SAE INTERNATIONAL

GOVERNMENT/ INDUSTRY

Digital Summit

February 2-3, 2021

sae.org/gim

Executive Leadership Provided By

mazda

Metrics and Models to Evaluate Driving Safety

D. LeBlanc, H. Liu, X. Yan, C. Flannagan, S. Feng (UMTRI)

UMTRI

DISCLAIMER

- The opinions, findings, and conclusions expressed in this presentation are those of the authors and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its contents or use thereof. If trade or manufacturers' names are mentioned, it is only because they are considered essential to the object of the publication and should not be construed as an endorsement. The United States Government does not endorse products or manufacturers.

Outline

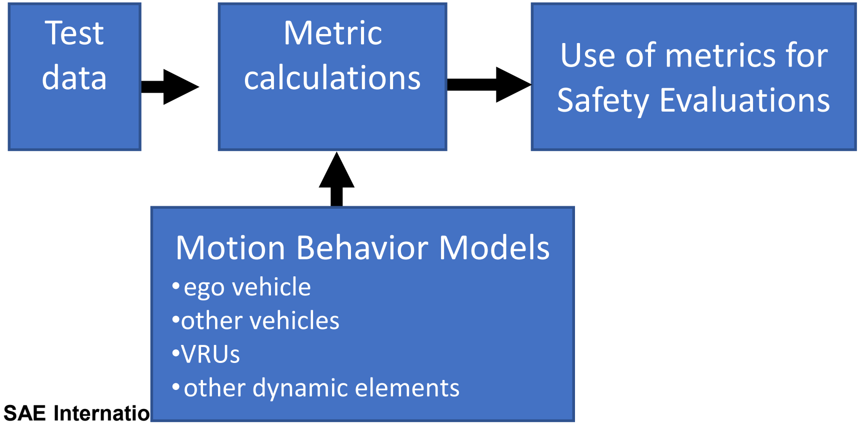
- Background
- Types of metrics and models
- Three existing metric/model approaches
- Examples in simulation
- Challenges

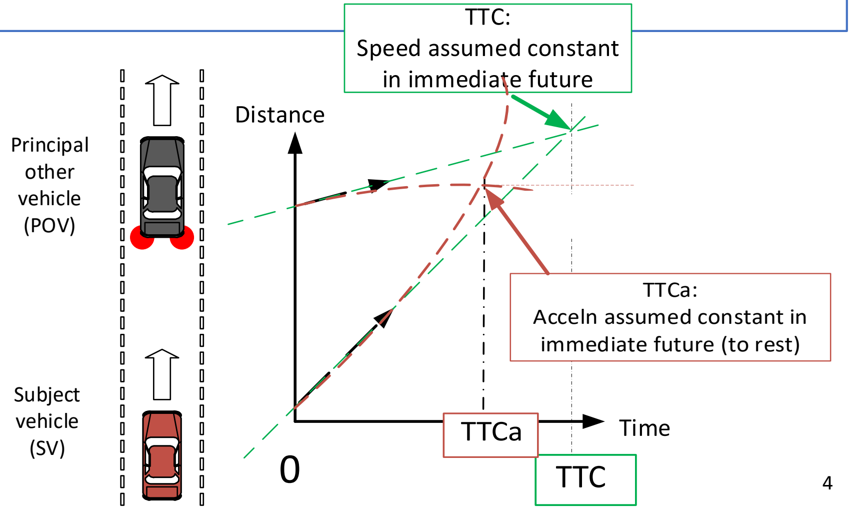
- NHTSA-sponsored project being conducted by UMTRI with project partner SAE International.

Definitions

- **Metric:** The output of an ongoing calculation performed as a “vehicle under test” is operated.
    - Reflects safety-related interactions with other road users and other dynamic elements.
- **Models:** Many metrics use models (mathematical descriptions) of the expected motion behavior of other traffic and/or the vehicle under test.

- **Example:** Time to collision is a metric computed at time ‘0’ using one of many models:
    - Both vehicles remain at their current speeds (TTC), or
    - Both vehicles remain at their current accelerations (TTCa), or
    - Other traffic may suddenly maneuver, within specified bounds.





