FORD'S USE OF DRIVING SIMULATOR TECHNOLOGY FOR AUTOMATED DRIVING FEATURE DEVELOPMENT

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Technical Leader
VIRTTEX driving simulator
Agenda

- Driving Simulators at Ford
- Driver Research Methods, Levels of Autonomy
- L2, L4 Studies Conducted in VIRTTEX
  - Overview
  - Simulating Automated Driving Features
  - Motion Scaling and Motion Drive Algorithms
  - Examples
Driving Simulators at Ford

Early 1990s → Today

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Driving Simulators at Ford

Static HMI Simulators

Static NVH Simulator
SQ & P/T NVH design/evaluation

Dynamic Driving Simulator (2013)
- Vehicle Dynamics technology exploration and tuning
- Basic ADAS feature reviews
- Suspension studies

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Driving Simulators at Ford

VIRTTEX

VIRtual Test Track EXperiment

Displays
- 360° Field-of-View

Inside VIRTTEX
- Realistic sound cues
- Steering feedback

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<table>
<thead>
<tr>
<th></th>
<th>Acceleration</th>
<th>Velocity</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal/ Lateral</td>
<td>&gt; 0.6g</td>
<td>&gt; 1.2m/s</td>
<td>± 1.6m</td>
</tr>
<tr>
<td>Vertical</td>
<td>1.0g</td>
<td>1.0m/s</td>
<td>± 1.0m</td>
</tr>
<tr>
<td>Pitch/ Roll</td>
<td>&gt; 200deg/s²</td>
<td>&gt; 20deg/s</td>
<td>± 20 deg</td>
</tr>
<tr>
<td>Yaw</td>
<td>&gt; 200deg/s²</td>
<td>&gt; 20deg/s</td>
<td>± 40 deg</td>
</tr>
</tbody>
</table>
Driver Research Methods

- **Naturalistic Data Collection**
  - Sampled People, Real Cars, Real Roads (Focus on *Today*)

- **Field Operational Tests**
  - Sampled People, Modified Cars, Real Roads (Focus on *Tomorrow*)

- **Driving Simulation**
  - Sampled People, Virtual Cars, Virtual Roads (Focus on *Today, Tomorrow and Beyond*)

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Higher

Behavior

Knowledge

Performance

Certainty

Lower
<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Accel</th>
<th>Monitoring</th>
<th>Fallback</th>
<th>Driving Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>• The full-time performance by the human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Drive Assistance</td>
<td>• Driving mode-specific execution by a driver assistance system of <em>either steering or acceleration/deceleration</em> • Human driver performs all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>• Driving mode-specific execution by a driver assistance system of <em>steering and accel/decel</em> • Human driver performs all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>• Driving mode-specific performance by an automated driving system of all aspects of the driving task • <em>Human driver will respond appropriately to a request to intervene</em></td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>• Driving mode-specific performance by an automated driving system of all aspects of the driving task • <em>Even if a human driver does not respond appropriately to a request to intervene</em></td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Many driving modes</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>• Full-time performance by an automated driving system of all aspects of the dynamic driving task <em>under all roadway and environmental conditions</em> that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>

https://en.wikipedia.org/wiki/Autonomous_car
L0-L1 Safety Studies in VIRTTEX

- **Types of studies**
  - Driver distraction
  - Alerts for
    - Lane Departure Warning (LDW)
    - Forward Collision Warning (FCW)
  - Drowsy driver

- **Study Results**
  - Quantitative/Objective data
    - E.g., brake/steer reaction times
  - Subjective data
L2, L4 Studies in VIRTTEX

- **Driver Performance**
  - Driver take-over / re-engagement and Driver Controllability to safety relevant event
    - External event (example: surprise forward collision event)
    - AV system event (example: sub-system fault)
  - **Distraction Mitigation** – Keeping drivers in the loop

- **Comprehension**
  - Driver take-over / re-engagement for L2 strategy
  - **Situational Awareness** – How much information should be presented to the driver...
    - ... about the driving environment?
    - ... about what the vehicle senses?
## Various techniques to simulate Automated Driving Features

