Connecting Collision Avoidance Driver Support and Autonomous Vehicle Systems

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Potential Blend of Autonomous Vehicle Systems for Driver Support

- A blend that allows the driver to remain as a pilot, but takes care of the pilot and passengers when the pilot gets in trouble or needs assistance.

- Provides autonomous driving under certain conditions

- Provides corrective action when pilot fails to or is unable to recognize a hazard

- Informs driver to improve situational awareness
Scenario Crash Distributions

- **Rear-End** - (1,729,000): The front of a following vehicle strikes the rear of a lead vehicle, both traveling in the same direction.
- **Pedestrian** - (54,000): A moving vehicle collides with a pedestrian
- **Crossing Paths** - (1,447,000): One moving vehicle cuts across the path of another, initially approaching from either lateral or opposite directions, in such a way that they collide at or near a junction.
- **Opposite Direction** - (134,000): A vehicle strikes another vehicle in the adjacent lane, traveling in the opposite direction, resulting in a frontal or sideswipe impact.
- **Animal** - (272,000): A moving vehicle collides with an animal.
- **Off-Roadway** - (1,222,000): The first harmful event occurs off the roadway after a vehicle in transport departs the travel portion of the roadway. [subset of these crashes are Trees/Poles]

Volpe Pre-Crash Scenario Typology

<table>
<thead>
<tr>
<th>No.</th>
<th>Scenario</th>
<th>Cost ($)</th>
<th>Rel. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control Loss Without Prior Vehicle Action</td>
<td>$15,796,000,000</td>
<td>13.18%</td>
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<tr>
<td>2</td>
<td>Lead Vehicle Stopped</td>
<td>$15,388,000,000</td>
<td>12.84%</td>
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<tr>
<td>3</td>
<td>Road Edge Departure Without Prior Vehicle Maneuver</td>
<td>$9,005,000,000</td>
<td>7.51%</td>
</tr>
<tr>
<td>4</td>
<td>Vehicle(s) Turning at Non-Signalized Junctions</td>
<td>$7,343,000,000</td>
<td>6.13%</td>
</tr>
<tr>
<td>5</td>
<td>Straight Crossing Paths at Non-Signalized Junctions</td>
<td>$7,290,000,000</td>
<td>6.08%</td>
</tr>
<tr>
<td>6</td>
<td>Running Red Light</td>
<td>$6,627,000,000</td>
<td>5.53%</td>
</tr>
<tr>
<td>7</td>
<td>Vehicle(s) Not Making a Maneuver - Opposite Direction</td>
<td>$6,407,000,000</td>
<td>5.35%</td>
</tr>
<tr>
<td>8</td>
<td>Lead Vehicle Decelerating</td>
<td>$6,390,000,000</td>
<td>5.33%</td>
</tr>
<tr>
<td>9</td>
<td>LTAP/OD at Signalized Junctions</td>
<td>$5,749,000,000</td>
<td>4.80%</td>
</tr>
<tr>
<td>10</td>
<td>LTAP/OD at Non-Signalized Junctions</td>
<td>$5,137,000,000</td>
<td>4.29%</td>
</tr>
<tr>
<td>11</td>
<td>Vehicle(s) Changing Lanes - Same Direction</td>
<td>$4,247,000,000</td>
<td>3.54%</td>
</tr>
<tr>
<td>12</td>
<td>Pedestrian Crash Without Prior Vehicle Maneuver</td>
<td>$4,022,000,000</td>
<td>3.36%</td>
</tr>
<tr>
<td>30</td>
<td>Pedalcyclist Crash With Prior Vehicle Maneuver</td>
<td>$523,000,000</td>
<td>0.44%</td>
</tr>
<tr>
<td>31</td>
<td>Vehicle Turning Right at Signalized Junctions</td>
<td>$355,000,000</td>
<td>0.30%</td>
</tr>
<tr>
<td>32</td>
<td>Road Edge Departure While Backing Up</td>
<td>$350,000,000</td>
<td>0.29%</td>
</tr>
<tr>
<td>33</td>
<td>Lead Vehicle Accelerating</td>
<td>$273,000,000</td>
<td>0.23%</td>
</tr>
<tr>
<td>34</td>
<td>Evasive Action With Prior Vehicle Maneuver</td>
<td>$198,000,000</td>
<td>0.17%</td>
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<tr>
<td>35</td>
<td>Object Crash With Prior Vehicle Maneuver</td>
<td>$155,000,000</td>
<td>0.13%</td>
</tr>
<tr>
<td>36</td>
<td>Animal Crash With Prior Vehicle Maneuver</td>
<td>$120,000,000</td>
<td>0.10%</td>
</tr>
<tr>
<td>37</td>
<td>Other</td>
<td>$764,000,000</td>
<td>0.64%</td>
</tr>
</tbody>
</table>

