Examining the safety effects of mixed-traffic with automated and human-driven vehicles

TexITE Houston Chapter

INTRODUCTION

What is an Autonomous Vehicle (AV) ?

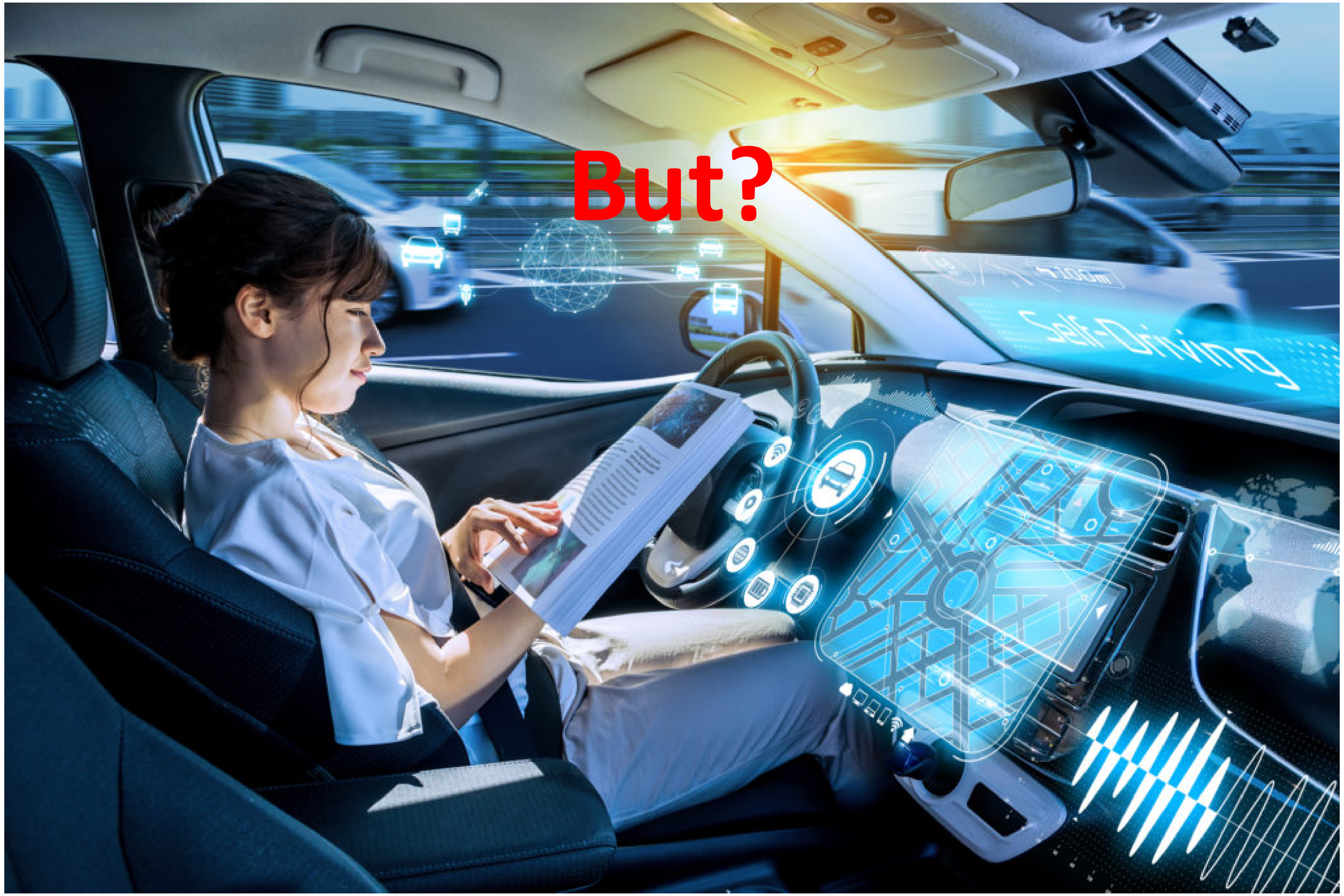
- Also called **self-driving or driverless cars**
- Cars that can move and guide itself without human input
- Example: **Google's Waymo**, which is a fully autonomous hybrid-minivan

Google's Waymo Autonomous Car

Potential Benefits of AVs

- **Increased safety** – Approximately 1.2 million people die in traffic accidents every year as 90% of serious crashes occur due to human error.
- **Better mobility and less traffic** – Autonomous cars can communicate with one and another and identify the most optimal route which could reduce congestion.
- **Reduced costs** – A NHTSA study showed motor vehicle crashes in 2010 cost $242 billion. Eliminating the vast majority of motor vehicle crashes could erase these costs.

INTRODUCTION



How will safety be affected before we get to fully automated vehicles?

https://innovationatwork.ieee.org/autonomous-vehicles-for-today-and-for-the-future/

Automated Vehicles Safety

Why People Keep Rear-Ending Self-Driving Cars

Human drivers (and one cyclist) have rear-ended self-driving cars 28 times this year in California—accounting for nearly two-thirds of robocar crashes.

In California alone, self-driving cars have been involved in nearly 50 crashes so far in 2018. Why are so many of them rear-ended? ANDREI STANESCU/ALAMY

https://www.wired.com/story/self-driving-car-crashes-rear-endings-why-charts-statistics/

Automated Vehicles Safety

ELSEVIER

Transportation Research Procedia
Volume 45, 2020, Pages 161-168

Traffic Accidents with Autonomous Vehicles: Type of Collisions, Manoeuvres and Errors of Conventional Vehicles' Drivers

Đorđe Petrović [a], Radomir Mijailović [a], Dalibor Pešić [a]

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Applying statistical analysis, we were found that the type of collision "rear-end" more often in traffic accidents with autonomous vehicles. Types of collisions "pedestrian" and "broadside" were less in traffic accidents with autonomous vehicles.

