Drive Cycle Development and Real-world data in the United States

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Outline

• Drive cycle development history in US
  – FTP & off-cycle
  – Inventory cycles
  – Other cycle development
• SAFD vs Vehicle Specific Power
• New driving activity data
• US EPA 5-cycle fuel economy labeling
  (drive cycle weighting)
• Next steps

Apologies for the American units!
Why drive cycles are important

- Serve as a standardized measurement stick for emissions and fuel economy
- Can compare across vehicles (benchmark)
- Manufacturers design vehicles to meet standards set by cycles and test procedures
- Serves as proxy for “average” or typical driving
- Emissions standards are strongly dependent on the cycle and test procedure
- Drive cycles also change over time, with infrastructure, policy (speed limits), and technology (power:weight)
FTP cycle development
US Federal Test Procedure

• LA4 (City, UDDS) Developed in the late 1960’s to describe typical driving (acquired in Los Angeles)
• The highway HFET cycle was developed to describe a typical rural route (acquired outside Ann Arbor, MI in the 1970s)
• These 2 cycles used to describe fuel economy in the US
• US06 (aggressive) and SC03 (A/C) cycles developed based on “3 cities data” of instrumented vehicles from Baltimore, Spokane, Atlanta.
  – REP05, REM01, SC03 were developed to cover the full range of driving, but were simplified to US06 and SC03, while FTP remained in place
  – These cycles are extreme to prevent “cycle beaters”
Inventory Cycles - California

• Implemented new base cycle
  – LA92 – determined from driving in LA in early 1990’s (40kph)
  – More representative of 1990’s driving

• Facility Cycles (speed correction factors)
  – 12 unified correction cycles (UCC) mainly from chase car data in LA
  – From 4 to 95kph
  – Chosen by mean speed, speed-acceleration frequency distribution, positive kinetic energy (PKE), load, maximum acceleration, maximum deceleration, percent idle, percent acceleration, distance, etc
  – These cycles are used to correct the base emission factor from LA92 to other speeds
CARB
LA92 &
CO₂ speed
correction
factor
US EPA Inventory Cycles

- USEPA - Facility cycles (1997)
  - Developed by Sierra Research from 3 cities chase car data (Baltimore, Spokane, LA)
  - 11 cycles based on roadway type and congestion level (+ramp)
  - Each cycle lasts ~10 minutes
  - Matched second-by-second segments of chase car data by comparing SAFDs (speed acceleration frequency distribution)
  - Can find on EPA website under MOBILE6 technical support documentation
Speed/Acceleration Frequency Distribution (SAFD)
EPA & Sierra cycle specifications

- time in acceleration/deceleration
- time at cruise
- time at idle
- maximum speed
- average speed
- average or predominant speed during cruise
- maximum acceleration/deceleration rate
- maximum power
- length (time and miles)
- stops per mile
- average positive kinetic energy (PKE) change per mile and specific power
- distributions of speed and acceleration
USEPA Cycle development (cont’d)

• Microtrips were chosen based on how well they matched the specifications

• Cycle choice criteria
  – lowest sums of differences on SAFD
  – matching real world power (2va)
  – Segments shortened or lengthened

• Cycles used for (emissions) “speed correction factors” and for speed dependent transportation planning in MOBILE6 (emissions inventory model)
UC-Riverside CE-CERT International Vehicle Emission Model

• data collection and cycle development for rapid emissions inventory estimation
  – Almaty, Kazakhstan
  – Beijing, China
  – Lima, Peru
  – Mexico City, Mexico
  – Nairobi, Kenya
  – Pune, India
  – Santiago, Chile
  – Sao Paulo, Brazil
  – Shanghai, China

http://www.issrc.org/ive/
Vehicle Specific Power: an alternate metric for cycle manipulation

- MOVES is EPA inventory model replacing MOBILE
- MOVES is a modal model based on VSP activity
- Cycle metric should be based on a more physically causal variable for emissions formation: e.g.
  - Road load (tractive) Power
  - \( P \sim A v + B v^2 + C v^3 + M v a^* \)
    - A,B,C are vehicle target coastdown coefficients
    - * including road grade
- VSP = \( P/M \) (M is mass of vehicle)
  - Divided by mass since emissions (measured in g/km) is largely independent of vehicle mass
- With VSP distributions and proper modal data, emissions can be converted from one drive cycle to another
- This approach has been validated by a number of studies
VSP Distribution in MOVES

Distribution of Time by Mode

Percent of Time

VSP/Speed Bin  kW/tonne

Rural Restricted  Urban Unrestricted

0-25 mph  0-40 kph
25-50 mph  40-81 kph
>50 mph, >80kph
Cycle Development requires data

- Much second by second data has already been collected
- But these were not collected with harmonization in mind, so data is scattered and inconsistent
- Require new and more rigorous analysis methods
Real world driving data since 3 cities & LA92

