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# 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

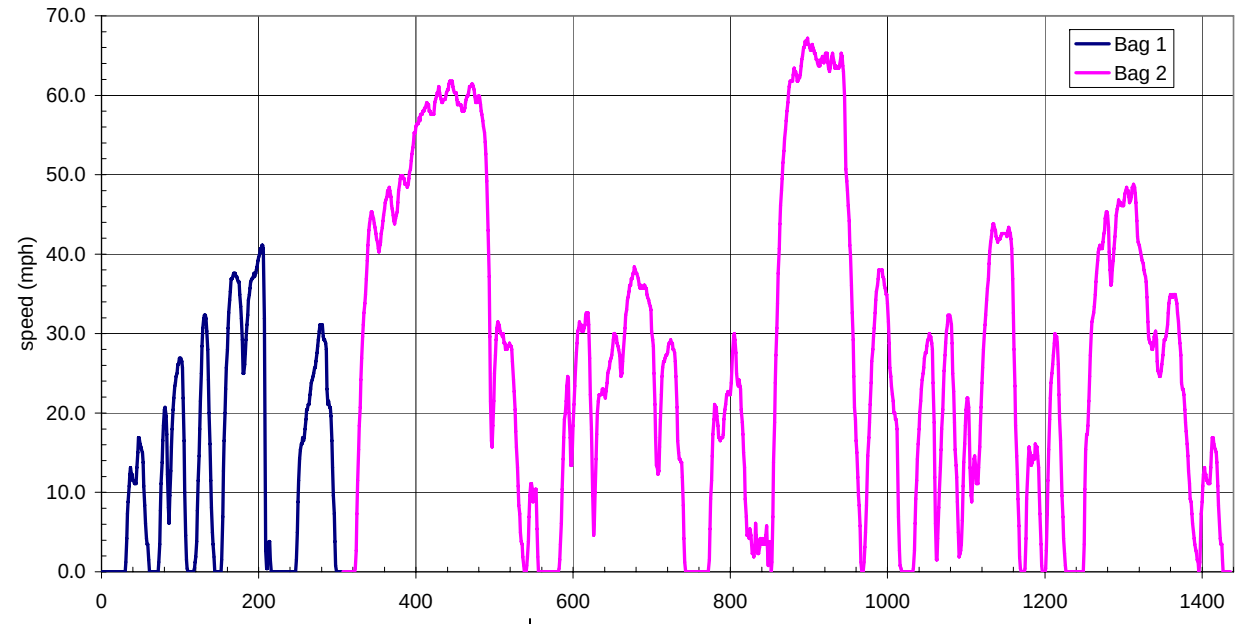
## US Federal Test Procedure

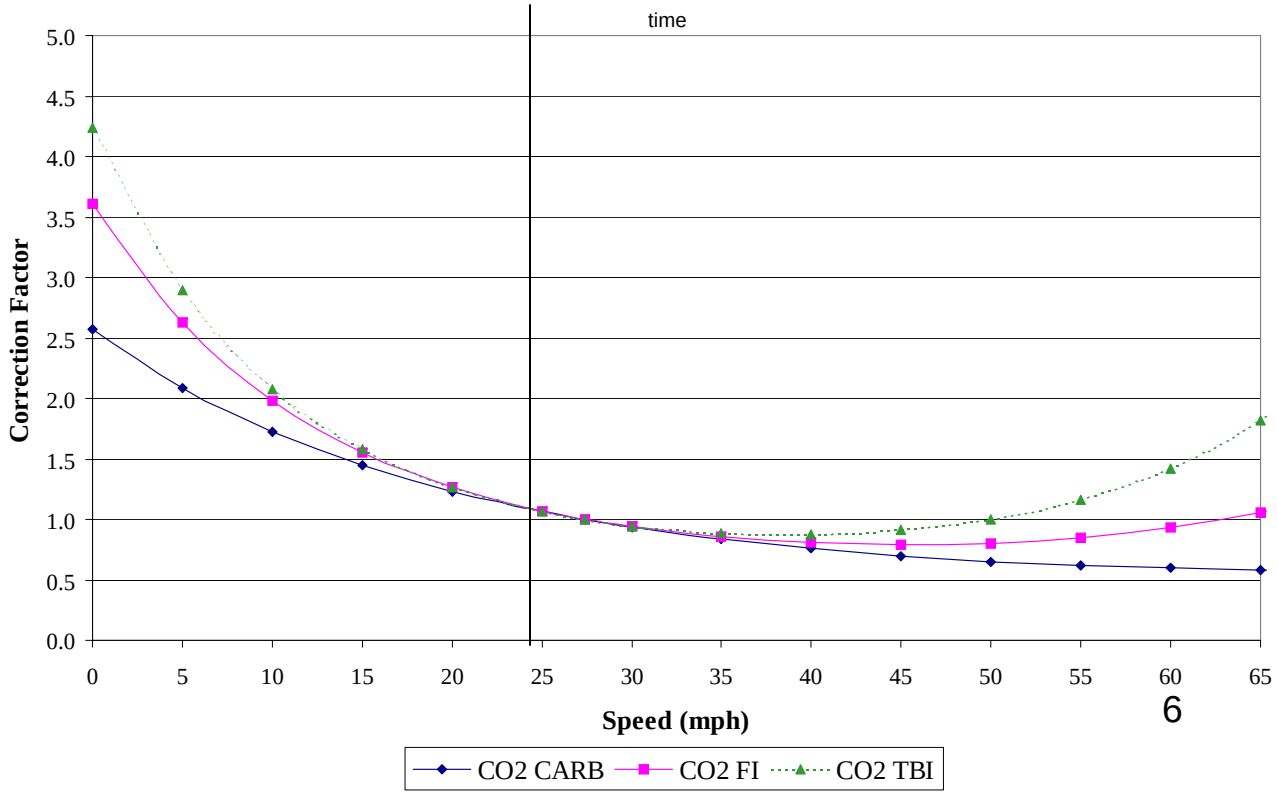
- LA4 (City, UDDS) Developed in the late 1960's to describe typical driving (acquired in Los Angeles)
- The highway HFET cycle was developed to describe a typical rural route (acquired outside Ann Arbor, MI in the 1970s)
- These 2 cycles used to describe fuel economy in the US
- US06 (aggressive) and 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 & $CO_2$ speed correction factor

