Safe Autonomous Mobility — Human Cognition & Behavior in Automated Driving Systems

John K. Lenneman, Ph.D.

Collaborative Safety Research Center

Human-Technology Integration

TOYOTA MOTOR NORTH AMERICA | CSRC Collaborative Safety Research Center TOYOTA

CSRC OVERVIEW

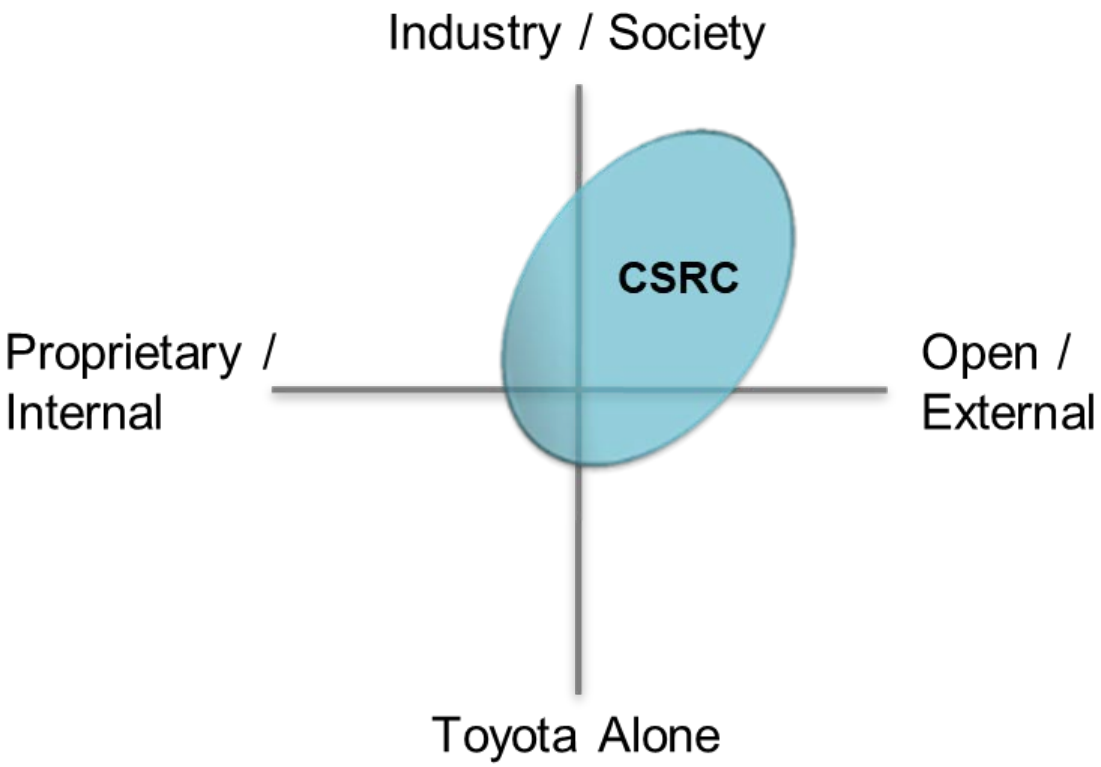
CSRC NEXT

2017-2021

RESEARCH AREAS

- Automated Vehicle Technology and Mobility Solutions
- Human-Technology Integration
- Occupant Sensing and Detection

Research Business Model



CSRC

WHAT WE DO PROJECTS TEAM PARTNERS NEWS

https://csrc.toyota.com/

TOYOTA COLLABORATIVE SAFETY RESEARCH CENTER

By partnering with leading universities, hospitals, research institutions and federal agencies, Toyota Collaborative Safety Research Center is focused on safety research projects with the goal developing and bringing to market new and advanced safety technologies.

WHAT IS A MENTAL MODEL

Mental model = Understanding of operation

Not understanding how these products work can have disastrous consequences

OVERALL PROJECT GOALS

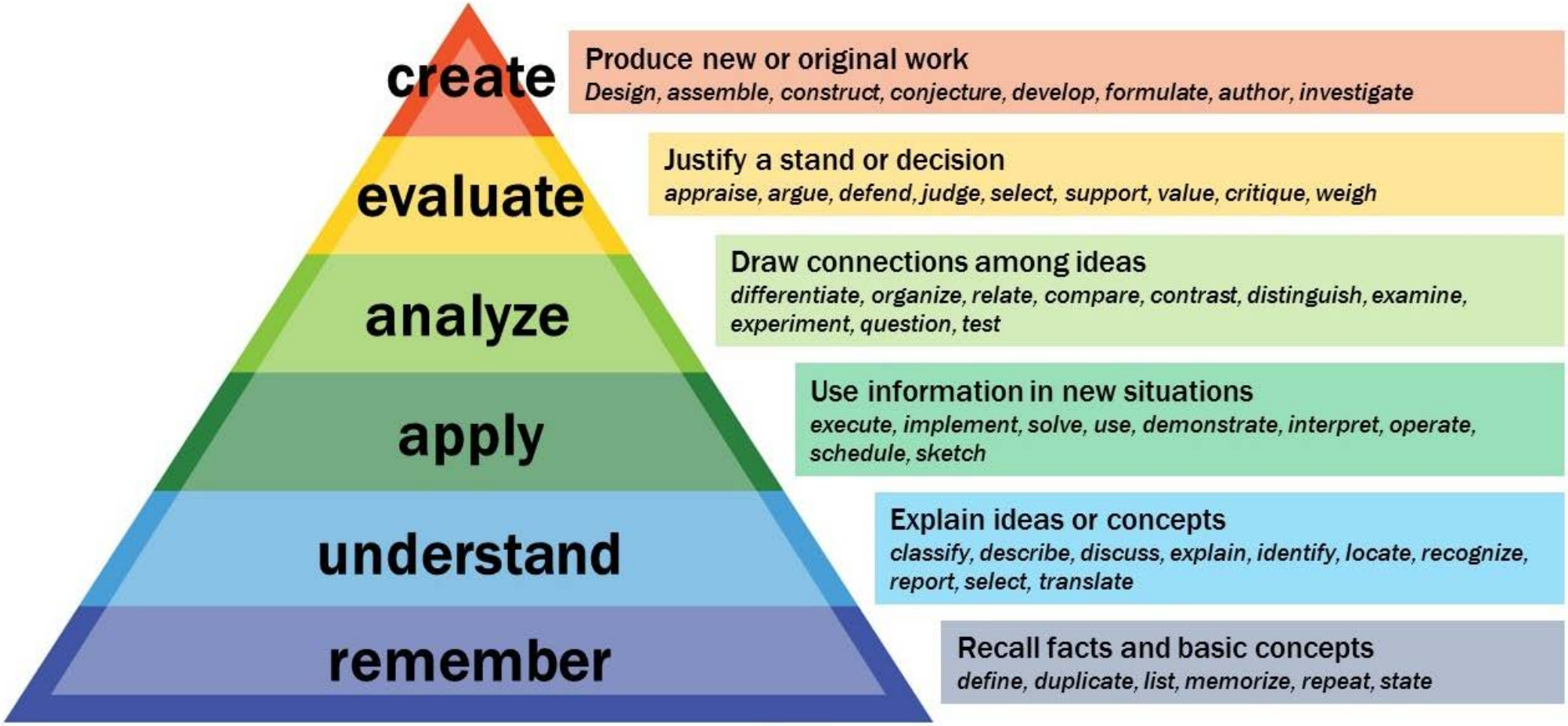
- With regard to ADAS/ADS technologies:
  - What are the nature of, and variants of drivers' mental models?
  - How are drivers' mental models formed?
  - How do drivers' mental models change over time?
  - What are the sources of change?
    - Specific events that occur while driving
    - Exposure to other sources of information (vehicle manual, service people, friends, Internet, ads, etc.)

