Mental Models in Automated Vehicles: Conceptual and Methodological Issues

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Agenda

• Mental Models in ADS - Overview

• Mental Models in ADS - Key Topics

• Implications for Measuring Mental Models

• What’s Next? An Overview of On-Going Research
Mental Models in ADS-Overview

• What are Mental Models?

• Why are Mental Models important for ADS?

• What types of Mental Models are relevant?
Key Topic: Automation Levels & Mental Models

• There are 3 features of ADS that are particularly challenging for the development and maintenance of Mental Models:

1. The changing role of the driver
2. Uncertainties about driver information needs
3. Abrupt transitions between manual & automated vehicle control
Key Topic: Level 2 and Level 3 Change the Role of the Driver

Active Operator  →  Passive Supervisor
Key Topic: Uncertainties about Driver Information Needs

SAE J3016™ LEVELS OF DRIVING AUTOMATION

What does the human in the driver's seat have to do?

- **SAE LEVEL 0**: You are driving wherever these driver support features are engaged – even if your feet are off the pedals and you are not steering.
- **SAE LEVEL 1**: You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety.
- **SAE LEVEL 2**: You are not driving when these automated driving features are engaged – even if you are seated in “the driver’s seat.”
- **SAE LEVEL 3**: When the feature requests, you must drive.
- **SAE LEVEL 4**: These automated driving features will not require you to take over driving.
- **SAE LEVEL 5**: These automated driving features can drive the vehicle under all conditions.

What do these features do?

**Example Features**

- **SAE LEVEL 0**
  - These features are limited to providing warnings and momentary assistance.
  - Example: automatic emergency braking, blind spot warning, lane departure warning.

- **SAE LEVEL 1**
  - These features provide steering or brake/acceleration support to the driver.
  - Example: lane centering OR adaptive cruise control.

- **SAE LEVEL 2**
  - These features provide steering AND brake/acceleration support to the driver.
  - Example: lane centering AND adaptive cruise control at the same time.

- **SAE LEVEL 3**
  - These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met.
  - Example: traffic jam chauffeur.

- **SAE LEVEL 4**
  - These features can drive the vehicle under all conditions.
  - Example: local driveless taxi, pedals/steering wheel may or may not be installed.

- **SAE LEVEL 5**
  - Same as level 4, but feature can drive everywhere in all conditions.
Key Topic: Uncertainties about Driver Information Needs

You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety.
Key Topic: Transitions and Mental Models

• Functionally-accurate mental models can help drivers anticipate situations or conditions that require a transition.

• Transitions can happen with very little warning and at times when the driver’s ability to respond is low.

• If they reflect limitations or failures of the ADS, the driver may not know how to recover.
Key Topic: The Role of the HMI

• The Human-Machine Interface (HMI) is the primary means by which the system communicates to the driver.

• Considerable research is available to support basic design requirements for the HMI

• The challenges presented by ADS require new approaches to conceptualizing and developing next-generation HMIs
Implications for Measuring Mental Models

• Study multiple mental models beyond just system understanding:
  • Basic operation
  • Driver behaviors
  • Vehicle behaviors

• Test mental models repeatedly; they change to reflect:
  • Information (e.g., training)
  • Feedback (from the HMI)
  • Experience (system operation when facing system limitations and failures)

• Measure mental models using a range of techniques:
  • Subjective measures; e.g., questionnaires or focus groups
  • Gaze behavior
  • Driver interactions with the HMI
  • Driver willingness to engage in secondary tasks
  • Driver responses to alerts/failures/transitions
A Conceptual Framework

- Mental Models
  - Short-term and long-term
  - Includes understanding and expectations

- Initial Experience/Exposure to the Vehicle
  - Driver Factors

- TRUST

- Attitudes and Behaviors
  - Vigilence
  - Engagement
  - Secondary tasks

- Safety-Relevant Outcomes
  - Readiness to respond
  - Situation awareness
  - Attention to conditions

ADS Design, including the HMI

Experience with the ADS
What’s Next? An Overview of On-Going Research

Conducting a NHTSA-funded project to support vehicle safety research by examining issues relating to:

1. The relationship between drivers’ mental models of ADS
2. How mental models impact the development of appropriate versus inappropriate trust in ADS.
Simulator Studies

• Series of driving simulator studies with type of instruction and critical events as key independent variables. Texting task used as a non-driving-related task.
Independent Variable 1 = Instruction Type to Manipulate the Mental Model

1. Basic Instruction:
   • How to engage/disengage the system
   • Review of status icons on the HMI
   • Very basic system operation information

