AN OPEN, TRANSPARENT, TECHNOLOGY NEUTRAL INDUSTRY-DRIVEN APPROACH TO SAFETY

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HUMAN DRIVING TODAY
The balance between safety & efficiency

What do humans do?

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


IMPLICIT RULES OF THE ROAD
Essential for Navigating Complex Scenarios


DIGITIZING SAFE DRIVING
How do we formalize these concepts so AVs can safely and efficiently navigate?

RESPONSIBILITY SENSITIVE SAFETY

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

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

On a Formal Model of Safe and Scalable Self-driving Cars

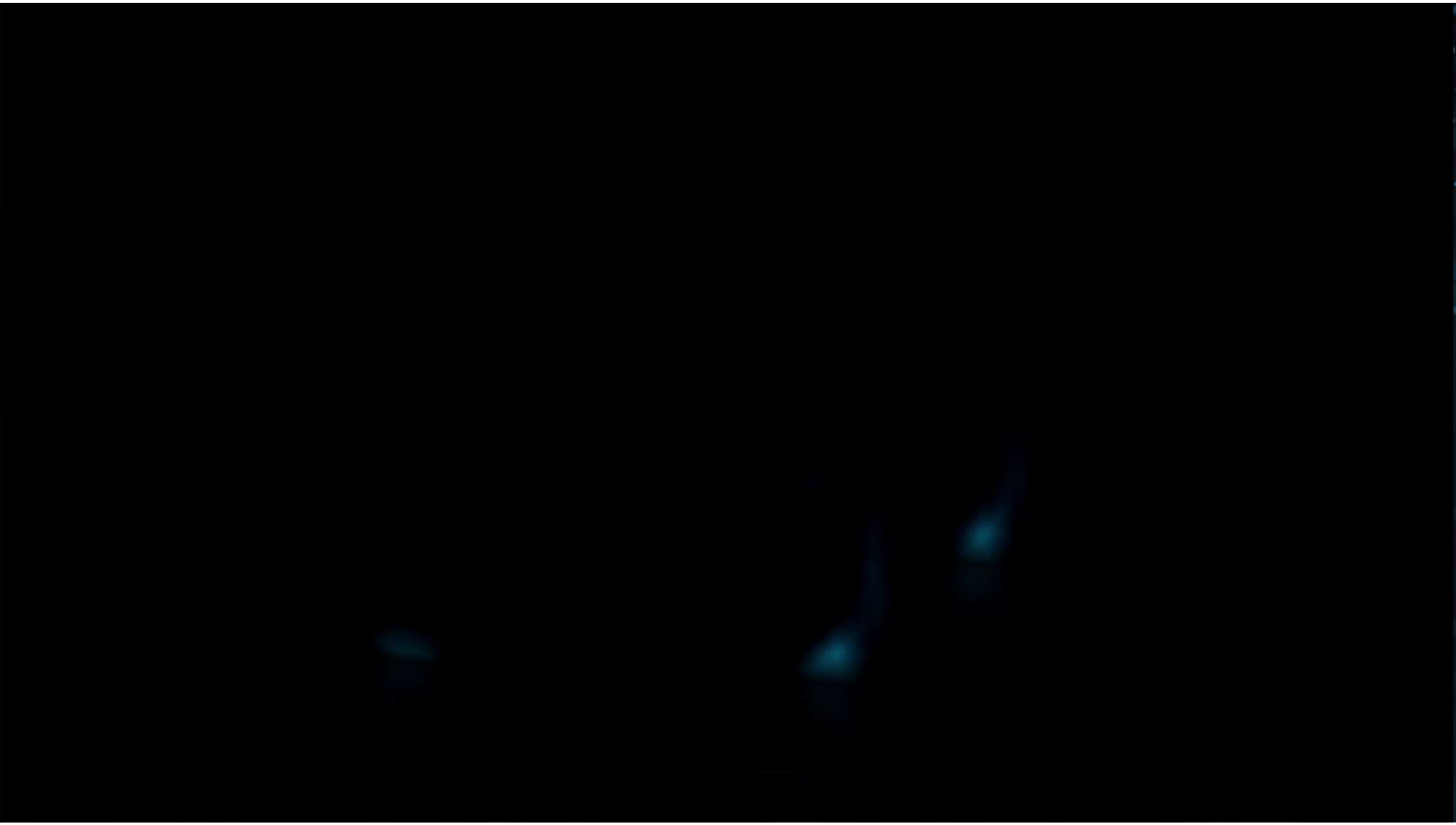
Shai Shalev-Shwartz, Shaked Shammah, Amnon Shashua

Mobileye, 2017

Abstract

In recent years, car makers and tech companies have been racing towards self driving cars. It seems that the main parameter in this race is who will have the first car on the road. The goal of this paper is to add to the equation two additional crucial parameters. The first is standardization of safety assurance — what are the minimal requirements that every self-driving car must satisfy, and how can we verify these requirements. The second parameter is scalability — engineering solutions that lead to unleashed costs will not scale to millions of cars, which will push interest in this field into a niche academic corner, and drive the entire field into a "winter of autonomous driving". In the first part of the paper we propose a white-box, interpretable, mathematical model for safety assurance, which we call Responsibility-Sensitive Safety (RSS). In the second part we describe a design of a system that adheres to our safety assurance requirements and is scalable to millions of cars.

http://arxiv.org/abs/1708.06374



RESPONSIBILITY SENSITIVE SAFETY (RSS)

