Drivers’ Reactions to Automated Vehicles: why do partially automated vehicles crash?

Professor Neville A. Stanton, PhD, DSc, C.Psychol., C.Eng. C.ErgHF
Chair in Human Factors Engineering
Transportation Research Group
Faculty of Engineering and the Environment
University of Southampton
Southampton, UK

n.stanton@soton.ac.uk
www.hfesoton.com
Russell Group University – Research-led
17,000 undergraduate and 7,000 postgraduate students

“The University of Southampton has the only engineering faculty in the UK to receive the highest research rating (5*) across all disciplines”
Driving simulator (2016)
Overview

- Vehicle automation rather than autonomy?
- What goes wrong?
- Why do automated vehicles crash?
- What can be done?
- Conclusions and warnings
## SAE J3016™ Levels of Driving Automation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Levels

- **0: No Driving Automation**
  - You drive; vehicle can provide driving assist features

- **1: Driving Automation Assistance**
  - Either steering or braking assist but not at the same time

- **2: Partial Driving Automation**
  - Steering AND braking assist together as support feature only; human driver must supervise

- **3: Conditional Driving Automation**
  - Automation of full driving task with human fallback; driver must respond promptly when alerted

- **4: Conditional Driving Automation**
  - Full automation but only in predetermined conditions; human must drive when system is not engaged

- **5: Full Driving Automation**
  - You never have to drive anywhere unless you want to

---

Copyright © 2014 SAE International. The summary table may be freely copied and distributed provided SAE International and J3016 are acknowledged as the source and must be reproduced AS-IS.
# SAE J3016™ Levels of Driving Automation

<table>
<thead>
<tr>
<th>SAE Level</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Cruise Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking Helper-L1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active Lane Centering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking Helper-L2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highway Pilot-L2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Jam Pilot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated Driving System-L3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated Driving System-L4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking Valet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated Driving System-L5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0     | No Driving Automation  
You drive; vehicle can provide driving assist features  |
| 1     | Driving Automation Assistance  
Either steering or braking assist  |
| 2     | Partial Driving Automation  
Steering AND braking assist together as support feature only; human driver must supervise  |
| 3     | Conditional Driving Automation  
Automation of full driving task with human fallback; driver must respond promptly when alerted  |
| 4     | Conditional Driving Automation  
Full automation but only in pre-determined conditions; human must drive when system is not engaged  |
| 5     | Full Driving Automation  
You never have to drive anywhere unless you want to  |
## Fatalities

<table>
<thead>
<tr>
<th>Date</th>
<th>Country</th>
<th>City, State</th>
<th>OEM</th>
<th>Model</th>
<th>Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>20(^{th}) January 2016</td>
<td>China</td>
<td>Handan, Hebei</td>
<td>Tesla</td>
<td>Model S</td>
<td>Driver</td>
</tr>
<tr>
<td>7(^{th}) May 2016</td>
<td>USA</td>
<td>Williston, FL</td>
<td>Tesla</td>
<td>Model S</td>
<td>Driver</td>
</tr>
<tr>
<td>18(^{th}) March 2018</td>
<td>USA</td>
<td>Tempe, AZ</td>
<td>Uber/Volvo</td>
<td>XC90</td>
<td>Pedestrian</td>
</tr>
<tr>
<td>23(^{rd}) March 2018</td>
<td>USA</td>
<td>Mountain View, CA</td>
<td>Tesla</td>
<td>Model X</td>
<td>Driver</td>
</tr>
<tr>
<td>1(^{st}) March 2019</td>
<td>USA</td>
<td>Delray Beach, FL</td>
<td>Tesla</td>
<td>Model 3</td>
<td>Driver</td>
</tr>
<tr>
<td>25(^{th}) April 2019</td>
<td>USA</td>
<td>Miami, FL</td>
<td>Tesla</td>
<td>Model S</td>
<td>Pedestrian</td>
</tr>
</tbody>
</table>
Be prepared to take control....

