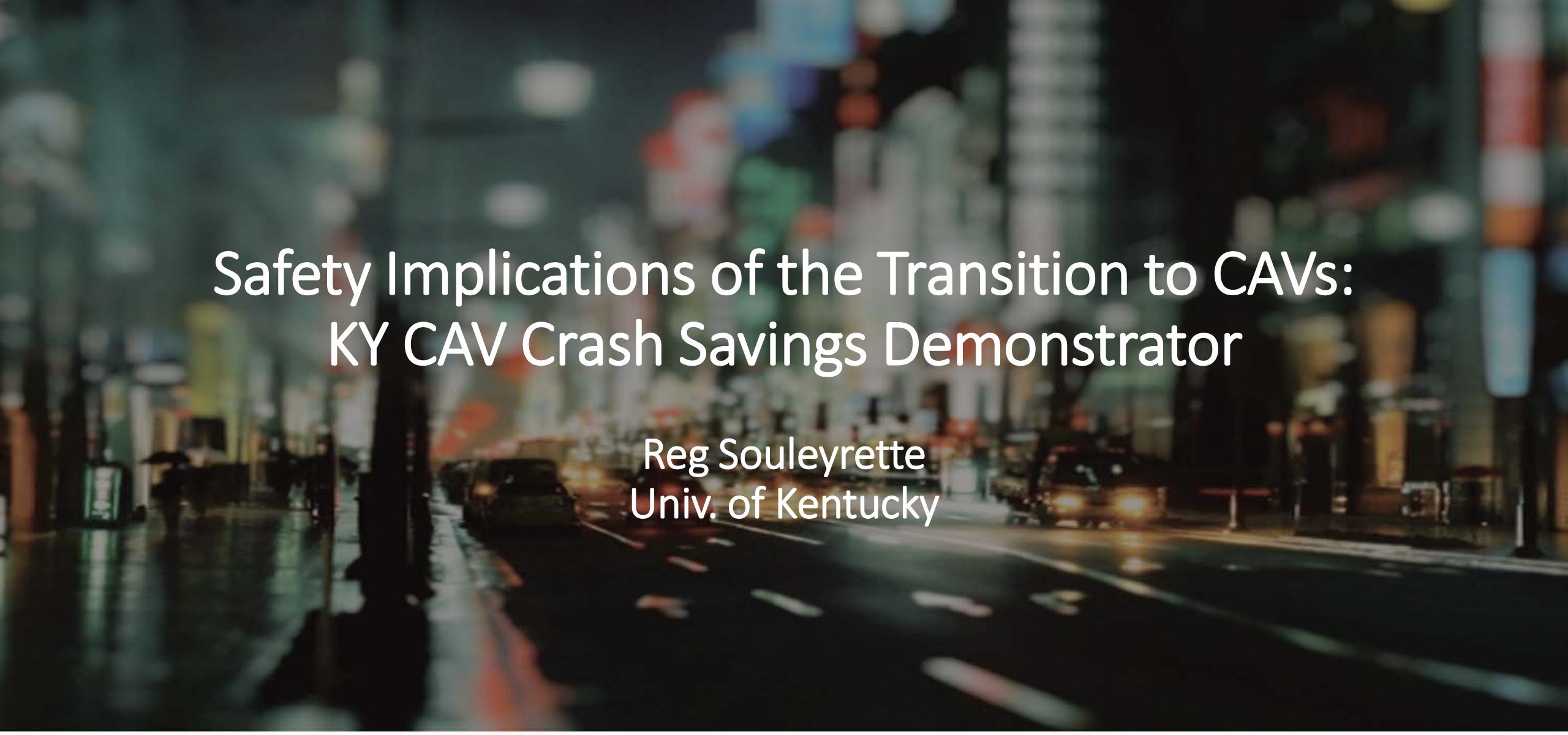


Safety Implications of the Transition to CAVs: KY CAV Crash Savings Demonstrator

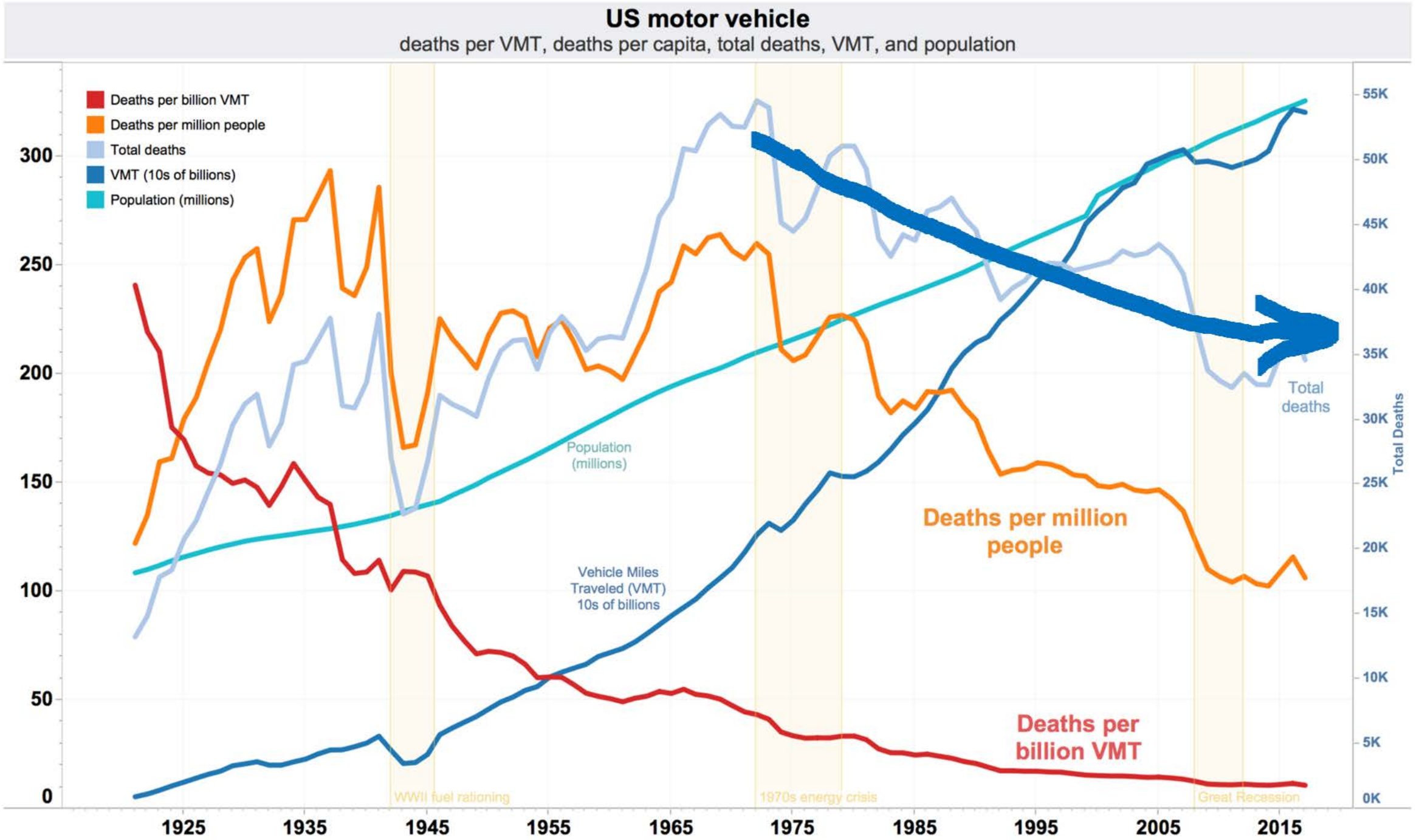
Reg Souleyrette
Univ. of Kentucky

EXCELLENCE IN MOTION

Outline

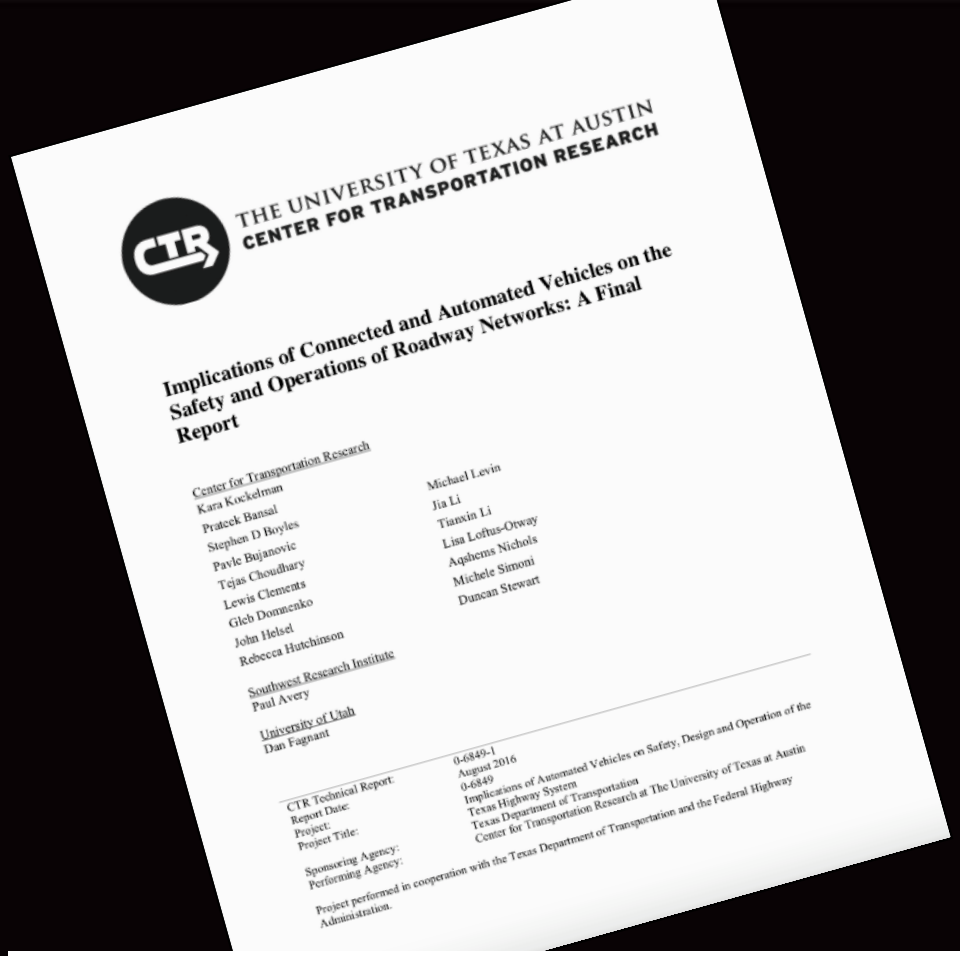
- Motivation (for studying CAV safety and transition)
- Opportunity (potential for crash reduction)
- Underlying trends/components
- Predicting Safety
- Predicting Safety for CAVs
- KY CAV Crash Savings Demonstrator
- Next Steps

Motivation



https://en.wikipedia.org/wiki/Motor_vehicle_fatality_rate_in_U.S._by_year#/media/File:US_traffic_deaths_per_VMT,_VMT,_per_capita,_and_total_annual_deaths.png

The Rand Study



THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Implications of Connected and Automated Vehicles on the Safety and Operations of Roadway Networks: A Final Report

Center for Transportation Research
Kara Kockelman
Prateek Bansal
Stephen D Boyles
Pavle Bujanovic
Tejas Choudhary
Lewis Clements
Gleb Domnenko
John Helsel
Rebecca Hutchinson
Michael Levin
Jia Li
Tianxin Li
Lisa Loftus-Otway
Aqshems Nichols
Michele Simoni
Duncan Stewart

Southwest Research Institute
Paul Avery

University of Utah
Dan Fagnant

CTR Technical Report: 0-6849-1
Report Date: August 2016
Project: 0-6849
Project Title: Implications of Automated Vehicles on Safety, Design and Operation of the Texas Highway System
Sponsoring Agency: Texas Department of Transportation
Performing Agency: Center for Transportation Research at The University of Texas at Austin

