Automated Vehicles and the Road Ahead

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Why Automated Vehicles? – The Benefits

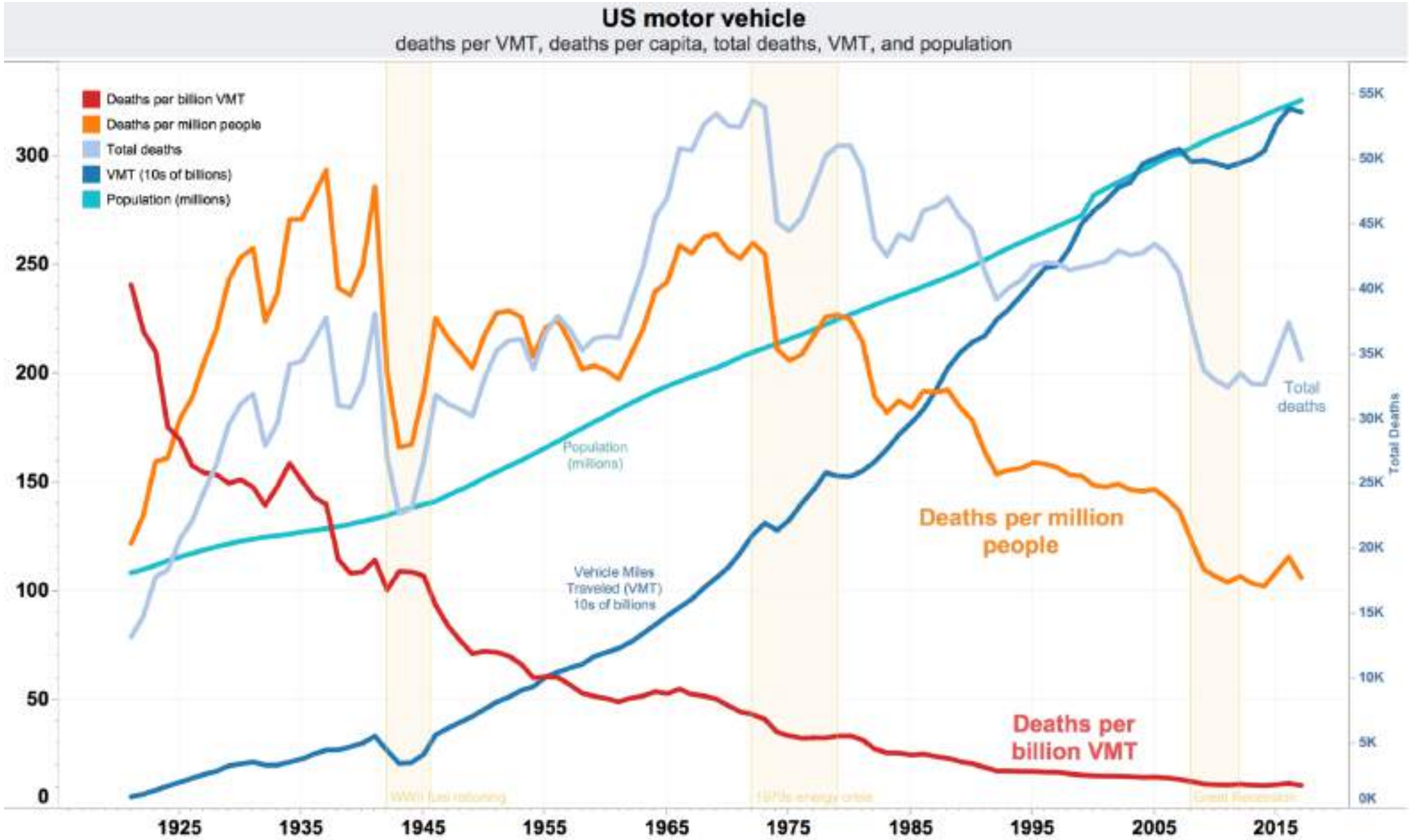
- Safety
  - **94%** of crashes are attributable to human decisions
  - **37,133** fatalities on US roadways in 2017.

- Mobility and Productivity
  - Average commuter spent **42 hours** last year in traffic
  - Less traffic congestion

- Environmental
  - Less pollution
  - More energy independence
  - Less infrastructure = More green spaces

And…we simply want to do other things behind the wheel!

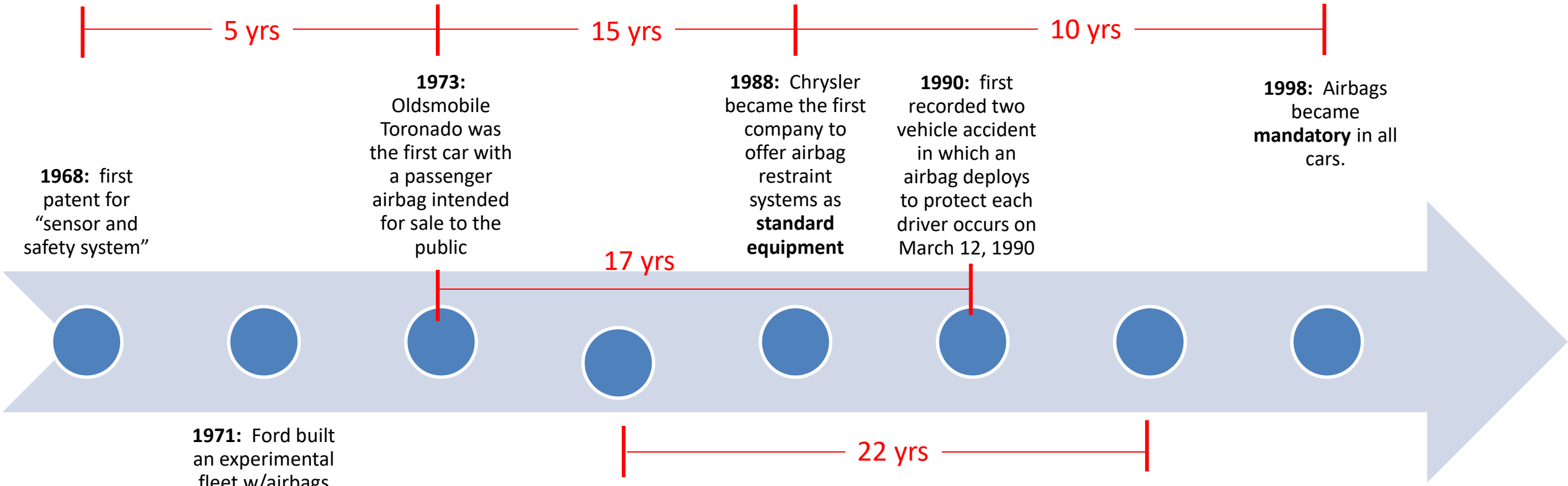
https://www.pokemon.com/us/pokemon-video-games/pokemon-go/



