Analyzing Fuel Saving Opportunities through Driver Feedback Mechanisms

DOE Annual Merit Review

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Organization: NREL

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Project ID: VSS007

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Project Overview

Timeline

Activities specific to current effort:

- Started in FY10
- Ending in FY11
- Project is 90% complete

Barriers Addressed

- Portfolio approach necessary to achieve GHG reduction goals
  - Long turnover time for legacy fleet
  - Assessing fuel savings potential
- Deploying/encouraging efficient driving (to benefit all vehicles)
- Consumer reluctance to purchase/ implement new technologies

Budget

Corresponding funding:

- Total (all DOE): $400k

Project Partners

- Social science/human factors experts (driver receptiveness consultations)
- Commercial fleets and insurance companies (deployment discussion for high incentive applications)

GHG = greenhouse gas

(Details on collaboration slide)

Project Summary

Driving style changes can save fuel

- “Ideal” cycles yield dramatic savings
  - 30%-60% with same vehicle and powertrain
  - Gives outer bound (only achievable with automated vehicle/traffic control)
- Constrained by real-world driving, savings still significant
  - 20% for giving up aggressive driving habits
  - 5%-10% possible for moderate drivers

Existing methods may not change many people’s habits

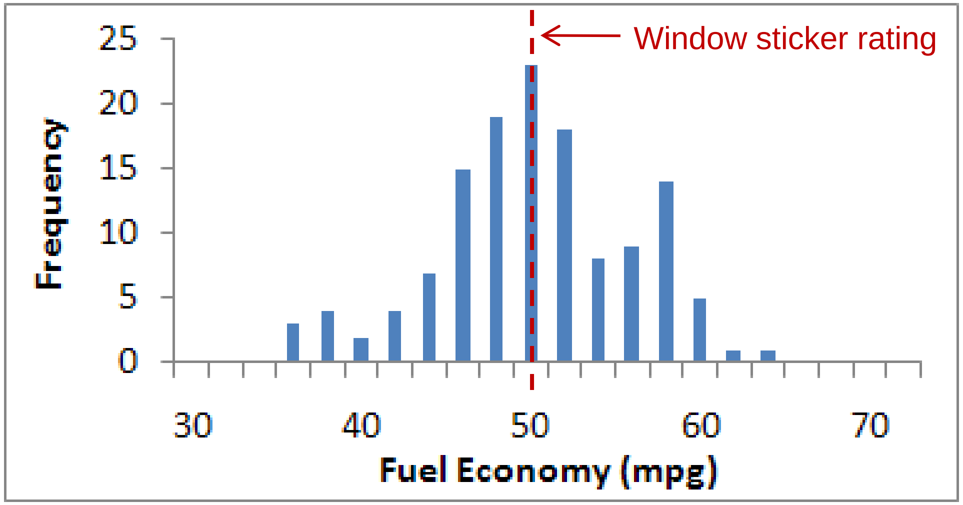
- Other driving behavior influences dominate
  - Surrounding vehicles; In a hurry; Available vehicle power; Etc.
- Current feedback approaches unlikely to have broad impact
  - Often deliver accurate information and instruction
  - But not in the simplest and easiest way to overcome other influences
- High fuel prices/other incentives needed for wide adoption
  - Combined with simple, low cost approach

Relevance

Drive Cycle = Important Fuel Use Factor

"Your mileage will vary" based on driving style

2010 Prius Fuel Economy Histogram for 133 Drivers*



Stands to reason that broad adoption of efficient habits could have large aggregate fuel savings benefit

- Shift overall MPG distribution higher for all vehicles
  - (Some distribution will remain due to factors such as weather, traffic, etc.)

* Data accessed from www.fueleconomy.gov on March 9, 2011

Legacy Fleet Energy Efficiency

>200 million existing vehicles, often in-service >15 yrs

- New technologies take a while to penetrate the fleet
- Improving efficiency of current vehicles can have a broad impact
- Fleet mpg will be slow to change without addressing legacy vehicles

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Approach

Quantify Fuel Saving Opportunities

Savings from improving individual driving profiles

- Outer bound from total cycle optimization
- Consider range of driving types from real-world sample
- Identify most important factors to improve
  - Efficiency analysis from incremental cycle improvements
- On-road experiments over repeated routes
  - Confirm savings potential from implementing efficiency strategies

Prevalence of inefficient/suboptimal driving

- Identify proportion of aggressive drivers with large savings potential vs. moderate drivers with less savings potential
  - Based on real-world sample
- Combine for aggregate savings estimate

Identify/Understand Behavior Influences

Literature review and expert consultation

- Driver behavior influences
  - Effect of social norms; Attention span/time horizon; Etc.
- Driver feedback issues
  - Fuel savings potential; Receptiveness likelihood; Design considerations; Driver distraction

Observe factors impacting on-road decisions

- Considerations for different conditions
  - Driving style
  - Route type
  - Traffic
- Identify barriers to adopting efficient behaviors

Assess Various Feedback Approaches

Survey existing examples

- Consider savings potential for different behavior changes
  - E.g., reducing speed, accel/decel and idling time
- Test out/review devices

Evaluate based on other project findings

- Can the approach work?
  - Accurate information and instruction conveyed effectively?
- Are people likely to use it?
  - Easy to use?
  - Avoids unintended consequences?
  - Helps trump other behavior influences?

Provide results to DOE

- Interim report (Sept 2010)
- Milestone report on driver feedback fuel savings opportunity (Feb 2011)

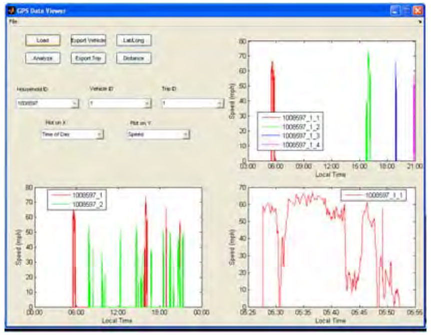
Accel/decel = acceleration and deceleration

Technical Accomplishments

Cycle Improvement Savings
Real-World Profiles from GPS Travel Survey

Data from 2006 survey in San Antonio and Austin, TX

- 783 full day, sec-by-sec drive cycles
- Captures real-world aggressiveness, distances, etc.



