Studying driver behavior, driver variability, and user characteristics to improve traffic models and tools

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PERSONAL INTRODUCTION

EDUCATION

Ph.D., 2009	Civil & Coastal Engineering, University of Florida, Gainesville, Florida.
M.S., 2005	Civil & Coastal Engineering, University of Florida, Gainesville, Florida.
Diploma, 2003	Rural and Surveying Engineering, (five-year program) National Technical University of Athens, Athens, Greece.

EMPLOYMENT

8/2020 – present	**Associate Professor,** University of Kansas, Lawrence, Kansas.
8/2014 – 8/2020	**Assistant Professor,** University of Kansas, Lawrence, Kansas.
11/2012 – 8/2014	**Postdoctoral Associate,** University of Florida, Gainesville, Florida.
1/2011 – 1/2013	**Transportation Researcher**, National Technical University of Athens, Athens, Greece.
8/2009 – 11/2012	**Transportation Engineering Consultant,** ANKA Consulting, Athens, Greece.

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RESEARCH WORK

1. "CIVIC Innovation Challenge: Connecting underrepresented youths with employment opportunities" NSF
2. "Optimizing Highly Automated Vehicle Systems for People with Cognitive Disabilities" US DOT
3. "NCHRP 15-66: Operational Performance and Safety Effects of Arterial Weaving Sections" TRB
4. "Alternative Designs to Alleviate Freeway Bottlenecks at Merge/Diverge and Weaving Areas" FHWA
5. "Narrowing Freeway Lanes and Shoulders to Create Additional Travel Lanes" FHWA
6. "Promoting the Transportation Systems Management & Operations Program in Kansas" KDOT
7. "Modeling Driver Aggressiveness and its Impact on Safety Using Biobehavioral Methods" USDOT
8. "2016 Work Zone and Guardrail Safety Training Grant" FHWA
9. "Providing Crash Data Analysis Services for the Kansas Department of Transportation" KDOT
10. "Improving the Accuracy and Applicability of Kansas Traffic Data" KDOT
11. "Evaluation of Ramp Metering Effectiveness Along the I-35 Corridor in the Kansas City Metropolitan Area" KDOT

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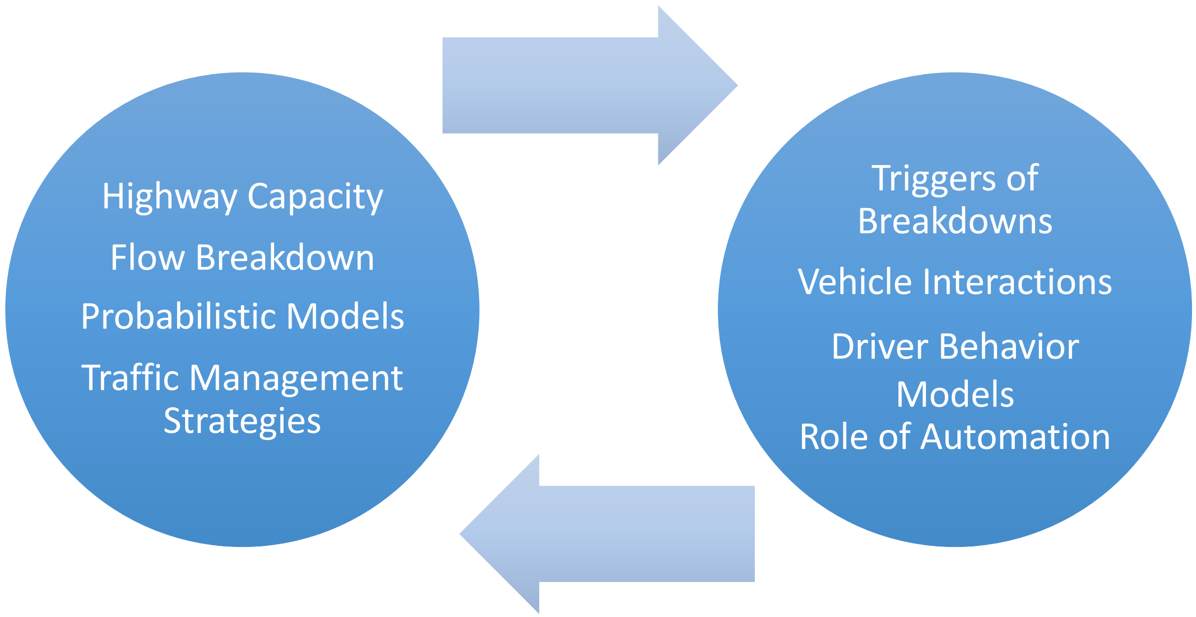
INTRODUCTION



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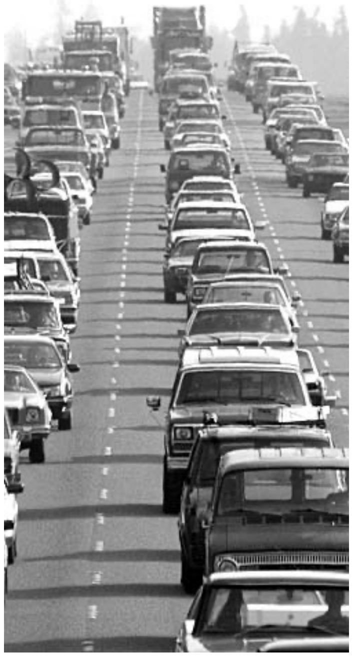
DRIVER BEHAVIOR AT FREEWAY RAMP MERGES

Objectives:

- Investigate how driver behavior affects traffic operations and gap acceptance decisions at freeway merging segments;

- Explore the relationship between vehicle interactions and breakdown events.