ADAS = Advanced Driver-Assistance Systems; ADS = Automated Driving Systems

ANTICIPATED OUTCOMES

- Taxonomy of drivers' mental models
  - Indicates the most important dimensions or aspects of users' MM that can be used to characterize and classify them.
  - The taxonomy may help to explain differences between drivers' behavior and changes in their behavior over time.
- Description of the information and experiences that influence formation of drivers' mental models.
- Description of the information and experiences that influence changes in drivers' mental models over time.
- Links between drivers' mental models and specific behaviors

Bloom's Taxonomy



Bloom, B. S.; Engelhart, M. D.; Furst, E. J.; Hill, W. H.; Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain. New York: David McKay Company

OUR END GOAL

"Understanding" is not our end goal → Safety/Efficiency is #1 goal

APPLICATIONS

Mental models can be influenced through the HMI/technology

Mental models can be influenced through education/training

TWO PROJECTS

A BEHAVIORAL EVALUATION OF MENTAL MODEL DEVELOPMENT

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A NEUROERGONOMIC EVALUATION OF MENTAL MODEL DEVELOPMENT

GEORGE MASON UNIVERSITY

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A BEHAVIORAL EVALUATION OF MENTAL MODEL DEVELOPMENT

The Rockville Institute

September 2017 – Current

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CURRENT STATUS

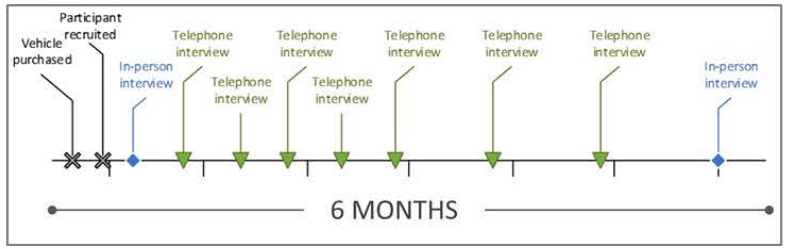
SEP 2017 Subjective/qualitative research → Objective/behavioral research CURRENT

Focus Groups

- Discussions with new vehicle owners regarding their experiences with ADAS/ADS technologies

Longitudinal Interviews

- 44 new vehicle purchases
- Initial and final in-person interviews.
- Regular interviews will be held via phone over the next 6 months.



On-road Naturalistic Observation

- 20 new vehicle owners will be recruited.
- Must have purchased their vehicle in the last month.
- Target vehicles include those with TSS/LSS:

FOCUS GROUPS

Methods

- Three 7-10 person focus groups.
- Participants grouped on “tech savviness”
  - Group 1: Mixed levels
  - Group 2: High level
  - Group 3: Low level
- New vehicle purchase in the last year with at least 2 advanced safety systems (no requirement on brand).
- Sample discussion topics include:
  - Understanding of systems and underlying technology (influential factors, level of detail, accuracy)
  - Confidence in systems
  - Emotion towards systems
  - System use patterns

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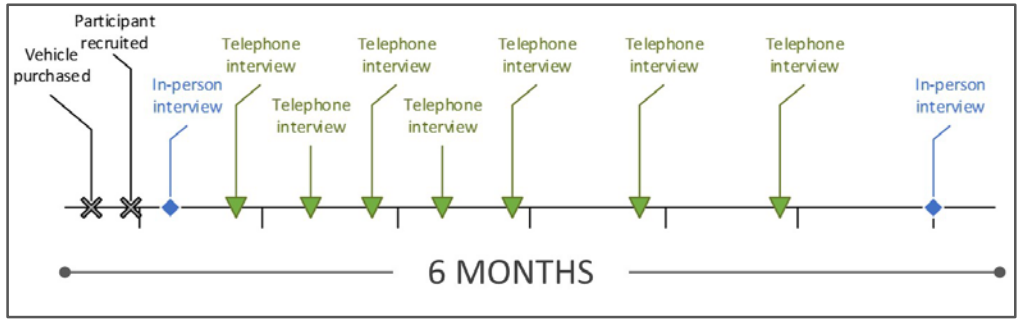
LONGITUDINAL INTERVIEWS

Methods



- 44 new vehicle owners that:
  - Purchased in the last month
  - No brand restriction
  - Must have at least one lateral and one longitudinal vehicle assistance system.
- Subjects will be interviewed
  - At the beginning of a 6-month data collection window.
  - Every 2-4 weeks following

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LONGITUDINAL INTERVIEWS

Methods

- Initial Inventory

1. Van der Laan, J., Heino, A., De Waard, D. (1997).A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research - Part C: Emerging Technologies, 5*.
2. Hoyle, R., Stephenson, M., Palmgreen, P., Lorch, E., Lewis, R., Donohew, L. (2002). Reliability and validity of a brief measure of sensation seeking. *Personality and Individual Differences, 32*, 401–414.
3. Cordazzo, S., Scialfa, C. & Ross, R. (2016). Modernization of the Driver Behaviour Questionnaire. *Accident Analysis & Prevention, 87,* 83-91.
4. Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. *Psychological monographs: General and applied, 80*, 1.

Technology Acceptance Scale & Brief Sensation Seeking Scale

My judgments of my driver assist features are… (please tick a box on every line)

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

How much do each of these statements describe you? – For each statement, please indicate your level of disagreement or agreement by placing a check mark in the most appropriate column.

Statement	1 Strongly Disagree	2 Disagree	3 Neither Disagree Nor Agree	4 Agree	5 Strongly Agree
1. I would like to explore strange places.					
2. I get restless when I spend too much time at home.					
3. I like to do frightening things.					
4. I like wild parties.					
5. I would like to take off on a trip with no pre-planned routes or timetables.					
6. I prefer friends who are excitingly unpredictable.					
7. I would like to try bungee jumping.					
8. I would love to have new and exciting experiences, even if they are illegal.					

Driver Behavior Questionnaire

No one is perfect. Even the best drivers make errors or commit violations at some time or another. Many of these are trivial, but others are potentially more dangerous. The questionnaire is very simple. It lists a number of errors and violations that people have experienced or observed while driving. For each item, you are required to indicate how often, if at all, this kind of thing has happened to you-say, over a period of about the last year.

How often do you do each of the following (for example, in the past month)?		Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
1	Attempt to drive away from traffic lights in third gear.	0	1	2	3	4	5
2	Check your speedometer and discover that you are unknowingly travelling faster than the legal limit.	0	1	2	3	4	5
3	Lock yourself out of your car with the keys still inside.	0	1	2	3	4	5
4	Become impatient with a slow driver in the outer lane and overtake on the inside.	0	1	2	3	4	5
5	Drive as fast along country roads at night on low beams as on high beams.	0	1	2	3	4	5
6	Attempt to drive away without first having switched on the ignition.	0	1	2	3	4	5
7	Drive especially close or 'flash' the car in front as a signal for that driver to go faster or get out of your way.	0	1	2	3	4	5
8	Forget where you left your car in a multi-level parking garage.	0	1	2	3	4	5
9	Distracted or preoccupied, realize belatedly that the vehicle ahead has slowed, and have to slam on the brakes to avoid a collision.	0	1	2	3	4	5
10	Intend to switch on the windscreen wipers, but switch on the lights instead, or *vice versa*.	0	1	2	3	4	5
11	Turn left on to a main road into the path of an oncoming vehicle that you hadn't seen, or whose speed you had misjudged.	0	1	2	3	4	5
12	Misjudge your gap in a parking garage and nearly (or actually) hit adjoining vehicle.	0	1	2	3	4	5

Rotter's Locus of Control Scale

For each question select the statement that you agree with the most

1. a. Children get into trouble because their patents punish them too much.

   b. The trouble with most children nowadays is that their parents are too easy with them.

2. a. Many of the unhappy things in people's lives are partly due to bad luck.

   b. People's misfortunes result from the mistakes they make.

3. a. One of the major reasons why we have wars is because people don't take enough interest in politics.

   b. There will always be wars, no matter how hard people try to prevent them.