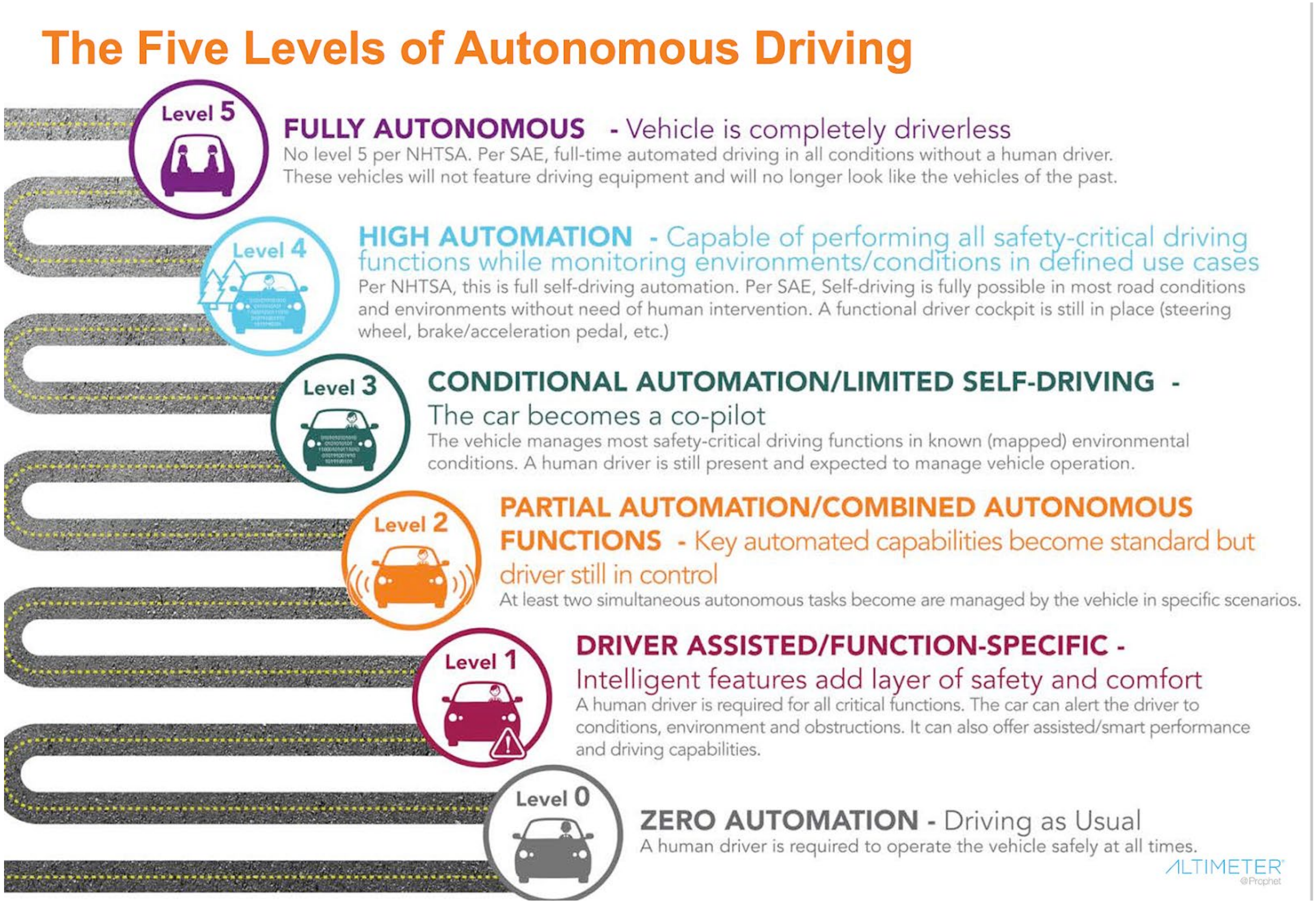
https://www.sciencedirect.com/science/article/pii/S2352146520301654

Automated Vehicles Safety

- Waymo reported 11 actual rear-end collisions involving its cars and one simulated collision. In eight of the actual collisions, another car struck a Waymo car while it was stopped; in two of the actual collisions, another car struck a Waymo car moving at slow speeds; and in one of the actual collisions, another car struck a Waymo car while it was decelerating. The simulated collision modeled a Waymo car striking a decelerating car.

https://venturebeat.com/2020/10/30/waymos-driverless-cars-were-involved-in-18-accidents-over-20-month/

Level of Automation



PROBLEM STATEMENT

To investigate if there is any mismatch between human drivers' expectations and AVs decisions in a car-following scenario at stop-controlled intersections

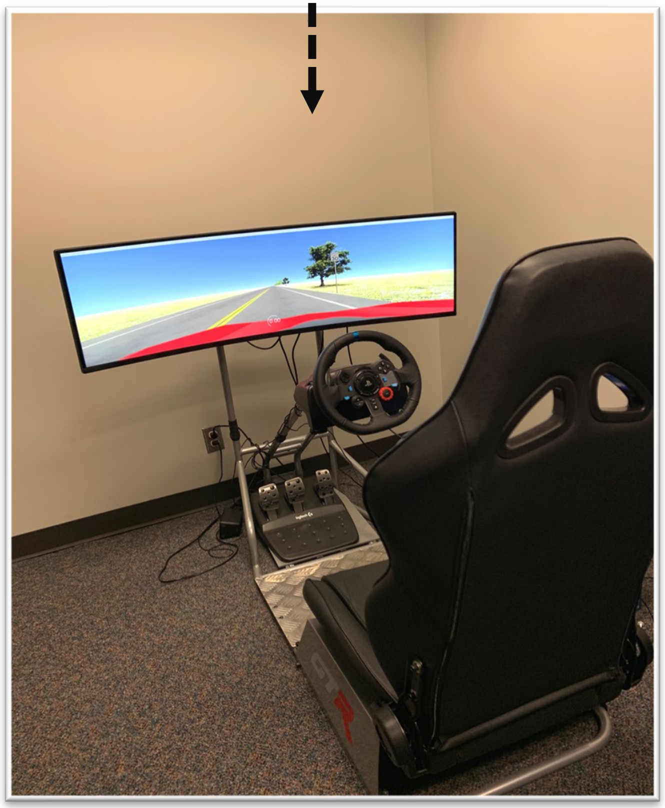
Project Objectives:

- **Examine the braking behavior** of participants in the following vehicle behind two different types of lead vehicles (designated AV and Human-like) while stopping at a stop-controlled intersection.
- **Analyze the acceleration behavior** of test participants and the two kinds of leading vehicles after stopping at the stop-controlled intersection.
- **Evaluate the performance of popular Surrogate Safety Measures (SSMs)** in detecting potential near-crash events (low and high risk).
- **Classify the potential near-crash events from the safe events** using a random forest classifier for two different data sampling techniques and examine significant factors influencing near-crashes.

