Objective Data Collection

• Relevant vehicle data:
  – Steering angle, lane position, accelerator pedal position, brake pressure, …

• Relevant scenario data:
  – Timing of number reading task, lateral deviation profile/timing, LDW mode, …

• Video Data. Quad-split digital video of the drive:
  1. View of the driver from passenger side B-pillar
  2. The forward view of the driving scene
  3. View of the driver’s face from the DSM
  4. View of the IVIS screen
Methods: Lateral Deviation

- Non-physical “lateral deviation” $Y(t)$
  - A small lateral profile is added to everything except the motion control system
  - Most drivers believe they generated the lane departure

A: Lane width = 3.37m (11 ft)
B: Vehicle width = 2.07m (82 in)
C: Vehicle centered in lane has ~0.65m from vehicle edge to lane edge
Lateral Deviation Example

- **Lateral Deviation**
- **Steering Wheel Angle**
- **Lane Position**
- **Motion Platform Lateral Accel**

Time
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

• SAVE-IT LDWs generated ~1ft past shoulder line
  – Previous VIRTTEX studies have shown that drivers are fairly vigilant for a 20-30 minute drive and rarely go past the shoulder line by more than 1 foot. [Also, see Nuisance warnings below]
  – **Change to system:**
    • Decreased lane width parameter by 0.8 m (+/-0.4 m ⇔ +/- 1.3 ft)
    • LDWs are generated when tire hits shoulder line (vehicle moves 0.65m laterally from center of lane)

• **Nuisance warnings**
  – Elimination of nuisance warnings is a benefit with the adaptive LDW. Drivers will see little difference/benefit without nuisance warnings in non-adaptive mode. Thus, we need to generate nuisance warnings in the non-adaptive condition.
  – **Change to system:**
    • Reduced definition of lane width by +/-0.4 m achieves this.
    • Pilot data indicates that drivers get ~4-5 nuisance warnings in non-adaptive mode
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

• **True positive during adaptive LDW**
  – If the driver isn't registered with correct timing for adaptive LDW mode, then they will not get a true positive during the entire adaptive LDW segment. [Need 2 seconds of distraction, with at least 1 second in lane before departure]
  – Adjusting climate control and VIRTTEX number reading tasks are only tasks where drivers have a good chance of meeting conditions for adaptive LDW
  – **Change to study:**
    • Only the VIRTTEX number reading task is used with lateral deviation
Methods: Lateral Deviation

- Non-physical "lateral deviation" – a small lateral profile is added to everything except the motion control system
  - Most drivers believe they generated the lane departure
  - Parameters adjusted so LDW is generated ~2 seconds into number-reading task (car moves laterally 0.65m)
Methods: Lateral Deviation

- Consequence of timing
  - Not much time after onset of LDW before end of task
  - Likely that driver will be completing task at same time they are reacting to the LDW.
Results: Analysis of Lateral Deviation Events

• Data culling for drivers departing lane to the right
  – Each driver experienced a lateral deviation during both non-adaptive and adaptive LDW modes
    • Start with $N = 40$ possible events for each mode
  – **Non-Adaptive LDW ($N = 37$)**
    • 2 drivers caught the lateral deviation and did not receive a LDW
    • 1 driver caught the lateral deviation, but received a warning by over-correcting (LDW on left side)
  – **Adaptive LDW ($N = 38$)**
    • 1 driver caught the lateral deviation and did not receive a LDW
    • 1 driver caught the lateral deviation, but received a warning by over-correcting (LDW on left side)
    • **Note: 7 drivers departed the lane and did not receive a LDW (more on this later...)**
Results: Analysis of Lateral Deviation Events

- Driver response is onset of steering correction
  - CAMP algorithm used to calculate steering onset
  - All calculated compared to drivers’ videos
  - 7 responses (9%) modified based on comparison of driver video and vehicle data (e.g. “double-steer”)