4. a. In the long run people get the respect they deserve in this world

   b. Unfortunately, an individual's worth often passes unrecognized no matter how hard he tries

5. a. The idea that teachers are unfair to students is nonsense.

   b. Most students don't realize the extent to which their grades are influenced by accidental happenings.

6. a. Without the right breaks one cannot be an effective leader.

   b. Capable people who fail to become leaders hive not taken advantage of their opportunities.

7. a. No matter how hard you try some people just don't like you.

   b. People who can't get others to like them don't understand how to get along with others.

8. a. Heredity plays the major role in determining one's personality

   b. It is one's experiences in life which determine what they're like.

9. a. I have often found that what is going to happen will happen.

   b. Trusting to fate has never turned out as well for me as making a decision to take a definite course of action.

10. a. In the case of the well prepared student there is rarely if ever such a thing as an unfair test.

    b. Many times exam questions tend to be so unrelated to course work that studying in really useless.

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Assessment of Drivers' Mental Models of Advanced Safety Equipment

Interview Guide for Longitudinal Study

Authors
James Jenness
Neil Lerner
Sarah Yahoodik

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Research for the Advancement of Social Science

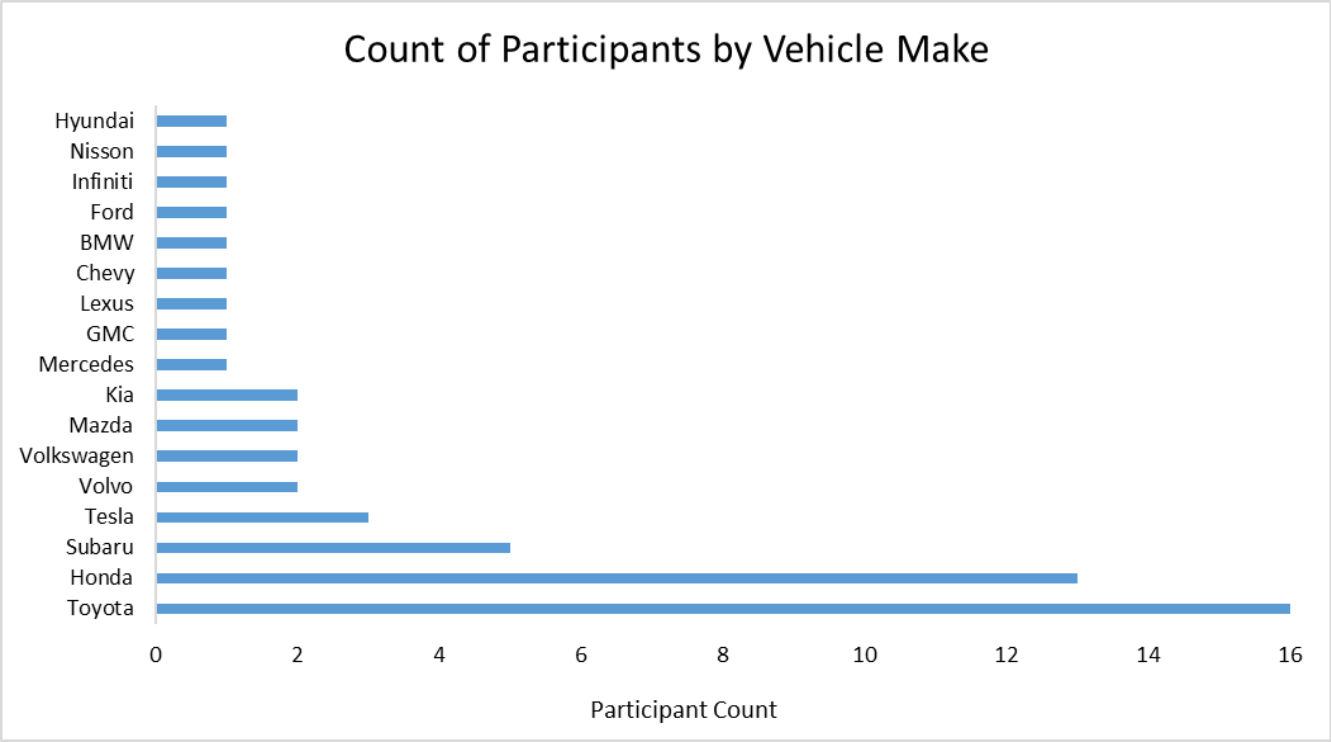
Interview Guide for Phase 2

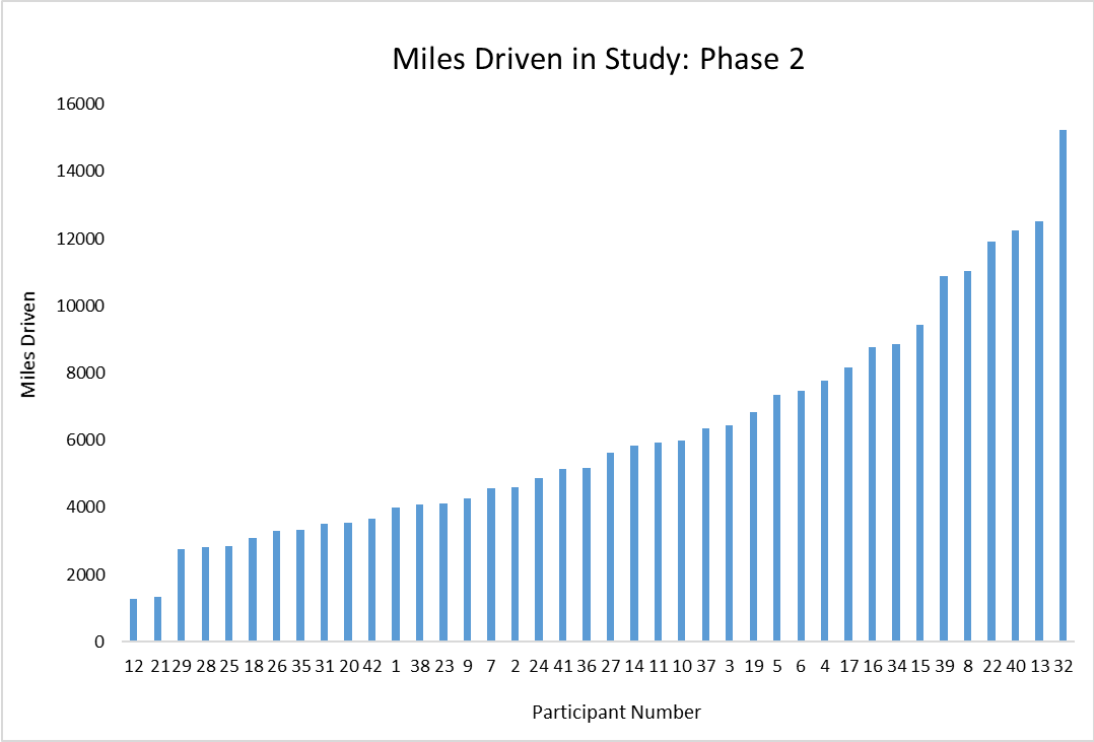
Initial Intake Interview (in-vehicle)

[administer questionnaires about user characteristics]

- How long did you have your previous car?
- We are interested in getting your perspective on various aspects of your new car. To start with, how long have you had the car?
- About how many miles have you driven? *[check odometer at some point to get verification]*
- Are you the only driver of this vehicle? *[if not]* Who else drives it? What percent of the driving of this car is done by you?
- What were some of the features that were important to you when you decided on this car? In other words, what were some things you know you wanted before you bought the car?
- I would like you to give me a tour of this car. Let's get inside and start the engine. Walk me through the features it has and how you use them. I will be videotaping you as you do this so that we have a record of what you are referring to. *[researcher is in rear seat, shooting video over the subject's shoulder]*
  - *[When they finish, if they have skipped over safety features of interest, do not ask about them specifically. Failure to mention at this point is actually data. Encourage them to continue in more detail, without pointing to specific features]*
- Just to be sure you got everything, let's go through the car from left to right, focusing on features near the driver's seat.
  - *[Step out of vehicle and sit at desk or other location to complete interview]*