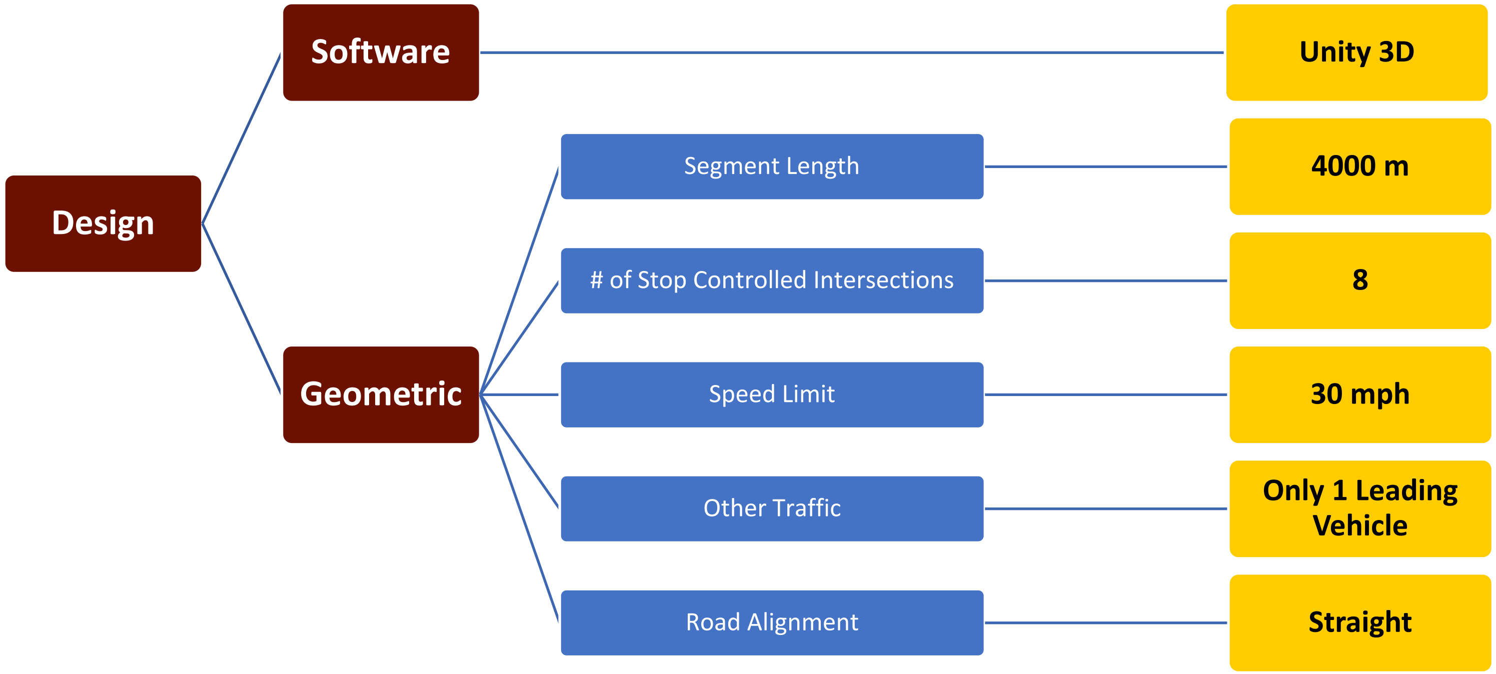
METHODOLOGY

Experiment Design

Driving Simulator



Simulation Environment



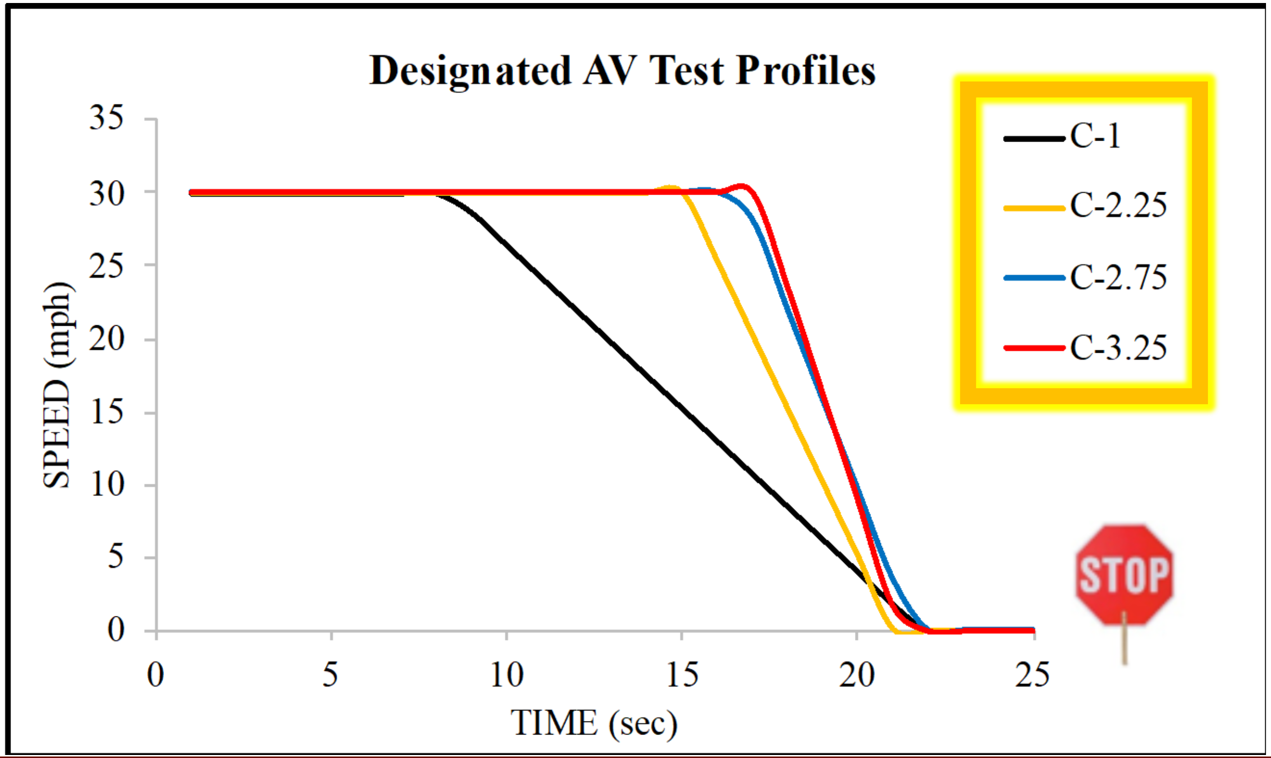
Test Car-Following Scenarios

Scenario 1

AV-Human

- Leading vehicle designated as an **AV**
- **24 participants** follow this leader — 12 males and 12 females recruited
- **4 designed test speed profiles**

Mean Age = 24.8 yrs
Std. Dev. = 2.43 yrs



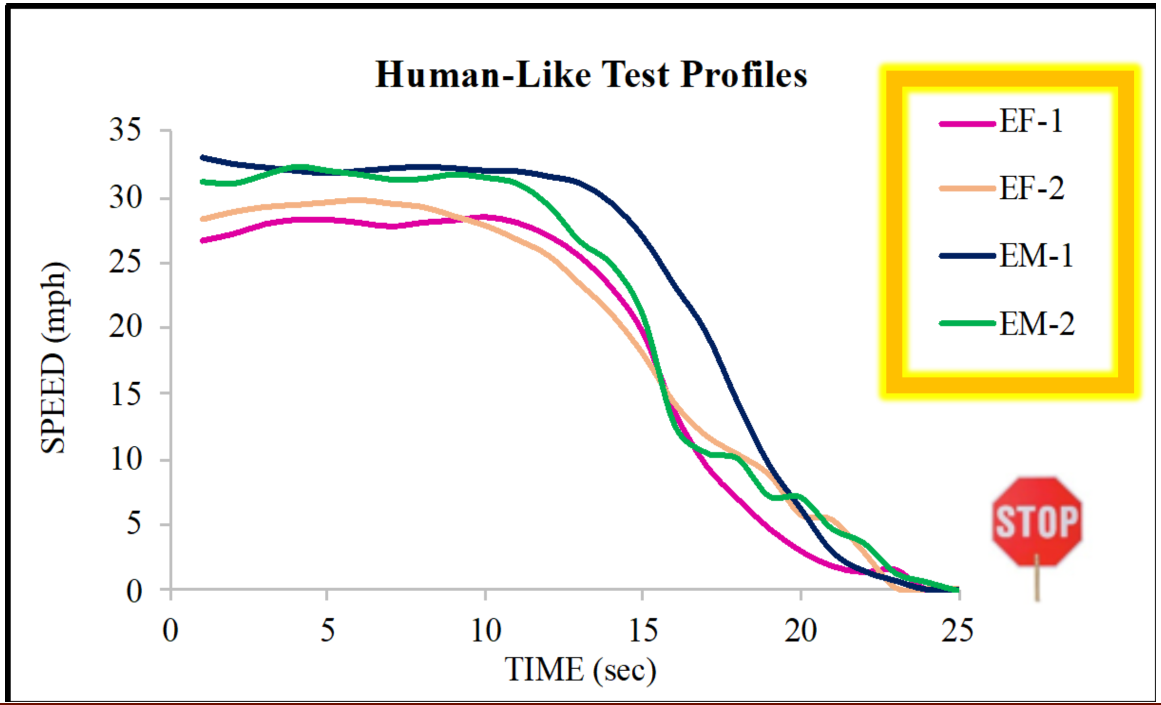
Profile	Max. Speed (mph)	Avg. Acceleration Rate (m/s^2)	Max. Deceleration Rate (m/s^2)
C-1	**30**	**0.5**	**-1**
C-2.25			**-2.25**
C-2.75			**-2.75**
C-3.25			**-3.25**

