Reducing Greenhouse Gas Emissions through Intelligent Transportation System Solutions

June 1, 2016
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- **RESEARCH** — Producing “state of knowledge” white papers and interdisciplinary research projects

- **EDUCATION** — Developing model curricula for graduate programs and advanced training programs

- **ENGAGEMENT** — Informing the policy-making process at the local, state, and federal level
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Presentation Outline:

• Energy and emissions impacts of traffic
• Intelligent Transportation Systems
• Connected and Automated Vehicle Research
Transportation: Energy and Emissions

- Pollutant emissions (CO, HC, NOx, PM) have been addressed for years under the Clean Air Act
- Several “non-attainment” areas still exist across the U.S.
- Major push now to stabilize greenhouse gases (GHG) to below levels emitted today (while still meeting energy needs)
- Transportation accounts for 33% of U.S. CO₂ emissions
- 80% of transportation CO₂ comes from cars and trucks
- Transportation-related CO₂ and vehicle fuel economy are directly related
How do we minimize energy and emissions impacts from transportation?

• **Build cleaner, more efficient vehicles:**
  - make vehicles lighter (and smaller) while maintaining safety
  - improve powertrain efficiency
  - develop alternative technologies (e.g., electric vehicles, hybrids, fuel-cell)

• **Develop and use alternative fuels:**
  - Bio and synthetic fuels (cellulosic ethanol, biodiesel)
  - electricity

• **Decrease the total amount of driving:** **VMT reduction methods**
  - Better land use/transportation planning
  - Travel demand management

• **Improve transportation system efficiency**
  - Better Traffic Management techniques
  - ITS, Connected Vehicles, Vehicle Automation
General Components of a Transportation-based Environmental/Energy Inventory:

- environmental factors
- vehicle activity
- fleet composition
CO$_2$ Emissions as a Function of Average Traffic parameters

Vehicle Activity Database containing sample vehicle velocity trajectories

CMEM (microscopic fuel consumption/emissions model)

\[
\ln(y) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4
\]

Real-world activity
Steady-state activity

Average Speed (mph)

CO$_2$ (g/mi)
Different strategies to reduce on-road (pollutant and GHG) emissions & energy

Ramp metering, signal synchronization, incident management, etc.

better enforcement, speed limiters, active accelerator pedal, etc.

Traffic flow smoothing techniques

Variable speed limit Intelligent speed adaptation Etc.

CO₂ (g/mi)

Average Speed (mph)
Key ITS Research Areas with Energy/Emissions Impacts

Advanced Vehicle Control and Safety Systems: Vehicles

Advanced Transportation Management Systems: Systems

Advanced Transportation Information Systems: Behavior

*indirect versus direct energy/emissions savings*
Key ITS Research Areas with Energy/Emissions Impacts: **Vehicles**

**Advanced Vehicle Control and Safety Systems:**

- Longitudinal and Lateral Collision Avoidance
- Intersection Collision Avoidance
- Adaptive Cruise Control, Intelligent Speed Adaptation
- Automated Vehicles and Roadway Systems

*eliminating accidents, smoother traffic flow*
Key ITS Research Areas with Energy/Emissions Impacts: Systems

Advanced Transportation Management Systems:

- Traffic Monitoring and Management
- Corridor Management
- Incident Management
- Demand Management and Operations

eliminating congestion
efficient operation
Key ITS Research Areas with Energy/Emissions Impacts: 

**Behavior**

Advanced Transportation Information Systems:

- Route Guidance
- En-Route Driver Information
- Traveler Service Information → connection to Transit
- Electronic Payment Services → variable pricing

*reduced driving*  
better efficiency  
*travel demand management*
Emergence of “Environmental-ITS” Research Programs

- Safety-ITS
- Mobility-ITS
- Environmental-ITS: direct environmental benefits

New ECO-ITS Programs in Europe, U.S., and Asia:

USDOT:
- FHWA-Exploratory Advanced Research Program
- UTC centers (including NCST)
- Connected (and Automated) Vehicles
**Connected Vehicles:** providing better interaction between vehicles and between vehicles and infrastructure

- increased **Safety**
- better **Mobility**
- lower **Environment impact**
## Connected Vehicle Applications:

### V2I Safety
- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Spot Weather Impact Warning
- Reduced Speed/Work Zone Warning
- Pedestrian in Signalized Crosswalk Warning (Transit)

### V2V Safety
- Emergency Electronic Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Left Turn Assist (LTA)
- Blind Spot/Lane Change Warning (BSW/LCW)
- Do Not Pass Warning (DNPW)
- Vehicle Turning Right in Front of Bus Warning (Transit)

### Agency Data
- Probe-based Pavement Maintenance
- Probe-enabled Traffic Monitoring
- Vehicle Classification-based Traffic Studies
- CV-enabled Turning Movement & Intersection Analysis
- CV-enabled Origin-Destination Studies
- Work Zone Traveler Information

### Environment
- Eco-Approach and Departure at Signalized Intersections
- Eco-Traffic Signal Timing
- Eco-Traffic Signal Priority
- Connected Eco-Driving
- Wireless Inductive/Resonance Charging
- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Traveler Information
- Eco-Ramp Metering
- Low Emissions Zone Management
- AFV Charging / Fueling Information
- Eco-Smart Parking
- Dynamic Eco-Routing (light vehicle, transit, freight)
- Eco-ICM Decision Support System

### Mobility
- Advanced Traveler Information System
- Intelligent Traffic Signal System (I-SIG)
- Signal Priority (transit, freight)
- Mobile Accessible Pedestrian Signal System (PED-SIG)
- Emergency Vehicle Preemption (PREEMPT)
- Dynamic Speed Harmonization (SPD-HARM)
- Queue Warning (Q-WARN)
- Cooperative Adaptive Cruise Control (CACC)
- Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
- Emergency Communications and Evacuation (EVAC)
- Connection Protection (T-CONNECT)
- Dynamic Transit Operations (T-DISP)
- Dynamic Ridesharing (D-RIDE)
- Freight-Specific Dynamic Travel Planning and Performance
- Drayage Optimization

### Road Weather
- Motorist Advisories and Warnings (MAW)
- Enhanced MDSS
- Vehicle Data Translator (VDT)
- Weather Response Traffic Information (WxTINFO)

### Smart Roadside
- Wireless Inspection
- Smart Truck Parking

Objectives:

• Identify connected vehicle applications that could provide environmental impact reduction benefits via reduced fuel use, more efficient vehicles, and reduced emissions.

• Facilitate and incentivize “green choices” by transportation service consumers (i.e., system users, system operators, policy decision makers, etc.).

• Identify vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-grid (V2G) data (and other) exchanges via wireless technologies of various types.

• Model and analyze connected vehicle applications to estimate the potential environmental impact reduction benefits.

• Develop a prototype for one of the applications to test its efficacy and usefulness.
ECO-SIGNAL OPERATIONS
- Eco-Approach and Departure at Signalized Intersections (similar to SPaT)
- Eco-Traffic Signal Timing (similar to adaptive traffic signal systems)
- Eco-Traffic Signal Priority (similar to traffic signal priority)
- Connected Eco-Driving (similar to eco-driving strategies)
- Wireless Inductive/Resonance Charging

ECO-LANES
- Eco-Lanes Management (similar to HOV Lanes)
- Eco-Speed Harmonization (similar to variable speed limits)
- Eco-Cooperative Adaptive Cruise Control (similar to adaptive cruise control)
- Eco-Ramp Metering (similar to ramp metering)
- Connected Eco-Driving (similar to eco-driving)
- Wireless Inductive/Resonance Charging
- Eco-Traveler Information Applications (similar to ATIS)

