How to Investigate Potential Automation in Accidents

Investigations Involving Advanced Driver Assistance Systems (ADAS)
Man Machine or In Between

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What Is An Investigation?

Definition and scope depends on purpose and audience

To the Police officer

When scene is documented, damage recorded, interviews complete, review for traffic violations

To the accident investigator

Probable Cause is established after developing fact based analysis

To the engineer

Review for failure and design corrections

To the lawyer

Collection of potential monetary damage

All Investigations Follow Time-Proven Process

FIRST – Who has <u>jurisdiction</u> and responsibility <u>to lead</u> the investigation?

(Investigator In Charge, IIC)

Four types of investigation are:

Criminal - Government
Safety - Government
Civil – Litigation about monetary damages between individuals &/or companies
Technical – Typically manufacturers

Government has first rights, especially with fatalities
Companies support Government
Government must recognize proprietary needs of companies

SECOND – Leadership must agree on process or how to refine to circumstances

THIRD – Gather facts BEFORE analysis

Facts, Analysis, Findings, and Probable Cause

FACTS Documentation of: Physical evidence Maintenance records Phone records Medical records Weather conditions Interview statements etc	ANALYSIS Only after facts collected: Comparison of facts such as Physical evidence vs maintenance records Comparing Interviews etc	FINDINGS What specific factors led to the accident Define what was not involved If this Then that	PROBABLE CAUSE Short statement The accident was caused by an inattentive driver and design unable to …

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Collect Factual Data By Breaking Into Focal Groups

Groups work in defined focal areas, such as:

- Driver and human factors
  - People involved, their training, and backgrounds
- Vehicle(s) and systems design,
  - Previous similar events,
  - Maintenance records,
- Roadway, including barriers, markings, etc
- Weather and other environmental factors,
- Traffic, communications, radar or other recordings,


2017 Mountain View, California

Conduct daily organizational meetings

Share factual findings with other groups and leadership

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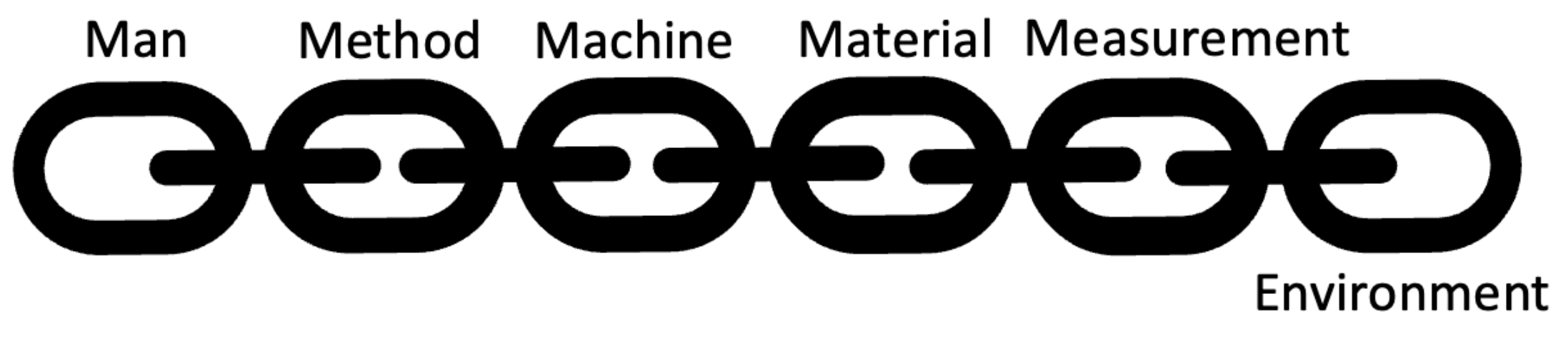
Use the “Five M’s and E” As **The Facts To Look For**

The factual links used to document a causal chain.

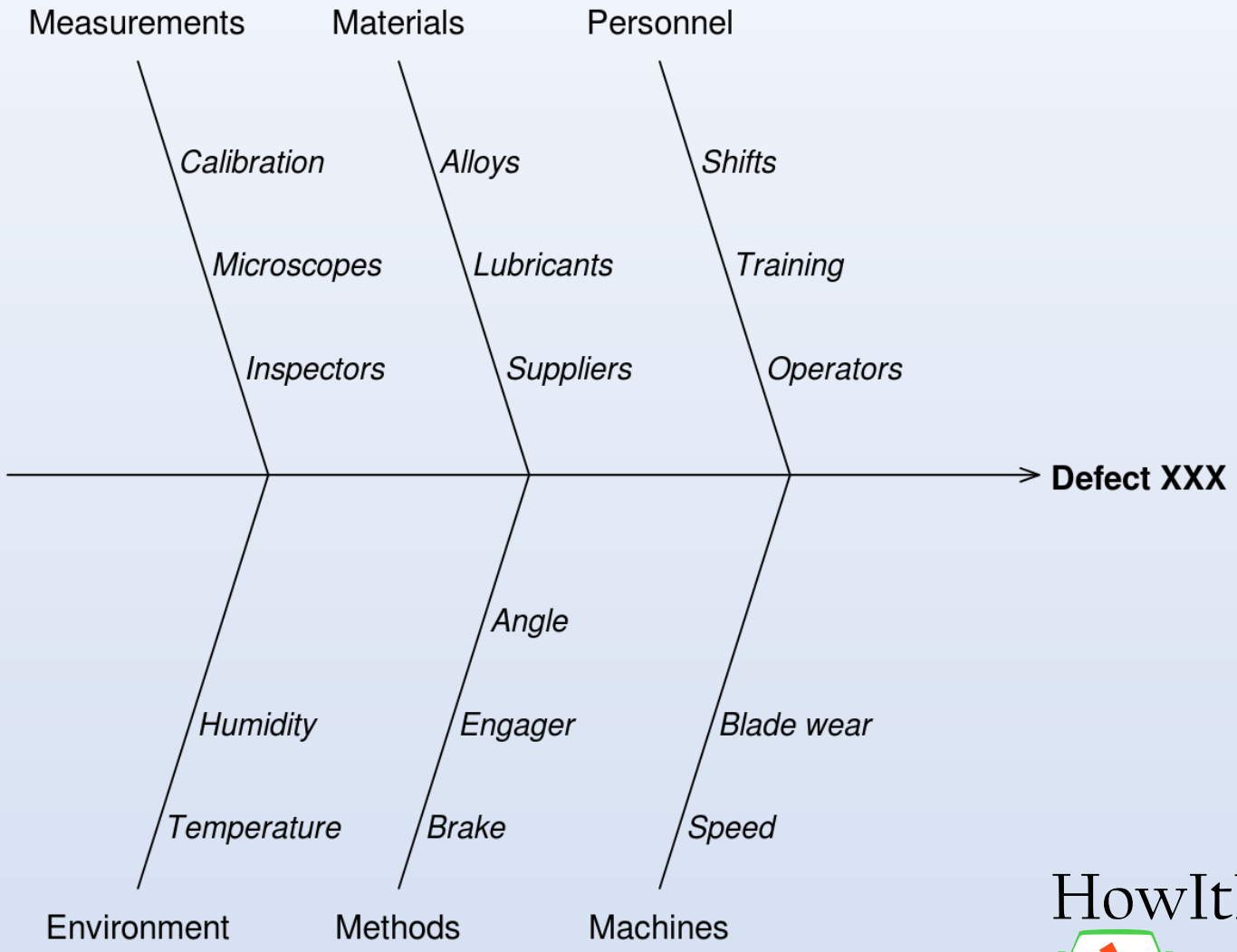


Numerous Ways To Categorize And Record The Facts Found

Still valid method adapted from 1920s Ishikawa "Fish Bone" diagrams

The 5 Ms & E:

- Man
- Machine
- Method
- Material
- Measurement
- Environment



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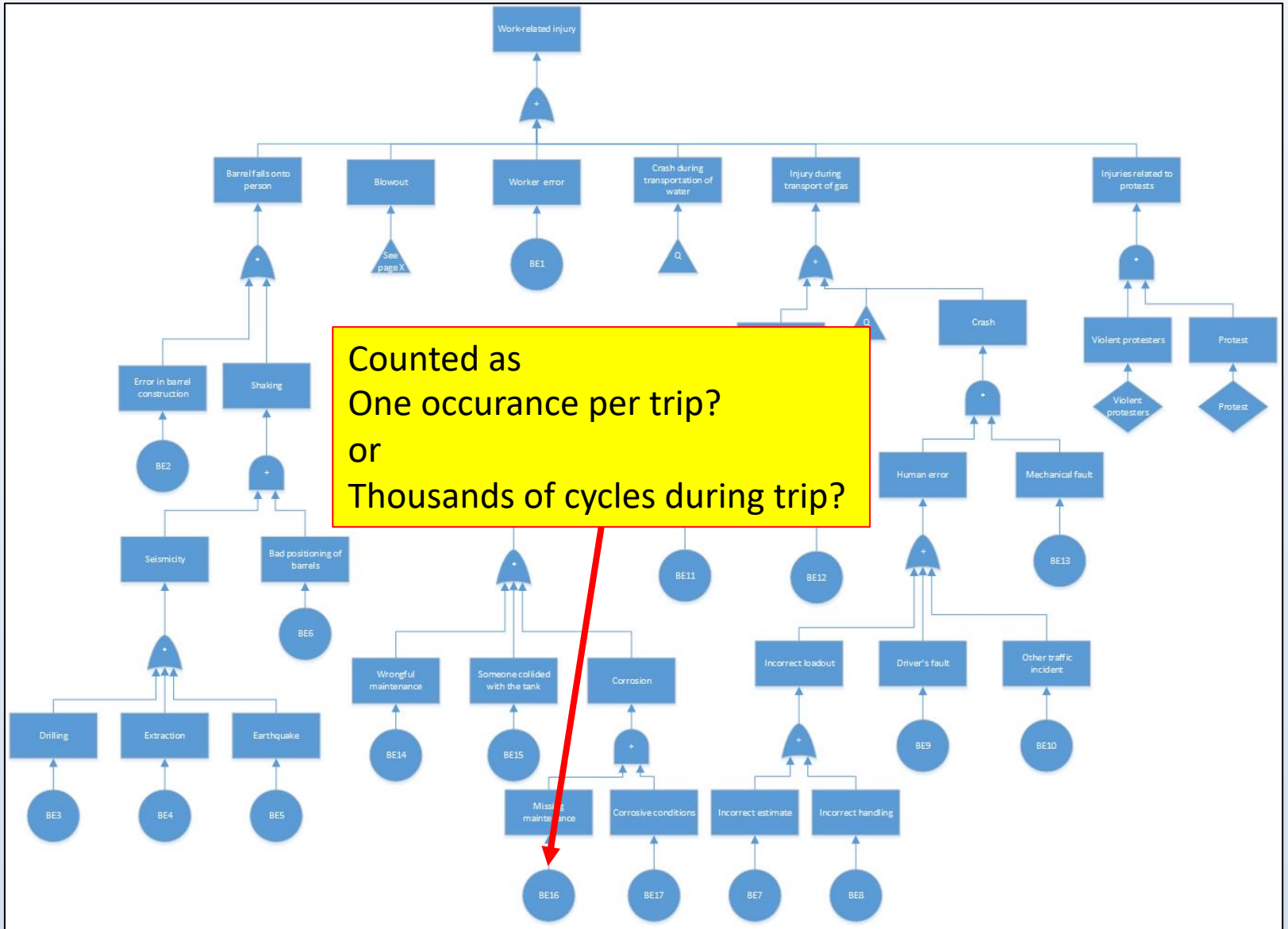
Software Based Logic Fault Trees Needed In Complex Investigations

Risk analysis software tools can have thousands of cells

Due to compounding of errors, **<u>increasing the number of cells results in decreasing validity</u>**



Source: http://wiki.doing-projects.org/index.php/Fault_tree_analysis

Summary: Various Investigation Processes Exist & Most Have Validity

Factual:

Simplest is to keep asking "Why?"

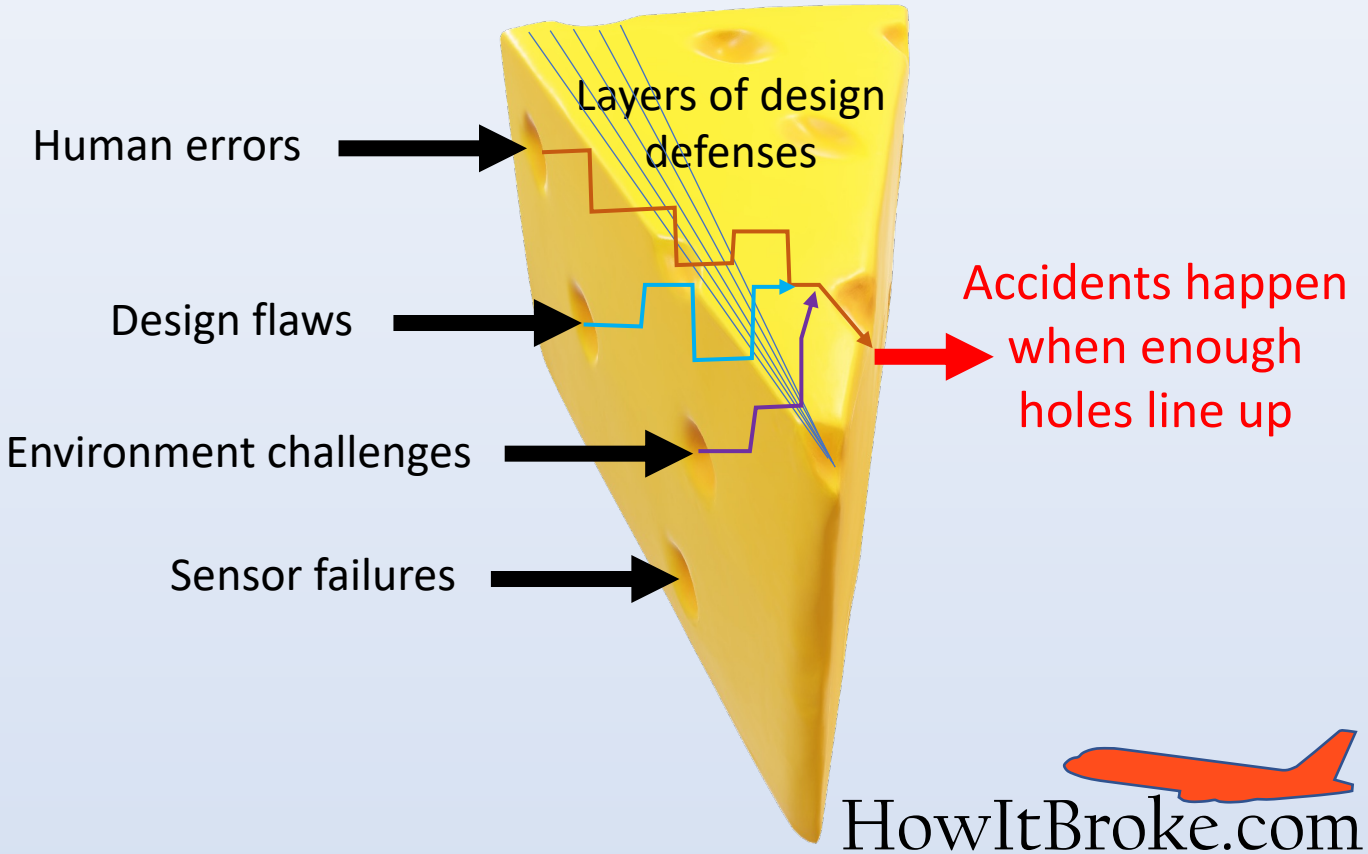
5 Why Method:
Why – Battery is dead
Why – No charge system output
Why – Alternator belt broken
Why – Belt worn to failure
Why – Inadequate maintenance

Too simplistic for most problems

Analysis:

Swiss cheese model

Design defenses and most accidents involve multiple contributing factors



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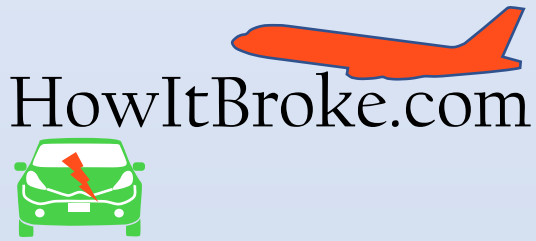
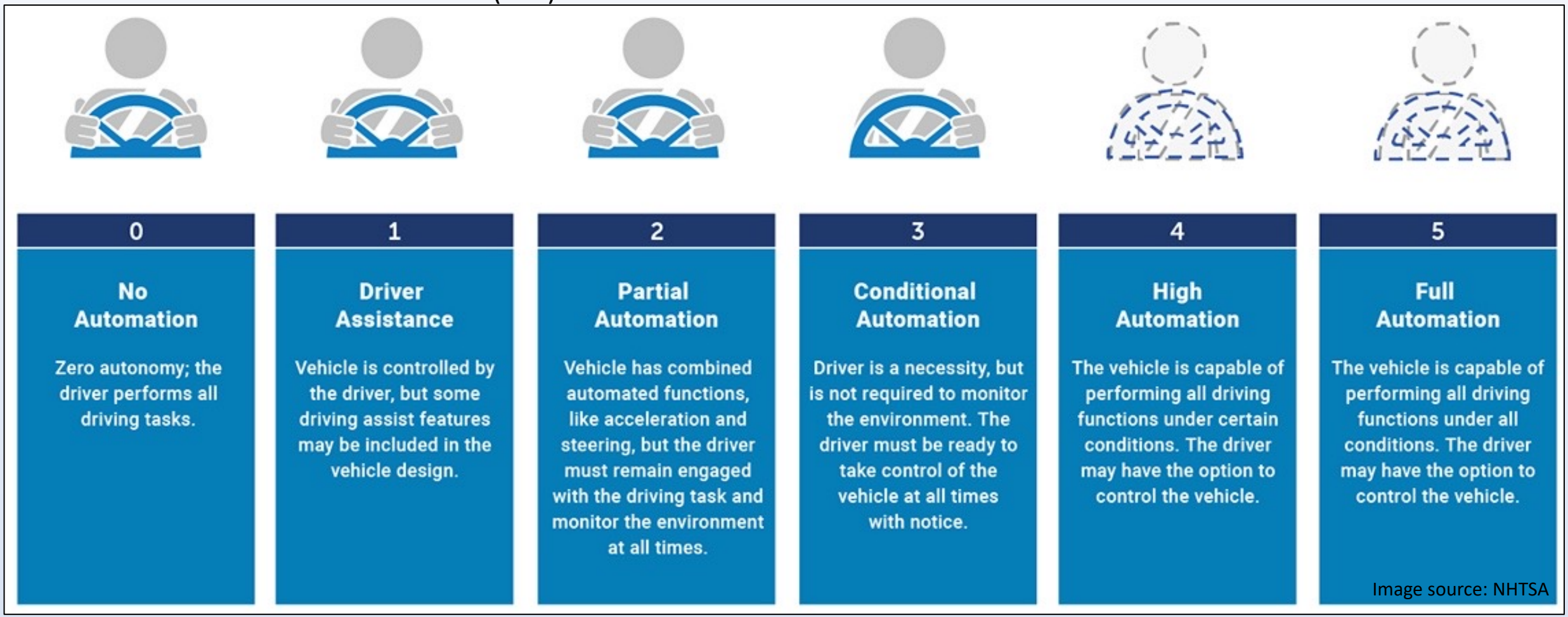
Advanced Driver Assistance Systems (ADAS)



Levels Of Advanced Driver Assistance Systems (ADAS)

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS



SAE J3016 and ISO 22736 Contain definitions for features and levels of control

Surface Vehicle Recommended Practice J3016 was developed by the SAE On-Road Automated Driving Committee, and the first version was published on January 16, 2014. The revised standard released on September 30, 2016, gave a taxonomy for six levels of driving automation. The June 2018 revision retains the six levels of automation with slightly modified descriptions (accessed December 6, 2019).

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Unforeseen Hazards - Accident Involving Class 4 Vehicle on Public Road

UBER Advanced Technologies demonstrator, Tempe AZ, March 18, 2018

49-year-old pedestrian attempted to push bicycle across road without crosswalk

Toxicology showed drugs capable of impairing perception and judgement

Vehicle a modified 2017 Volvo SC90 Sport Utility Vehicle

Driver distracted by personal cell phone

ADAS detected a target 5.6 seconds prior to impact

Never classified as pedestrian or predicted path

Collision at 39 mph

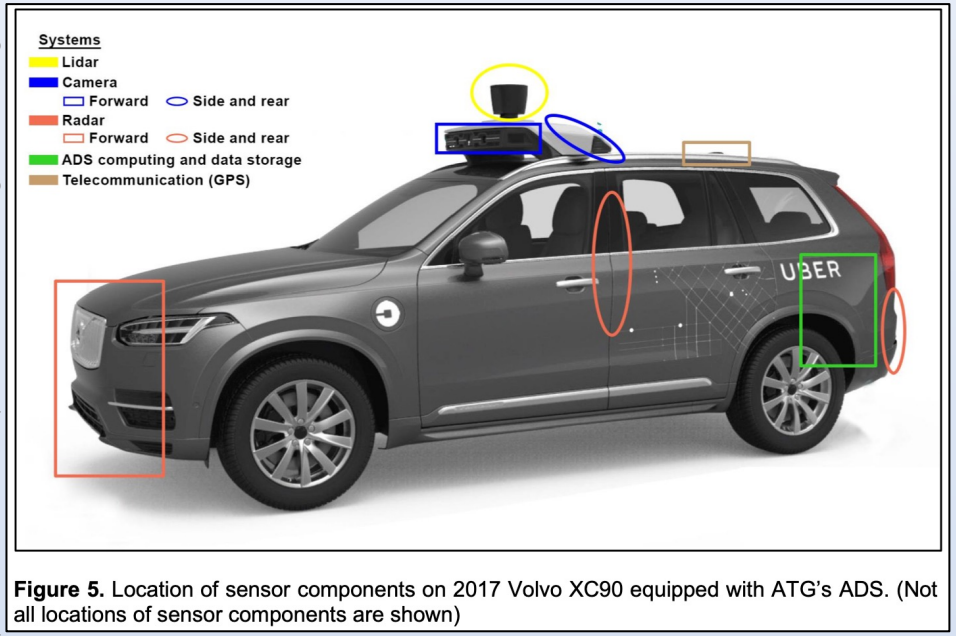
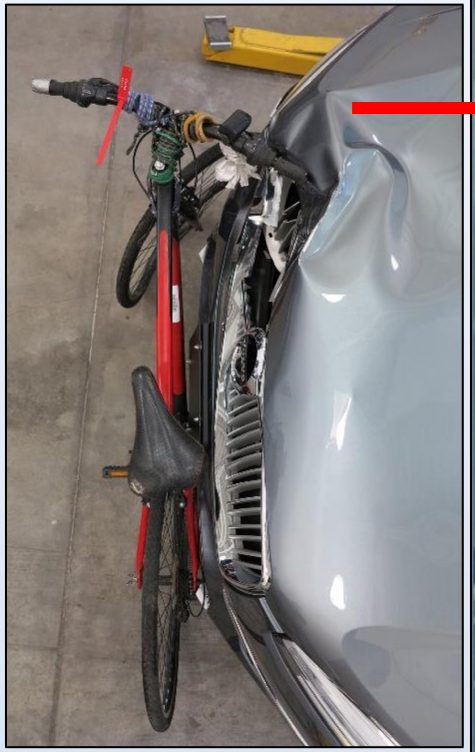
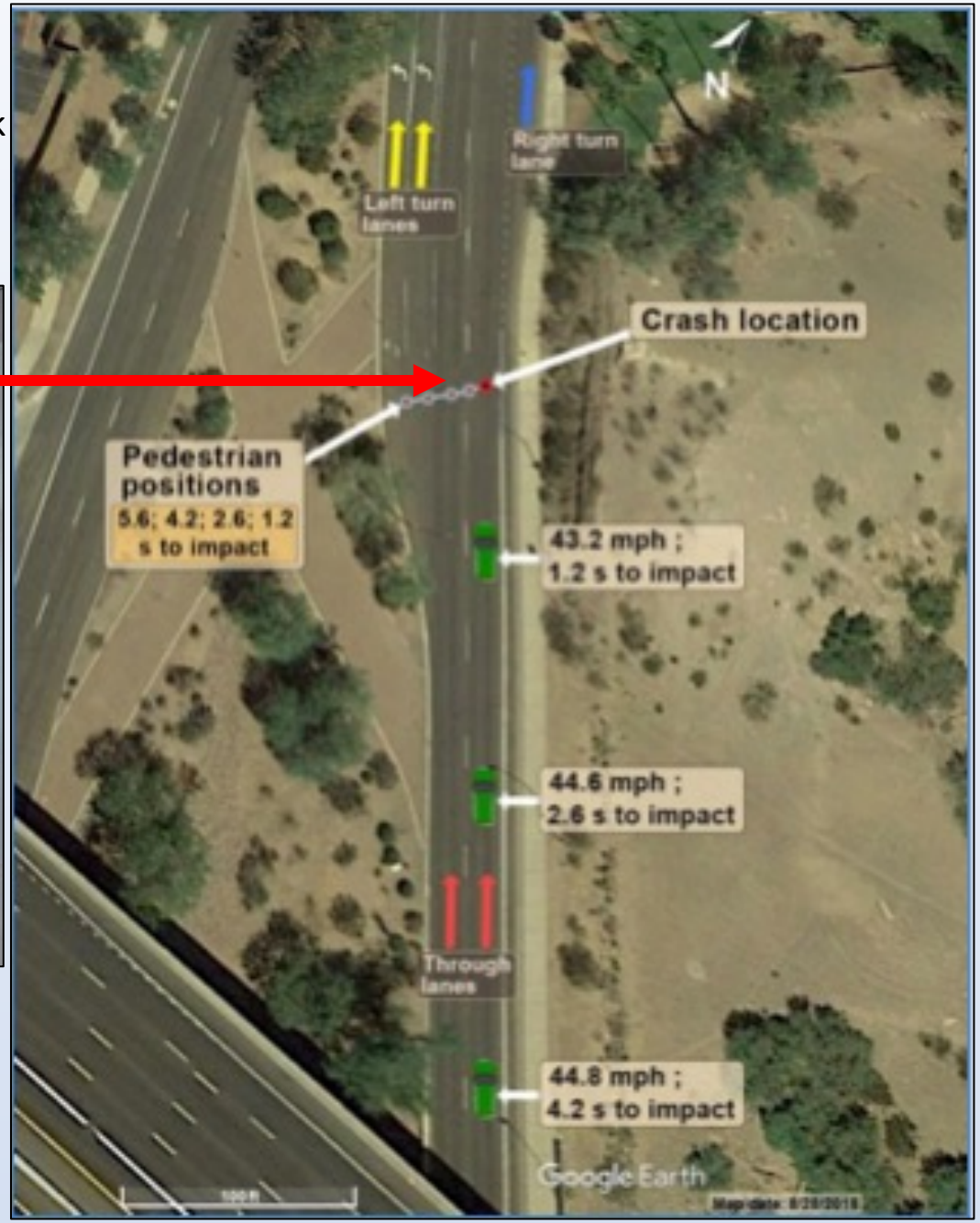


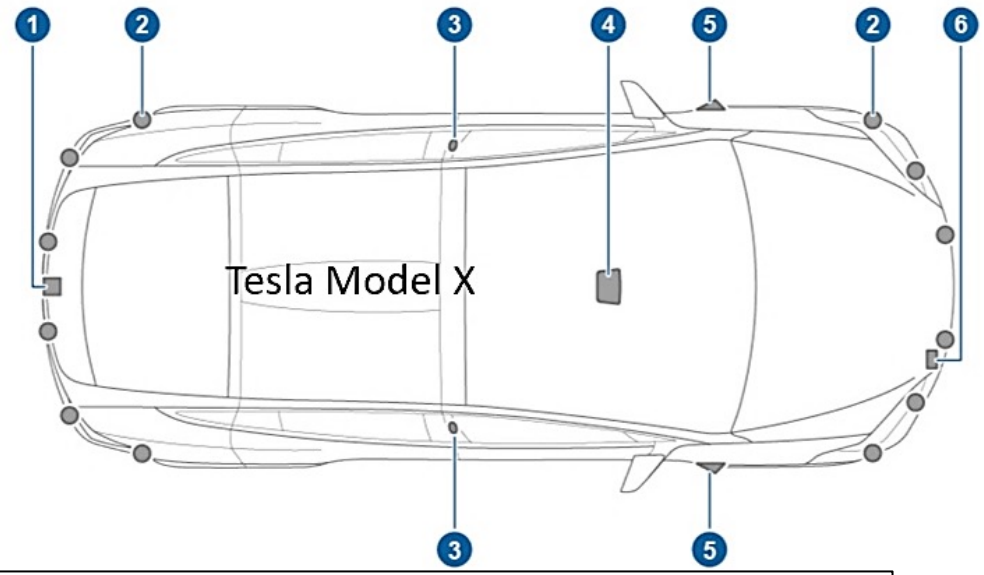
Figure 5. Location of sensor components on 2017 Volvo XC90 equipped with ATG's ADS. (Not all locations of sensor components are shown)



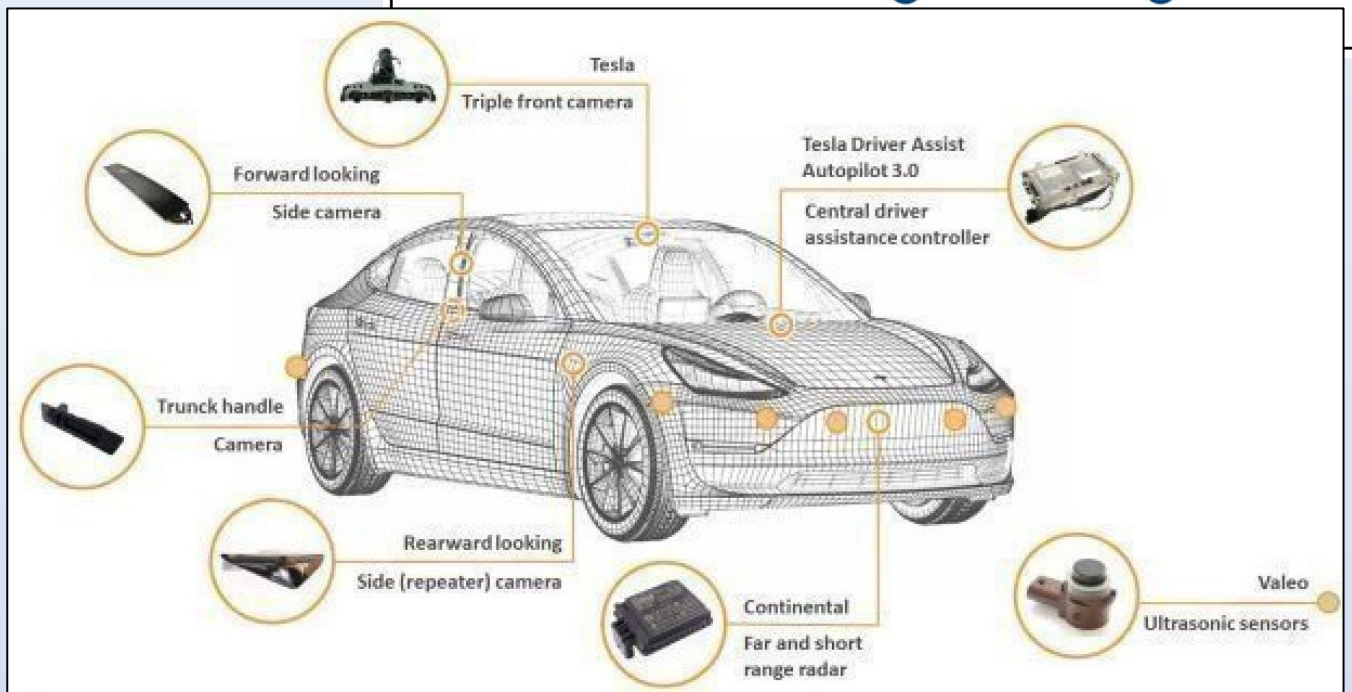
NTSB HWY18MH010



Embedded ADAS Sensors – Tesla Model 3 Cameras, Radar, Ultrasonic Locations



1. Camera mounted above the rear license plate
2. Ultrasonic sensors in front and rear bumpers
3. Camera mounted in each door pillar
4. Three cameras mounted above rearview mirror
5. Camera mounted to each front fender
6. Radar mounted behind front bumper on right side



