Modeled Exploration of Proposed Safety Assessment Metrics for ADS

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A Typical Automated Driving System (ADS) Safety Assessment Approach

Establish a set of test scenarios.

Deploy test subject in the scenario.

• High-fidelity simulation
• Controlled track testing
• Real-world test

Observe and Analyze Outcomes

• Whether a collision occurs
• Proposed metric behavior
The Time-to-Collision metric [Lee, 1976] for longitudinal motion safety assessment has dominated the field for decades. 

$$TTC = \frac{dx}{dv}$$

$$TTC = \infty ?$$
Introduction of Safety Assessment Metric Concepts within the Non-collision Regime

- Forward Reachability [Althoff, et.al., 2014]
- Instantaneous Safety Metric (ISM) [Every, et.al., 2017]
- Responsibility-sensitive Safety (Intel-RSS) [Shai, et.al., 2017]
- Criticality Metric [Junietz, et.al., 2018]
- Safety Force Field [NVIDIA, 2019]
Overview

Some suggest that ADS safety assessment metrics can be used to influence ADS safe driving policy choices through casting them as certain optimization / constraint fulfillment problem.

Modeled exploration of such perspective provides an opportunity to intrinsically understand the relation among various existing and proposed metrics/methods.
A Unified Safety Measure of TTC beyond Longitudinal Dimension

The subject vehicle (SV) would be considered safe with respect to policy for $T$ seconds in the future presented with the current traffic configuration.

Current traffic configuration

The subject vehicle (SV) would be considered unsafe with respect to policy in $t$ seconds presented with the current traffic configuration.
A Unified Safety Measure of TTC beyond Longitudinal Dimension

The subject vehicle (SV) would be considered safe with respect to policy for T seconds in the future presented with the current traffic configuration.

SV would be considered unsafe with respect to policy in t seconds presented with the current traffic configuration.
A Typical Optimization Problem

The operator

The controlled variable

Target function

Minimize

subject to

The constraints
Model the Operator

How aggressive can real-world traffic be?

Everyone maintains the current states.

Cooperative collision avoidance.

Traffic objects maintain the current states.

Test subject seeks for collision avoidance.

Test subject seeks for collisions.

The traffic object creates the worst-case scenario and the test subject seeks for collision avoidance.

\[ J(\cdot) \]

\[ \max_{u_0,u_1} J(\cdot) \]

\[ \min_{u_0,u_1} J(\cdot) \]

\[ \min_{x} J(x) \]

subject to \( x \in X \)

\[ \max_{u_0} J(\cdot) \]

\[ \min_{u_0} J(\cdot) \]

\[ \min_{u_1,u_0} \max J(\cdot) \]
Model the Constraints

What can a vehicle do?

\[
\begin{aligned}
& \min_x J(x) \\
\text{subject to} & \quad x \in X
\end{aligned}
\]
Model the Target Function

How to model measure of safety?

**Collision**  \[ J(\cdot) = \inf_{i=1,\ldots,k} d(x_i, x_0) \]

**Artificial Target**  \[ J(\cdot) = \inf_{i=1,\ldots,k} \{w^T R_i\} \]

A weighted summation of various safety-related terms

\[ w_1 \times \text{longitudinal margin} + w_2 \times \text{lateral margin} + w_3 \times \text{longitudinal acceleration} + w_4 \times \text{lateral acceleration} \] [Junietz, et.al., 2018]
Proposed Metrics in Context

- Forward Reachability [Althoff, et.al., 2014]
- Criticality Metric [Junietz, et.al., 2018]
- Responsibility-sensitive Safety (Intel-RSS) [Shai, et.al., 2017]
- Classic TTC [Lee, 1976]
- Instantaneous Safety Metric (ISM) [Every, et.al., 2017]
- Safety Barrier Certificates [Ames, et.al.]

\[
\min \max_{u_1, u_0} J(\cdot)
\]

\[
\max_{u_0, u_1} J(\cdot)
\]

\[
\min_{u_0, u_1} J(\cdot)
\]

T.B.D.
Observations from Modeled Metrics

Coupling various designs of components in an optimization and/or constraint fulfillment formulation, one can derive infinitely many ADS safe operation policy alternatives.

Optimization problems are generally non-convex.

Various simplifications, assumptions are then proposed either explicitly or implicitly to make a trackable solution in practice.
Example: Lead Vehicle Following

The *Lead-vehicle Following* Scenario

Following distance

\[ \text{Following distance} \]

SV velocity

SV

POV

20 m/s
Example: Lead Vehicle Following

\[ J(\cdot) \]

\[ \min_{u_0} \max_{u_1} J(\cdot) \]

\[ \min_{u_0,u_1} J(\cdot) \]

\[ \text{Hybrid}(\rho) \]

Everyone maintains the current states.

The traffic object is aggressive.

Everyone is aggressive.

Considered Safe*

Considered Unsafe*

* \( \text{Hybrid}(\rho) = \begin{cases} \min_{u_0,u_1} J(\cdot), t = 0 & \text{if } t < \rho \\ \min \max_{u_0,u_1} J(\cdot, t - \rho), t = 0 & \text{if } t \geq \rho \end{cases} \)

* With respect to cost function, safe driving policy threshold, established constraints, and optimization method
Example: Lead Vehicle Following

- **EV control profile**: The acceleration capability is a function of velocity determined by a combined analysis of real electrical vehicle tests and simulations.

- **Naive control profile**: The acceleration capabilities are constant for all speeds.

\[ J(\cdot) \quad \min \max J(\cdot)_{u_1 \ u_0} \quad \min J(\cdot)_{u_0,u_1} \quad \text{Hybrid}(\rho) * \]

*With respect to cost function, safe driving policy threshold, established constraints, and optimization method*
Example: Lead Vehicle Following

Presented with the same traffic scene, one can arrive at completely different safety assessment results with different assumptions of traffic patterns and vehicle control capabilities.
Preliminary Observations

Establishing a clear, single “ADS safety assessment metric” is not trivial

More considerations are needed to establish meaningful, public acceptable, practical constraints, and cost functions as well as consistent assumptions/simplifications.

A simultaneous solution of multiple driving policies with respect to various metrics could also be considered.

This would need cooperation among multiple engineering and non-engineering disciplines.
Thanks

QUESTIONS