Test Car-Following Scenarios

Scenario 2

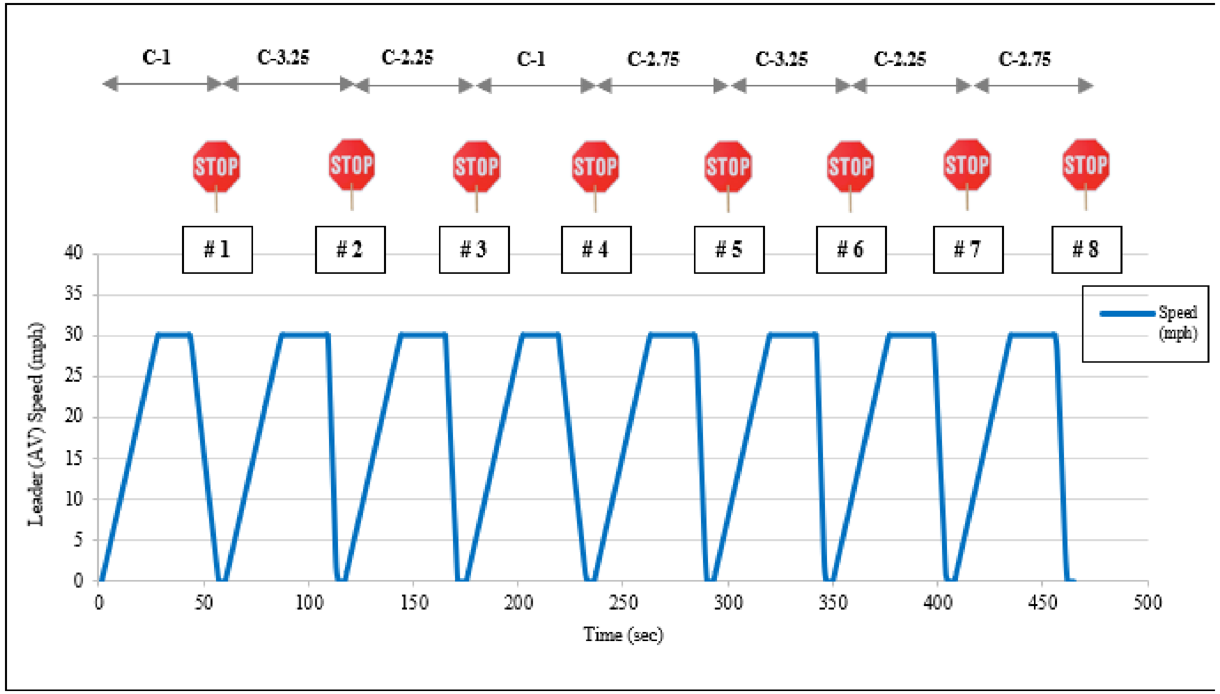
HUMAN-Human

- Leading vehicle is **HUMAN-like**
- **24 participants** follow this leader — 12 males and 12 females recruited (*Mean Age = 25.3 yrs*, *Std. Dev. = 2.12 yrs*)
- 4 speed profiles recorded from **4 human drivers**

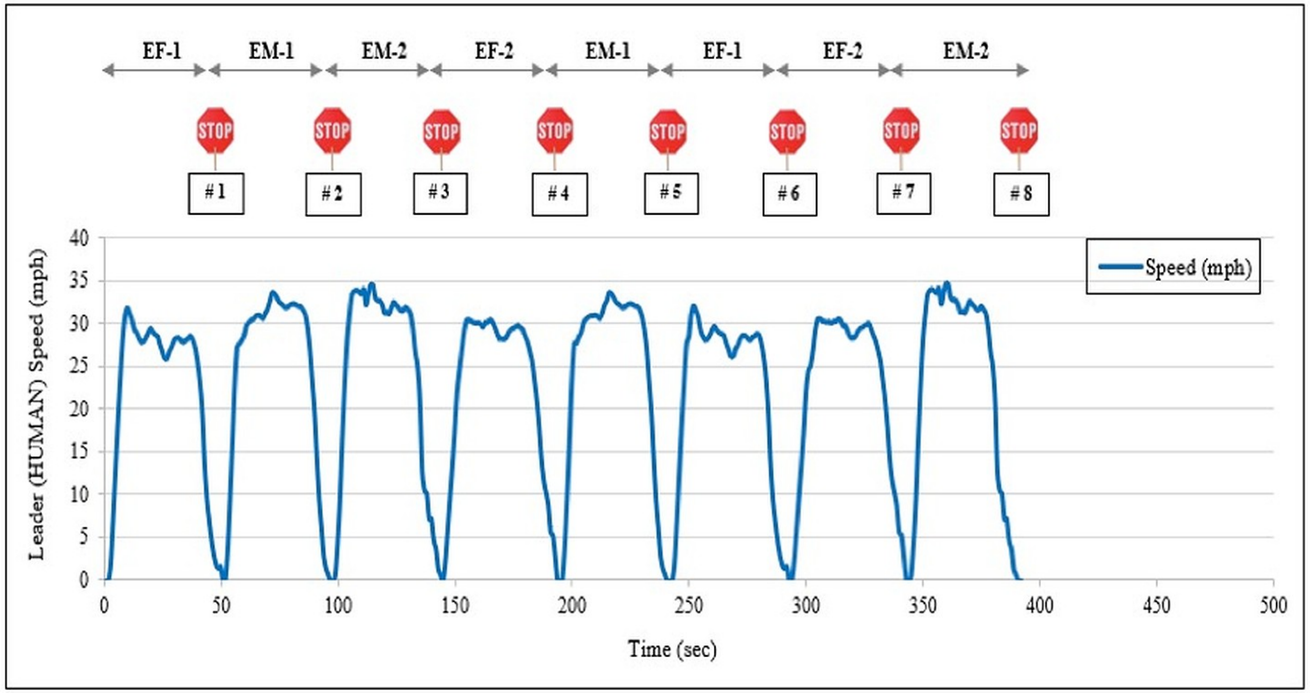


Profile	Extracted from	Max. Speed (mph)	Avg. Acceleration Rate (m/s²)	Max. Deceleration Rate (m/s²)
EF-1	Female	31.70	0.41	**-2.68**
EF-2	Female	30.40	0.42	**-1.68**
EM-1	Male	33.51	0.50	**-2.38**
EM-2	Male	34.47	0.46	**-3.73**

Designated AV Leader Speed Profile

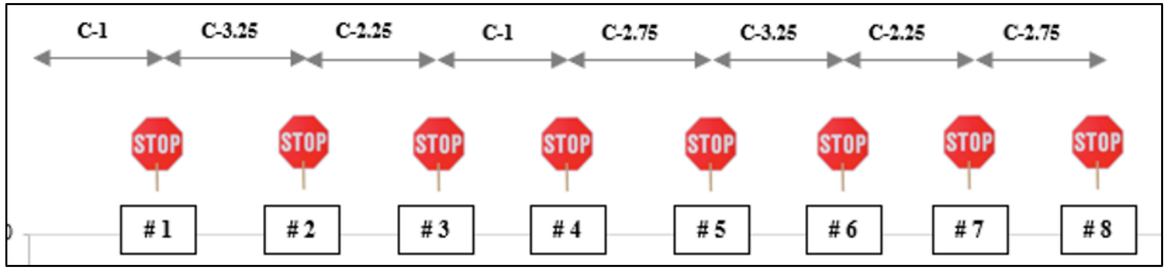


HUMAN-like Leader Speed Profile



❖ In both car-following scenarios, **one test speed profile is assigned to the leading vehicle** till it reaches a stop-controlled intersection

❖ After stopping at the intersection, **the profile is switched** to a different one