ECO-TRAVELER INFORMATION
- AFV Charging/Fueling Information (similar to navigation systems providing information on gas station locations)
- Eco-Smart Parking (similar to parking applications)
- Dynamic Eco-Routing (similar to navigation systems)
- Dynamic Eco-Transit Routing (similar to AVL routing)
- Dynamic Eco-Freight Routing (similar to AVL routing)
- Multi-Modal Traveler Information (similar to ATIS)
- Connected Eco-Driving (similar to eco-driving strategies)

ECO-INTEGRATED CORRIDOR MANAGEMENT
- Eco-ICM Decision Support System (similar to ICM)
- Eco-Signal Operations Applications
- Eco-Lanes Applications
- Low Emissions Zone's Applications
- Eco-Traveler Information Applications
- Incident Management Applications

LOW EMISSIONS ZONES
- Low Emissions Zone Management (similar to Low Emissions Zones)
- Connected Eco-Driving (similar to eco-driving strategies)
- Eco-Traveler Information Applications (similar to ATIS)
Eco-Approach and Departure at Signalized Intersections

Vehicle Equipped with the Eco-Approach and Departure at Signalized Intersections Application (CACC capabilities optional)

V2I Communications: SPaT and GID Messages

V2V Communications: Basic Safety Messages

Roadside Equipment Unit

Traffic Signal Controller with SPaT Interface

Traffic Signal Head

Source: Noblis, November 2013
Eco-Approach and Departure Scenario Diagram

Intersection of interest
Variations of Analysis:

- Signal timing scheme matters: fixed time signals, actuated signals, coordinated signals
- Single intersection analysis and corridor-level analysis
- Congestion level: how does effectiveness change with amount of surrounding traffic
- Single-vehicle benefits and total link-level benefits
- Level of Automation: driver vehicle interface or some degree of automation
- Field Studies: typically limited to a few instrumented single vehicles, constrained infrastructure
- Simulation Modeling: multiple vehicles, examining the sensitivity of other variables
Eco-Approach and Departure at Signalized Intersections Application: Modeling Results

- **Summary of Preliminary Modeling Results**
  - 10-15% fuel reduction benefit for an equipped vehicle;
  - 5-10% fuel reduction benefits for traffic along an uncoordinated corridor
  - Up to 13% fuel reduction benefits for a coordinated corridor
    - 8% of the benefit is attributable to signal coordination
    - 5% attributable to the application

- **Key Findings and Takeaways**
  - The application is less effective with increased congestion
  - Close spacing of intersections resulted in spillback at intersections. As a result, fuel reduction benefits were decreased somewhat dramatically
  - Preliminary analysis indicates significant improvements with partial automation
  - Results showed that non-equipped vehicles also receive a benefit – a vehicle can only travel as fast as the car in front of it

- **Opportunities for Additional Research**
  - Evaluate the benefits of enhancing the application with partial automation:
    - GlidePath
FHWA GlidePath Project: Eco-Approach and Departure using a Partially Automated Vehicle

Location:
- Turner Fairbanks Highway Research Center, 30 mph test track

Vehicle:
- Ford Escape Hybrid developed by TORC with ByWire XGV System
- Full-Range Longitudinal Speed Control

Testing and Demo:
- March 2015

Results:
- 5% energy savings over manual driving using human driving interface
- 21% energy savings over manual driving, using automation
FHWA/Caltrans Exploratory Advanced Research Project: *Eco-Approach and Departure with Actuated Signals, in Traffic*

**Location:** El Camino Real, Northern California

**Vehicle:** Nissan Altima equipped with radar for vehicle detection, new algorithms to process actuated signal phase and timing information

**Testing and Demo:** Fall 2015

**Results:** 2% - 5%
Eco-Traffic Signal Timing Application

Application Overview

- Similar to current traffic signal systems; however the application’s objective is to optimize the performance of traffic signals for the environment
- Collects data from vehicles, such as vehicle location, speed, vehicle type, and emissions data using connected vehicle technologies
- Processes these data to develop signal timing strategies focused on reducing fuel consumption and overall emissions at the intersection, along a corridor, or for a region
- Evaluates traffic and environmental parameters at each intersection in real-time and adapts the timing plans accordingly

