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Accident avoidance by active intervention for Intelligent Vehicles


# Cooperative Adaptive Cruise Control (CACC): Combining Sensor and V2V Communication Data to Improve Performance, Driver Acceptance and Highway Capacity

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# Outline

- Limitations of (conventional) sensor-only ACC
- Enhancements from addition of communication
  - Car following accuracy and smoothness
  - String stability
  - Driver confidence
  - Shorter time gaps

- Human factors experiment with naïve drivers
- Driver choices of time gaps
- Simulations of traffic flow impacts

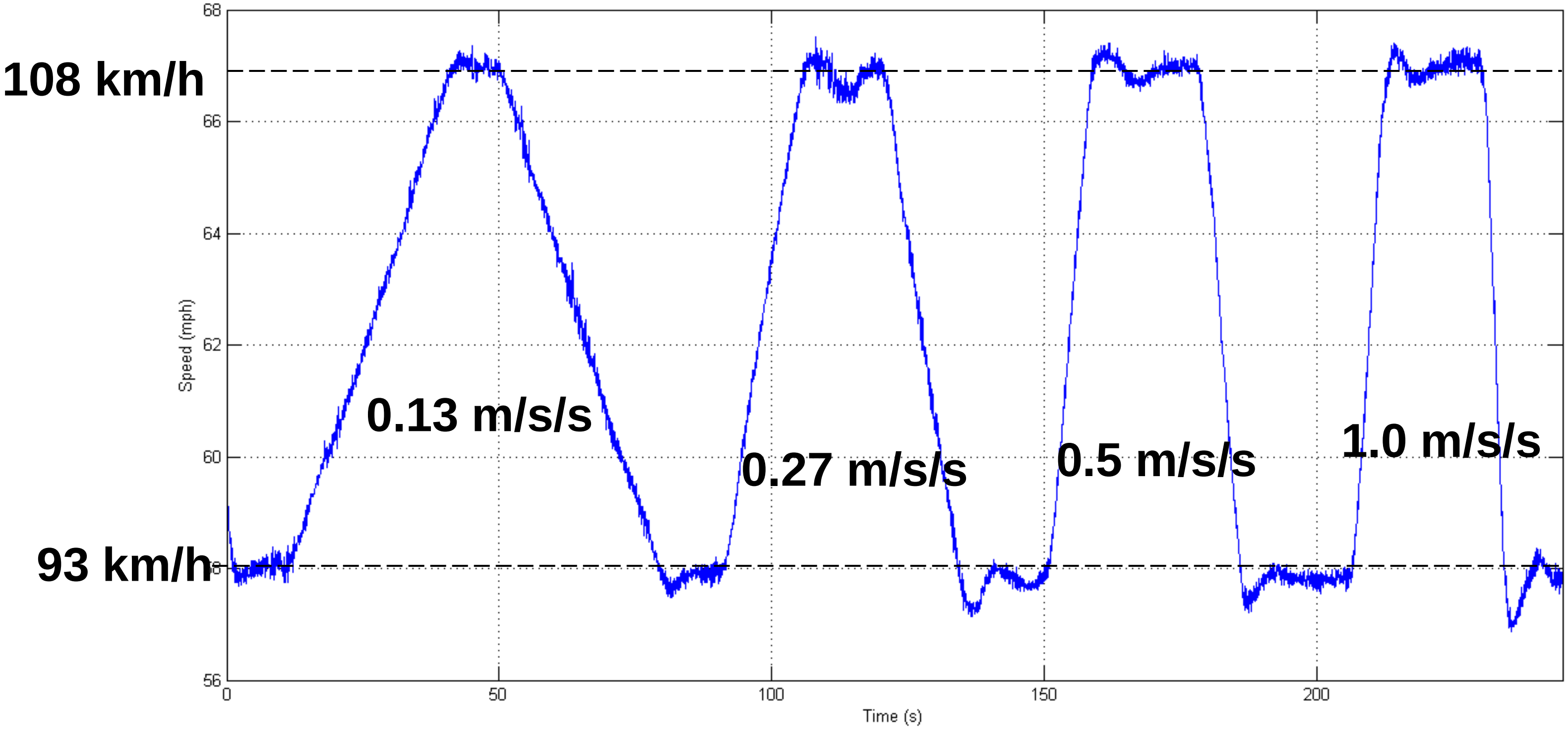
# Limitations of (Sensor-only) Adaptive Cruise Control

- **Can only respond to immediately preceding vehicle (no preview of disturbances further forward)**
- **Sensor range limit (up to ~150 m) insufficient for large traffic speed differences**
- **Delays in target acquisition and release when forward vehicles change lanes**
- **Noisy forward range measurements requiring heavy filtering, introducing response delays**
- **Cannot measure forward vehicle acceleration or deceleration**