Investigate complete cycle optimization

- Select handful of cycles representing range of driving sample
- Outer bound efficiency improvements
  - Eliminate unnecessary stop-and-go and idling
  - Implement ideal vehicle speed and acceleration rate
- 30%-60% fuel savings possible
  - With same vehicle and powertrain
  - Would require vehicle/traffic flow automation to actually achieve
- On today's roads only incremental cycle improvements achievable

GPS = global positioning system

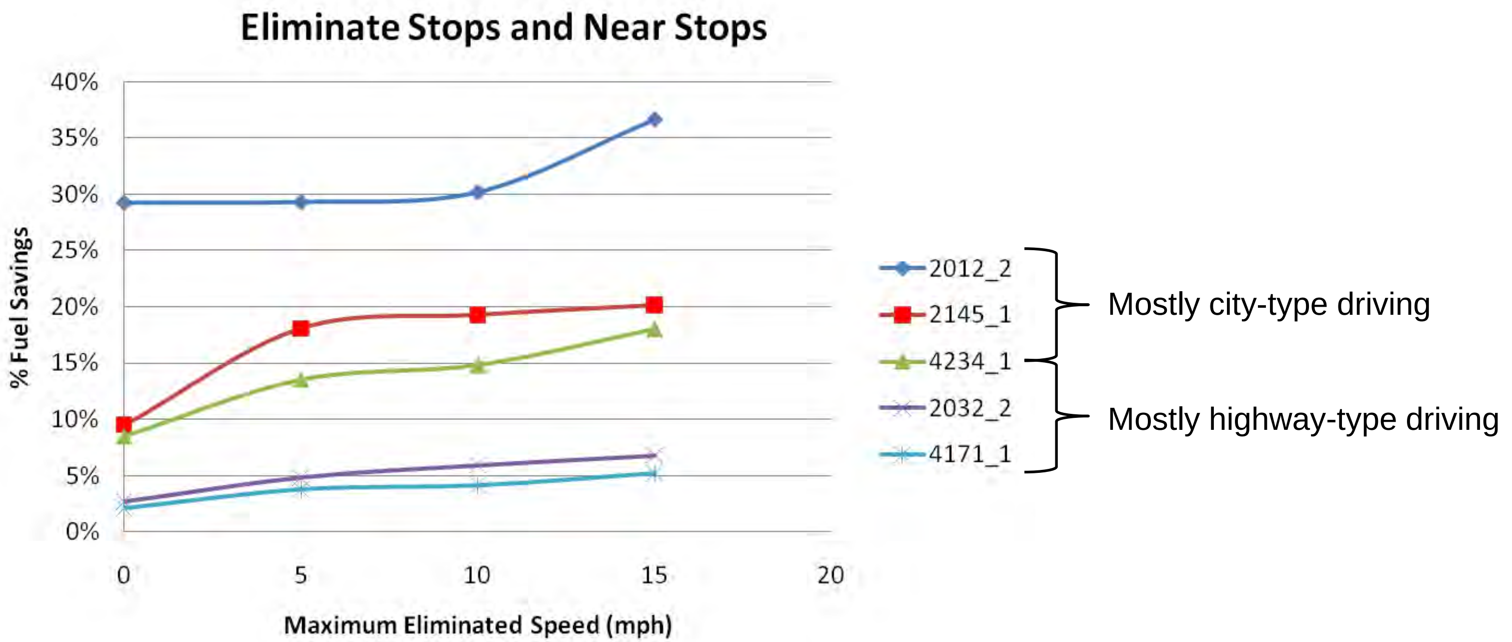
Accomplishments

Cycle Improvement Savings

Incremental Adjustments to Real-World Driving Samples

Accel/Decel = dominant efficiency factor in urban driving

- Most important to reduce frequency of stop-and-go/slow-and-go
  - Such cycle smoothing possible by paying attention farther ahead (e.g., slightly slowing early to avoid getting stopped at a red light)
- Reducing accel/decel rate also helps, but is less important
  - (Eliminated accel/decel events will have a rate of zero)