Autopilot ‘Upgrade’

Collision analysis

Models and Methods for Collision Analysis
A guide for policymakers and practitioners

Professor Neville A Stanton
Human Factors Engineering, University of Southampton
March 2019

https://www.racfoundation.org/research/safety/models-and-methods-for-collision-analysis
Timeline 18\textsuperscript{th} March 2018

- **6:30 p.m.**: 44-year-old Rafaela Vasquez arrives for work at the Uber facilities in Tempe, Arizona.

- **9:14 p.m.**: Vasquez leaves the Tempe facilities in a self-driving 2017 Volvo XC90 operated by Uber to run an established test route through downtown Tempe.

- **9:39 p.m.**: The vehicle is switched to autonomous mode.

- A report from Tempe police states Vasquez begins streaming "The Voice" on the Hulu app on a cellphone. During this time, the Tempe police state that Vasquez can be seen frequently looking down at the lower center console area near her knee and frequently smirking and laughing. Her hands are not visible in the frame of the surveillance footage. Police determine she looks down 204 times over the course of 11.8 miles. Her eyes were off of the road for 6 minutes and 47 seconds during this period (i.e., over 25\% of time). \textit{This report is not yet substantiated by NTSB.}

- **9:58 p.m.**: Vasquez looks up while driving northbound on Mill Avenue toward Curry Road, approximately 0.5 seconds before the crash. She attempts to swerve left before striking 49-year-old Elaine Herzberg at 39 mph (speed zone posted at 45 mph) as she crosses the street mid-block. Hulu’s records also show the streaming of the show ended at this time.

- Vasquez calls 911 and is released later that night after speaking to police. She stated she was monitoring the self-driving system interface and neither her business or personal phones were in use.
Figure 2. View of the self-driving system data playback at about 1.3 seconds before impact, when the system determined an emergency braking maneuver would be needed to mitigate a collision. Yellow bands are shown in meters ahead. Orange lines show the center of mapped travel lanes. The purple shaded area shows the path the vehicle traveled, with the green line showing the center of that path.
Paths of pedestrian and vehicle
Junction approach (daytime)
Paved median (no crossing sign)
## Actor Map

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>International influences</td>
<td>International Standards Organisation</td>
</tr>
<tr>
<td>National committees</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>Regulatory bodies and associations</td>
<td>California regulators, Arizona regulators</td>
</tr>
<tr>
<td>Company management and local area government</td>
<td>Uber, Volvo, Urban planners</td>
</tr>
<tr>
<td>Technical and operational management</td>
<td>Uber engineers</td>
</tr>
<tr>
<td>Driving processes</td>
<td>Driver, Cyclist</td>
</tr>
<tr>
<td>Equipment and environment</td>
<td>Automated vehicle, Road, Median, Junction, Bicycle, Signage</td>
</tr>
</tbody>
</table>
Driver and pedestrian
Uber tech/op management
Uber company management

International influences

National committees

Federal and State Government

Regulatory bodies and associations

Company management and local area government

Technical and operational management

Driving processes

Equipment and environment

Investment opportunities around automated vehicles → Competition to release first fully-autonomous vehicle → Decision to engage in on-road testing → Decision to move testing program to Arizona → Decision to stop testing in California → Uber fail to obtain permits for California → Uber dispute over requirement for test permits

Vehicle collides with cyclist at 39 mph

Decision to disable Volvo City Safety System → Development of Arizona testing program → Design of Uber vehicle automation system

Cyclist decides to cross away from crosswalk

Cyclist under the influence

Location of homeless shelter → Brick paved walking path → City safety system disabled → Driver intervenes too late → Driver sees cyclist → Driver intermittently glancing at road → Uber automated vehicle test initiated → Driver monitoring Uber display and tagging events → Uber display → Uber automated vehicle test initiated → Vehicle placed in self-driving mode → Vehicle detects object in road → Vehicle classifies object at 3rd attempt → Computer decides emergency braking is required → AEB unable to respond → Driver intervenes too late → Driver sees cyclist → Driver intermittently glancing at road → Uber display

Mobile phone streaming ‘The Voice’ → System does not alert driver to obstacles → Driver intervenes too late → Driver sees cyclist → Driver intermittently glancing at road → Uber display