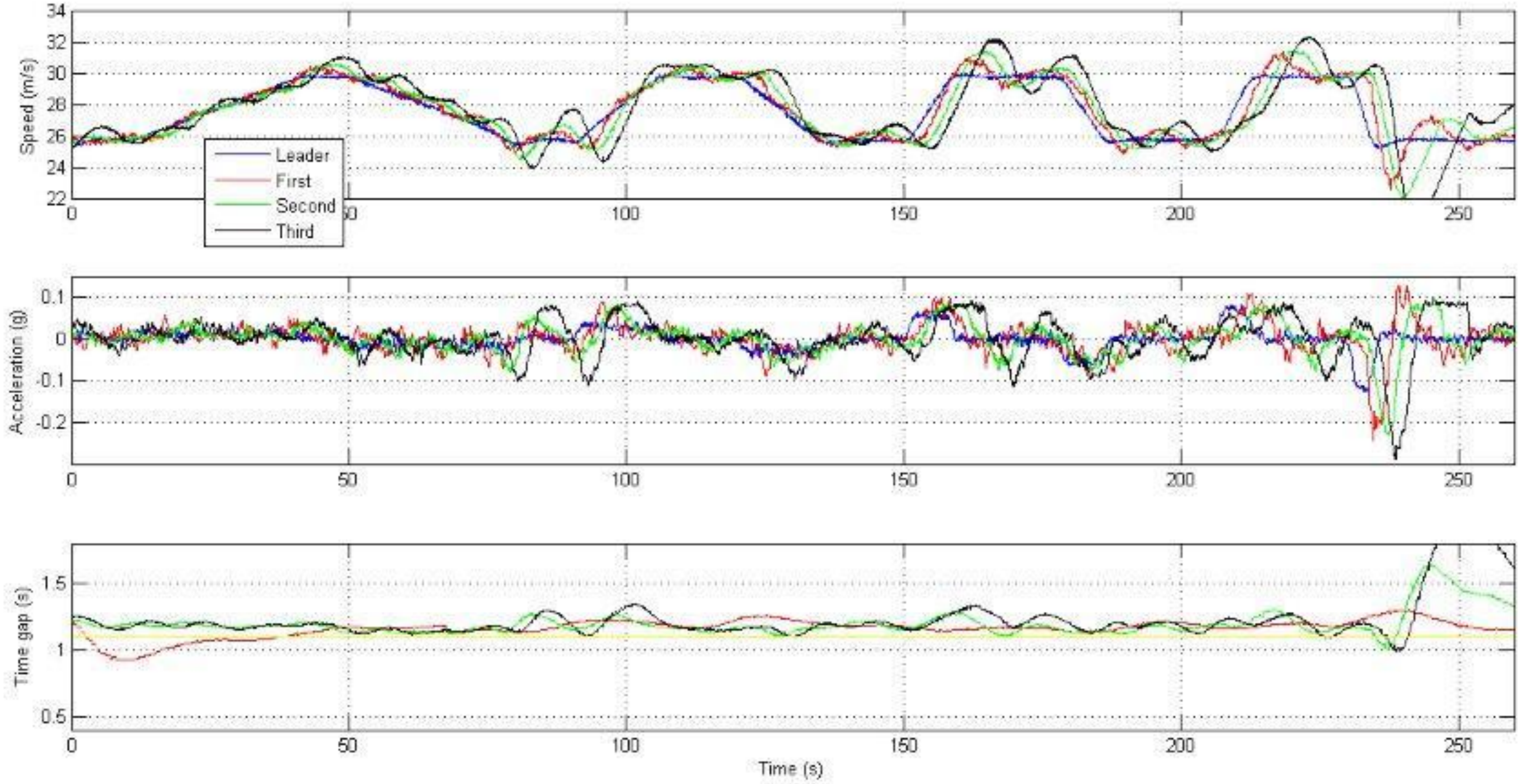
# String Stability Challenges

- **Lack of preview information about vehicles ahead of immediate predecessor**
- **No measurements of predecessor vehicle accelerations**
- **Imperfect measurements of predecessor vehicle speed (at best, only speed *difference* relative to host vehicle)**
- **Measurement lags from filtering to reduce noise (radar glinting off different parts of target vehicle)**
- **Complex interactions when mixing vehicles with widely varying car following behavior**
  - **Smart Traffic Flow Research Consortium experiments in Japan demonstrated problems**

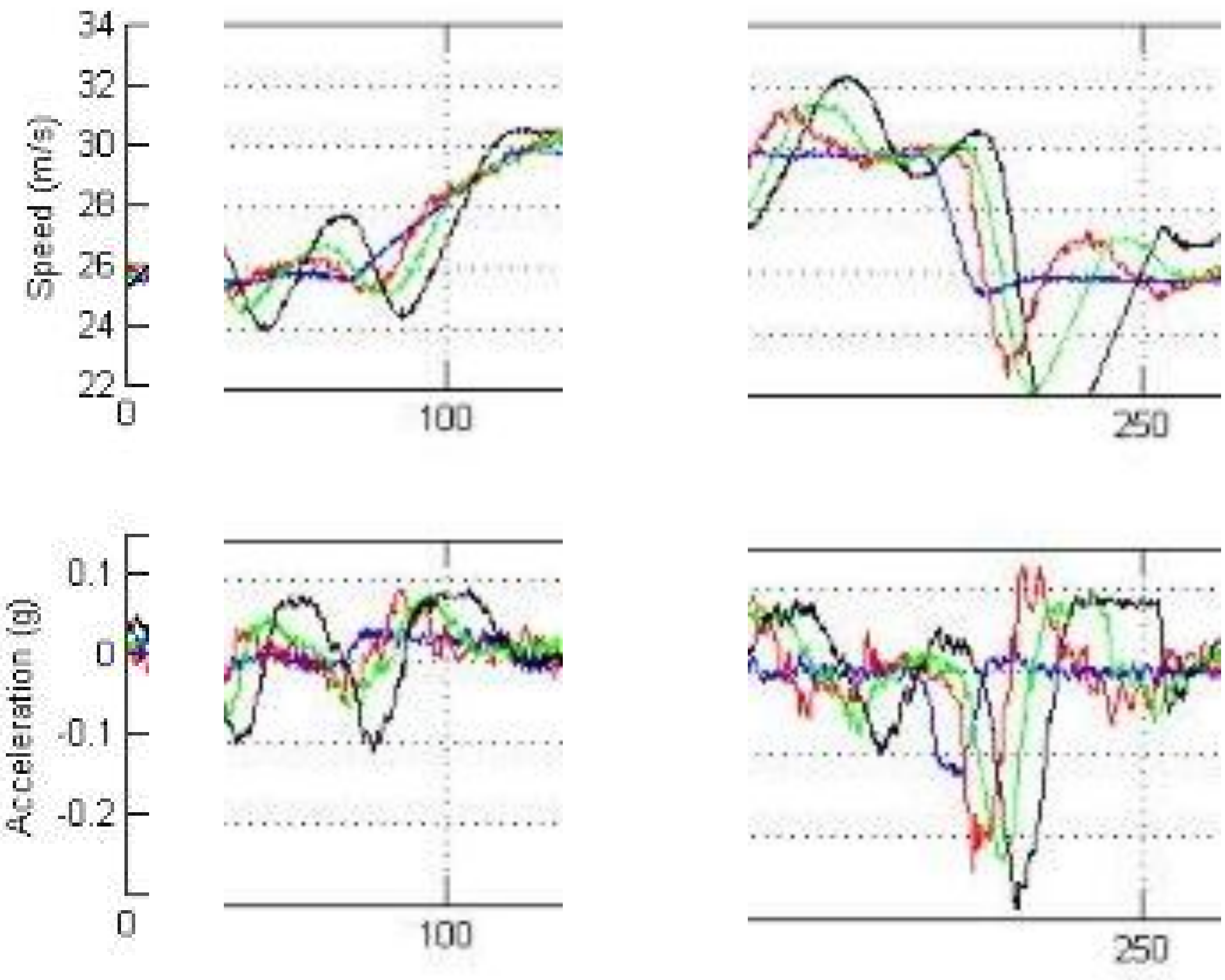
# Test Case:
# Moderate Traffic Speed Changes by Forward Vehicle