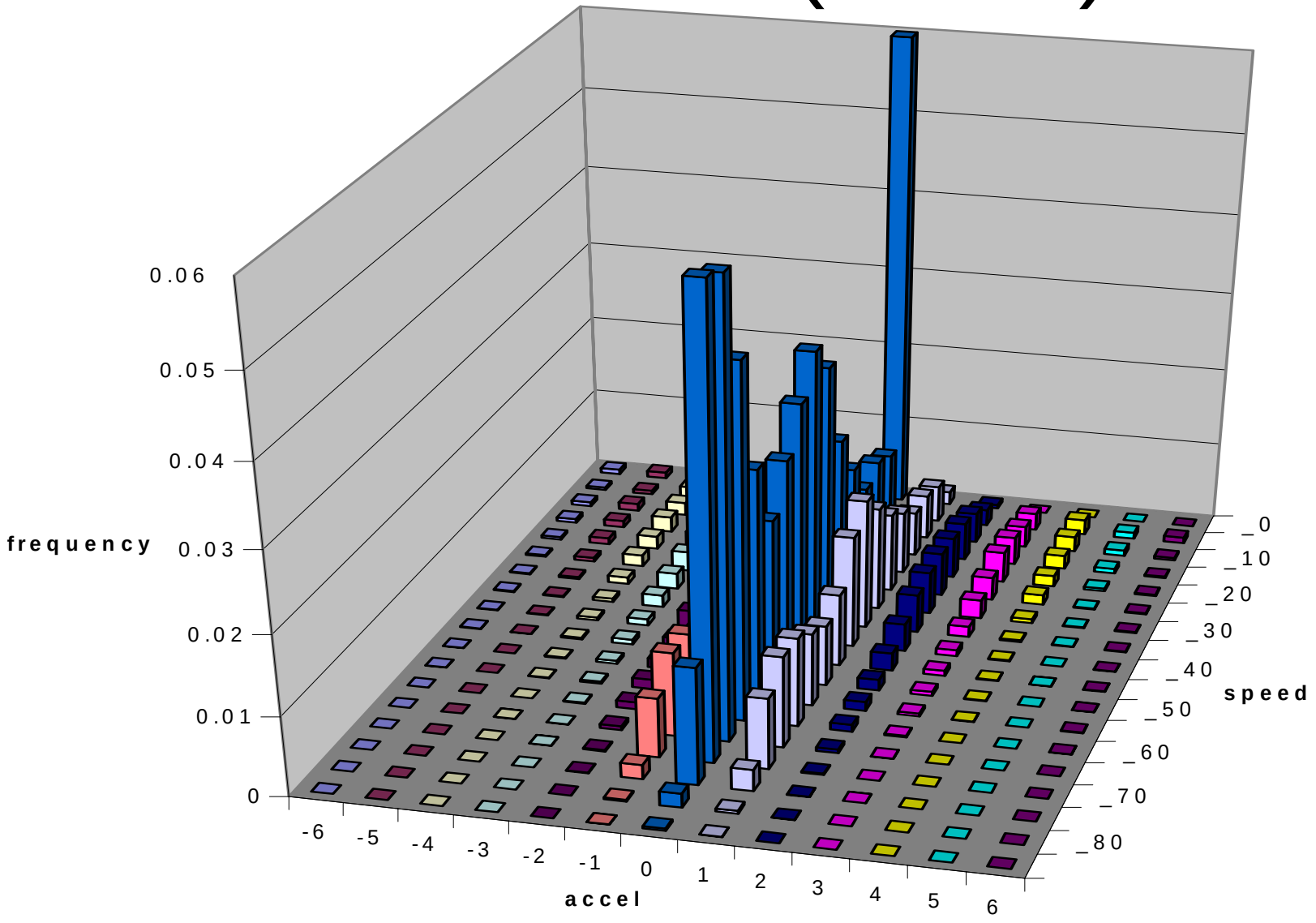


# US EPA Inventory Cycles

- 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

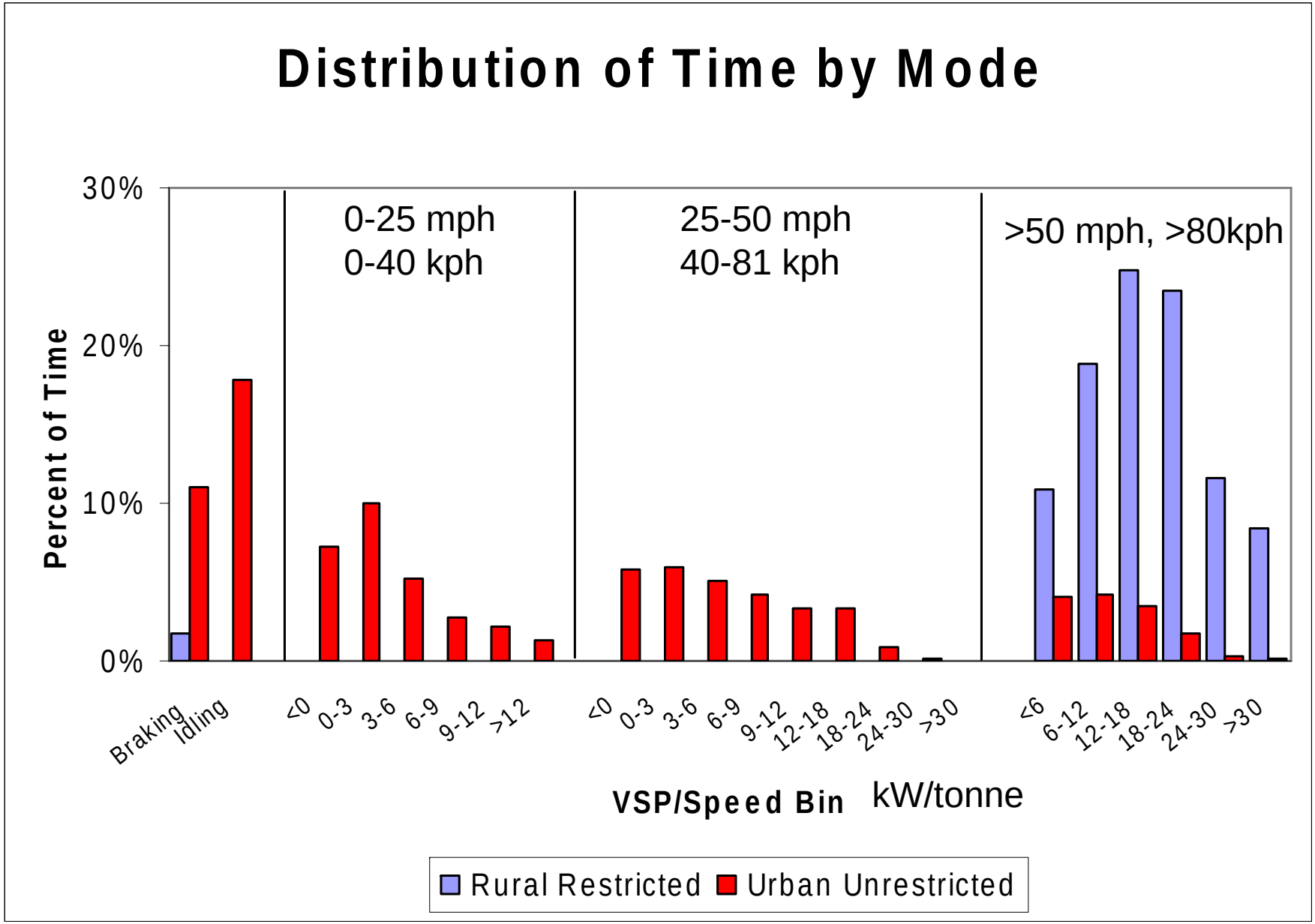
- data collection and cycle development for rapid emissions inventory estimation
  - Almaty, Kazakhstan
  - Beijing, China
  - Lima, Peru
  - Mexico City, Mexico
  - Nairobi, Kenya
  - Pune, India
  - Santiago, Chile
  - Sao Paulo, Brazil
  - Shanghai, China

