METRICS AND ASSUMPTIONS IN SAFETY ASSURANCE

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<u>Special thanks & Content Credit to:</u>
IEEE P2846 WG
SAE ORAD V&V TF
Institute for Automated Mobility

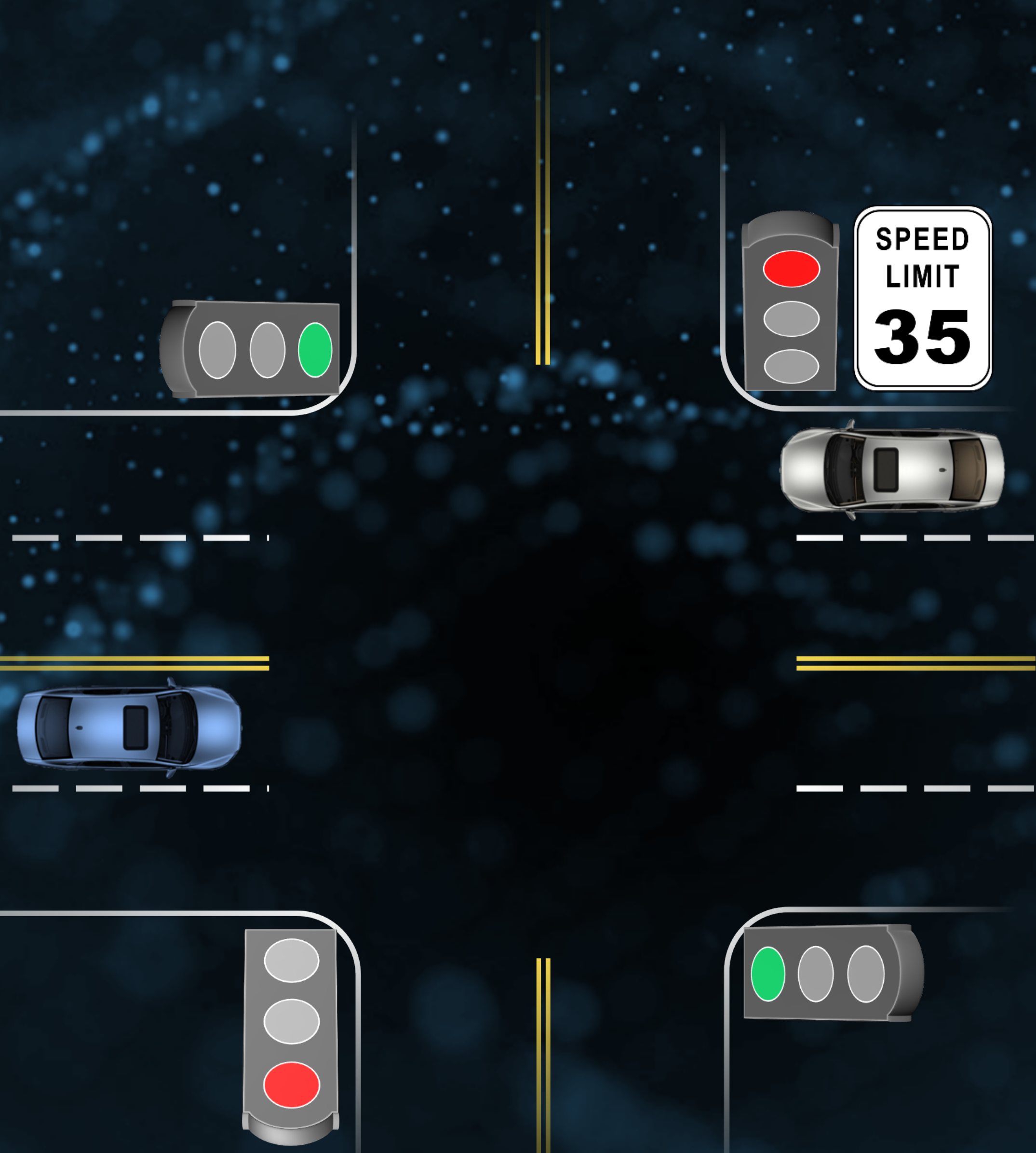
What does “Driving Safely” mean?

