Vulnerable Road User Safety in the (Partially) Autonomous Age: Research Methods and Critical Issues

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About me

• MS Civil Engineering, ITS-Davis ‘05
• City of Sacramento 2005-07
• City of Davis 2007-2011
• PhD Urban Studies ’17
• Assistant Prof, A&M, 2017-now
Jargon and acronyms

• VRUs – vulnerable roadway users
• Accident – Crash, collision
• ADAS – Advanced Driver Assistance Systems
• AV – autonomous vehicles
• Partially-/Conditionally-/Semi-Autonomous – requires involvement from a human driver
• Self-driving? Driverless?
SAE Int’I Levels of Automation

The five stages of autonomy

0. DRIVER 1. FEET OFF 2. HANDS OFF 3. EYES OFF 4. MIND OFF 5. PASSENGER

No assistance Assisted Partially automated Highly automated Fully automated Autonomous

Human Transfer of responsibility Machine

Sources: Evercore ISI, SAE International

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NHTSA/SAE Levels of Automation

The 5 levels of driving automation

For on-road vehicles

<table>
<thead>
<tr>
<th>Level</th>
<th>Human driver monitors the road</th>
<th>Automated system monitors the road</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>NO AUTOMATION</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>DRIVER ASSISTANCE</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>2</td>
<td>PARTIAL AUTOMATION</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>3</td>
<td>CONDITIONAL AUTOMATION</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>4</td>
<td>HIGH AUTOMATION</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>5</td>
<td>FULL AUTOMATION</td>
<td>SOME DRIVING MODES</td>
</tr>
</tbody>
</table>

No steering and acceleration/deceleration
Monitoring of driving environment
Fallback when automation fails
Automated system in control

Source: SAE International

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The evolution of driverless cars

The motorist dream of having fully automated vehicles on the road inches toward reality.

0. No automation
A human driver performs all driving tasks.

1. Drive assistance
Driver-assistance system either steers or controls speed using information about the driving environment. A driver is expected to perform all other aspects of driving.

2. Partial automation
One or more driver-assistance systems both steer and control speeds using information about the driving environment. A driver is still expected to perform all other aspects of driving.

3. Conditional automation
An automated driving system can perform most tasks, but there's an expectation that a passenger will respond to a request to intervene.

4. High automation
An automated driving system can perform all tasks, even if a passenger does not respond to a request to intervene.

5. Full automation
The automated driving system performs all driving tasks, full time, under all road and environment conditions that can be managed by a human driver.

Source: MarketWatch research, SAE International
The original “trolley problem” (1905)

What should the man in blue do?

Image credit: moralmachine.mit.edu
The original “trolley problem” (1905)

What should the man in blue do?
The trolley problem on the highway to heaven (aka The Good Place)
A flurry of research – in some fields

Web of Science search of topics
A flurry of research – on some topics

Web of Science search of topics

<table>
<thead>
<tr>
<th>Year</th>
<th>AV</th>
<th>w/Ped</th>
<th>w/Cyclist</th>
</tr>
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<tbody>
<tr>
<td>2010</td>
<td>332</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>321</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>428</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>418</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>496</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2015</td>
<td>704</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>2016</td>
<td>853</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>2017</td>
<td>1,072</td>
<td>25</td>
<td>4</td>
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<tr>
<td>2018</td>
<td>1,522</td>
<td>38</td>
<td>3</td>
</tr>
<tr>
<td>2019</td>
<td>475</td>
<td>13</td>
<td>3</td>
</tr>
</tbody>
</table>
MIT’s Moral Machine

• 2 million people, 10 languages, 233 countries = 40 million decisions

• In the main interface of the Moral Machine, users are shown **unavoidable accident** scenarios with two possible outcomes, depending on whether the autonomous vehicle swerves or stays on course

(emphasis mine)
In this case, the self-driving car with sudden brake failure will continue ahead and drive through a pedestrian crossing ahead. This will result in...

Dead:
- 1 homeless person

In this case, the self-driving car with sudden brake failure will swerve and drive through a pedestrian crossing in the other lane. This will result in...

Dead:
- 1 male executive

Image credit: moralmachine.mit.edu
The Moral Machine

What should the self-driving car do?

In this case, the self-driving car with sudden brake failure will continue ahead and crash into a concrete barrier. This will result in...