- Now let's focus on some safety features of your car. I would like us to focus particularly on the kind of safety features we call "driver assist" features. These are the kinds of features that help the driver by giving warnings, or other information, or maybe automatically do steering or braking. So when we talk about your car's driver assist or safety features, I want to talk about things that interact with you when you are driving, not things like air bags or electronic stability control or crash resistant frames. I want you to tell me about the features that provide driver assistance to help you drive safely.
  - First off, do you have any of these driver assist features on your new car?
  - Did you have any of these on your previous vehicle?
  - Let's try to get a big picture look at what your car does and how it all works. Let's say you were describing how your car's driver assist package worked to someone who had never heard of it, a 12-year-old, just to keep it simple. In a few sentences, how would you tell them about it? What is your idea and


Count of Participants by Vehicle Make
Hyundai
Nisson
Infiniti
Ford
BMW
Chevy
Lexus
GMC
Mercedes
Kia
Mazda
Volkswagen
Volvo
Tesla
Subaru
Honda
Toyota
0
2
4
6
8
10
12
14
16
Participant Count


Miles Driven in Study: Phase 2
Miles Driven
16000
14000
12000
10000
8000
6000
4000
2000
0
12 21 29 28 25 18 26 35 31 20 42 1 38 23 9 7 2 24 41 36 27 14 11 10 37 3 19 5 6 4 17 16 34 15 39 8 22 40 13 32
Participant Number

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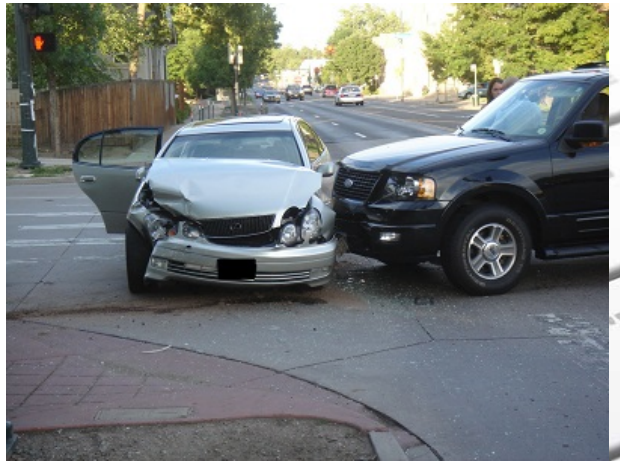
Sample learnings of what fosters mental model development and related subjective experiences



Memorable events are a big driver of mental model formation

Drivers often perform trial and error to help develop mental models

Emotions developed during system use can impact mental model development

Subjective evaluations of technology (trust, usefulness) impact mental models

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Samples of how users describe the technology and dimension that influence their description

A teacher

83-year-old aunt back seat driver

A robot

A weird relationship

Complexity:
The level of detail retained in one's understanding.

Holism:
The level of integration of ADAS/ADS technologies in the vehicle.

Anthropomorphism:
The amount of human characteristics used in one's understanding.

5 WAYS OF THINKING ABOUT ADAS/ADS

- Medium MM complexity
- Highest self-report of low accuracy of technology (final)
- Highest self-report as viewing systems as "totally lumped" (final)
- Lowest self-reported "mostly lumped" (final)
- Highest self-report of no mechanical skills (initial & final)

- Medium MM complexity
- Highest self-report of low accuracy of technology (final)
- Highest self-report as viewing systems as "totally lumped" (final)
- Lowest self-reported "mostly lumped" (final)
- Highest self-report of no mechanical skills (initial & final)

- High MM complexity (initial & final)
- Highest self-report of high accuracy of technology (initial & final)
- Highest self-report of high functional accuracy (initial & final)
- Highest self-reported "love" of technology (initial & final)
- Lowest self-reported appreciation (initial & final)
- One the highest responses of very positive (initial & final)
- Highest self-reported as "mostly split" (initial & final)
- Highest self-reported "totally split" (final)
- High anthropomorphism (initial & final)
- Highest self-reported mechanical/computational skills (initial & final)

- Medium MM complexity
- Highest self-report of low accuracy of technology (final)
- Highest self-report as viewing systems as "totally lumped" (final)
- Lowest self-reported "mostly lumped" (final)
- Highest self-report of no mechanical skills (initial & final)
- One of the highest responses of no machine learning (initial & final)
- Highest satisfaction score (initial & final)

- Vehicle is a servant
- Low MM complexity
- Highest response to medium accuracy of technology
- Lowest self-report of high accuracy of technology
- Highest self-report as somewhat positive and somewhat negative (i.e., polarizing; final)
- Highest self-report of "no anthropomorphism"
- Lowest self-reported mechanical computational skills (initial)
- Highest self-report of "useful" (initial & final)
- Lowest satisfaction score (final)

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ON-ROAD DRIVER BEHAVIOR STUDY

Methods

- 16 vehicle owners:
  - 11 purchased in the last month; 5 with no restriction.
  - Target vehicles that have Toyota Safety Sense or Lexus Safety System+
- Subjective interview approach similar to longitudinal interview study

Corolla

RAV4

Camry

LS

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ON-ROAD DRIVER BEHAVIOR STUDY: METHODS

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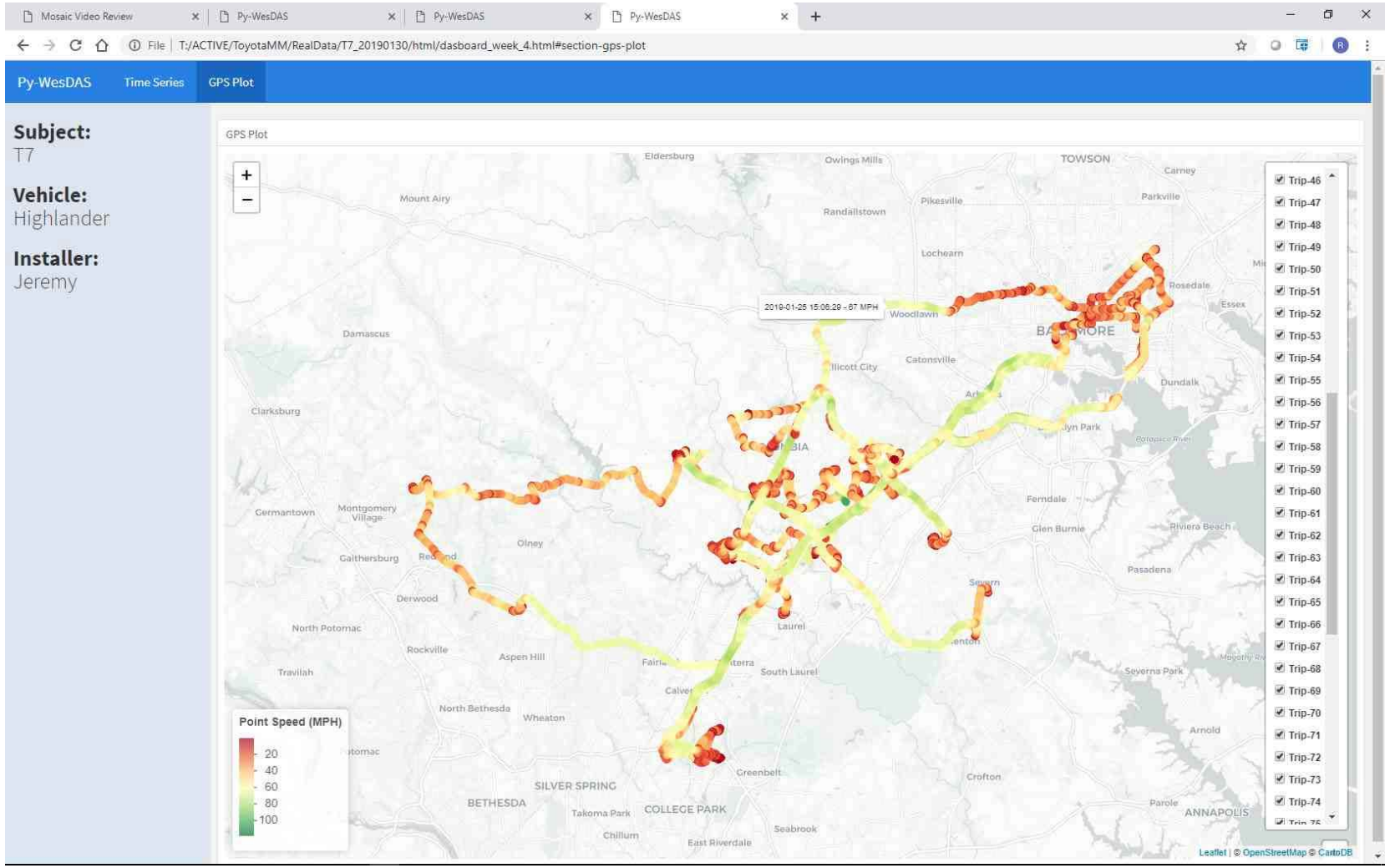
ON-ROAD DRIVER BEHAVIOR STUDY: METHODS