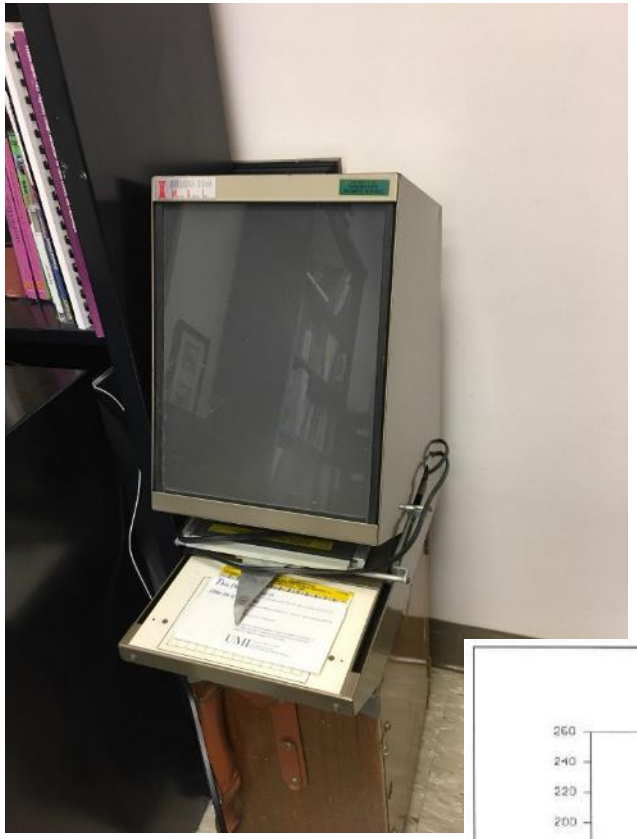
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Examining accident reports involving autonomous vehicles in California

Francesca M. Favarò, Nazanin Nader, Sky O. Eurich, Michelle Tripp, Naresh Varadaraju

Published: September 20, 2017 • https://doi.org/10.1371/journal.pone.0184952

https://www.youtube.com/watch?v=Ybr41Sy7K3g



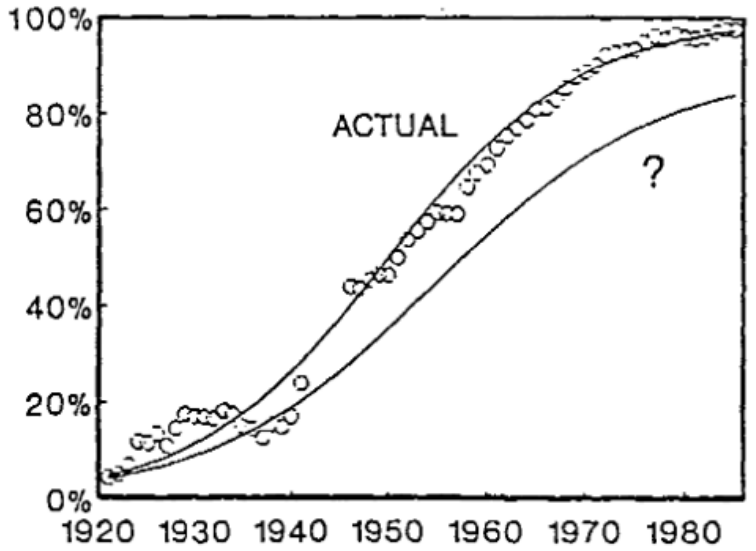
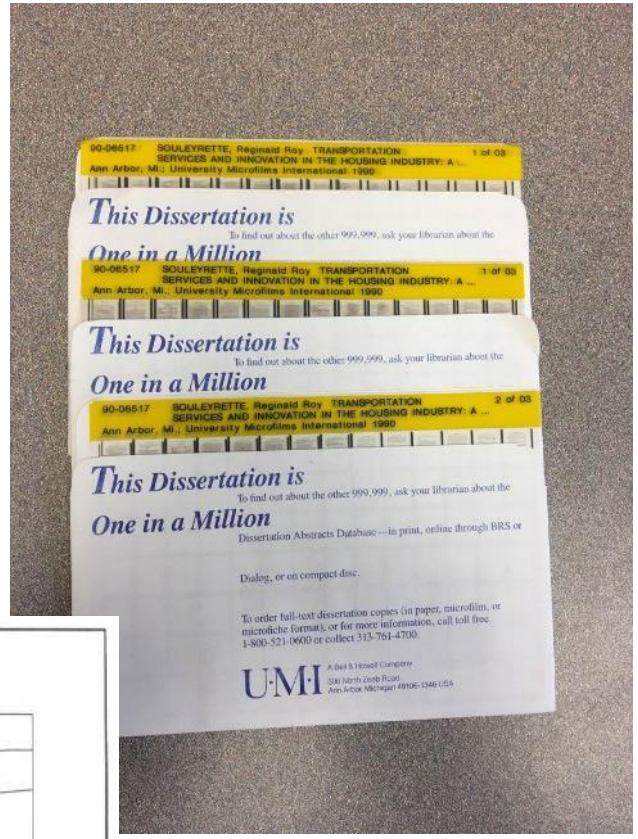
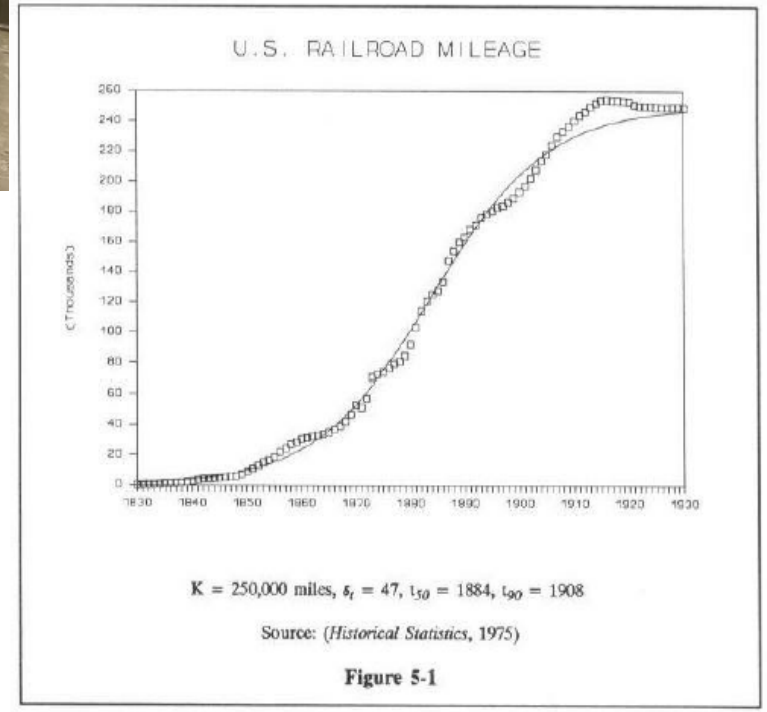