FORMALIZE

Human notions of safe driving

IDENTIFY

A Dangerous Situation

EXECUTE

The Appropriate Response

Keep a safe distance longitudinally & laterally

Safe distance compromised in both directions

Brake to restore safe longitudinal distance

RULES OF RSS

Rules to verify AV safety & performance

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

BREAKING DOWN RSS'S ARCHITECTURE

Doer-Checker

Safety Envelope

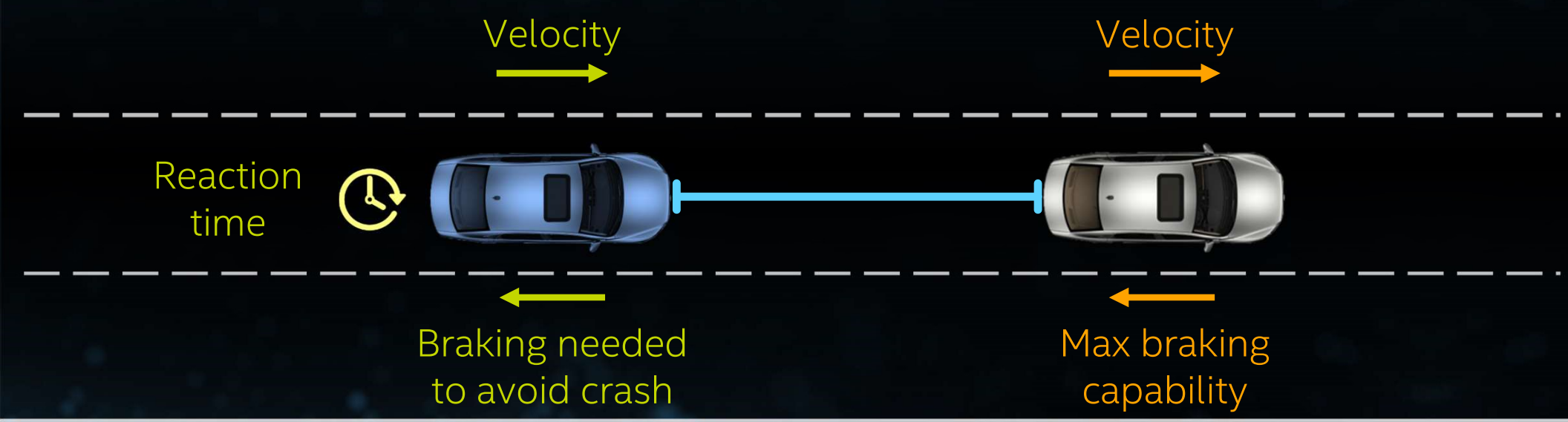
Defining the threshold between safety and danger

Determine the **Proper Response** based on the rule that was violated

WHAT DETERMINES SAFE DISTANCE?

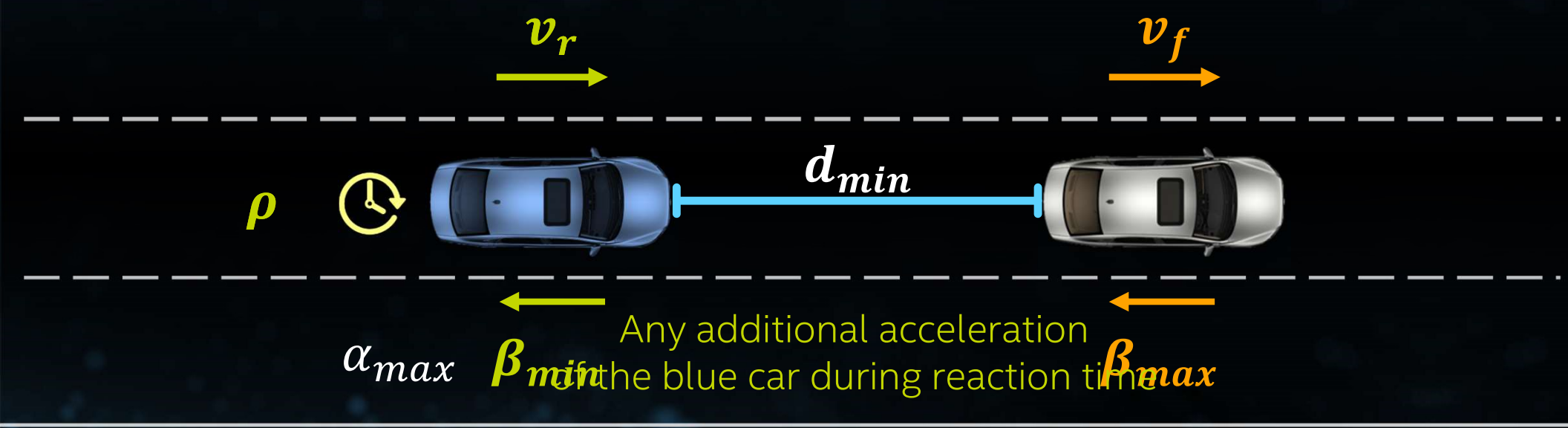
If the lead car brakes, how much space do I have to avoid hitting it?