https://en.wikipedia.org/wiki/Motor_vehicle_fatality_rate_in_U.S._by_year

A little history of the Airbag….

"We can no longer tolerate unsafe automobiles," President Lyndon B. Johnson.

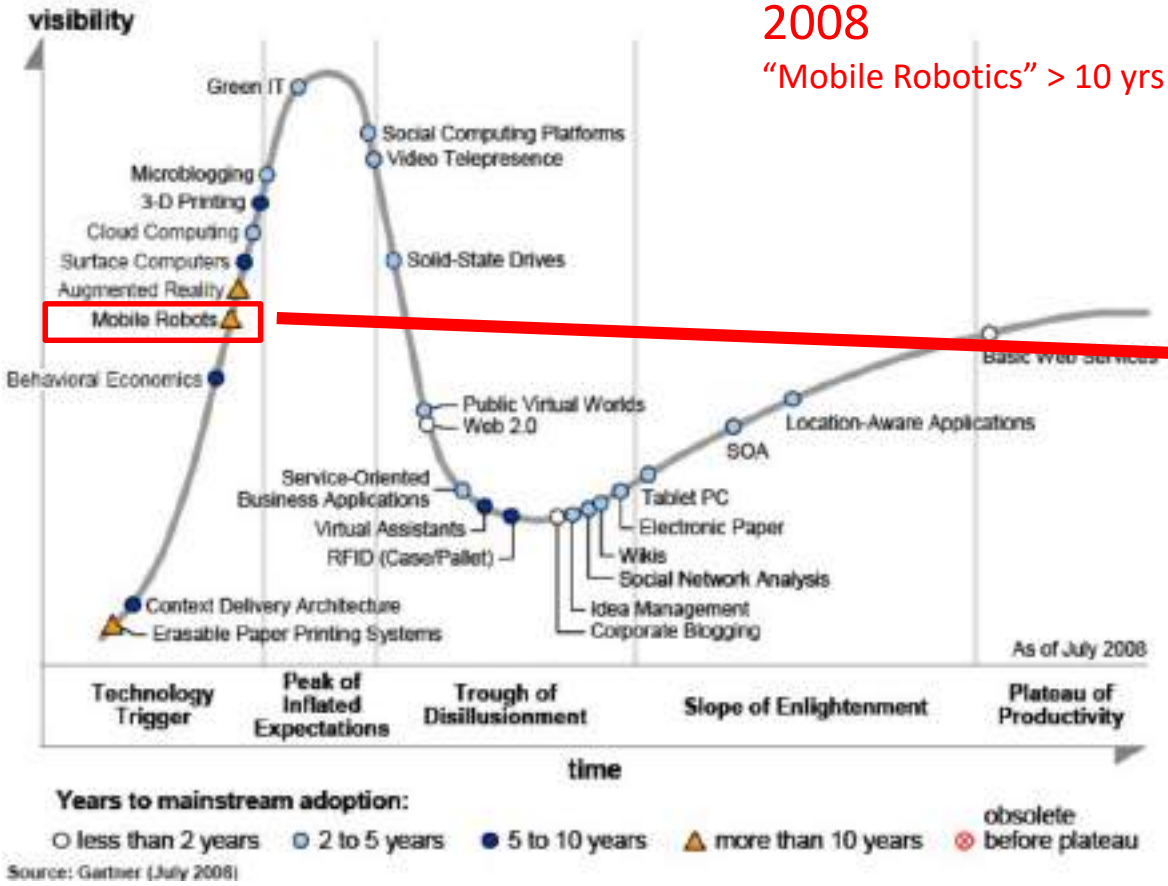


https://www.thoughtco.com/history-of-airbags-1991232
https://www.consumeraffairs.com/news04/2006/airbags/airbags_invented.html
http://www.secondchancegarage.com/public/history-of-airbags.cfm