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Ford-specific models (MIL)</td>
<td>• Use (Simulink) model that is planned for the Feature</td>
<td>• Model often not fully developed/debugged</td>
</tr>
<tr>
<td>“Autonomous mode” in scenario simulation software</td>
<td>• Use when general AV/ADAS capability is needed</td>
<td>• Can require “tuning”, particularly with motion-based simulators</td>
</tr>
<tr>
<td>Playback of a recorded drive</td>
<td>• Use when existing simulation technology doesn’t exist, or</td>
<td>• Can require many recording to get the one that is “just right”</td>
</tr>
<tr>
<td></td>
<td>• When a simulator driver can create a drive that will feel realistic and stay within the motion system capabilities.</td>
<td></td>
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Motion Scale

- Motion scale must match the scenario under test
  - Lateral motion generally scaled above 50%
    - Driver can feel Feature Lateral Control (e.g., lane-keeping)
    - Driver Lateral Control is more realistic [e.g., DSC-NA 2001 “The Effect of Lateral Motion Cues During Simulated Driving”, Greenberg, Artz, Cathey]
  - Longitude motion generally scaled above 40%
    - Driver can feel Feature Longitude Control (e.g., headway maintenance)
    - Driver Longitude Control is challenging (next slide)
- Classical Motion Drive Algorithm for longitude
- $K_x = \text{scale factor applied to specific force}$
  - Typically reduced to contain expected worst-case longitudinal motion
Motion Scale: Mixed Longitudinal Scaling

- **Example: Automated Driver Feature and Driver Mixed With Driver Braking**
  - Automated Feature typically < 0.1 g
  - Driver braking typically > 0.3 g for 1-2 seconds

- **Conflicting Goals:**
  1. Minimize motion scaling for Driver braking (Minimize motion limiting)
  2. Maximize motion scaling for Feature (Feel headway maintenance)

- **Typical global longitudinal scaling in VIRTTEX is < 0.2 for sustained, hard braking**
  - Goal (1) is met; no motion limiting.
  - Goal (2) is not met. Driver experiences < 0.02 g
Motion Scale: Mixed Longitudinal Scaling

- **Solutions: Different Scales for Driver and Feature**
  1. [E.g., DSC 2008 “Motion control techniques for subjective testing in motion-based driving simulators,” Blommer, Greenberg]
  2. \( \text{Scale} = \text{FeatureScale} \times \text{FeatureOn} + \text{DriverScale} \times [1 - \text{FeatureOn}] \)

- **Example:**

  ![Graph showing motion scale examples]
  - Manual Driving: DriverScale = 0.17
  - Automated Feature: FeatureScale = 0.6
Common Characteristics Across Studies

- **Representative driving conditions**
  - Interstate driving, 60-70mph
  - Suburban/Rural driving, 35/55 mph

- **For Driver Performance Studies: Use alternate reason for study purpose.**
  - Don’t tell participant about safety-critical event

- **Secondary Task (Distraction Task):**
  - Visual distractions
  - Manual-visual distractions (e.g., tablet games)

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Common Characteristics Across AV Studies

- **Scenario is designed to expose drivers to representative motion, visuals, sounds, etc**
  - Example: Motion deceleration/acceleration as adapting to lead vehicle speeds
  - Driver Performance Studies: Scenario of safety-critical event looks similar to earlier parts of the drive

- **Study minimally-trained drivers**
  - Trained on general operation of system both before drive, and first part of the drive.
  - No training or description of critical take-over / re-engagement systems
  - Driver’s typically experience one safety-critical event at end of the drive. Can only surprise drivers once!!
L2 Driver re-engagement to a surprise, safety-critical event

Study Factors
- Automated Driving Feature strategy
- Secondary tasks

Measurements
- Eyes-off-road times
- Driver response time

Key simulation methods
- Automation simulated by combination of Ford-specific and Scenario software
- Mixed longitudinal scaling
  - Automated Driving Feature provides initial deceleration cue at onset of safety-critical event
  - Driver response likely to have large deceleration
Host vehicle in right lane, approaches guardrail and Jersey barriers (1-3)

System fault triggered while vehicle has Jersey barriers near the shoulder line (3).

**NOTE:** Guardrail and Jersey barrier appear earlier in the drive with no system fault.

**Key simulation methods**

- Automation simulated by combination of Ford-specific and Scenario software
- Key Simulator motions === Key Vehicle motions
  - lateral kinematics, steering wheel angle, etc
Example: Trust in Automation as function of Situational Awareness Displays in L4

Key simulation methods

- Automation simulated by playback of recorded drive
  - Multiple starts/stops, lane changes
- Scenario was deterministic
Thank You