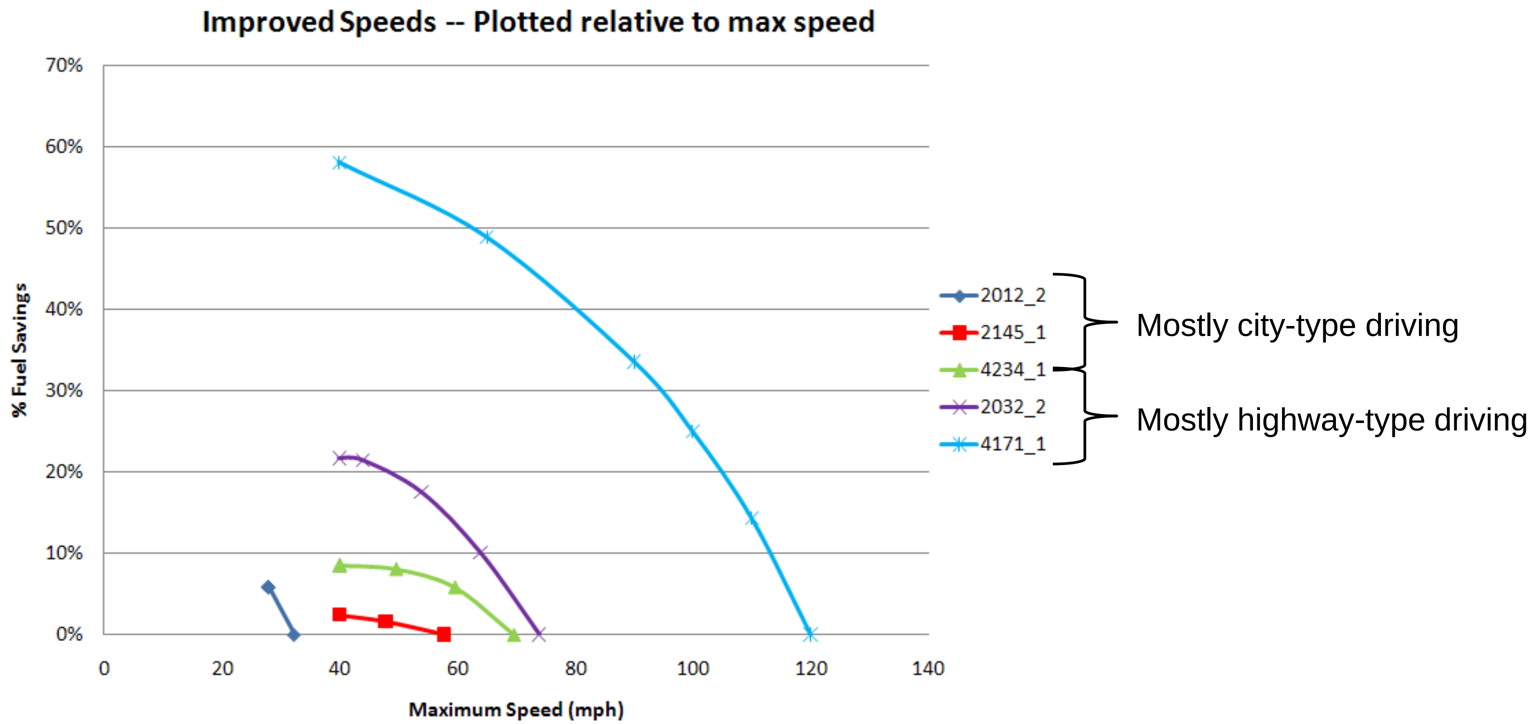


Cycle Improvement Savings

Incremental Adjustments to Real-World Driving Samples

High speeds = dominant factor in highway driving

- High aero drag at extreme speeds leads to large fuel use
- Savings related to magnitude of original speed relative to optimal speed
  - 40-50 mph optimal for the simulated vehicle

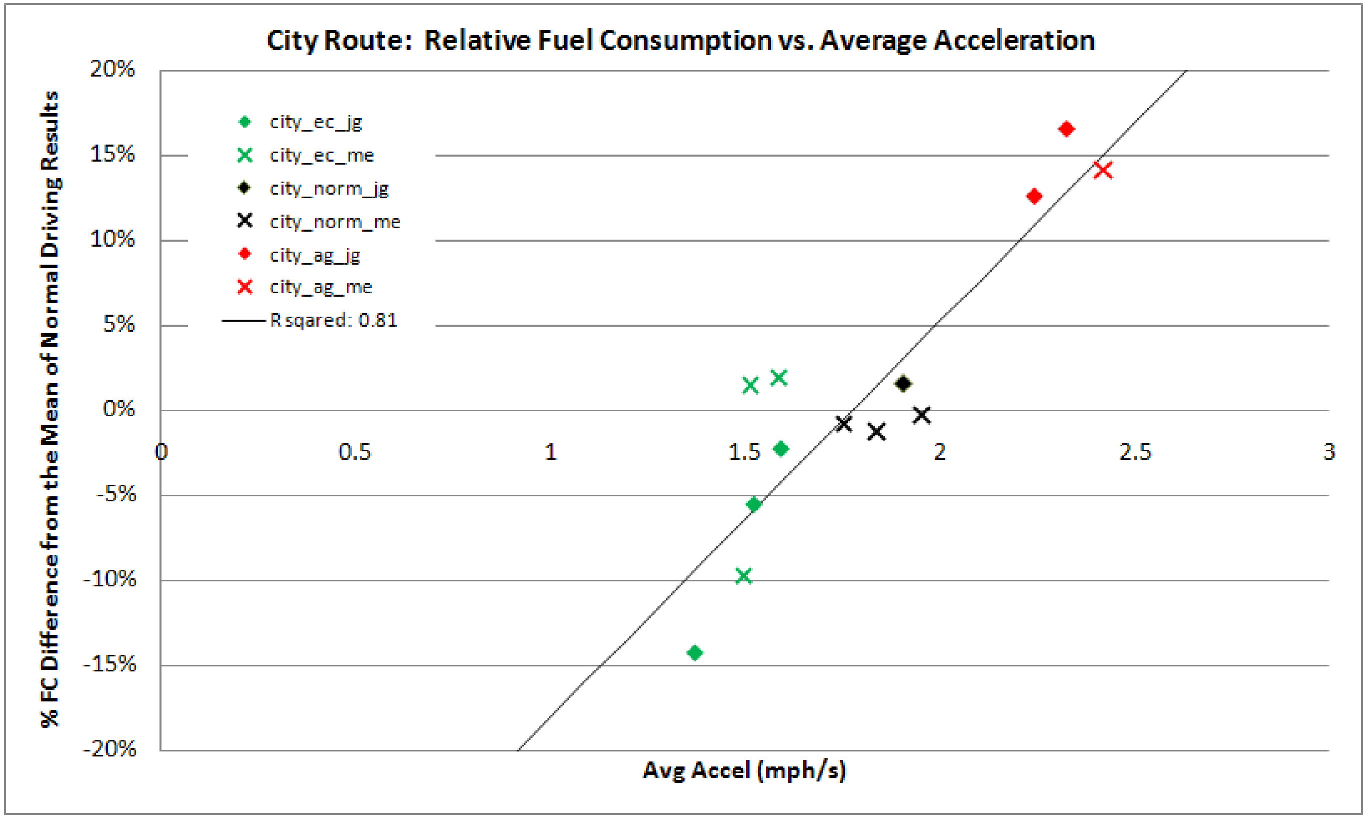


aero drag = aerodynamic drag (proportional to velocity squared)