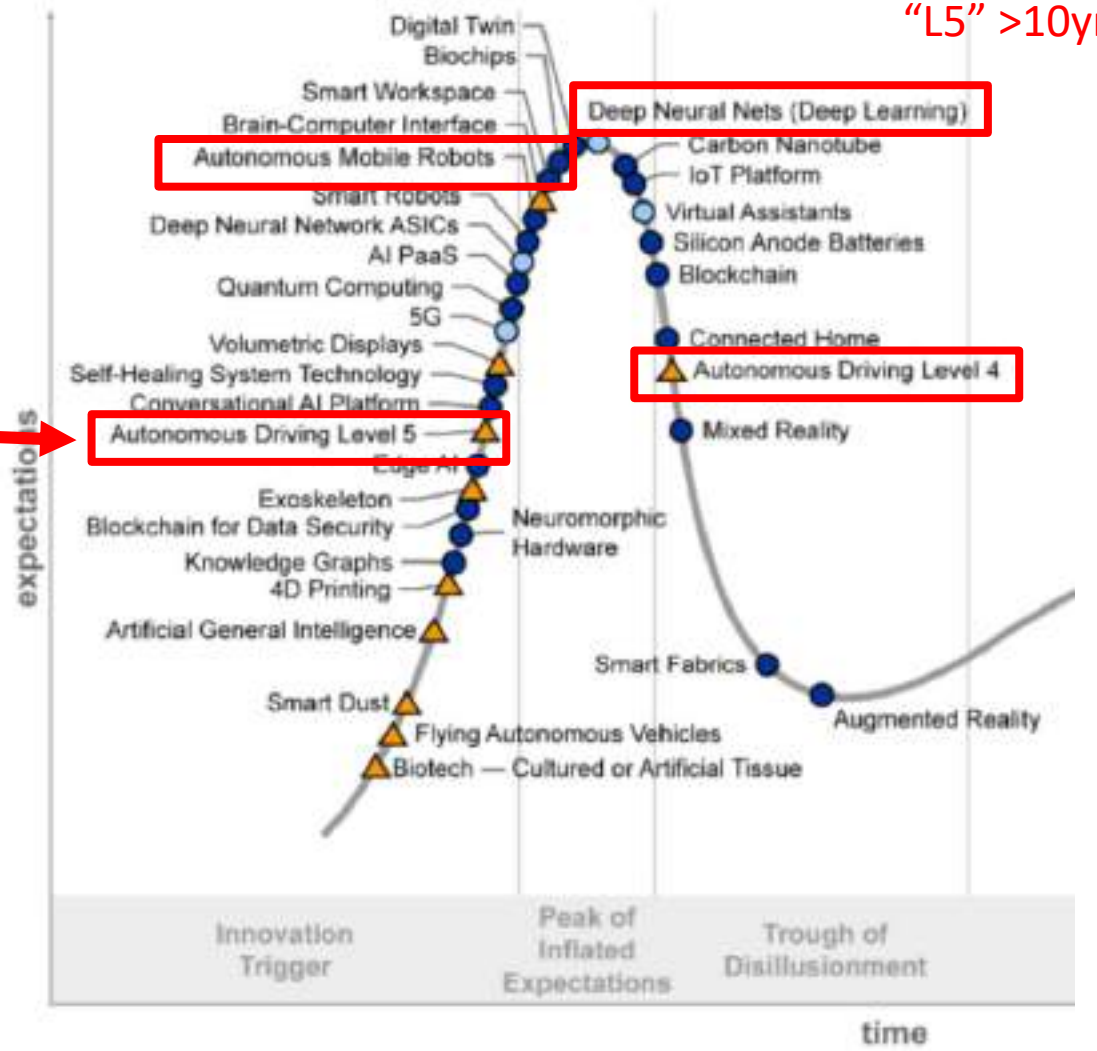
Dissecting the Hype:
10 years of development and well over $80B in investment….

2018
"L4" >10yrs
"L5" >10yrs

2008
"Mobile Robotics" > 10 yrs



https://techcrunch.com/2008/08/18/where-are-we-in-the-hype-cycle/



"According to the Brookings Institute from late last year, more than $80B has been invested in the industry between 2014 and 2018."
https://247wallst.com/autos/2018/03/20/will-80-billion-investment-in-self-driving-cars-be-a-waste/

Dissecting the Hype

2001: Congress mandated that 1/3 of all operational ground combat vehicles be unmanned by 2015.

2015: Musk predicted a fully autonomous Tesla by 2018.
"I almost view it as a solved problem. We know exactly what to do, and we'll be there in a few years."

OEM	Public Statements (from 2/19/2019 article below)	Investments
Ford	"Level 4 vehicle in **2021**, no gas pedal, no steering wheel, and the passenger will never need to take control of the vehicle in a predefined area."	$1 billion investment in Argo AI
Toyota	"none of us in the automobile or IT industries are close to achieving true Level 5 autonomy, we are not even close."	$1 billion investment in Toyota Research Institute
GM	"We expect to be the first high-volume auto manufacturer to build fully autonomous vehicles in a mass-production assembly plant."	$581 million to acquire self-driving car start-up, Cruise Automation, $500 million investment in Lyft
Volvo	"It's our ambition to have a car that can drive fully autonomously on the highway by **2021**."	$300 joint venture with Uber
Honda	"cars that can at least drive themselves on highways by **2020**."	
Daimler	"…expects large-scale commercial production to take off between **2020 and 2025**."	
Renault -Nissan	"So we know that autonomy is something of high interest for the consumers. This is the first brick — one-lane highway. Then you're going to have multi-lane highway, and then you're going to have urban driving. All of these steps are going to come before 2020. […] **2020** for the autonomous car in urban conditions, probably **2025** for the driverless car."	
BMW	"highly and fully automated driving into series production by **2021**."	
Hyundai	"We are targeting for the highway in **2020** and urban driving in **2030**."	$1.7 billion in R&D

https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/

Public statements on availability

Company	Statement Date	Level	Available
NVIDIA	10/26/2017	"fully autonomous"	2022
Audi	1/5/2017	"drive itself"	2020
NuTonomy	8/29/2016	"self-driving in 10 cities"	2020
Delphi and Mobileye	8/23/2016	Level 4	2019
Ford	8/16/2016	"fully self driving, no wheels or pedals, several years longer to sell to public"	2021
BMW	5/12/2016	"self-driving iNext"	2021
GM	5/10/2016	"self-driving in general"	2020
VW	4/23/2016	"self-driving in general"	2019
Ford	2/27/2016	Level 4	2020
Baidu	10/8/2015	"self-driving by 2019, mass production by 2021"	2019
Toyota	10/8/2015	"autonomous highway driving"	2020
Tesla	9/23/2015	"fully autonomous 2018 plus 1-3 years for regulatory approval"	2018
Uber	8/18/2015	"driverless fleet by 2030"	2030
Ford	2/9/2015	"fully autonomous, but maybe not Ford"	2020
Audi	10/22/2014	"A8 drive itself with full autonomy"	2017
Tesla	10/15/2014	"true autonomous, sleep and wake up at destination, 2023 then add 2-3 years for regulatory"	2023
JLR	10/3/2014	"fully autonomous"	2024
Daimler	1/12/2014	"fully autonomous, maybe no steering wheel"	2025
Nissan	8/27/2013	"fully autonomous available to consumer, drive in urban traffic, no detailed 3D maps"	2020
Nissan	1/14/2013	"driverless cars"	2020
Continental	12/18/2012	"fully autonomous"	2025
Intel	10/22/2012	"driverless cars"	2022
Google	10/2/2012	"driverless cars on the market"	2018

