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

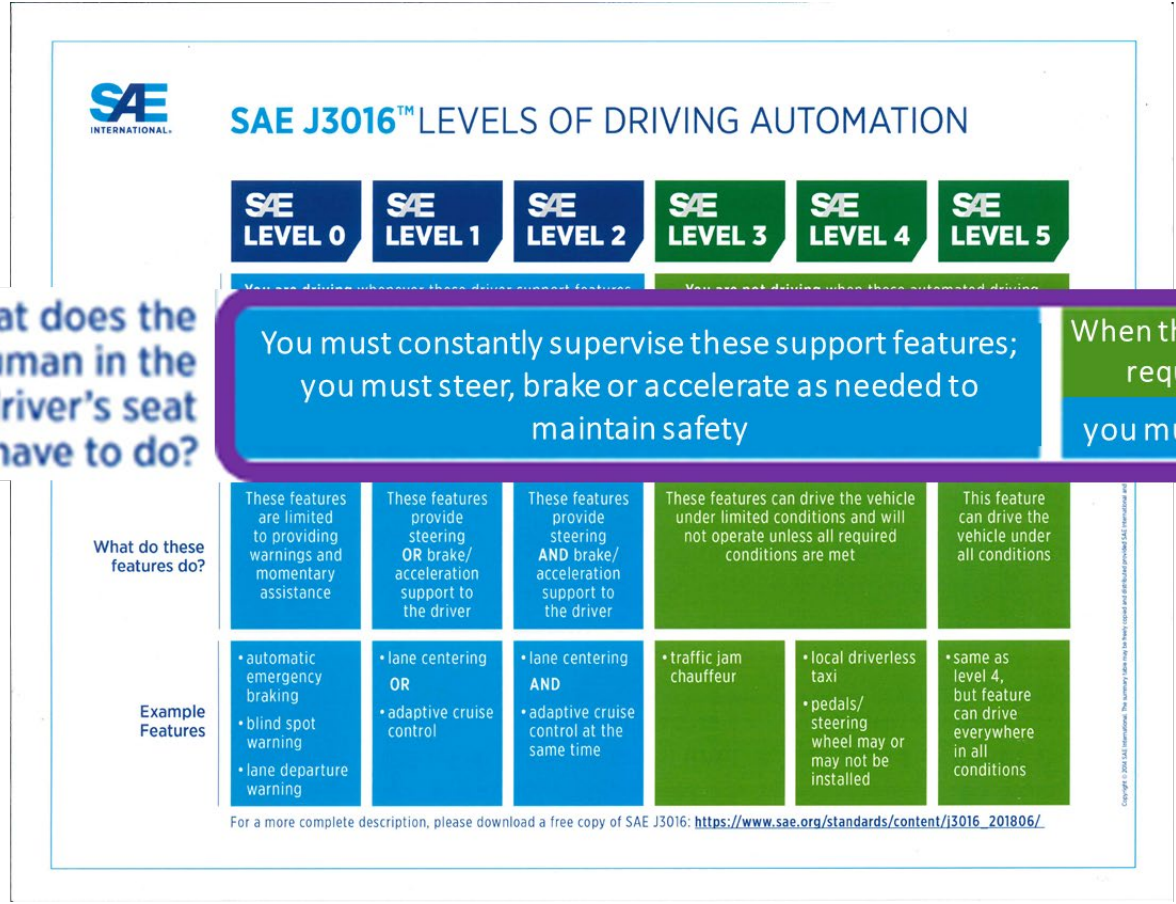
Active Operator → **Passive Supervisor**

Key Topic: Uncertainties about Driver Information Needs

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Key Topic: Uncertainties about Driver Information Needs



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.