FIGURE 9 Wallboard market penetration.

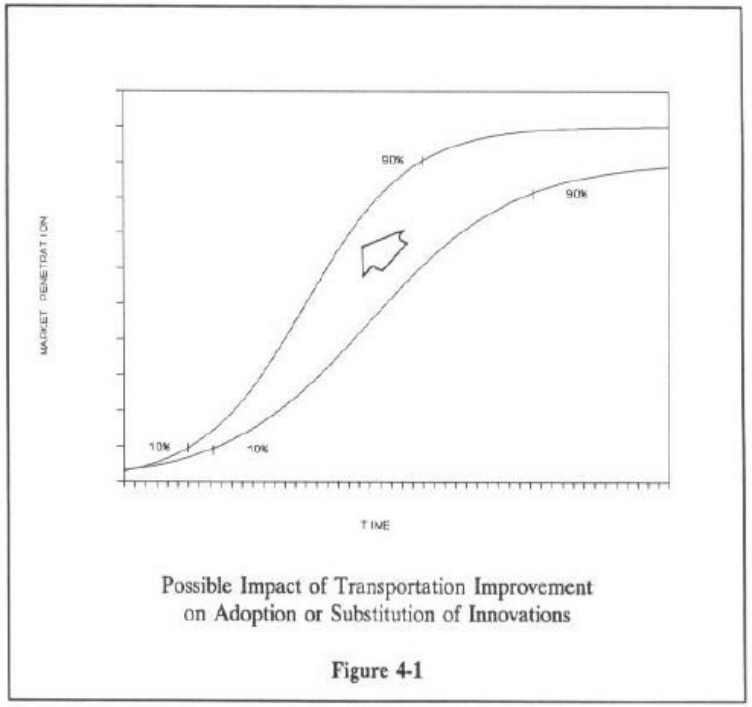




K = 250,000 miles, δ_t = 47, t_{50} = 1884, t_{90} = 1908

Source: (*Historical Statistics*, 1975)