- Volpe have classified 37 Pre-Crash Scenarios
- Each scenario depicts vehicle movements and dynamics, and identifies the critical event occurring just prior to the crash.
- An intent of the Volpe 37 is to provide a common framework for researchers.
- Pre-crash scenarios are rated with estimates of occurrence, economic cost and functional years lost.

Ultimate Active Safety Goal is to Eliminate All Accidents

Active Safety systems: *Help improve driving performance...*

Current States
- Bring distracted driver back to attention.
- Inform driver when judgment is inaccurate.
- Support driver action.

Future States
- Take control of the vehicle...

Active Safety Timeline

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ACC started production ~1999 (Jaguar/Mercedes), and most major brands have a form of Gen1 in production in 2008.

Function Descriptions

- **Adaptive Cruise Control (ACC)**
  - Maintains headway to in-path vehicle
  - ~0.3g braking
  - Headway driver adjustable ~1.5 to 3 seconds
  - Tracks in-path vehicle in traffic and most curves

- **Collision Mitigation by Braking (CMbb) and Forward Collision Warning (FCW)**
  - Driver warning settings
  - Brake system precharged to achieve ~ 0.1g
  - Target Emergency Brake Assist adjusted threshold
  - Audio, Visual, Haptic driver interface
LDW started production ~2004 (Infiniti/Citroen). There are examples of all Gen2 features in current 2008 OEM production.

Function Description

- **CMbB and FCW – Gen1 plus**
  - Warning and automatic braking to pedestrians
  - Up to full automatic braking in certain situations
- **Lane Departure Warning (LDW)**
  - Track lane marks with computer vision
  - Lane excursion detection
  - Audible + telltale visual driver interface
- **Lane Keeping Assist (LKA)**
  - Electric steering actuator
  - Lane centering goal
- **Driver Monitoring**
  - Driver lane keeping performance
  - Driver attention estimation using camera on driver
- **ACC – Gen1 ACC plus**
  - Stop and Go capability enabled by mid range radar(s)

Typical Scenarios

- Moving & Stopping & Starting
- Cut-in
- Stationary Vehicles
- Pedestrian
- LDW & LKA
- Driver Monitoring

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Typical Scenarios

Moving & Stopping

Cut-in

Stationary Vehicles

Pedestrian & Large Animal

Oncoming Vehicles

Crossing Path at Intersections

Lane Keeping & Dimon

Curve Overspeed Warning & Control

Function Description

• **CMbB and FCW – Gen2 plus**
  • Night pedestrian capability (IR headlights)
  • Crossing paths at intersection scenarios
  • Rear crash
  • Steering-based avoidance
  • Vehicle2Vehicle communication for extended sensor capability

• **LKA – Gen2 plus**
  • Lane keeping actuator in LDW scenario
  • Emergency lane assist for oncoming scenario

• **Curve Speed Warning and Control**
  • Enabled by navigation system road curvature preview

• **ACC + LKA**
Potential Sensor fusion

- Sensors to Fuse
  - Multiple forward Radar FOV
  - Vision System
  - Side/ Rear Looking Radar
  - Electronic Horizon
  - Road Friction Estimate
  - Direct Driver Monitoring
  - Front/Rear Ultrasonics
  - V2V Communications
Evolution Continuing