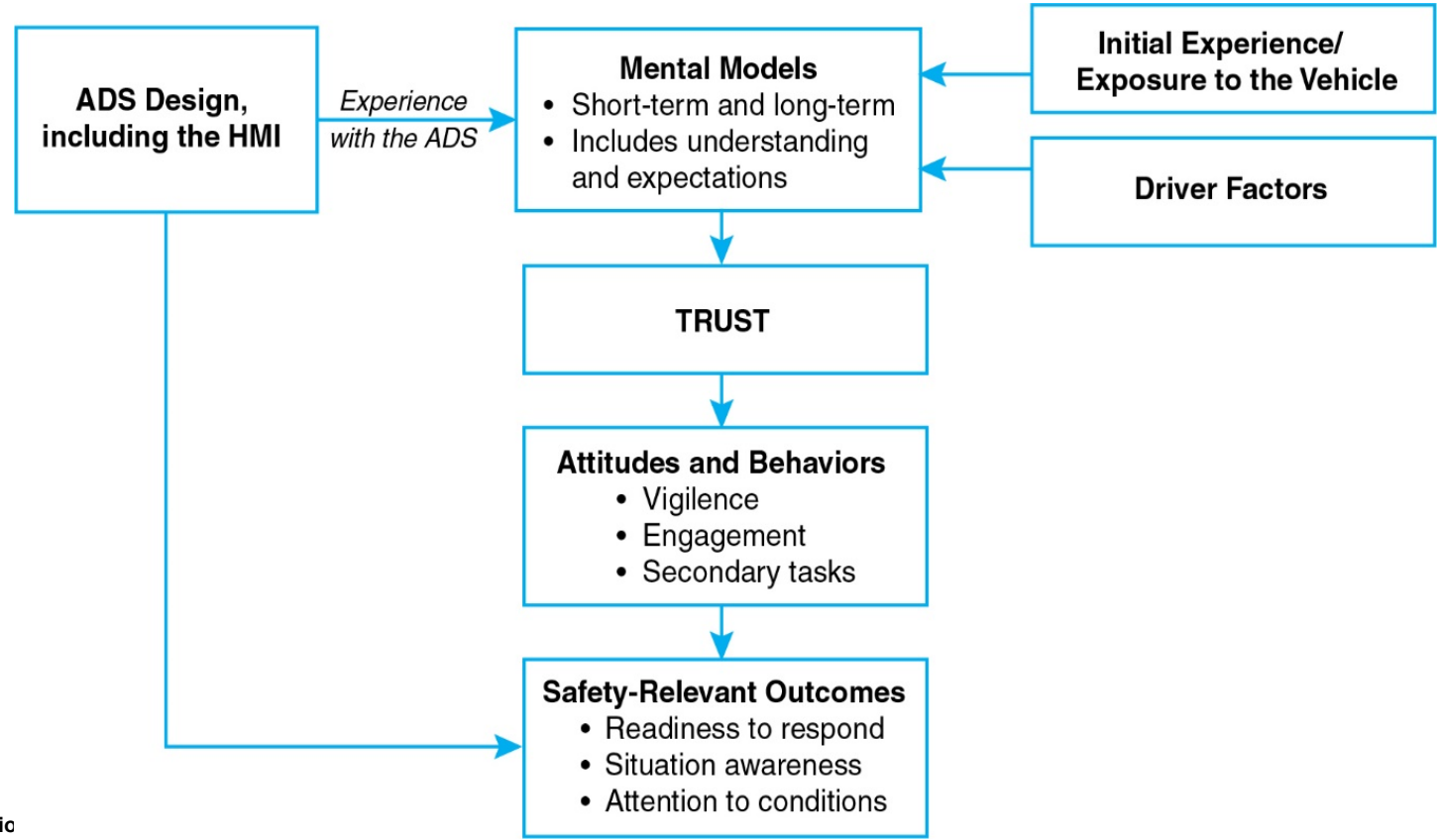
- Considerable research is available to support basic design requirements for the HMI

- 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



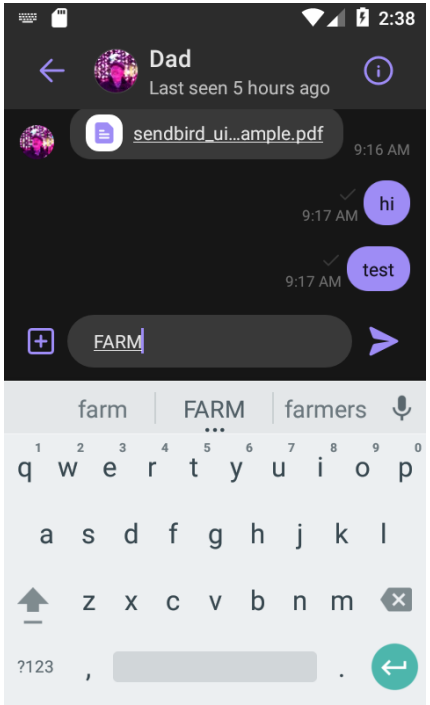
What's Next? An Overview of On-Going Research

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)

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

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

HMI – Basic Status Icons

ADS System Activity Associated with Driver Instrument Display Icon	Icon, Color, and File Name
ADS on Stand-by. ADS interruption (will revert to standby until activation requirements are met again).	 • White
ADS on and active. Pressing the ADS button activates the ADS. *A brief tone and the change of icon color to green provides feedback.*	 • Green
ADS is on and active, but environment conditions have triggered an Uncertainty Alert.	 • Orange
ADS is on and active, but environmental conditions have triggered a Request to Intervene.	 • Red

Examples of Measures and Variables

MEASURES	DESCRIPTION	VARIABLES
Components of Mental Models		
Understanding of system capabilities	Knowledge before/after experience using the system	Accuracy scores for questions pertaining to operator behavior in given scenarios on the Mental Models questionnaire
Understanding of automation level	Knowledge before/after experience using the system	Accuracy scores for questions pertaining to vehicle behavior in given scenarios on the Mental Models questionnaire
Effect of training on behavior	Changes in understanding of system use, capabilities, and automation level by level of training	Change in accuracy on the Mental Models questionnaire between 1st and 2nd administration for Basic Instruction and Detailed Instruction groups

Examples of Measures and Variables

MEASURES	DESCRIPTION	VARIABLES
Trust in the Automation		
Locus of control	Willingness to engage in NDRT (texting task)	Percentage of total fixations looking away from roadway while automation is engaged
	Willingness to allow an automated driving system to control the driving task	Time elapsed between automatic system disengagement following Request to Intervene (RTI), and system re-engagement by the participant
	Visual monitoring of roadway environment and vehicle behavior	Percentage of total fixations to driving-related ROIs under Normal Driving and Limitation scenarios
Self-reported trust	Difference in self-reported trust of the automated system between initial training and end of study	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
	Self-reported trust	Coding of spontaneous commentary by participants relevant to their feelings of trust in the automated system

Contact Info

- Thank You

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