EXPLICIT TRAFFIC RULES

Establish **priority of road agent interests** to avoid collisions

- Come to complete stop at red lights
- Don't cross a double-yellow line
- Obey posted speed limits
- Yield to other road users when posted

Set limits on vehicle operation



IMPLICIT RULES OF THE ROAD

A **general set of principles** applied by the driver

- Keep a safe distance from the car in front of you
- Drive cautiously under limited visibility
- Don’t drive slow in the fast lane
- Don’t cut off other drivers

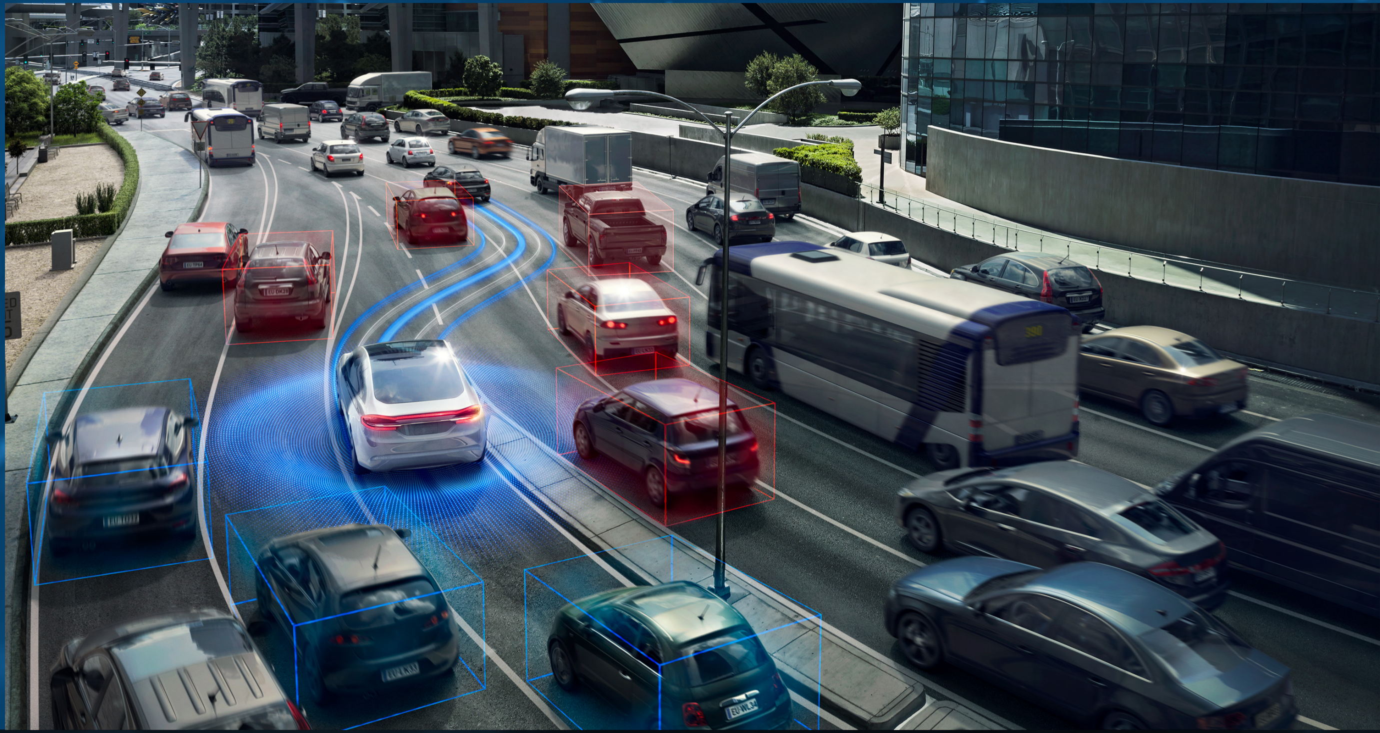
Flexible, culturally dependent

RESPONSIBILITY SENSITIVE SAFETY

RSS digitizes the implicit rules of the road, **providing a check on AV decision-making, and a technology-neutral performance benchmark for regulators**

An open, transparent, technology neutral **safety model** for autonomous driving

Flexible, culturally tunable



RULES OF RSS

RULES TO DRIVE SAFELY

1. Do not hit someone from behind
2. Do not cut-in recklessly
3. Right-of-Way is given, not taken
4. Be careful in areas with limited visibility
5. If you can avoid a crash without causing another, you must