Work design of 8 hour shifts with one driver

Decision to obtain permits for California

Decision to stop testing in California

Decision to move testing program to Arizona

Decision to engage in on-road testing

Competition to release first fully-autonomous vehicle

Investment opportunities around automated vehicles

Decision to disable Volvo City Safety System

Development of Arizona testing program

Design of Uber vehicle automation system

Vehicle collides with cyclist at 39 mph
### International Influences

- Investment opportunities around automated vehicles
- Competition to release first fully-autonomous vehicle
- Decision to engage in on-road testing
- Decision to move testing program to Arizona
- Decision to stop testing in California
- Uber fail to obtain permits for California
- Uber dispute over requirement for test permits
- California regulators revoke Uber vehicle registrations
- DMV requests appropriate testing permits

### Company Management and Local Area Government

- Decision to disable Volvo City Safety System
- Development of Arizona testing program
- Design of Uber vehicle automation system
- Work design of 8 hour shifts with one driver

### Technical and Operational Management

- Vehicle placed in self-driving mode
- Vehicle detects object in road
- Vehicle classifies object at 3rd attempt
- Computer decides emergency braking is required
- AEB unable to respond
- Vehicle collides with cyclist at 39 mph

### Driving Processes

- Driver monitoring Uber display and tagging events
- Driver watching the video
- Driver intermittently glancing at road
- Driver sees cyclist
- Driver intervenes too late
- Cyclist decides to cross away from crosswalk
- Cyclist under the influence

### Equipment and Environment

- Uber display
- Mobile phone streaming ‘The Voice’
- System does not alert driver to obstacles
- City safety system disabled
- Brick paved walking path
- Location of homeless shelter
- Pedestrian signage small and unlit
### Federal and state government

#### International influences

<table>
<thead>
<tr>
<th>National committees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal and State Government</td>
</tr>
<tr>
<td>Legal framework allows on-road testing of autonomous vehicles on public roads</td>
</tr>
<tr>
<td>State governments allow testing on public roads</td>
</tr>
<tr>
<td>Perceived economic growth associated with testing</td>
</tr>
<tr>
<td>Arizona Governor encourages testing in Arizona</td>
</tr>
</tbody>
</table>

#### Regulatory bodies and associations

<table>
<thead>
<tr>
<th>Company management and local area government</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment opportunities around automated vehicles</td>
</tr>
<tr>
<td>Competition to release first fully-autonomous vehicle</td>
</tr>
<tr>
<td>Decision to engage in on-road testing</td>
</tr>
<tr>
<td>Decision to move testing program to Arizona</td>
</tr>
<tr>
<td>California regulators revoke Uber vehicle registrations</td>
</tr>
<tr>
<td>DMV requests appropriate testing permits</td>
</tr>
</tbody>
</table>

#### Technical and operational management

| Decision to disable Volvo City Safety System |
| Development of Arizona testing program |
| Design of Uber vehicle automation system |
| Work design of 8 hour shifts with one driver |

#### Driving processes

| Uber automated vehicle test initiated |
| Vehicle placed in self-driving mode |
| Vehicle detects object in road |
| Vehicle classifies object at 3rd attempt |
| Computer decides emergency braking is required |
| AEB unable to respond |
| Driver intervenes too late |
| Driver sees cyclist |
| Driver intervenes too late |
| Cyclist decides to cross away from crosswalk |
| Cyclist under the influence |

#### Equipment and environment

| Uber display |
| Mobile phone streaming ‘The Voice’ |
| System does not alert driver to obstacles |
| City safety system disabled |
| Brick paved walking path |
| Location of homeless shelter |
| Pedestrian signage small and unit |

**Vehicle collides with cyclist at 39 mph**
Governor Ducey’s executive order released in March 2018 that opened the door to AV testing in Arizona. The order states in Section 3:

*Testing of autonomous vehicles on public roads that do not have a person present in the vehicle shall be allowed only if such vehicles are fully autonomous, provided that a person prior to commencing testing or operation of fully autonomous vehicles, has submitted a written statement to the Arizona Department of Transportation, or if already begun, has submitted a statement to the Arizona Department of Transportation within 60 days of the issuance of this Order…*

Elsewhere, the EO goes on to describe a requirement for a law enforcement interaction protocol, also required within 60 days of testing. The EO was released on the 1st March 2018 and Elaine Herzberg was killed on the 18th March 2018, well within the 60 day window.

