U N I T E D S T A T E S
DEPARTMENT OF TRANSPORTATION

Eco-Traffic Signal Timing Application: Preliminary Modeling Results

Applications for the Environment: Real-Time Information Synthesis (AERIS) Program

Fall/Winter Webinar Series

January 29th, 2014

Presentation Overview

- AERIS Eco-Traffic Signal Timing Application
- Eco-Traffic Signal Timing Application Algorithm
- Modeling Results and Analyses
- Conclusions and Future Research

Eco-Traffic Signal Timing Concept

The application seeks to optimize traffic signals, with an environmental focus, using data from connected vehicle technology

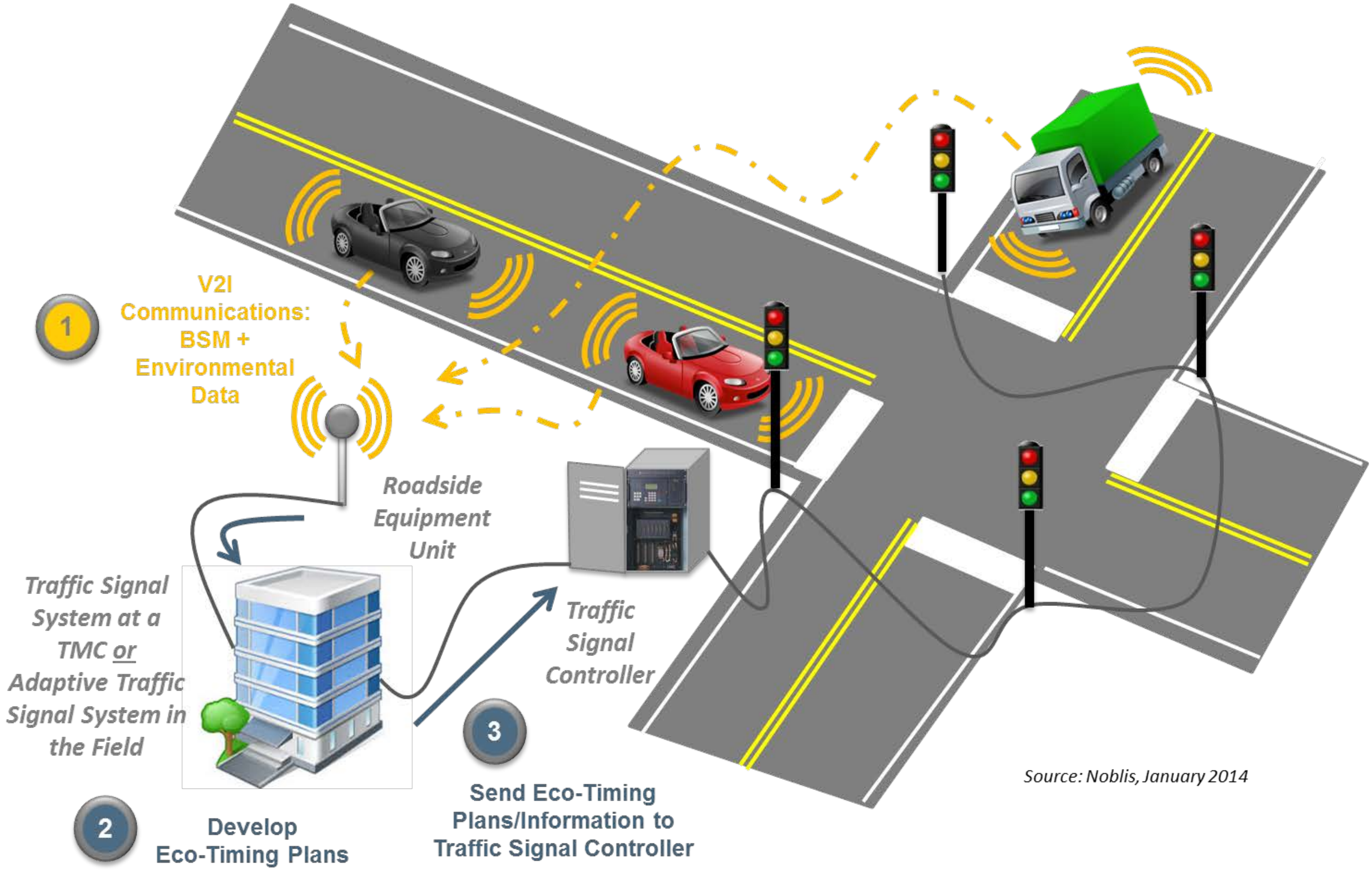
- Use connected vehicle technology to process and record emissions data at signalized intersections, such as fuel consumption and overall emissions along a corridor, or for a region
- This information is used to create an **optimized** signal timing plan with the AERIS objective of minimizing environmental impact and fuel consumption

Eco-Traffic Signal Timing Concept

The Eco-Traffic Signal Timing Application seeks to answer the following questions:

- *Can a signal timing plan that is optimized for the environment be created using connected vehicle data?*
- *What does an environmentally optimized timing plan look like?*
- *What, if any, are the trade-offs in optimizing for the environment and optimizing for mobility?*

Eco-Traffic Signal Timing Concept



Eco-Traffic Signal Timing Hypothesis

If the Eco-Traffic Signal Timing application is used to dynamically adjust **signal phase and timing plans** based on vehicle emissions characteristics and fuel consumption, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:

- **2%–3%** under **partial** connected vehicle penetration
- **4%–6%** under **full** connected vehicle penetration

Eco-Traffic Signal Timing Concept

There are many methods of signal timing optimization that have been used or are currently in use today:

- ***Aggregation optimization methods*** such as the Highway Capacity Manual hand optimizations or industry standard optimization programs such as Synchro that develop timings "after the fact."
- ***Adaptive optimization methods*** that use collected traffic data to change the green times, cycle lengths, and signal offsets to meet changing traffic patterns, such as SCATS, SCOOTS, RHODES, etc.