- 5% Energy Benefit
Eco-Traffic Signal Priority Application

Application Overview

- Allows either transit or freight vehicles approaching a signalized intersection to request signal priority
- Considers the vehicle’s location, speed, vehicle type (e.g., alternative fuel vehicles), and associated emissions to determine whether priority should be granted
- Information collected from vehicles approaching the intersection, such as a transit vehicle’s adherence to its schedule, the number of passengers on the transit vehicle, or weight of a truck may also be considered in granting priority
- If priority is granted, the traffic signal would hold the green on the approach until the transit or freight vehicle clears the intersection
- ~ 4% Energy Benefit for freight; ~ 6% for all vehicles
Eco-Speed Harmonization Application

Application Overview

- Collects traffic information and pollutant information using connected vehicle-to-infrastructure (V2I) communications
- The application assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds near bottleneck and other disturbance areas
- Receives V2I messages, the application performs calculations to determine the optimal speed for the segment of freeway where the bottleneck, lane drop, or disturbance is occurring
- The optimal “eco-speed” is broadcasted by V2I messages from roadside RSE equipment to all connected vehicles along the roadway

~ 5% Energy Benefit
Eco-Cooperative Adaptive Cruise Control (CACC) Application

Application Overview

- Eco-CACC includes longitudinal automated vehicle control while considering eco-driving strategies.

- Connected vehicle technologies can be used to collect the vehicle’s speed, acceleration, and location and feed these data into the vehicle’s ACC.

- Receives V2V messages between leading and following vehicles, the application performs calculations to determine how and if a platoon can be formed to improve environmental conditions.

- Provides speed and lane information of surrounding vehicles in order to efficiently and safely form or decouple platoons of vehicles.
Eco-Cooperative Adaptive Cruise Control (CACC) Application: Modeling Results

- **Summary of Key Modeling Results**
  - Up to 19% fuel savings on a real-world freeway corridor
  - Up to an additional 7% fuel savings when using a dedicated “eco-lane” instead of general purpose lane on the freeway corridor
  - Up to 42% travel time savings on a real-world freeway corridor

- **Key Findings and Takeaways**
  - The presence of a single dedicated “eco-lane” leads to significant increases in overall network capacity
  - Drivers may maximize their energy and mobility savings by choosing to the dedicated “eco-lane”

- **Opportunities for Additional Research**
  - Increasing the number of dedicated lanes will likely further improve results
  - Quantifying relationship between platoon headway and increased network capacity is also of interest
**ECO-SIGNAL OPERATIONS**

- Eco-Approach and Departure at Signalized Intersections *(similar to SPaT)*
- Eco-Traffic Signal Timing *(similar to adaptive traffic signal systems)*
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**Traffic Energy Benefits**

- 10% energy savings
- 5% energy savings
- 6% energy savings

**ECO-LANES**

- Eco-Lanes Management *(similar to HOV Lanes)*
- Eco-Speed Harmonization *(similar to variable speed limits)*
- Eco-Cooperative Adaptive Cruise Control *(similar to adaptive cruise control)*
- Eco-Ramp Metering *(similar to ramp metering)*
- Connected Eco-Driving *(similar to eco-driving)*
- Wireless Inductive/Resonance Charging
- Eco-Traveler Information Applications *(similar to ATIS)*

**LOW EMISSIONS ZONES**

- Low Emissions Zone Management *(similar to Low Emissions Zones)*
- Connected Eco-Driving *(similar to eco-driving strategies)*
- Eco-Traveler Information Applications *(similar to ATIS)*

**AERIS OPERATIONAL SCENARIOS & APPLICATIONS**
Merging of Connected Vehicles and Automation

Autonomous Vehicle
Operates in isolation from other vehicles using internal sensors