![Graph showing LDW TYPE = NON-ADAPTIVE with various indices such as latdev*2, laneExcursion*10, swa, swavel/10, swaacc/200, ldw_warn*10, reversal_series, distraction_state, pose_not_fwd*5. The focus is on the steering onset indicated by an arrow.]
Results: Analysis of Lateral Deviation Events

- Response Time: Time from **start of distraction task** until steering onset

Driver’s initial response is after last number is displayed

Only ~25-30% of drivers responded before display of last number.
Results: Analysis of Lateral Deviation Events

- Response Time: Time from **start of distraction task** until steering onset
- ANOVA with pooled errors for
  - Gender
  - All interactions ≥ 2nd order

Data transformed by $y' = y^2$ to meet normality assumptions of ANOVA

**General Linear Model: TR_RT_distract [sec] versus LDW_mode**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDW_mode</td>
<td>fixed</td>
<td>2</td>
<td>0, 1</td>
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</tbody>
</table>

Analysis of Variance for TR_RT_distract [sec], using Adjusted SS for Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
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</thead>
<tbody>
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<td>529.592</td>
<td>529.592</td>
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</table>
Results: Analysis of Lateral Deviation Events

- Response Time: Time from **lane departure** until steering onset

Driver’s initial response is before lane departure (but not enough to overcome lateral deviation)
Results: Analysis of Lateral Deviation Events

- Response Time: Time from lane departure until steering onset
- ANOVA with pooled errors for
  - Gender
  - All interactions ≥ 2nd order

Data transformed by $y' = y^2$ to meet normality assumptions of ANOVA

### General Linear Model: TR_RT_lane_edge_right [sec] versus LDW_mode

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<th>Factor</th>
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<th>Levels</th>
<th>Values</th>
<th>Factor Values</th>
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<td>LDW_mode</td>
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Analysis of Variance for TR_RT_lane_edge_right [sec]_1, using Adjusted SS for Tests

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<th>Adj SS</th>
<th>Adj MS</th>
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</table>
Results: Analysis of Lateral Deviation Events

- Response Time: Time from **LDW** until steering onset
- ANOVA: LDW mode is not statistically significant

The 7 drivers that departed the lane and did not receive a LDW are removed from Adaptive data set (N = 31)

Driver’s initial response is before LDW
Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 6 drivers in Adaptive mode had delayed activation of LDW
  - Delay caused by requirement that Pose Not Forward = 1 for at least 2 sec

The 7 drivers that departed the lane and did not receive a LDW are removed from Adaptive data set (N = 31)
Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 6 drivers in Adaptive mode had activation of LDW past lane edge
  - Delay caused by requirement that **Pose Not Forward** = 1 for at least 2 sec

- Sub 8:
  - Driver starts out near lane edge
  - PNF = 1 near end of 1st number

- Sub 18:
  - Slight steering bias to right as reading numbers
  - PNF = 1 near end of 1st number

- Sub 22:
  - Slight steering bias to right as reading numbers
  - PNF = 1 near end of 1st number

- Sub 31:
  - Slight steering bias to right as reading numbers
  - PNF = 1 near end of 1st number

- Sub 16:
  - PNF = 1 initially, then briefly went to 0 even though driver was still looking down

- Sub 40:
  - Slight steering bias to right as reading numbers
  - PNF = 1 near in 3rd number even though visually distracted at beginning

- 4 drivers: delayed activation caused by 2-second rule

- 2 drivers: delayed activation caused by DSM registration and 2-second rule
Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 7 drivers in Adaptive mode experienced no LDW during lane departure
  - Caused mostly by 2-second distracted rule, and DSM registration issues
    - Sub 3:
      - DSM registration was reasonable
      - Driver looked forward and PNF registered as 0 right before slightly departing the lane
    - Sub 6:
      - Combination of DSM registration, 1-second, and 2-second distracted rules
      - By the time the DSM registered distracted, the driver departed the lane and self-corrected within 2 seconds. Also departed lane ~1sec after PNF = 1.
    - Sub 10:
      - DSM registration issue; driver originally registered as PNF = 1, but then PNF = 0 right before departing lane
    - Sub 11:
      - DSM registration issue; driver registered as PNF = 0; driver rotated head to read numbers
    - Sub 19:
      - DSM registration issue; driver originally registered as PNF = 1
      - Driver then did check-glance; PNF went to 0 and stayed at 0 even after going back to task
    - Sub 34:
      - Combination of DSM registration, 1-second in lane rule
      - By the time the DSM registered distracted, the driver departed the lane in less than 1 sec
    - Sub 39:
      - DSM registration issue; always registered as PNF = 0; driver rotated head to read numbers