http://www.driverless-future.com/?page_id=384

Tesla's Bold Claims

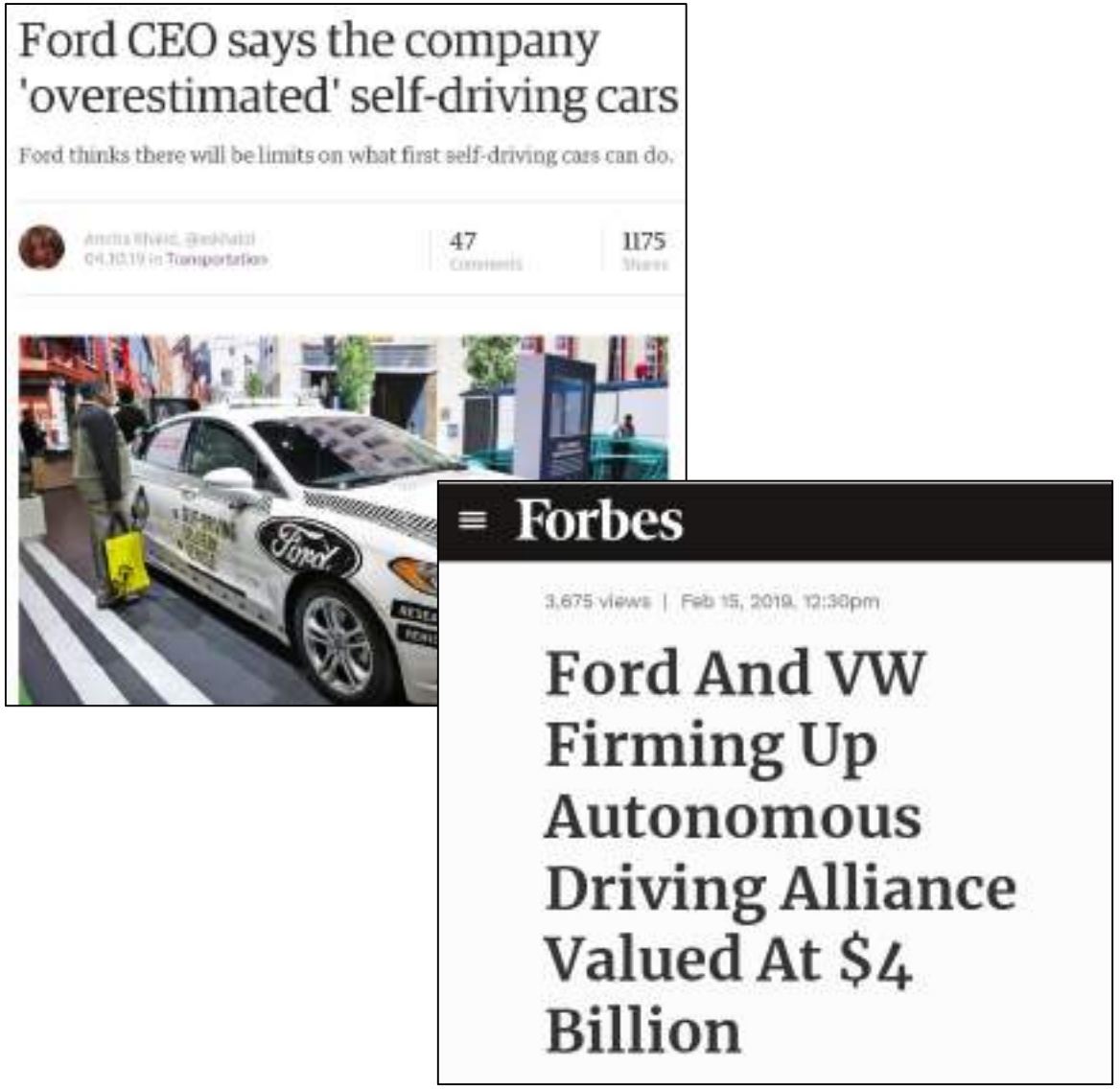
- "Musk estimated that by the middle of 2020, Tesla's autonomous system will have improved to the point where drivers will not have to pay attention to the road.
- He said the company will roll out autonomous taxis next year in some parts of the US. The service will allow Tesla owners to add their cars to a Tesla network, which he said would be akin to Uber or Airbnb.
- "We will have more than one million robotaxis on the road," Musk said. "A year from now, we'll have over a million cars with full self-driving, software... everything."
- These cars will be Level 5 autonomy with no geofence, which is a fancy way of saying they will be capable of driving themselves anywhere on the planet, under all possible conditions, with no limitations. There are no cars on the road today that are Level 5."

https://www.theverge.com/2019/4/22/18510828/tesla-elon-musk-autonomy-day-investor-comments-self-driving-cars-predictions

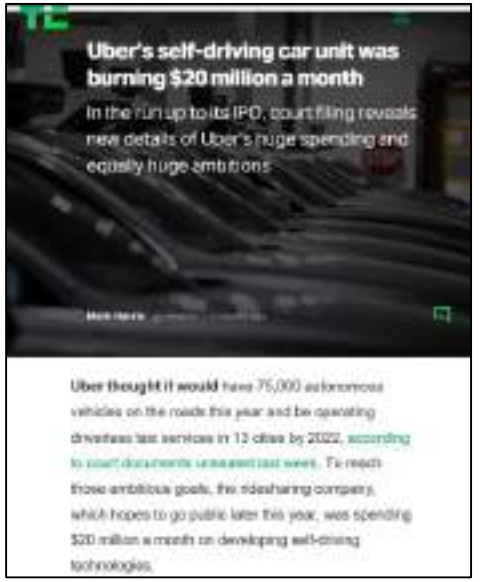
Ford's Realization

"We overestimated the arrival of autonomous vehicles," said Hackett, who once headed the company's autonomous vehicle division, at a Detroit Economic Club event on Tuesday. While Ford still plans on launching its self-driving car fleet in 2021, Hackett added that "its applications will be narrow, what we call geo-fenced, because the problem is so complex."