Dead:
- 1 female athlete
- 2 male athletes

4 / 13

In this case, the self-driving car with sudden brake failure will swerve and drive through a pedestrian crossing in the other lane. This will result in:

Dead:
- 1 large woman
- 2 large men

Image credit: moralmachine.mit.edu
The Moral Machine

What should the self-driving car do?

In this case, the self-driving car with sudden brake failure will continue ahead and crash into a concrete barrier. This will result in...

Dead:
- 1 baby
- 1 large woman

In this case, the self-driving car will swerve and drive through a pedestrian crossing in the other lane. This will result in...

Dead:
- 1 baby

Note that the affected pedestrians are abiding by the law by crossing on the green signal.

Image credit: moralmachine.mit.edu
The Moral Machine

What should the self-driving car do?

In this case, the self-driving car with sudden brake failure will swerve and drive through a pedestrian crossing in the other lane. This will result in...

Dead:
- 3 girls
- 1 female doctor
- 1 female executive

Note that the affected pedestrians are flouting the law by crossing on the red signal.

Image credit: moralmachine.mit.edu
The Moral Machine

What should the self-driving car do?

In this case, the self-driving car with sudden brake failure will swerve and drive through a pedestrian crossing in the other lane. This will result in ...

Dead:
- 1 woman
- 1 large woman
- 1 female executive
- 1 large man
- 1 girl

Note that the affected pedestrians are abiding by the law by crossing on the green signal.

In this case, the self-driving car with sudden brake failure will continue ahead and crash into a concrete barrier. This will result in ...

Dead:
- 1 elderly woman

Image credit: moralmachine.mit.edu
In this case, the self-driving car with sudden brake failure will continue ahead and drive through a pedestrian crossing ahead. This will result in...

Dead:
- 1 male athlete
- 1 male doctor

Note that the affected pedestrians are abiding by the law by crossing on the green signal.

In this case, the self-driving car with sudden brake failure will swerve and drive through a pedestrian crossing in the other lane. This will result in...

Dead:
- 1 cat
- 1 dog

Note that the affected pedestrians are flouting the law by crossing on the red signal.
Shouldn’t AVs be better than trolleys?

• “Sudden brake failure” and “unavoidable accident” ??

• A moral decision not addressed in the trolley problem: Should AV vehicles be traveling fast enough in the vicinity of pedestrian crossings that they would kill people in the case of a crash?
The trolley before the horse problem

• Take Cadillac's Super Cruise system, the hands-free driving assistant that can navigate most U.S. highways on its own, **as long as the driver stays attentive**. It's considered the most robust system on the market in terms of reliability and safety, and **yet it continues to have problems when sunlight causes it to abruptly disengage**.

(emphasis mine)
Contract.

Navigate on Autopilot (Beta)

Navigate on Autopilot does not make your Model 3 autonomous. Like other Autopilot features, the driver is still responsible for the car at all times.

When Navigate on Autopilot is enabled your Model 3 will determine which lane you need to be in and when. In addition to ensuring you reach your intended exit, Autopilot will watch for opportunities to move to a faster lane when you’re caught behind slower traffic. When you reach your exit, your Model 3 will depart the freeway, slow down and transition control back to you.

Use Navigate on Autopilot only if you will pay attention to the road, keep your hands on the steering wheel, and be prepared to take over at any time. Your Model 3 will indicate when a lane change or exit is coming, but you are still responsible for monitoring the environment and maintaining control.

When using Navigate on Autopilot always visually check your environment and blindspots before confirming automatically-initiated lane changes as traffic may be rapidly approaching. As is the case with all driving, be extra careful around blind corners, highway interchanges, and exits.

When exiting highways, remember that Autopilot will not stop on its own at stop lights or stop signs, or yield for merges.

Do you want to enable Navigate on Autopilot while it is in Beta?

[ ] NO

[ ] YES
Why Teslas run into parked fire trucks

• “The only safe scenario would be don’t move,” says Aaron Ames, from Caltech’s Center for Autonomous Systems and Technologies. That doesn't exactly work for driving. “You have to make reasonable assumptions about what you care about and what you don’t.”
9. Standard safety tech: All RAV4s come standard with Toyota's Safety Sense suite of semi-autonomous driver-assistance technologies, including pre-collision warning with pedestrian detection, adaptive cruise control, lane-departure warning with steering assist, automatic high beams, lane-tracing assist, and traffic-sign assist.

Tesla is updating Model 3 to allow higher power output for longer periods, increases top speed

Tesla is working on a new software update that would enable Model 3 owners to drive at higher...
Pedestrians: a barrier to be overcome?