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ADAS Sensors – Tesla Model 3 Cameras, Radar, Ultrasonic Functions

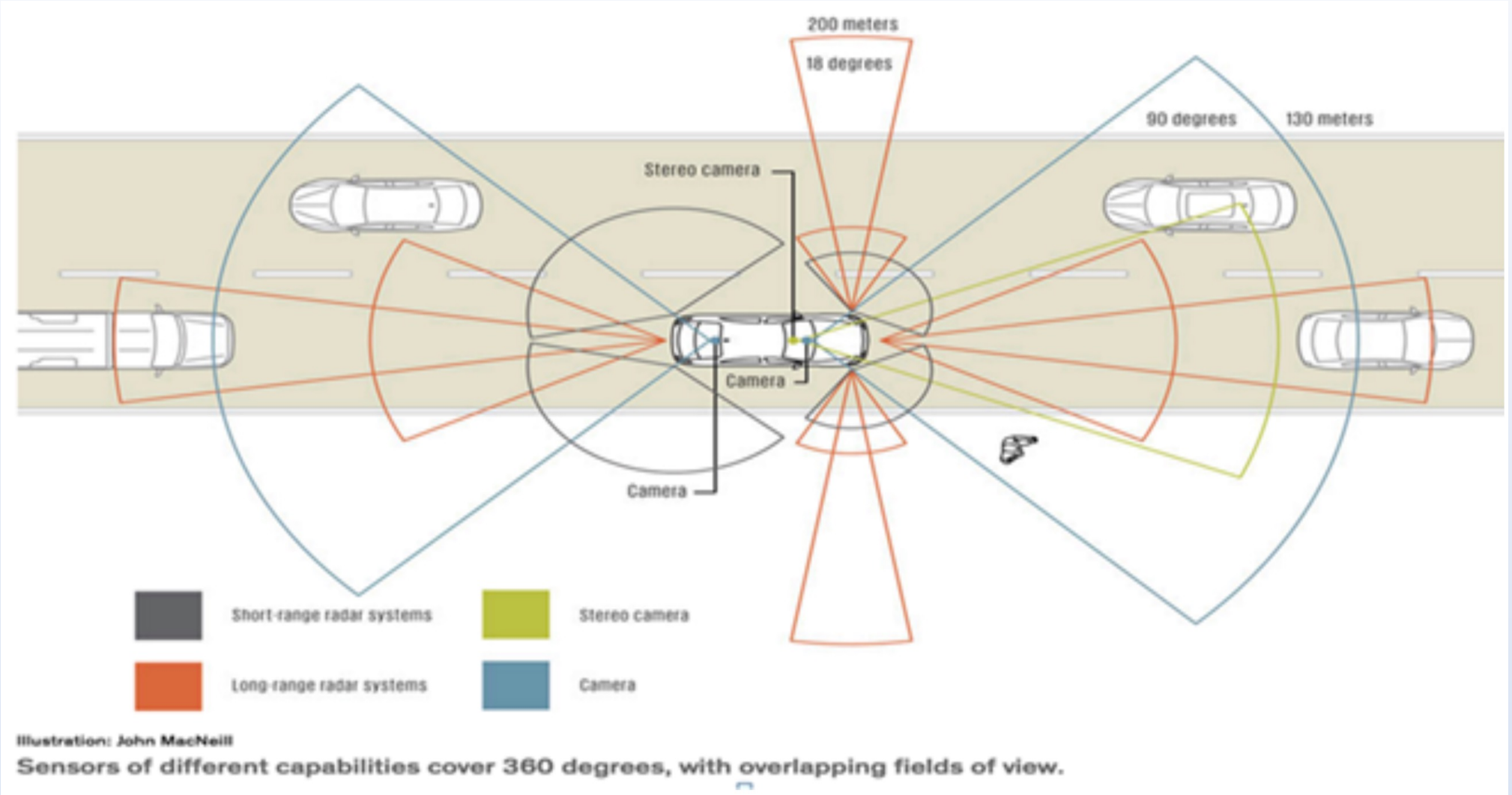

Illustration: John MacNeill

Sensors of different capabilities cover 360 degrees, with overlapping fields of view.

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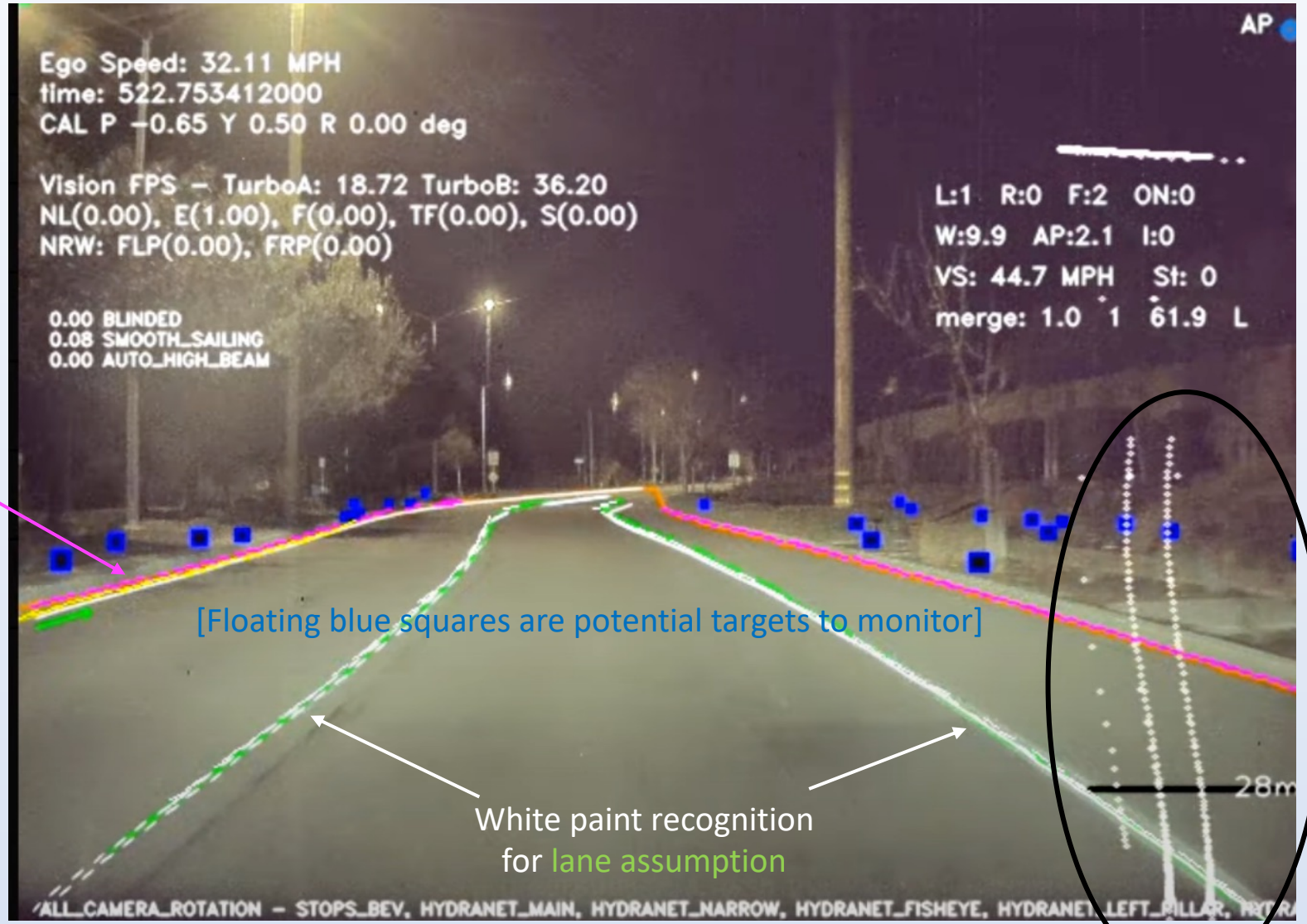
Integrated Sensor System – Simple background



Curb assigned a location and profile

[Floating blue squares are potential targets to monitor]

White paint recognition for lane assumption

Map view created for what is visible

Map created is continuously compared to GPS map

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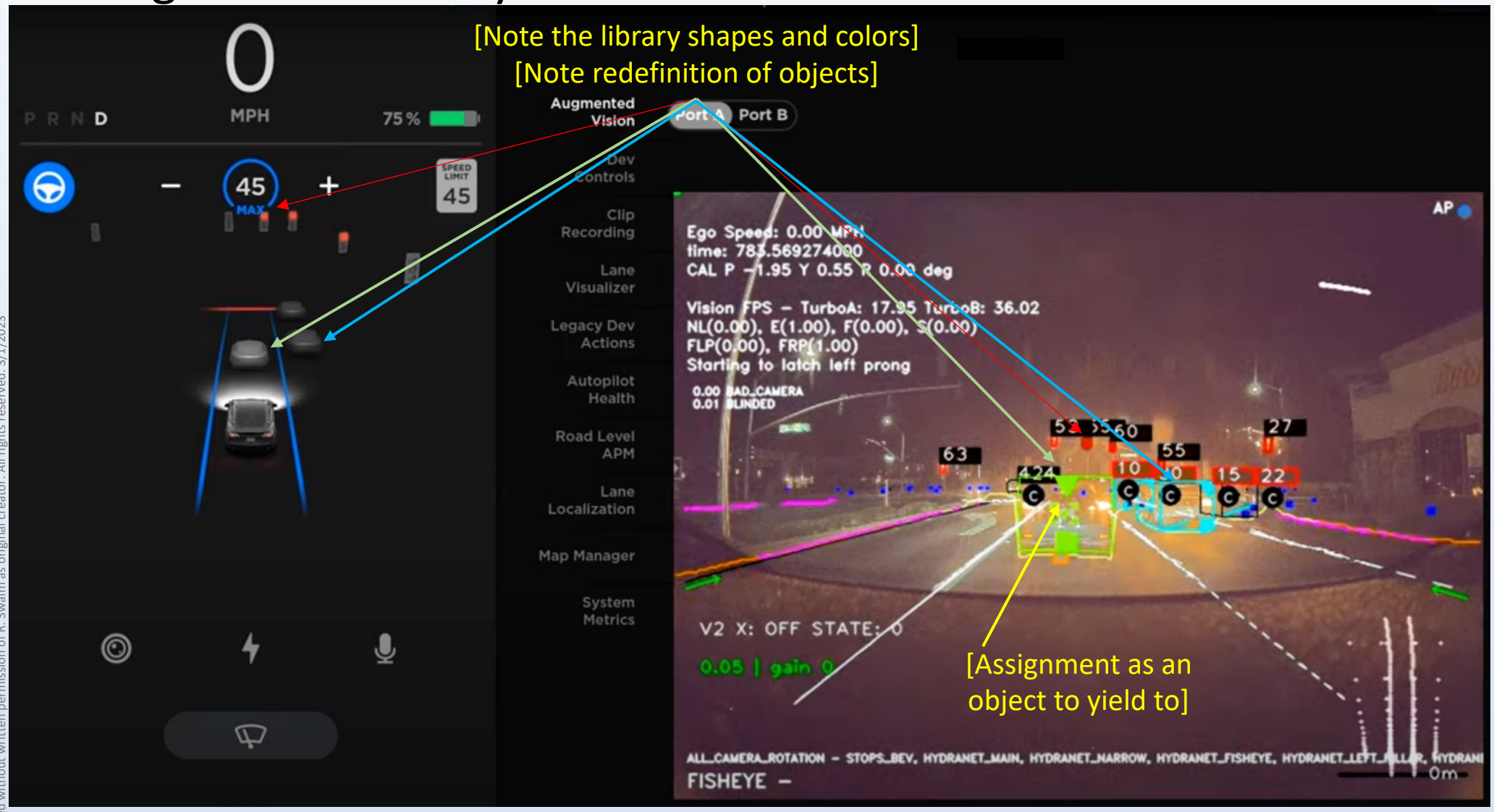
Integrated Sensor System – Urban Environment



Note:

Wire frames for vehicles assigned a shape on left,

Caution on green wire frame ahead to yield to,

Traffic light colors,

Assignment of lane and curb definitions

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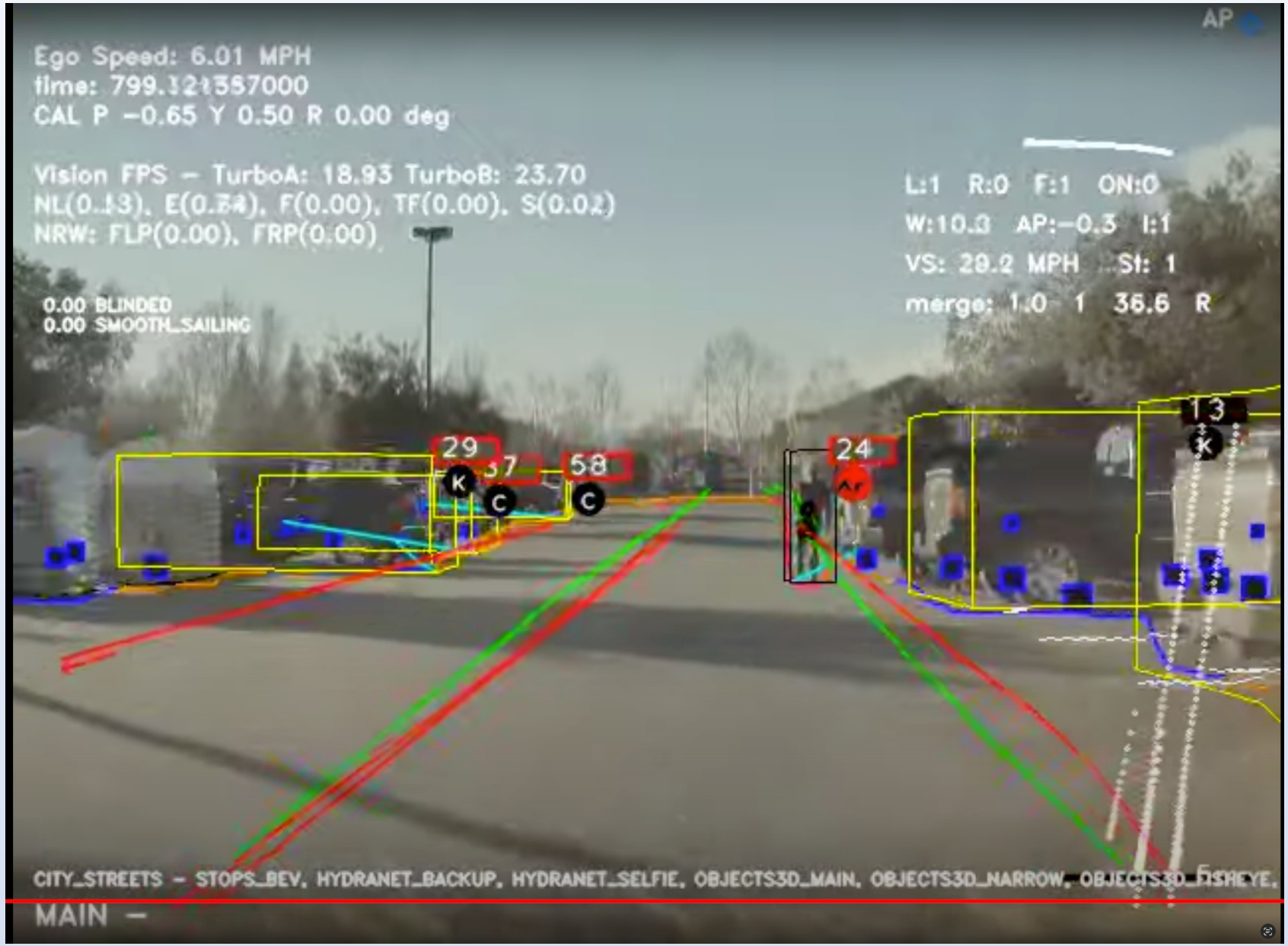
Integrated Sensor System

