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A Method for Evaluating Automated Vehicle Safety

Joshua L. Every (Presenter)
Transportation Research Center Inc.

John Martin and Frank Barickman
NHTSA

Sughosh Rao, Scott Schnelle and Bowen Weng
Transportation Research Center Inc.

Overview

- Definitions.
- Challenges in automated vehicle testing.
- Introduction of concept.
- Explanation of current implementation.
- Conclusions from current development and ongoing research.

Definition

- Instantaneous Safety Metric (ISM)
  - A measurement of safety not only related to the outcome of a situation, but also related to the probably of a collision occurring had actions varied.

Traditional Test Procedure Development

Identify a safety problem

Select a scenario, or set of scenarios, in which the system is desired to improve safety

Test systems in these scenarios

Develop criteria to classify system performance

Challenges

- This type of systems has a goal of proceeding through an environment safely. There are two main challenges in determining if a system will consistently accomplish this goal.
  1. Environments are infinitely variable
     – This can be overcome by either performing a large amount of real world testing, or through simulation.
  2. Safety is not simply a result.
     – Just because a collision didn't occur doesn't mean a drivers actions were safe.

Thought Experiment

- Suppose you are driving down the road and you ask yourself, “If something were to happen right now and I needed to avoid it what could I do?”
- Upon reviewing your situation you arrive at the conclusion that there are four basic options you can choose from.
  - Brake up to full vehicle capability.
  - Accelerate up to full vehicle capability.
  - Steer up to full capability to the left.
  - Steer up to full capability to the right.
- After realizing these options it is next natural to ask yourself, “If I do this where will I end up?”

Simplifying Assumptions in this prediction

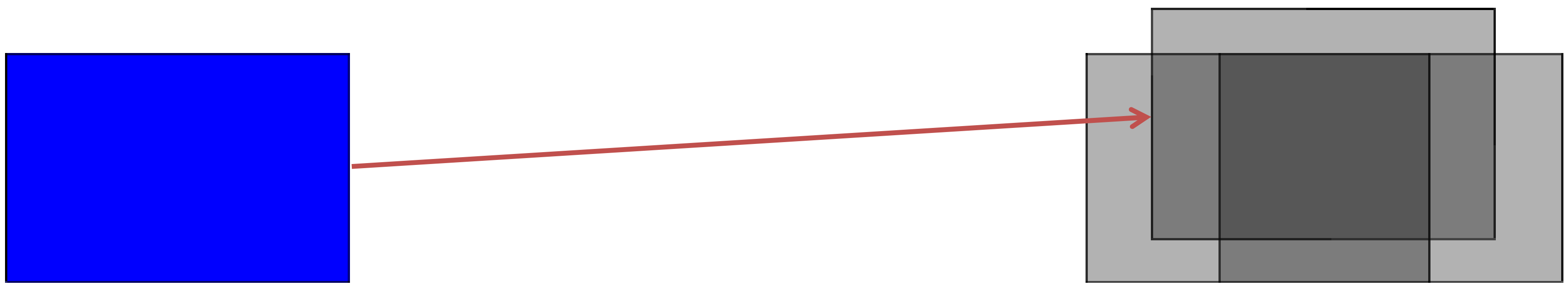
- We are only looking a short distance into the future.
  - The same accelerations are maintained for the complete interval.
- Vehicle reaction time and jerk limits are ignored.
  - The selected acceleration is achieved from the Time=0.
- The vehicle behaves according to the defined model.
  - This is assumed to be true even for very high accelerations.