# Responses by Standard ACC Cars (3 followers)



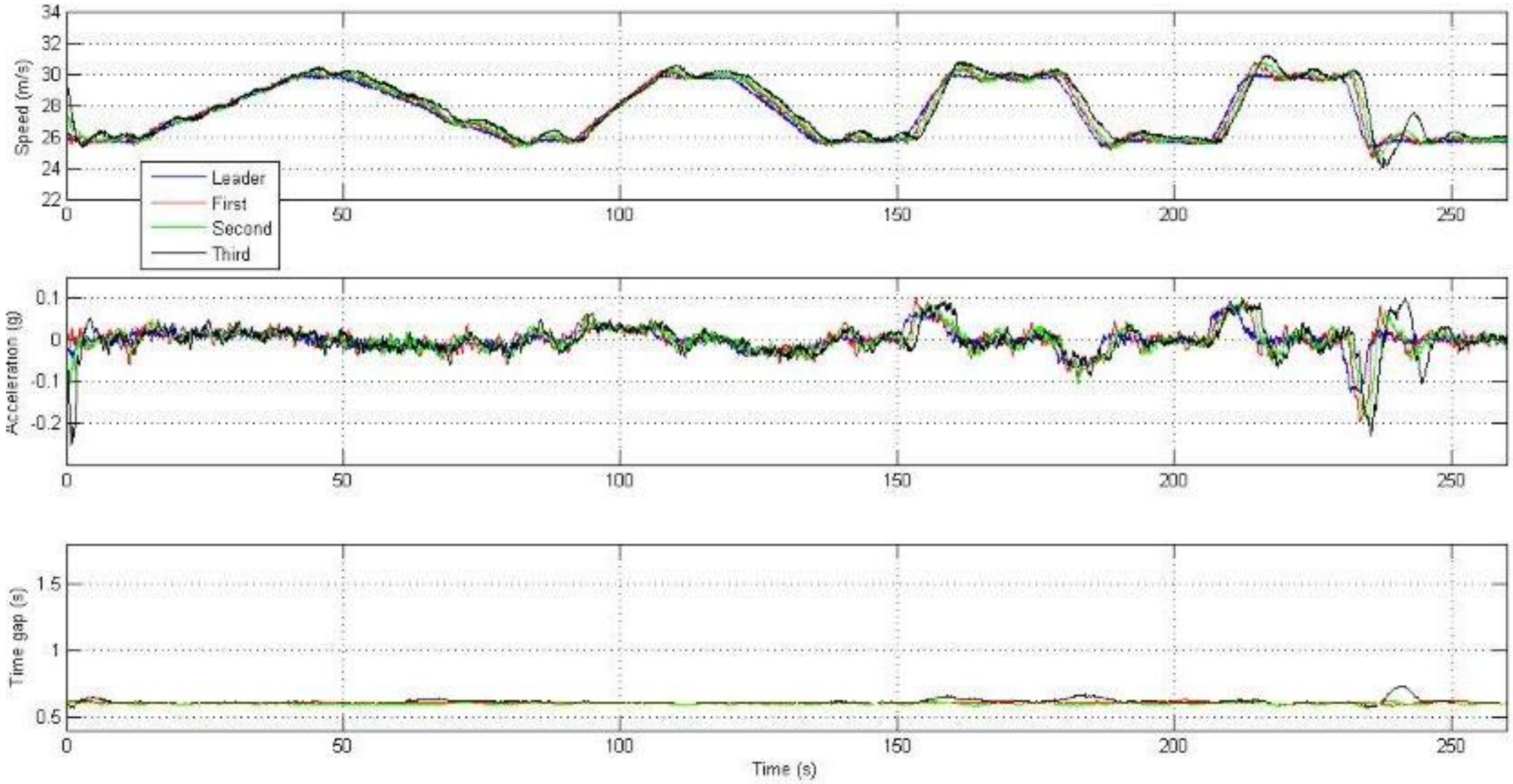
# Zoom in on Transient ACC Responses



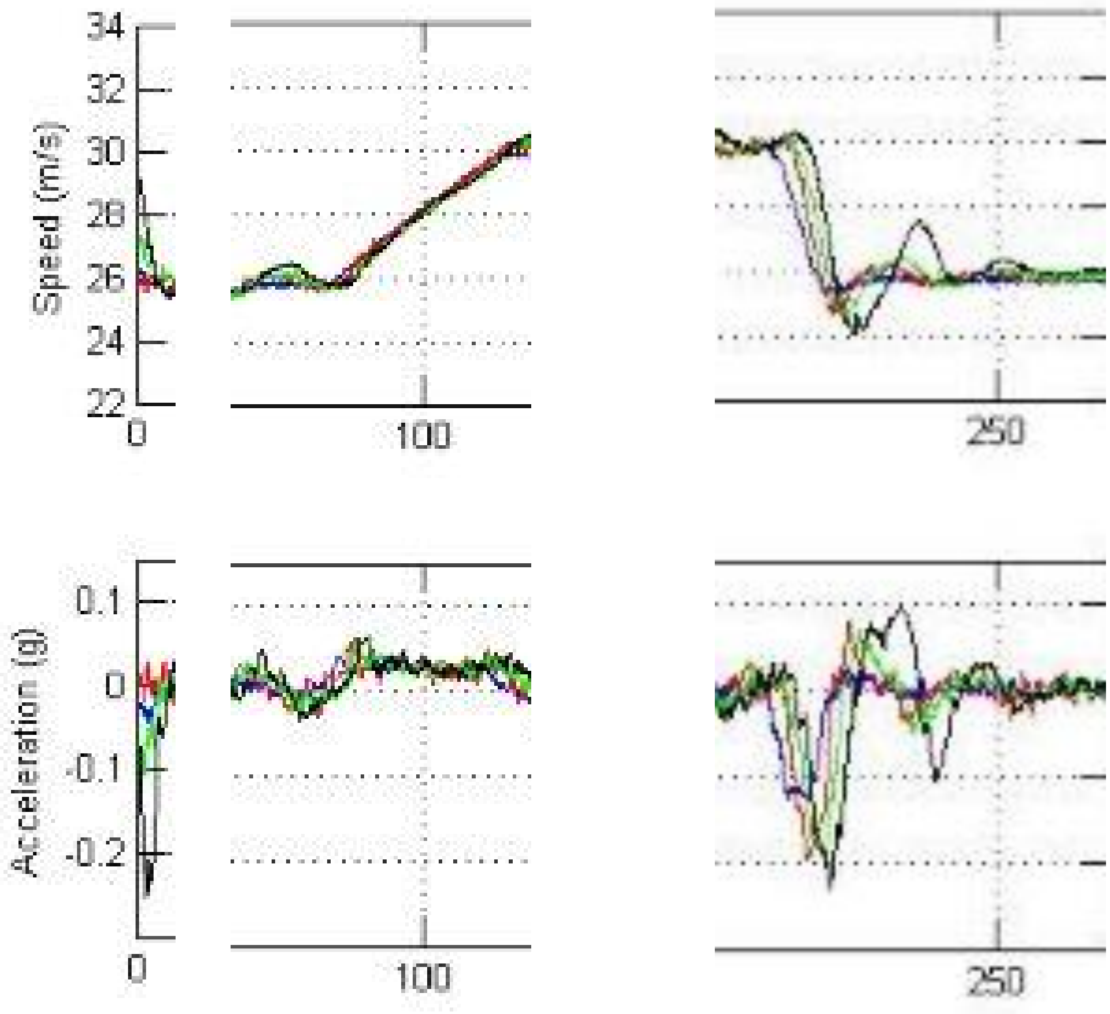
# Cooperative ACC (CACC)

- **V2V cooperation enables higher ACC performance capabilities**
  - Smaller gaps → higher lane capacity and fewer cut-ins
  - Faster response to lead vehicle changes → enhanced traffic flow stability
- **I2V cooperation enables dynamic adjustment to traffic conditions**
  - Change set speed and gap to promote active traffic management goals
  - Reduce speed prior to traffic slow-downs (effectively extending sensor range)

# V2V Cooperative ACC Responses (3 followers)



# Zoom in on Cooperative ACC Transient Responses



# CACC with V2V Cooperation

- **Prior traffic simulations showed that CACC with 0.5 s time gap could double lane capacity**
- **Human factors experiment was conducted to determine driver acceptance of short CACC gaps for daily commute trips**
- **CACC enables car following at gaps of 1.1, 0.9, 0.7 or 0.6 seconds (compared to 2.2, 1.6 or 1.1 seconds with standard ACC)**
- **Results of experiment determined gap values to use in new simulation, predicting achievable lane capacity increases**