- 1 driver: effected by 2-second rule
- 2 drivers: effected by DSM registration
- 4 drivers: effected by DSM registration and 2-second rule
Summary for Driver and LDW system performance

- Difficult to ascertain differences in driver reaction time to lane departure
  - Not much time after lane departure before end of task
  - Most drivers (~70-75%) were completing task at same time they were reacting to the lane departure

- 13 drivers (33%) in Adaptive mode experienced delayed activation of LDW or no LDW
  - 6 drivers experienced delayed activation of LDW
    - Combination of 2-second rule and DSM registration issues
  - 7 drivers never experienced a LDW even though they departed the lane
    - 6 of 7 due at least partly to DSM registration issues
    - 5 of 7 due at least partly to 2-second distracted rule

- Evaluation of Workload Managers is very dependent on system algorithms and parameters
Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 7 drivers in Adaptive mode experienced no LDW during lane departure
  - Caused mostly by 2-second distracted rule, and DSM registration issues
  - Sub 3:
    - DSM registration was reasonable
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    - By the time the DSM registered distracted, the driver departed the lane in less than 1 sec
  - Sub 39:
    - DSM registration issue; always registered as PNF = 0; driver rotated head to read numbers

1 driver: effected by 2-second rule
2 drivers: effected by DSM registration
4 drivers: effected by 2-second rule and DSM registration
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

• **Large variation in lane position at LDW activation**
  - SAVE-IT LDW algorithm appears to use yaw rate and lateral rate as inputs. Although these are likely useful inputs, this will be a confounding variable (i.e. noise) in generating LDWs, and also driver's development of a mental model for adaptive LDW.
  - **Change to system:**
    - Set yaw rate to 0 (CAN message 0x600)
    - Set lateral rate to 0 (CAN message 0x4E2)

• **SAVE-IT LDWs generated ~1ft past shoulder line**
  - Previous VIRTTEX studies have shown that drivers are fairly vigilant for a 20-30 minute drive and rarely go past the shoulder line by more than 1 foot. [Also, see Nuisance warnings issue on next slide]
  - **Change to system:**
    - Decreased lane width parameter by 0.8 m (+/-0.4 m ≈ +/- 1.3 ft) (CAN message 0x4E2).
    - LDWs are generated when tire hits shoulder line (vehicle moves 0.65m laterally from center of lane)
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

• **Nuisance warnings**
  – Elimination of nuisance warnings is a benefit with the adaptive LDW. Drivers will see little difference/benefit without nuisance warnings in non-adaptive mode. Thus, we need to generate nuisance warnings in the non-adaptive condition.
  – **Change to system:**
    • Reduced definition of lane width by +/-0.4 m achieves this.
    • Pilot data indicates that drivers get ~4-5 nuisance warnings in non-adaptive mode

• **Sensitivity of DSM**
  – DSM is not registering drivers as being distracted for most of the tasks. The most reliable tasks for getting "distracted" registrations are adjusting climate control and VIRTTEX number reading.
  – **Change to system:**
    • Delphi re-calibrated DSM
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

• True positive during adaptive LDW
  – If the driver isn't registered with correct timing for adaptive LDW mode, then they will not get a true positive during the entire adaptive LDW segment. [Need 2 seconds of distraction, with at least 1 second in lane before departure]
  – Adjusting climate control and VIRTTEX number reading tasks are only tasks where drivers have a good chance of meeting conditions for adaptive LDW
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