These methods, however, all mostly rely on mobility measures, such as throughput and delay for optimization

Eco-Traffic Signal Timing Concept

- The method of most signal timing optimizations is to vary a combination of signal timing parameters at one or more intersections in order to minimize the impacts on a **“performance measure”**
- To minimize the performance measure, the signal parameters that could be adjusted include:
  - Green times for each phase
  - Cycle length of each intersection
  - Signal offset of each intersection
  - Phasing sequence

Eco-Traffic Signal Timing Concept

- There are many possible performance measures that can be used to optimize the signal timings:
  - Vehicle Throughput
  - Delay/Travel Time
  - Average Vehicle Stops
  - Fuel Consumption
  - Vehicle Emissions
- The AERIS program seeks to minimize environmental impacts, so **Carbon Dioxide (CO_2)** was used as the measure of the Eco-Traffic Signal Timing Application

Eco-Traffic Signal Timing Concept

- However, the ability to optimize all of these signal variables is quite complicated (too many solutions/combinations exists), so the team decided to use a procedure called a **Genetic Algorithm (GA)** to find signal timing plans that are optimized for the environment
- A Genetic Algorithm is a method of finding an optimal solution from a large set of possible solutions using Darwin's Theory of Evolution, or **"survival of the fittest"**

Introduction to Genetic Algorithms (GA)

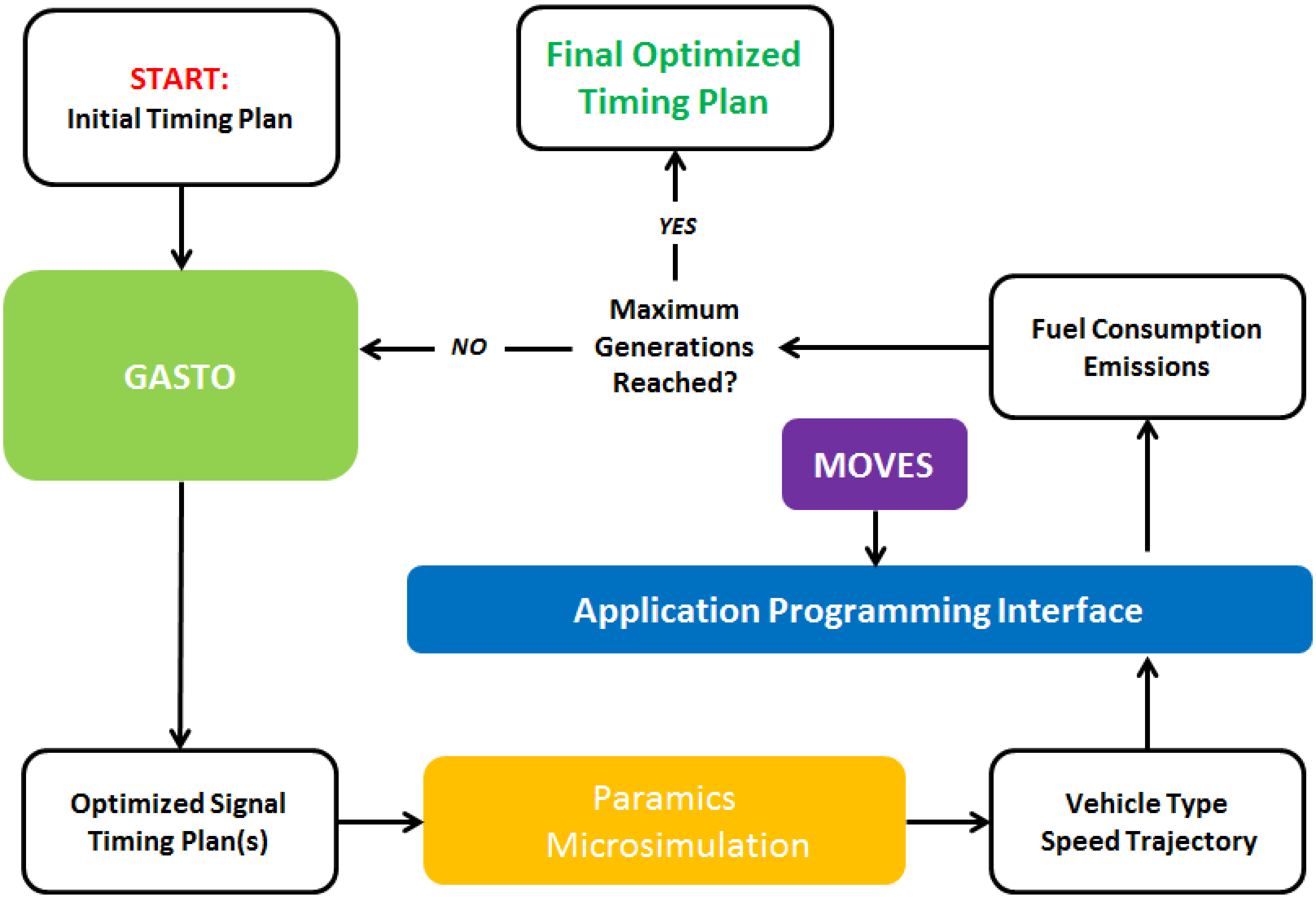
- The GA is started with a **set of solutions** (signal timing plans) called a **population** which are tested for fitness against each other
- The “best” solutions from the previous population are taken and used to form the next **generation**, with the hope of improving the population of solutions as iterations pass
- Using this method, more suitable timing plans are more likely to be carried forward, while “sub-optimal” solutions are discarded
- This process is then repeated until the desired number of generations has passed, with the best solution of the final population chosen as the **optimal timing plan**

Eco-Traffic Signal Timing Application Implemented Using a GA

To implement the GA for the Eco-Traffic Signal Timing Application, there were three vital components:

- Genetic Algorithm Component: a new program was developed, named the **Genetic Algorithm for Signal Timing Optimization (GASTO)**, which created the populations of timings to test during the optimization
- Microsimulation Component: in order to test the timing plans created by GASTO, **Paramics** microsimulation program was used
- Environmental Monitoring Component: the environmental modeling program **MOVES** was coded as an API to use with Paramics that provided real-time emissions from the simulation