Metrics are needed for Implicit Rules of the Road

SAE ORAD Validation and Verification Task Force

Charter: *Definitions, information, best practices, and testing methodologies to support the V&V of Automated Driving Systems (ADSs), as defined in SAE Standard J3016, sufficient to give consumers, industry, and governments confidence in the functionality and safety of ADSs.*

J3016: Safety Principles for Automated Driving Systems

- **Developmental**
- **Design and Operation**
- **Deployment**

→

J3XXX: Metrics for operational performance competency Assessments in the verification and validation of automated driving system

Metrics are needed for Implicit Rules of the Road

IAM Institute *of* Automated Mobility

Shaping the future of transportation safety, science, and policy

Proposed Metrics for ADS-Equipped Vehicles

2020-01-1206 Published 14 Apr 2020

SAE INTERNATIONAL

Driving Safety Performance Assessment Metrics for ADS-Equipped Vehicles

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Citation: Wishart, J., Como, S., Elli, M., Russo, B. et al., "Driving Safety Performance Assessment Metrics for ADS-Equipped Vehicles," SAE Technical Paper 2020-01-1206, 2020, doi:10.4271/2020-01-1206.

Abstract

The driving safety performance of automated driving system (ADS)-equipped vehicles (AVs) must be quantified using metrics in order to be able to assess the driving safety performance and compare it to that of human-driven vehicles. In this research, driving safety performance metrics and methods for the measurement and analysis of said metrics are defined and/or developed.

A comprehensive literature review of metrics that have been proposed for measuring the driving safety performance of both human-driven vehicles and AVs was conducted. A list of proposed metrics, including novel contributions to the literature, that collectively, quantitatively describe the driving safety performance of an AV was then compiled, including proximal surrogate indicators, driving behaviors, and rules-of-the-road violations. These metrics, which include metrics

and the quantification of key aspects of driving safety performance. The identification and exploration of metrics focusing explicitly on AVs as well as proposing a comprehensive set of metrics is a unique contribution to the literature. The objective is to develop a concise set of metrics that allow driving safety performance assessments to be effectively made and that align with the needs of both the ADS development and transportation engineering communities and accommodate differences in cultural/regional norms.

Concurrent project work includes equipping an intersection with a sensor suite of cameras, LIDAR, and RADAR to collect data requiring off-board sources and employing test AVs to collect data requiring on-board sources. Additional concurrent work includes development of artificial intelligence and computer vision-based algorithms to automatically calculate the metrics using the collected data. Future work

Phase 1: Metrics Definition

- 50+ papers reviewed
- Defined set is a mix of existing, adapted, and novel metrics
- Each metric has:
  1. Definition
  2. Data Source Taxonomy
  3. Subjectivity Taxonomy
  4. Observable Variables
  5. Formulation
  6. Subjective Assumptions/Thresholds
  7. Origin
  8. Justification for Inclusion

Minimum Safe Distance-Related	Universal	Grey Box Testing	Traffic Engineering-Related
Minimum Safe Distance Violation	Collision Incident	Human Traffic Control Violation Rate	Time-to-Collision
Proper Response Action	Rules-of-the-Road Violation	Human Traffic Control Detection Error Rate	Modified Time-to-Collision
Minimum Safe Distance Factor		ADS Active	Post-Encroachment Time
		Achieved Behavioral Competency	Aggressive Driving
		Minimum Safe Distance Calculation Error	

Minimum Safe Distance Violation (MSDV)

- **Definition**: Minimum Safe Distance Violation (MSDV) is defined as an instance in which the actions of the ego vehicle result in encroaching upon its safe boundaries with another (safety-relevant) entity within the scenario environment, as defined by current velocities and acceleration capabilities of both entities. The safety boundaries (aka safety envelope) are defined by clear lateral and longitudinal distances defined by the RSS model that the vehicle should maintain towards surrounding road users in order to prevent the ego-vehicle to be the cause of a road accident.
- **Formulation**: mainly Sections 3.1, 3.3 and 3.4 from RSS:

$$MSDV' = \begin{cases} 1 & if\ d^{lat} < d_{min}^{lat} \ \wedge\ d^{long} < d_{min}^{long^*} \\ 0 & else \end{cases}$$

$$MSDV = \begin{cases} 1 & if\ MSDV = 1\ \wedge\ Originated\ by\ ego\ vehicle \\ 0 & else \end{cases}$$

Proper Response Action (PRA)