DATA COLLECTION

PART A: Focus Groups

- Investigate drivers' thinking process and intended actions at freeway-ramp merges

- Identify factors that affect gap acceptance decisions and merging interactions

PART B: Instrumented Vehicle Experiment

- Collect data to develop models of driver behavior

FOCUS GROUP EXPERIMENTS

- Identified factors that affect drivers' gap acceptance decisions.
- Identified factors that affect drivers' decisions to initiate cooperative merge or forced merge.
- Freeway vehicles prefer to change lanes and avoid decelerating.
- Driver behavior: criterion of selfishness for defining behavioral categories.
  → Aggressiveness depends on the task and the traffic conditions.
- Congested conditions: Driver behavior displays less variability
  → more predictable.

Kondyli and Elefteriadou, 2009

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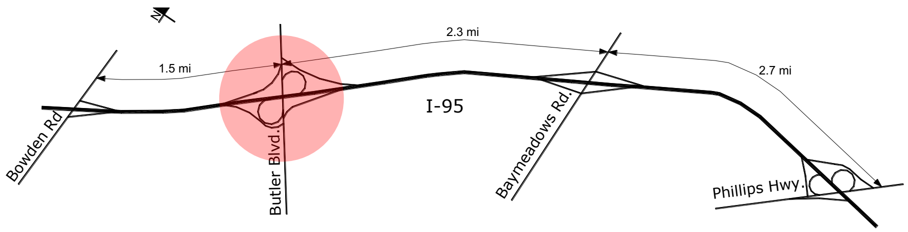
INSTRUMENTED VEHICLE EXPERIMENT

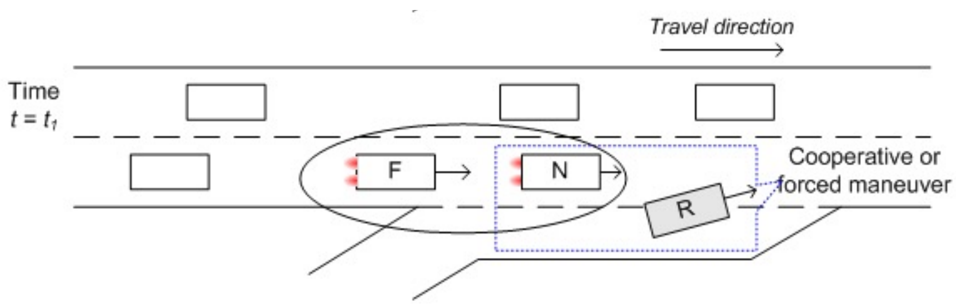
- GPS;
- mounted cameras;
- hard drive equipment;
- 31 participants;
- Drivers testimonials during experiment.



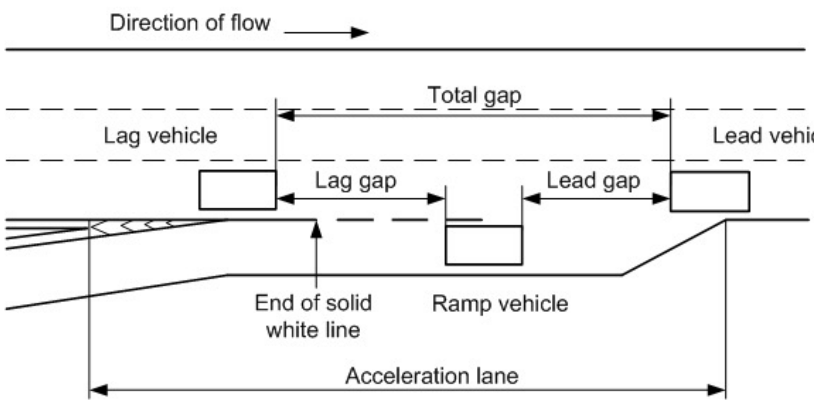
Kondyli and Elefteriadou, 2012

MERGING MANEUVER TYPES

1. ***Free merges:*** no obvious interaction between the merging vehicle and the mainline vehicle
2. ***Cooperative merges:*** the mainline vehicle yields to the ramp vehicle by either slowing down or changing lanes, to create an acceptable gap
3. ***Forced merges:*** clear conflict between the two vehicles. The merging vehicle initiates the maneuver and the mainline vehicle reacts by either slowing down or changing lanes



GAP ACCEPTANCE



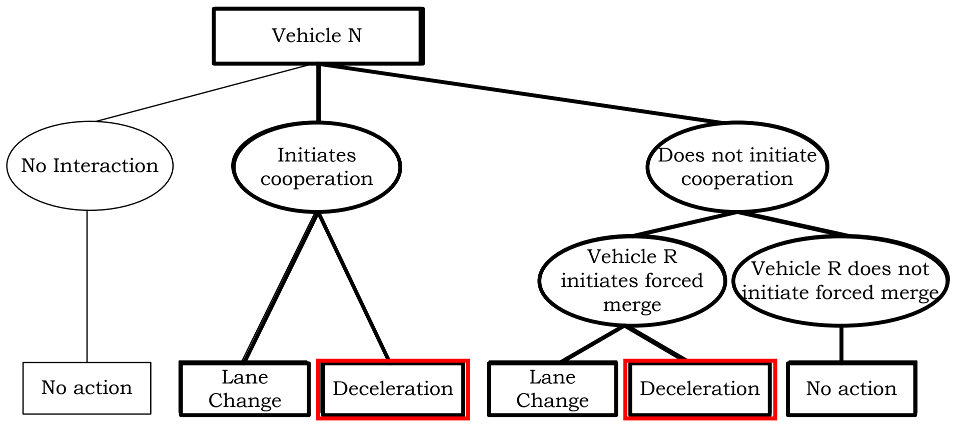
Function of:

- Merging maneuver
- Driver's aggressiveness
- Ramp geometry and position of ramp vehicle
- Ramp vehicle acceleration

$$\ln(G_R^{total}) = 5.343_{(33.46)} + 0.141_{(1.86)} * M^{free} - 0.324_{(-2.80)} * DT^{agr} * M^{forced}$$

$$- 0.262_{(2.46)} * DT^{agr} * M^{coop} - 0.445_{(-2.43)} * \frac{l}{D} - 0.005_{(-1.66)} * k + 0.032_{(1.84)} * a_R$$

FREEWAY VEHICLE BEHAVIOR



Kondyli and Elefteriadou, 2011

$$P(MergingTurbulence) = \frac{1}{RampFlowRate}\sum_{N=1}^{n} P_N(Dec)$$

$$P_N(DEC_t) = P_N\left(DEC, s_{t,N} = coop / s_{t-1,N} = normal\right) + P_N\left(DEC, s_{t,N} = forced / s_{t-1,N} = normal\right)$$

MNL Model: Deceleration model due to cooperative merge

$$V_{dec,N}^{coop} = 0$$

$$V_{CL,N}^{coop} = 4.179 + 0.002*(D-l) - 0.018*y - 0.071*k$$

$$V_{no-action,N}^{coop} = 2.055 + 0.002*(D-l) - 0.724*N_r$$
$$-0.144*(\min(0, V_{avg} - V_N)) + 0.008*y*DT^{non-agr}$$

$$Adjusted \quad R^2 = 21.6\% \qquad LL = -39.499$$

Freeway Vehicle Choices:

- Do not initiate cooperation
- Change lanes
- Decelerate (least preferred)

$(D\text{-}l)$ = distance to the end of the acceleration lane (ft)
y = distance between ramp and freeway vehicle (ft)
k = average freeway density (veh/mi/ln)
N_r = cluster size
$(V_{avg}\text{-}V_N)$ = freeway average speed less the subject freeway vehicle speed (mph)
$Dt^{non\text{-}agr}$ = driver type dummy for non-aggressive drivers

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Binary Logit Model: Deceleration model due to forced merge

$$V_{no-action,N}^{normal} = 0$$

$$V_{dec,N}^{forced} = -15.28 + 0.10 * k + 21.64 * l / D$$

$$+1.14 * N_r * DT^{agr} + 0.88 * a_r$$

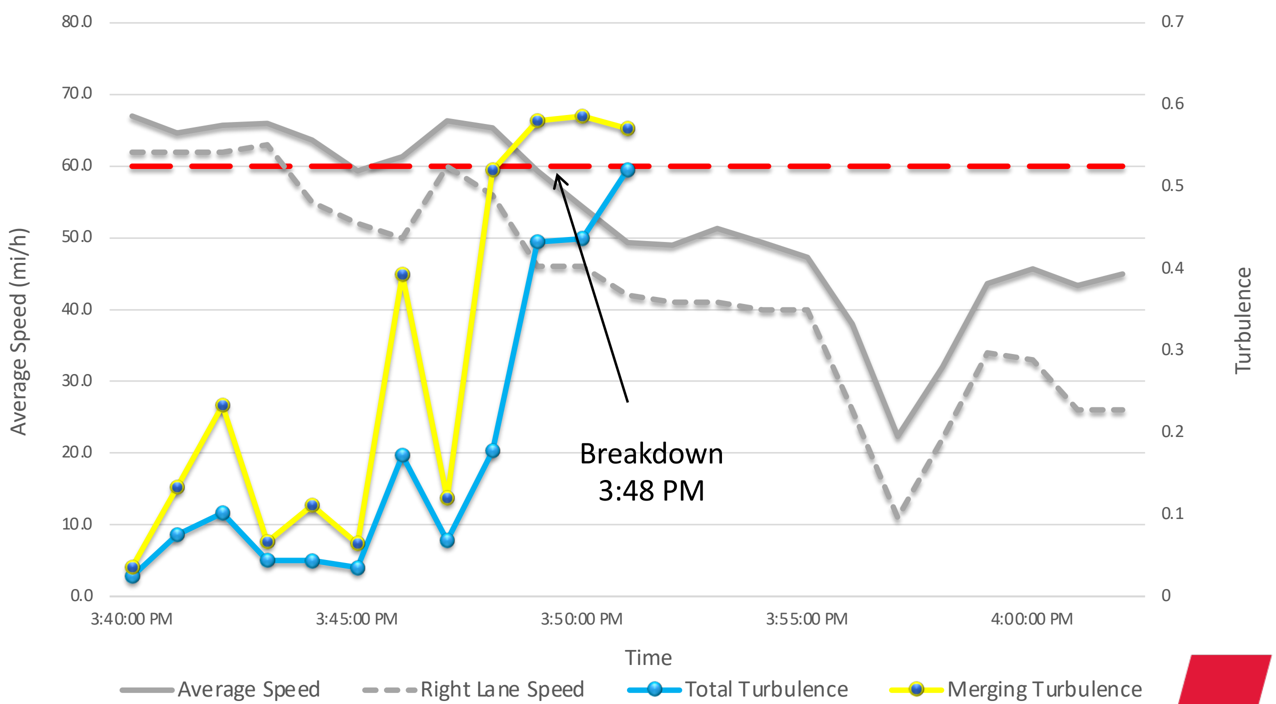
$$Adjusted \quad R^2 = 61.9\% \quad LL = -11.060$$

Ramp Vehicle Choices:

- Do not initiate forced merge
- Initiate forced merge

(l/D) = proportion of acceleration lane used
k = average freeway density (veh/mi/ln)
a_r = ramp vehicle acceleration (ft/s^2)
N_r = cluster size
Dt^{agr} = driver type dummy for aggressive drivers