We can determine safe distance based on the following variables



WHAT DETERMINES SAFE DISTANCE?

$$d_{min} = \left[v_r \rho + \frac{1}{2} \alpha_{max} \rho^2 + \frac{(v_r + \rho \alpha_{max})^2}{2\beta_{min}} - \frac{v_f^2}{2\beta_{max}} \right]_+$$



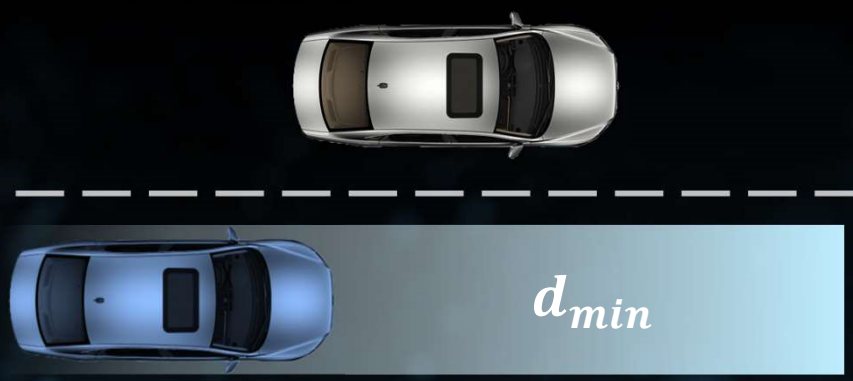
DEFINE DANGEROUS SITUATION

Time t is dangerous for cars c_1 , c_2 if *both* longitudinal and lateral distances between them are non safe

t is t dangerous

DERIVE A PROPER RESPONSE

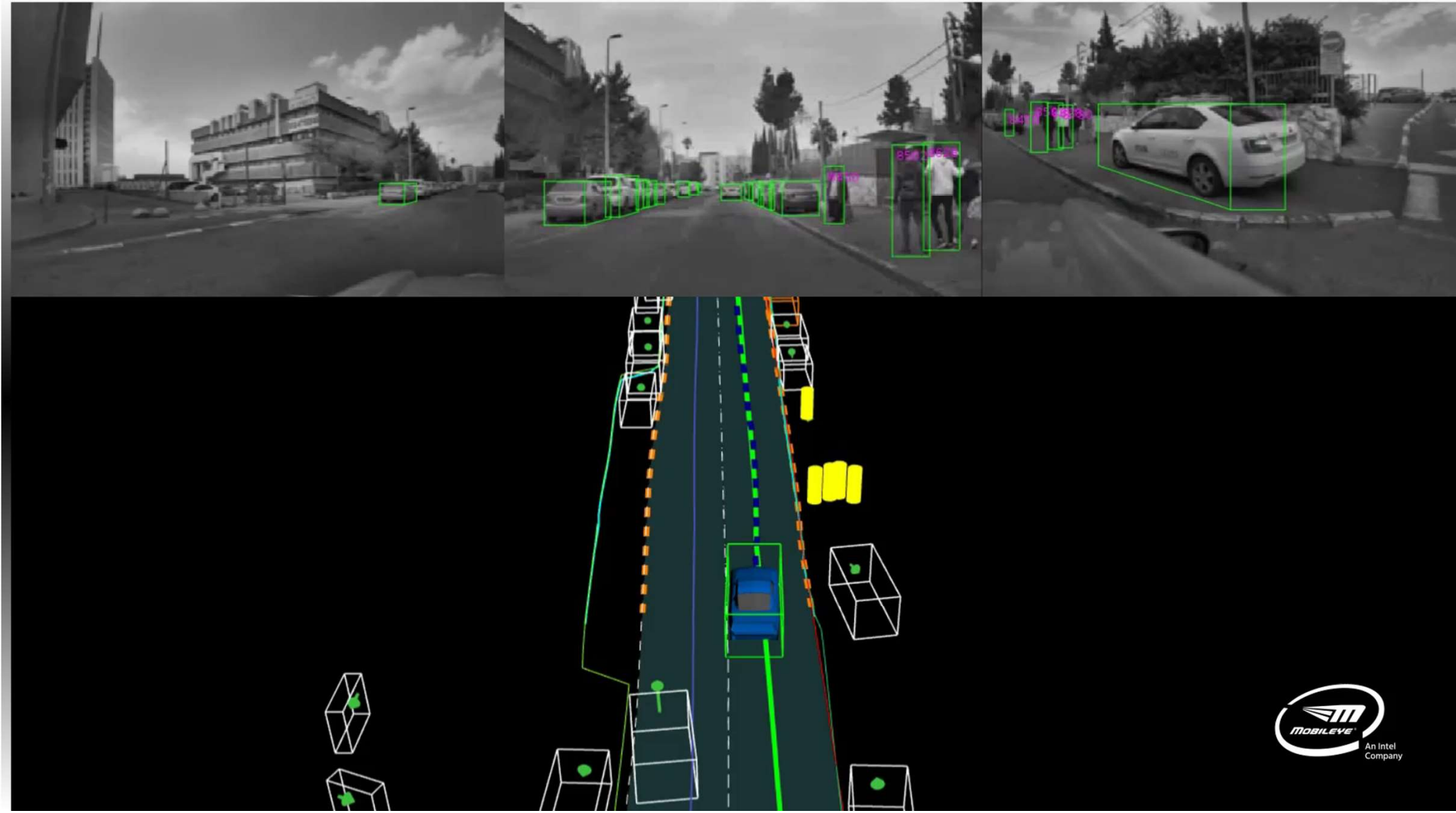
Though the silver car initiated the dangerous situation,
the blue car still ought to brake to return to a safe distance



LIMITED VISIBILITY & OCCLUDED AREAS

When sensing capabilities are physically limited,
We must exhibit caution

Does it work?