Metrics may depend on the data and the user

Metrics may depend on:

- Scale of driving exposure
- Completeness & accuracy of the data
- Knowledge of the ADS

Presentation's focus:

- Extensive exposure: crash counts and injuries
- Limited exposure: surrogate metrics

- Completeness: White box, black box
- Accuracy, e.g, accelerations of other actors

- E.g., Modeling ADS response:
  Simple models (acceleration bounds)
  Vs. High-fidelity simulation models

Safe driving aspects and metrics

Safe driving during early deployment may be defined along multiple dimensions:

- Defensive driving
- Crash-imminent situations
- Compliance with traffic rules
- Other responsible driving habits

→

Avoiding crashes, especially at-fault crashes

…and these dimensions may each require different metrics.

Types of Metrics and Dimensions of Safe Driving

One categorization of metric types:

- Kinematic metrics
- Traffic rule compliance metrics
- Crash involvement metrics

Mapping metric types to the dimensions of safe driving:

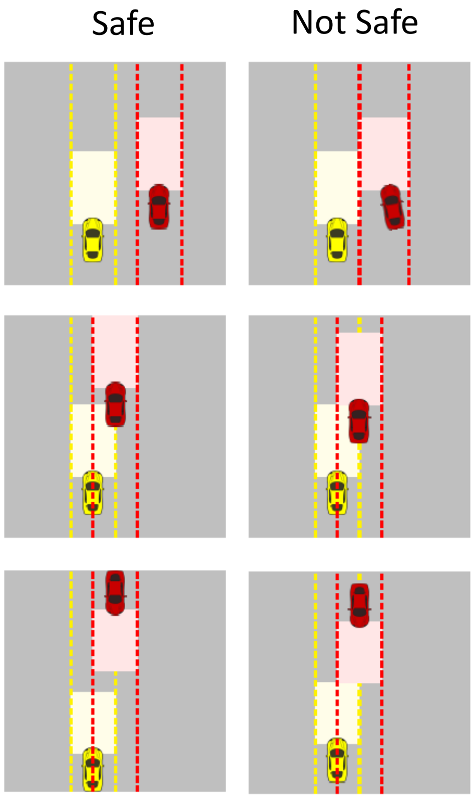
	Metric Types	
Dimensions of safe driving	Kinematic Metrics	Traffic Rule Compliance
Defensive driving	Primary	Secondary
Crash-imminent response	Primary	
Traffic rule compliance	Secondary	Primary
Responsible driving habits	Primary	Secondary

Continuum of Measures and Models
(from simple to complex)

Observations			Decisions
Direct and instantaneous measurements “Instantaneous”	Simple ‘if’ metrics “1D”	Sophisticated “model-based” metrics “2D model-based”	Safety-assuring models “Safety envelopes”
Range, speed, lane position, post-encroachment, accel level	Simple TTC, accel required (UMTRI & others over decades)	MPRISM, Pegasus criticality	Responsibility-Sensitive Safety (RSS), Safety Force Field
What is happening.	What may happen if… (1-D assumptions).	What may happen if…, (2-D or model assumptions).	What must happen, assuming…

Responsibility-Sensitive Safety (RSS) Model (2017)

- Five safety rules of RSS
  1. Don't hit the car in front of you. → d_{min}^{long}
  2. Don't cut in recklessly. → d_{min}^{lat}
  3. Right of way is given, not taken.
  4. Be cautious in areas with limited visibility.
  5. If you can avoid a crash without causing another one, you must.
- A snapshot is considered as not safe if both longitudinal and lateral safety distance are violated.



[1]

Shalev-Shwartz, S., Shammah, S., & Shashua, A. (2017). On a formal model of safe and scalable self-driving cars. arXiv preprint arXiv:1708.06374.