Destination & route prefs

Navigation System
- Manages global route / reroutes if local route is violated or changed
- Delivers electronic horizon local route links (waypoints, speed limits, etc)

External Sensors & Fusion
- All targets (moving & stationary) along with lane tracking

Vehicle-centered Command and Control
- Local map populated with targets
- Driver monitor
- Nominal & emergency drive commands

Vehicle Actuators

Research & Advanced Engineering
Future Evolution

Destination & route prefs

Navigation System

Navigation map may need to be augmented

Vehicle-centered Command and Control

Local map populated with targets

driver monitor

Driver provides autodriver with route

Nominal & emergency drive commands

Vehicle Actuators

Upgrade local map representations

Need to add capability to create local path trajectories for nominal maneuvers based on local map and road rules.

Expand on command state machines to operational conditions including auto-manual handoff

Sensor set expansion for increased capability (e.g., intersection sensing via V2x)

Extend with eyelid and physiological measures

All targets (moving & stationary) along with lane tracking

Expand on command state machines to operational conditions including auto-manual handoff

External Sensors & Fusion

Vehicle Actuators

Driver
provides
autodriver
with route

External Sensors & Fusion

Navigation map may need to be augmented

Vehicle-centered Command and Control

local map populated with targets

driver monitor

Need to add capability to create local path trajectories for nominal maneuvers based on local map and road rules.

Nominal CNC expanded beyond ACC and LKA to handle more complex behaviors.

Upgrade local map representations

Extend with eyelid and physiological measures

All targets (moving & stationary) along with lane tracking

Expand on command state machines to operational conditions including auto-manual handoff

Sensor set expansion for increased capability (e.g., intersection sensing via V2x)
Levels of Driver Support Behaviors – Existing and Potential

- Adaptive cruise control (Gen1)
- Collision avoidance by braking (Gen2)
- Lane keeping (Gen2/3)
- Situation awareness aid to driver [information]
- Passing and lane change maneuver
- Short interval [on demand by the driver]
- Freeway ramp to ramp
- Intersection traversal
- Home garage to work parking lot
Opportunities and Challenges

- CADS contains several of the basic building blocks of full driver support behavior.
- Collaboration opportunities exist to extend CADS capability toward evolving levels of autonomous or semi-autonomous capability.
- Driver must remain in the loop to manage overall system.
- System must be robust to road conditions, traffic variations and environmental conditions.
Cruise control with lane keeping (CC+LKA).
- No lane changes, no lead vehicle.
- Host stays in same lane, through straight and curved freeway road segments.
- Speed set by driver and driver engages system

Adaptive cruise control with lane keeping (ACC+LKA)
- ACC keeps headway to lead vehicle
- Speed set by driver
Freeway Driving 2 Lane Travel

- ACC following slower than setpoint threshold to lead vehicle.
- FDA or driver threshold set
- No traffic in left lane
- Perform lane change left 1 lane

- ACC following slower than setpoint threshold to lead vehicle.
- FDA or driver threshold set
- Traffic in left lane detected, and determined to be pacing with sufficient lane change gap.
- Perform lane change left 1 lane
Freeway Driving 2 Lane Travel

- ACC following slower than setpoint threshold to lead vehicle.
- FDA or driver threshold set
- Traffic in left lane detected, and determined to be overtaking
- Do not perform lane change

- ACC following slower than setpoint threshold to lead vehicle.
- FDA or driver threshold set
- Traffic in adjacent lane moving faster than setpoint and ahead or equal to lead vehicle.
- No overtaking vehicles behind.
- Perform lane change left.
**Freeway Driving 2 Lane Travel**

**FDA 3.1**
- ACC overtaking slower than setpoint threshold adjacent lane vehicle.
- FDA or driver threshold set
- No other traffic ahead
- Perform lane change right once acceptable gap formed.

**FDA 3.2**
- ACC overtaking slower than setpoint threshold adjacent lane vehicle
- FDA or driver threshold set
- Additional slower vehicle(s) in goal lane (right lane)
- Continue in left lane until acceptable lane change gap exists.
- Perform lane change right to goal lane.