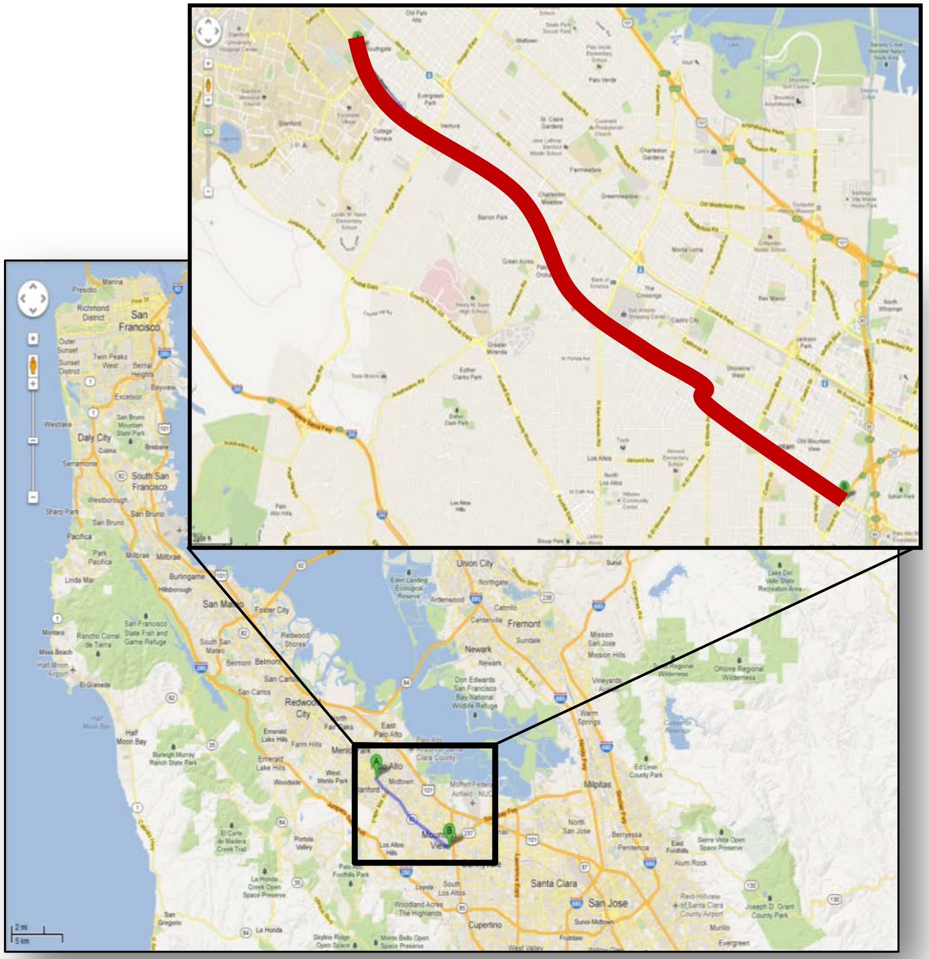
Eco-Traffic Signal Timing Application Implemented Using a GA



