Project 5: Reducing Freeway Emission Via Ramp Metering Control

Area Coordinator:
Dr. Heng Wei  
Associate Professor, Transportation Engineering  
Department of Civil & Architectural Engineering & Construction Management  
College of Engineering and Applied science  
PO Box 210071, University of Cincinnati  
Office: 792 Rhodes Hall  
Phone: 513-556-3781  
E-mail: heng.wei@uc.edu

Sub-Area Coordinator:
Dr. Jonathan Corey  
Assistant Professor, Transportation Engineering  
Department of Civil & Architectural Engineering & Construction Management  
College of Engineering and Applied science  
PO Box 210071, University of Cincinnati  
Office: 796 Rhodes Hall  
Phone: 513-556-6554  
E-mail: coreyjn@ucmail.uc.edu

Dr. Mingming Lu  
Associate Professor, Environmental Engineering  
Department of Biomedical, Chemical, and Environmental Engineering (BCEE)  
College of Engineering and Applied Science  
PO Box 210012, University of Cincinnati  
Cincinnati, OH 45221-0012  
Office: 797 Rhodes Hall  
Phone: 513-556-0996  
E-Mail: mingming.lu@uc.edu

Graduate Research Assistants:  
Ms. Bei Zhao  
M.S. Student in Transportation Engineering  
Office: 729 Engineering Research Center  
Phone: 763-333-0790(C)  
E-Mail: zhaobi@mail.uc.edu

Mr. Omar Almutairi and Mr. Hui Ren (volunteer GRAs)  
Ph.D. Students in Transportation Engineering  
Office: 729 Engineering Research Center  
E-Mail: almutaoe@mail.uc.edu; renhi@mail.uc.edu

Project Summary
Increased traffic congestion and associated vehicle emissions impacts ambient air quality and thus the health of drivers and urban dwellers. One essential question that emerges is: Does controlling the entering rate of traffic flow into the freeway, so that it remains at a moderate level of service, reduce the vehicle emissions and impact ambient air quality to be within acceptable limits? A practical solution to freeway congestion is the ramp metering system that controls vehicles entering into the freeway from an on ramp. The challenge in creating this model is twofold, How can the design of the ramp metering system be effective in mitigating congestion while also reducing vehicle emission? As shown by Figure 1, by controlling the entering rate, the traffic flow in the freeway will remain at a moderate level of service.
and capacity due to the reduction of interrupted traffic from the ramp. At the same time, it is also expected to reduce vehicular emissions, crashes and travel time, which in reality will greatly improve the safety and quality of peoples’ daily lives.

The project goal is to help the teachers gain a hands-on experience in understanding the mechanics of operation of a ramp metering system and the resulting vehicular emissions. Teacher learn how traffic flow can be mathematically modeled in a real freeway-ramp system and how this mathematical model can be simulated to study what design parameters of a real-world freeway-ramp system result in moderate level of service and capacity in the freeway and minimum air pollution due to vehicular emissions both on the freeway and the ramp. (Refer to Figure 1, which presents the basic elements of such a system.) The result will help increase teachers’ awareness of relating math and science knowledge to a real-world societal problem of freeway congestion and safety. The microscopic traffic simulation tool, VISSIM, and environmental analysis computer tool, MOVES, will be introduced to the teachers. The microscopic traffic simulation tool, VISSIM, stimulates (using dynamic mathematical, graphical and animation interfaces) movements and interactions of road users through ‘car-following’ and ‘lane-changing’ algorithms. The computer analysis tool, MOVES, estimates on-road vehicle emissions for given quantified traffic flow activities and attributes, thus describing the physical and environmental features of the roadway infrastructure. These two tools, VISSIM and MOVES, when used together provide a cost-effective way to test the effect of traffic control measures, including the ramp metering system.

![Figure 1: Illustration of Ramp Metering Operation (left) and Simulated System (right)](image)

In this project, the teachers will get a hand-on experience in using sensors that measure Particulate Matters diameters of 2.5 micrometers or less (i.e., PM2.5) and Nitrogen Dioxide (NO2) levels. The teachers will also learn how to use a GPS Data Logger unit to record their track, time and location for viewing on a mapping application such as Google Earth. Figure 2 shows pictures of a PM2.5 and NO2 sensor, and a GPS Data Logger. The near-road PM2.5 and/or NO2 data along with the GPS-based traffic data will be used to study how traffic situation impacts vehicle emission. This will be an authentic learning tool for the teachers to take back to their classroom. Such vehicular emissions vary significantly depending on the location (higher within city limits) and pollutant sources and can adversely affect the health of road travelers. The students will recognize the role of transportation engineers in solving this pressing every-day problem.
The research tasks will be completed in 7 weeks (6 of these weeks will be actually devoted to the research project), including the following activities that are specifically designated for the 2015 summer RET project:

**Week 1:** The teachers will be taking an *Engineering Foundations* course along with other groups of teachers involved in the summer project.

**Week 2:** The teachers will participate in training seminars to learn basics of ramp metering, background literature review, analysis methods, and the scope of research tasks for the project. A real simulation example using VISSIM and MOVES for an on-going EPA project will be showcased to the teachers.

**Week 3:** Collection of GPS travel and PM2.5 and/or NO2 monitoring data, and relevant traffic flow data at the project site will be conducted under the supervision of the graduate student mentors. The field data collected will be analyzed under the supervision of the graduate student mentors.

**Weeks 4-5:** Using last year’s RET research project’s findings, the teachers will build a ramp metering system for the case study site in the VISSIM environment, and learn how to use it as a simulation tool to reduce vehicle emission from freeway traffic by adjusting the ramp metering system’s operational design parameters. The teachers will learn the mathematics and scientific principles involved in traffic operation and control in this part of the project. The teachers will also be developing their classroom implementation plan to take this experience back to the classroom.

**Week 6:** The teachers will compile the research results from the above tasks. From this they will develop an engineering design process activity and incorporate it in their classroom implementation plan.

**Week 7:** The teachers will be preparing a final Power Point Presentation, a Research Report, a poster, a short video and a NSF Summary report.

In addition to the RET research project, a field trip will be arranged to visit the statewide traffic management center (TMC) in Ohio Department of Transportation Center Office in Columbus, Ohio (shown in Figure 3). This trip is expected to provide an authentic experience on real-world traffic operation and management.

**Figure 2: Illustration of PM2.5 and NO2 Sensor and GPS Data Logger**

**Figure 3: TMC in Columbus, Ohio**
Possible Ideas for Classroom Implementation

The teachers could develop a classroom implementation unit around the theme of “Math: how is it used to solve real-world problems?” The unit will help students understand how math and science is used to solve a traffic congestion, safety and pollution problems for a site near their school by designing an appropriate ramp metering system and recommending its installation. Students will use mathematics to estimate the design parameters using field data. In addition, they will make inferences about the relationship between the ramp metering system design parameters and the impact on traffic conditions in the freeway and air pollution in the ramp and freeway. Also, they will calculate the PM2.5 or NO2 pollutant exposure level to commuters and finally understand how emission reduction is impacted by control measures.