MERGING TURBULENCE



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FINDINGS AND RECOMMENDATIONS

- Development of a gap acceptance model that considers drivers' degree of aggressiveness and maneuver type
- Development of a merging turbulence model that captures vehicle interactions and the triggers for vehicle decelerations considering drivers' aggressiveness
- Evaluation of merging turbulence model based on macroscopic observations
- Inclusion of the effect of driver behavior on vehicle interactions for refining or developing microsimulation models

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CAR FOLLOWING BEHAVIOR

- Car-following models considered: Pitt, modified Pitt, Gipps, MITSIM
- Calibration by traffic conditions, weather conditions, and driver type for speed and spacing, using instrumented vehicle data

Model	Parameters	Calibration with all drivers and conditions	Calibration by condition				Calibration by driver type		
			Uncongested	Congested	Rain uncongested	Rain congested	Aggressive	Average	Conservative
Gipps	a_n (m/s^2)	3.30	3.30	2.94	3.30	3.30	3.30	3.11	3.30
	b_n (m/s^2)	−3.40	−4.56	−2.00	−2.33	−2.00	−5.00	−2.19	−4.44
	$\acute{b}$ (m/s^2)	−3.40	−4.56	−2.00	−2.33	−2.00	−5.00	−2.19	−4.44
Pitt	k(s)	0.45	0.46	0.13	0.75	0.38	0.36	0.70	0.47
	b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
MITSIM	α^+	0.50	0.96	0.50	4.00	0.67	0.50	0.50	0.50
	β^+	−1.00	−0.90	−1.00	1.00	−1.00	−0.81	−1.55	−0.85
	γ^+	−1.00	−0.88	−1.00	2.16	−1.00	−0.84	−1.00	−0.93
	α^-	1.25	0.55	1.25	0.58	1.31	1.20	2.00	1.19
	β^-	1.00	0.00	1.00	2.00	1.15	0.69	0.00	0.13
	γ^-	1.00	−0.26	1.00	2.31	1.00	1.13	0.65	0.30
Modified Pitt	K	0.12	0.16	0.45	0.07	0.18	0.12	0.21	0.16
	h (s)	0.86	0.72	1.91	1.10	0.93	0.78	0.89	0.67
	L_l (m)	6.71	6.71	6.71	6.71	6.71	7.81	9.76	7.34

Soria, Elefteriadou, and Kondyli, 2014

CAR FOLLOWING BEHAVIOR

- All models were more accurate in predicting car-following under congested traffic conditions. This occurs because there is much less freedom and variability in driver behavior during congested conditions.
- The MITSIM and Gipps models were better in predicting average driver behavior.
- Both conservative and aggressive driver behaviors were better predicted when calibrated by driver type, particularly for non-congested conditions.
- Congested conditions were better predicted when the parameters are calibrated by condition.
- Uncongested conditions were better predicted when the parameters are calibrated by driver type.
- Variability of the various car-following parameter values when considering different driver types and also when considering varying traffic and weather conditions.

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LANE CHANGING BEHAVIOR

- Instrumented vehicle lane changing analysis by driver type.
- Cluster analysis revealed four driver type groups.
- Lane change duration varies by driver type. Aggressive drivers have shorter lane change durations compared to conservative drivers.
- Accepted gaps follow the Gamma distribution. Lane change durations follow the Johnson Su (similar to lognormal) distribution.
- Degree of congestion affects lane changing operations. Lane changing duration is greater in congested conditions than in uncongested conditions. The accepted average size is also smaller.

Hill, Elefteriadou, and Kondyli, 2015

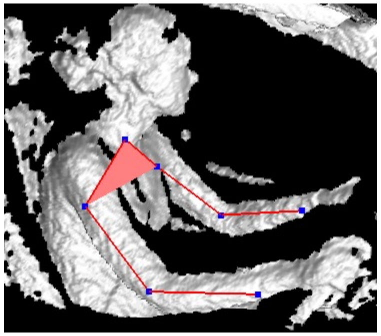
3D BODY POSTURE

Goal:

- Develop a novel approach that tracks body movements and investigate the relationship between potentially unsafe driving maneuvers and the actual driver body posture.

Method:

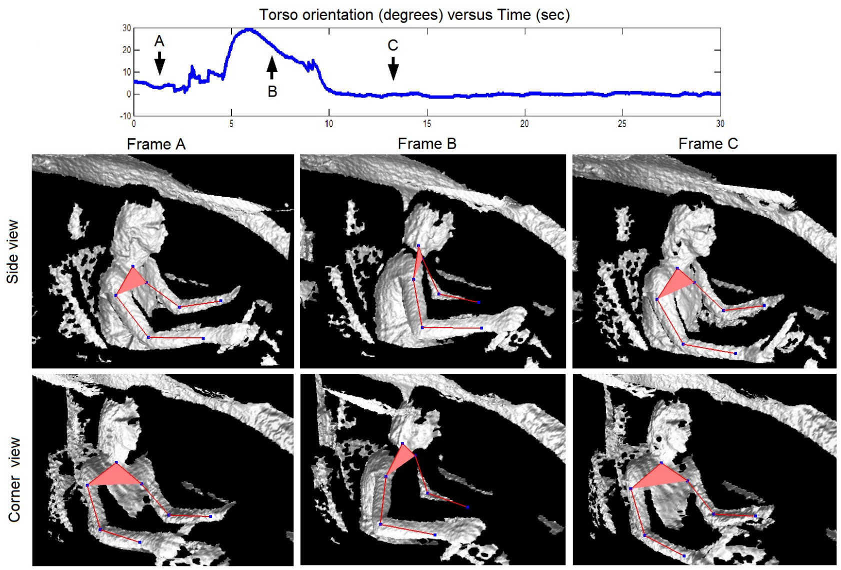
- Monitor drivers
- Traffic conditions
- Marker-less motion tracking algorithm
- Eye tracking