Connected Vehicle
Communicates with nearby vehicles and infrastructure

Connected Automated Vehicle
Leverages autonomous and connected vehicle capabilities
Vehicle Automation and Traffic System Operations

- In general, full or partial vehicle automation can help with traffic system operations

- Traffic operations with autonomous vehicles will not likely change much
  - Mobility and Environmental impacts will remain the same or could even get worse
  - Partial Automation Example: automated cruise control (ACC) has been shown to have negative traffic mobility impacts

- Traffic operations with connected automated vehicles will likely have a improved mobility and environmental impacts
Different Intersection Management Systems

Stop signs

Traffic light

Intersection reservation system with automated connected vehicles

Source: David Kari, UCR, 2014
Roundabout Merge Assist (RMA)

- Human drivers entering a round-about typically slow down to look for hazards such as other vehicles, bicyclists, and pedestrians.
  - Slowing down reduces intersection throughput and increases vehicle emissions/energy
Roundabout Merge Assist (RMA)

• Human drivers entering a round-about typically slow down to look for hazards such as other vehicles, bicyclists, and pedestrians.
  – Slowing down reduces intersection throughput and increases vehicle emissions/energy

• Automation of round-about merging via automated merging and lateral maneuvers ...
  1. Improves intersection throughput
  2. Reduces vehicle emissions/energy consumption
  3. Is a natural stepping stone to true continuous flow intersections
Why Automate Roundabouts?

Roundabouts are an excellent choice for incorporating lane merging maneuvers.

1. Automating roundabouts is safer than automating traditional 4-way intersections (fewer conflict points).
Why Automate Roundabouts?

Roundabouts are an excellent choice for incorporating lane merging maneuvers.

2. Automating roundabouts is *less complex* than automating traditional 4-way intersections (Automated Merging Maneuvers vs. Autonomous Intersection Management)

Automating traditional 4-way intersections requires reservation-based AIM
(infrastructure calculates and broadcasts specific vehicle trajectories)

Automating roundabouts requires only automating lane merge maneuvers
(infrastructure support is not strictly required)
Ultimate Arterial Lane Merge Scenario is with *Continuous Flow Intersections*

1. Substantial travel time and energy benefits are achievable via CFIs
2. Automation of lateral and weaving maneuvers opens the door to improved infrastructure design and architecture
3. Parallel development of infrastructure and vehicles is the preferred approach
Intelligent Transportation Systems Take Away Points:

• ITS goals and strategies of improving safety and improving traffic performance (i.e. mobility) often reduce energy consumption and CO$_2$ emissions as a side benefit.

• Dedicated ITS strategies and systems can be designed to explicitly reduce energy consumption and CO$_2$ emissions: U.S. AERIS, Japan Energy ITS, EU EcoMove.

• Each ITS strategy can potentially reduce CO$_2$ emissions by approximately 5 – 15%; however with multiple strategies, greater savings can be achieved (ignoring induced demand).
Synergies and Tradeoffs of Safety, Mobility, and Environment

Safety
- Collision avoidance
- Increased spacings

Safety & Energy:
- Electronic Brake Lights
- Conservative automated maneuvers

Mobility
- CACC
- Higher speeds
Automation Take Away Points:

• Partial and full automation can provide better energy & emission results compared to human-machine interfaces, depending on design of control system.

• With automation, system design trade-offs will exist between safety, mobility, and the environment (e.g., automated maneuvers).

• Connected automated vehicles will likely have greater improvements in mobility and environment compared to autonomous vehicles.

• Potential induced demand effects: vehicle automation will likely increase travel demand so it may be necessary to also consider travel demand management techniques.
Reducing Greenhouse Gas Emissions through Intelligent Transportation System Solutions

This presentation is based on the NCST white paper: Intelligent Transportation Systems for Improving Traffic Energy Efficiency and Reducing GHG Emissions from Roadways
Download here: http://ncst.ucdavis.edu/research/white-papers/

More white papers and research at: ncst.ucdavis.edu