Figure 5-1

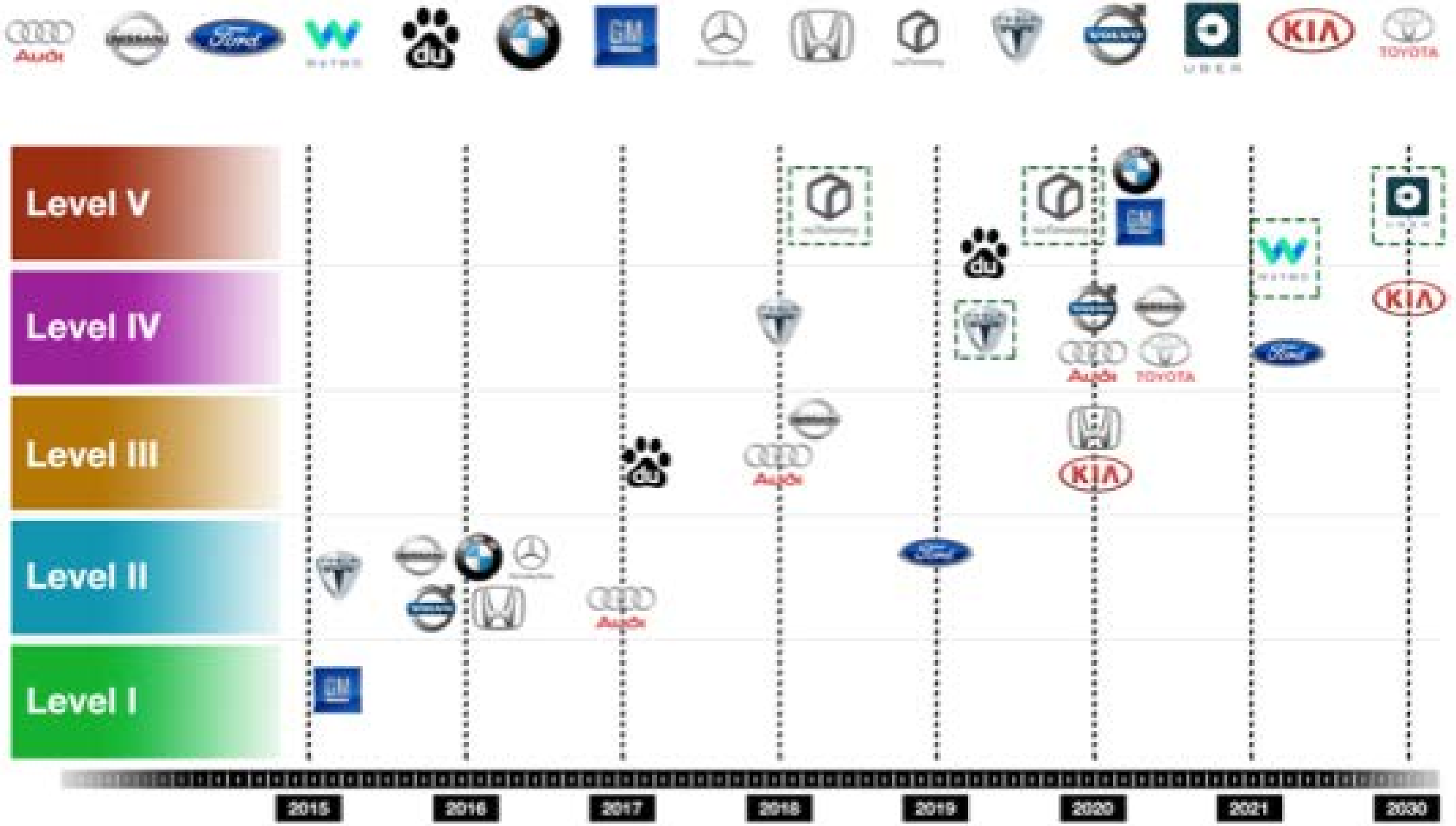


Possible Impact of Transportation Improvement on Adoption or Substitution of Innovations