• Chase car:
  – Los Angeles 2000

• Instrumented Vehicle:
  – US EPA Ann Arbor shootout data 2001
  – Kansas City data 2004-2005
  – Atlanta (Georgia Tech) 2001-2004
    • 1600+ vehicles, 800+ households, GPS, accelerometer, OBD
    • Vehicles instrumented for 2-3 years
    • Most comprehensive activity data in existence
    • Data excellent source for start activity as well
    • Due to privacy concerns, data has a finite lifetime

15
Los Angeles Comparison
Speed

More time is spent at high speeds in 2000 than in 1992. Speed limits were increased during this period.
More time is spent at high acceleration in 2000 than in 1992.
### Operating Modes for MOVES VSP bins

<table>
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<th>VSP Class (kW/tonne)</th>
<th>Speed Class (mph)</th>
<th>1-25</th>
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For coast and cruise,
- 13 modes retained from MOVES2004, plus
- 8 modes added for MOVES2006 formerly bins 26 and 36

**PLUS**
- One mode each for idle, and decel/braking

*Gives a total of 23 opModes*
Los Angeles in 1992 compared to 2000

Los Angeles then and now

- **Los Angeles 1992 (no idle)**
- **Los Angeles 2000 (no idle)**

Fraction of activity

- VSP bin
- <25 mph
- 25-50 mph
- >50 mph

VSP bin 25-50 mph
Other Factors:
California (2000) Urban vs Rural

Rural driving is faster than urban driving
SouthEast Michigan Shootout data

- 15 PEMS instrumented vehicles.
- Driven by US EPA or SENSORS employees in calendar year 2001.
- Note: Drivers were not randomly chosen.
- Avg. distance driven per vehicle : 52 miles
- Average speed : 31.2 mph
Kansas City (Round 1.5 Only)

- US EPA study 2004-2005
- Instrumented vehicles (not chase car) from random population of newer vehicle owners
- PEMS (Portable Emissions Measurement System) equipped to measure emissions and activity.
- Drivers measured for 15,000-30,000 seconds (battery lifetime)
- Measured conventional as well as hybrid vehicles
- Avg. distance driven per vehicle: 41 miles
- Average speed: 30.1 mph
Speed acceleration frequency distributions

- Based on a 2-dimensional matrix of speed and accelerations
Recent surveys have the more high speed, high power driving. LA driving is the most aggressive, & may be comparable to US06.
Conventional vs Hybrid Activity

Hybrid driving is slightly less aggressive than conventional vehicles.
5-Cycle fuel economy labeling

• Previously, label fuel economy was based on a 2 cycle number: city and highway
  – Real-world fuel economy effects were captured with a 20% correction factor

• Thesis: Real-world driving can be described by a linear combination of existing drive cycles

• If weighted properly the activity and fuel economy can be captured better than a fixed correction factor

• The key is to use cycles with a broad enough range to capture the VSP profile
  – US driving activity is mainly represented by a linear weighting of 3 cycles: FTP(city), HFET, and US06
Other relevant 5 cycle issues

• Through a combination of FTP (city), highway, US06, cold FTP, and hot SC03 (air conditioning) real-world driving was bracketed

• Result: fuel economy label became more representative of what vehicle owners would truly get throughout a year of driving

• Potential lessons for harmonization:
  – VSP weighting methodology can be a powerful tool
  – May be able to represent different regions through a combination (and proper weighting) of drive schedules
Comparison of FTP, NEDC, JC08

- The NEDC and JC08 have similar VSP profiles – in hot start, should have similar emissions
- Main difference likely due to sequence following starts
Conclusions

• US has a long history of drive cycle development
• Much new data exists in the US for a harmonization project (with more coming)
• Driving has been getting faster and more aggressive with each passing decade
• VSP activity is a powerful (yet simple) tool to characterize and combine drive cycles and to compare driving from different regions
Issues for future consideration

• Definition of “city” vs “highway” (urban vs extra-urban)
  – City can include high speed driving and highways can be congested stop and go
• Starts/km variability
• Shift schedules
• Scaling drive cycle for small engine “cars”
Next steps

• We should analyze the existing data especially the Atlanta data before it is destroyed
• Should agree on QA/QC procedures for data
• As well as a methodology for cycle generation and comparing “representativeness”
• The US EPA is going to start collecting second by second activity and emissions data from real-world operation from a variety of cities
Appendix
Data Limitations

• OBD data is noisy when used for accelerations
• GPS is noisier than OBD
• Should make an effort to determine best filtering mechanism compared to directly measured accelerations
  – Accelerometer, 5th wheel, etc.
• Do accelerations matter?
  – Certification tests have x% error band for drivers to follow cycles
  – But Robot drivers and computer simulations can follow cycles exactly, so the exact cycle trace can matter