Applying STPA to Automotive Adaptive Cruise Control System

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Enhancing Automotive System Safety

• Roadway and driver (1889 – 1960s)
  – Better roads, speed limit
  – Driver license 1913
  – Blaming the “nut behind the wheel”

• Vehicle design for crash survival and defective vehicle recalls (1960s – Today)
  – Blame the large automotive companies
  – NHTSA and Recall
  – Federal Motor Vehicle Safety Standards (FMVSS)

• Vehicle design for crash avoidance & driver override (Today and Tomorrow?)
  – http://www.cbc.ca/video/#/Shows/The_National/1242568525/ID=2210171357 (5’57” Mercedes, and 8’30” Lincoln parallel parking)
Automotive Systems Today and Tomorrow

- **Cyber Physical Systems** - complex embedded devices networked to control physical hardware components.
- Software intensive.
- Automating many human tasks.
- The development teams are multidisciplinary and globally distributed.
The Powertrain Control Software System

- 1 production-level software
- 117 software modules (red dots)
- 1423 interactions (black lines)
- 39 such production software releases per year
- <2 weeks per release

Hommes, DETC2008-­‐DTM-­‐49140
Adaptive Cruise Control Design

Vehicle cruise control set at 70 mph
Radar detects slower vehicle ahead, reduces speed to return vehicle to a pre-set following distance
Cruise control adjusts to the lead vehicle's speed and reverts to the original speed if traffic clears

Hommes, IDETC 2012 - 70527
Accident, Hazard

• **Accident**: vehicle occupants are injured while ACC is engaged.

• **Hazards**:  
  • H1: ACC did not maintain a safe distance from the object in the front, resulting in collision.
  
  • H2: ACC slows down the vehicle too abruptly, and vehicle is rear-ended.
System Safety Constraints and Requirements

• **Design constraints:**
  • ACC should not let the vehicle gets in contact with the object ahead.
  • ACC should not brake too abruptly.

• **Design requirements:**
  • ACC shall maintain a TBD amount of distance between the vehicle and the object in front when engaged.
  • ACC shall limit vehicle deceleration to no more than TBD m/s^2.
Example: ACC – BCM Control Loop

- Operator
  - Tactile input
  - Visual Feedback
  - Tactile input

- Instrument Cluster
  - CAN Message
  - ACC Status
  - Braking Status
  - Vehicle Speed
  - Throttle opening
  - Throttle Position
  - Air
  - Acceleration Signal

- ACC Module
  - Distance
  - Target Vehicle Speed

- Engine Control Module
  - Throttle opening
  - Throttle Position

- Electronic Throttle Body
  - Air

- Brake Control Module
  - Braking Signal
  - CAN Message
  - ACC Status

- Brake Pedal
  - Braking Signal
  - Wheel Speed

- Brake
  - Friction

- Vehicle

- Accelerator Pedal
  - Tactile input

- Lead Vehicle
  - Radar

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Reformatted Control Loop

Control Action:
Brake Signal from ACC to BCM
## STPA Step 1: Unsafe Control Actions

<table>
<thead>
<tr>
<th>Control Action</th>
<th>Not Providing Causes Hazard</th>
<th>Providing Causes Hazard</th>
<th>Wrong Timing or Order Causes Hazard</th>
<th>Stopped too Soon or Applied Too Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake Signal from ACC to BCM</td>
<td>Vehicle does not brake when the distance to the lead vehicle is less than the value set by the operator. (H1)</td>
<td>Commanded deceleration amount is too small when the vehicle is too close to the object in the front. (H1)</td>
<td>Braking is commanded too late when the distance to the lead vehicle is too close. (H1)</td>
<td>Braking stops before the safety distance between the vehicles are reached. (H1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Braking is commended when the distance to the lead vehicle is larger than the set value. (H2)</td>
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<tr>
<td></td>
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<td>Braking is too fast/harsh when the didistance to the lead vehicle is less than the set value. (H2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STPA Step 2: Causal Analysis with Guidewords

Leveson 2012
Causal Analysis Results

Unsafe Control Action:
Vehicle does not brake when the distance to the object in front is less than preset value.
Unsafe Control Action: Vehicle does not brake when the distance to the object in front is less than preset value.

Delayed Operation
Causal Analysis Results (3)

Unsafe Control Action:
Vehicle does not brake when the distance to the object in front is less than preset value.

- Misalignment of brake shoes/pads.
- Missing fluid pressure for hydraulic lines.
- No current/voltage to actuator.
Unsafe Control Action:
Vehicle does not brake when the distance to the object in front is less than preset value.
Causal Analysis Results (5)

Unsafe Control Action:
Vehicle does not brake when the distance to the object in front is less than preset value.

- Dirt accumulation on wheel rotation sensor.
- Wire disconnection.
- Communication bus faults, overload, message priority.
Assess the Effectiveness of STPA

• The outcome of STPA was a list of component design requirements that will ensure top level safety goal.

• Compare with actual industry design specifications.
  – Unable to do so because of proprietary nature of the design specifications.
Assess STPA (2)

• Compared with ISO 22179 and SAE J2399.
  – Many more detailed requirements than what is in the standards.
  – Industry standards are the lowest common denominators among the manufacturers.
  – Can only compare with categories of requirements.

• Compared with actual implementation in production vehicles.
  – Warning signals among manufacturers
  – Warnings in driver’s manual
Categories of Requirements Missing in Industry Standards

• Driver control authority vs. computer automation authority
  – The importance of vehicle state feedback information (warning lights/sounds/icons) for driver
  – Driver mental model inconsistency with vehicle state (complacency and distracted driving)

• Sensor and actuator
  – Hardware quality
  – Degradation
Categories of Requirements Missing in Industry Standards (2)

• Communication bus
  – Delays
  – Signal priority

• Controls software errors
  – Delay in processing inputs
  – Parameter calibration errors
  – Control software algorithm process model
  – Software handling of signal priority

• Service and maintenance requirements
Comparison with Implementation

1. Significant difference in the implementation of warning messages and signals among OEM’s and across models.

Example: ACC Malfunction Lights (Credit: Zoepf)

Porsche  Toyota  Volvo  Nissan

2. Leaving a lot of the limitations of ACC in the drivers’ manual.
   
   - NISSAN INFINITI EX 2010, 21 pages (ACC feature), 16 warnings and 1 caution.
   - Ford Lincoln MKX 2010, 7 pages (ACC feature), 10 warnings.
Summary

• This was our first attempt to apply STPA to a modern automotive electronics feature.
• The method works.
• The analysis identified many more safety critical requirements than what is identified in the industry standards.
• STPA can be a very powerful method to identify safety critical design requirements, and prevent accidents in the first place.
• Industry collaboration will further improve our understanding of the effectiveness of the method, and how to integrate it with the current product development process.
Thank you!

Question?

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