Kondyli,Sisiopiku and Barmpoutis, 2015

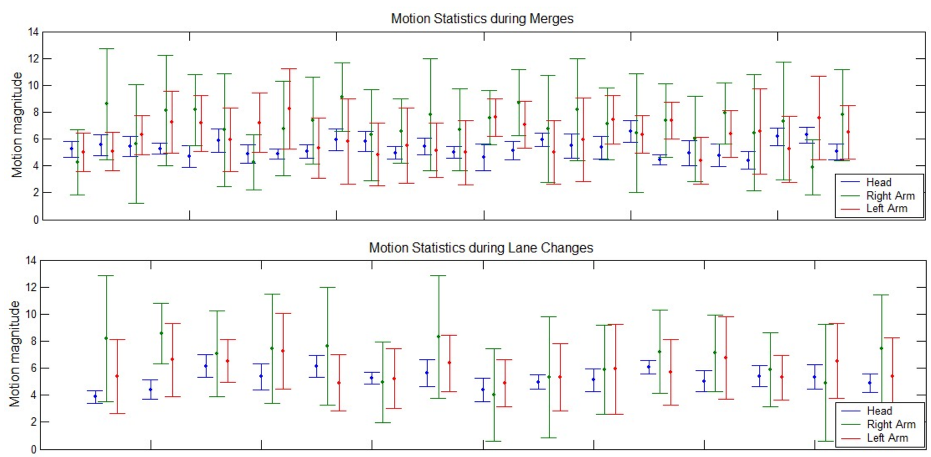
3D BODY POSTURE

- Naturalistic data collection
- 35 participants
- Real-time 7-point skeleton tracking: right wrist, right elbow, right shoulder, neck, left shoulder, left elbow, and left wrist.



3D BODY POSTURE

- Investigation of driver posture and interaction with other vehicles
- Observations of real-life driving conditions
- Development of a novel algorithm for tracking drivers' arms and head movement

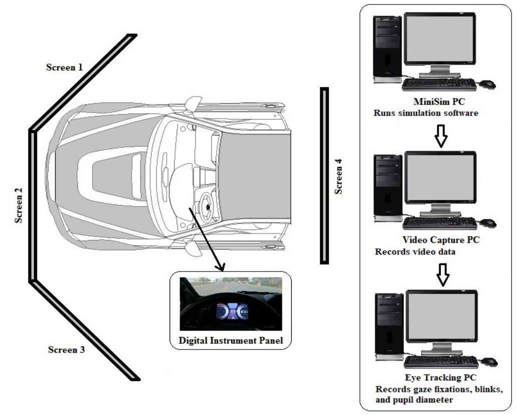


ADAPTIVE CRUISE CONTROL

Objective:

Effects of ACC on car-following behavior and awareness

- Control and treatment driving scenarios involving car-following under various levels of task difficulty and distraction
- Cognitive workload was measured using a detection response task (DRT) device
- 18 participants (9 male, 9 female)



Kummetha, Kondyli, and Schrock, 2018

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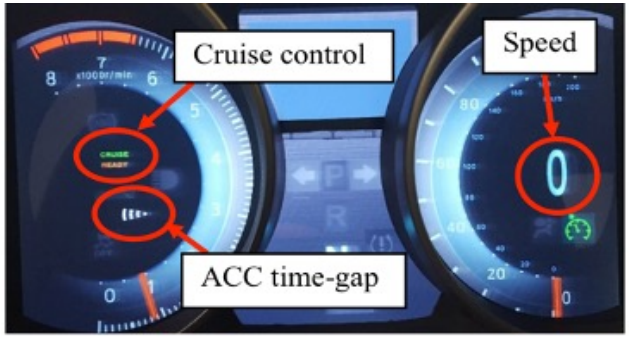
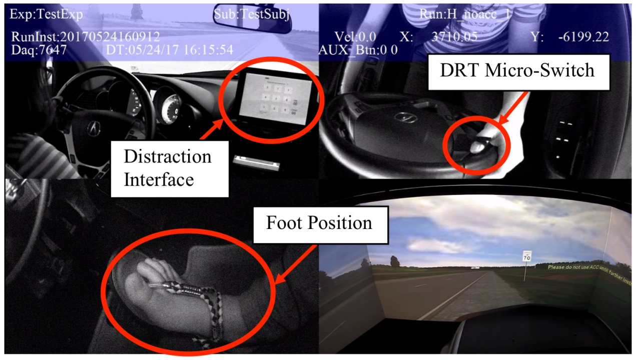
ADAPTIVE CRUISE CONTROL

- Participants reach lower max speeds and longer spacing when driving with ACC
- Increased reaction times, brake force and deceleration rates when driving with ACC
- Workload is reduced with ACC - Secondary tasks performed better
- ACC vehicles should be equipped with emergency braking or active collision avoidance system to compensate for these effects