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
- $P \sim Av + Bv^2 + Cv^3 + Mva^*$
  - 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



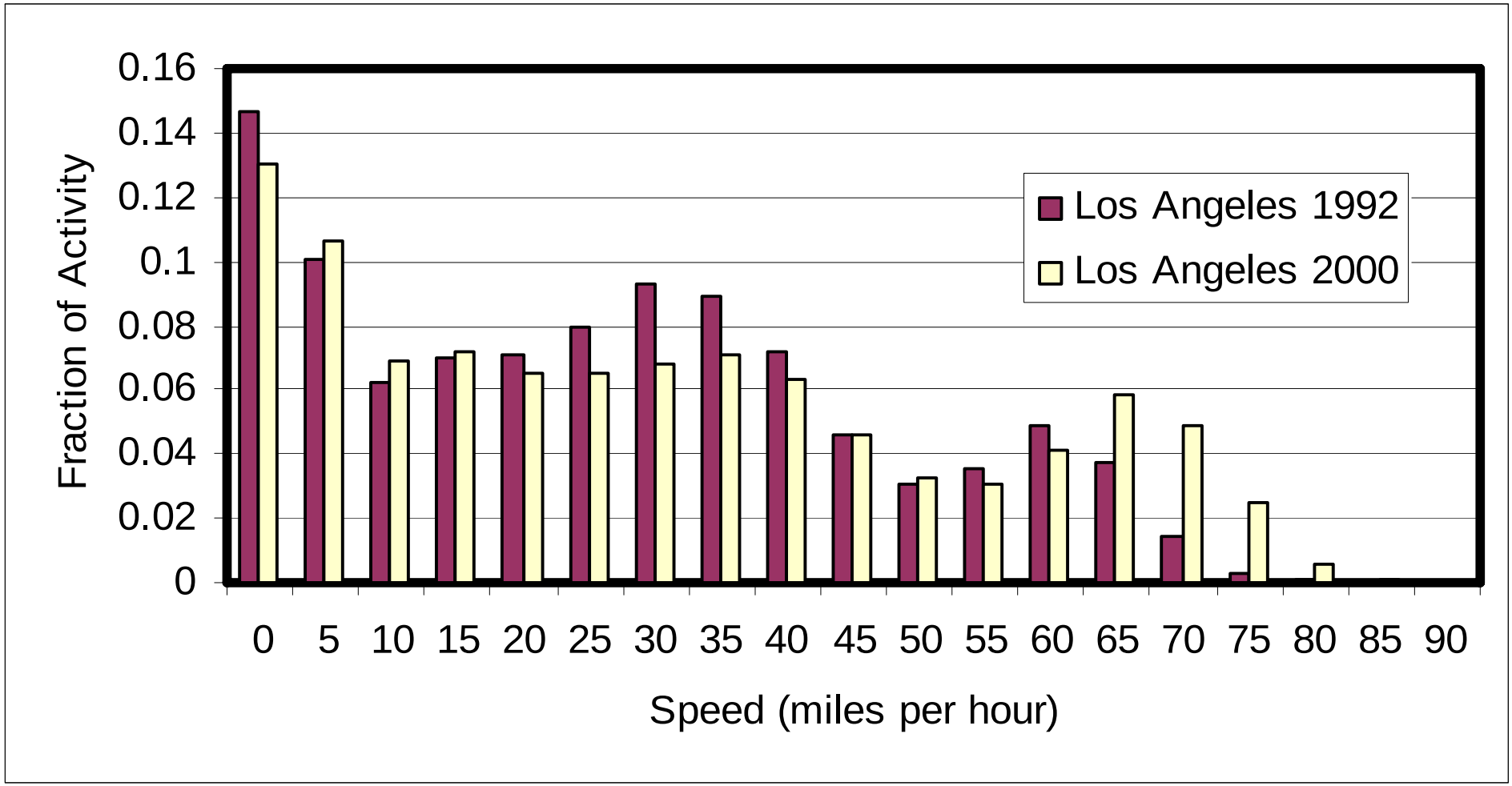
# Cycle Development requires data

- 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