# CACC Driving at Four Gap Settings

**1.1 s** **0.9 s**


**0.7 s** **0.6 s**

# Lead Vehicle Braking Transient, 1.1 s Gap

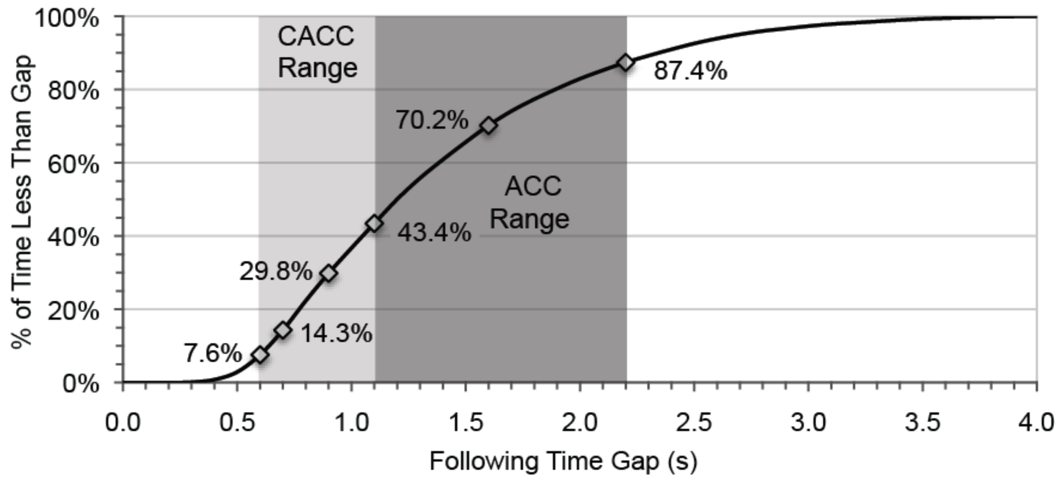
**ACC**

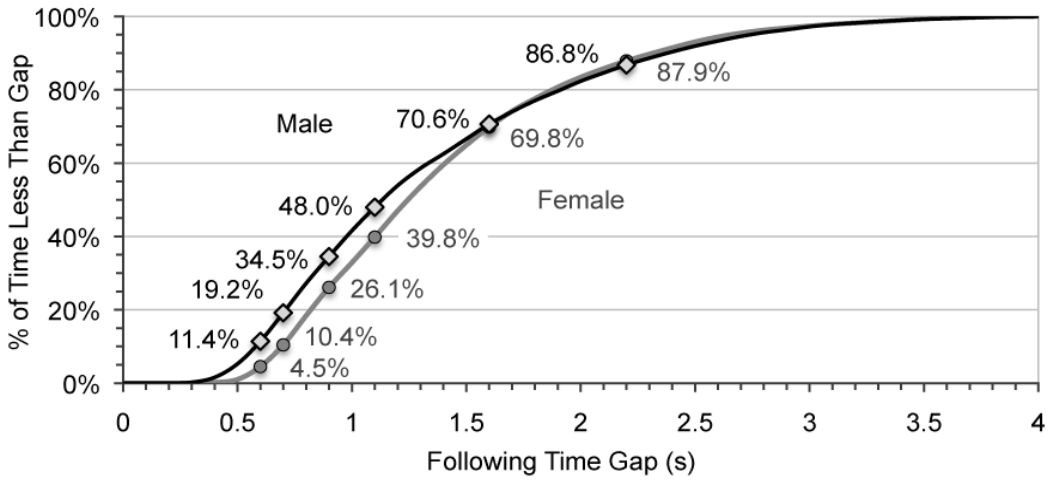
**CACC**

# Human Factors Testing

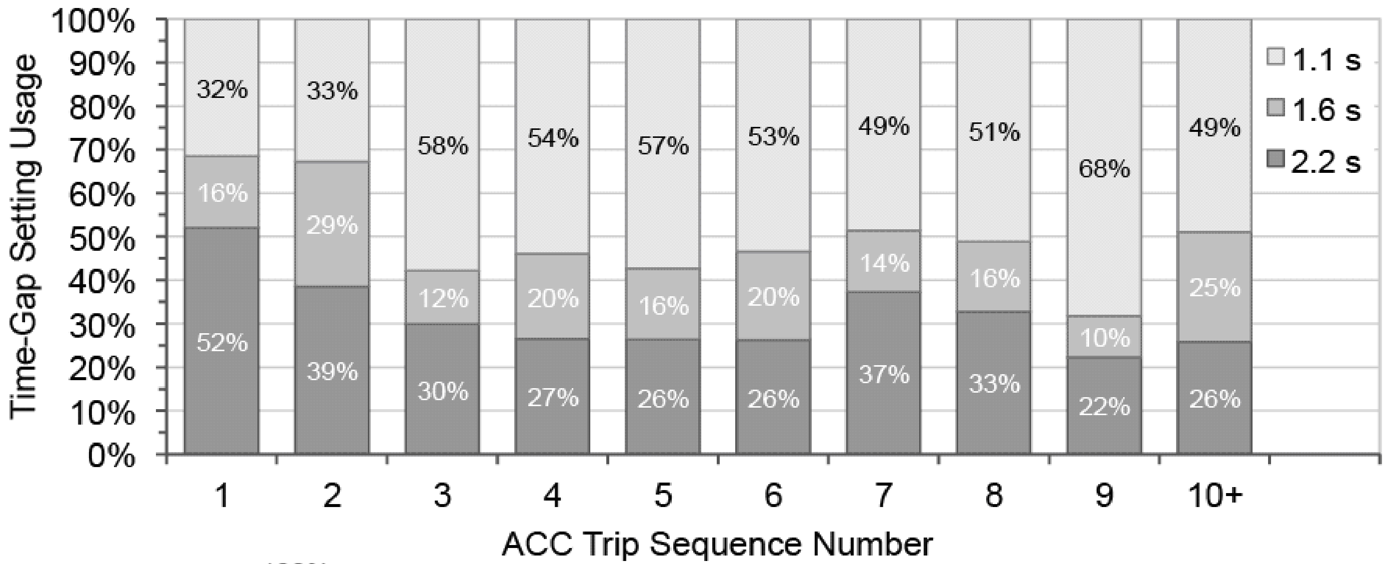
- 16 participants, gender balanced
- Two weeks of driving with unaided baseline, ACC and CACC, focused on daily commute trips
- Drivers choose the gap settings they prefer
- Analysis of results for:
  - Gaps and speeds chosen vs. learning time
  - Gender effect
  - Comparison of ACC and CACC
  - Subjective assessments (surveys)