https://www.engadget.com/2019/04/10/ford-ceo-says-the-company-overestimated-self-driving-cars/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS91cmw_c2E9dCZyY3Q9aiZxPSZlc3JjPXMmc291cmNlPXdlYiZjZD0yJnZlZD0yYWhVS0V3anF1czd1d1luaUFoVkhzNndLSGZjNUNNOFFGakFCZWdRSUJoQUImdXJsPWh0dHBzJTNBJTJGJTJGd3d3LmVuZ2FkZ2V0LmNvbSUyRjIwMTklMkYwNCUyRjEwJTJGZm9yZC1jZW8tc2F5cy10aGUtY29tcGFueS1vdmVyZXN0aW1hdGVkLXNlbGYtZHJpdmluZy1jYXJzJTJGJnVzZz1BT3ZWYXcxVjZLUU80TXlEMVNJRkdWZ0NHMmhy&guce_referrer_sig=AQAAAK13Lx371y6-pkc1C_jBNcEHs534l9LYVPagrqJ2-7FdW0IuLGN0hEUToXOnsnSlwd0kvIe5pbvt6mc5lbUQhOMAOge00bKchA9kcn6kVtTcnph_wxU0u7h1-6vGndrrfrdMmBgk0FXiaQeTF_BJrXDOxRl-JDQV0-fQG-TQyEhy



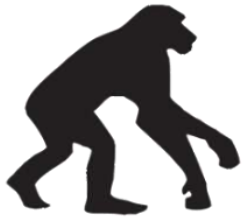
More Investments, Acquisitions, and Consolidation



What is an Automated Vehicle, Robot Car, Self Driving Car, etc?

What is an Automated Driving System?

Level 0
"No Driving Automation"



Level 1
"Driver Assistance"

CURRENT

"Hands/Feet Off, Brain On"

CURRENT

"Brain Off" Certain Places

"Brain Off" Everywhere

Level 2
"Partial Driving Automation"

Level 3
"Conditional Driving Automation"

Level 4
"High Driving Automation"

Level 5
"Full Driving Automation"

Automated Driving System Evolution

Level 2
Avoidance: Driver
Fallback: Driver
Area: Limited

Level 3
Avoidance: System
Fallback: Driver
Area: Limited

Level 4
Avoidance: System
Fallback: System
Area: Limited

Level 5
Avoidance: System
Fallback: System
Area: Unlimited

So, why aren't these ready for prime time?

Fallback to the Human (Level 3 → Level 4)

- Studies and incidents have shown that humans often come to trust a system very quickly.
- Once a person is actively disengaged from the driving process, it can take multiple seconds to regain situational awareness in order to take effective control.

Automation Anywhere, Anytime (Level 4 → Level 5)

- No system has encountered all possible scenarios.
- How do you train and verify a system will work in every scenario that it will encounter?

Perception Challenges in Adverse Conditions

- Long Ranger Sensing Necessary for Higher Speeds and Increased Reaction Times
- Some sensing modalities are better at ranging, some better at context, and some are better in degraded weather conditions. This increases the cost when redundancy is considered.

- **Visible-spectrum cameras:** range and effectiveness are severely limited in heavy rain, snow, or dense fog.
- **LIDAR sensors:** can reflect off raindrops, snowflakes, or other particles, surrounding the vehicle in false positives.
- **Radar** is least affected by most of the adverse conditions that afflict the visible-spectrum sensors, but has the significant drawback of reduced resolution.

Infrastructure Markings

- Lane line detection has become more prevalent in available systems for lane departure warning, lane keep assist and vehicle automation.
- Often, these systems rely on relatively pristine lane markings and can often fail in the presence of faded or ambiguous lines or other markers (such as Botts' dots or other raised reflective markers).

Infrastructure Signage

- Detection of road signage has greatly improved in recent years, interpreting speed limit signs, stop signs, and others.
- Traffic signals have proven to be more difficult: their configurations vary widely, they often appear in cluttered visual environments, and they are often smaller visually than other signage.

The Last Mile

- 65% of the roads in the US are paved. (63% Worldwide)
- Many homes in the US have driveways 20-100 meters long.
- Lane Markings on roads and in parking lots are not always visible.
- "Major" objects change each season.
- As recently as 2014, Google had mapped approximately 2,000 miles of roads.
- Also as of 2014, the United States alone has 2,744,171 miles of paved road and an additional 1,421,083 miles of unpaved road.

Select States (kilometers)	Total	Paved	Unpaved	% Unpaved
Texas	512,656	357,499	155,157	30%
California	273,822	160,797	113,026	41%
Michigan	195,426	99,667	95,759	49%
Nebraska	154,802	82,499	72,303	47%
Alaska	25,088	4,857	20,231	81%
Total US:	**6,584,739**	**4,214,233**	**2,370,506**	**36%**

Understanding Intent of other Drivers (Vehicles) and Pedestrians

- What is this guy trying to communicate?
- Eye contact
- Hand Gestures
- Body (vehicle) language
- Derive intent

Sensor Processing and Generalization

- How do you train and verify that a system will work in every scenario that it will encounter?

- Newer techniques, such as deep learning, seem to broaden the ability to generalize processing in various scenarios, but how to you validate what is inside if it can be a black box?

Dynamic Environments and Vulnerable Road Users

Cyber Vulnerabilities

Self-Driving Cars Can Be Hacked By Just Putting Stickers On Street Signs

Tuesday, August 08, 2017 Wang Wei

Car Hacking is a hot topic, though it's not new for researchers to hack cars. Previously they had demonstrated how to hijack a car remotely, how to disable car's crucial functions like airbags, and even how to steal cars.

http://thehackernews.com/2017/08/self-driving-car-hacking.html?m=1

But the latest car hacking trick doesn't require any extra ordinary skills to accomplished. All it takes is a simple sticker onto a sign board to confuse any self-driving car and cause accident.