# Los Angeles Comparison Speed

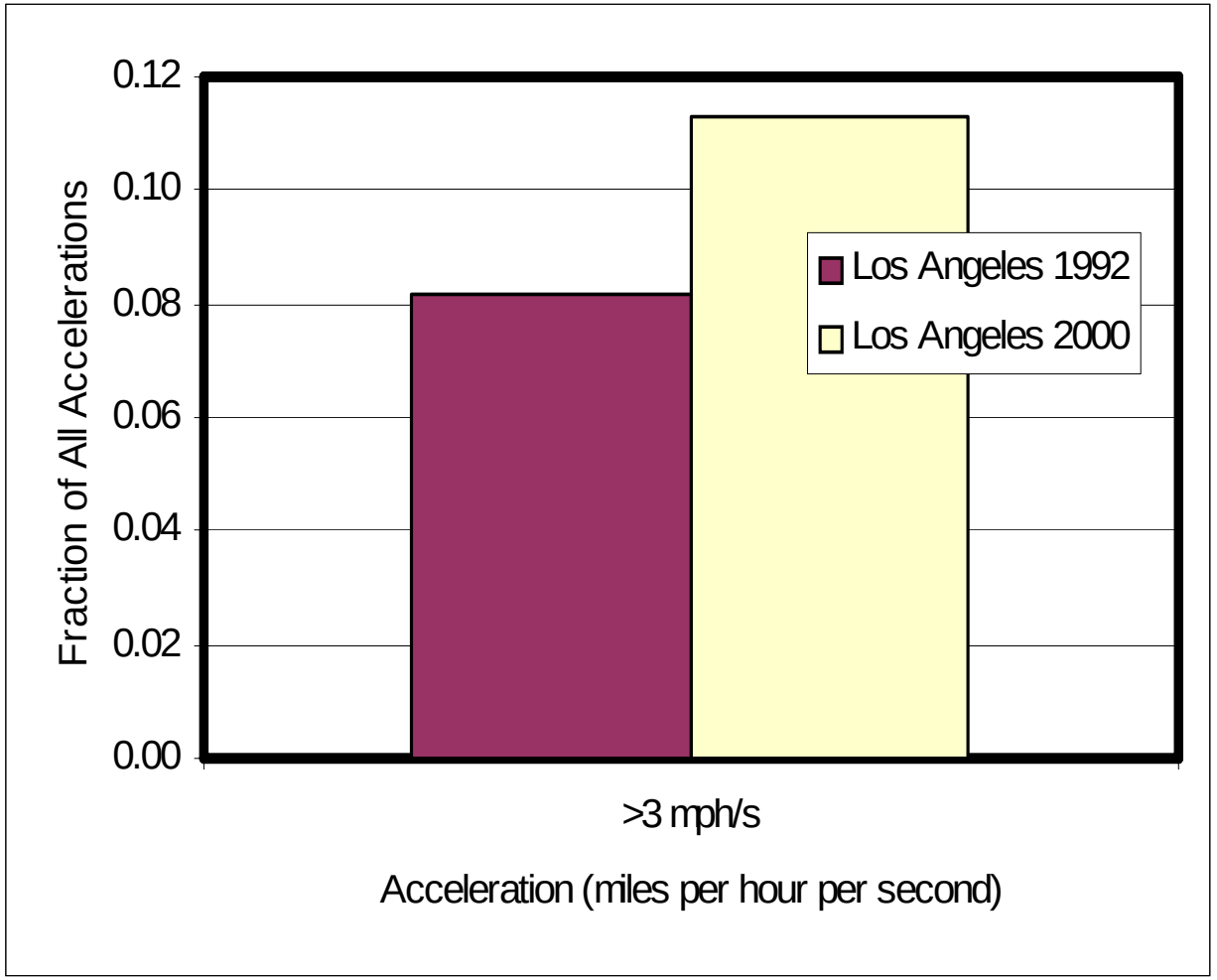



**More time is spent at high speeds in 2000 than in 1992.**

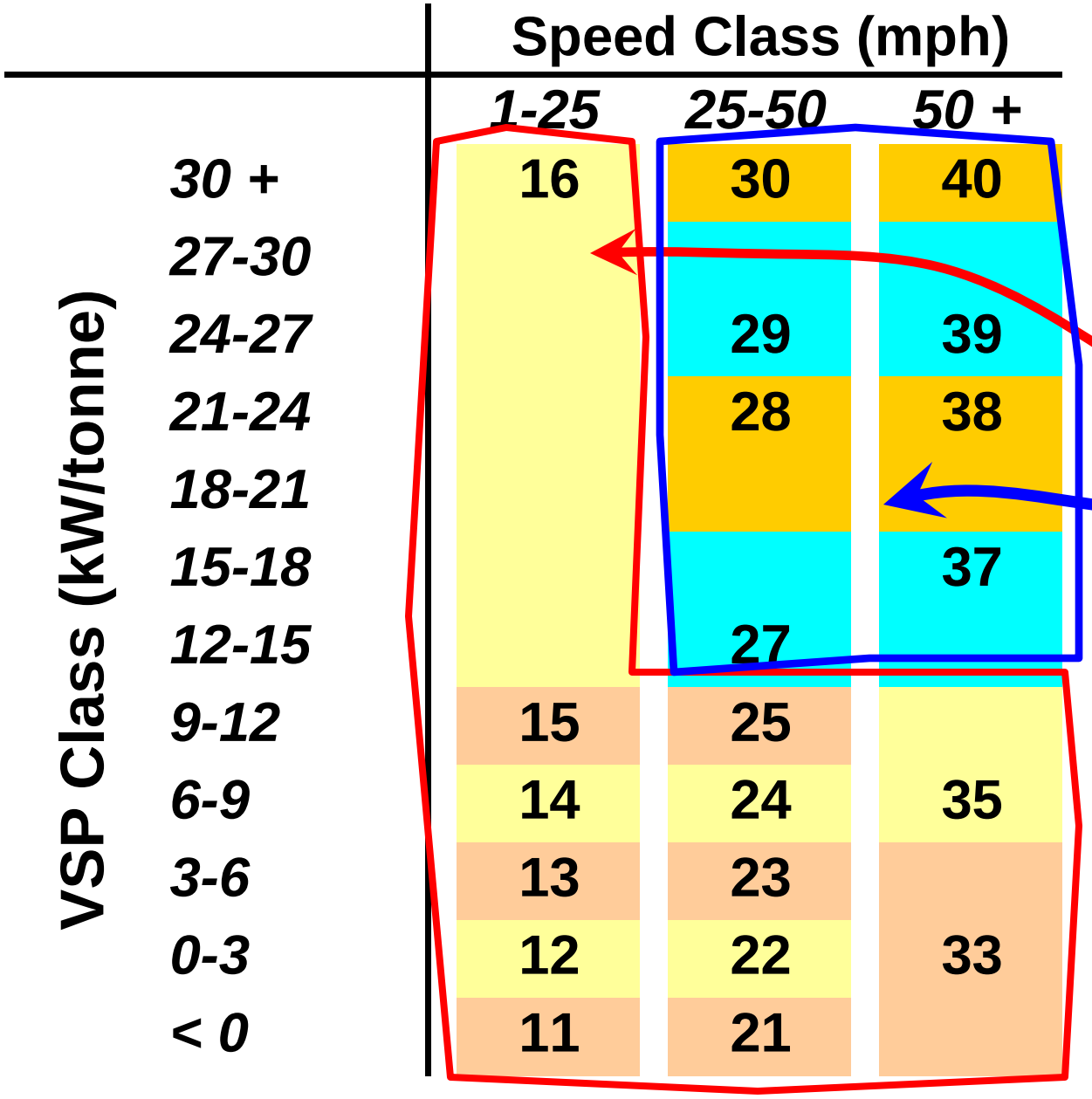
**Speed limits were increased during this period**

# Los Angeles Comparison Acceleration

More time is spent at high acceleration in 2000 than in 1992.