Congested area assignment of shapes to vehicles and pedestrian



Note:

Block wire frames for vehicles,

Pedestrian recognition,

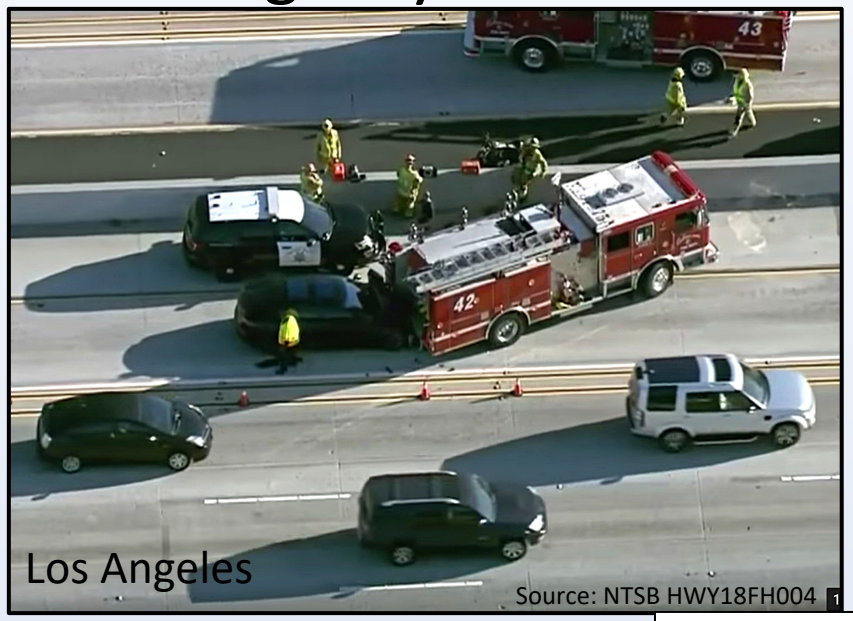
Assignment of lane and curb definitions

Map creation

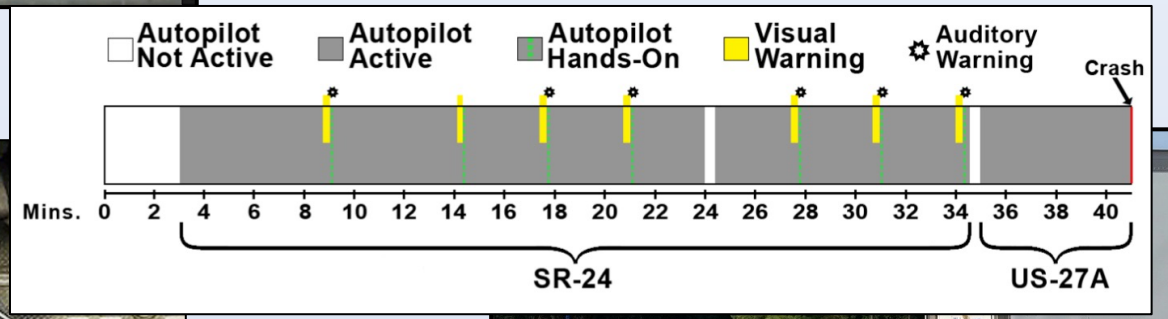
Model S Drove Beneath Trailer - Why?

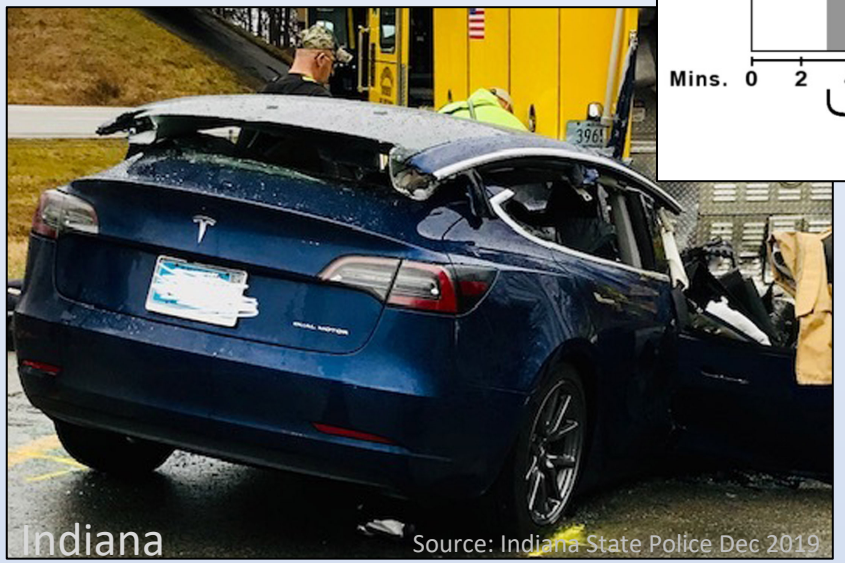
Williston FL, May 7, 2016, 4:36pm, NTSB/HAR-17/02

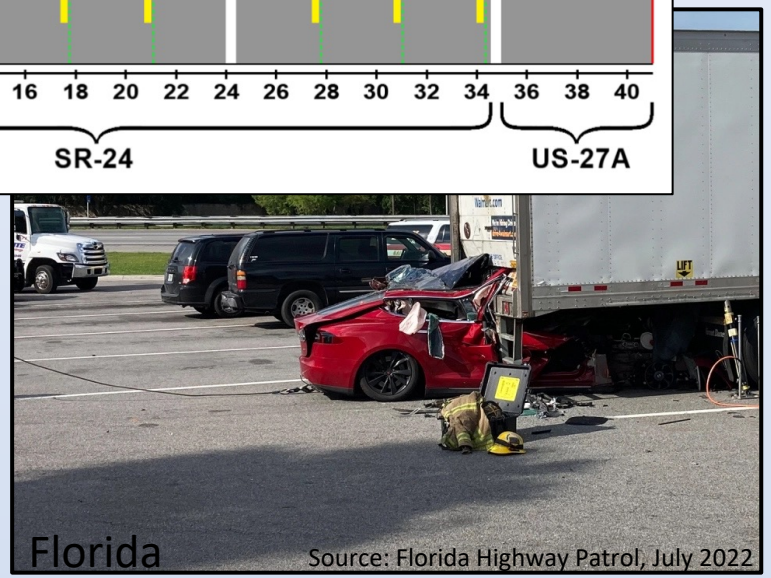
16 Emergency Vehicles Plus Others Struck



Issue #1
Driver Inattentiveness and
"Pavlov's Dog" Response







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Issue #2: Cameras and radar assigning block shapes have difficulty in differentiating stationary items high enough to pass under

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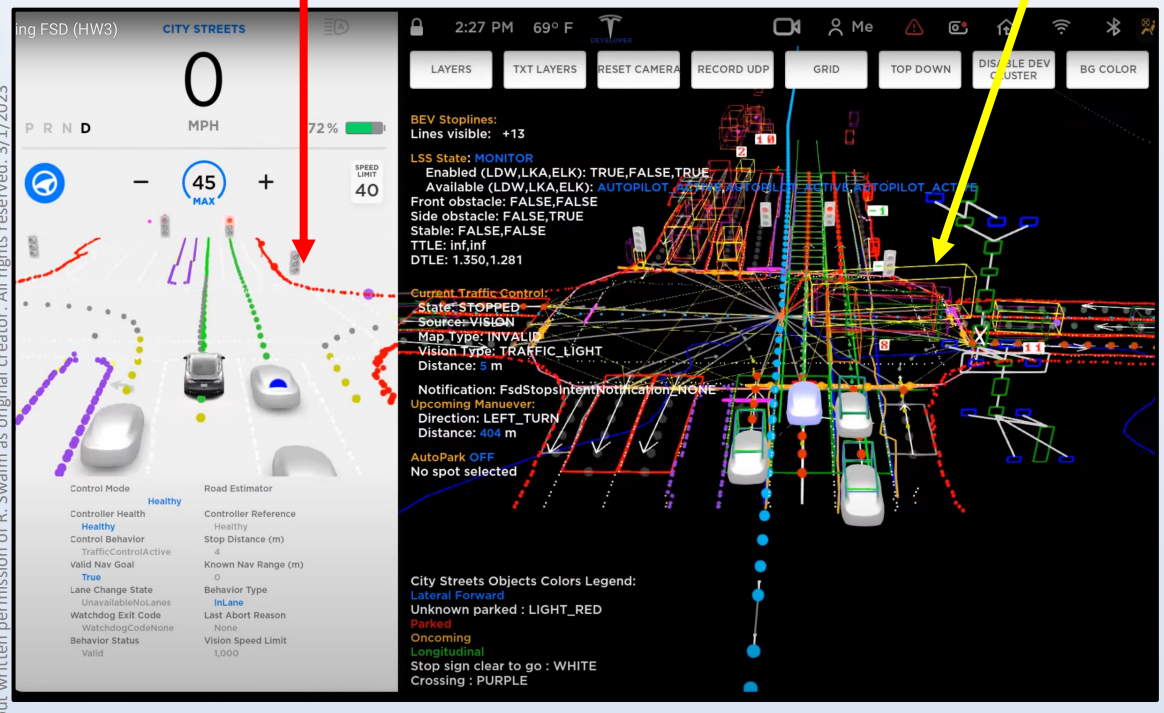
Example: Recognition of Crossing Truck at Intersection (Car Stopped)

Is it a truck three feet above the road?
An overpass?
A sign to drive under?

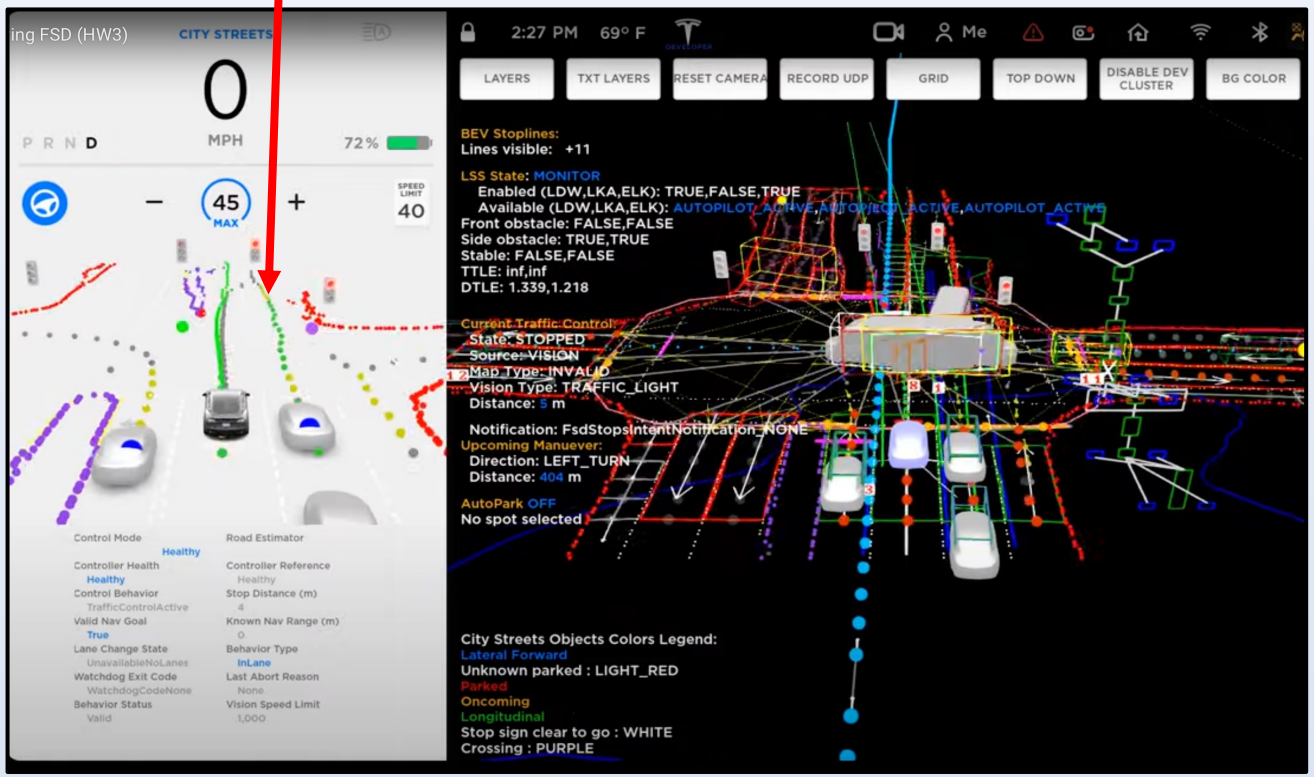
No truck

Yellow block for potential truck



Still no truck

Assignment then indecision (Cab at both ends)