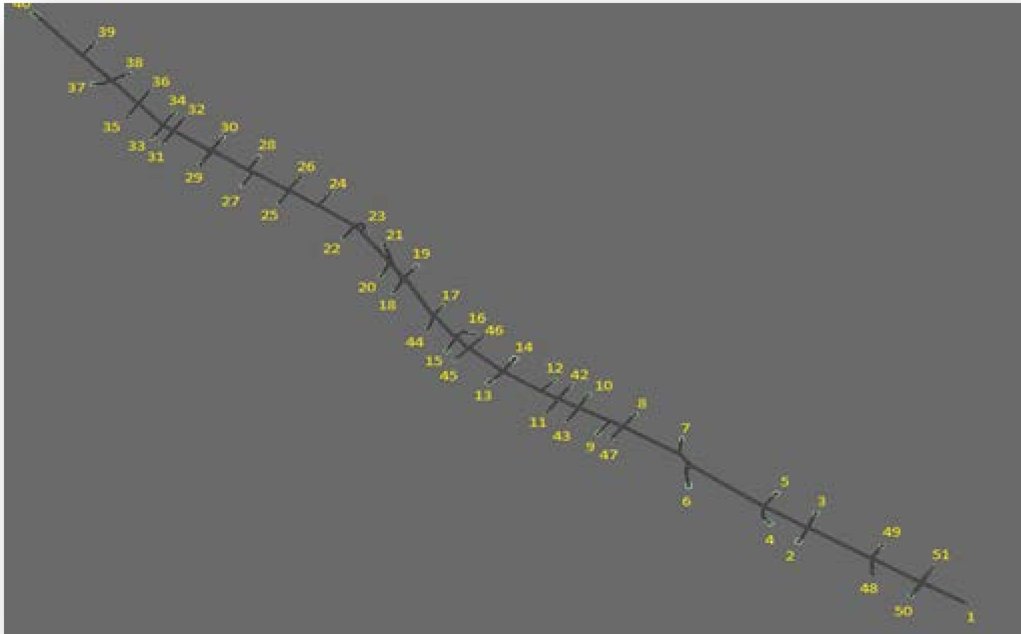
SIMULATION MODELING

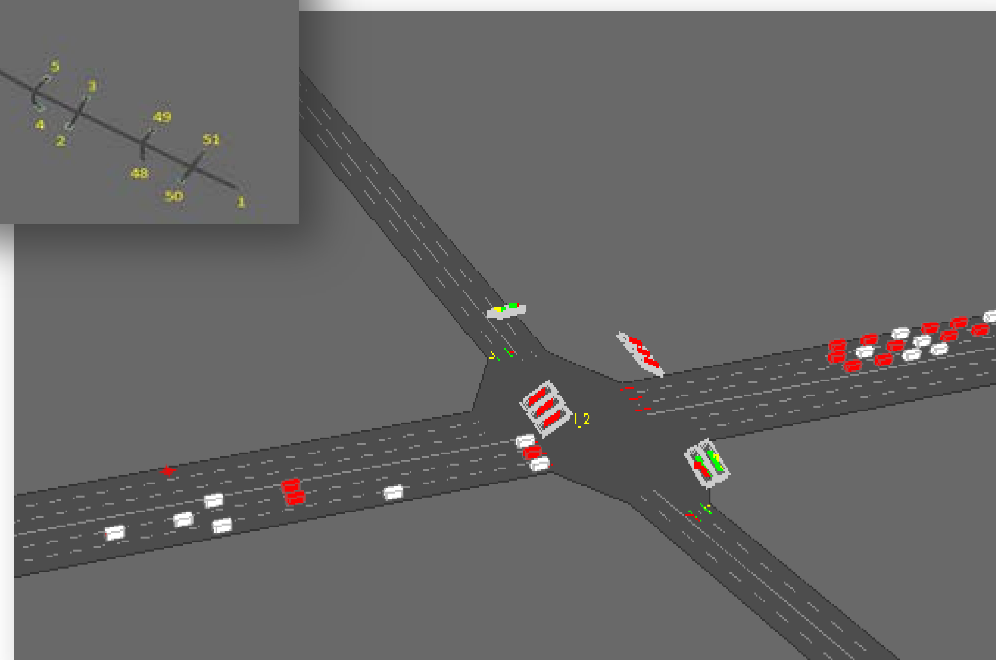
Region of Modeling: El Camino Real in Northern California

- 6-mile segment between
  - Churchill Ave in Palo Alto and Grant Rd in Mountain View
- 2005 Network and Demand conditions
- 27 signalized intersections
- **Fixed-Timing** and **well coordinated** signals
- Mostly three lanes in each direction
- Parallel to the US-101 freeway



Region of Modeling: El Camino Real in Northern California





Region of Modeling: El Camino Real in Northern California

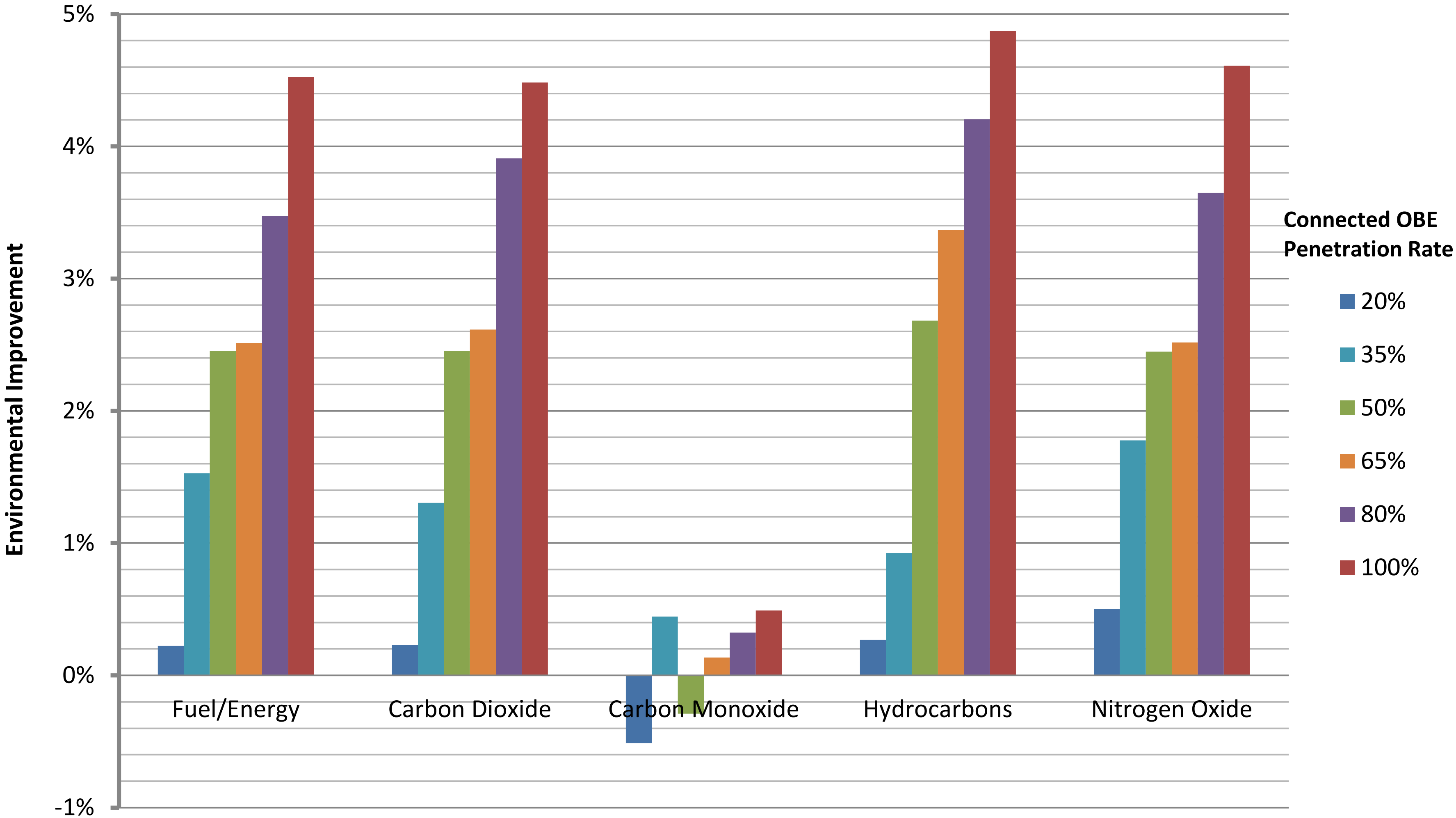
- Conduct detailed simulation modeling and test benefits under different **traffic conditions**, **network conditions**, **technology penetration rates**, and other variables
- Simulation parameters (car-following logic, lane-change behavior) calibrated using NGSIM data sets
- The resultant signal timing plans were initially tested on a small, 3-intersection model as a proof-of-concept to test the genetic algorithm
- After the initial tests, the application was tested on a full corridor model of the El Camino Real, near Palo Alto, CA
- Later tie-in with travel demand models and other AERIS applications