# Operating Modes for MOVES VSP bins




***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**

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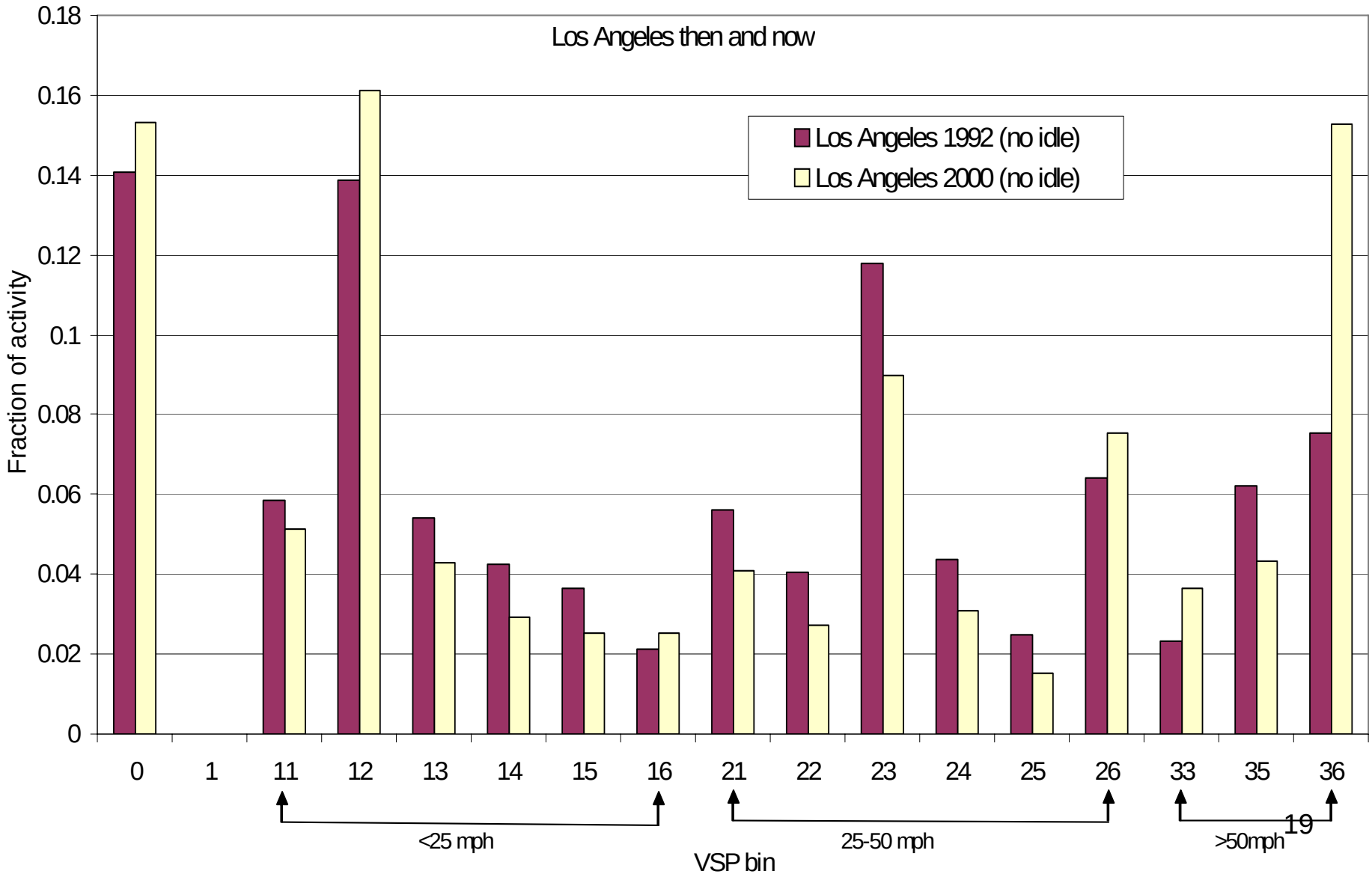
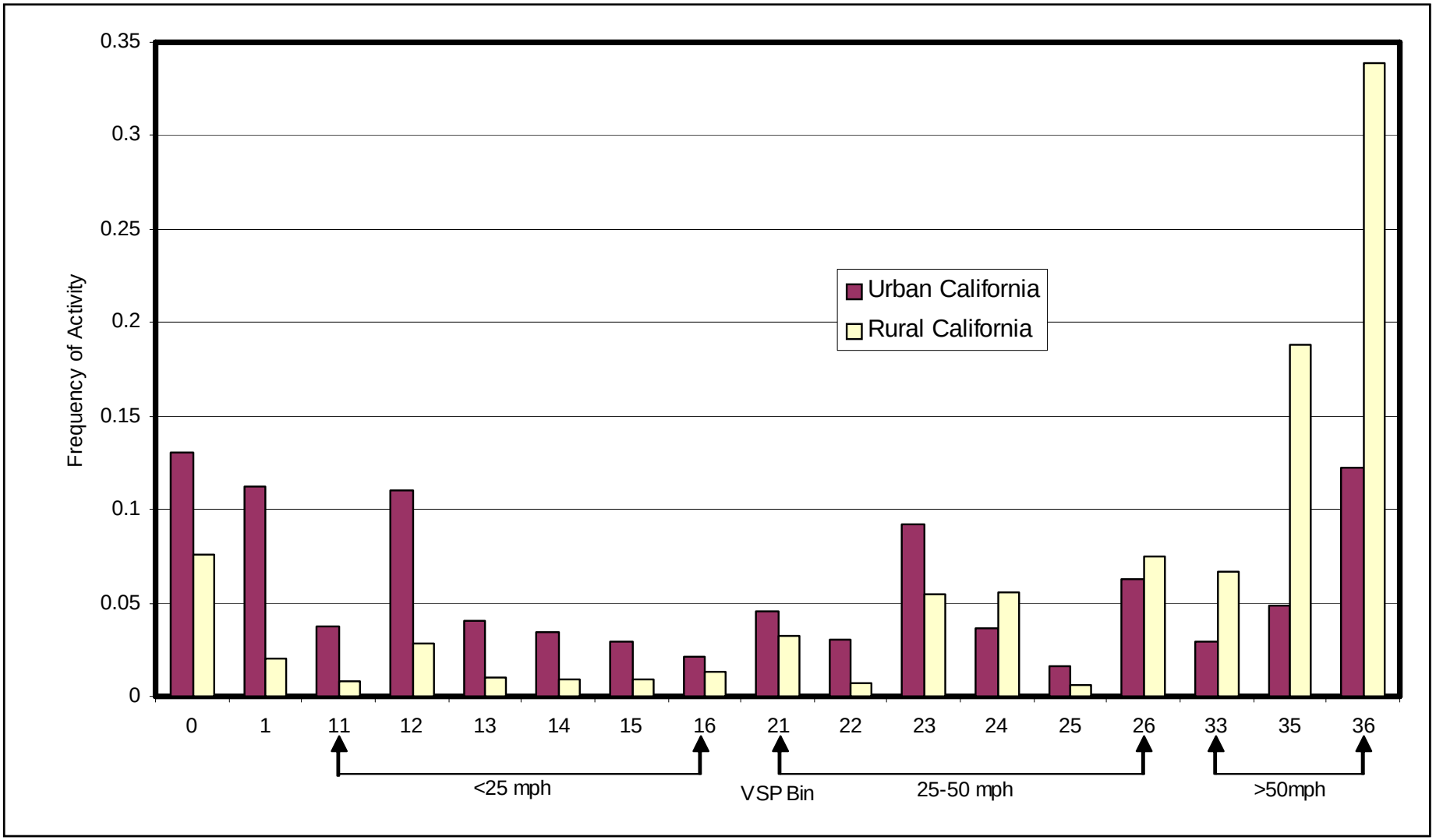
***Gives a total of***
**23 opModes**