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DATA REDUCTION AND ANALYSIS

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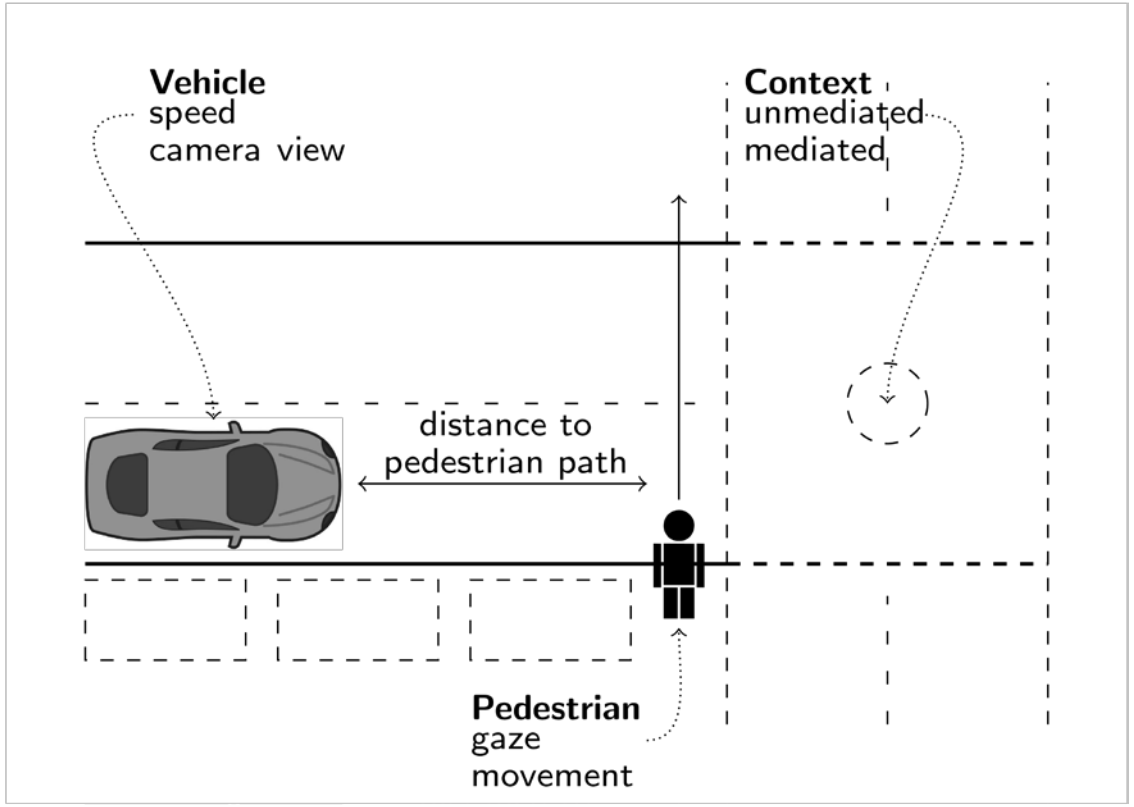
DRIVING REQUIRES COMMUNICATION