# Baseline Car Following Behavior

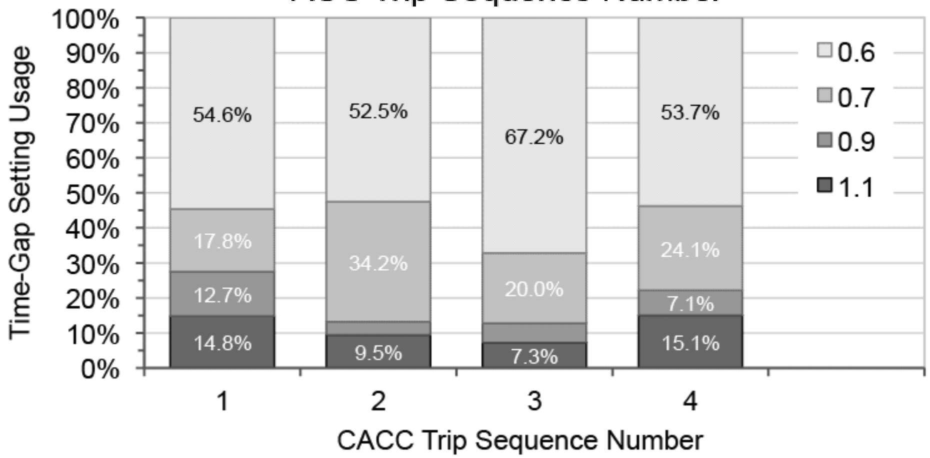


# Time Gaps Chosen as a Function of Experience Using the System




ACC

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