# Los Angeles in 1992 compared to 2000



# Other Factors: California (2000) Urban vs Rural




**Rural driving is faster than urban driving**

# SouthEast Michigan Shootout data

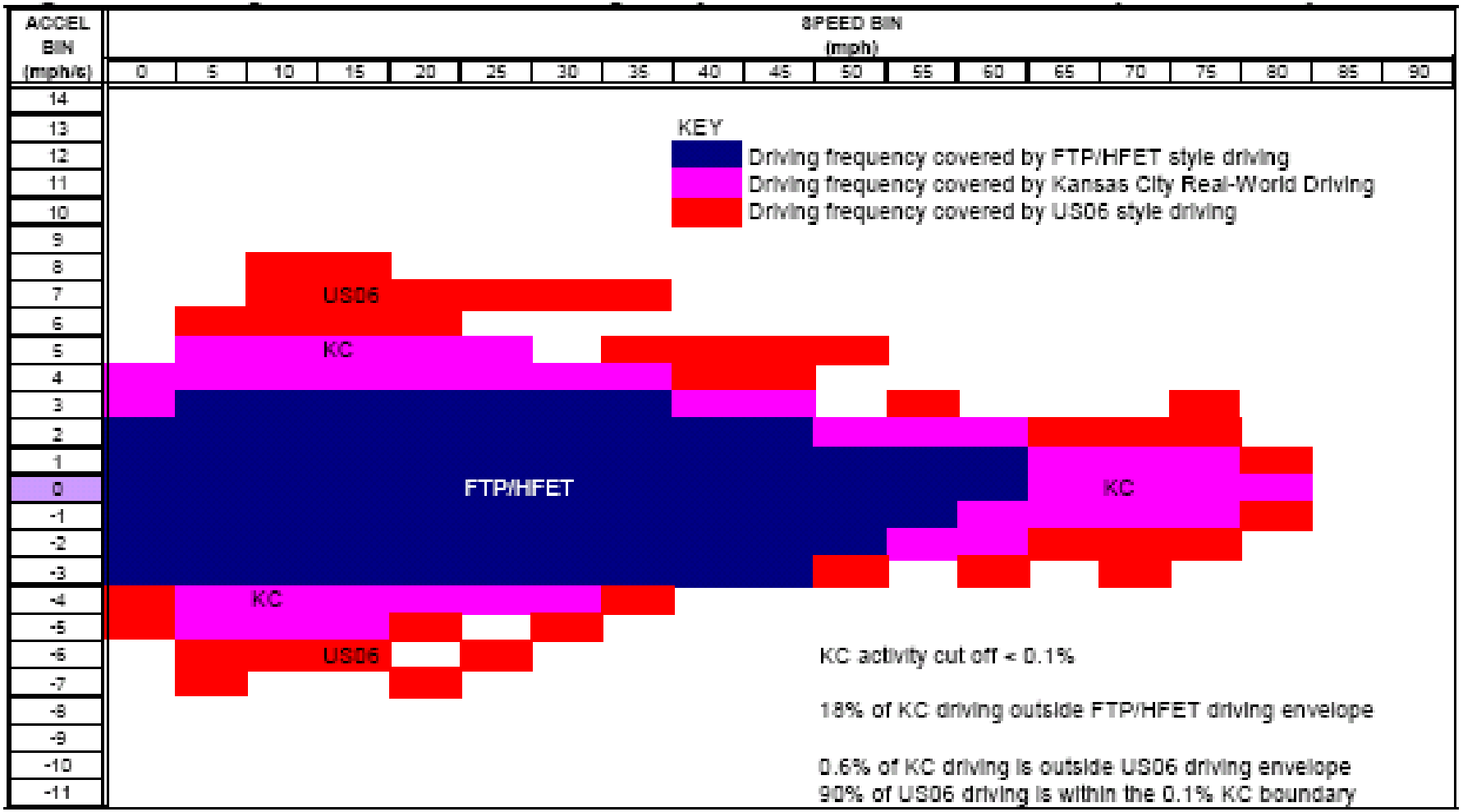
- 15 PEMS instrumented vehicles.
- Driven by US EPA or SENSORS employees in calendar year 2001.
- Note: Drivers were not randomly chosen.
- Avg. distance driven per vehicle : 52 miles
- Average speed : 31.2 mph

# Kansas City (Round 1.5 Only)

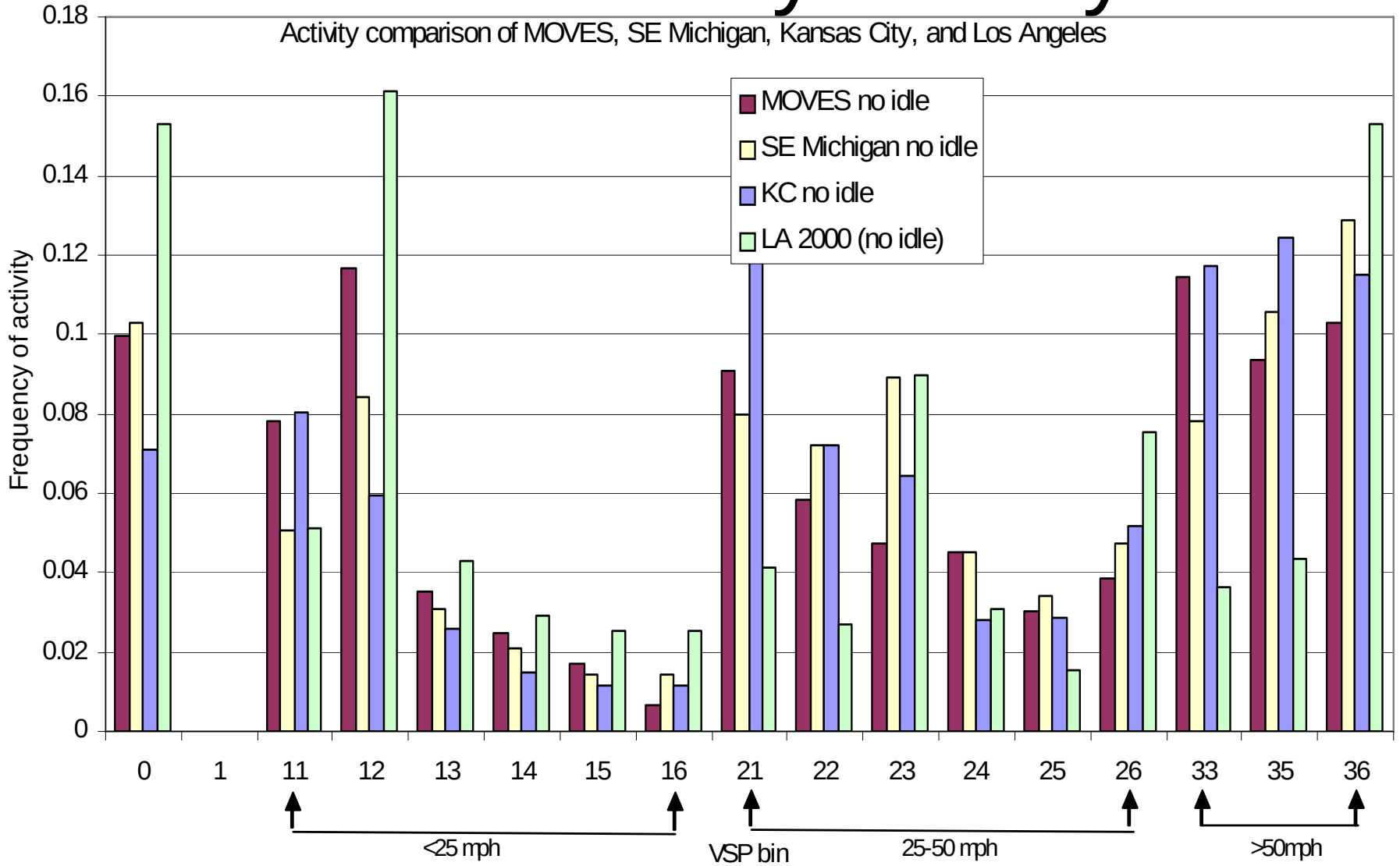
- US EPA study 2004-2005
- Instrumented vehicles (not chase car) from random population of newer vehicle owners
- PEMS (Portable Emissions Measurement System) equipped to measure emissions and activity.
- Drivers measured for 15,000-30,000 seconds (battery lifetime)
- Measured conventional as well as 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