MOBILEYE
An Intel Company

What’s the catch?

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$$d_{min} = \left[v_r \rho + \frac{1}{2} \alpha_{max} \rho^2 + \frac{(v_r + \rho \alpha_{max})^2}{2\beta_{min}} - \frac{v_f^2}{2\beta_{max}} \right]_+$$

WHAT IS B_{MAX}?

Values for braking, acceleration, reaction time are not static, but dynamic based on the situation.

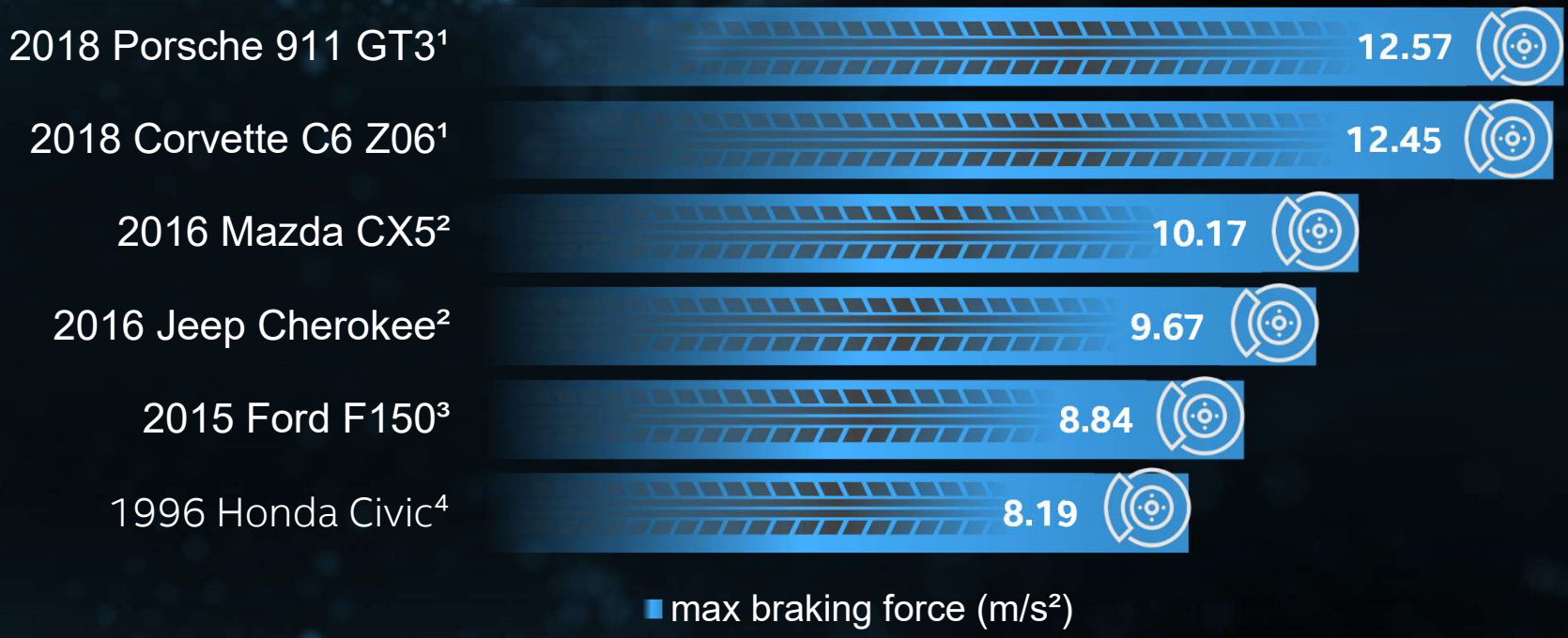
How do we determine the **reasonable expectations of other agents?**

EXPECTATION #1: BRAKING CAPABILITY

Different cars have different braking.
Different braking means different **stopping distances**