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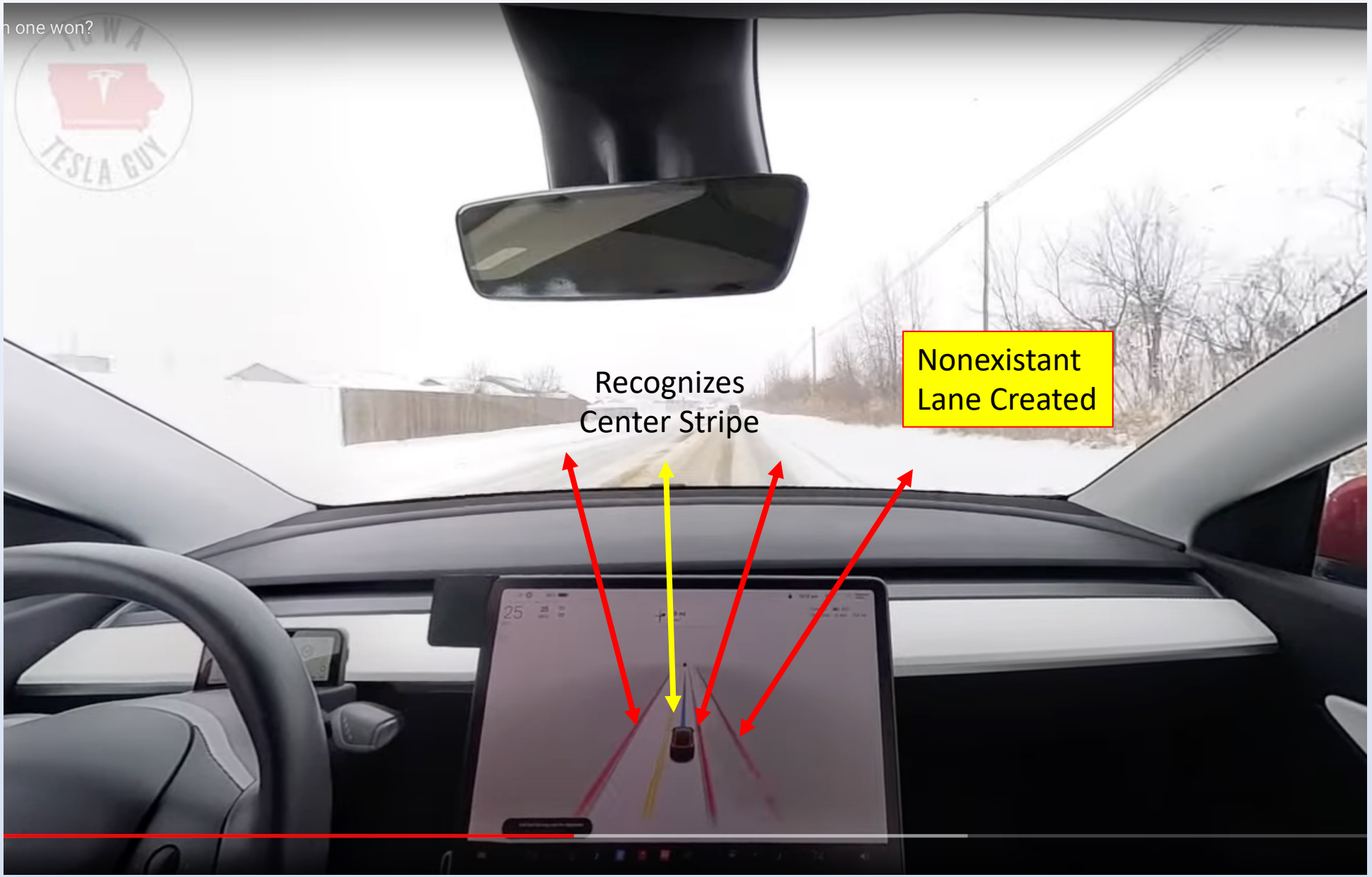
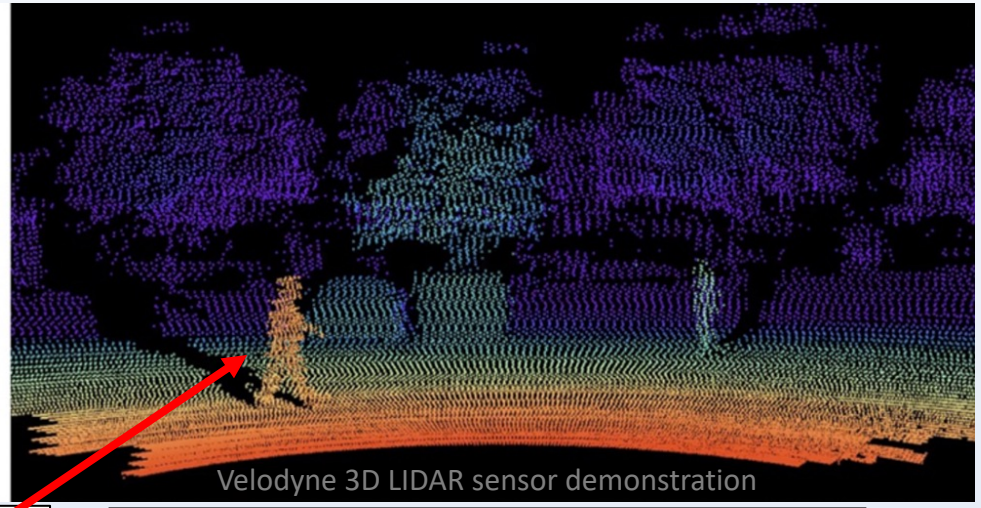
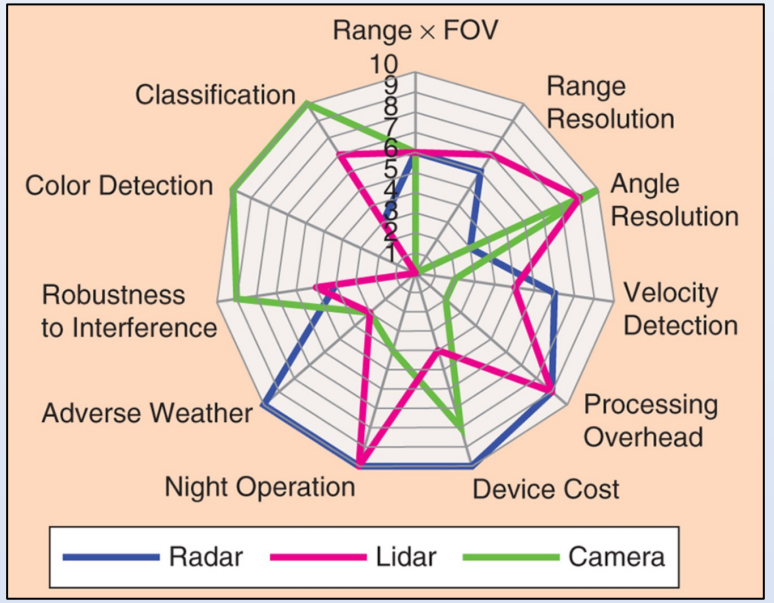
Weather and Road Conditions Can Degrade Sensors



LIDAR: Features to Integrate With Cameras and Radar



Performance Compared Under Specific Conditions	Camera	RADAR	LiDAR
Dark, Little to No Light	Will Not Work	Very Good (Not Effected by Light Conditions)	Very Good
Variable Lighting Condition	Blinds the Camera	Very Good (Not Effected by Light Conditions)	Very Good
Adverse Weather (Rain, Snow and Fog)	Shortens Range	Very Good	Shortens Range
Angular Resolution	Poor at Long Range	Currently (2-5 Deg) Developmental (0.5-1 Deg)	0.1 Degree
Color & Contrast	Yes	No	No Color, Limited Contrast Info
Cost of Today Technology	2 Mega Pixel Resolution (Low Cost)	24/77 GHZ RADAR (Medium Cost)	Commercialized LIDAR System (Higher Cost)



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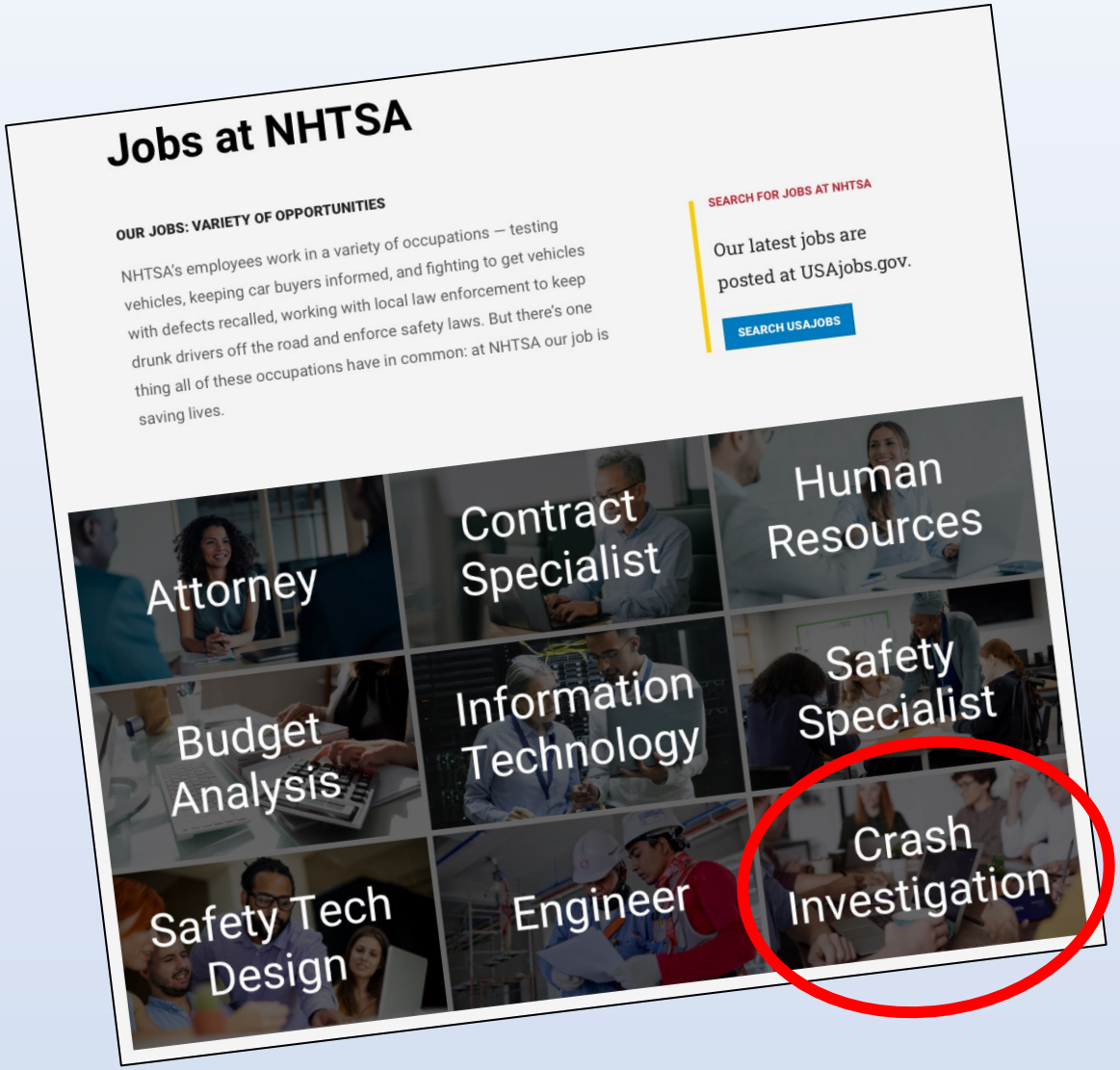
Now that you are experts
CONGRATS ON YOUR NEW JOB!!!

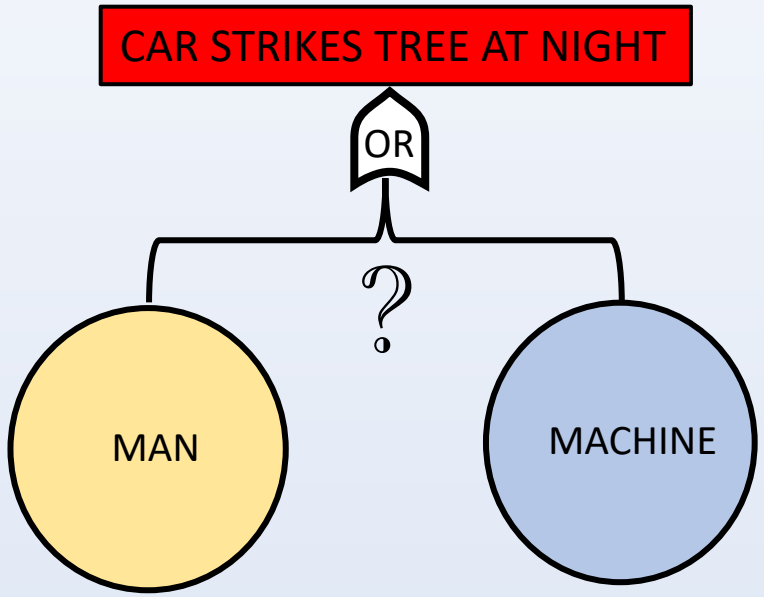


As part of Office of Defect Investigations (ODI)

You are part of a team investigating accidents involving ADAS.

Question - Should ADAS be banned?

ADAS Accident Investigation in College Park, MD



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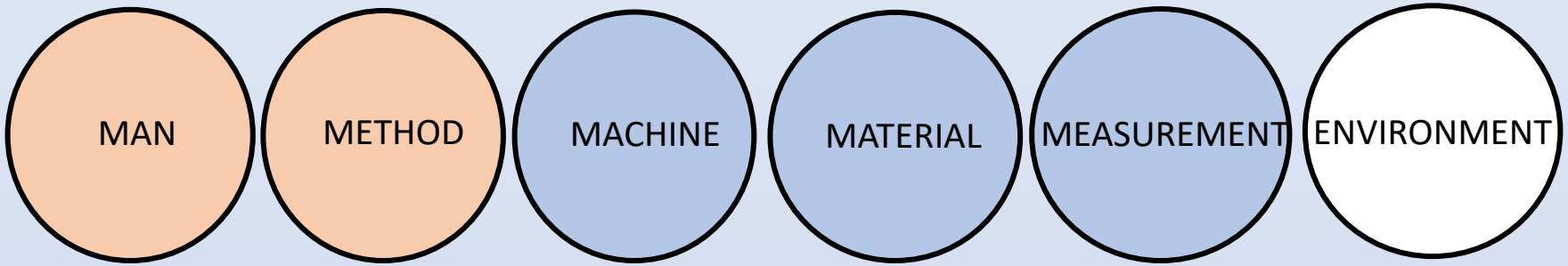
Failure Logic Tree

CAR STRIKES TREE AT NIGHT

Collect basic facts for each of the
5 Ms & E:



Interview Notes of driver (Man)

Daisy DooRite, age 21,
123 Snobbish Court, College Park, MD,
Tel 301-XXX-YYYY

- Time of accident about 1 am.
- Was coming back to school from home in New Haven, CT after early dinner with parents.
- Boring drive due to lots of weekend traffic and sat on I-95 for periods of time.
- Ran out of drinks and wanted one to stay awake. Was waiting to arrive to use toilet.
- Near school was driving through the woods because I-95 was still so backed up. The road is dark but is a good back route.
- At time of accident the car was on autopilot and driver had hand on bottom of steering wheel. It never disengaged.
- The car just decided to turn the wrong way.
- Couldn't use the car phone because she had her boy friend's and it wouldn't hook up to the car. Did have charge cable.
- Driver slammed on the brakes but car wouldn't stop and the steering wheel was torn out of drivers' hands.
- No injuries. Intends to hire lawyer to sue car manufacturer.
- [*Police on scene reported no evidence of alcohol or drug impairment. Tesla call center reported collision at 2:21am*]


Vehicle at tow lot


Tree struck in curve

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Start of 48 Hour Driver History (Man)

Date	Time	Item	Source
X/13/202X		[Fill in for previous day]	
X/13/202X	20:30	At house of friend	Driver interview
X/14/202X	00:30	Went to bed	Driver interview
X/14/202X	02:30	End of texting	Phone records
X/14/202X	07:00	Awoke to shop with Mother	Mother interview
X/14/202X	17:00	Departed parents house	Driver interview
X/14/202X	17:10	Receipt for Coca Cola and pretzels	Receipt in vehicle
X/14/202X	19:30 [est]	Toilet stop	Driver interview
X/14/202X	22:00 [est]	Toilet stop	Driver interview
X/15/202X	02:21	Accident	Vehicle data

Actual rest started

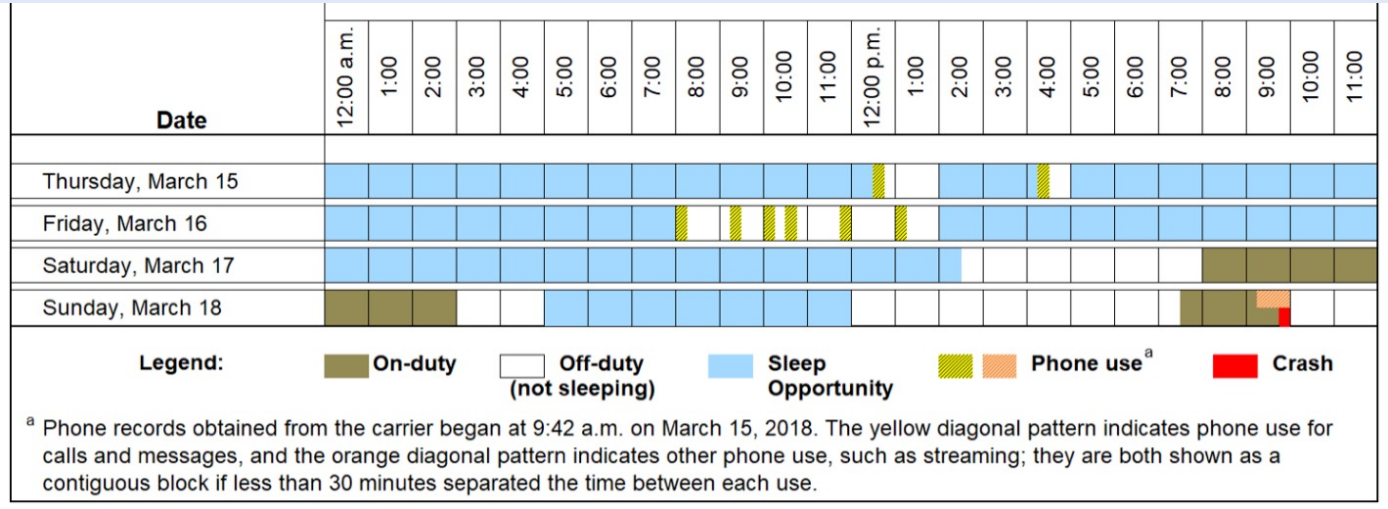
4.5 Hours sleep

9:21 Underway

19:21 Hours awake

Actual example from UBER ATG collison with bicycle:

NTSB HWY18MH010

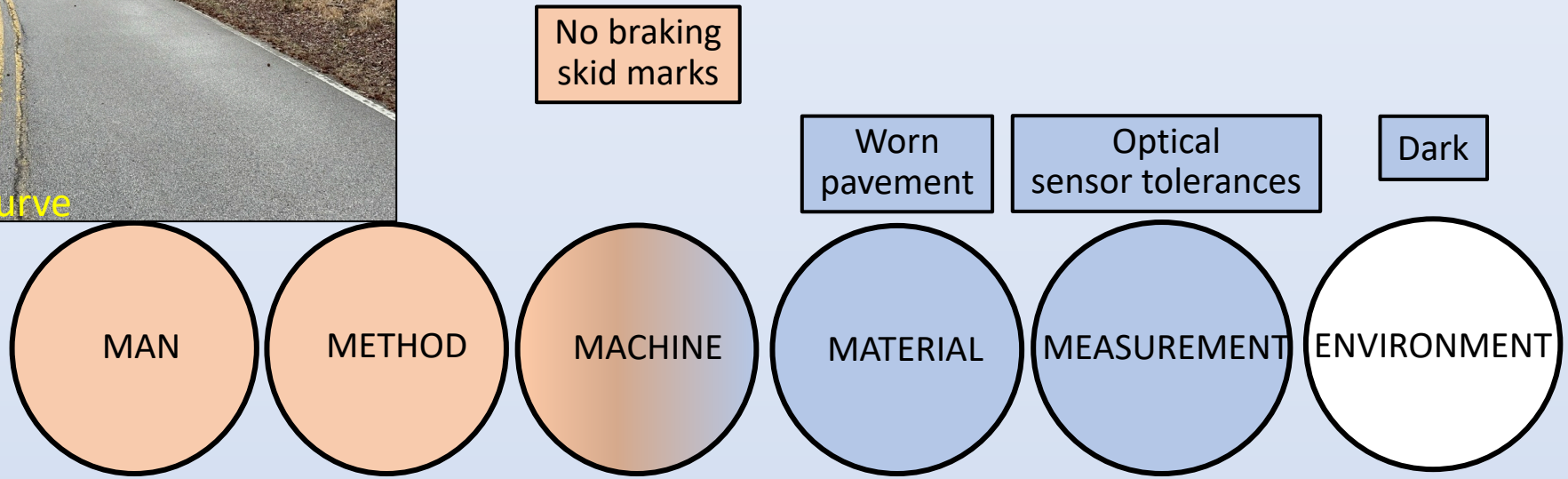


Failure Logic Tree – What do you notice at scene? (Environment)

SCENE:

- Dark location with no street lights. Posted 35 mph
- Dry pavement with no skid marks observed
- Straight wheel marks through dirt to tree
- Pavement markings worn and road edge partially obscured with leaves
- Passed a house security camera showing speed of 40 mph

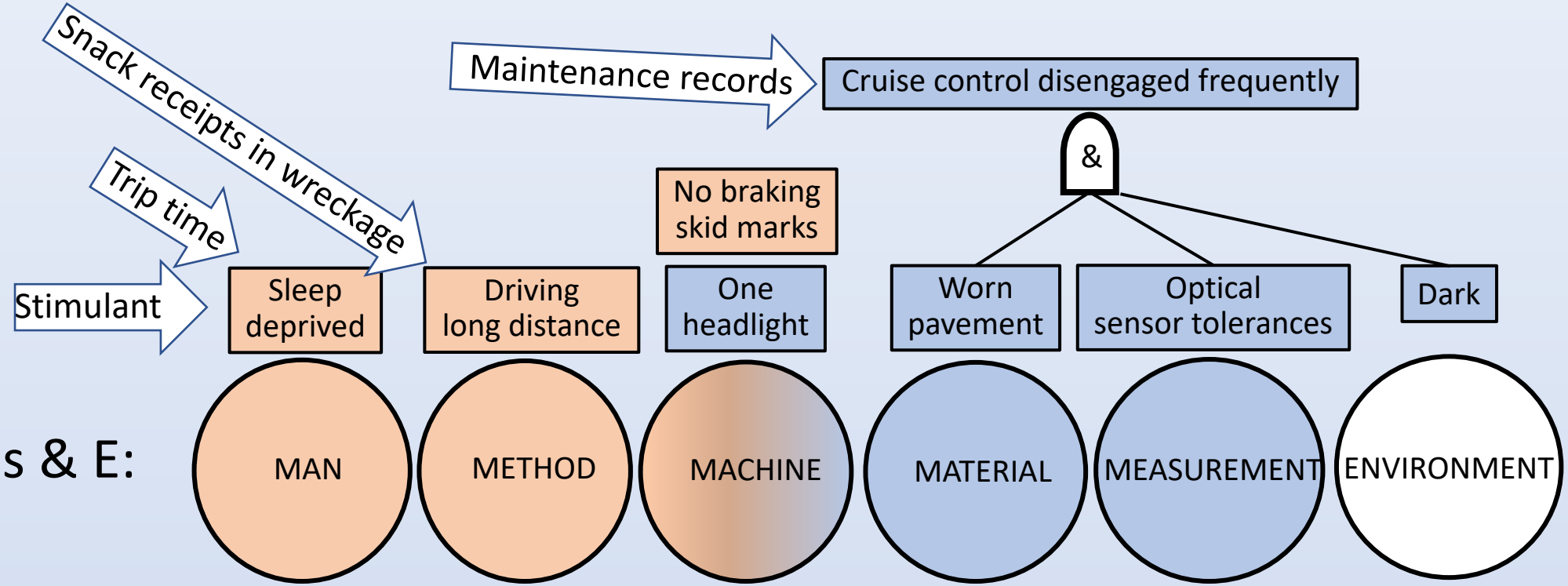
5 Ms & E:



Failure Logic Tree – Vehicle (Machine)

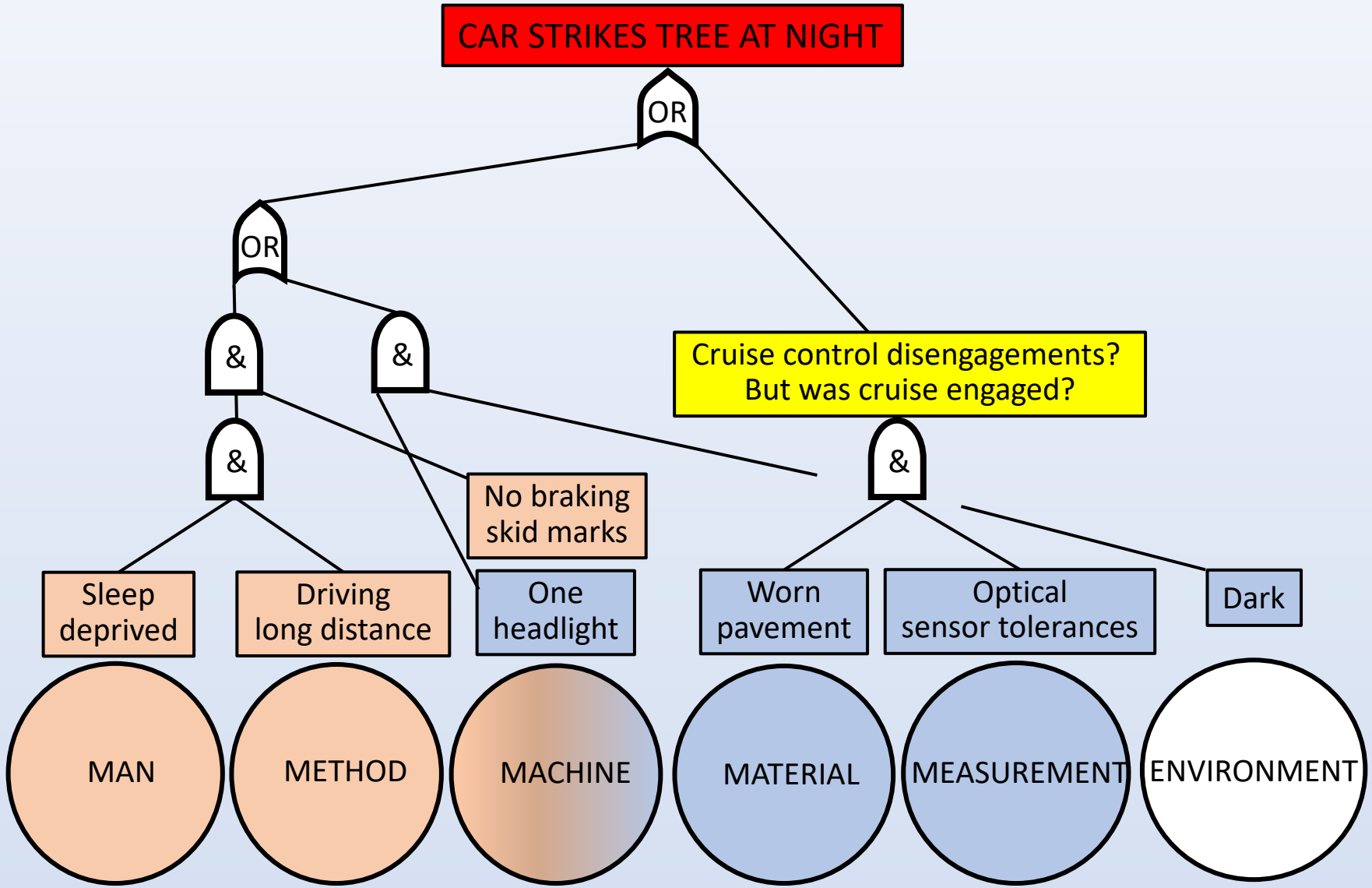
VEHICLE FINDINGS:

- Time on receipt for pretzels and Cokes from store in Connecticut
  - Long trip time [*9 hours to 2:21 am*]
  - Long driving distance [*300 miles*]
  - Six empty Coca Cola cans [*Effects of stimulant wearing off*]
- One headlight tested inoperative after accident
- Dirty windshield ahead of driver mirror [*Contains triple camera lens*]
- Glovebox service receipts state cruise control disengages periodically



Failure Logic Tree – Combined Man and Machine Facts

Now it could be the driver OR the car



Failure Logic Tree – Combined Man and Machine Facts

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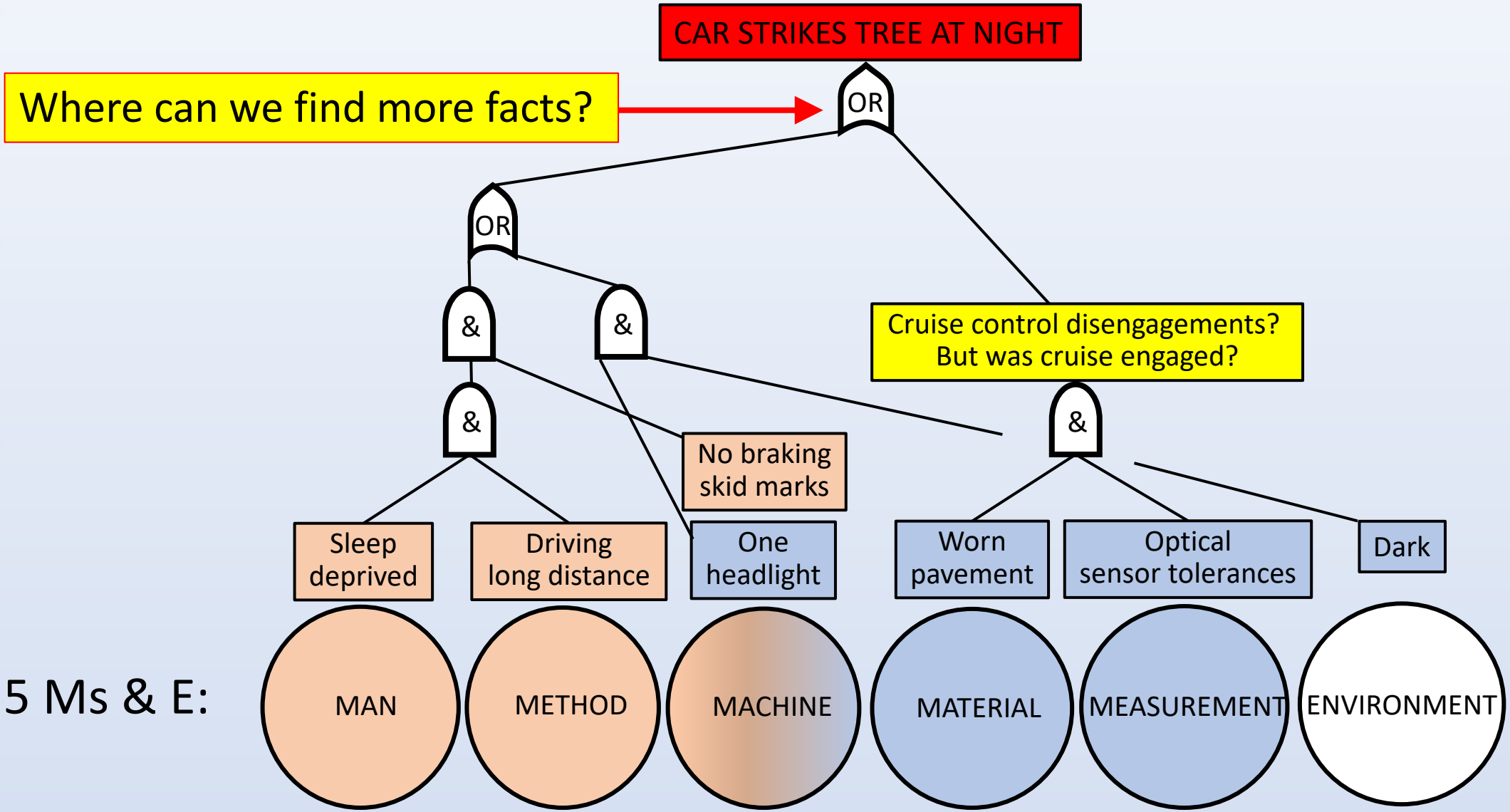
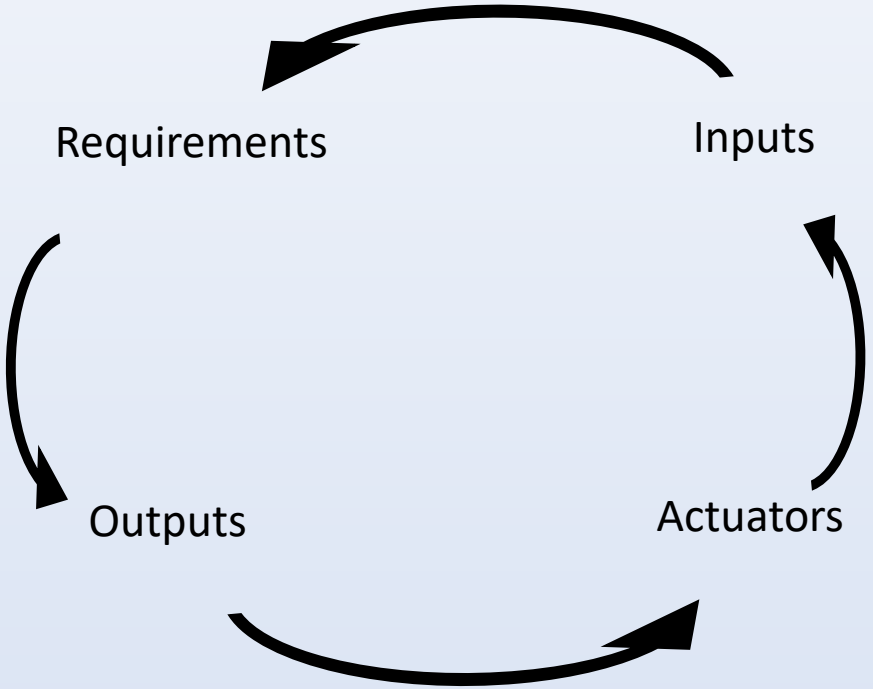