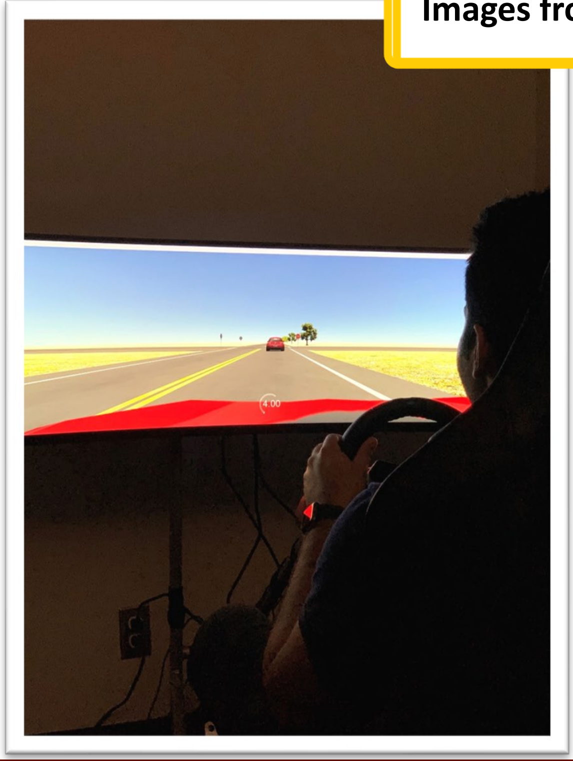


Experiment Procedure

Participant walks in → A 5-min trial run → Participant is **randomly assigned** to one of the two car-following scenarios → Participant follows the leading vehicle **(AV or HUMAN-like)**

Leading Vehicle in the car-following scenario

Images from the experiment



RESULTS: Descriptive Statistics

AV-Human (Scenario 1)

Descriptive Statistics

Variables	Units	Mean	Std. Dev.	Min.	Max.
Ego Speed	mph	**18.48**	11.21	0	47.65
Leader Speed	mph	**19.20**	10.88	0	30.00
Ego Acc./Dec.	m/s^2	-0.17	1.04	-8.00	3.00
Leader Acc./Dec.	m/s^2	0.02	0.79	-3.25	1.00
Clearance	m	**24.64**	23.36	-6.77	135.53

Correlation Matrix

Variables	Ego Speed	Leader Speed	Ego Acc./Dec.	Leader Acc./Dec.	Clearance
Ego Speed					
Leader Speed	**0.85**				
Ego Acc./Dec.	0.18	0.28			
Leader Acc./Dec.	-0.30	-0.10	0.29		
Clearance	0.32	0.33	0.15	-0.17	

- **A serious (uphill) positive correlation between the participants' and the AV leader's average speed**
- Potential reason: **Participants closely following the designated AV**

Descriptive Statistics

HUMAN-Human (Scenario 2)

Descriptive Statistics

Variables	Units	Mean	Std. Dev.	Min.	Max.
Ego Speed	mph	**21.36**	13.23	0.00	63.45
Leader Speed	mph	**22.11**	11.31	0.00	34.58
Ego Acc./Dec.	m/s^2	-0.31	1.49	-8.00	3.00
Leader Acc./Dec.	m/s^2	0.00	1.23	-8.00	3.00
Clearance	m	**46.06**	37.35	-1.70	139.94

Correlation Matrix

Variables	Ego Speed	Leader Speed	Ego Acc./Dec.	Leader Acc./Dec.	Clearance
Ego Speed					
Leader Speed	**0.50**				
Ego Acc./Dec.	0.37	0.42			
Leader Acc./Dec.	0.14	0.24	0.27		
Clearance	-0.31	-0.13	-0.23	0.09	

- **No serious correlation** between the participants' and the HUMAN-like leader's **average speed**
- Participants **closely followed the designated AV leader** (approx. half the average clearance in the other scenario)
- **Faster ego speeds** while following the human-like leader

Two sample T-tests

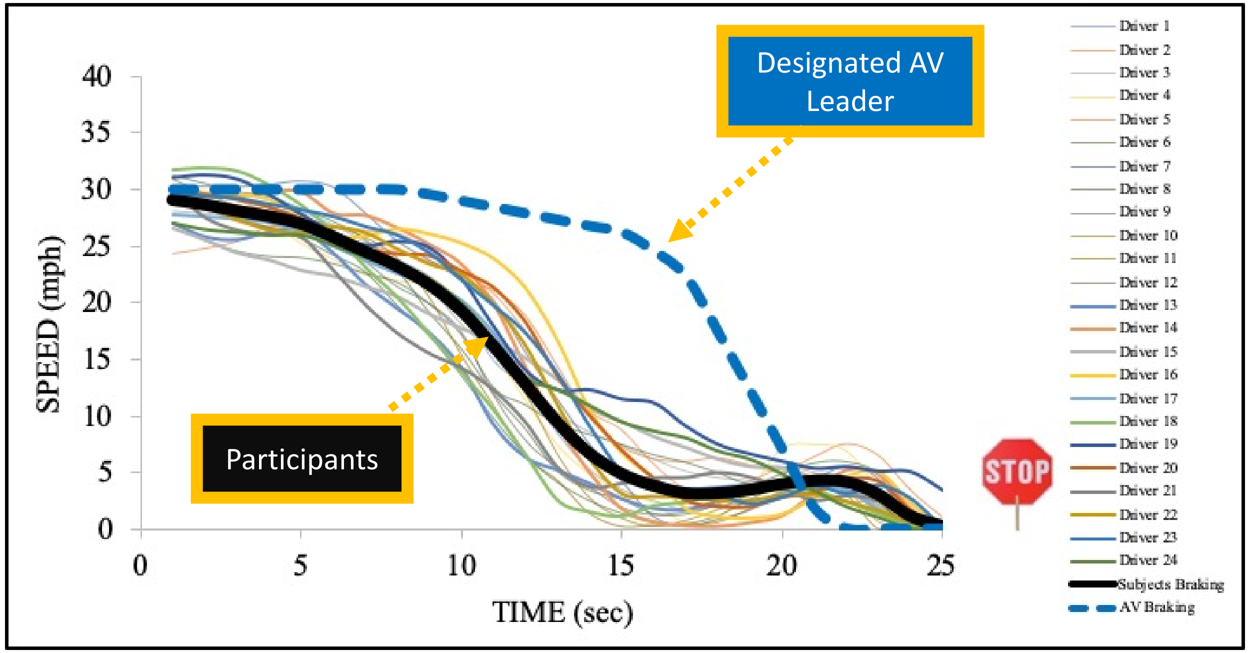
Overall	Participants Driving in	Mean	Std. Dev.	t-value	Two-tailed p-value	Different ($p < 0.05$)
Avg. Clearance (m)	Scenario 1	**24.64**	23.36	48.50	< 0.0001	Yes
	Scenario 2	**46.06**	37.35			
Avg. Ego Speed (mph)	Scenario 1	**18.48**	11.21	16.22	< 0.0001	Yes
	Scenario 2	**21.36**	13.23			