NOT ALL CARS ARE CREATED EQUAL

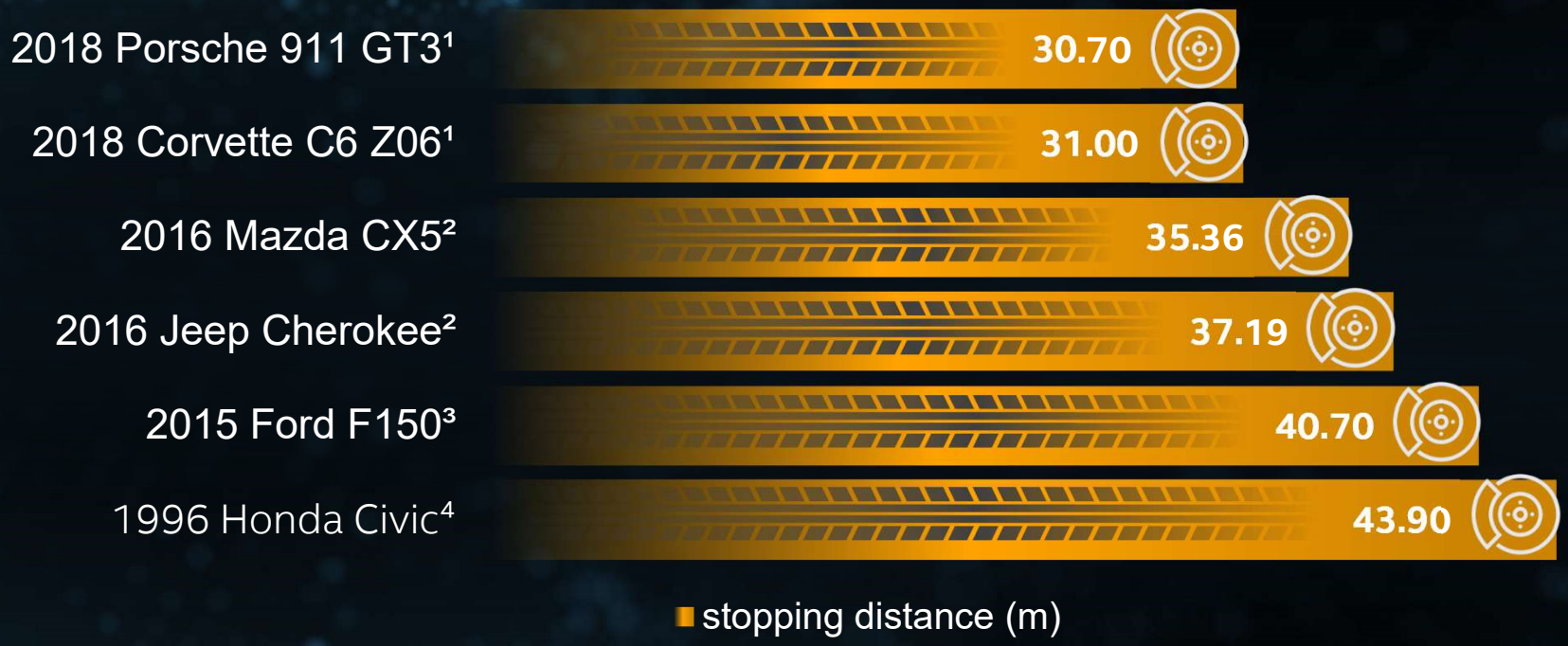
What should we assume for β_{max} as a result?



1 https://www.brembo.com/en/company/news/50-special 2 https://www.motortrend.com/cars/mazda/cx-5/2016/small-crossover-comparison-big-test/
3 https://special-reports.pickuptrucks.com/2015/01/2015-annual-physical-braking.html 4 https://www.motortrend.com/cars/honda/civic/1996/1996-honda-civic-ex-wrapup
Calculations were made using initial velocity, v_i (100kph or 60mph) and stopping distances, d, with the formula: force= v_i / (d*(2/v_i))

NOT ALL CARS ARE CREATED EQUAL

A Porsche stops 13m sooner than a Civic



1 https://www.brembo.com/en/company/news/50-special 2 https://www.motortrend.com/cars/mazda/cx-5/2016/small-crossover-comparison-big-test/
3 https://special-reports.pickuptrucks.com/2015/01/2015-annual-physical-braking.html 4 https://www.motortrend.com/cars/honda/civic/1996/1996-honda-civic-ex-wrapup
Calculations were made using initial velocity, v_i (100kph or 60mph) and stopping distances, d, with the formula: force= v_i / (d*(2/v_i))

EXPECTATION #2: TRAFFIC VIOLATIONS

Sometimes breaking a traffic rule is socially acceptable, and can be the safer choice

SHARE THE ROAD

We typically forgive drivers that violate the rules in this context

Will we grant autonomous vehicles the same forgiveness?

EXPECTATION #3: OBJECTS IN THE ROAD

When tire treads, debris, and other things can appear in the blink of an eye, what do we do?

WHEN WE HAVE THE SPACE

Our proper response can be an evasive maneuver

What if we do not have the space?

?

IF WE DON'T, WE MAY HAVE NO CHOICE

So the question remains:

How should AVs respond to these scenarios?

EXPECTATION #4: PEDESTRIANS

How the traits of the road dictate our assumptions about pedestrian behavior


NEIGHBORHOODS WITHOUT SIDEWALKS
Are likely to have people
walking along & playing in the street


NEIGHBORHOODS WITH SIDEWALKS
Pull people away from the street, allowing cars to safely operate at higher speeds

RSS: A FORMAL MODEL FOR AV SAFETY

A mathematical model that formalizes common notions of safe driving

RSS can help answer important questions for AVs:

What does it mean to drive safely?

What constitutes a dangerous situation?