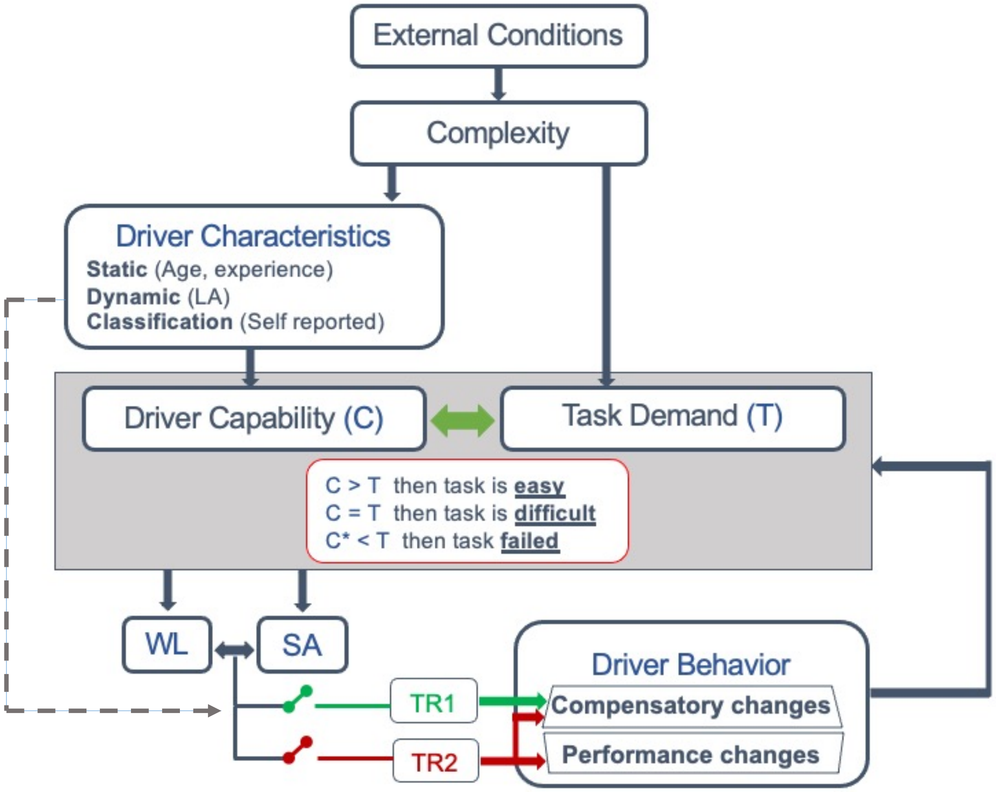
Research Need:

- Lack of a behavioral component
- Account for complexity
- Efficient calibration

Main Objectives:

- Investigate relationship between driver variability, car-following behavior, and performance compensation due to increasing task difficulty.
- Examine various constructs to develop and validate an extension to the intelligent driver model (IDM).

FULL FRAMEWORK



Adapted from Hoogendoorn et al., 2013

MODIFICATION TO IDM

$$a_n(t) = a_{max}\left[1 - \left(\frac{v_n(t)}{(\alpha)v_0(t)}\right)^{\delta} - \left(\frac{s^*{}_n(t)}{s_n(t)}\right)^2\right]$$

$$s^*{}_n(t) = s_0 + \left(\frac{1}{\alpha}\right)T_n v_n(t) + \frac{v_n(t)\Delta v_n(t)}{2\sqrt{a_{max}b_{max}}}$$

$$\mathbf{0 < \alpha \leq 1}$$

$\alpha: performance\ and\ compensation\ coefficient$

$$\alpha = e^{\beta_o+\beta_1 * Distraction} * LA^{\beta_2} * SA^{\beta_3} * WL^{\beta_4} * Lead\ v(t)^{\beta_5}$$

DRIVING SIMULATOR TASK DEMAND

Increasing task demand

Name	Composition	Work zone	Traffic density	Lane changes/ deviations	Distraction
Preliminary	4-lane divided highway at varying speeds. 0% heavy vehicles.	None	0-3 pc/mi/ln (LOS A)	None	None
Level 1	4-lane divided highway at 70 mph. 0% heavy vehicles.	None	25-28 pc/mi/ln (LOS B/C)	Low (1 pc/mi)	None
Level 2	4-lane divided highway at 70 mph. 0% heavy vehicles.	None	35-38 pc/mi/ln (LOS D/E)	Low (1 pc/mi)	None
Level 3	4-lane divided highway at 70 mph. 10% heavy vehicles.	Inactive: left shoulder closed	35-38 pc/mi/ln (LOS D/E)	Medium (2-3 pc/mi)	None
Level 4	10-lane divided freeway at 70 mph. 20% heavy vehicles.	Active on both sides: 3 lanes closed	25-28 pc/mi/ln (LOS B/C)	High (3-5 pc/mi)	None
Level 5	10-lane divided freeway at 70 mph. 20% heavy vehicles.	Active on both sides: 3 lanes closed	35-38 pc/mi/ln (LOS D/E)	High (3-5 pc/mi)	None
Level 6	10-lane divided freeway at 70 mph. 20% heavy vehicles.	Active on both sides: 3 lanes closed	35-38 pc/mi/ln (LOS D/E)	High (3-5 pc/mi)	Yes (secondary task)

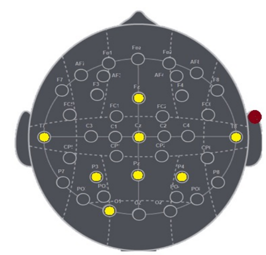
90 participants

DATA COLLECTION

- Workload
  - Task evoked pupillary response (TEPR)
  - Index of Cognitive Activity (ICA)
  - Changes in heart rate
  - NASA-Task Load Index (NASA-TLX)
- Situation Awareness
  - Situation Awareness Rating Technique (SART)
  - Changes in time to comprehension via gaze overlay
- Level of Activation
  - EEG power spectral density
- Driver Performance
  - Driving simulator variables