- **Definition**: Proper Response Action (PRA) is defined as an instance of an action (longitudinal and/or lateral acceleration) taken by the ego vehicle to restore itself to its calculated safety boundaries after a safe distance violation has occurred. The PRA must occur at a pre-determined time and rate in order to be deemed a sufficient response.
- **Formulation:**

$$PRA = \begin{cases} 1 \quad if\ MSDV' = 1\ \wedge \begin{pmatrix} a^{lat} \notin [a^{lat}_{min,accel}, a^{lat}_{max,accel}]\ \vee \\ a^{long} \notin [a^{long}_{min,accel}, a^{long}_{max,accel}] \end{pmatrix} \\ 0 \quad else \end{cases}$$

Minimum Safe Distance Factor (MSDF)

- **Definition:** Minimum Safe Distance Factor (MSDF) is defined as a multiple of the minimum lateral and longitudinal safe distances maintained by an ego vehicle from surrounding entities. It is the ratio of measured distances (lateral and longitudinal) to the calculated safe distances (lateral and longitudinal).
- **Formulation:**

$$MSDF^{lat} = \frac{d^{lat}}{d_{min}^{lat}}$$

$$MSDF^{long} = \frac{d^{long}}{d_{min}^{long}}$$

Human Traffic Control Detection Error Rate (HTCDER)

- **Definition:** Human Traffic Control Detection Error Rate (HTCDER) is a confirmation that the ego vehicle can detect the direction(s) of a human traffic control (HTC) actor (which may include a direction to violate one or more rules of the road).
- **Formulation:**
- $HTCDER = \frac{GTI - CDI}{GTI}$
- $GTI = Number\ of\ Ground\ Truth\ Instructions$
- $CDI = Number\ of\ Correctly\ Detected\ Instructions$

But what are we really measuring?

Assumptions!

IEEE P2846: ASSUMPTIONS FOR MODELS IN SAFETY-RELATED AV BEHAVIOR

Assumptions in safety models are at the heart of an AV's ability to "drive safely"

Ex: What should an AV assume is the maximum braking of a leading car?

Ex: What should an AV assume is the maximum velocity of an occluded pedestrian?

Industry and Government must align on what are the reasonable and foreseeable assumptions that an AV's safety model should use when operating in the real world.

Scope: Required minimum set of assumptions along with informative attributes of safety models, verification methods, and an example model conformant with the standard.

Members: >25 Entities, representing OEM's, MaaS Providers, Tier 1's, Suppliers, Universities and Governments, globally!

Contributions: RSS, SFF, Rulebook and more.

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Qi Hommes
Waymo

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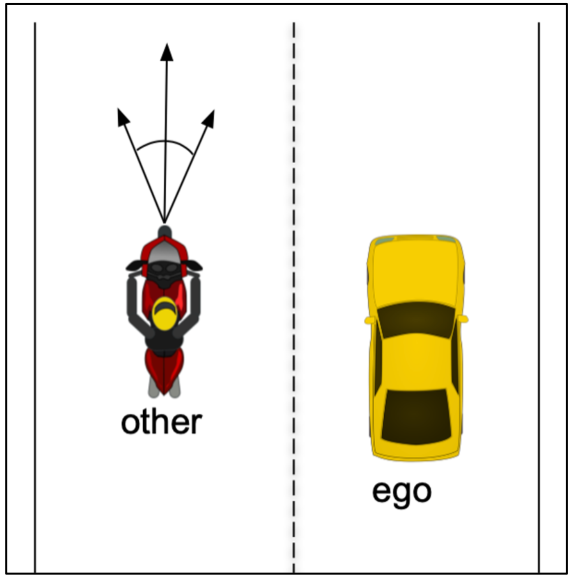
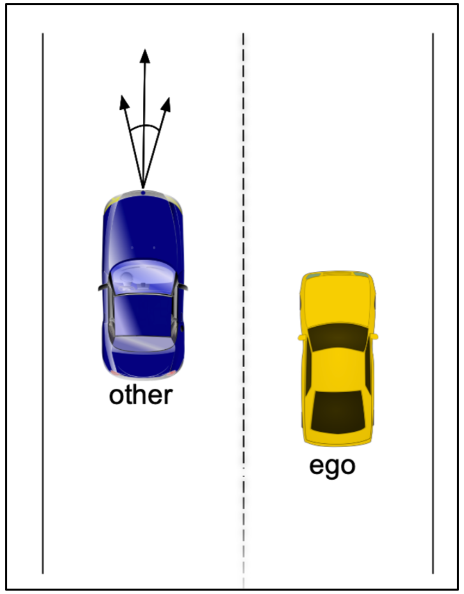
FUNCTIONAL SCENARIO 1: MAINTAINING LATERAL CLEARANCE