2. Detailed Instruction:
   • Basic information plus video with:
     • Detailed description of system capabilities and limitations.
     • Specific scenarios/examples that they will encounter while driving and how the system will respond to them.
Independent Variable 2 = Event Type

1. **Limitation:** Scenarios that can be resolved without driver intervention. Triggers Uncertainty Alert (orange icon + simple tone) (6 scenarios)

<table>
<thead>
<tr>
<th>Segment Type</th>
<th>HMI/System Response</th>
<th>Specific Scenario</th>
<th>Segment Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-Up</td>
<td>Normal operation</td>
<td>Merge onto highway from right shoulder</td>
<td>M1</td>
</tr>
<tr>
<td>Normal Driving</td>
<td>Normal operation once activated</td>
<td>Driving, no events</td>
<td>ND</td>
</tr>
<tr>
<td>Limitation</td>
<td>Uncertainty Alert to normal operation</td>
<td>Degraded lane markings</td>
<td>LK_Lim1</td>
</tr>
<tr>
<td>Limitation</td>
<td>Uncertainty Alert to normal operation</td>
<td>Stopped vehicle with hazard lights</td>
<td>FW_Lim1</td>
</tr>
<tr>
<td>Failure</td>
<td>Uncertainty Alert to Request to Intervene</td>
<td>Tunnel</td>
<td>LK_Fail2</td>
</tr>
<tr>
<td>Failure</td>
<td>Uncertainty Alert to Request to Intervene</td>
<td>Construction zone with lane drop</td>
<td>FW_Fail2</td>
</tr>
</tbody>
</table>

2. **Failure:** Scenarios that require driver intervention. Triggers Uncertainty Alert (orange icon + simple tone), then Request to Intervene (red icon + repeating tone) (4 scenarios)
# HMI – Basic Status Icons

<table>
<thead>
<tr>
<th>ADS System Activity Associated with Driver Instrument Display Icon</th>
<th>Icon, Color, and File Name</th>
</tr>
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<tbody>
<tr>
<td>ADS on Stand-by. ADS interruption (will revert to standby until activation requirements are met again).</td>
<td>![White Icon]</td>
</tr>
<tr>
<td>ADS on and active. Pressing the ADS button activates the ADS. <em>A brief tone and the change of icon color to green provides feedback.</em></td>
<td>![Green Icon]</td>
</tr>
<tr>
<td>ADS is on and active, but environment conditions have triggered an Uncertainty Alert.</td>
<td>![Orange Icon]</td>
</tr>
<tr>
<td>ADS is on and active, but environmental conditions have triggered a Request to Intervene.</td>
<td>![Red Icon]</td>
</tr>
</tbody>
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## Examples of Measures and Variables

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<th>MEASURES</th>
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<td><strong>Understanding of system capabilities</strong></td>
<td>Knowledge before/after experience using the system</td>
<td>Accuracy scores for questions pertaining to operator behavior in given scenarios on the Mental Models questionnaire</td>
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<tr>
<td><strong>Understanding of automation level</strong></td>
<td>Knowledge before/after experience using the system</td>
<td>Accuracy scores for questions pertaining to vehicle behavior in given scenarios on the Mental Models questionnaire</td>
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<td><strong>Effect of training on behavior</strong></td>
<td>Changes in understanding of system use, capabilities, and automation level by level of training</td>
<td>Change in accuracy on the Mental Models questionnaire between 1st and 2nd administration for Basic Instruction and Detailed Instruction groups</td>
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<td><strong>Locus of control</strong></td>
<td>Willingness to engage in NDRT (texting task)</td>
<td>Percentage of total fixations looking away from roadway while automation is engaged</td>
</tr>
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<td></td>
<td>Willingness to allow an automated driving system to control the driving task</td>
<td>Time elapsed between automatic system disengagement following Request to Intervene (RTI), and system re-engagement by the participant</td>
</tr>
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<td>Visual monitoring of roadway environment and vehicle behavior</td>
<td>Percentage of total fixations to driving-related ROIs under Normal Driving and Limitation scenarios</td>
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<td><strong>Self-reported trust</strong></td>
<td>Difference in self-reported trust of the automated system between initial training and end of study</td>
<td>Difference in Likert scores selected for questions relevant to trust in automation presented on a self-report trust questionnaire after driving task, compared to scores selected after initial driving task</td>
</tr>
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<td>Self-reported trust</td>
<td>Coding of spontaneous commentary by participants relevant to their feelings of trust in the automated system</td>
</tr>
</tbody>
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Contact Info

• Thank You

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