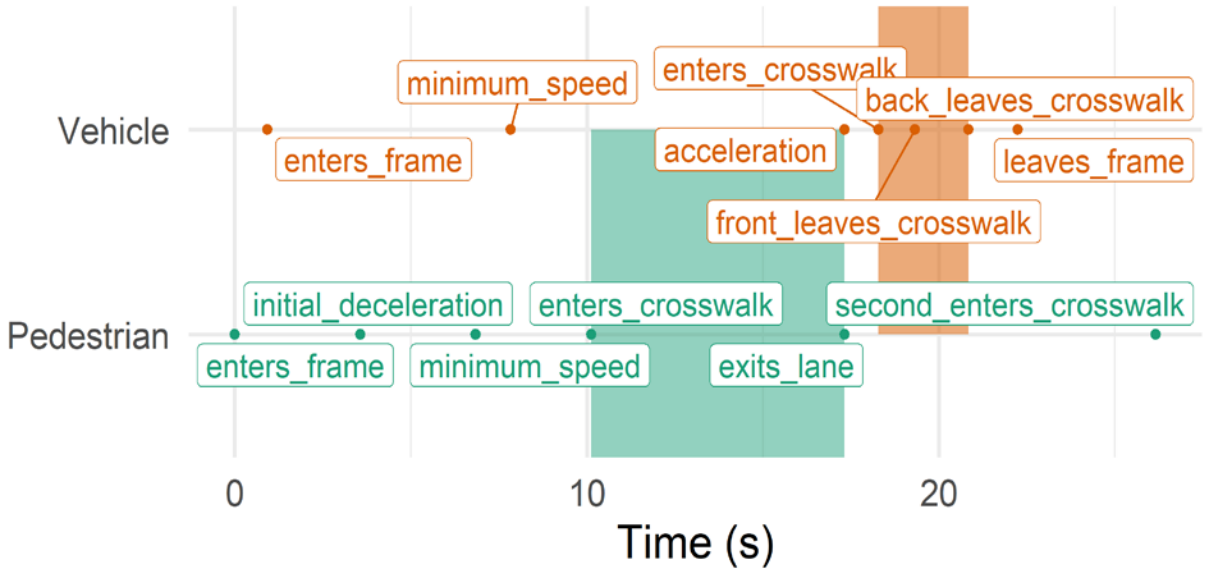
MIT AGELAB
Life Tomorrow

Movement communicates & explicit communication is limited



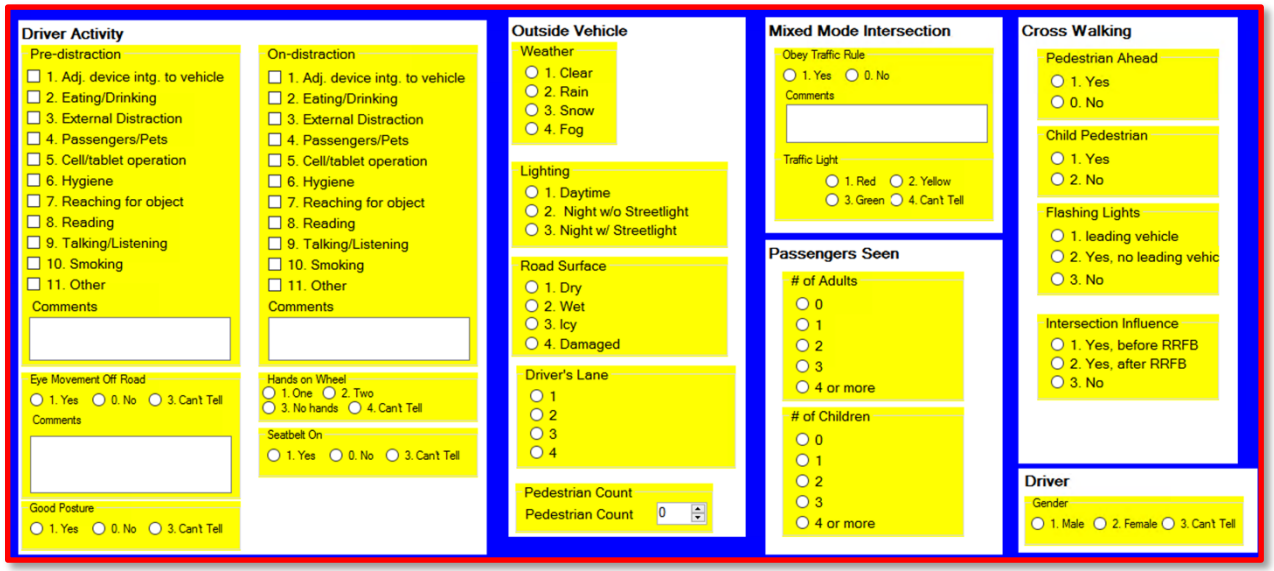
DRIVING REQUIRES COMMUNICATION

- Interactions create safety margins, efficiency, & politeness
- Stopping short could be interpreted as “courteous”



ASSESSING DRIVING BEHAVIOR IN COMPLEX SCENARIOS

UNIVERSITY of WASHINGTON



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ASSESSING DRIVING BEHAVIOR IN COMPLEX SCENARIOS

UNIVERSITY of WASHINGTON

Model 3

$$\log \frac{P(Y_{ij} = \text{Distracted})}{P(Y_{ij} = \text{Not distracted})} = (\beta_{00} + \gamma_{0j}) + \boldsymbol{\beta}^T \boldsymbol{X}_{ij}$$

$\boldsymbol{X}_{ij}$ is a vector of explanatory variables including, e.g.,

- Pre-distraction status
- Pedestrian ahead
- Signal status
- Weather condition
- Traffic influence

Model 4

$$\text{SDS}_{ij} = (\beta_{00} + \gamma_{0j}) + \boldsymbol{\beta}^T \boldsymbol{X}_{ij} + \epsilon_{ij}$$

$\boldsymbol{X}_{ij}$ is a vector of explanatory variables including:

- Change in distraction
- Pedestrian ahead
- Signal status
- Weather condition
- Traffic influence

Summary Results of Model 3 (Universal Distraction Model) and Model 4 (Universal Speed Change Model) for All Scenarios

	(3) On-distraction (all scenarios)		(4) Change in speed (all scenarios)	
	Exp(beta)	P-value	Beta	P-value
(Intercept)	**0.46**	**0.002**	**3.92**	**< 0.001**
Male	0.82	0.056	0.33	0.062
Pre-distraction (base: no) – yes	**7.02**	**< 0.001**	-	-
Hands on wheel (base: no hands)				
Can't tell	**0.30**	**< 0.001**	0.23	0.664
One hand	**0.46**	**0.001**	0.50	0.202
Two hands	**0.24**	**< 0.001**	0.75	0.072
Speed limit	-	-	**-0.55**	**< 0.001**
Direction (base: straight)				
Left	-	-	**-2.48**	**< 0.001**
Right	-	-	**2.65**	**< 0.001**
Road surface (base: dry)				
Icy	1.15	0.548	**1.19**	**0.002**
Wet	1.12	0.269	0.27	0.118
Adult passengers (base: no) – yes	**2.92**	**< 0.001**	-0.05	0.747
Child passengers (base: no) – yes	**1.96**	**< 0.001**	-0.14	0.589
Traffic influence (base: no) – yes	**1.43**	**< 0.001**	**-2.28**	**< 0.001**
Change in distraction complexity	-	-	**-2.44**	**< 0.001**
Scene complexity (base: simple)				
Simple-medium	1.22	0.121	**-6.75**	**< 0.001**
Medium	**1.62**	**< 0.001**	**-7.35**	**< 0.001**
Medium-complex	**1.32**	**0.04**	**-6.56**	**< 0.001**

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Wisconsin
MIT AgeLab

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MODEL

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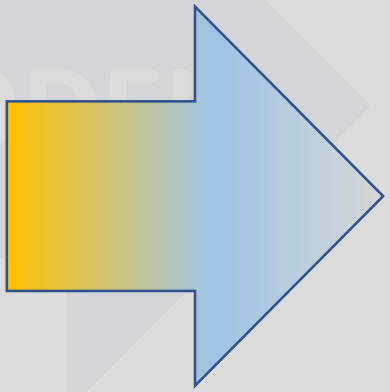

A NEUROERGONOMIC EVALUATION OF MENTAL MODEL DEVELOPMENT

George Mason University

September 2017 – Current

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GEORGE MASON UNIVERSITY

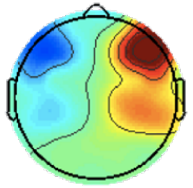
GEORGE MASON UNIVERSITY

Subjective/qualitative research

- Determining information used to develop mental models
- Examining factors (including user experience and temporal changes) leading to changes in mental models.

Objective/neuroergonomic research

- Neuroergonomic research provides insight into cognition not gleaned through behavioral or subjective measures



Phase 1 Sep 2017 – Dec 2018

ADAS Info Survey

Verbal Protocol Study

Diary Study

Phase 2 Oct 2018 – Current

Sample research issues:

- The effect of pre-existing mental models.
- Acceptance, performance and mental model change following interaction with the system.
- Efficacy of various education approaches
- Individual differences

SURVEY METHODS

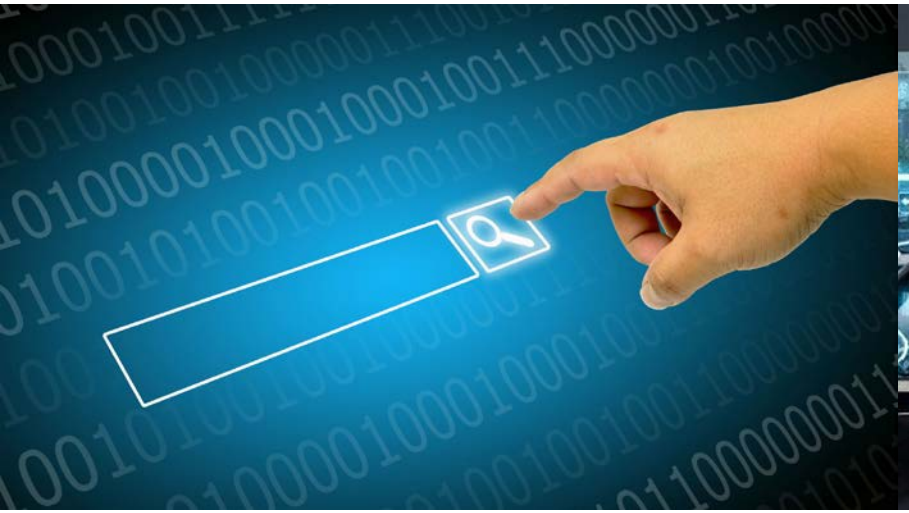
- 450 respondents
- Subjects paid $ to complete an online questionnaire

If you learn about Advanced Driver Assistance Systems (ADASs) from a car dealership...

	Not at all	Slightly	Moderately	Fairly	Extremely
How reliable is this source?	○	○	○	○	○
How trustworthy is this source?	○	○	○	○	○
How likely is this source to influence your overall opinion on ADASs	○	○	○	○	○

INITIAL FINDINGS

WHAT ARE YOU MOST LIKELY TO USE TO LEARN ABOUT ADAS/ADS TECHNOLOGIES?