Pegasus Criticality Metric (PCM) (2018)

- The goal is to optimize the AV trajectory to minimize the criticality within a fixed look-ahead horizon subject to certain constraints (vehicle dynamics, safety):

$$\min_{\boldsymbol{u}(\boldsymbol{k})=\{a_x(k),a_y(k))\}} \sum_{k=1}^{N} \left[w_x R_x(k) + w_y R_y^2(y) + w_{ax} \frac{a_x^2(k)}{(\mu_{max} g)^2} + w_{ay} \frac{a_y^2(k)}{(\mu_{max} g)^2} \right]$$

Long. margin | Lat. margin | Long. accel. | Lat. accel.

SV dynamics	1. State dynamics. 2. Kamm circle.
SV safety	Don’t hit objects or leave road.

Junietz, P., Bonakdar, F., Klamann, B., & Winner, H. (2018). Criticality metric for the safety validation of automated driving using model predictive trajectory optimization. IEEE Intelligent Transportation Systems Conference (ITSC).

Model Predictive Instantaneous Safety Metric (MPrISM) (2020)

- A model predictive TTC metric that considers the most dangerous maneuver of a background vehicle and the best response of the subject vehicle over a fixed look-ahead time horizon.
- Major Assumption: There exists ***only 1 non-cooperative*** background vehicle and all other vehicles will comply with the subject vehicle to avoid collisions.
- The optimization problem:

$$h_i^*(t) = \min_{u_i} \max_{u_0} (h_i(x, u, t + T\Delta)),$$

Vehicle dynamics	1. State dynamics. 2. Kamm circle.

where $h_i(x, u, t) = \|x_i(t) - x_0(t)\|_2$.

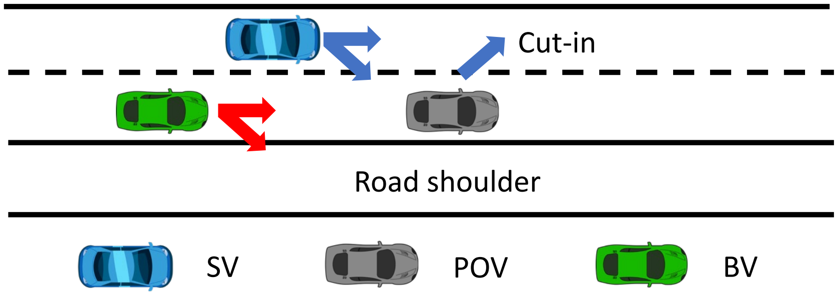
Weng, B., Rao, S. J., Deosthale, E., Schnelle, S., & Barickman, F. (2020). Model Predictive Instantaneous Safety Metric for Evaluation of Automated Driving Systems. arXiv preprint arXiv:2005.09999.

Simulation of Different Safety Metrics

- The vehicle will be marked as all red when identified as not safe. Play speed: 0.5x.

Safety metric considerations

- Different categories of vehicles need to be considered
  - Subject vehicle (SV)
  - Background vehicles (BVs)
  - Principle other vehicle (POV)
- Behavior assumptions
  - Traffic rules
  - Responsible behaviors
  - Cooperative behaviors
- Model parameters
  - Vehicle types
  - Geographical differences



Example scenario: When the POV makes a cut-in maneuver, different behavior assumptions for the SV and BVs will lead to different safety metrics.

Additional Considerations

- Metrics should be aware that the subject vehicle may be constrained in its avoidance maneuver when other vehicles are nearby (“boxed in”).

- Metrics should not reward avoidance maneuvers that result in a new and equal or greater risk of crash with a third vehicle.

- When defining or using metrics, consider how to normalize for exposure during testing, such as heavy congestion.

Next Steps

- Complete analysis of existing methods
- Propose enhanced versions of existing approaches
- Develop a holistic approach for consideration by the community including ideal properties for 3rd party evaluations

Study Partners

SAE International partner: Tim Weisenberger

NHTSA COR: Alrik Svenson

THANK YOU

Dave LeBlanc

University of Michigan – UMTRI

Ann Arbor, MI USA

(734) 936-1063

leblanc@umich.edu

Henry Liu

University of Michigan – UMTRI and Civil & Environmental Engineering

Ann Arbor MI USA

(734) 764-4354

henryliu@umich.edu