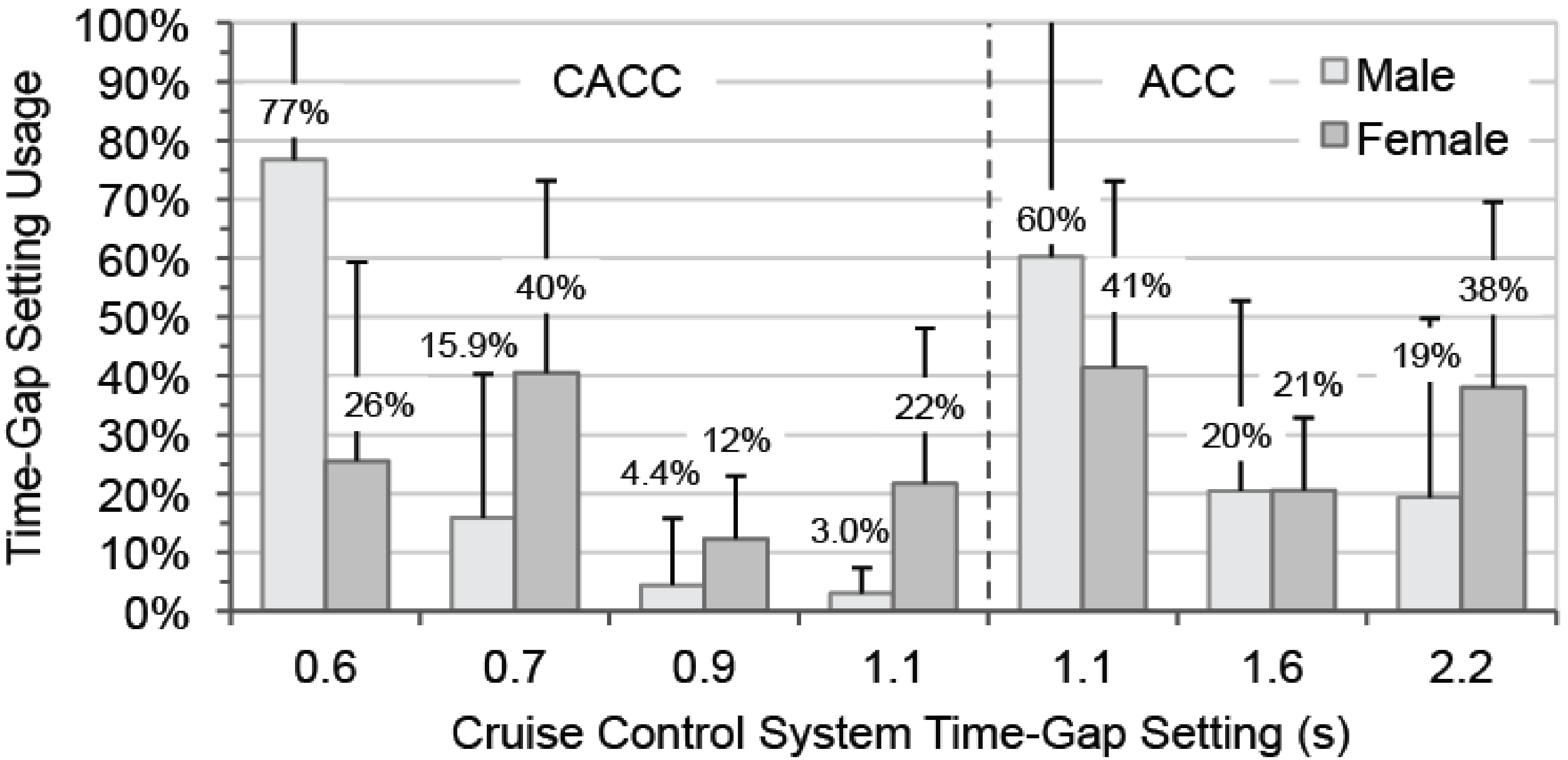
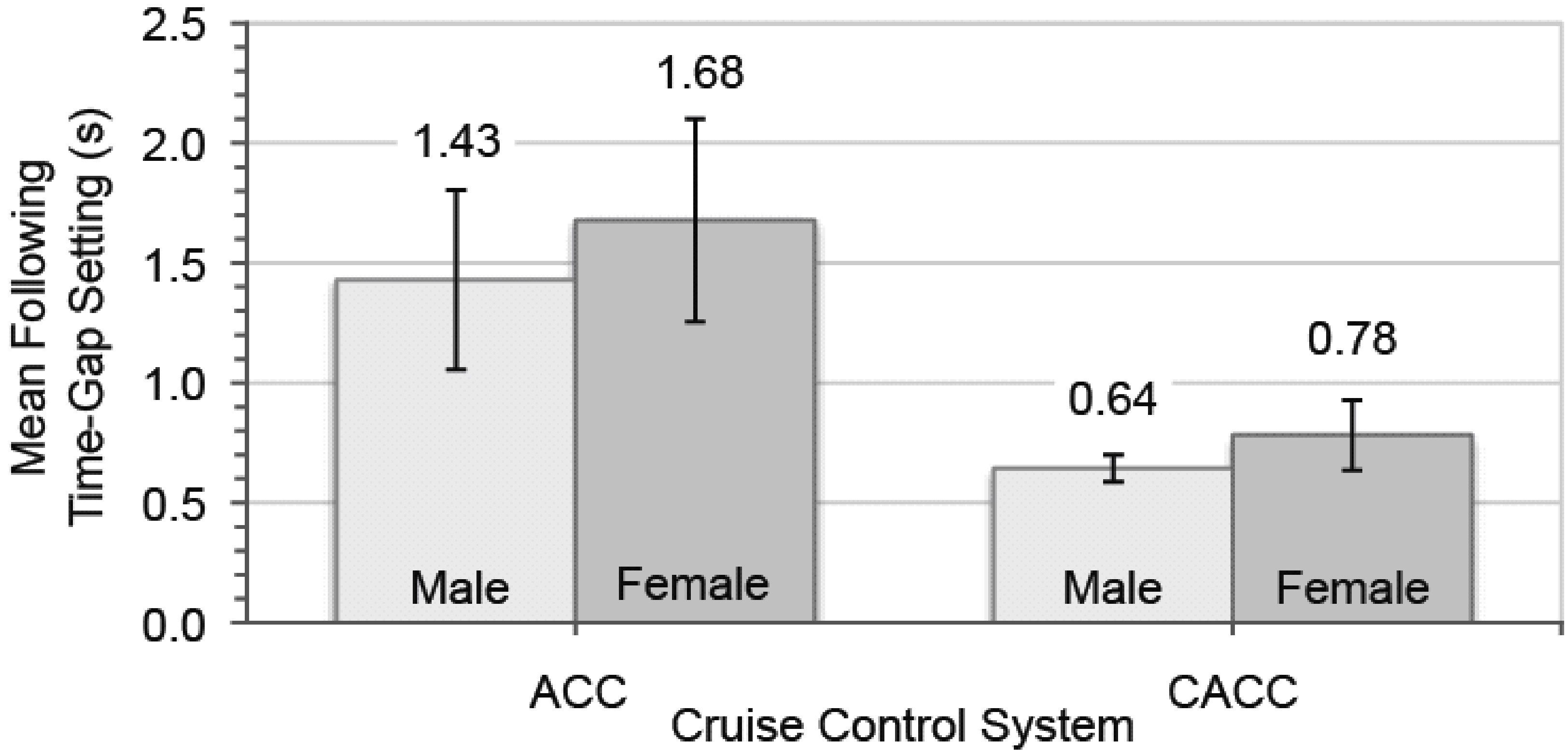
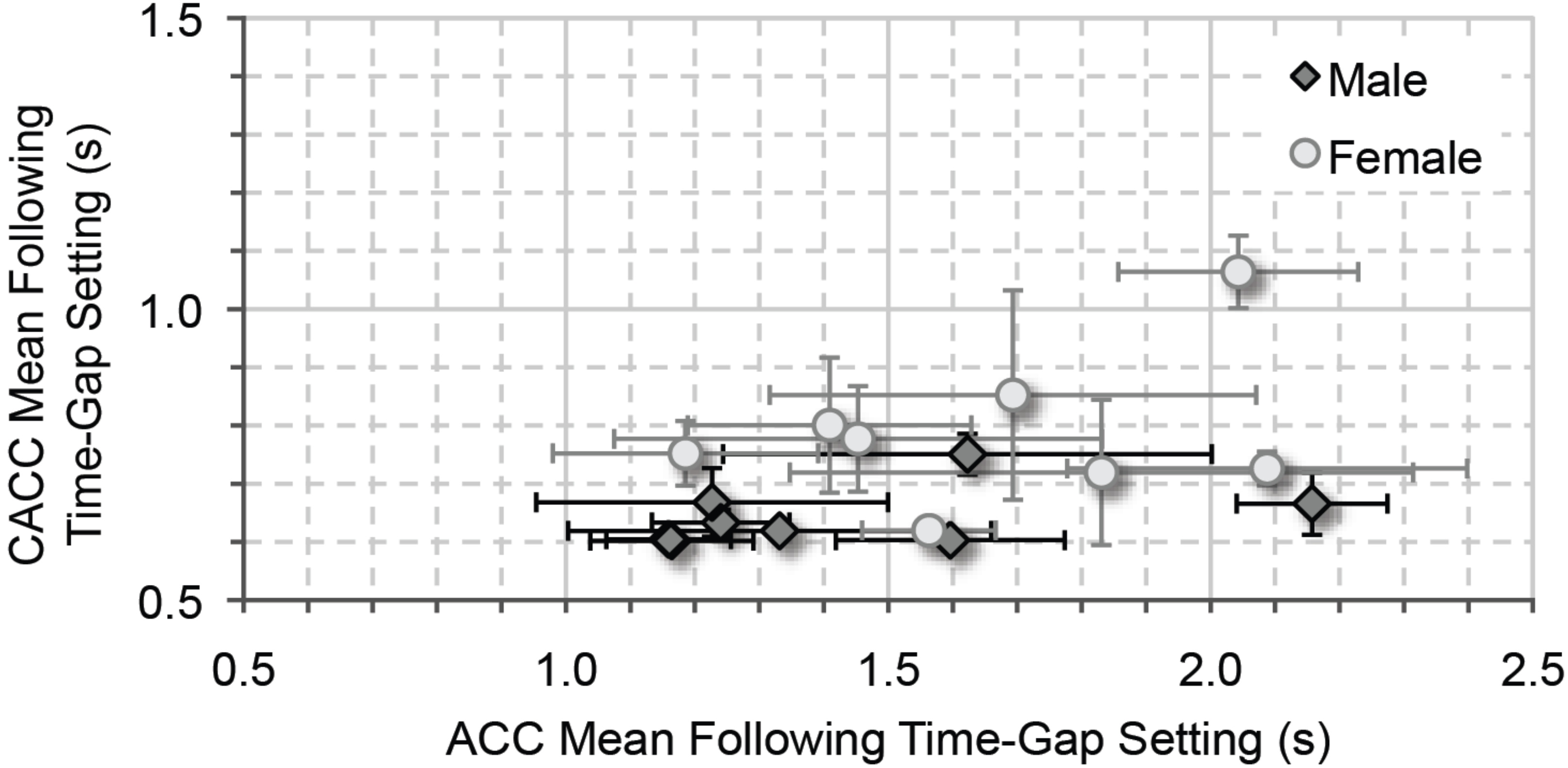
# Distribution of Time Gap Selections