Modeling Results and Analyses

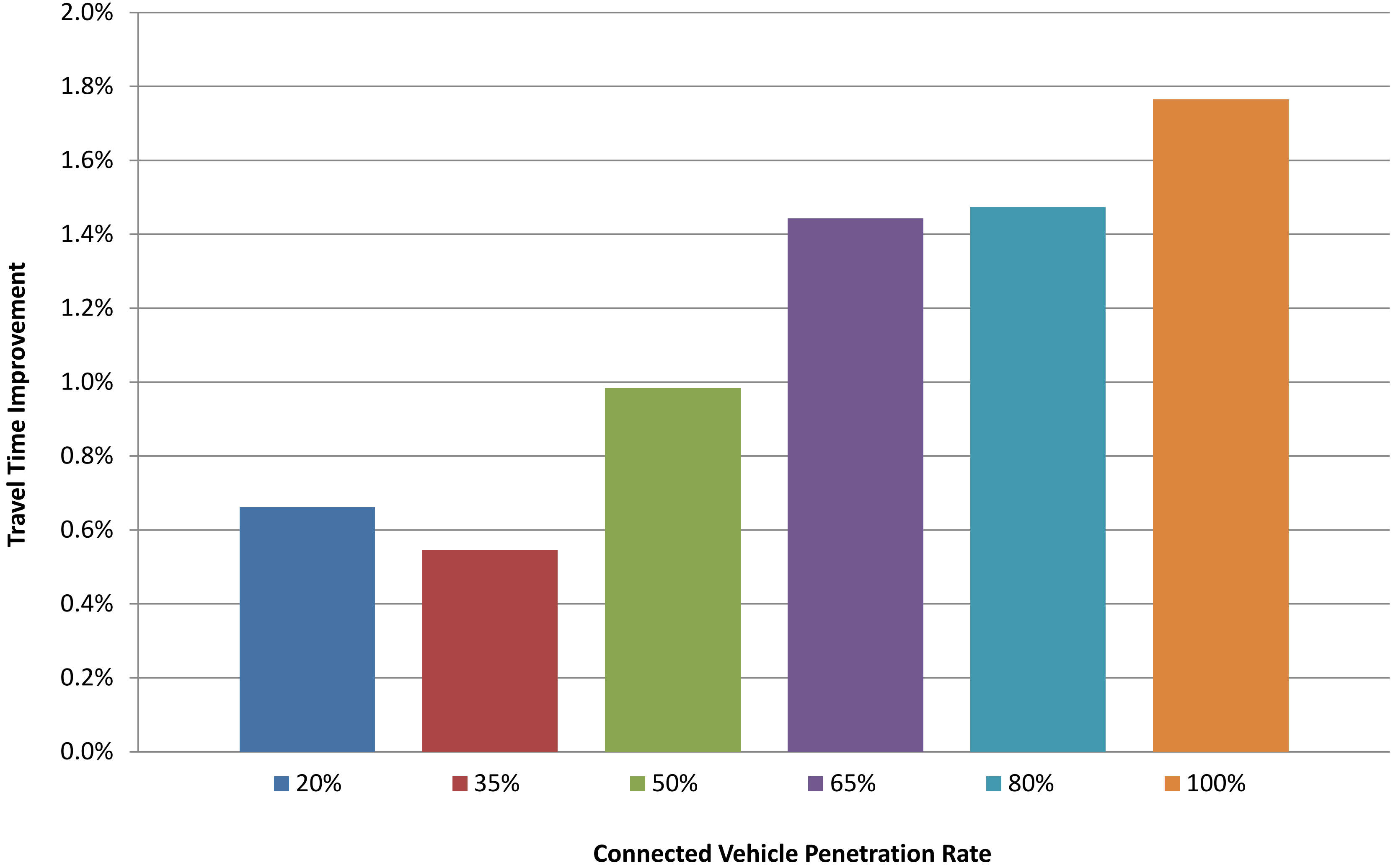
It was important to test different parameters, to understand the impact of the application in different situations, such as:

- **Penetration rate** of the connected vehicle technology, specifically the penetration of the on-board equipment
- Different levels of **congestion** (expressed by the volume to capacity [v/c] ratio)
- Different **percentage of trucks** in traffic along the corridor
- Differences of optimizing for an **emission** target versus a **delay** target