• Zimmerman, founder of urban planning concern group Designing Hong Kong, described the autonomous bus as a “beeping monster”, referring to an anti-collision mechanism that chimes and stops the bus whenever it detects objects in its immediate vicinity.

• “If [such buses] have to drive through a heavily pedestrianised area, they basically have to stand still all the time,” Zimmerman told the Post.
But who will think of the robots??

- Selman says New York City is a relatively safe place to test them because of rapid developments in artificial intelligence and obstacle avoidance. [and yet:]
- “One issue in New York will be that there’s nothing to prevent a pedestrian from stepping out in the road and causing the cars to brake,” Selman says. “I call it bullying of the self-driving cars.”
Why Not Just Retrain Pedestrians to Make Self-Driving Vehicles Safer?

By Jeremy Kahn | August 17, 2018
Virtual reality

Source: Crossing the road in the world of autonomous cars by Stamp Siripanich at Teague Labs https://link.medium.com/rLZQ1gC6GV
AV communication: Eye contact?
AV communication:

Source: Crossing the road in the world of autonomous cars by Stamp Siripanich at Teague Labs https://link.medium.com/rLZQ1gC6GV

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Is technology objective?

• “Predictive Inequity in Object Detection”
  aka humans are creating AV as racist as we are

• Not time of day or occlusion (blocked view)

• Composition of the training set:
So until we perfect our robot overlords . . .
The near-term role of AV in the trolley problem

• Level 2: Car, while steering and controlling speed, fails to see people in roadway, so an alert driver is needed to see and avoid hazard

• Level 3: Car is steering and controlling speed, sees complex roadway environment and alerts driver that they need to re-engage in driving task and take control

(all of these assume travel speeds low enough to actually stop in time)
Humans at (near?) the wheel

- The experience helped confirm a thesis Coelingh and Volvo had been testing: A car with any level of autonomy that relies upon a human to save the day in an emergency poses almost insurmountable engineering, design, and safety challenges, simply because humans are for the most part horrible backups. They are inattentive, easily distracted, and slow to respond. "That problem's just too difficult," Coelingh says.

Source: Wired Magazine, 01/01/17
Lane maintenance systems still a turnoff for many drivers
This is your brain on automation

THE VERY HUMAN PROBLEM
BLOCKING THE PATH TO SELF-DRIVING CARS

The Crash of the Boeing 737 Max Is a Warning to Drivers, Too

Pilots usually have to understand their autonomous planes. We should understand our autonomous cars.

By HENRY GRABAR
Drivers are “horrible back-ups”

“For now they are oppress’d with travel, they
Will not, nor cannot, use such vigilance
As when they are fresh.”

- Will Shakespeare, *The Tempest*, 1610
Drivers do not treat all people equally

Strange but True: Helmets Attract Cars to Cyclists

Although you might not want to leave your protective gear at home, just know that if you do, drivers will be a lot more scared of hitting you.
Human drivers are biased

Racial Bias Extends to the Crosswalk

TAGS: ATTITUDES | DECISION MAKING | DISCRIMINATION | DRIVING | IMPLICIT BIAS | RACIAL ATTITUDE | SOCIAL PSYCHOLOGY | TRAVEL

Study: drivers less likely to brake for African American pedestrians
How people feel about bicyclists

Source: Goddard (2017)

*based on bicyclist silhouette
Stereotypes about bicyclists

Percentage of respondents who attributed characteristic to each type of bicyclist

**Fit**

**Skilled**

**Follows the rules**

**Courteous**

**Predictable on the road**

*based on bicyclist silhouette

Source: Goddard (2017)
Those pesky pedestrians and bicyclists

Local news coverage subtly, but consistently blames vulnerable road users for crashes.

Media treat crashes as isolated incidents, and not as a systemic issue.

These issues obscure potential solutions to curb VRU deaths.