Machine - Continuous Loop of Automated Systems

Brain functions consider and create outputs
For muscles to act
Followed by senses reporting status of the movement back to the brain



Brains

Senses (& feed-back)

Muscles

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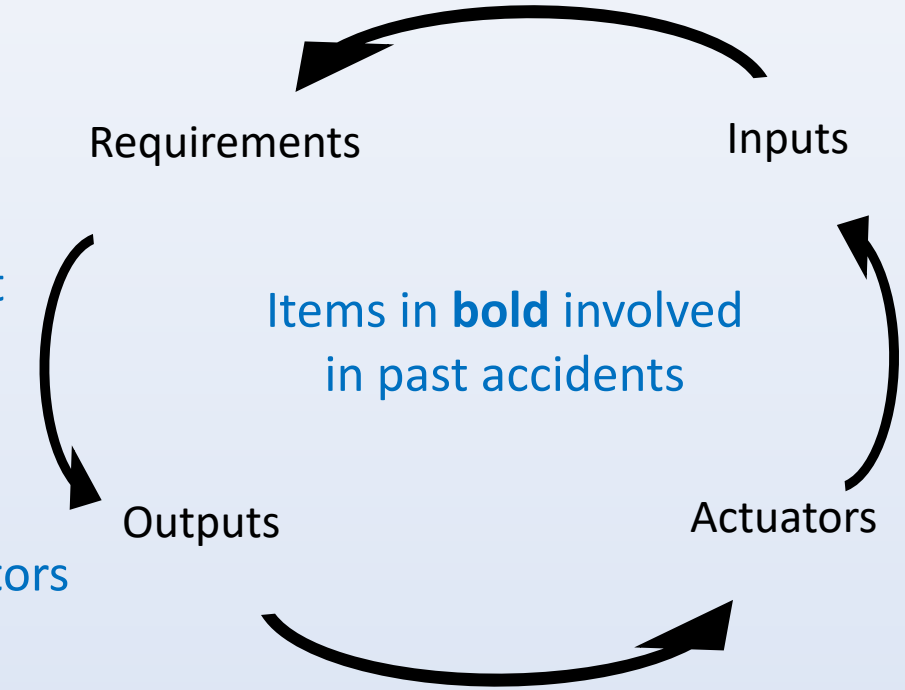
Continuous Loop of Automation is Similar to Anatomy

Brains

Design assumptions
- Potential software **conflicts**

Databases & lookup tables
Calculate position
Compute delta to requirement
Buffers, timers, and filters
Compute needed corrections

Guidance commands to actuators
Displays to humans



Senses (& feed-back)

Driver mechanical & **switches**
GPS & other **NAV**
Camera and **optical sensors**
RADAR, LIDAR, & **RF based**
Environmental sensors
Feedback of device positions

Muscles

Mechanical
Electric
Hydraulic

Need more data!

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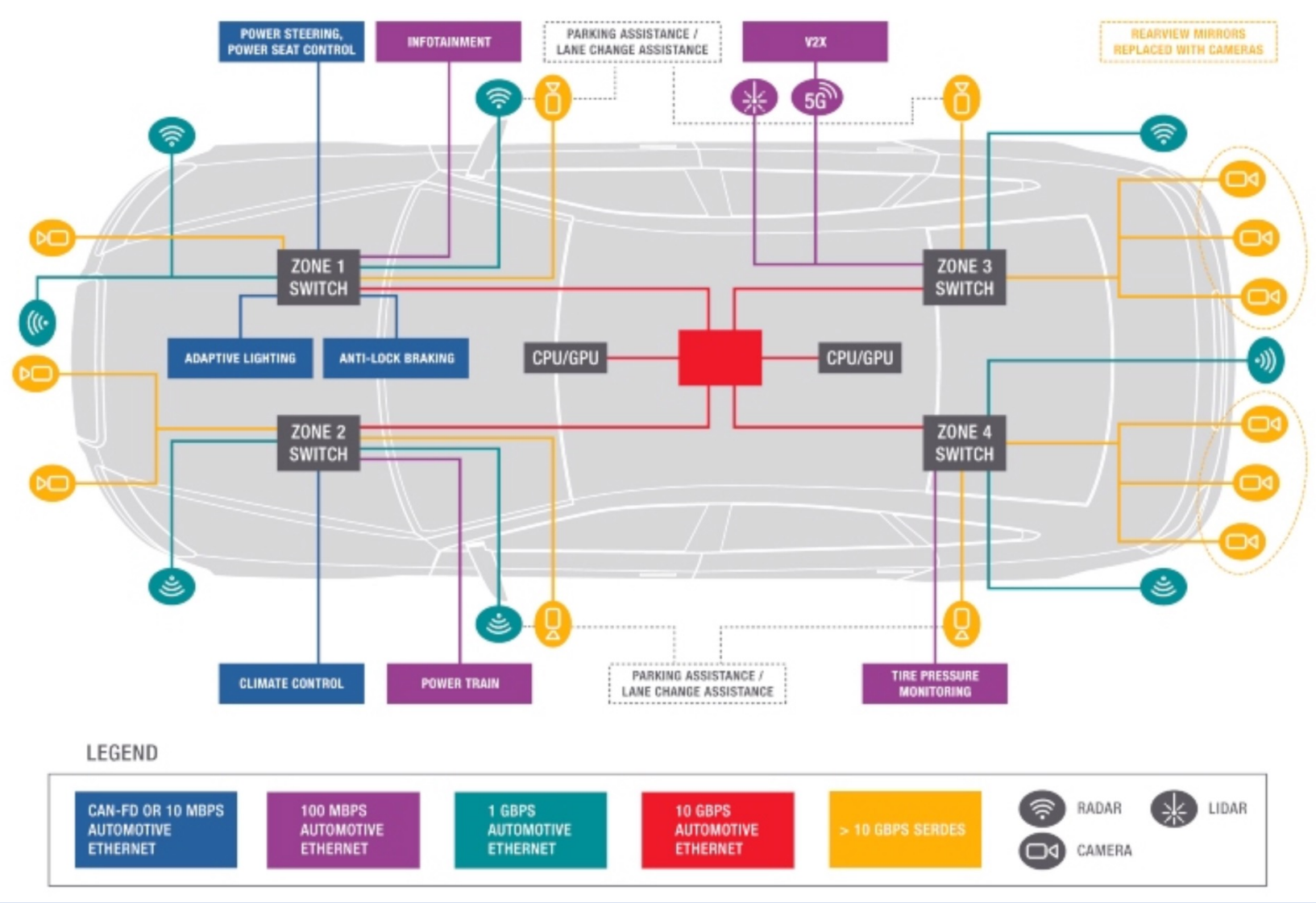
Data?

Most of these are recorded



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Vehicle Data Recorders

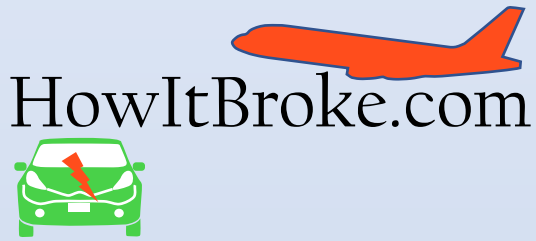
Information Access Depends on Type of Investigation

Criminal – Government may not release ANY data

Safety – Government may release partial data, typically not video or audio

Civil – Typically requires court subpoena. May be denied.

Technical – May or may not get access



Data and Recordings

Frequently embedded in multiple devices for various types of information

Vehicle devices typically not hardened like aviation "Black Boxes

May contain dozens to thousands of parameters such as:

Speed, Lat/Long (GPS), seat belt use, airbag deployment, impact sensor states, fault logging (OBD), automation engagement and level, cell temps and detailed EV battery data, motor temp, transmission status, ABS, ESC, throttle position, atmospheric pressure, OAT, headlight use, wiper use, door alerts, etc,

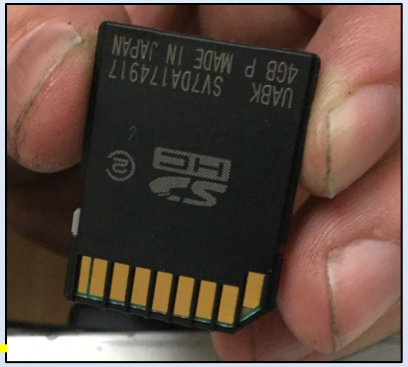
Parameter recording rates differ

Example: Seatbelt status upon change of state vs vehicle speed at least once/second

Data Sources

Restraint Control Module (RCM)

Media Control Unit (MCU)



Five Seconds of RCM Data

HWY18FH011, Mountain View CA, 3/23/2018

TESLA

Event Data (Event 1)

Time (sec)	Vehicle Speed (km/h)	Accelerator Pedal (%)	Rear Motor Speed (rpm)	Service Brake	Stability Control	ABS Activity
-5.0	102	0	6799	Off	On	Off
-4.5	101	0	6713	Off	On	Off
-4.0	100	0	6641	Off	On	Off
-3.5	100	0	6612	Off	On	Off
-3.0	100	0	6689	Off	On	Off
-2.5	101	0	6766	Off	On	Off
-2.0	104	0	6937	Off	On	Off
-1.5	107	0	7104	Off	On	Off
-1.0	109	0	7284	Off	On	Off
-0.5	112	0	7433	Off	On	Off
0.0	114	0	7584	Off	On	Off

From Media Control Unit and Autopilot ECU:
Precise time, Speed, Steering wheel position, Accel pedal position, Driver brake pedal, A/P Status, Faults, Longitudinal and Lateral G forces, lead vehicle distance

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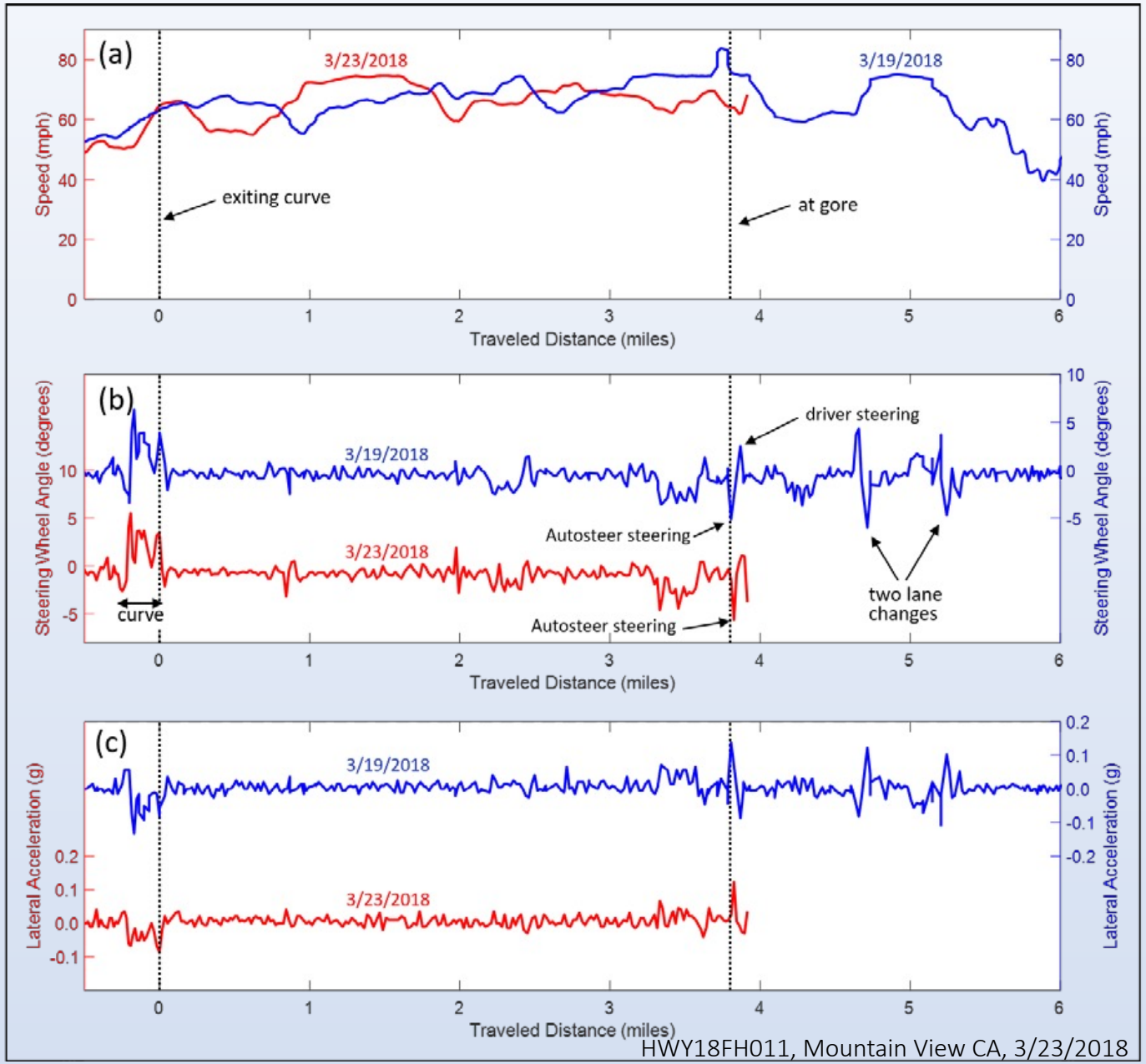
Example of Carlog Data Showing Driver Taking Control



HWY18FH011, Mountain View CA, 3/23/2018

Other Parameters Available Include:

Speed,
Lat/Long (GPS),
Sensor buffers for LIDAR/RADAR/etc
Seat belt use,
Airbag deployment,
Impact sensor states,
Fault logging (OBD),
Automation engagement and level,
Cell temps and detailed ev battery data,
Motor temp,
Transmission status,
ABS,
ESC,
Throttle position,
Atmospheric pressure,
OAT,
Headlight use,
Wiper use,
Door alerts,
Etc,

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Recording devices to look for

ON VEHICLE (Some require continuous 12V source)

- Vehicle event recorder (Precise time of accident, speed, G forces, etc)
- Onboard video recorder
- Motor controller memory,
- EV Battery Battery Management System (BMS)
- Anti-skid braking system memory (ABS)
- Other . . .