Data in each scenario is coming from 24 participants

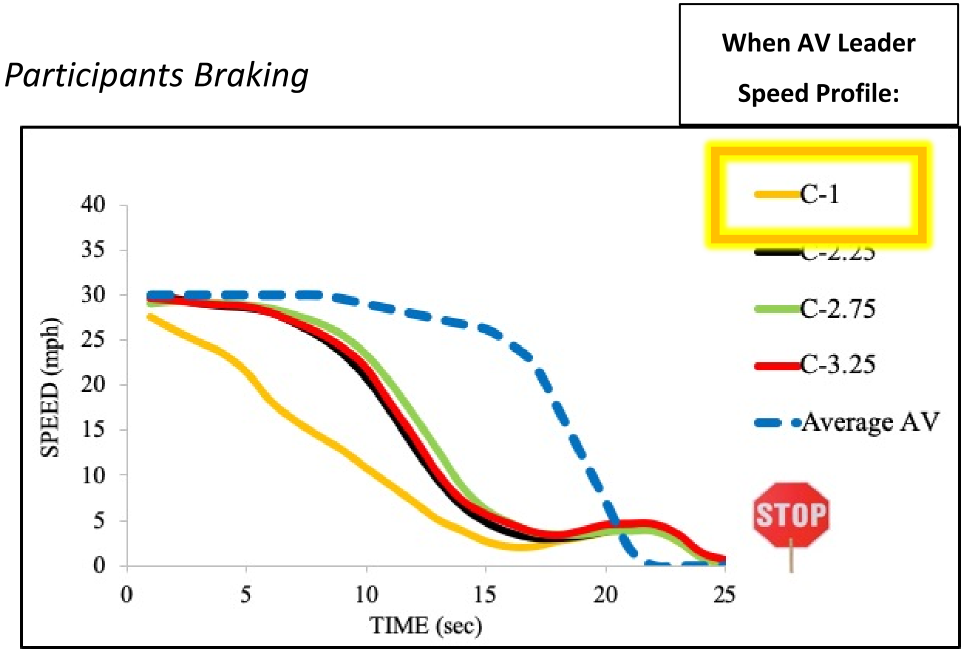
** Two-sample t-tests were performed with significance level set to 5%*

Braking Comparison (Scenario 1)

Braking Comparison: Participants vs AV



Participants Braking



- There is a **difference** in the **average braking speeds of the participants and the designated AV**

- **Significant difference** in the braking speeds of the **participants** following the AV leader braking with **C-1 profile, and the average AV.**

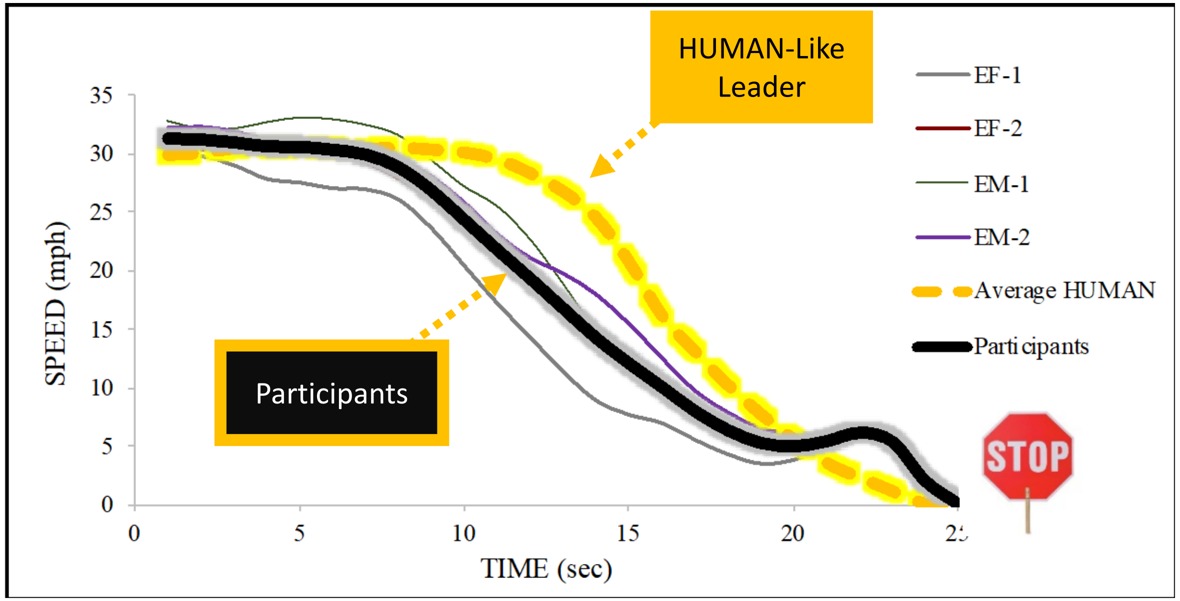
Two-tailed p-value = ***0.0396* < 0.05*** *(t=2.10; std. error = 0.28)*

Two-tailed p-value = ***0.0007* < 0.05*** *(t=3.63; std. error = 2.98)*

*Scenario 1: AV leader and Scenario 2: Human-like Leader; * Two-sample t-tests were performed with significance level set to 5% Data in each scenario is coming from 24 participants*

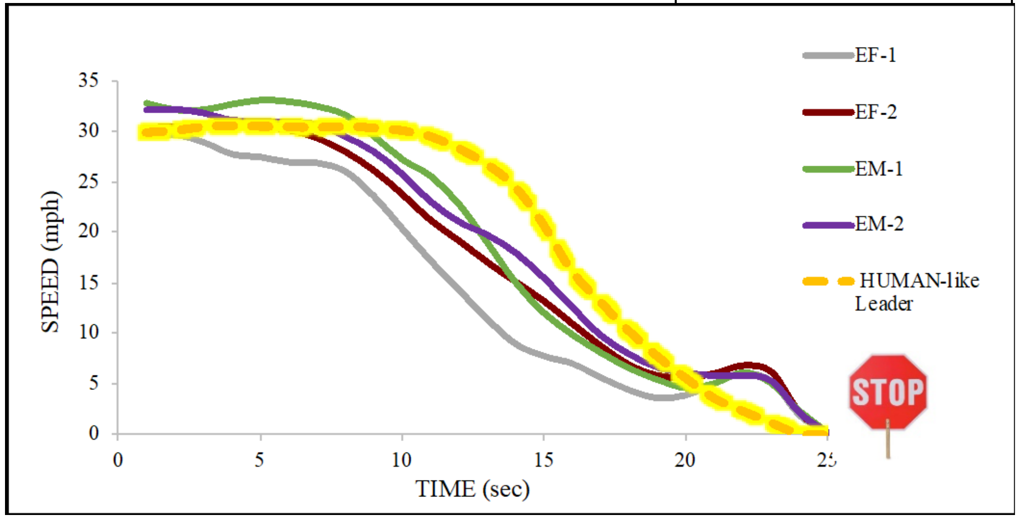
Braking Comparison (Scenario 2)

Braking Comparison: Participants vs Human-Like Leader



Participants Braking

When HUMAN-Like Leader Speed Profile:



- There is **no difference** in the **average braking speeds of the participants and the HUMAN-like leader**

  *Two-tailed p-value = **0.85 > 0.05***

- **No difference** in the braking speeds of the **participants**, and **the HUMAN-like leader.**

  *Two-tailed p-value = **0.0007* < 0.05***

Parameters	Participants Driving in	Mean	S.D.	t-value	p-value	Different ($p < 0.05$)
Avg. Clearance During Braking (m)	Scenario 1	**19.56**	10.10	2.73	0.008	**Yes**
	Scenario 2	**30.81**	17.44			

- **Participants** in the following vehicle performed braking maneuvers **behind the designated AV at relatively short clearances**

*Scenario 1: AV leader and Scenario 2: Human-like Leader; * Two-sample t-tests were performed with significance level set to 5% Data in each scenario is coming from 24 participants*

Risk Analysis

Identify Potential Conflict Events using Six SSMs

Detect Potential Near-Crash Events

SSMs Performance

Classify Safe and Potential Near-Crash Events

Quantify Significant Factors

Potential Conflict Events

When the assigned threshold of any one or more surrogate measures gets violated at any time instant of car-following by the following vehicle, the instant is characterized as **a 'Potential Conflict Event'**

Parameters	AV-Human	HUMAN-Human
No. of Potential Conflict Events	670	780
Avg. Ego Speed (mph)	**18.41**	**23.26**
Avg. Leader Speed (mph)	**12.51**	**14.69**
Avg. Ego Acceleration/Deceleration (m/s^2)	-0.65	-0.70
Avg. Leader Acceleration/Deceleration (m/s^2)	-1.23	-0.82
Avg. Clearance (m)	**12.19**	**15.44**