Phoenix metro area has one of the highest pedestrian fatality rates in the US

**IN WITNESS THEREOF,** I have hereunto set my hand caused to be affixed the Great Seal of the State of Arizona.

*Governor*

**DONE** at the Capitol in Phoenix on this First day of March in the Year Two Thousand and Eighteen and of the Independence of the United States of America the Two Hundred and Thirty-Sixth.

**ATTEST:**

*Secretary of State*
National committees

Absence of SAE technical standards

Legal framework allows on-road testing of autonomous vehicles on public roads

State governments allow testing on public roads

Perceived economic growth associated with testing

Arizona Governor encourages testing in Arizona

California regulators revoke Uber vehicle registrations

DMV requests appropriate testing permits

Investment opportunities around automated vehicles

Competition to release first fully-autonomous vehicle

Decision to engage in on-road testing

Decision to move testing program to Arizona

Decision to stop testing in California

Uber fail to obtain permits for California

Uber dispute over requirement for test permits

Decision to disable Volvo City Safety System

Development of Arizona testing program

Design of Uber vehicle automation system

Decision to initiate Uber automated vehicle test

Vehicle detected object in road

Vehicle classifies object at 3rd attempt

Computer decides emergency braking is required

AEB unable to respond

Vehicle collides with cyclist at 39 mph

Driver sees cyclist

Driver intervenes too late

Cyclist decides to cross away from crosswalk

Cyclist under the influence

Location of homeless shelter

Pedestrian signage small and util
AcciMap

International influences
- Absence of ISO technical standards

National committees
- Absence of SAE technical standards

Federal and State Government
- Legal framework allows on-road testing of autonomous vehicles on public roads
- State governments allow testing on public roads
- Perceived economic growth associated with testing
- Arizona Governor encourages testing in Arizona

Regulatory bodies and associations
- California regulators revoke Uber vehicle registrations
- DMV requests appropriate testing permits

Company management and local area government
- Investment opportunities around automated vehicles
- Competition to release first fully autonomous vehicle
- Decision to engage in on-road testing
- Decision to move testing program to Arizona
- Decision to stop testing in California
- Uber fails to obtain permits for California
- Uber dispute over requirement for test permits

Technical and operational management
- Decision to disable Volvo City Safety System
- Development of Arizona testing program
- Design of Uber vehicle automation system
- Work design of 8 hour shifts with one driver

Driving processes
- Uber automated vehicle test initiated
- Vehicle placed in self-driving mode
- Vehicle detects object in road
- Vehicle classifies object at 3rd attempt
- Computer decides emergency braking is required
- AEB unable to respond
- Vehicle collides with cyclist at 39 mph
- Driver monitoring Uber display and tagging events
- Driver watching the voice
- Driver intermittently glancing at road
- Driver sees cyclist
- Driver intervenes too late

Equipment and environment
- Uber display
- Mobile phone streaming 'The Voice'
- System does not alert driver to obstacles
- City safety system disabled
- Brick paved walking path
- Location of homeless shelter
- Pedestrian signage small and unlit
- Cyclist decides to cross away from crosswalk
- Cyclist under the influence
Q. Can we improve the design of the testing regime?