Cycle Improvement Savings

On-Road Routes Repeated Using Different Driving Styles

- Considerable spread within each driving type, but clear savings benefit moving from aggressive to normal to energy conscious
  - 30% difference between best and worst fuel efficiency
- Savings correlate with average acceleration on city route



ec = energy conscious;
norm = normal;
ag = aggressive

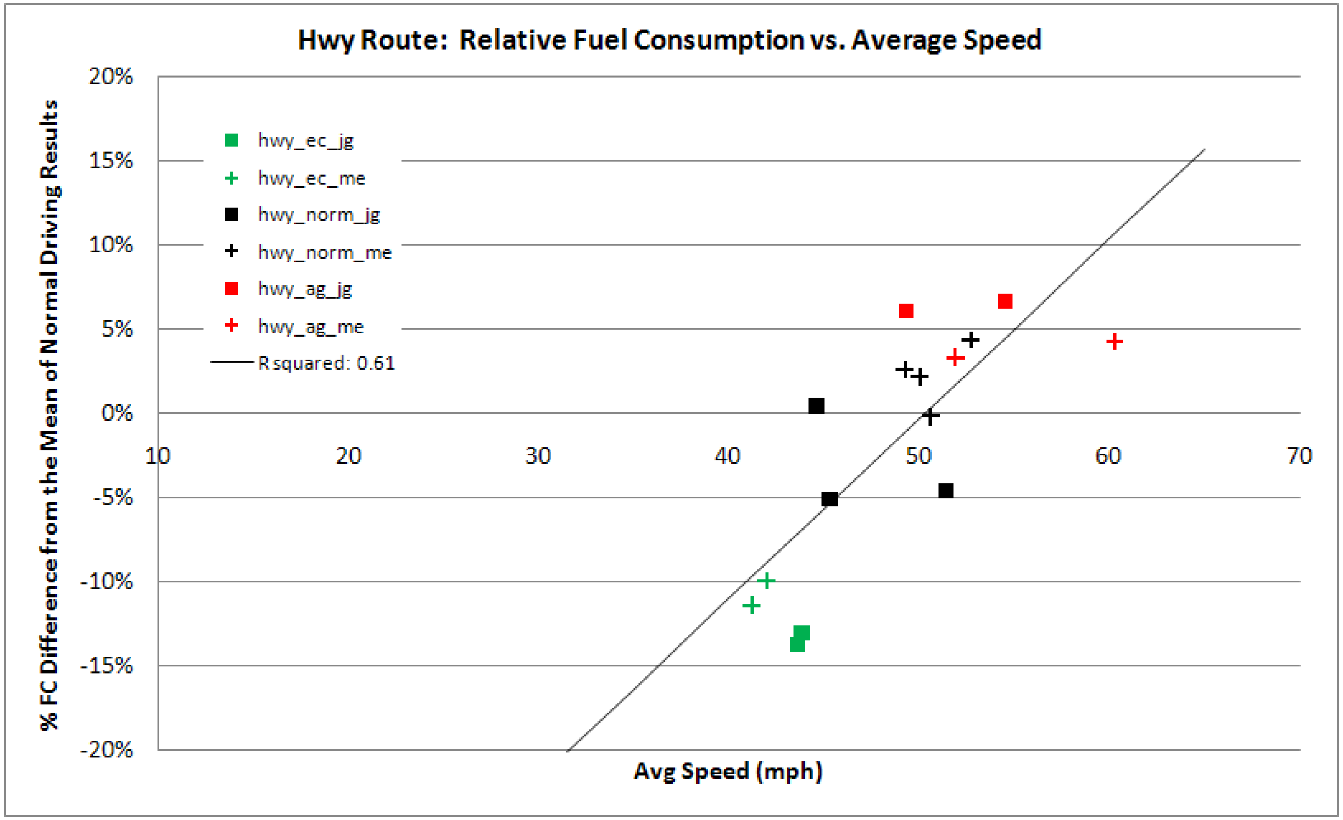
Driving type description followed by drivers' initials

Accomplishments

Cycle Improvement Savings

On-Road Routes Repeated Using Different Driving Styles

- Similar findings for highway route
  - Less total spread (20%), but top speed in “aggressive” testing much lower than many extreme speeds observed in the real-world sample
- Savings correlate with average speed on the highway (hwy) route



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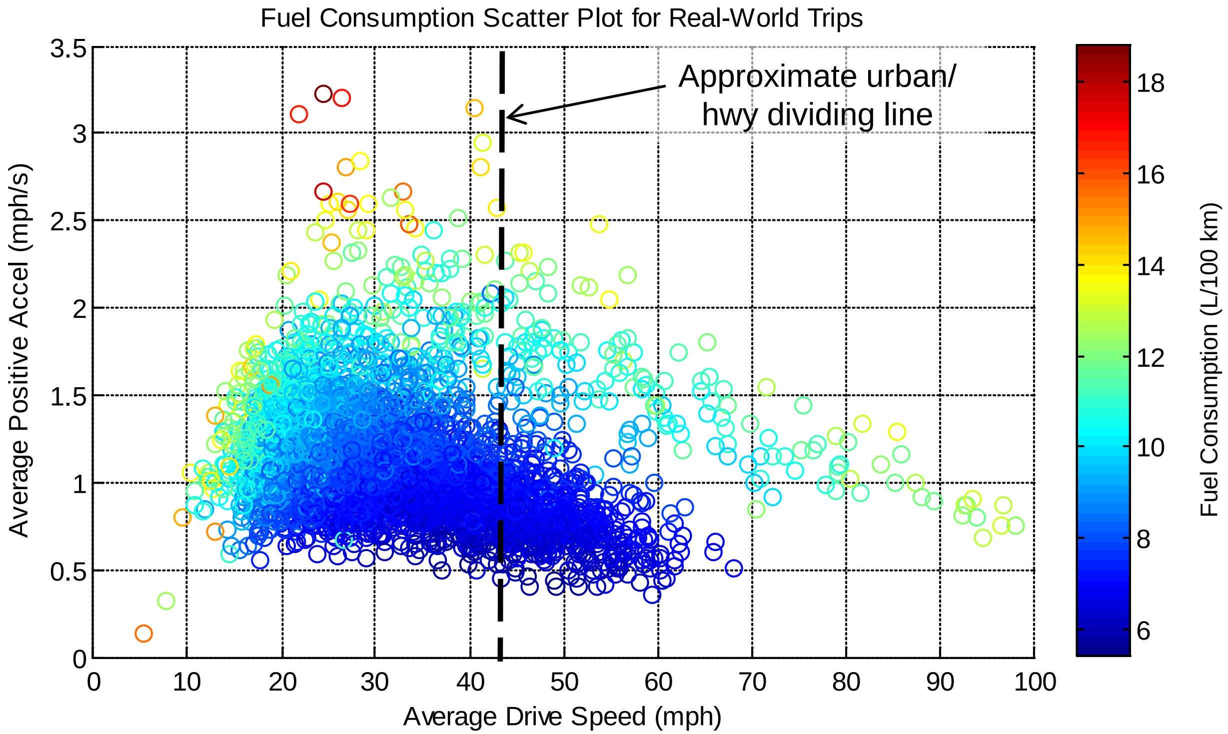
Prevalence of Inefficient/Suboptimal Driving