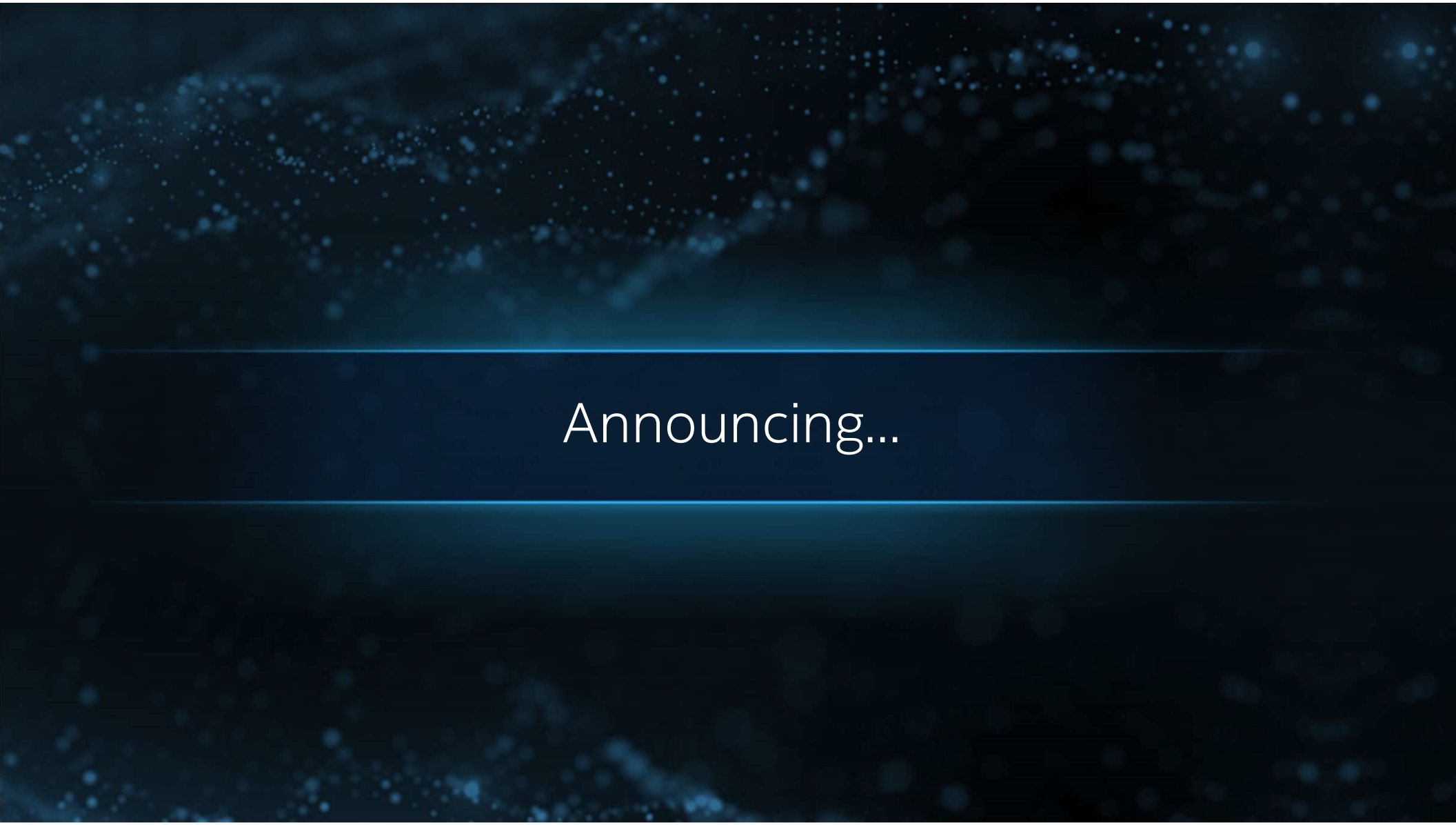
What is the proper response to a dangerous situation?

What does it mean to be reasonably cautious?

What assumptions can the AV make about the behavior of others?

In the hands of regulators, RSS provides an **objective, technology neutral, performance benchmark**