INITIAL FINDINGS

MORE LIKELY TO RELY ON…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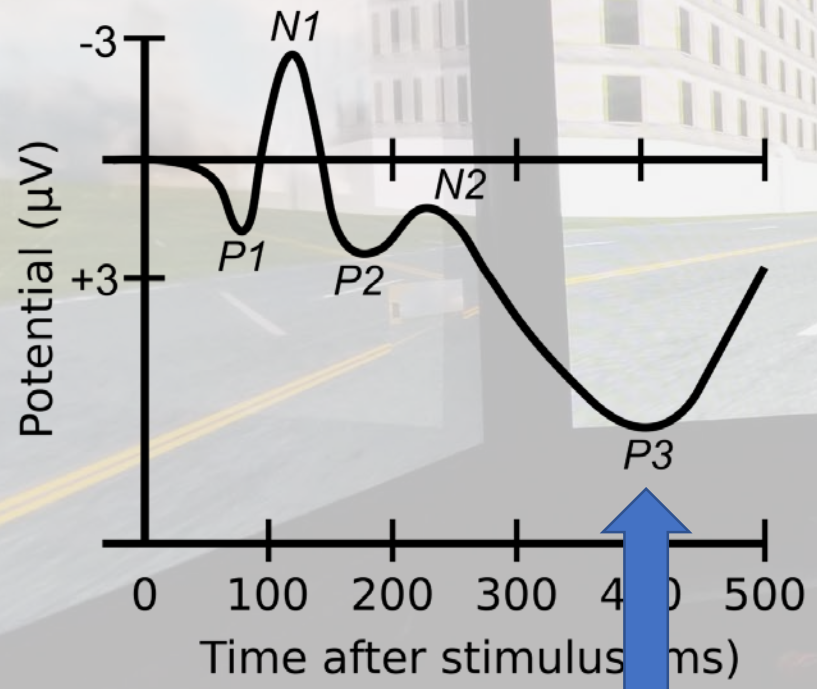
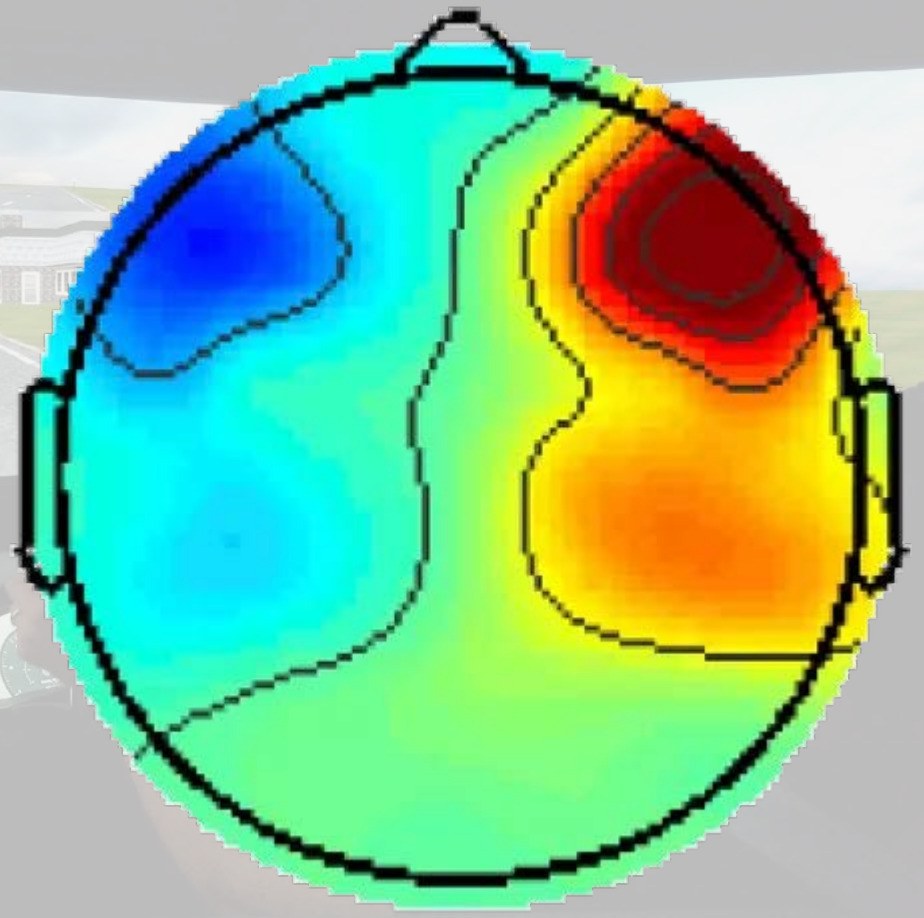
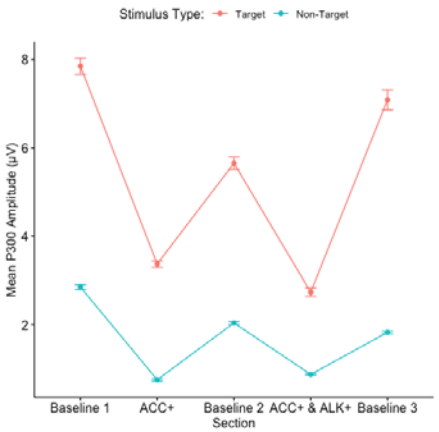


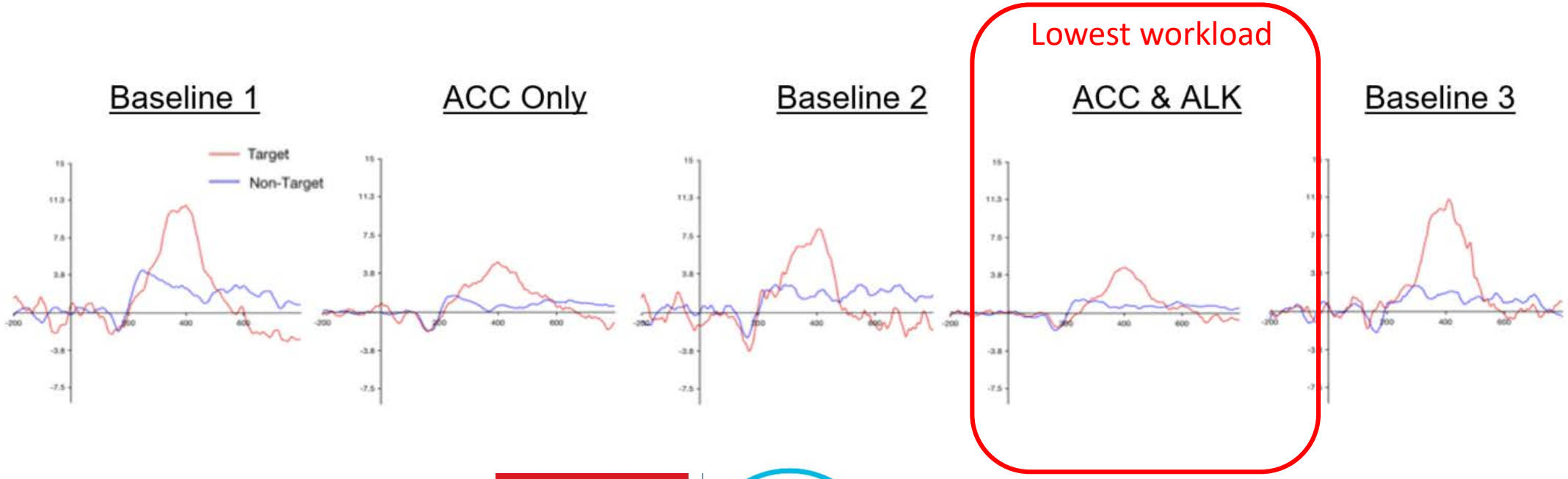


Reflects workload that can be moderated by mental model

Right hemisphere dominant = positive affect due to better mental model

Varying combinations of ADAS/ADS technologies manifest as significant differences in cognitive workload