Real-world sample separated into nearly 4,000 trips

- Evaluated prevalence of inefficient behaviors (histogram analysis, etc.)
  - Primarily high accel in urban and high speed in highway driving
  - Low urban speeds and high highway accelerations also play a role



Literature Review Insights
Of Driving Behavior Influences and Issues

- Driving influences on road load and fuel saving potential
  - Similar findings to NREL analyses
  - Suggest multi-faceted approach needed (driver feedback, policy, incentives, marketing, etc.)
- Effect of social norms
  - Deviation from median increases accident likelihood
  - Positive pressure from peer comparison can help
- Potential adoption and use of feedback systems
  - Interest closely tied to fuel price
  - May need to provide additional incentive
  - Finite time window in which user will pay attention to device
- Potential driver distraction
  - Voice/audible feedback can help minimize
  - Also important to minimize required cognitive load

Accomplishments

Driving Style Considerations

Observations from On-Road Driving Experiments

- Mild accelerations and speeds can annoy people
  - Angry honks during two out of eight energy-efficient drives
  - Free-flow traffic generally exceeds the posted speed limit
- Various impacts of even light vs. moderate traffic volume
  - Light traffic makes efficient driving easier for motivated drivers, but harder for unmotivated drivers (other cars zip by rather than tailgate)
  - Heavier traffic can increase stop and go for all vehicles, but may limit excessive fuel use from aggressive drivers
- Other important factors
  - Time urgency – running late leads to more fuel use; efficient driving easier for relaxed tourist/“Sunday drive”
  - “Difficult” to only lightly push into pedal for powerful vehicles
  - Financial hardship may motivate mode change before driving style change

Photo from iStock/793722

Accomplishments

Approach Assessment

		Can the Approach Work? Information and instruction effectively conveyed? (0-10)			Are People Likely to Use It? Easy to use, avoids unintended consequences and trumps other behavior influences? (0-10)			De-rated Opportunity			
		Accel/Decel	Speed	Idle	Accel/Decel	Speed	Idle	Accel/Decel	Speed	Idle	Total
OBD-Connected Aftermarket Device	Low potential	6	8	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	10	10	10	4	4	4	2.4%	2.8%	0.4%	5.6%
	Comments	+ Heads-up display of mpg & accel/speed metrics + Progressively more challenging lessons/tutorials - May require calibration - Benefit vs. confusion of multiple metrics - No idle feedback			+ Easy connection to OBD - Included mount did not readily work - Significant purchase price ($200) - Drained car battery when not driven - Unable to pass all lessons - Distraction potential			Examples PLX Kiwi Eco Way			
Smart Phone Apps (using device GPS and/or accelerometer)	Low potential	5	6	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	8	8	4	4	5	4	1.9%	2.8%	0.2%	4.9%
	Comments	+ Accelerometer provides fairly good feedback + GPS provides fairly good speed readouts - Idle feedback limited w/o OBD - No feedback of actual mpg w/o OBD - Occasional accuracy issues (e.g., in tunnels, etc.)			+ No need to buy device if you already have a phone - May interfere with other uses of phone - Requires mounting in vehicle - Accelerometer requires calibration			Examples DriveGain GreenMeter			
OEM Dashboards	Low potential	8	8	5	1	1	1	0.5%	0.6%	0.1%	1.1%
	High potential	10	10	10	7	7	5	4.2%	4.9%	0.5%	9.6%
	Comments	+ Some are very well designed (Fusion, Insight) + Access to OBD data for high fidelity feedback (Idle not really a feedback issue for HEVs)			+ No installation/configuration required + Always in front of you + Access to OBD data - high fidelity feedback - Not all vehicles so equipped - Even fewer include improvement instruction			Examples Ford Fusion Honda Insight			
GPS Navigation Devices with Feedback Integrated	Low potential	2	6	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	4	8	4	4	5	4	1.0%	2.8%	0.2%	3.9%
	Comments	+ GPS provides fairly good speed feedback - No accelerometer; derivation from speed low-fi - Idle feedback limited w/o OBD - No feedback of actual mpg w/o OBD - Occasional accuracy issues (e.g., in tunnels, etc.)			+ Multi function (nav, eco-driving) means lower cost + May be already installed + Could include routing advice around traffic - May need to toggle off of nav screen for feedback - Cost to trade in/buy new to get one with feedback			Examples Garmin Eco-Route			
Offline Analysis/Driver Training	Low potential	5	5	5	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	7	7	7	4	4	4	1.7%	2.0%	0.3%	3.9%
	Comments	+ Device can access the right data - Customized advice for driver - No real-time feedback			+ Zero potential for distraction - Requires recalling training - Requires remembering to log into feedback site - No support for putting concepts into practice			Examples Driving Change by Enviance Fiat Eco Drive: Website Report			
Haptic Pedal Feedback	Low potential	6	2	0	1	1	0	0.4%	0.1%	0.0%	0.5%
	High potential	9	5	0	7	4	0	3.8%	1.4%	0.0%	5.2%
	Comments	+ Integrated with vehicle computer data + Immediate feedback at point of application - May only address extreme throttle requests (and not promote complete smoothing)			+ No installation / configuration + No visual distraction - Must be calibrated to avoid people turning it off - Must have an equipped vehicle			Examples Ford SAE paper Nissan ECO Pedal			

Penetration rate hurdles even for “best” approaches

- Dashboard feedback
  - Few vehicles so equipped
- Smartphone and OBD
  - Requires purchasing/ repurposing and mounting a device

OBD = on-board diagnostic port; OEM = original equipment manufacturer

Collaboration/Coordination and Proposed Future Work

Consultation with Subject Area Experts

Social science insights on potential driver receptiveness

- University of Colorado, Institute of Behavioral Science
  - Lessons learned from analogous studies of building energy efficiency feedback devices
- Gloworm Insights
  - Recommendations for evaluating human factors/ design issues for driver feedback approaches