Figure 4-1

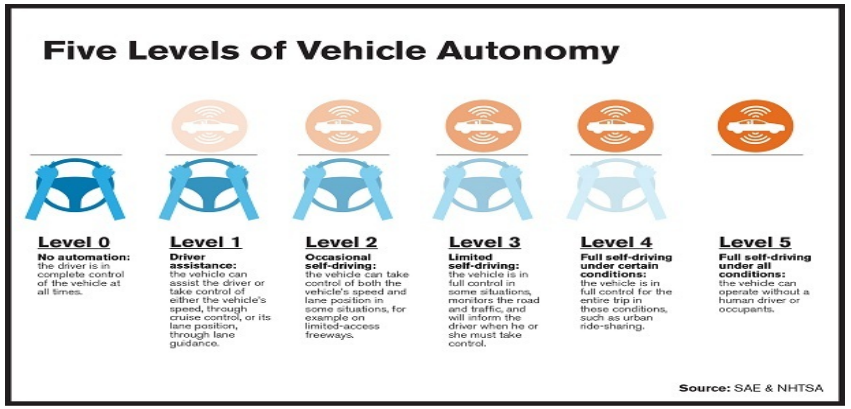
Opportunity

So, now we've got this cool, new technology



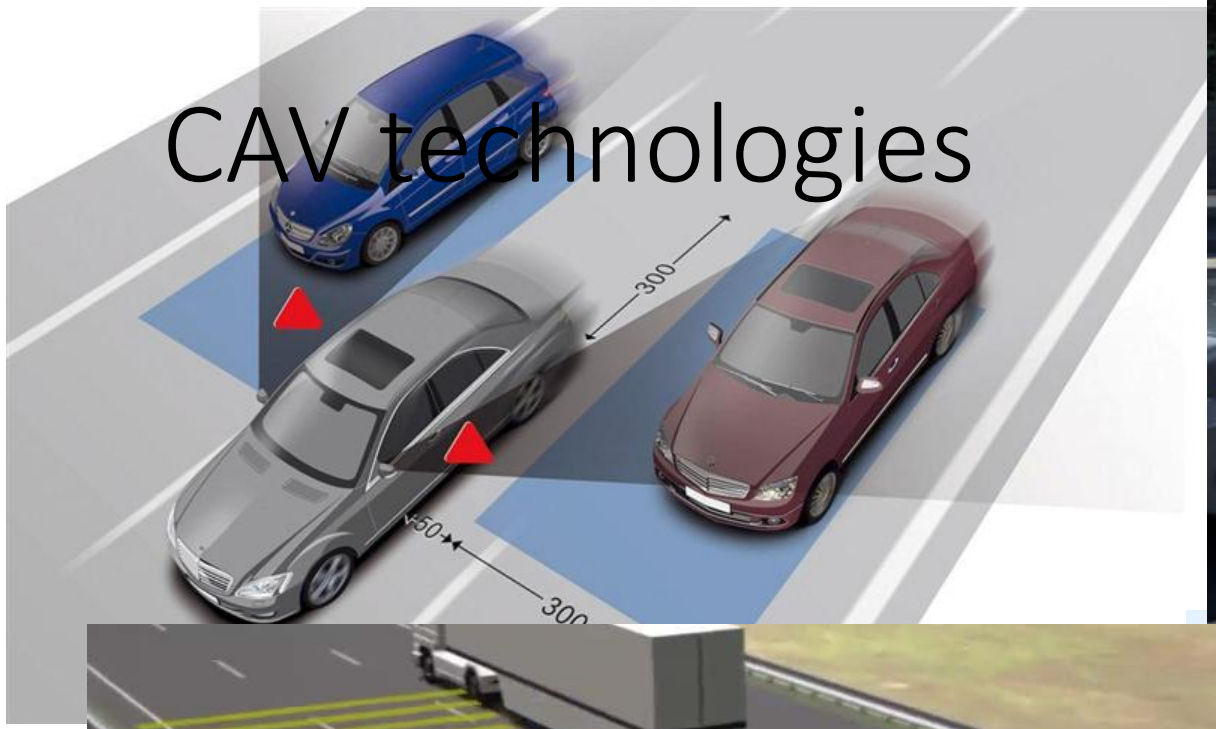
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0184952