FOVIO FX3 eye-tracker

Polar H10 chest strap



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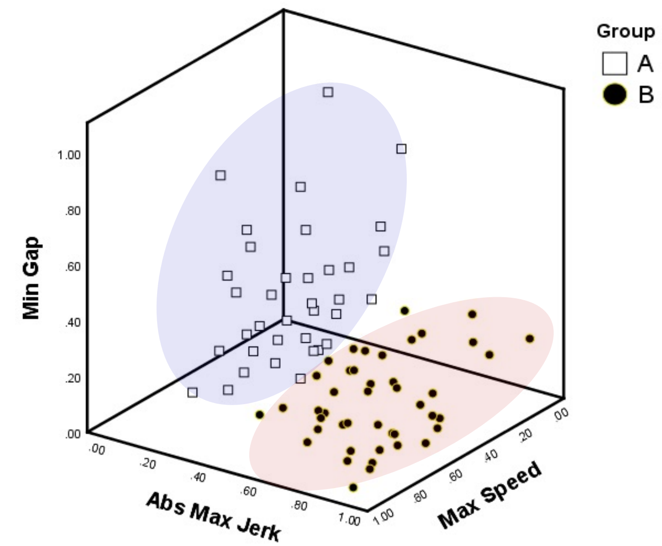
DEVELOPMENT OF b-IDM

Gp	N	Min Gap (s)	Max Jerk (m/s^3)	Max Speed (m/s)
A	36	1.12 ± 0.51	4.29 ± 1.40	35.7 ± 1.27
B	44	0.67 ± 0.23	8.16 ± 1.30	37.0 ± 1.55
P-values < 0.001				



Compare: calibrated IDM – Group IDM – b-IDM

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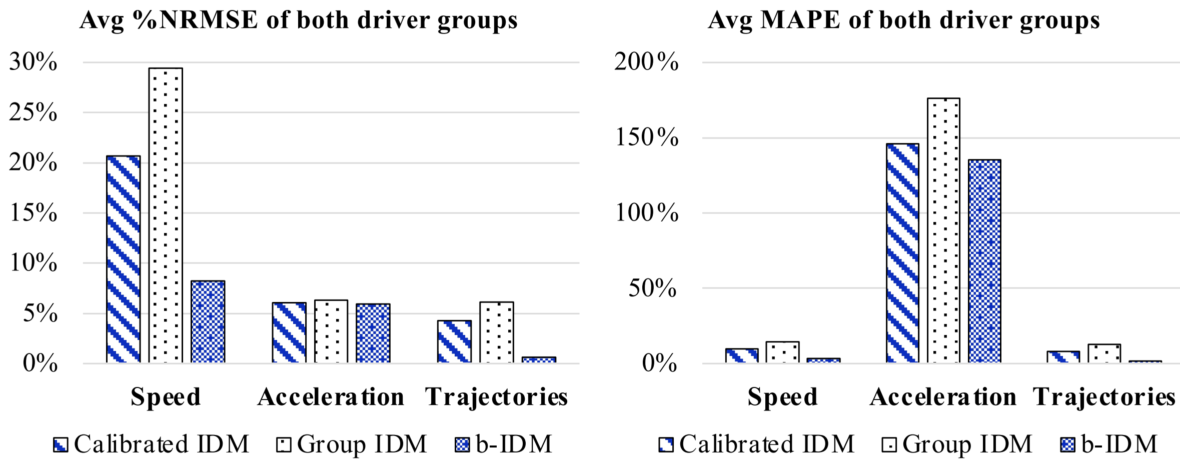
GOODNESS-OF-FIT



(a) (b)

$$\% \, NRMSE = \frac{\sqrt{\sum_{t=1}^{n} (\hat{y}_t - y_t)^2 / n}}{y_{max} - y_{min}} \times 100 \, \%$$

$$MAPE = \frac{100 \, \%}{n} \sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right|$$

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CONCLUSIONS

- Methodology captured various levels of WL and SA.
- Driver types were derived from two distinct clusters.
- b-IDM provided better group trajectory predictions, although the improvement to acceleration predictions was minimal.
- Extend framework to partial automation

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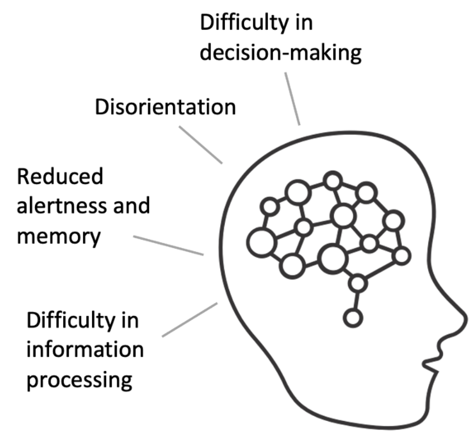
INCLUSIVENESS IN AUTOMATED VEHICLE DESIGN

- Call for innovative design solutions to enable people with physical, sensory, and cognitive disabilities to use highly-automated vehicles
- Seeking solutions to common barriers, such as:
  - Locating a vehicle
  - Entering/exiting a vehicle
  - Securing passengers and mobility equipment
  - Interacting with vehicle in routine and emergency situations
- Stage I: proof of concept
- Stage II: functional prototype development
- https://www.transportation.gov/accessibility/inclusivedesign

INCLUSIVENESS IN AUTOMATED VEHICLE DESIGN

- Who? Target group: people with cognitive disabilities
  - mild cognitive impairment
  - mild/moderate dementia
- Why? Motivation: automated vehicles can prolong their mobility and independence
- How? Key functions that provide assistance for:
  - Identifying vehicle
  - Inputting trip information
  - Interacting with vehicle during emergency and normal operation