Implementation discussions for high-incentive applications

- Navistar International Corp.
  - Providing fuel efficiency feedback to commercial fleets
- Progressive Insurance
  - Enhancing usage-based insurance product to provide fuel efficiency feedback

Recommendation 1:
Leverage Applications with Enhanced Incentives

Commercial vehicle fleets

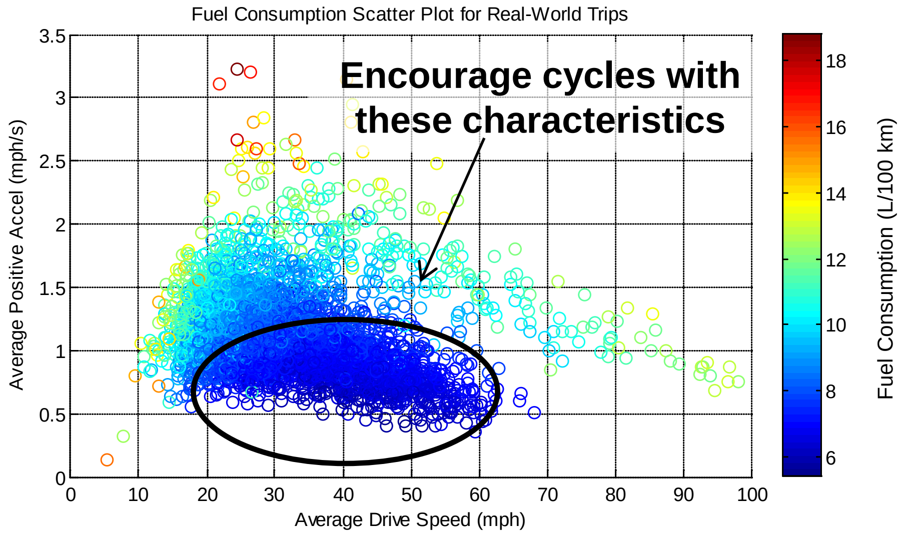
- High fuel savings motivation
  - Strong connection to bottom line
- Fleet managers can influence driver behavior

Usage-based insurance

- Helps insurers better assess risk
  - Policyholder discounts exchanged for measurements of distance driven, frequency of high speeds and accelerations, etc.
- Potential double-benefit for drivers
  - Same factors increase fuel use and insurance risk
  - Behavior change could reduce fuel and auto insurance expenses
- Insurer would make sure feedback does not create driver distraction

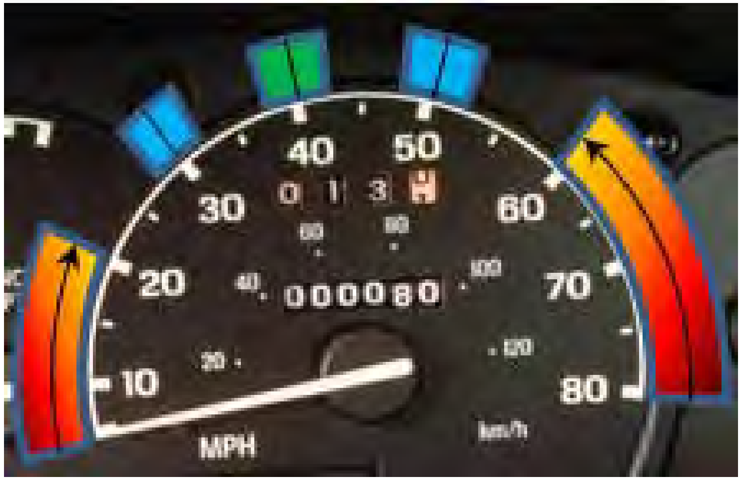
Photos from iStock / 7734733 & 14940205

Recommendation 2:
Prepare a Simple and Widely Deployable Approach



- Rising fuel prices could increase receptiveness to efficiency instruction
- Effective approach could combine general advice with reference points added to existing vehicle gauges, e.g.:

1) Watch the road, obey the law and drive safely (contributing to an accident will NOT save fuel).
2) Avoid speeds below ~20 mph and above ~60 mph (mpg progressively worsens in these regions).
3) Hold speed at a steady value in the 25-55 mph range (e.g., keep centered on or between the color bars).
4) Slow down by letting off on the gas rather than by using the brake, and do so early to minimize time at very low speeds.
5) Above 10 mph, accelerate slowly (so that at least 2–3 sec passes for every 10 mph increase in speed).
6) Turn off engine when parked (do not idle).



Modified from PIX 05472

Recommendation 3:
Make It Increasingly Automatic

Implement “green driving assist” feature

- Similar to other advancements giving the vehicle more responsibility
  - Lane keep assist; Adaptive cruise control; Automated parking; Early brake application for imminent collision avoidance; Etc.

Further benefits from further automation

- Dramatic automation technology advances in past two decades
  - Driven by highway safety, capacity improvement and defense research
  - Google and others have retrofitted component technologies into vehicles and logged thousands of autonomous driving miles on public roads
- Project suggests 30%-60% fuel savings potential
- Added benefits would drive demand (independent of fuel price)
  - Increased convenience and productivity; Reduced accidents and congestion
- Compounding fuel savings possible
  - Improved safety, traffic flow and guidance aspects
  - Facilitate vehicle weight/power reductions, and even roadway electrification

Reiterating Project Summary

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Special thanks to:

- Dr. Yury Kalish,
  DOE Vehicle Technologies Program

NREL contact:

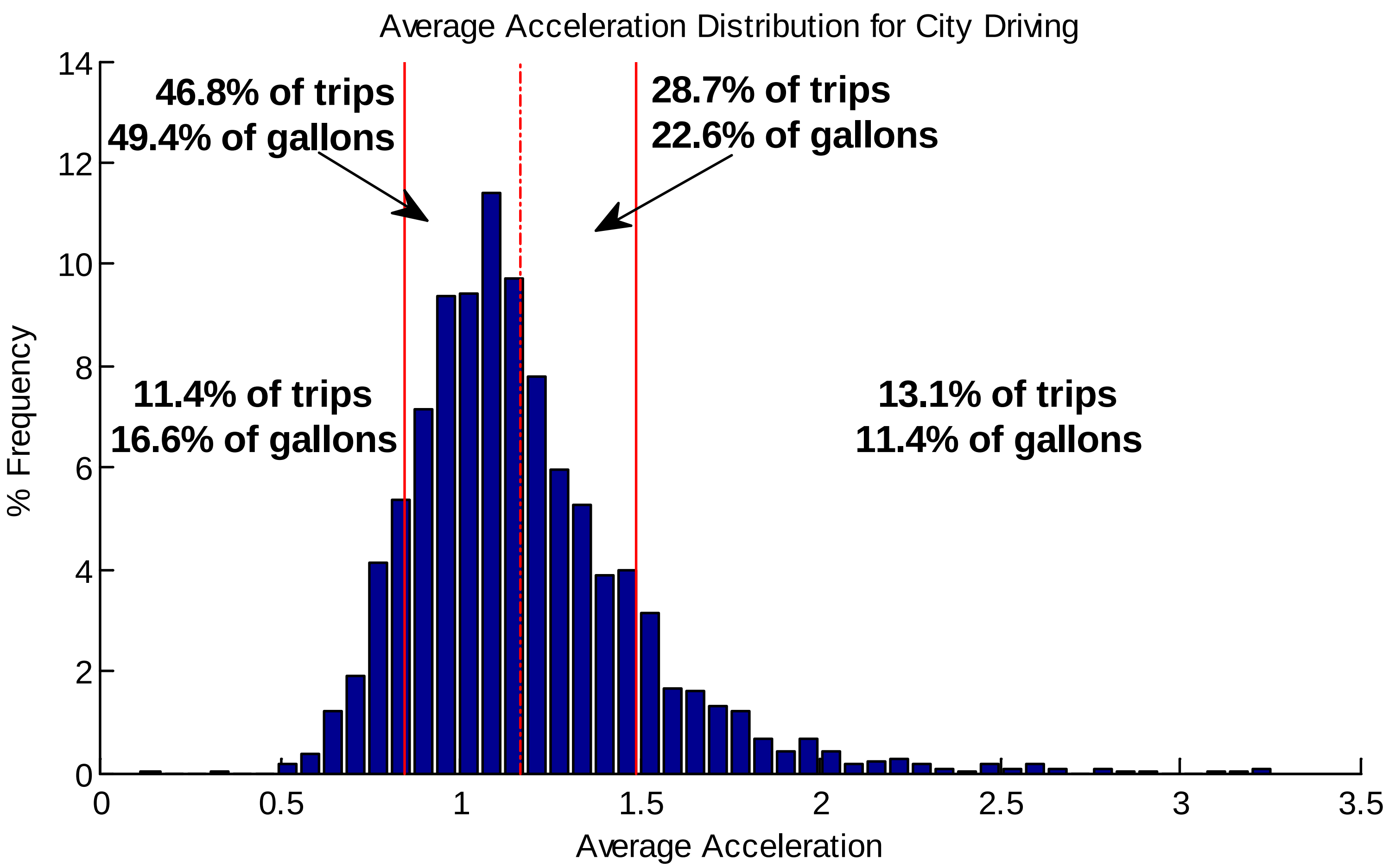
- Jeff Gonder – jeff.gonder@nrel.gov

Technical Back-Up Slides:

Description of Additional Accomplishments and Related/Synergistic Activities

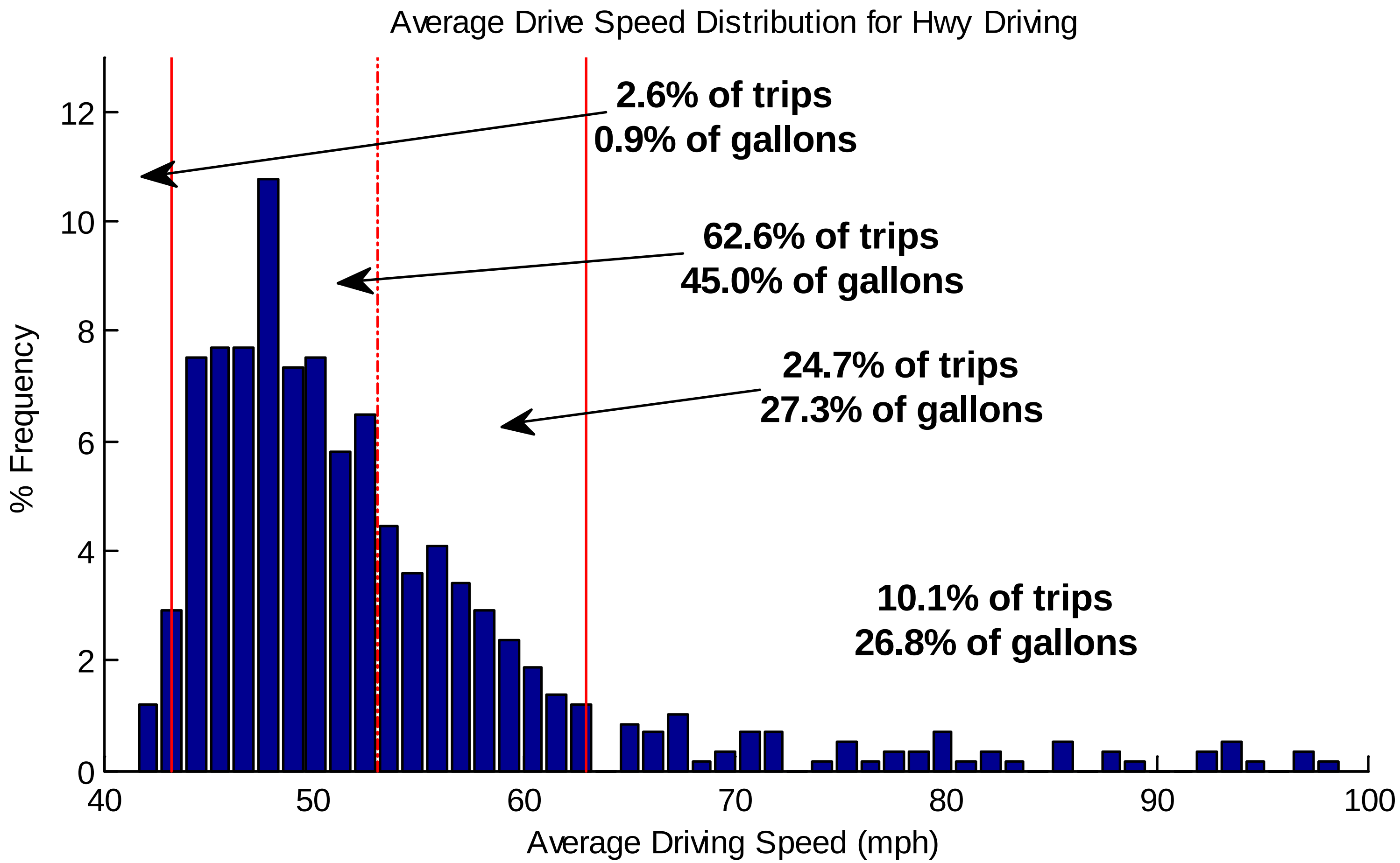
Variability of Real-World Driving Sample