No other agent is drifting or cutting into ego lane

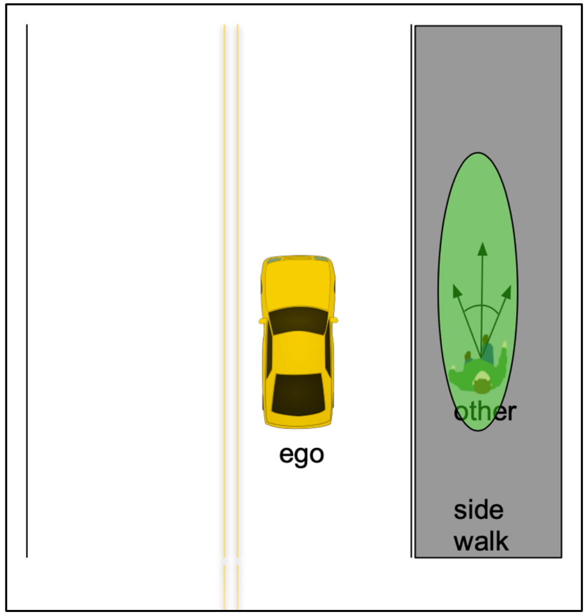
Lateral Velocity	$\lvert vel^{lat}(t)\rvert \leq vel^{lat}_{\max}$
Lateral Acceleration	$\lvert acc^{lat}(t)\rvert \leq acc^{lat}_{\max}$
Lateral Deceleration	$\lvert decel^{lat}(t)\rvert \geq decel^{lat}_{\min}$
Heading	$\lvert h(t)\rvert \leq h_{\max}$
Heading rate change	$\lvert h'(t)\rvert \leq h'_{\max}$



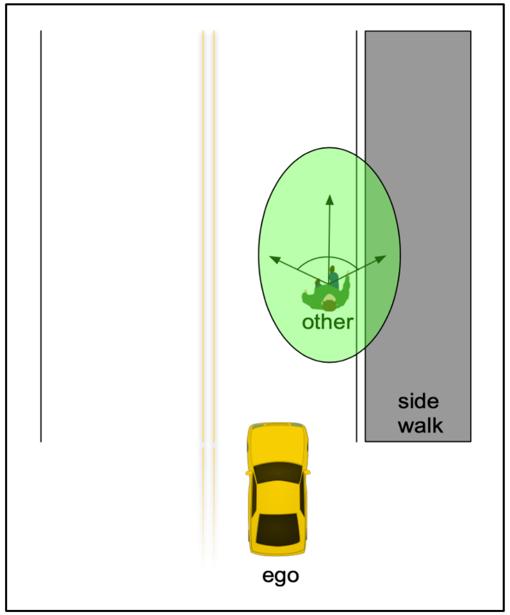
Motorcycle/Cyclist



Vehicle



Pedestrian on the sidewalk

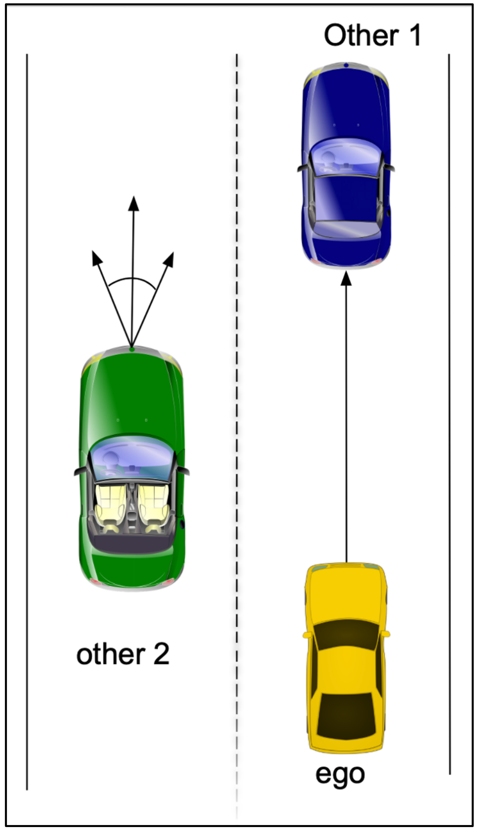


Pedestrian (already) on the road

Note: Lateral movement w.r.t a lane coordinate system

FUNCTIONAL SCENARIO 2: FOLLOWING WITHOUT TAILGATER

Front collision is avoidable, no evasive maneuver required. No tailgater, no other potential cut-ins from nearby vehicles, no VRU's, etc.