Possible Outcomes – Full Acceleration

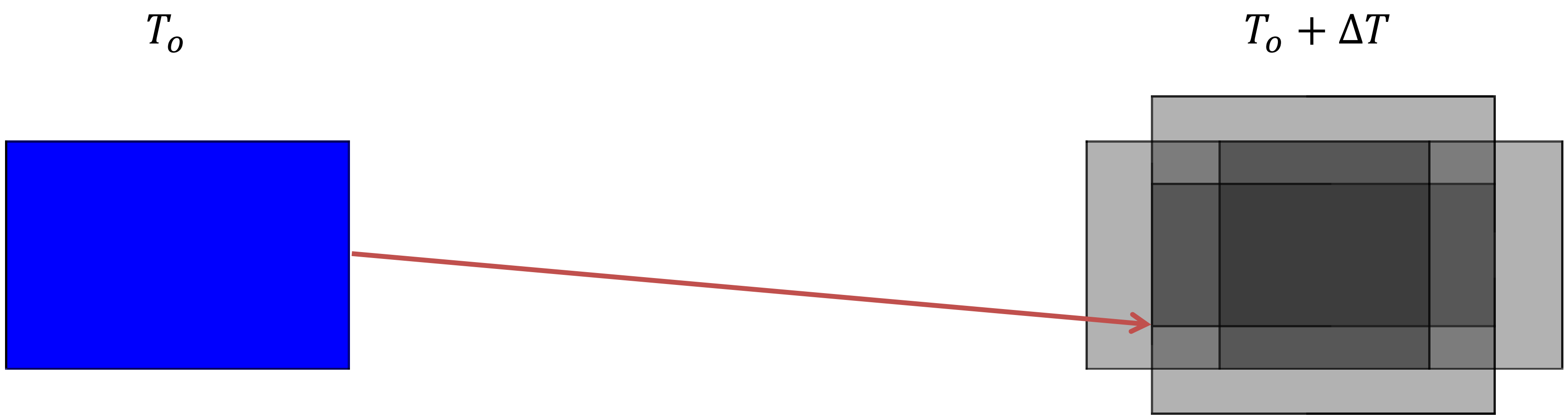
Possible Outcomes – Full Deceleration

Possible Outcomes – Full Left

T_o $T_o + \Delta T$



Possible Outcomes – Full Right

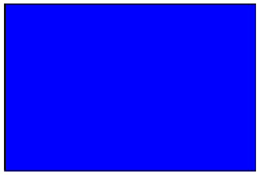


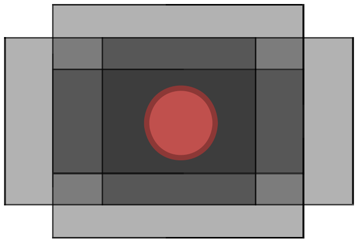
Interesting Regions

T_o $\qquad$ $T_o + \Delta T$

Extension of Result to Reality

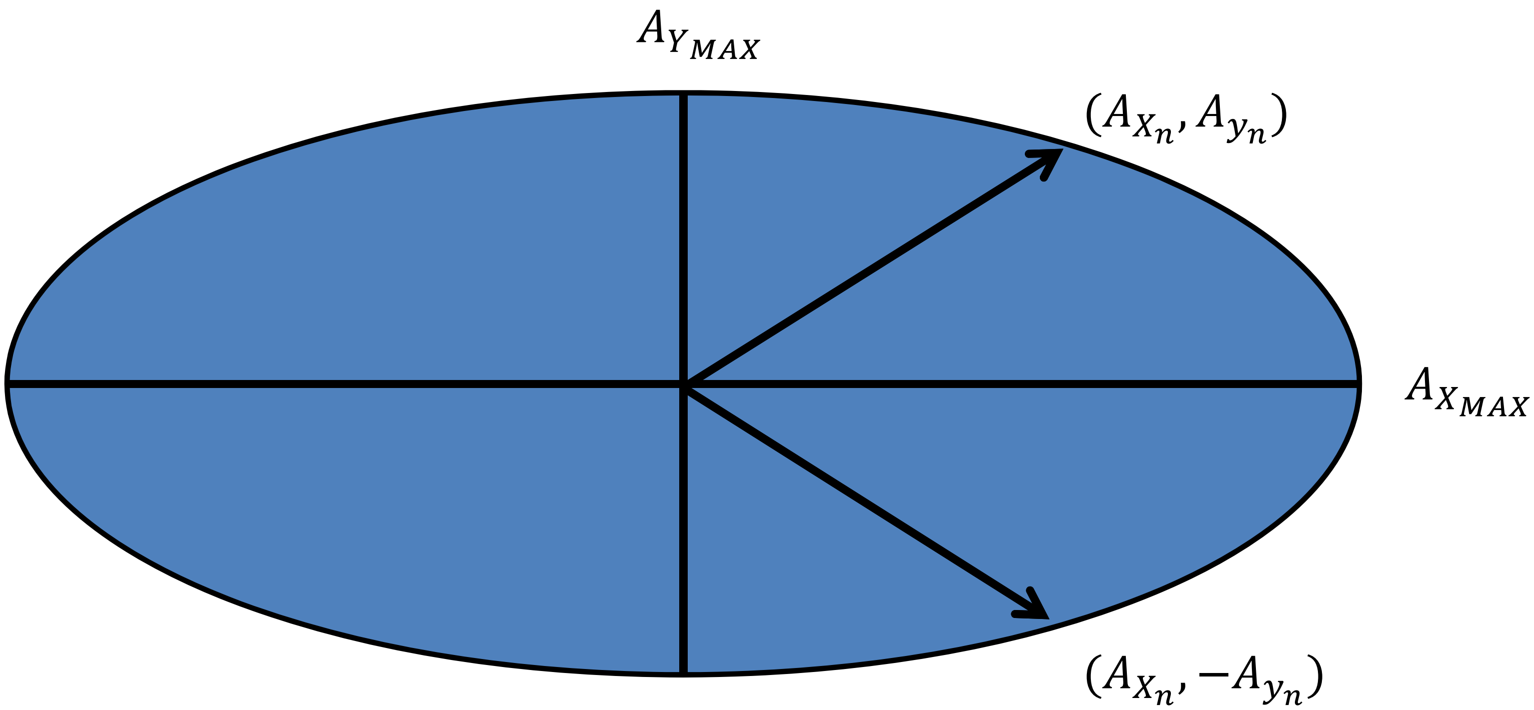
- In real situations the set of all extreme actions is not limited to these four cases.
- Applying any combination of these actions will produce a result which is related to the proportion by which these actions are pursued.
- If we look at the profiles defined by all possible combinations of actions, the facts of the previous example remain.
  - There exists a set of possible locations which the vehicle can occupy at a certain point in the future.
  - If there exists an object which intersects all of these profiles at some point in the future a collision cannot be avoided.





Can We Calculate this Region of Possibility?

- The set of possible accelerations (Ax and Ay) can be represented by and ellipse.
- Given any value of Ax there exist two corresponding values of Ay.



Can We Calculate this Region of Possibility?

- If we use a model that can be adapted to each Ay, Ax pair we can find the position and orientation given these inputs at some point in the future (**Reachable Set**).

- The set of **profiles** is constructed by placing the vehicle's outline according to the **Reachable Set**.

- The union of all **profiles** is the region of space that contains all points that may interact with a part of the vehicle.

- The intersection of all **profiles** is the region of space that contains all points that must interact with a part of the vehicle.

Basic Definitions Related to this Method

- Possible Space
  - Region of space where some part of the vehicle may exist, at a specific point in the future.

Basic Definitions Related to this Method

- Unavoidable Space
  - Region of space where some part of the vehicle must exist, at a specific point in the future.

