of ramp metering.

The field emissions team collected vertical flux emissions data on more days and over a longer data collection period than did the vehicle activity data collection team. On a number of occasions, the emissions measurement team observed traffic flow breakdown conditions (most likely due to an incident on the corridor), whereas vehicle activity data collectors never observed such conditions. Under these conditions, field monitoring did detect a statistically significant reduction in vehicle emissions from the corridor under forced flow conditions. These observations support the simulated results for breakdown conditions, which also predicted a reduction in mass emissions from the facility under forced flow conditions.
8.4 Guidelines for Optimizing the Air Quality Benefits of Metered Systems

The research results confirm previous ramp meter findings reported in the literature. First, and foremost, transportation planners and engineers should not install and operate ramp meter systems on corridors that will not significantly benefit from reduced mainline congestion. The emissions predictions under metered conditions were higher than the emissions from the comparable non-metered system for those conditions observed in the field and simulated. The emissions increase is the largest when the ramps are metered to provide a small increase in mainline flow speeds (e.g. under good level of service traffic flow conditions where metering increases speeds from 62 to 63 mph). The emissions increase (say between 1% and 4% for the 4-mile corridor) comes with reduced travel times of less than 5 seconds per vehicle. Under simulated conditions, the predicted emissions increases were larger (approximately 7%), but came at a slightly larger predicted travel time savings of approximately 25 seconds per vehicle. Given the field findings, the metered system currently in place on this I-75 Northbound section should probably be operated only when an incident, or other non-recurrent event, causes congestion problems on the corridor.

Simulation modeling predicted emissions changes resulting from operational changes on the ramps, mainline freeways, and the arterials. Under simulated high-flow conditions, the predicted NOx emissions increases associated with ramp metering were larger (in both mass emissions and percentage increase) than were predicted for the lower traffic flow conditions. HC emissions increases were roughly the same under simulated observed flow and high-flow conditions. However, these increases came with much larger increases in mainline freeway travel speeds. Metering under lower flow conditions was estimated to save approximately 25 seconds per freeway vehicle trip, but metering under high-flow conditions was estimated to save 82 seconds per freeway vehicle trip.

Although the simulation models do require significant improvement, the field and simulation results still indicate that analysts should perform detailed simulations before implementing metering systems. Simulation models can provide accurate volume estimates, although the speed and acceleration operating profiles are not accurate. Hence, the research team recommends coupling ramp metering simulation results with measured speed/acceleration profiles collected from existing systems (until the simulation models are improved). Meters will clearly provide mainline freeway congestion reduction and increased travel speed benefits. However, analysts should first ensure that implementation of the metering program will not significantly adversely affect traffic conditions on local arterials. Adverse conditions on arterials appear to be capable of more than offsetting mainline time savings. In the simulated observed flow scenario, the predicted 180 vehicle-hour benefit on mainlines was offset by a 100 vehicle-hour increase on ramps and 770 hour increase on arterials. In the simulated high-flow scenario, the predicted 620 vehicle-hour benefit on mainlines was offset by a 100 vehicle-hour increase on ramps and 770 hour increase on arterials. In both scenarios, ramp metering would have provided a system wide travel time reduction, had arterial travel times not increased. It is important to ensure that ramp queues do not spill back onto the local arterials.

Even when arterial operations are reasonably isolated from adverse effects of ramp metering (through proper ramp and signal timing design), it is still reasonable to expect that the emissions from the ramps and mainline freeway segments will increase under metering. Simulation results
indicated that metering would increase ramp and arterial NOx and HC emissions (Tables 6-5 and 6-6, assuming zero arterials impact). NOx and HC emissions were both predicted to increase by approximately 7% under observed flow conditions when metering is implemented. NOx and HC emissions were predicted to increase by 20% and 11% respectively under high-flow conditions when metering is implemented. Given the travel time savings that result from metering under high-flow, lane-closure, or other conditions that lead to forced flow conditions, regions may want to trade-off the increased emissions for the travel time savings.

Study results indicate that ramp metering should not be implemented on ramps with steep uphill grades and/or short acceleration zones for gaining free flow traffic speeds. The hard acceleration events on short uphill ramps exacerbate emissions. Ramp metering strategies may benefit significantly from new and innovative design strategies. Roadway designs that allow for the slowing of vehicle activity and dispersing of platoons in the ramp zone, without requiring vehicles to come to a complete stop, may provide significant benefit in ramp-related emissions reductions. Such strategies should be the subject of ongoing research efforts.

8.5 Regional Context of Ramp Metering and Air Quality

The 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). Therefore the estimated emissions increase due to ramp metering on this portion of the I-75 corridor accounts for less than 0.005 percent of the daily regional budget. This is for a small, four-ramp system. As metered systems increase in size, the relative impact will also increase. Nonetheless, it is apparent that even an extensive ramp metering system would not result in a large emissions change when compared to the regional budget. It is therefore important to keep in mind the current local emissions issues when evaluating the impacts of ramp metering and assessing the traffic congestion and operations tradeoffs in light of these emissions impacts.

8.6 Final Word

One of the most important findings of the study is that two assertions in conventional wisdom associated with the emissions impacts of ramp meter systems may not be correct. Some policy analysts have argued in the literature that ramp meter approaches will universally reduce vehicle emissions by reducing congestion levels. Other policy analysts have argued that because emissions from the ramps increase significantly when meters are in operation, that ramp meters are likely to increase system emissions. Neither of these positions appears to be correct:

- First, the field results and simulation modeling indicate that the emissions from the Atlanta I-75 system are not likely to decrease when meters are in operation for any of the operational scenarios examined. Were congestion levels to increase to extreme levels, metering may decrease emissions. However, the field team never observed such operating conditions in this corridor.

- The second position, that emissions increases on ramps are so great as to eliminate the emissions benefits on the mainline segments, also does not appear to be correct for this
corridor. While research indicates that ramp emission rates increase significantly, the net impact of increased ramp emissions is small because the ramps contribute only a small fraction of the system emissions. The controlling factor was the predicted increase in mainline emissions (the dominant contributor to total system emissions) when the meters were in operation. Thus, the emissions increase on the system was almost entirely due to the increase in speeds and loads on the mainline freeway segments when the meters were in operation.

The findings of this research are limited to the scope of the case study, providing an assessment of the potential emission impacts associated with Atlanta’s existing metered corridor. This research has provided two critical elements that will allow for more effective ramp metering and air quality research in the future. First, this research provided a basic analytical framework (data collection and analytical methods) that can be applied in future studies. Second, the research established a comprehensive dataset for ongoing analysis.

The research results indicate that ramp metering systems should not be operated when freeways are running at high levels of service. As freeway conditions approach flow breakdown, regions need to decide whether the tradeoff between increased emissions and reduced travel time warrants the implementation of the metering strategies. Simulation modeling tools and modal emissions models can help with this decision, even though there is still a great deal of uncertainty in both the simulation and emission rate model outputs used in such analyses. To provide a more complete picture of the potential air quality impacts of ramp metering, further fundamental research is required. As the modeling tools continue to evolve, the new modeling routines can be applied to the data collected for this project so that specific timing strategies can be properly evaluated.

The region needs to decide whether the reduced travel times from metering are worth potential increases in emissions. If so, the region will need to identify alternative means of reducing the emissions that may result from improved traffic flows on the freeway corridor. New freeway corridors that are likely to be metered may yield a small relative increase in the overall regional emissions inventory. Given the potential travel time savings of highway users (assuming arterial degradation can be avoided), it seems reasonable to pursue such alternatives to compensate for any predicted emissions increase. 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.