Macro-level Confusion on Whether AV's reduce fuel consumption?

APR 17, 2017 @ 12:07 AM 4,564

Big Fuel Savings From Autonomous

Jeff McMahon, CONTRIBUTOR

From Chicago, I write about green technology, energy, environment FULL BIO

Opinions expressed by Forbes Contributors are their own.

An attendee looks at an autonomous vehicle developed by Oxbotica while standing near an [+]

By 2050, connected autonomous vehicles could reduce fuel consumption by as much as 44 percent for passenger vehicles and 18 percent for trucks, according to a new study released by the Energy Information Administration.

https://www.forbes.com/sites/jeffmcmahon/2017/04/17/big-fuel-savings-from-autonomous-vehicles/#500e86e54390

-VS-

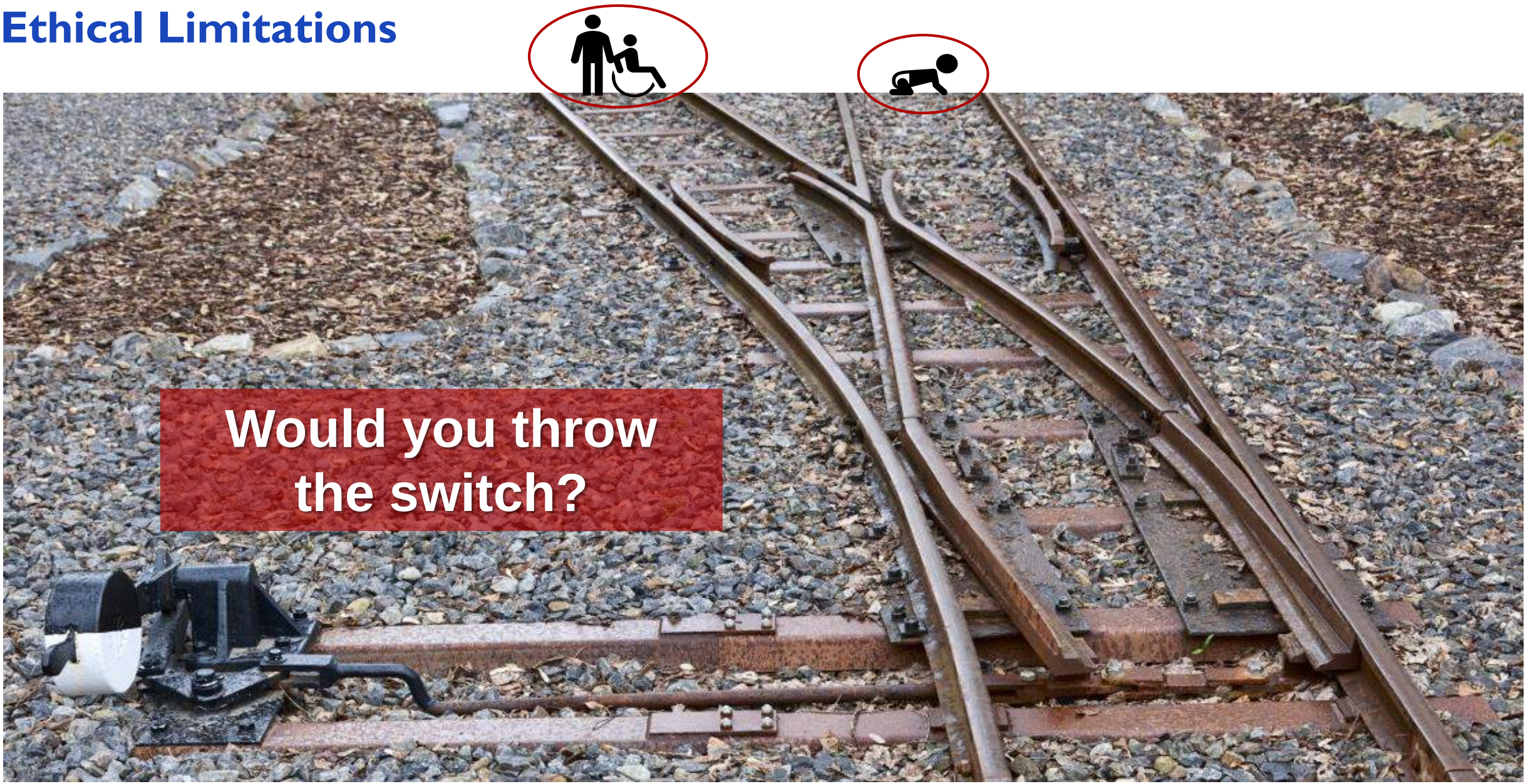
"Why Self-Driving Cars Might Not Lead to a Huge Drop in Fuel Consumption"

http://time.com/5027059/self-driving-cars-might-not-lead-to-drop-fuel-consumption/

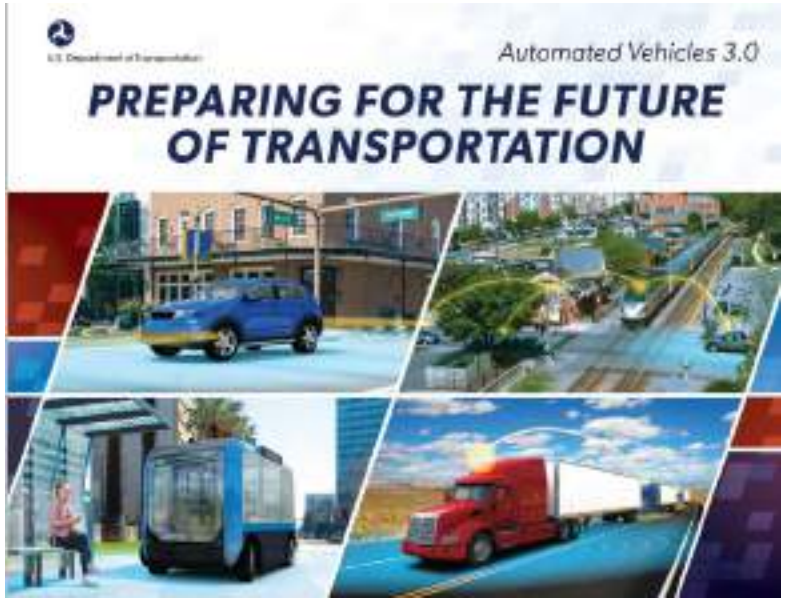
November 27, 2017 issue of TIME Magazine.