Average positive acceleration distribution in city trips



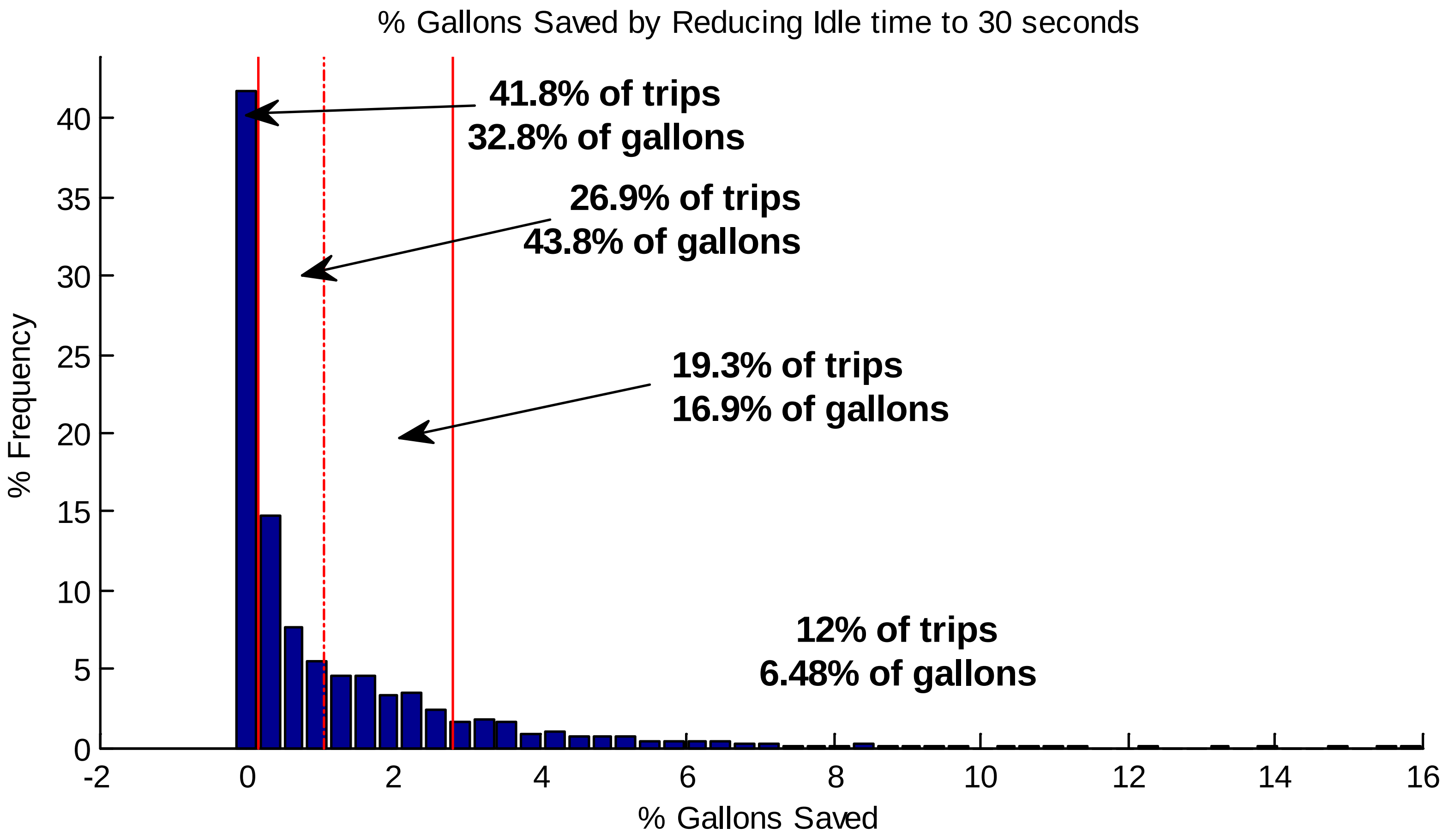
Variability of Real-World Driving Sample

Average driving speed distribution in highway trips



Variability of Real-World Driving Sample

Distribution of fuel savings from eliminating long idle periods



GPS Drive Cycle Data Availability

From the NREL-hosted Transportation Secure Data Center (TSDC)

www.nrel.gov/vehiclesandfuels/secure_transportation_data.html

- Secure archival of and access to detailed transportation data
  - Travel studies increasingly use GPS → valuable data
  - TSDC safeguards anonymity while increasing research returns
- Various TSDC functions
  - Advisory group supports procedure development and oversight
  - Original data securely stored and backed up
  - Processing to assure quality and create downloadable data
  - Cleansed data freely available for download
  - Controlled access to detailed spatial data
    - User application process
    - Software tools available through secure web portal
    - Aggregated results audited before release

NRC report*

Sponsored by the U.S. Department of Transportation (DOT)
Operated by the NREL Center for Transportation Technologies and Systems (CTTS); Contact: Jeff.Gonder@nrel.gov

GPS = global positioning system
* See recommendations from this 2007 National Research Council report: books.nap.edu/openbook.php?record_id=11865