Safe Transitions From Automated to Manual Driving

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Outline

- Vehicle automation
- Experiments of driver takeover when automation fails
- Improving safety of driver takeovers
- Conclusions and future work
Changing role of the driver

The driver may be requested to take over.
### Levels of automation

<table>
<thead>
<tr>
<th>BAS expert group&lt;sup&gt;1&lt;/sup&gt;</th>
<th>NHTSA&lt;sup&gt;2&lt;/sup&gt;</th>
<th>SAE J3016&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Role of the driver</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver only</td>
<td>Level 0 – No-Automation</td>
<td>Non-Automated</td>
<td>Full control</td>
<td>- (information and warning systems)</td>
</tr>
<tr>
<td>Assisted</td>
<td>Level 1 – Function-specific Automation</td>
<td>Assisted</td>
<td>Must permanently monitor. Resume control at any time.</td>
<td>CC, ACC, LKA, ESC</td>
</tr>
<tr>
<td>Partial automation</td>
<td>Level 2 - Combined Function Automation</td>
<td>Partial Automation</td>
<td>Must permanently monitor. Resume control at any time.</td>
<td>ACC and lane keeping, TJA</td>
</tr>
<tr>
<td>High automation</td>
<td>Level 3 - Limited Self-Driving Automation</td>
<td>Conditional Automation</td>
<td>Not required to monitor. Required to resume control after a certain lead time.</td>
<td>Lateral and longitudinal control automated</td>
</tr>
<tr>
<td>Full automation</td>
<td>Level 4 - Full Self-Driving Automation</td>
<td>High Automation</td>
<td>May be asked to but is not required to resume control.</td>
<td>Lateral and longitudinal control automated</td>
</tr>
</tbody>
</table>

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WHAT HAPPENS WHEN DRIVERS ARE REQUIRED TO TAKE OVER WHEN AUTOMATION FAILS?
How do drivers respond to failures of longitudinal automation provided by an ACC?

**STUDY #1**

Publication:
Unwanted acceleration

Car in front drives at 105 km/h (65 mph), automation in ego car accelerates unintentionally towards vehicle ahead (fails to keep the set distance and speed)

Braking or steering required to avoid collision
Complete and partial deceleration failure

1: Car in front brakes, automation in ego car does not brake
2: Car in front brakes, automation in ego car brakes less than necessary to avoid a collision

Braking or steering required to avoid collision
Results

Minimum Time-Headway (MTHW) and Minimum Time-To-Collision (MTTC)

Average collision speed:
- Complete deceleration failure: 2.5
- Partial deceleration failure: 2
- Unwanted acceleration: 1.5

\[
\begin{align*}
    t_{THW} &= \frac{d}{v_s} & \text{: Time-Headway} \\
    t_{TTC} &= \begin{cases} 
        \frac{d}{v_s - v_t} & \text{if } v_s > v_t \\
        \frac{d}{v_t} & \text{otherwise}
    \end{cases} & \text{: Time-To-Collision}
\end{align*}
\]
How does level of automation influence how drivers respond to failures?

**STUDY #2**

Publication:
**Complete and partial deceleration failures**

CDF: Car in front brakes, automation in **ego car does not brake**

SDF: Car in front brakes, automation in **ego car brakes less than necessary (~30% of full brake capacity)** to avoid a collision

MDF: Car in front brakes, automation in **ego car brakes less than necessary (~60% of full brake capacity)** to avoid a collision
Study 2
How does level of automation influence how drivers respond to failures?

- Driving simulator study with 36 participants
- Compared two levels of automation
  - Semi-automated: Longitudinal automation
  - Highly automated: Longitudinal and lateral automation
- Each subject experienced all three failures
  - Point-of-no-return events instead of collisions (see video)
Results

Number of “collisions”

<table>
<thead>
<tr>
<th></th>
<th>Semi-automated</th>
<th>Highly automated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate deceleration failure (MDF)</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Severe deceleration failure (SDF)</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Complete deceleration failure (CDF)</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>
IMPROVING SAFETY OF TRANSITIONS FROM AUTOMATED TO MANUAL DRIVING
Concept improving safety of transitions

Conceptual architecture

Vehicle state-space

Driver capability

Decision logic

Automation

Transition automation

Driver

Vehicle
Decision logic

\( \mathcal{V} \): All possible states

\( \mathcal{D} \): Set of states controllable by the driver

Give control to driver if states are within and stay within \( \mathcal{D} \) for \( t_{\text{takeover}} \) seconds

Examples

- T1: States start and stay within \( \mathcal{D} \)
- T2: States start within \( \mathcal{D} \) but leave
- T3: States start within \( \mathcal{D} \) but leave
- T4: States start outside but enter \( \mathcal{D} \)

Only T1 is considered safe for a driver takeover
Demonstration on longitudinal automation (adaptive cruise control)

\[ a_s, v_s \quad \text{with} \quad a_t, v_t \]

\( d \): inter-vehicle distance

\( a \): longitudinal acceleration

\( v \): longitudinal velocity
Procedure to estimate driver capability

1. Collect and filter out relevant data from manual driving
2. Estimate distribution functions system states
3. Identify bounds of driver capability at predefined limits in distributions
Evaluation on real world data

Transition initiated inside DCS

Transition initiated outside DCS
Conclusions and future work

• Drivers are more successful in controlling longitudinal automation failures when lateral automation is a manual task

• Partial deceleration failure may be less controllable than complete deceleration failure

• Driver capability estimation is a promising tool for preventing unsafe transitions to manual driving

• Need to further investigate what makes a transition to manual driving safe
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