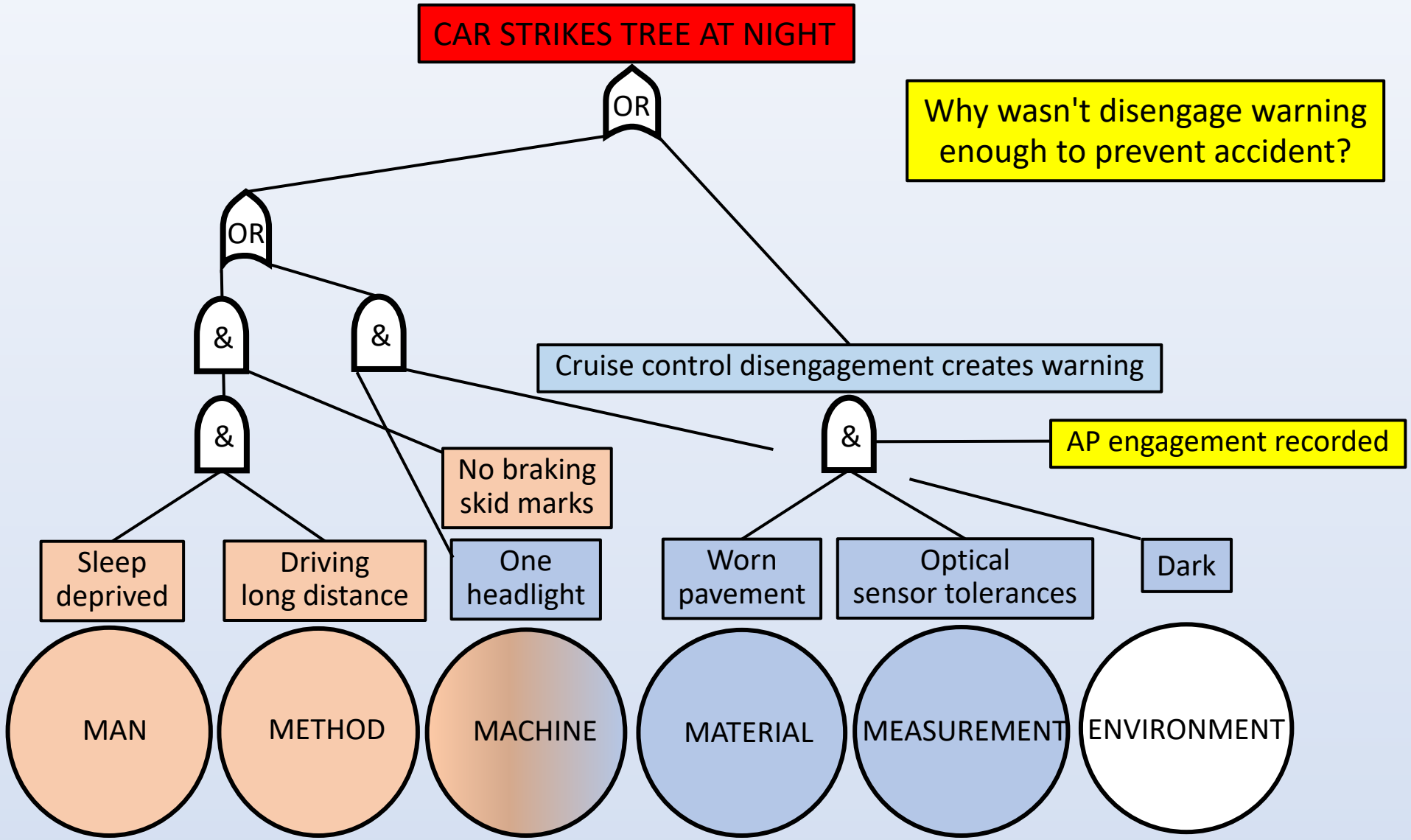
EXTERNAL

- Cell phone – phone, data, GPS, camera
- Roadway system - traffic video, timers, and other devices
- Stores and other business security cameras

DATA IS SELDOM COMPLETE.
For example the following items are frequently not all available at same time:

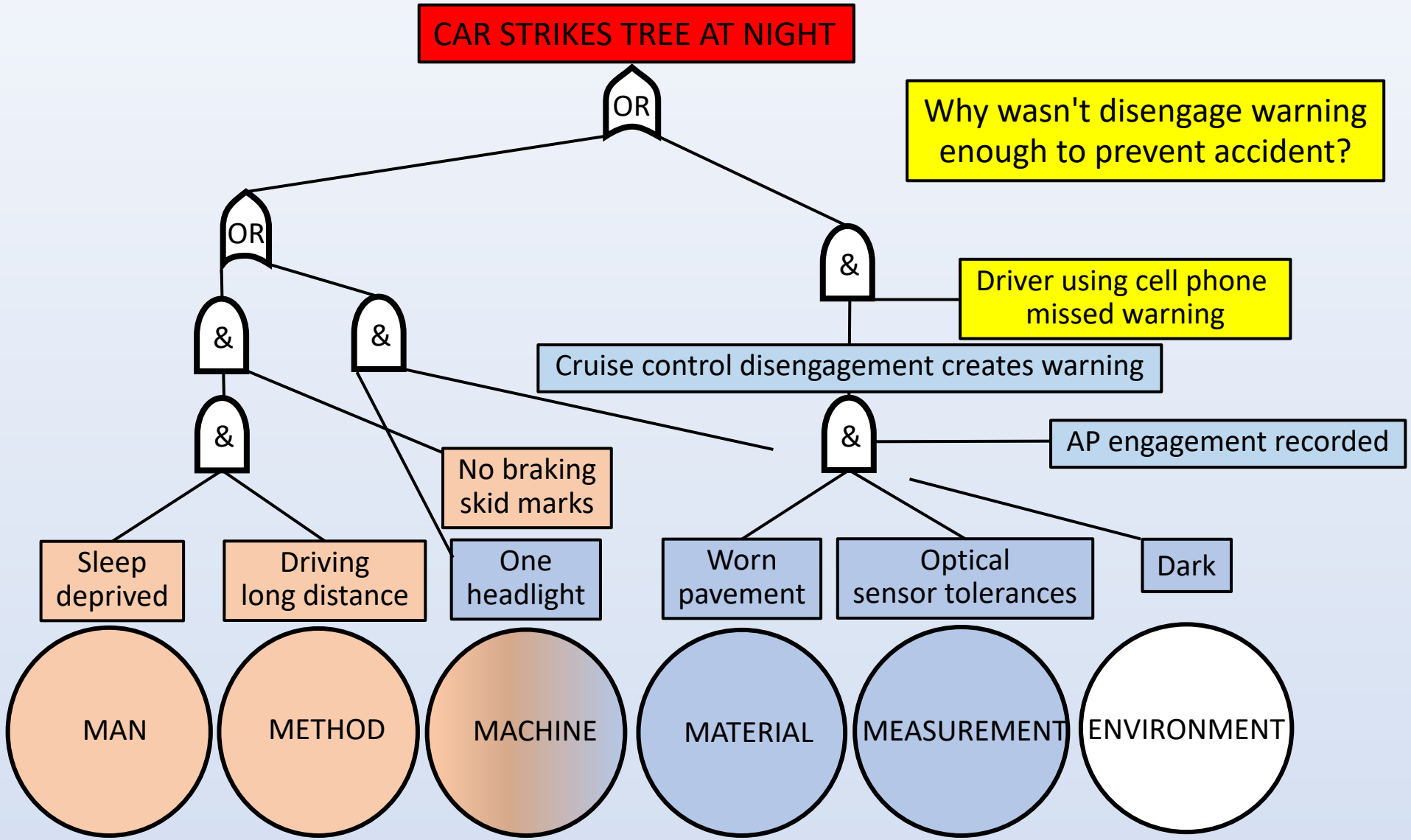
- Look up maps – Need constant update
- GPS
- Optical – Road markings, sign markings, surrounding structure, other objects
- LIDAR/RADAR/WAVE

Failure Logic Tree – Remaining Question



Failure Logic Tree – Subpoena Phone Records

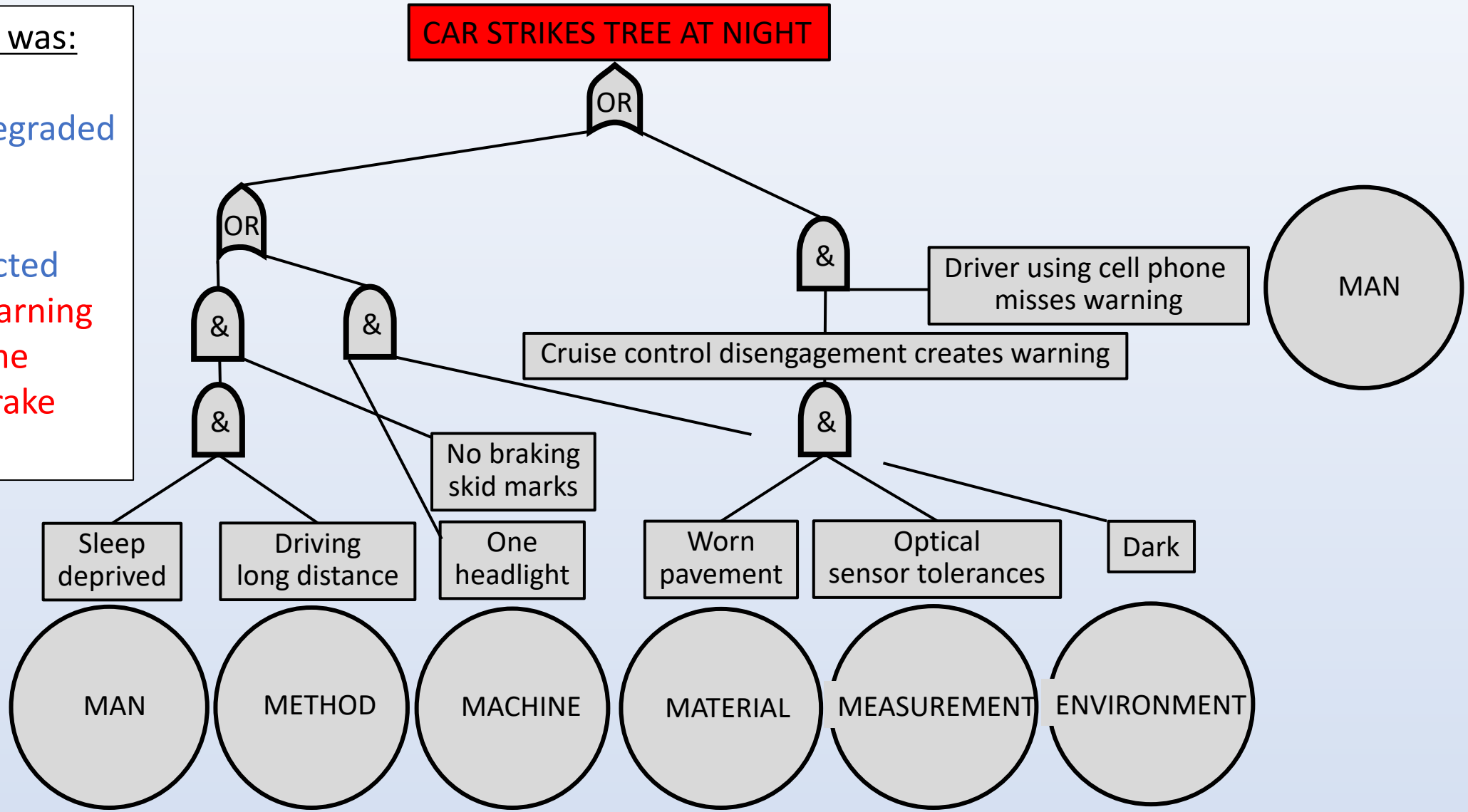
Driver iniated 11 separate calls during trip and received 5.
Most recent call initiated 7 minutes prior to accident time (2:21am).



Failure Logic Tree – FACTS LEAD TO ANALYSIS / SEQUENCE

Now we find contributing factors included BOTH the driver AND the car

Sequence found was:
Tired driver
Cruise system degraded
  Pavement
  Optical system
Cruise disconnected
Driver missed warning
  Using cell phone
Driver did not brake
Car struck tree



Chronology and Contributing Factors

As a result of the investigation and collection of all possible facts, a chronology for the accident was established which led to identification of the Contributing Factors:

Degraded / Fatigued driver: The accident time was at a low circadian rythym hour, driver cited sugar withdrawal symptoms, had driven a long distance, and been in vehicle for 9 hours.

The Cruise system operation was degraded due to:
- Worn pavement markings
- Optical system operation at the limits of design perception with the degraded pavement
- Dirt found over camera sensor array

The Cruise system disconnected.

The driver using the hands-on cell phone likely missed the warning that the automation system had disconnected.

The driver did not apply brakes on pavement.

The vehicle struck a tree.

Probable Cause

The Probable Cause for a case such as this example would likely identify the driver's degraded responsiveness and distraction as the primary cause.

The failed headlight and degraded Level 2 automation might be considered as Contributing Factors.

"What's it *[the autopilot]* doing now?"

Common airline crew saying heard on Cockpit Voice Recorders (CDR) after accidents

Lawrence Sperry patented first autopilot in 1912
Triple redundant systems in airlines today - yet ...

The #1 Autopilot related cause of accidents is human interface
Typically perception of autopilot performance was not what was expected

The #2 Cause was pilots disconnecting or getting "behind" the airplane

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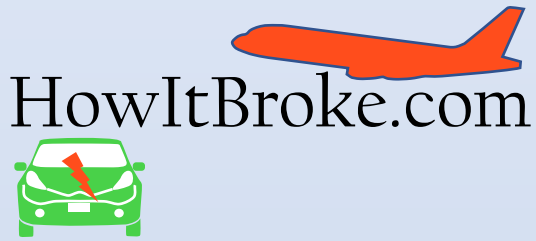
In Closing . . .

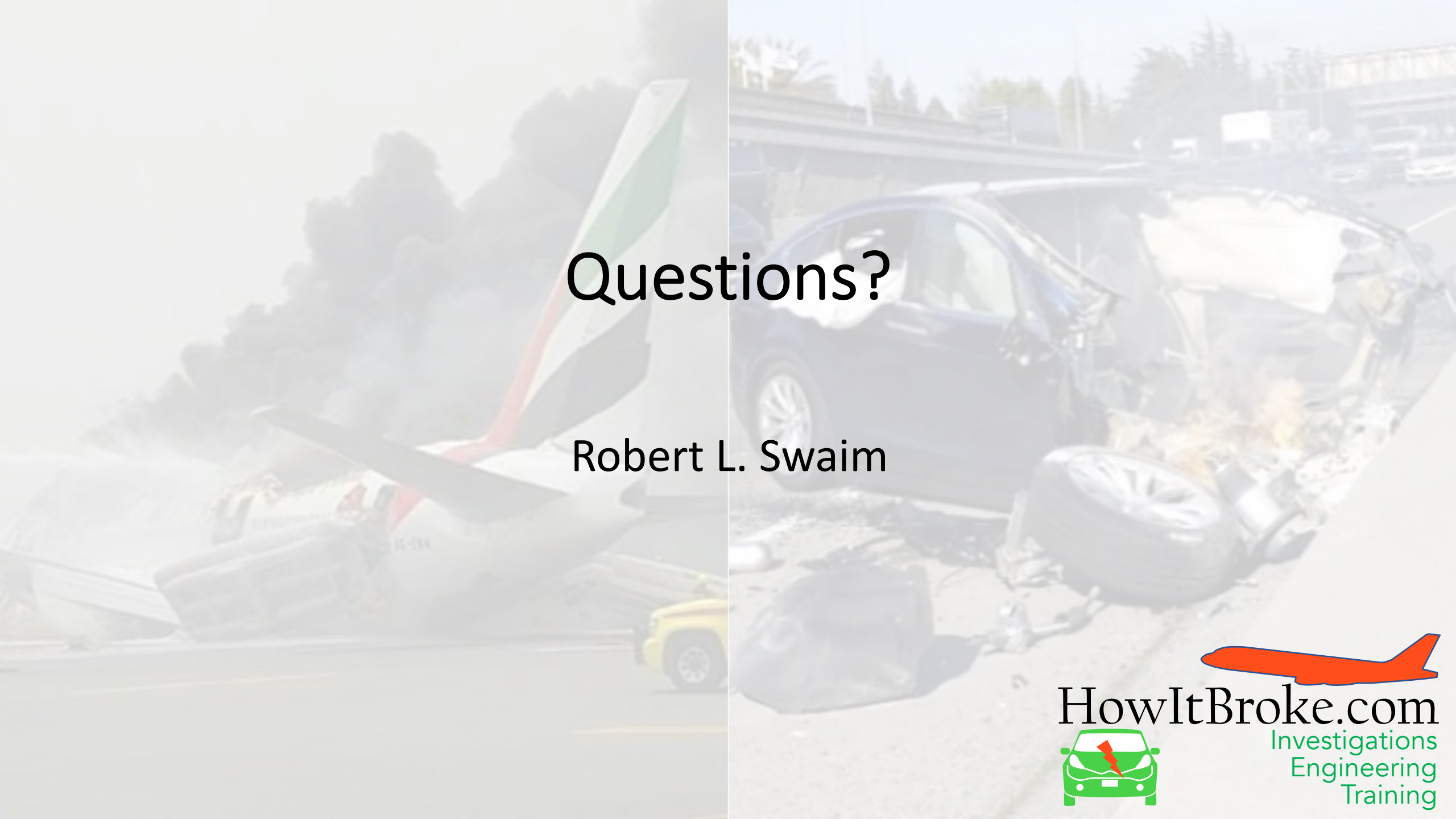
"Disappointment [*and frustration*] is **the gap that exists between our expectation and reality"** – Maxwell

Design to prevent frustration



Questions?

Robert L. Swaim



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