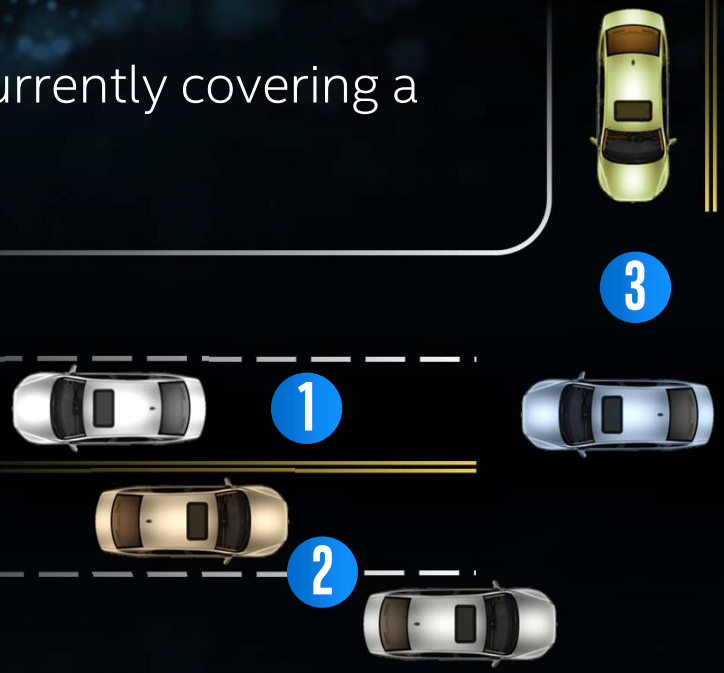
ASSESS SAFETY PERFORMANCE OF AVs


Announcing…

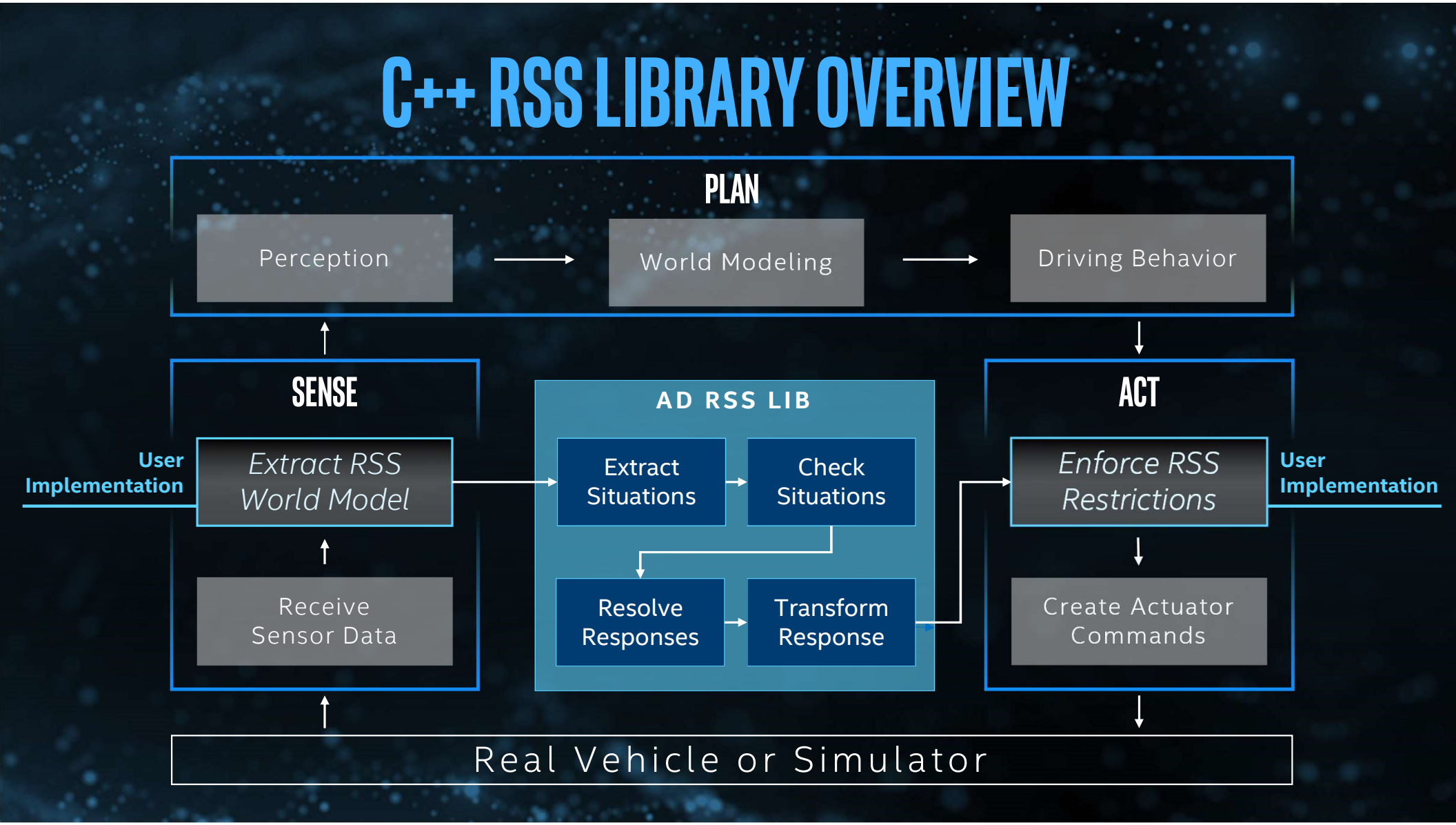
C++11 RSS LIBRARY

Standalone **Open Source Library** currently covering a subset of RSS rules

1. Longitudinal scenarios
   - Same and opposite direction
2. Lateral scenarios & Multilane roads
3. Intersection handling



https://intel.github.io/ad-rss-lib/


C++ RSS LIBRARY OVERVIEW
PLAN
Perception
World Modeling
Driving Behavior
SENSE
Extract RSS World Model
Receive Sensor Data
AD RSS LIB
Extract Situations
Check Situations
Resolve Responses
Transform Response
ACT
Enforce RSS Restrictions
Create Actuator Commands
User Implementation
User Implementation
Real Vehicle or Simulator

AV SAFETY: AN ISSUE LARGER THAN ONE COMPANY

What are we doing

INDUSTRY

Engaging with customers, competitors and consortia to have an open dialogue on AV safety

ACADEMIA

RSS Research Centers at Universities in USA, PRC and EU

GOVERNMENT / NGO'S

Understanding government expectations on transparency and verification of AV safety