Other 1

Longitudinal Velocity	$\lvert v^{lon}(t)\rvert \leq v_{\max}^{lon}$
Longitudinal Acceleration	$\lvert acc^{lon}(t)\rvert \leq acc_{\max}^{lon}$
Longitudinal Deceleration	$\lvert decel^{lon}(t)\rvert \leq decel_{\max}^{lon}$

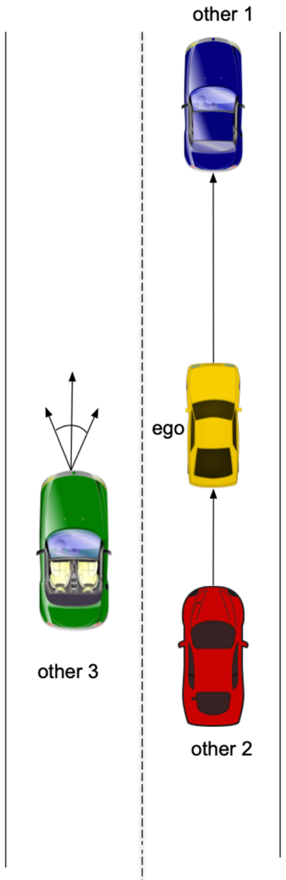
Other 2

Lateral Velocity	$\lvert vel^{lat}(t)\rvert \leq vel_{\max}^{lat}$
Lateral Acceleration	$\lvert acc^{lat}(t)\rvert \leq acc_{\max}^{lat}$
Lateral Deceleration	$\lvert decel^{lat}(t)\rvert \geq decel_{\min}^{lat}$
Heading	$\lvert h(t)\rvert \leq h_{\max}$
Heading rate change	$\lvert h'(t)\rvert \leq h'_{\max}$

Note: Longitudinal movement w.r.t a lane coordinate system

FUNCTIONAL SCENARIO 3: FOLLOWING WITH TAILGATER

Front collision is avoidable, no evasive maneuver required, and with a tailgater in the scene. No tailgater, no other potential cut-ins from nearby vehicles, no VRU's, etc.



Other 1

Longitudinal Velocity	$\lvert v^{lon}(t)\rvert \leq v_{\max}^{lon}$
Longitudinal Acceleration	$\lvert acc^{lon}(t)\rvert \leq acc_{\max}^{lon}$
Longitudinal Deceleration	$\lvert decel^{lon}(t)\rvert \leq decel_{\max}^{lon}$

Other 3

Lateral Velocity	$\lvert vel^{lat}(t)\rvert \leq vel_{\max}^{lat}$
Lateral Acceleration	$\lvert acc^{lat}(t)\rvert \leq acc_{\max}^{lat}$
Lateral Deceleration	$\lvert decel^{lat}(t)\rvert \geq decel_{\min}^{lat}$
Heading	$\lvert h(t)\rvert \leq h_{\max}$
Heading rate change	$\lvert h'(t)\rvert \leq h'_{\max}$

Other 2

Longitudinal Velocity	$\lvert v^{lon}(t)\rvert \leq v_{\max}^{lon}$
Reaction Time	$t^{react} \leq t_{max}^{react}$
Longitudinal Acceleration	$\lvert acc^{lon}(t)\rvert \leq acc_{\max}^{lon}$
Longitudinal Deceleration	$\lvert decel^{lon}(t)\rvert \geq decel_{\min}^{lon}$

SUMMARY SLIDE

METRICS AND ASSUMPTIONS ARE INEXORABLY LINKED

- The implicit rules of the road are what best represent “Driving Safely”
- “Drivingly Safely” is based on reasonable and foreseeable assumptions

INDUSTRY ACTIVITIES

IEEE SA STANDARDS ASSOCIATION

IEEE P2846

IAM Institute of Automated Mobility

Shaping the future of transportation safety, science, and policy

Metrics Research

SAE INTERNATIONAL®

(Proposed) Metrics Information Report

Join us in this important effort!