Identify Potential Conflict Events using Six SSMs

Detect Potential Near- Crash Events

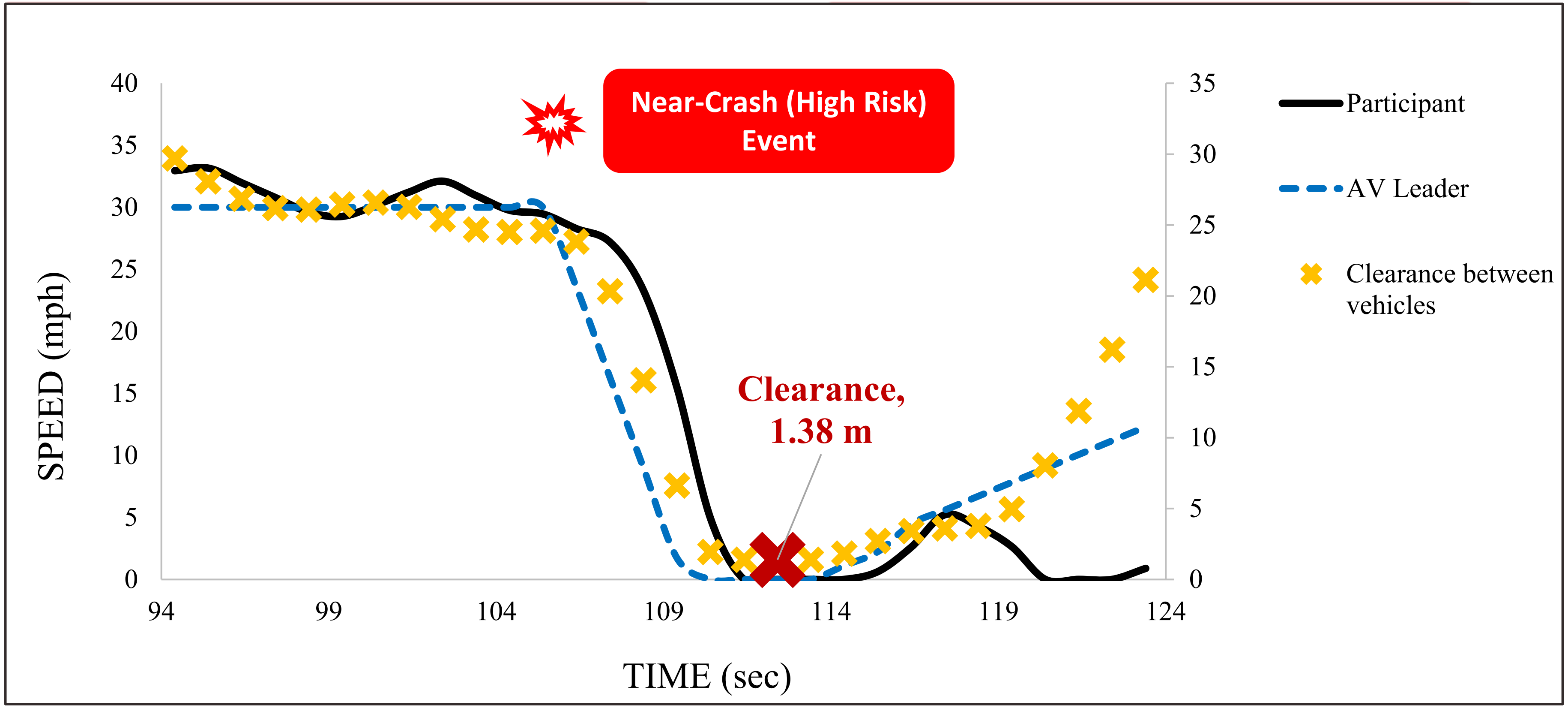
SSMs Performance

Classify Safe and Potential Near-Crash Events

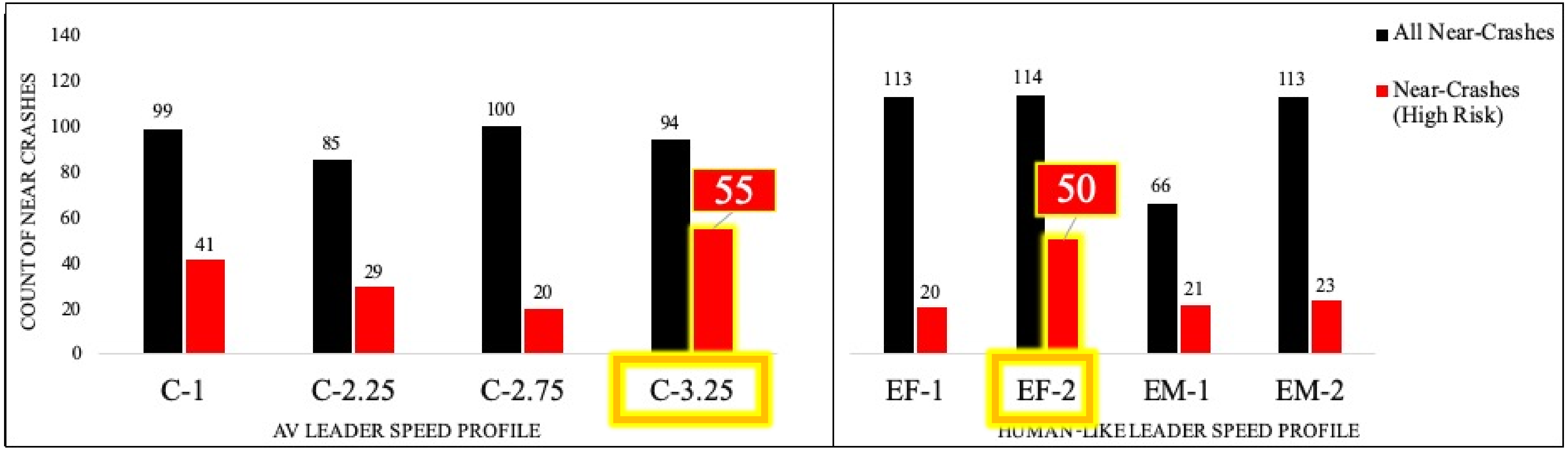
Quantify Significant Factors

Potential Near-Crash Events

- Low Risk — Clearance < 4 m
- **High Risk** — Clearance < 2 m



- Identify Potential Conflict Events using Six SSMs
- **Detect Potential Near- Crash Events**
- SSMs Performance
- Classify Safe and Potential Near-Crash Events
- Quantify Significant Factors



Near-Crashes	AV-Human	HUMAN-Human
	378	406

Near-Crashes	Males	Females
All	342	442
High Risk	88	171

- Allocating the **AV leader with C-3.25** profile in scenario 1 led to the **highest number of near-crashes (high risk) events**
- A similar count was seen when the **HUMAN-like leader** was driving with **EF-2 profile** ahead of the participants