- "One report from the Department of Energy found that automated vehicles could reduce fuel consumption for passenger cars by as much as 90%, or increase it by more than 200%."
- "Researchers expect that automated cars will lead to a sharp increase in the average miles traveled by a given vehicle"
  - "car owners will be free to travel further and more frequently"
  - "Workers may choose to live even further away from the office, opting to sleep in the car or use that time to squeeze in a workout."
  - "And, once in the city, car owners might instruct their vehicle to drive around in circles rather than pay for parking."

Ethical Limitations



Legal Limitations
USDOT Guidance



https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf

H. R. 3388

AN ACT

https://www.congress.gov/bill/115th-congress/house-bill/3388/text

AGENCY	NHTSA	FMCSA	FHWA	FTA
General Role	Responsible for keeping people safe on America's Highways.	Safety standards for Commercial Motor Vehicles and drivers.	Authority over Traffic Control Devices.	Provides financial and technical assistance to local public transit systems
Role as related to ADS	Developing safety performance standards for ADS-equipped vehicles.	Developing ADS regulations, including regulations that do not assume a human is in the CMV.	Updating the 2009 MUTCD to anticipate needs driven by ADS.	Providing tailored technical assistance to help transit systems create collaborative safety management systems.

https://www.quarles.com/publications/u-s-dot-outlines-role-of-federal-government-in-future-of-automation-and-mobility/

Role of Federal Government

- Establish performance-oriented, consensus-based, and voluntary standards and guidance for vehicle and infrastructure safety, mobility, and operations.
- Conduct targeted research to support the safe integration of automation.
- Identify and remove regulatory barriers to the safe integration of automated vehicles.
- Ensure national consistency for travel in interstate commerce.
- Educate the public on the capabilities and limitations of automated vehicles.

Role of State, Local, and Tribal Governments

- Review laws and regulations that may create barriers to testing and deploying automated vehicles.
- Adapt policies and procedures, such as licensing and registration, to account for automated vehicles.
- Assess infrastructure elements, such as road markings and signage, so that they are conducive to the operation of automated vehicles.
- Provide guidance, information, and training to prepare the transportation workforce and the general public.

States With Self-Driving Car Legislation

Number of states introducing legislation by year

Year	Number of States
2011	1
2012	6
2013	9 + DC
2014	12
2015	16
2016	20
2017	33
2018	15 AV Bills

http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx#Enacted Autonomous Vehicle Legislation

Continued Confusion over Federal vs State Regulation

Germany legalizes self-driving car tests

May 2017

German automakers won't have to bring their experimental autonomous cars to California for testing anymore. The country has just approved a law allowing companies to test their self-driving cars on its roads, so long as they follow a set of conditions. Perhaps the most important requirement is

https://www.engadget.com/2017/05/12/germany-self-driving-car-test-laws/

POLITICS

Self-Driving Car Safety Legislation Stalls in the Senate

Three Democratic senators place holds on bill that would ease restrictions on development of autonomous vehicles

Feb 2018

WASHINGTON—Legislation to remove regulatory obstacles to the development of self-driving vehicles is running into problems in the Senate, dimming prospects for the quick passage that many had expected

https://www.wsj.com/articles/self-driving-car-safety-legislation-stalls-in-the-senate-1518436800

Self-driving cars continue to face little resistance from the federal government

Mar 2018

https://www.theverge.com/2018/3/5/17080824/dot-autonomous-vehicle-listening-session-washington

AMERICANS CAN'T HAVE AUDI'S SUPER CAPABLE SELF-DRIVING SYSTEM

May 2018

Between Silicon Valley's disruption-happy tech giants and Detroit's suddenly totally on board automakers, it's easy to think of America as the center of the self-driving universe. And so it seems a bit backwards that Audi has decided to release the world's most capable semiautonomous driving feature in ... Europe.

https://www-wired-com.cdn.ampproject.org/c/s/www.wired.com/story/audi-self-driving-traffic-jam-pilot-a8-2019-availablility/amp

How Close Are We / What's a Good Metric?

Miles per Disengagement \ Company	2015	2016	2017	2018
Waymo	1,244.37	5,127.97	5,595.95	11,154.30
GM Cruise		54.01	1,254.06	5,204.90
Zoox			282.96	1,922.80
Nissan	14.01	141.34	208.63	210.50
Baidu			41.60	205.60
Drive.ai			43.59	83.00
NVIDIA			4.63	20.10
Telenav			32.00	6.00
Mercedes Benz	2.17	2.00	1.29	1.50
Delphi/Aptiv	41.14	17.57	22.35	
Bosch	1.50	0.68	2.41	

https://thelastdriverlicenseholder.com/2019/03/09/changes-in-disengagements-over-the-years/

- Were all miles the same difficulty/complexity?
- How do you count a disengagement?

The Information

EXCLUSIVE

Technical Glitches Plague Cruise, GM's $19 Billion Self-Driving Car Unit

By Amir Efrati · Friday Jun 7, 2019

In the middle of April, Honda Motor CEO Takahiro Hachigo hopped into a self-driving car prototype made by General Motors' Cruise Automation for a demonstration ride. It didn't go well. About 20 minutes in, the car's software suddenly turned itself off even as the car kept moving. A man sitting behind the wheel—the backup driver—had to take control. Attempts to restart the system failed, and a second Cruise vehicle had to pick up Mr. Hachigo to finish the demonstration.