REAL WORLD

Deploying RSS in our on AV Fleet in very challenging environments

2018 Rand Report: Measuring Automated Vehicle Safety

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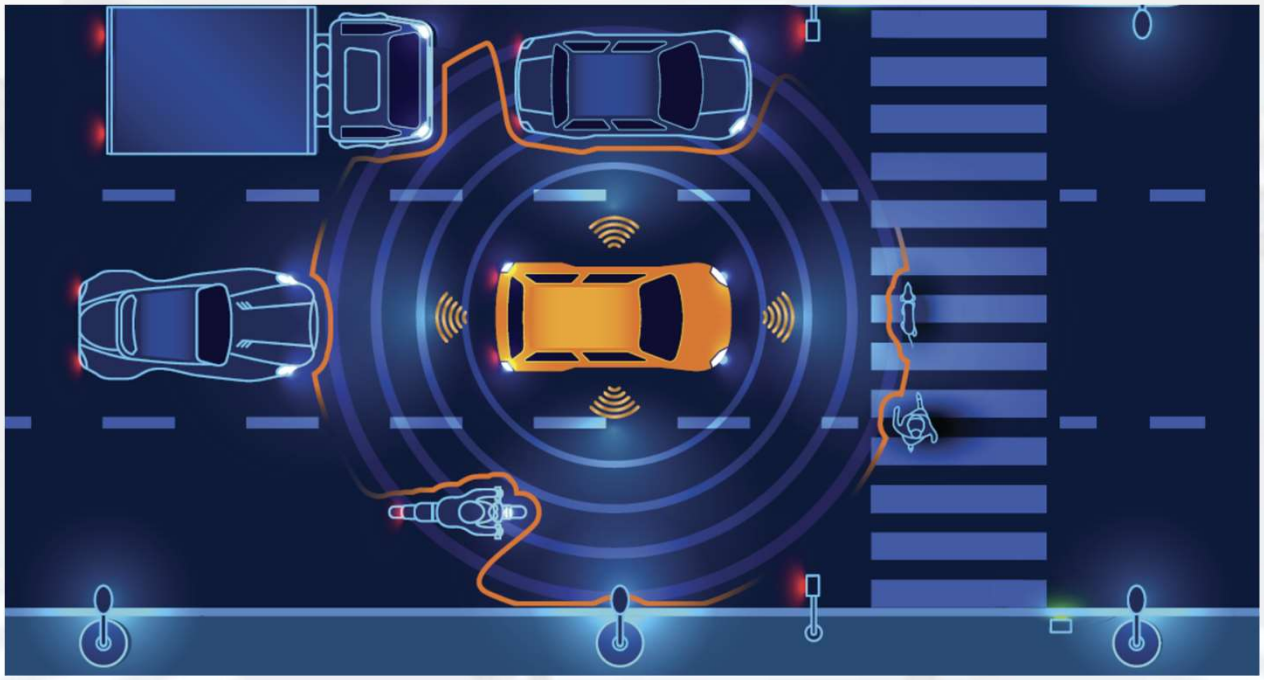
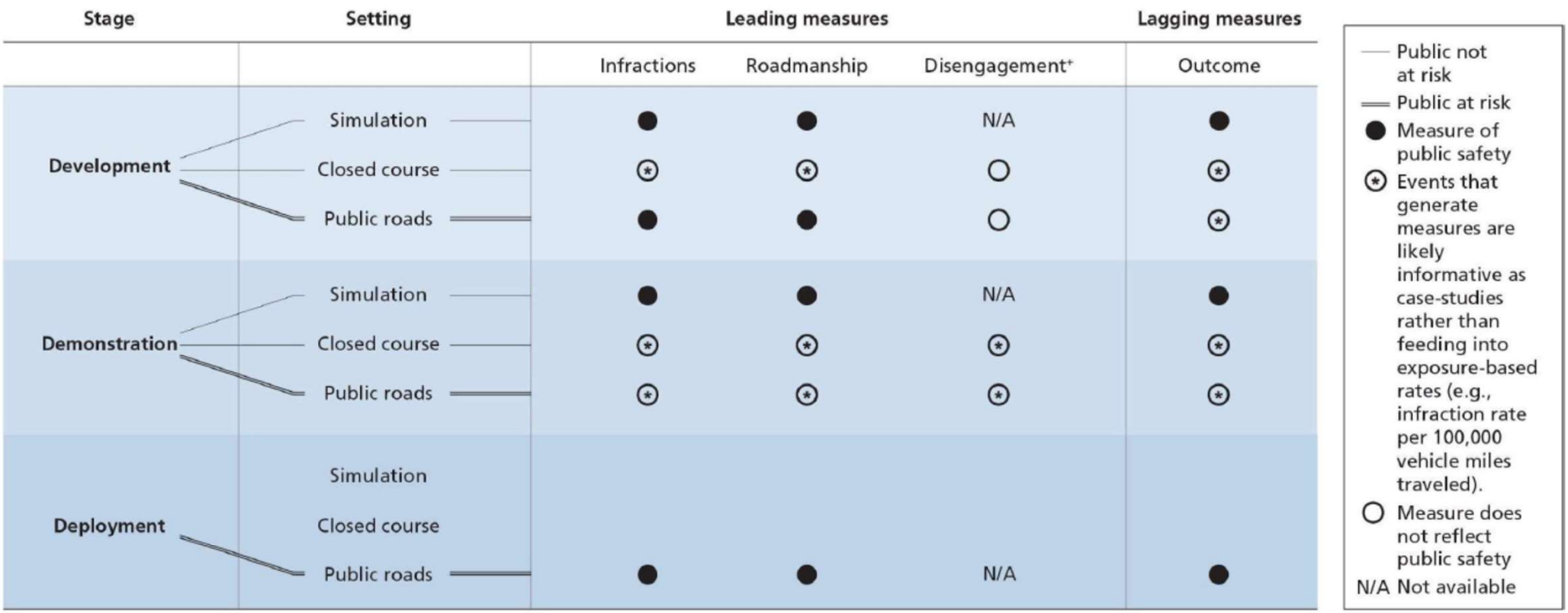


https://www.rand.org/pubs/research_reports/RR2662.html

A Safety Framework



+ This column assumed that, in the closed course and public road settings, a safety driver is available (either in the vehicle or remotely). If a safety driver is not present, this entire column would be N/A.

RAND Science, Technology, and Policy Program

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DRIVE SAFELY

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