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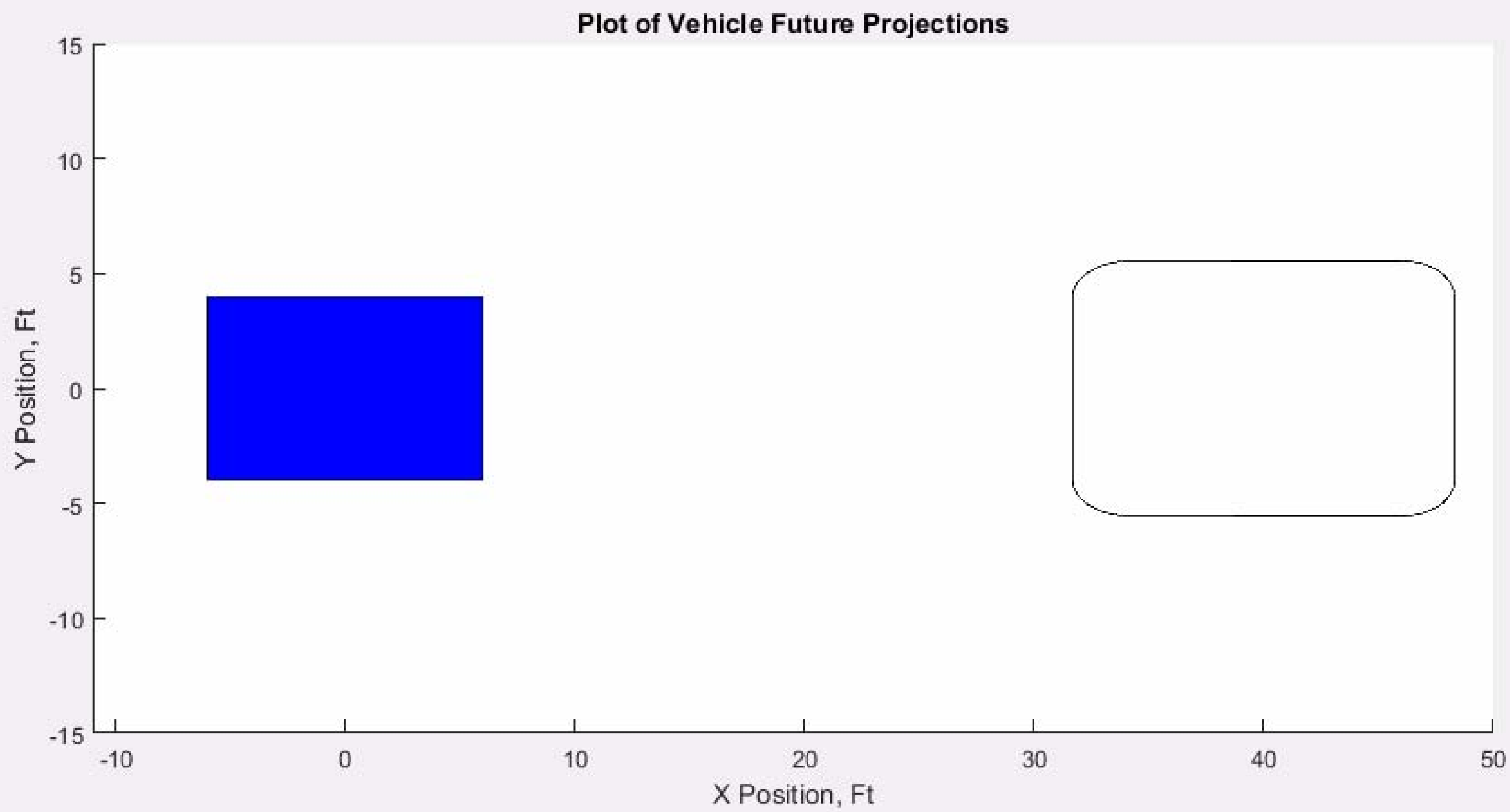
Future Boundaries at Various Prediction Times



Summary of Implementation

Compute all possible locations at the desired future point in time.

- A bicycle model is used to calculate positions.
- Motion is governed by either lateral acceleration or road wheel angle limits.
- Acceleration limits calculated using an ellipse defined by $A_{X_{MAX}}$ and $A_{Y_{MAX}}$

Place a rectangular representation of the vehicle at all possible points.

- Using geometric operations the possible and unavoidable space can be found.
- The possible space is the union of all rectangles
- The unavoidable space is the intersection of all rectangles.