The previously unreported glitch was embarrassing for GM, Cruise's majority owner, as Honda is an investor in the company, which was valued at $19 billion in its latest fundraising. More significantly, though, the software outage highlights the technological challenges faced by Cruise that have forced it to repeatedly delay the planned launch of a fully automated robotaxi service to the public, from the original time frame of 2018 to the very end of 2019, according to people with knowledge of the matter. Cruise's difficulties are just the latest reminder of how far self-driving car technology still has to go before being ready for broad commercial use.

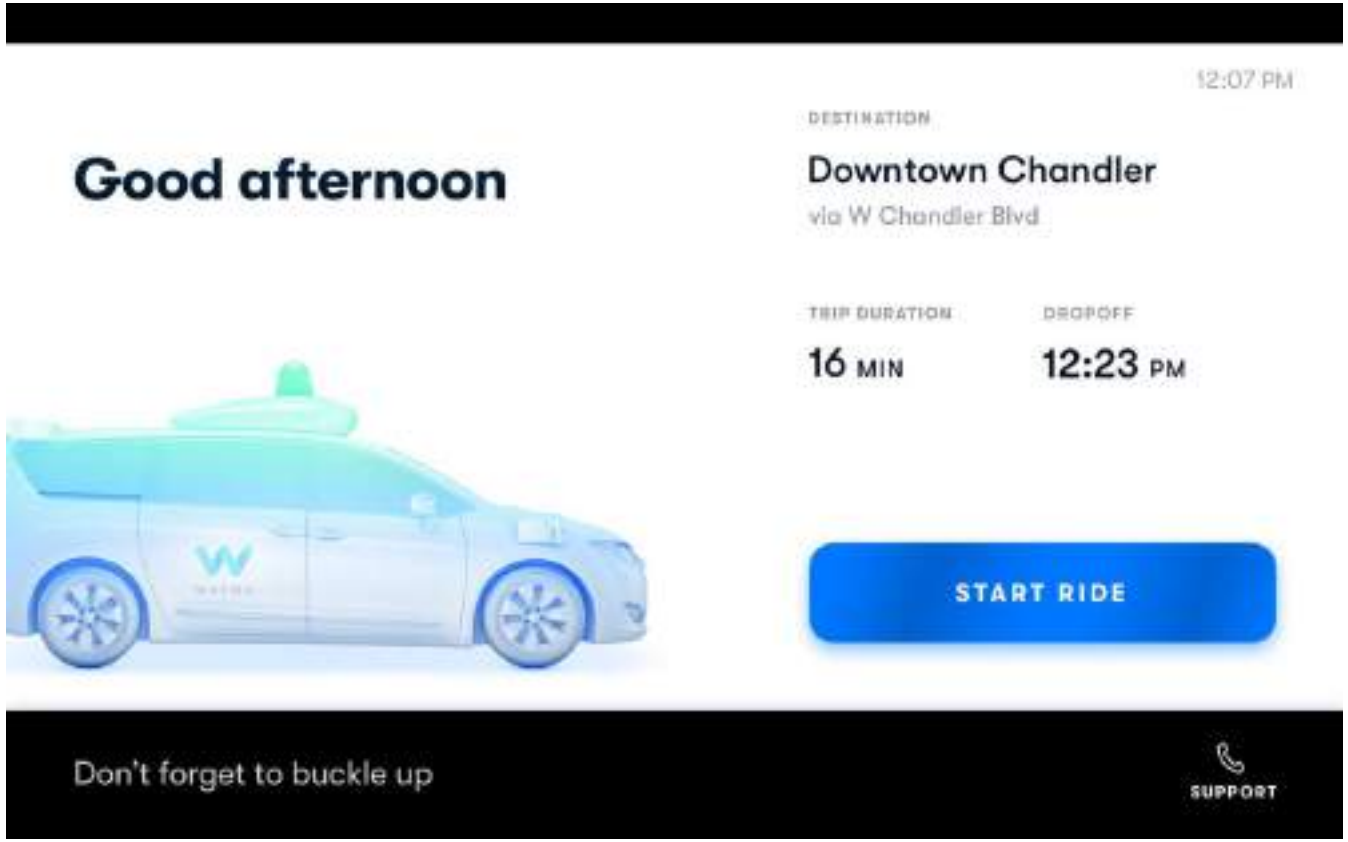
How Much Testing is Needed?

Statistical Question	How many miles (years[a]) would autonomous vehicles have to be driven...	Benchmark Failure Rate (A) 1.09 fatalities per 100 million miles?	(B) 77 reported injuries per 100 million miles?	(C) 190 reported crashes per 100 million miles?
	(1) without failure to demonstrate with 95% confidence that their failure rate is at most...	275 million miles (12.5 years)	3.9 million miles (2 months)	1.6 million miles (1 month)
	(2) to demonstrate with 95% confidence their failure rate to within 20% of the true rate of...	8.8 billion miles (400 years)	125 million miles (5.7 years)	51 million miles (2.3 years)
	(3) to demonstrate with 95% confidence and 80% power that their failure rate is 20% better than the human driver failure rate of...	11 billion miles (500 years)	161 million miles (7.3 years)	65 million miles (3 years)

[a] We assess the time it would take to compete the requisite miles with a fleet of 100 autonomous vehicles (larger than any known existing fleet) driving 24 hours a day, 365 days a year, at an average speed of 25 miles per hour.

https://www.rand.org/content/dam/rand/pubs/research_reports/RR1400/RR1478/RAND_RR1478.pdf

Waymo One



https://www.theverge.com/2018/12/5/18126103/waymo-one-self-driving-taxi-service-ride-safety-alphabet-cost-app

- Waymo One will only be available in four Phoenix suburbs where the company has been testing its vehicles for the last two years: Chandler, Mesa, Tempe, and Gilbert. The service area roughly equals 100 square miles
- Safety drivers back behind wheel

https://www.autoblog.com/2019/01/02/waymo-self-driving-vehicle-attacks/

Questions?

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