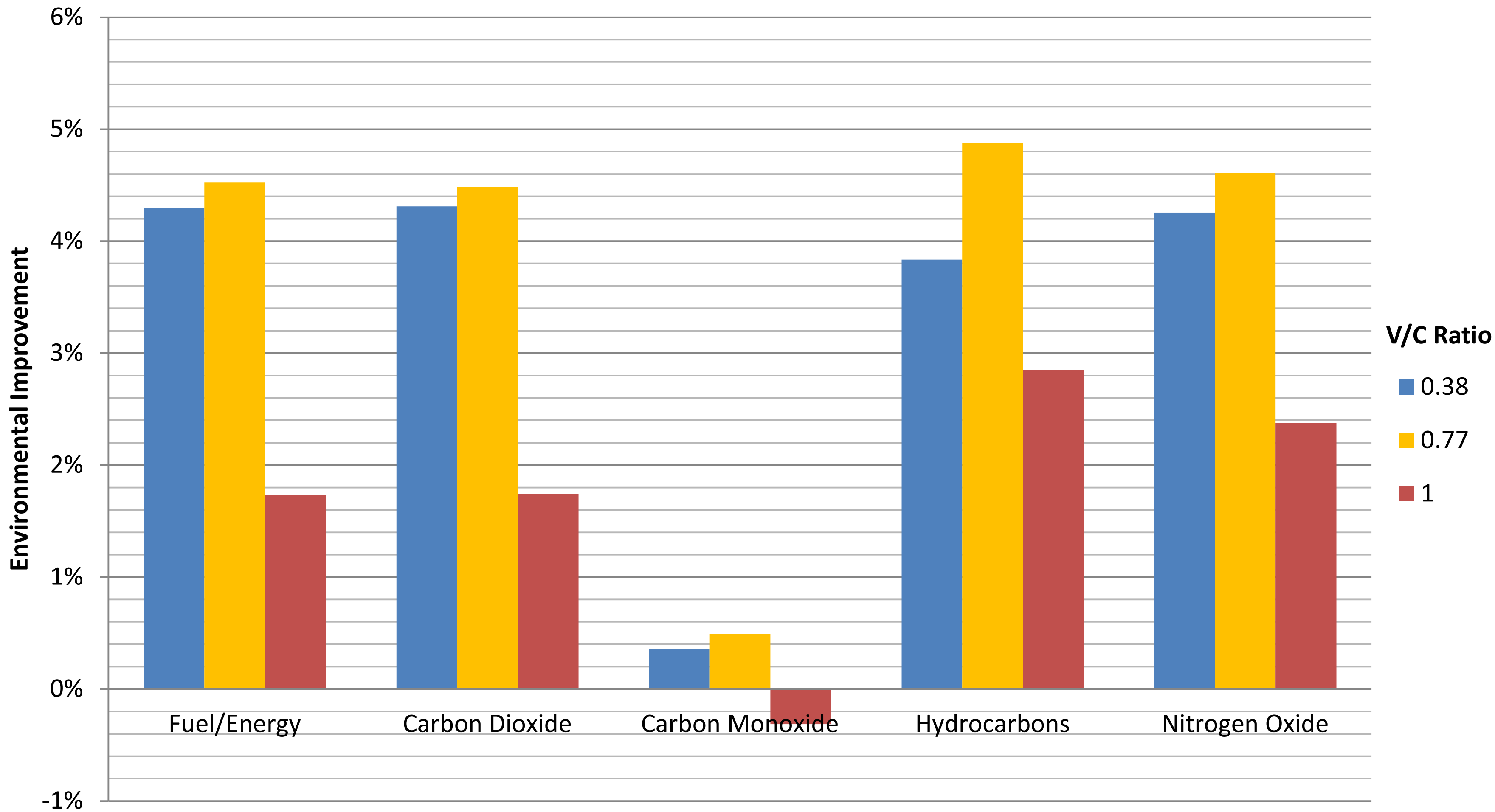
Impact of OBE Penetration Rates on Environmental Measures



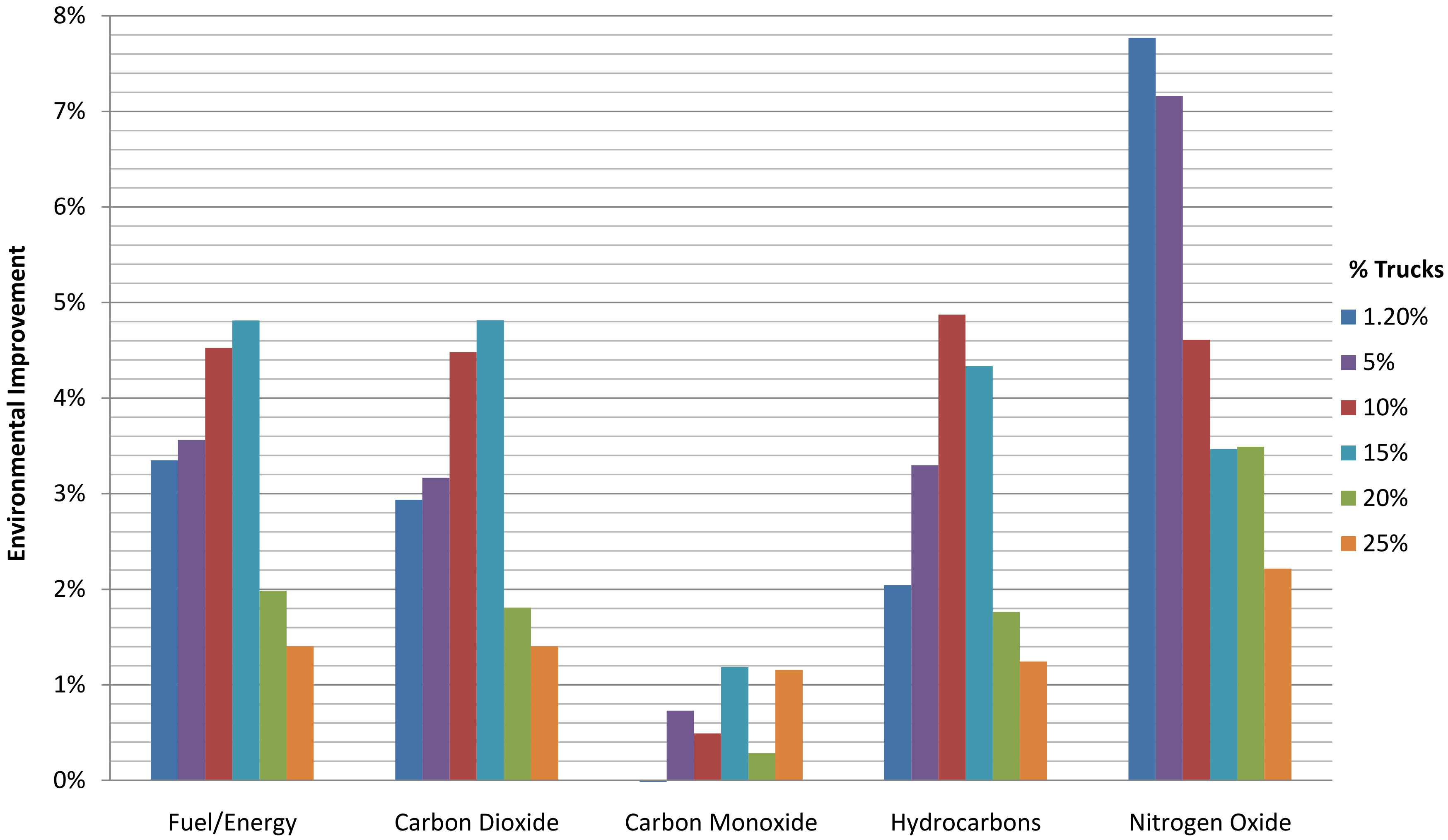
Impact of OBE Penetration Rates on Mobility While Optimizing for Environment