Source: Ralph, Iacobucci, Thigpen, & Goddard (2019). Graphic credit: Iacobucci

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Jaywalkers are a common sight in SF. This clip shows how our technology predicts this pedestrian’s trajectory, then slows to a stop in order for him to pass safely.
Current study: Driver’s emotions and attitudes during interactions with bicyclists

• Driving simulator with eye-tracking and biometric data
• Implicit Association Test (IAT)
• Survey of attitudes, self-reported behaviors, personal travel behavior, and demographics
*VERY* Interim data

- 80% of participants said driving near a bicyclist makes them nervous
- 56% said they are not comfortable deciding how close or fast to pass a bicyclist
- 80% said bicyclists should not hold up traffic
- 25% have honked, yelled, or gestured at a bicyclist who made them angry
- 93% get angry at bicyclists who break the rules but only 2% get angry at drivers who do
*VERY* Interim data

Implicit (i.e. subconscious) bias for drivers or bicyclists based on an Implicit Association Test (IAT)

Implicit bias toward Drivers or Bicyclists

<table>
<thead>
<tr>
<th>Percent of participants</th>
<th>Moderate or strong pro-bicyclist bias</th>
<th>Mild or no bias</th>
<th>Moderate or strong pro-driver bias</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>

*Χ² = .000, based on expected normal

Variation in driver proximity to bicyclist during an overtaking maneuver
Putting the horse back in front of the trolley*

In other words: “TECHNOLOGY CAN HELP US, BUT IT WON’T SAVE US.” – Tamika Butler, Toole Design Group, April 4, 2019

*With apologies for really torturing that metaphor
How do we define success?
The Safe Systems approach

• Autonomous and semi-autonomous technologies should be developed within a Safe Systems framework, NOT the other way around

**TRADITIONAL APPROACH**

- Traffic deaths are INEVITABLE
- PERFECT human behavior
- Prevent COLLISIONS
- INDIVIDUAL responsibility
- Saving lives is EXPENSIVE

**VISION ZERO**

- Traffic deaths are PREVENTABLE
- Integrate HUMAN FAILING in approach
- Prevent FATAL AND SEVERE CRashes
- SYSTEMS approach
- Saving lives is NOT EXPENSIVE
The Safe Systems approach

Liza Dixon
@lizadixon

Replying to @HalfonJesse @iboudway and 8 others

Much like NASA helps uncover solutions to problems on earth, I think AV dev can help us to become better/safer road users. It requires us to break down our processes/interactions, in order to train the system, the act of doing this makes us understand the entire ecosystem better.

11:40 AM · 09 Apr 19 · Twitter Web App
Waxing philosophical

“The truth is that civilization does not protect us from wild animals. It attempts, however imperfectly, to protect us from ourselves.” – Michael Crichton, Travels

“We do not have the luxury of giving up on creating moral machines” – Moral Machine team from MIT

We should not absolve ourselves of the responsibility to act morally as drivers, or plan and engineer a moral environment – Me
Thank you!

goddard@tamu.edu

@GoddardTara
EXTRA SLIDES
Your next car may not allow you to speed on the highway

More than 37,000 Americans have been killed in high-speed crashes in the past 25 years, and automakers are now under increasing pressure to limit the top speeds of vehicles.
<table>
<thead>
<tr>
<th>SAE Level</th>
<th>SAE Name</th>
<th>SAE Narrative Definition</th>
<th>Execution of Steering/Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (driving modes)</th>
<th>BAS Level</th>
<th>NHTSA Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task</td>
<td>Human Driver</td>
<td>Human Driver</td>
<td>Human Driver</td>
<td>N/A</td>
<td>Driver only</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration</td>
<td>Human Driver and Systems</td>
<td>Human Driver</td>
<td>Human Driver</td>
<td>Some Driving Modes</td>
<td>Partially Assisted</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>Part-time or driving mode-dependent execution by one or more driver assistance systems of both steering and acceleration/deceleration. Human driver performs all other aspects of the dynamic driving task.</td>
<td>System</td>
<td>Human Driver</td>
<td>Human Driver</td>
<td>Some Driving Modes</td>
<td>Partially Automated</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task - human driver does respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>Human Driver</td>
<td>Some Driving Modes</td>
<td>Highly Automated</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task - human driver does not respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some Driving Modes</td>
<td>Fully Automated</td>
<td>3/4</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some Driving Modes</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
How fragile is trust in AV tech?

UNSAFE?

Boeing’s cold-blooded risk calculation may tarnish trust in “self-driving” cars for years

By Michael J. Coren • 6 hours ago
SAE Levels of Automation

<table>
<thead>
<tr>
<th>No Automation</th>
<th>1 Driver Assistance</th>
<th>2 Partial Automation</th>
<th>3 Conditional Automation</th>
<th>4 High Automation</th>
<th>5 Full Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero autonomy; the driver performs all driving tasks.</td>
<td>Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.</td>
<td>Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.</td>
<td>Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.</td>
<td>The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.</td>
<td>The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.</td>
</tr>
</tbody>
</table>

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