Identify Potential Conflict Events using Six SSMs

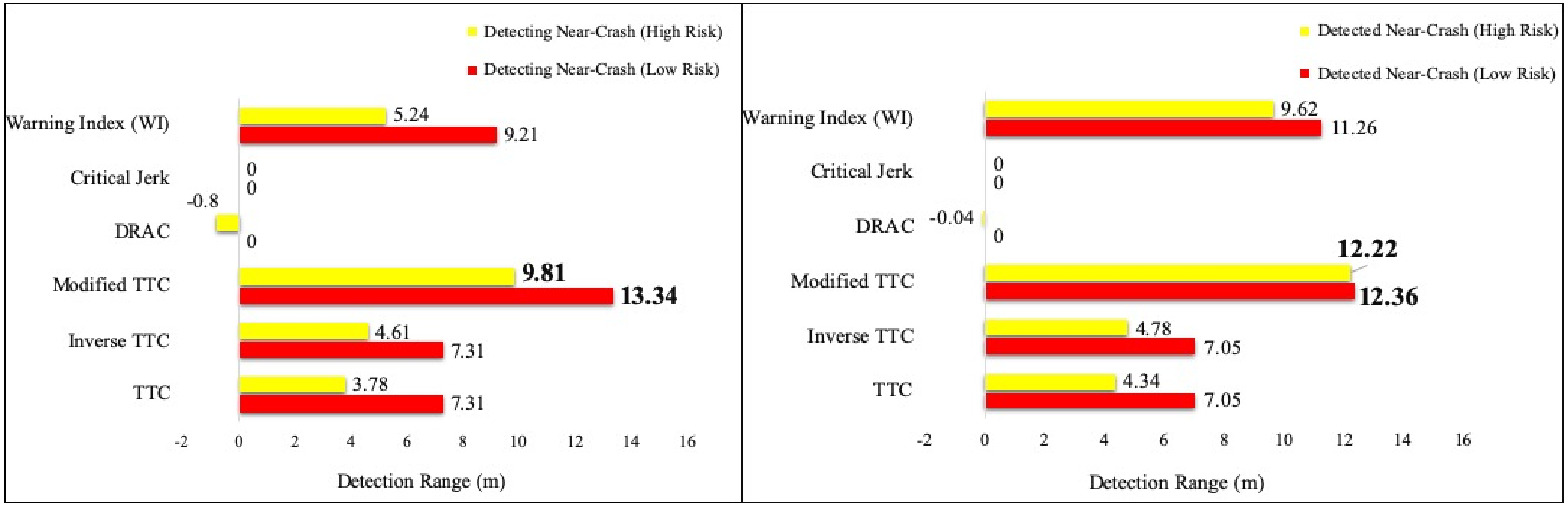
Detect Potential Near- Crash Events

SSMs Performance

Classify Safe and Potential Near-Crash Events

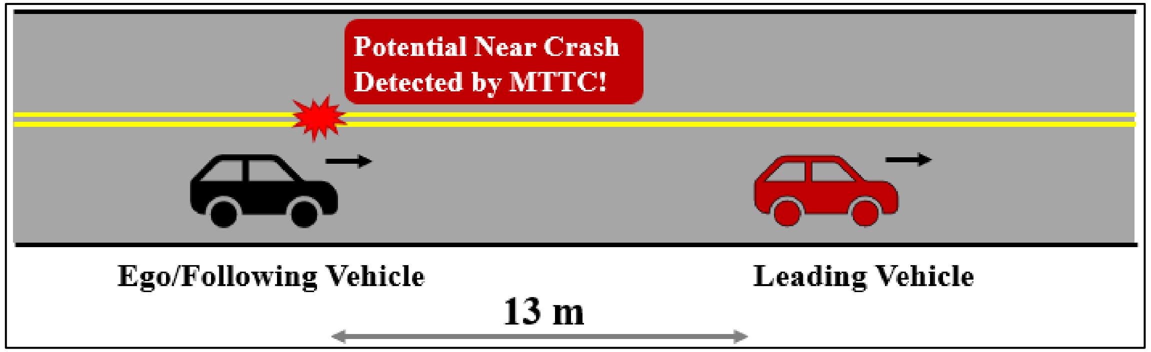
Quantify Significant Factors

Near Crash Detection Range of SSMs



- **MTTC's** near-crash event detection range (%): ~ **13 m**
- **MTTC's** near crash (high risk) event detection range (%): ~ **11 m**

Illustration:



Significant Factors Affecting Potential Near-Crash Classification

- Identify Potential Conflict Events using Six SSMs
- Detect Potential Near- Crash Events
- SSMs Performance
- Classify Safe and Potential Near-Crash Events
- **Quantify Significant Factors**

Derived from Undersampled data

- Based on **Mean Decrease Gini** *(RF algorithm)*
- For **AV-Human** scenario ⟶ Most significant: **Leader Acceleration/Deceleration**
- For **HUMAN-Human** scenario ⟶ Most significant: **Clearance between vehicles**
- **Logistic regression on the undersampled datasets** validated these findings

Logistic Regression Model:

R^2	Misclassification Rate
0.86	0.04

Term	Estimate	Std Error	Chi Square	Prob>Chi Sq.
Intercept	0.568617	0.5313891	1.15	0.2846
Long. Position	0.00024389	0.00017	2.06	0.1514
Clearance	-0.3908231	0.0478443	66.73	<.0001*
Relative Speed	1.43818486	0.1853836	60.18	<.0001*
Ego Acc.	0.90320181	0.1866967	23.40	<.0001*
Leader Acc.	-2.4457863	0.2842191	74.05	<.0001*
Gender	0.95224009	0.4071718	5.47	0.0194*

Predictor	Contribution	Rank
Leader Acc.	50.8467	1
Relative Speed	35.1829	2
Clearance	18.0660	3
Ego Acc.	12.5391	4
Long Position	9.8693	5
Gender	2.5092	6

Significant Factors Affecting Potential Near-Crash Classification

- Identify Potential Conflict Events using Six SSMs
- Detect Potential Near- Crash Events
- SSMs Performance
- Classify Safe and Potential Near-Crash Events
- **Quantify Significant Factors**

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- Based on **Mean Decrease Gini** *(RF algorithm)*
- For **AV-Human** scenario → Most significant: **Leader Acceleration/Deceleration**
- For **HUMAN-Human** scenario → Most significant: **Clearance between vehicles**
- **Logistic regression on the undersampled datasets** validated these findings

Logistic Regression Model:

R^2	Misclassification Rate
0.83	0.04

Term	Estimate	Std Error	Chi Square	Prob>Chi Sq.
Intercept	1.174	0.446	6.919	0.0085*
Long Position	0.000	0.000	0.913	0.3394
Clearance	-0.296	0.033	79.949	<.0001*
Gender	0.081	0.335	0.059	0.8087
Ego Speed	0.457	0.054	70.287	<.0001*
Leader Speed	-0.431	0.052	70.116	<.0001*
Ego Acc./Dec.	0.554	0.097	32.378	<.0001*

Predictor	Contribution	Rank
Clearance	29.7922	1
Leader Acc.	23.8478	2
Leader Speed	19.2116	3
Ego Speed	14.3613	4
Ego Acc.	7.5258	5
Long. Position	3.4342	6

CONCLUSIONS

- Braking behavior analysis indicated a **mismatch in the overall braking pattern** of the participants and the **designated AV leader.** However, **no such mismatch** between the participants and the human-like leader.

- Participants accelerated at **much faster rates (1.25 m/s^2)** after stopping at the stop-controlled intersections **than the designated AV (0.5 m/s^2)**. These rates resembled the rates when the participants followed the human-like leader.

- **MTTC outperformed** other five SSMs by **anticipating the near-crashes 10 seconds before their occurrence** at a range of ~13 m in the two car-following test scenarios.

- Participants in **Scenario 1 were more likely to be involved in near-crashes involving high risk** (145) with the **designated AV leader** than with the human-like leader in Scenario 2 (112).

- The participants showed a **higher tendency of near-crash involvement** while following the **AV leader** designated with **C-3.25 profile** and the **human-like leader** with **EF-2 profile**.

- **RF classifiers on the undersampled data** achieved the highest accuracy rates in predicting and classifying the potential near-crash events.

- **AV leader's acceleration/deceleration** in Scenario 1, and **clearance between vehicles** in Scenario 2 emerged as the most significant in potential near crash events classification

Thank you!

Questions?