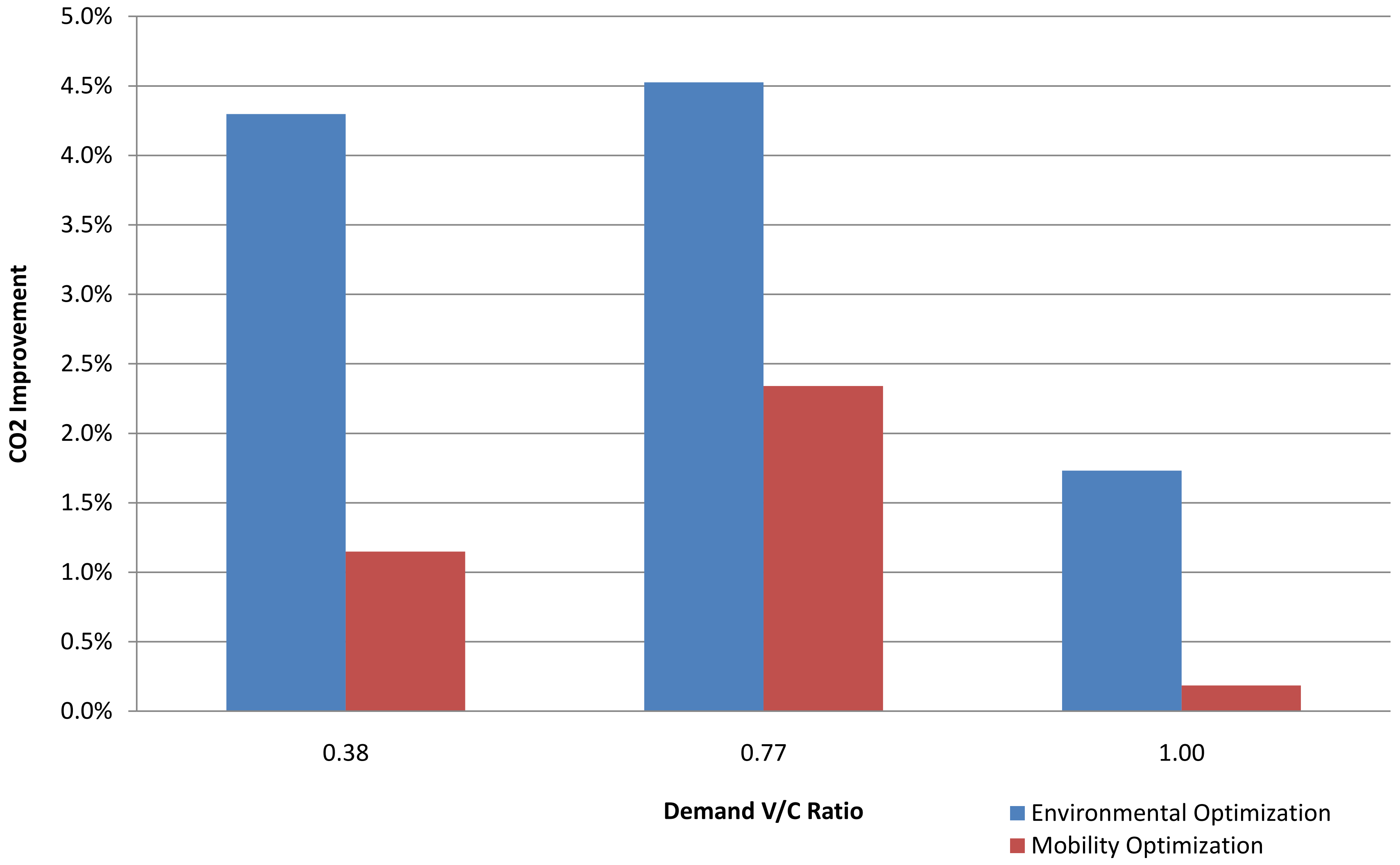
Congestion Ratio (V/C Ratio)