# Mean Time-Gap Preferences in Vehicle Following



# Driver-by-Driver Relationship Between ACC and CACC Gap Selections




(time-weighted usage statistics)

# Driver Survey - Preferences

- **Prefer ACC or CACC?**
  - **2 chose ACC, 8 chose CACC**
- **Which would you rather have?**
  - **2 chose no system**
  - **2 chose ACC**
  - **6 chose CACC**

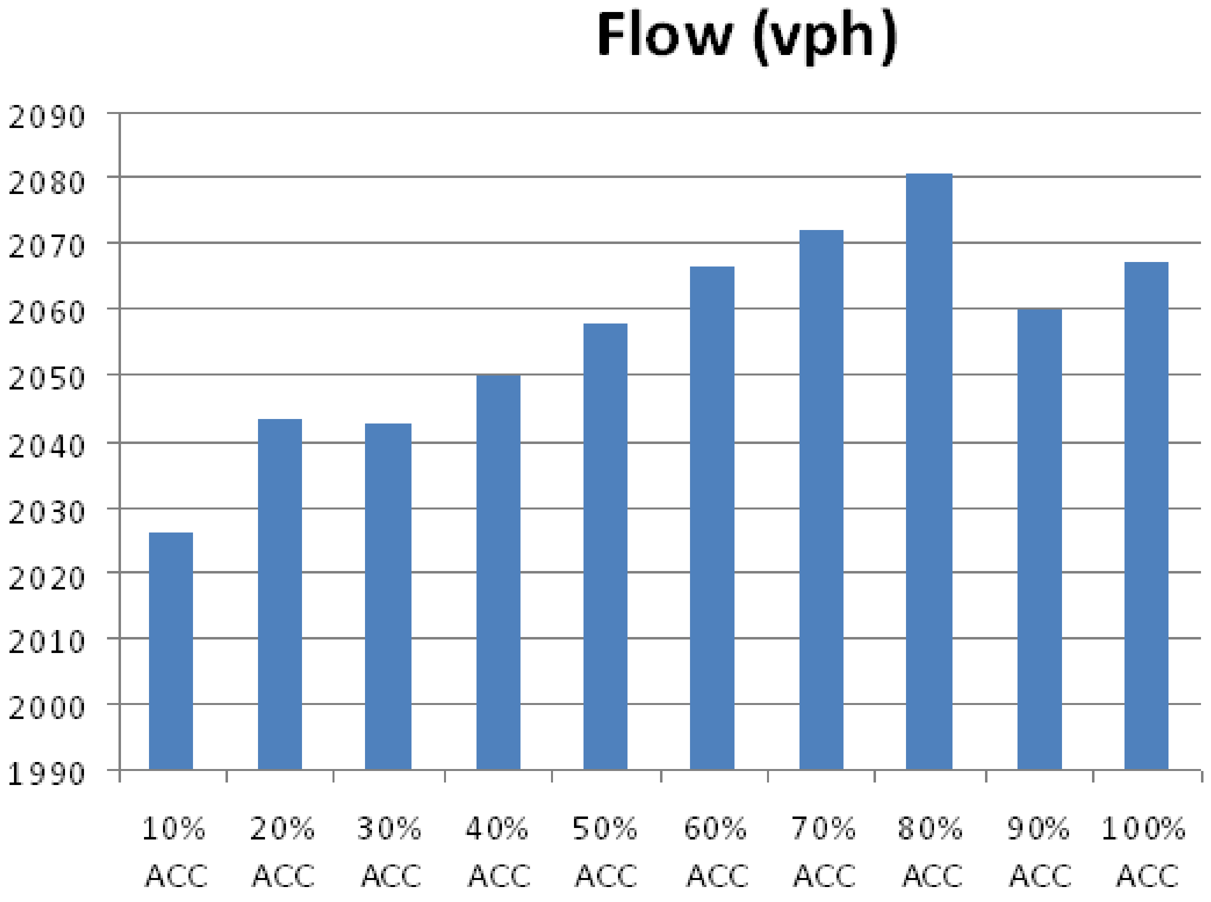
# Implications for Traffic Flow

- **Microscopic freeway simulation study, with varying percentages of vehicles:**
  - **CACC**
  - **ACC**
  - **“Here I am” (Vehicle Awareness Devices)**
  - **Unequipped**
- **Time gap distributions for CACC and ACC vehicles based on experimental findings**
- **State of the art model of driver car following and lane changing (from NGSIM program)**

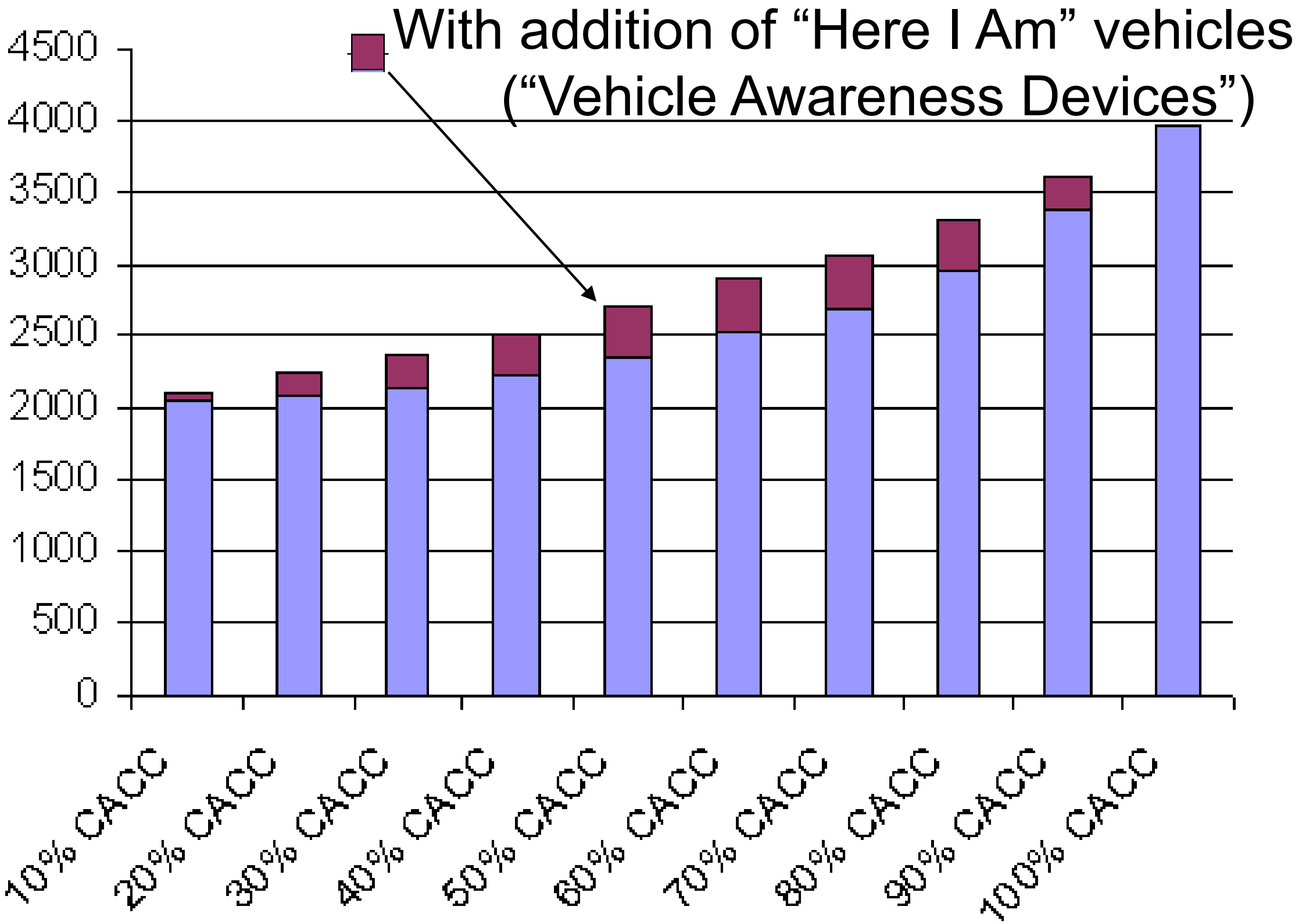
# Prior Literature on ACC Effects on Traffic Flow

- **Highly divergent results reported, based on diverse modeling assumptions about ACC and driver car following behaviors**
- **Some widely-cited papers claim large traffic stability improvements with even small market penetrations of sensor-based ACC**
  - **Over-simplified models by physicists**
  - **ACC car-following logic not based on real ACC behavior, but specifically designed to damp out traffic disturbances**