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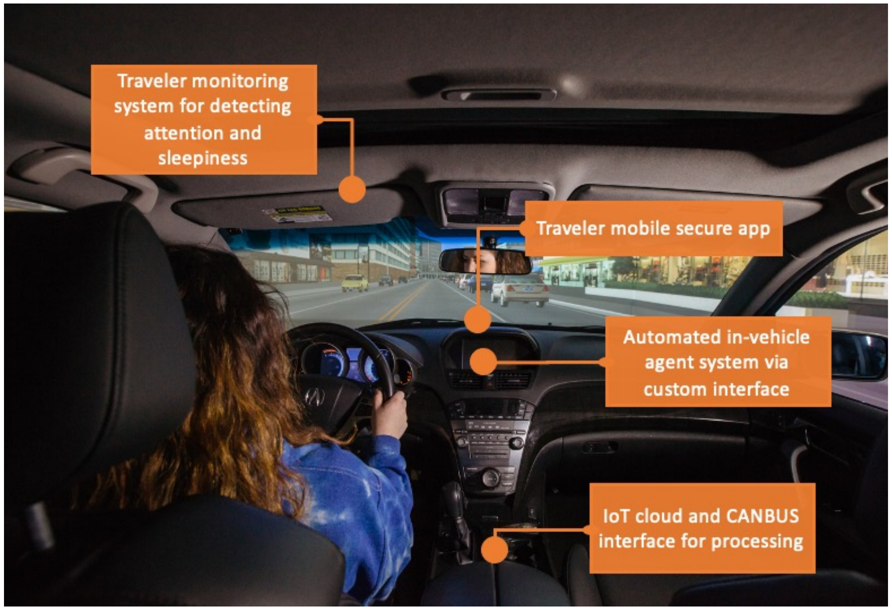
INCLUSIVENESS IN AUTOMATED VEHICLE DESIGN

1. Traveler Mobile Secure App
2. Traveler Monitoring System
3. Automated In-Vehicle Agent
4. IoT cloud and CANBUS interface for processing
5. Physical/software prototype integration



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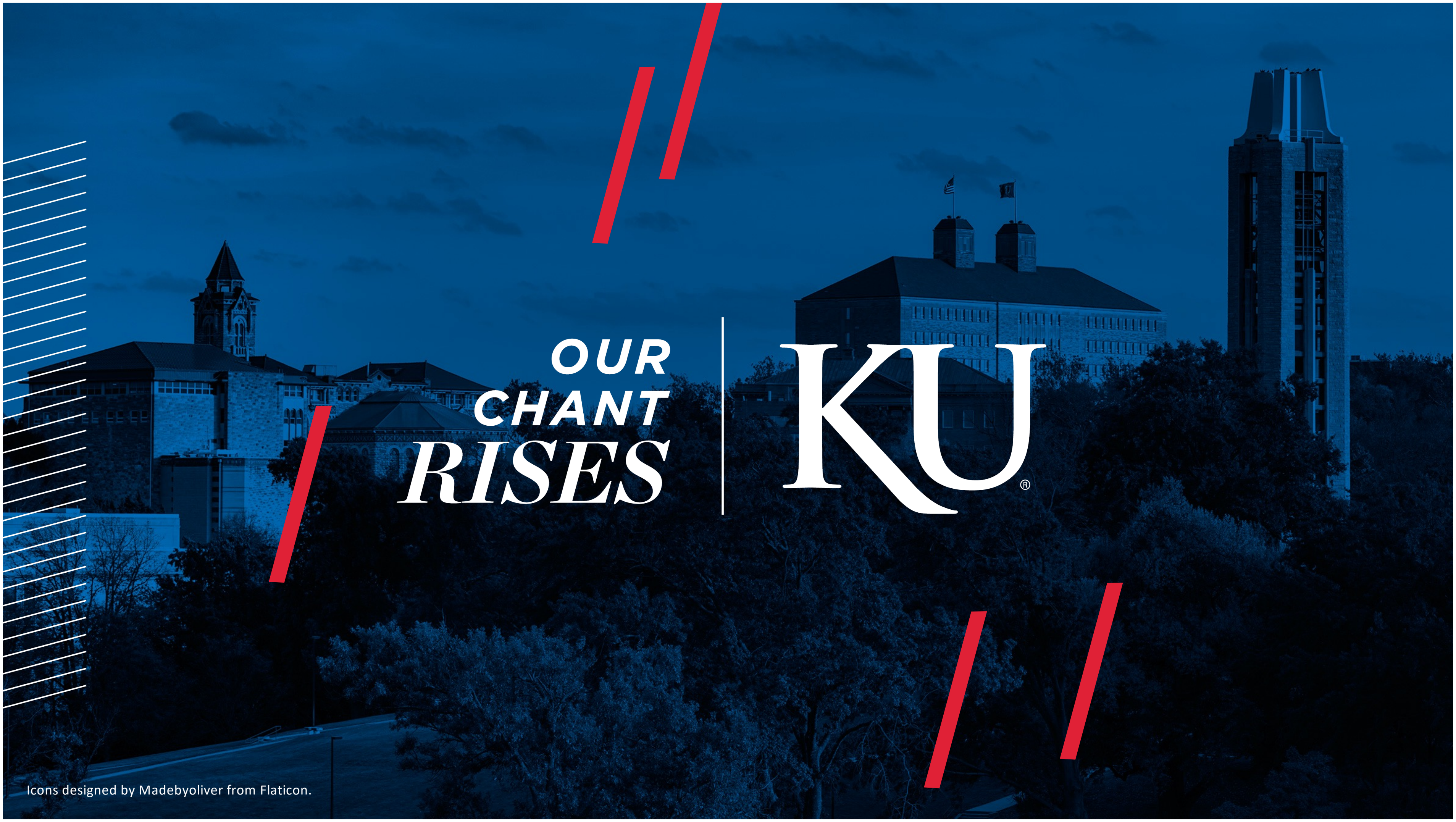
INCLUSIVENESS IN AUTOMATED VEHICLE DESIGN

1. Stage 1: conduct focus groups and interviews with SMEs, helthy older adults, older adults with MCI or mild/moderate dementia

2. Stage 2: conduct participatory design to develop prototypes

3. Stage 3: test prototypes and build demo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Icons designed by Madebyoliver from Flaticon.