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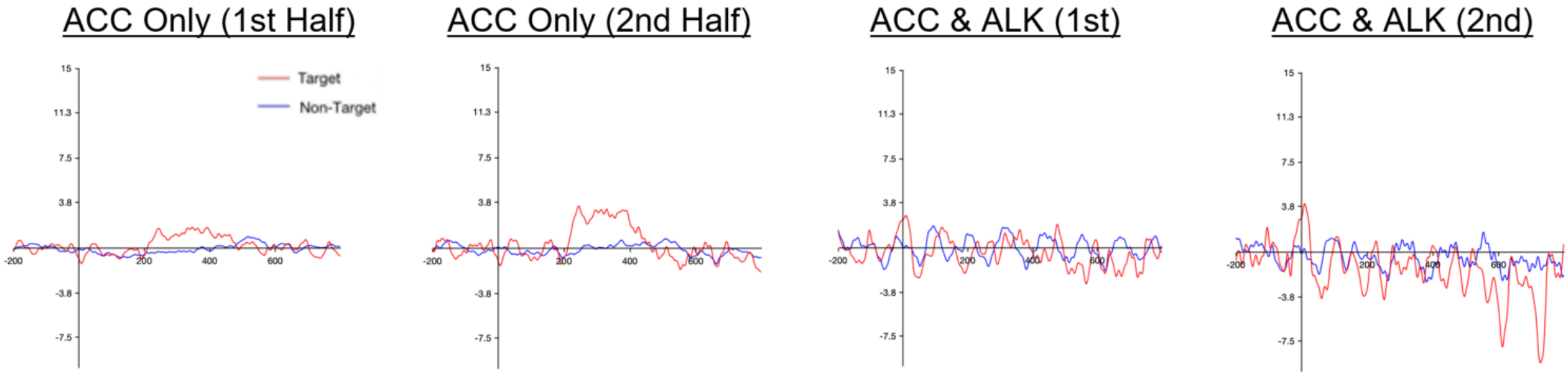
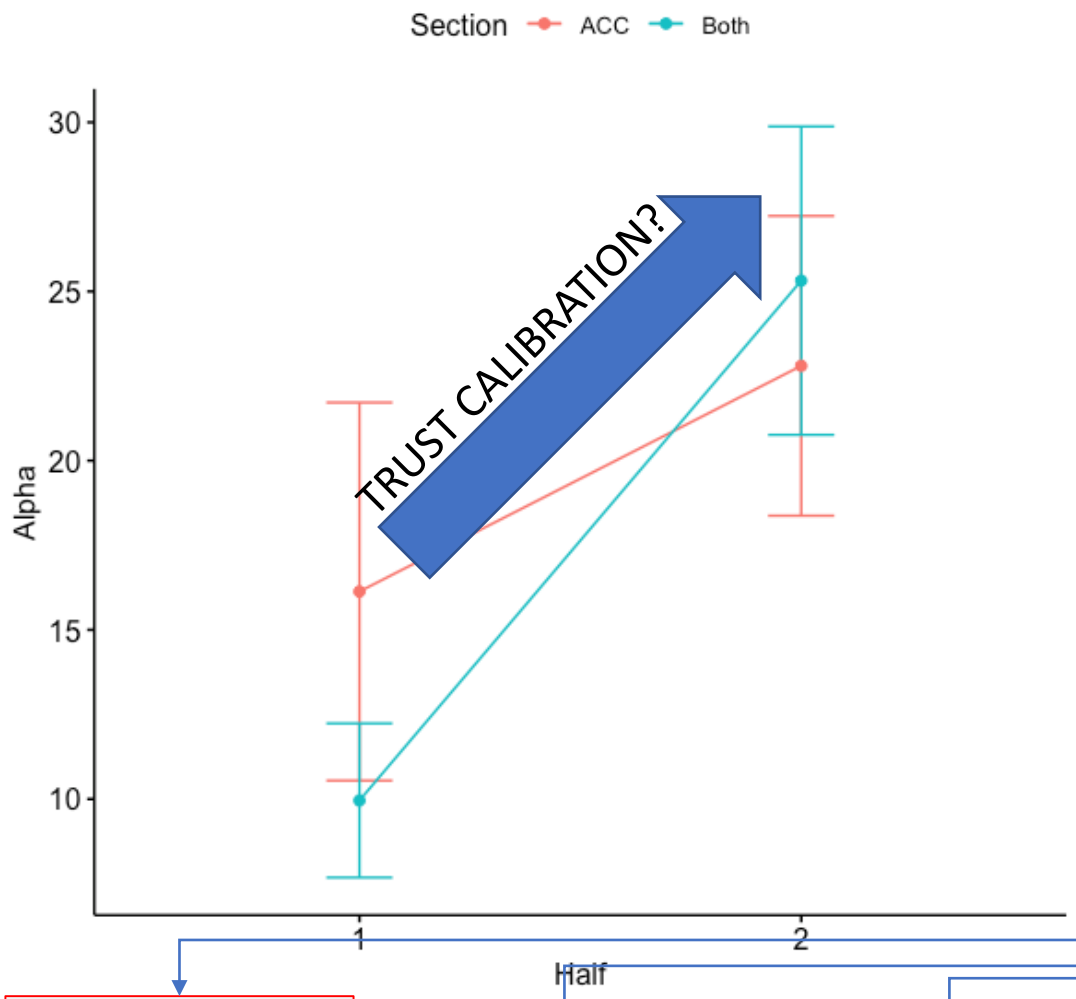
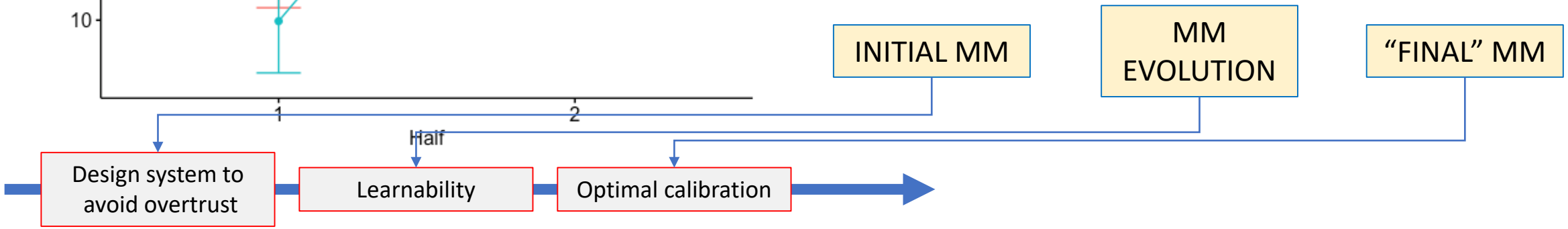
Workload associated with ADAS/ADS interaction changes over time





- Increased attention could indicate an increased understanding of system operation (i.e., technology capabilities an limitations)
- Trial and error leads to a greater understanding of when/where to allocate attention.



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JOHN K. LENNEMAN, PH.D

Dr. John Lenneman is a Senior Principal Engineer and Human-Technology Integration Research Director for the Collaborative Safety Research Center (CSRC) at Toyota Motor North America Research & Development Center (TMNA R&D) based in Ann Arbor, Michigan. In his current position, Dr. Lenneman is responsible for portfolio strategy and the execution of R&D projects.

INTERESTED IN COLLABORATING?

E-mail: john.lenneman@toyota.com
Cell: 734-730-6316

Note: If you are interested in learning more, feel free to contact John. Alternatively, you can use Google Scholar and search by the following terms to find out more:

John Lenneman, James Jenness, Carryl Baldwin, George Mason University, mental models, Josh Domeyer, Linda Boyle, or simply use one of the terms found in the presentation.