Interactions between possible and unavoidable spaces for multiple vehicles.

- These spaces on their own are interesting but not particularly useful.
- By analyzing the overlap of these spaces with those from other vehicles complex traffic interactions can be analyzed.
- There are four possible combinations resulting from interaction between the possible and unavoidable spaces of two vehicles (Vehicles A & B in this case).
  1. The possible space of both vehicles overlap. (Possible Interaction)
  2. The unavoidable spaces of both vehicles overlap. (Imminent Interaction)
  3. The unavoidable space of Vehicle A overlaps the possible space of Vehicle B. (Critical interaction for Vehicle A)
  4. The possible space of Vehicle A overlaps the unavoidable space of Vehicle B. (Critical Interaction for Vehicle B)

Possible Interactions

- All cases detected by finding overlap between two vehicles' possible spaces.

- Indicates that a collision between these two vehicles is possible at some point in time.

- As $\mathrm{time} \rightarrow \infty$ the possible space becomes infinitely large. Therefore a possible interaction occurs for all vehicles for a long enough look ahead time.

Imminent Interaction

- All vehicle profiles associated with the subject vehicles reachable set intersect all members of the traffic vehicle’s(s’) reachable set.

- Indicates that the situation has progressed to the point where a collision is imminent.
  - Assuming that the vehicles behave according to their models a collision will occur at some point in the future.

Critical Interactions

- Risk
  - “A situation involving exposure to danger.” (Google)
  - In this work we look to detect risk by finding situations where the occurrence (or lack) or a collision, is not longer controlled by the subject vehicle.
- Critical Interactions
  - An interaction between the subject vehicle and a POV, or group of POVs, in which the POV(s) can perform an action that the subject cannot avoid.
  - This type of scenario aligns with our general definition of risk in that we have limited influence on the outcome of this situation.
  - Given knowledge of POV behavior the level of risk the vehicle has been exposed to can be calculated.

Steps in Detection of Critical Interactions

1. If there is no interaction between the possible space of two vehicles then an interaction cannot be critical.
   – Allow certain cases to be ruled out and saves time in detection.

2. If a POV's possible space intersects the subjects unavoidable space the interaction is critical.
   – This is a sufficient but not necessary condition for non-point objects. Therefore it only detects a subset of the desired cases but may be more computationally efficient.

Detection of Critical Interactions (cont.)

- Detect if there exists a POV profile (or set of profiles for multiple POVs) that intersects profiles for all subject vehicle actions.
  - – An efficient algorithm is currently being developed to address these cases.

$$\begin{array}{cc} & \xrightarrow{\text{Subject Vehicle}} \\ \text{Traffic}\downarrow & \begin{bmatrix} I_{1,1}^{t_p} & I_{1,2}^{t_p} & \cdots & I_{1,N}^{t_p} \\ I_{2,1}^{t_p} & I_{2,2}^{t_p} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ I_{M,1}^{t_p} & \cdots & \cdots & I_{M,N}^{t_p} \end{bmatrix}^{N\,x\,M} \end{array}$$

Method Flow Diagram

Acceleration Map

- Provides a set of (Ax, Ay) pairs achievable by the vehicle which will be used for vehicle position calculations.

Vehicle Modeling

- Utilizes the desired acceleration pairs along with vehicle size parameters to calculate possible vehicle trajectories.