A. Yes, but we need to address all of the system levels simultaneously.

<table>
<thead>
<tr>
<th>System levels</th>
<th>Potential recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>International influences</td>
<td>Develop new standards for vehicle automation (e.g. head-up interface)</td>
</tr>
<tr>
<td></td>
<td>Develop new standards for on-road testing of vehicle automation (e.g. two testers in vehicle)</td>
</tr>
<tr>
<td>National committees</td>
<td>Develop new standards for vehicle automation</td>
</tr>
<tr>
<td></td>
<td>Develop new standards for on-road testing of vehicle automation</td>
</tr>
<tr>
<td>Federal and state government</td>
<td>Develop new laws on vehicle automation</td>
</tr>
<tr>
<td></td>
<td>Develop new laws for on-road testing of vehicle automation</td>
</tr>
<tr>
<td>Regulatory bodies and associations</td>
<td>Require permits for on-road testing of vehicle automation</td>
</tr>
<tr>
<td></td>
<td>Enforce new laws on vehicle automation</td>
</tr>
<tr>
<td></td>
<td>Enforce new laws for on-road testing of vehicle automation</td>
</tr>
<tr>
<td></td>
<td>Enforce permits for on-road testing of vehicle automation</td>
</tr>
<tr>
<td>Company management and local area government</td>
<td><strong>Uber</strong>: Undertake comprehensive driver task analysis</td>
</tr>
<tr>
<td></td>
<td>Undertake comprehensive analysis of human and technical risks</td>
</tr>
<tr>
<td></td>
<td>Analyse the workload of human driver with automation</td>
</tr>
<tr>
<td></td>
<td><strong>City Planners</strong>: Fence off central reservations that are not part of pedestrian crossings</td>
</tr>
<tr>
<td></td>
<td>Improve highway lighting</td>
</tr>
<tr>
<td>Technical and operational management</td>
<td>Conduct pilot studies with human drivers to discover potential problems</td>
</tr>
<tr>
<td></td>
<td>Share tasks between two drivers to ensure sufficient rests (eyes-out versus eyes-in tasks) and swap tasks regularly</td>
</tr>
<tr>
<td></td>
<td>Leave safety systems intact (including the AEB)</td>
</tr>
<tr>
<td>Driving processes</td>
<td>Fit dual controls to vehicle so that both drivers can drive the vehicle manually if required</td>
</tr>
<tr>
<td>Equipment and environment</td>
<td>Ensure that one driver is eyes-out at all times and swap tasks between drivers regularly</td>
</tr>
<tr>
<td></td>
<td>Place all nomadic devices (such as phones) in glovebox before the vehicle is driven</td>
</tr>
</tbody>
</table>

Secondary task performance


Validation of simulator

Mercedes Distronic Plus
Route driven manual and auto

Urban Route

Highway Route
NASA TLX – overall workload
Highway Auto – PCM

SCHEMA
5) I’m thinking about doing an overtake now
7) So, I get past this lorry,
11) oh, no. Blimey! [we’re going to crash]
13) And I didn’t trust it
15) …that was scary
   [safe headway breached]
20) if I hadn’t had grabbed it back then
   It would have ploughed into that lorry

ACTION
4) – another bit of input, it wants– okay, just given it.
8) and I’ll try indicating.
9) Check behind me
12) Brake.
14) I’m pulling out now
16) So, I think I’m going to have put that back on again.
17) Distronics on 70
19) hands off the wheel

WORLD
1)...there’s vehicles all around me. It feels quite heavy traffic.
2) So, we’ve dropped down to …
3) Icon observed
   [Put hands on steering wheel]
6) [Lorry observed]
10) ooh..we’re speeding up
18) We’re doing 60
The catch 22 of vehicle automation

Take away all of the driving tasks from the driver

BUT
The catch 22 of vehicle automation

Take away all of the driving tasks from the driver

BUT
The catch 22 of vehicle automation

Take away all of the driving tasks from the driver

BUT

Tell the driver they must be vigilant and be prepared to intervene as they are legally responsible for the vehicle
What have we learnt?

- **Automated automobiles are nearly upon us.....**
- **Problems with automation.....**
  - Not powerful enough (yet) to render driver redundant
  - Requires driver to monitor (continuously) and intervene (occasionally)
  - Attentional resources are yoked to task demand (which is substantially reduced in highly automated vehicles)
  - Reduced drivers readiness and timeliness to intervene
- **There maybe a design solution.....**
  - Only automate what you have to and when you have to
  - Support the driver rather than replace driver
  - ‘Background’ automation **not** ‘foreground’ automation
  - Design a ‘chatty’ co-pilot **not** a ‘silent’ auto-pilot
  - Gradual and graceful degradation in system failure
Thank you for your attention

If you have any further questions please contact me at:

n.stanton@soton.ac.uk

www.hfesoton.com

+44 (0) 2380 599065