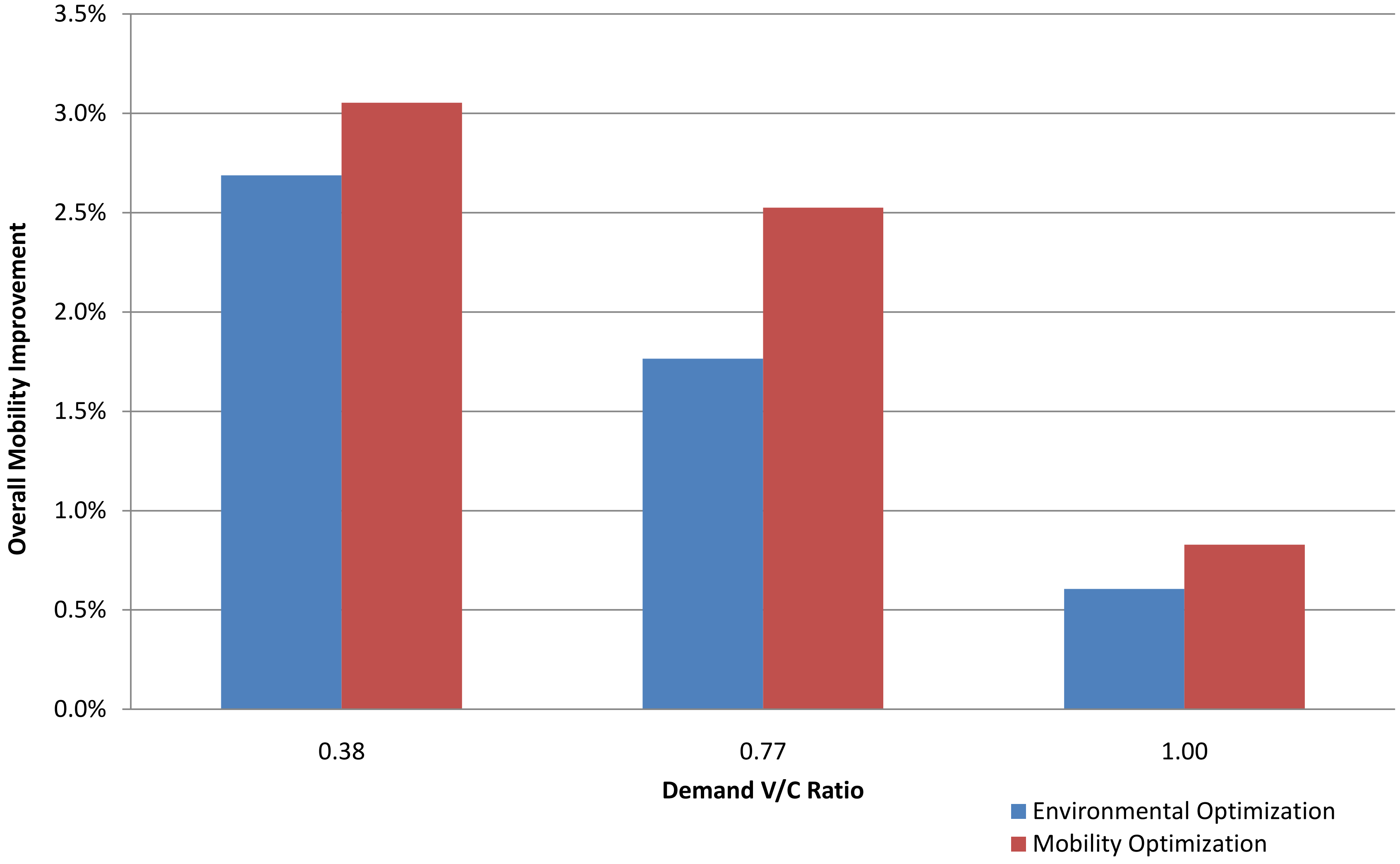
Percentage of Trucks in the Corridor



Emission vs. Mobility Optimization – CO_2



Emission vs. Mobility Optimization – Travel Time



Modeling Results and Analyses

At about 4.5% savings in Fuel Consumption for 100% penetration, how would this benefit the average user?

- Six mile corridor, average traffic congestion
- Light-duty vehicle, 24mpg, gasoline costs $4/gallon
- Baseline timing plan, vehicles spend **$1** to traverse
- Optimized plan, vehicles spend **~$0.95** to traverse
- Driving 8,000 miles a year → **$70** savings per year
- SUV Vehicle: savings of **$110** per year
- Fleet Operator (150 vehicles): **$16,500** per year of savings

Characteristics of the Eco-Timing Plan

For the El Camino Real corridor network, the following are the characteristics of an environmentally optimized signal plan:

- Side street and protected left-turn phases usually at their minimum green time, with the **green times** preferring the majority of mainline traffic
- This resulted in **cycle lengths** of the intersections much lower than the baseline, reducing from about 130 seconds to about 60-70 seconds, depending on the scenario modeled

CONCLUSIONS AND POTENTIAL FUTURE RESEARCH

Conclusions

- There is a **4%** to **5%** improvement in fuel consumption and environmental measures at full connected vehicle penetration, while a **1%** to **4%** at partial connected vehicle penetration in a **fully coordinated network**
- The application yields benefits at both congested and non-congested traffic conditions, which means that the application is viable for both **peak** and **off-peak** travel conditions
- Since the optimization of the signal timings is not done in real-time, other **high-latency communication methods can be used**, such as cellular or hybrid, rather than DSRC

Conclusions

- When optimizing using the genetic algorithm for both mobility or environmental objectives, there were better resultant emissions for the environmental objective of **5%** versus about **2%**, even though there are obvious correlations in the two objectives
- In addition to the environmental savings, a similar improvement in travel time is seen on the corridor with the optimized signal timing plans
- For the El Camino Real corridor, timing plans favor **low timings on the side streets**, with the majority of the green time allotted to the mainline of vehicle approaches

Potential Future Research

- More sensitivity analyses should be undertaken on a **“grid” type network area** to better understand the effects of coordination of signals with environmental-based signal optimization
- An improved future version of the GASTO program could look at localized emissions at intersections, rather than at the network level, in an attempt to create even more improved optimization of signal timing plans
- A future iteration of the GASTO program is intended to have the ability to test alternative phasing plans, phasing orders, and the ability to eliminate phases

Potential Future Research

- The timing plan that is generated by the GASTO program was not designed to produce an **actuated** timing plan
- Further research in to predicting emissions using real-time data could yield a method for an “online” **adaptive** environmental-based system, similar to SCATS or SCOOTS
- Future research could yield a more computationally efficient way to improve the speed of the genetic algorithm, allowing more generations and more population to be added without loss of time constraint

Research Team

Booz Allen Hamilton

- Balaji Yelchuru
- Sean Fitzgerel
- Sudeeksha Murari

University of New South Wales

- Travis Waller (Principal Investigator)
- Melissa Duell (Graduate Student)
- Stanley He (Graduate Student)

AERIS Research Team Partners

Upcoming AERIS Webinars

Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results

Wednesday, February 12th, 2014 at 1:00 pm ET

Registration

Persons planning to participate in the webinar should register online at

www.itsa.org/aerisfall2013

For more information on the AERIS program:

http://www.its.dot.gov/aeris/