Interaction Classification

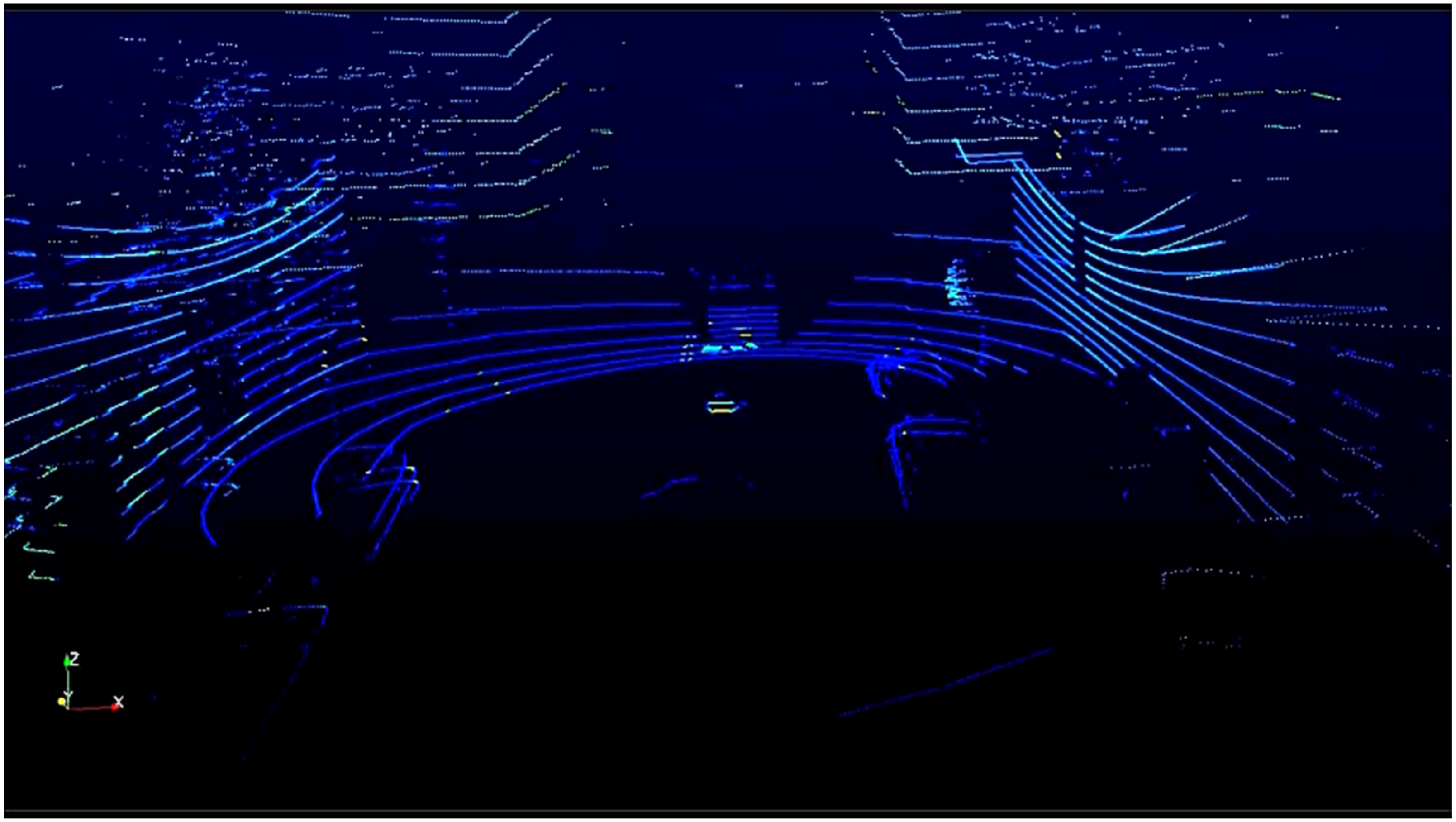
- Tests the set of profiles from the prior step to determine the current interaction classification.

Severity Analysis

- Reviews possible, critical and imminent interactions to quantify their severity.

Current and ongoing work in this area

Current and ongoing work in this area (cont.)



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Conclusions

- A framework for evaluating vehicle automation systems in simulation, proving ground and real world environments has been created.
- This method focuses on identifying situations in which the automation system has placed the vehicle in a position where the actions of other drivers are governing the outcome.
- The approach to constructing this framework allows various pieces to be changed without the complete method needing revised.
- Going forward this method can be utilized to compare various automation systems as they become available in a wide variety of situations and environments.

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QUESTIONS?