# Lane Capacity vs. ACC Market Penetration



# Lane Capacity vs. CACC Market Penetration

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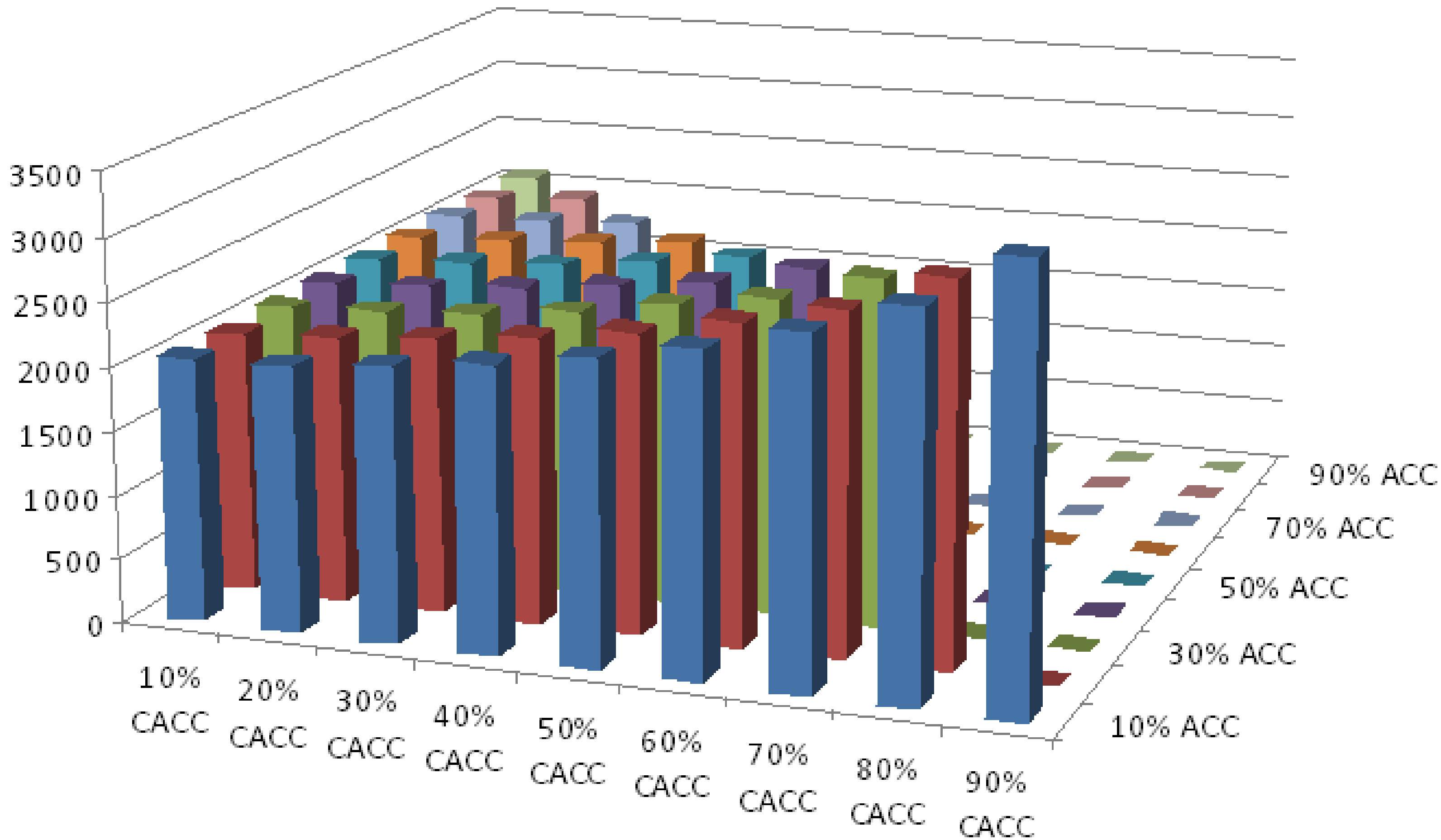
# Lane Capacity with ACC and CACC

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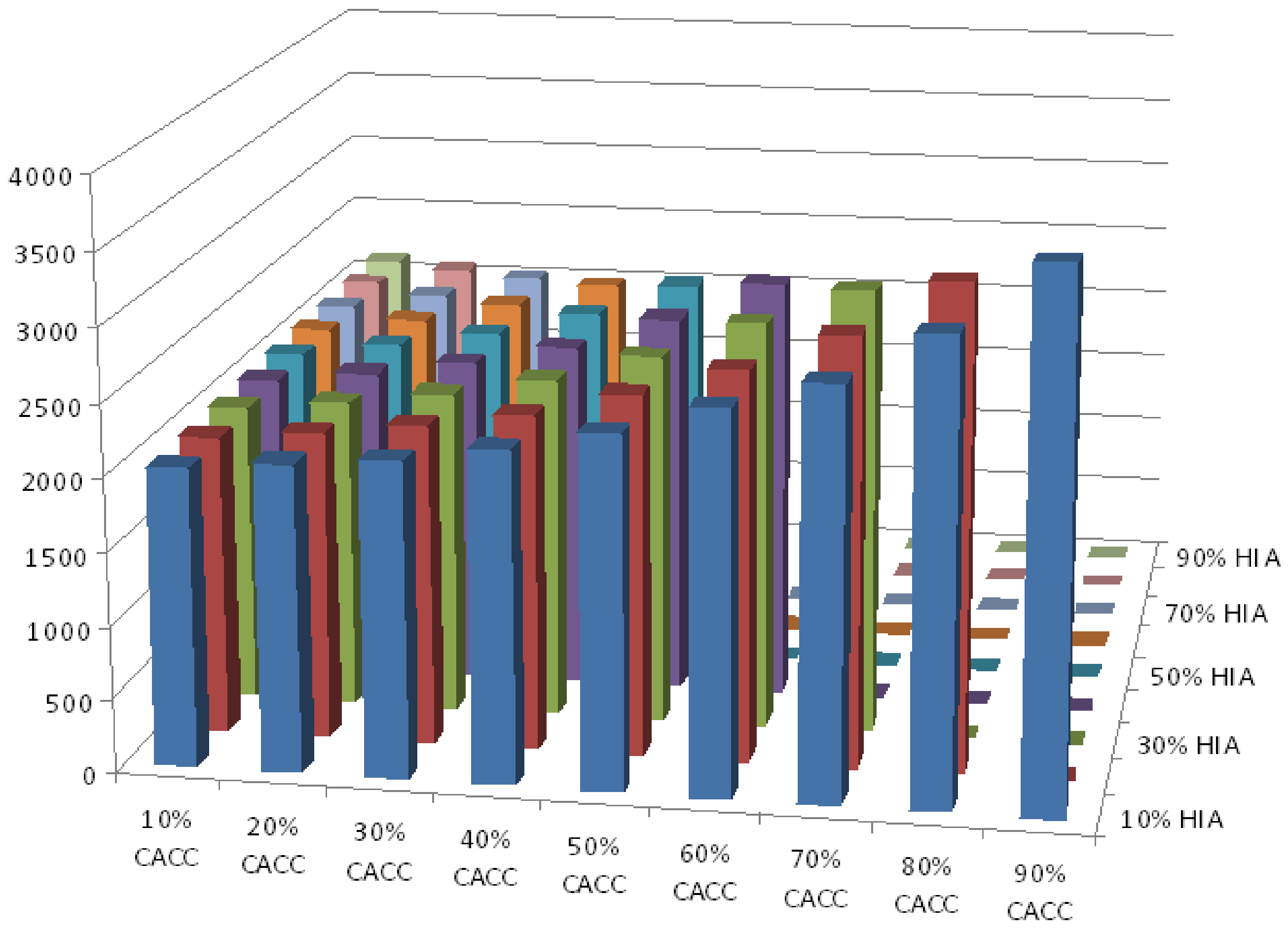
# Lane Capacity for CACC and VAD (HIA)



# Conclusions (1/2)

- Driver reactions to both ACC and CACC were very favorable (auto industry is losing a marketing opportunity)
- Gender differences in baseline car following behavior were maintained and even amplified in ACC and CACC usage
- Drivers liked the shorter gaps enabled by CACC and took advantage of them
- CACC car following gaps averaged ~45% of ACC gaps
- Smoothing of CACC control at mid-point of experiment did not change gap selections

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# Conclusions (2/2)

- Conventional ACC has negligible favorable effect on highway capacity, and may cause string stability problems
- CACC can potentially support up to 4000 vehicles per hour per lane with 100% MP
  - Growth is slow until MP levels are rather high
- VAD communication-enabled vehicles can improve capacity growth moderately at intermediate market penetrations of CACC

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# Thank you.

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