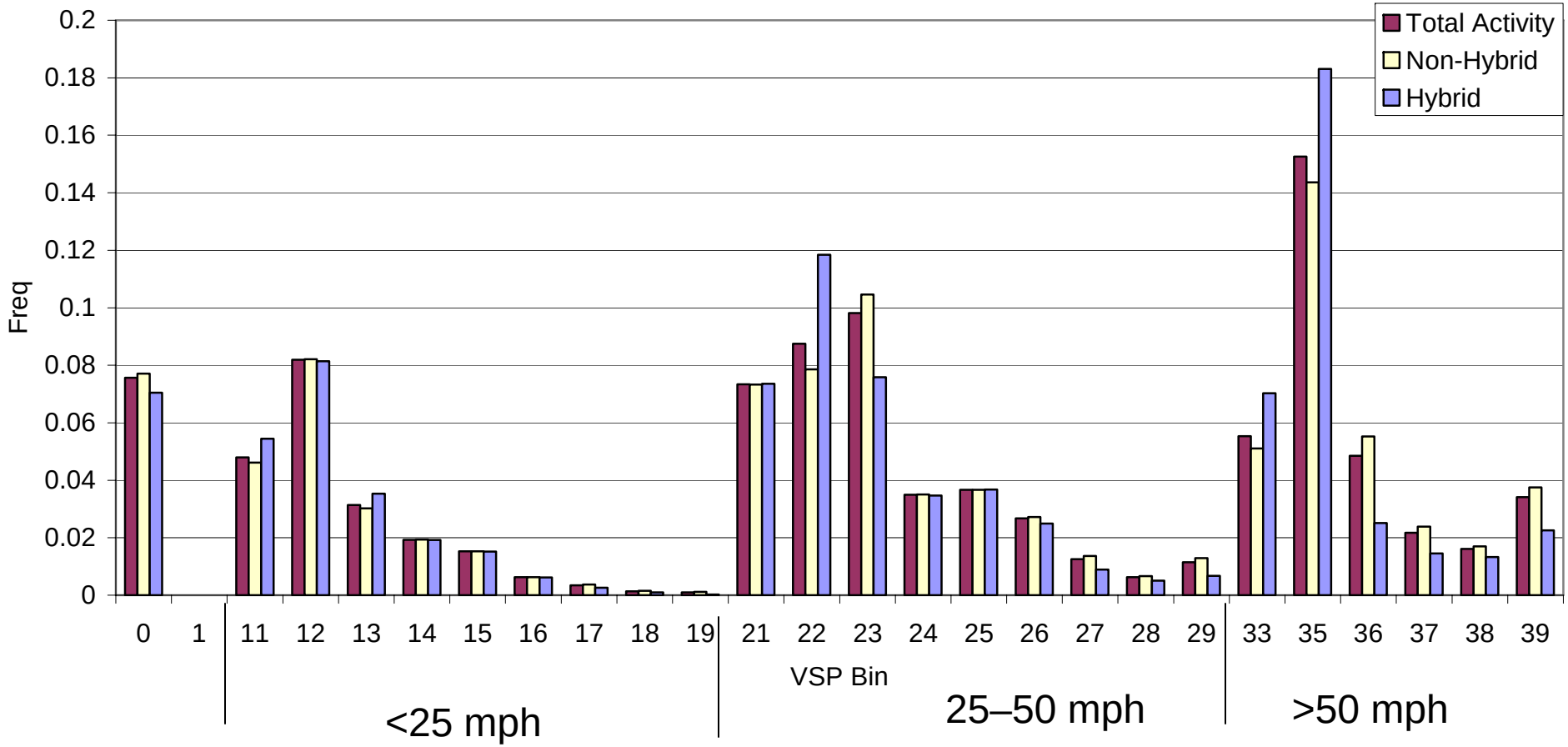
# Recent Activity Surveys




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

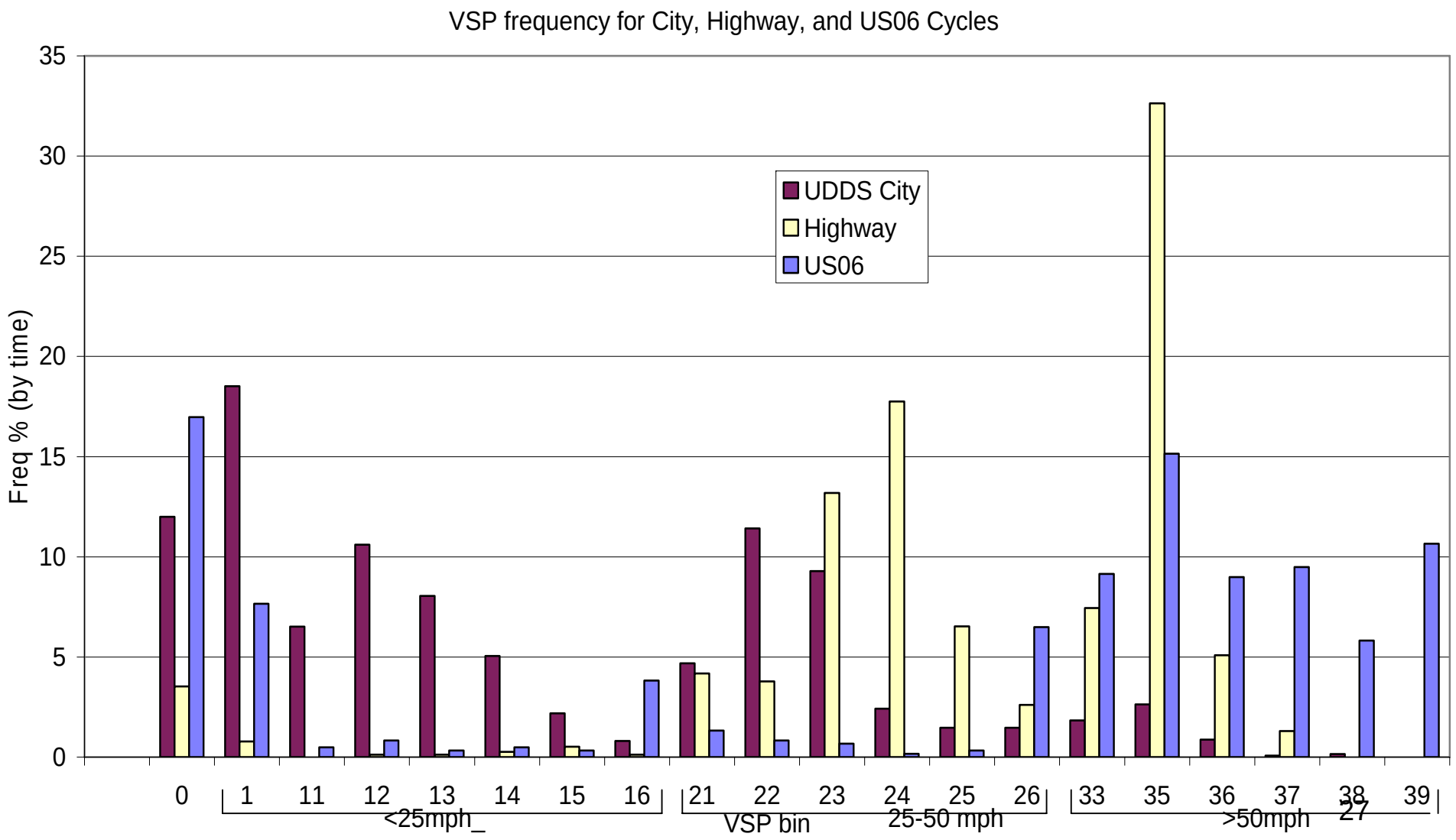



**Hybrid driving is slightly less aggressive than conventional vehicles**

# 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

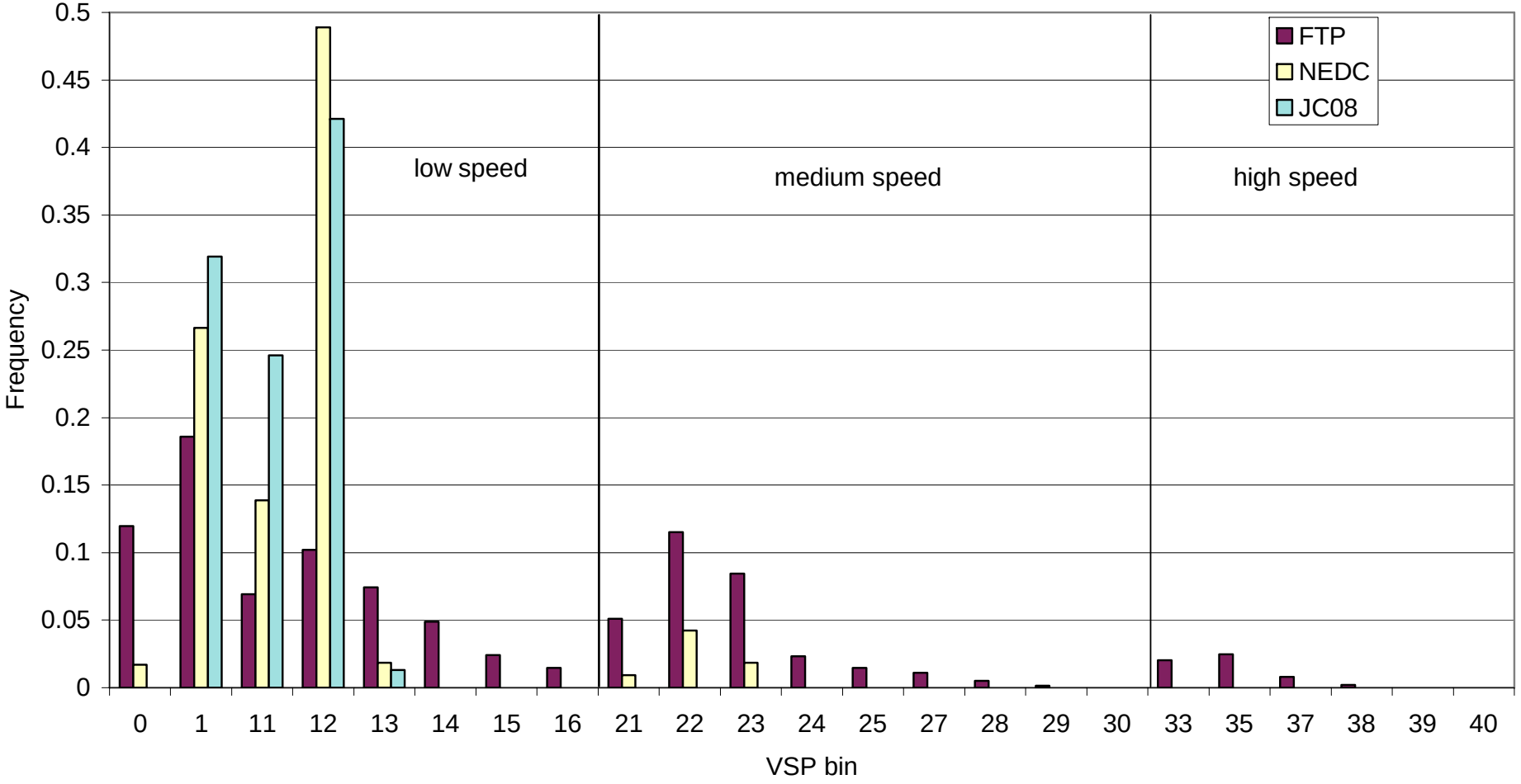
# VSP distribution of FTP, HWY & US06



# 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, 5$^{th}$ wheel, etc.
- Do accelerations matter?
  - Certification tests have x% eror band for drivers to follow cycles
  - But Robot drivers and computer simulations can follow cycles exactly, so the exact cycle trace can matter