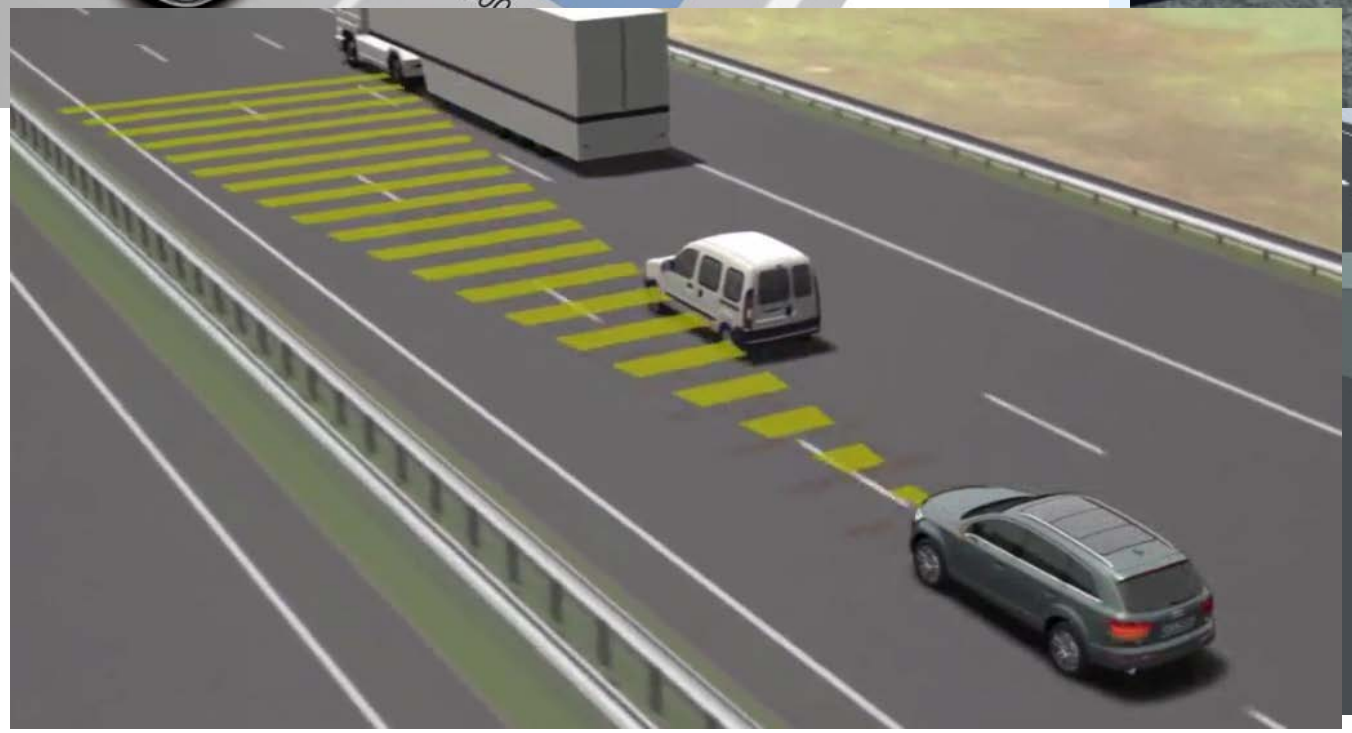
CAV technologies



- L0
  - Blind Spot Monitoring
  - Lane Departure Warning
  - Traffic Sign Recognition
  - Left-Turn Assist
  - Adaptive Headlights
- L1
  - Adaptive Cruise Control
  - Cooperative Adaptive Cruise Control
  - Automatic Emergency Braking
  - Lane Keeping (Page 10, good for striping)
  - Electronic Stability Control
  - Parental Control
- L2
  - Traffic Jam Assist
  - High Speed Automation
  - Automated Assistance in Roadwork and Congestion
- L3
  - On-Highway Platooning
  - Automated Operation for Military Applications
- L4
  - Google's Driverless Car (Not tested in bad weather)
  - Kill Switch
- L5
  - Fully Autonomous

CAV technologies





Safety the problem, CAVs the solution?

- They say 94% of crashes are due to human error
- but …can CAVs address all human factors?

“The human error components of walking, biking, motorcycle use will not be completely mitigated even with perfect automated vehicles. Also there is a residual category of tree falls on car, sinkhole, washed away in flood, suicide by auto, that won't be mitigated by smart cars” – S. Polzin, personal correspondence

Safety the problem, AVs the solution?

- Initially, mixing in AVs may make things worse (for some crash types)
  - Money spent on AVs could be spent on less-expensive “safer” cars
  - Money spent on making the infrastructure work with AVs and CAV-tech enabled cars could be spent making roads safer for non-CAVs*
  - Interactions between AVs and non-CAVs may be more dangerous than a driver-operated system
  - Effectiveness requires proper use, can be a distraction, users compensate for risk
- In the long run even, some things might be “worse” …

* some improvements may help both types of cars

FROM SLATE, NEW AMERICA, AND ASU

Self-Driving Cars Will Make Organ Shortages Even Worse

We need to prepare for that now.

By Ian Adams and Anne Hobson

A pilot model Uber self-driving car on display on Sept. 13 in Pittsburgh.

Bill green lighting semi-autonomous rigs advances

16% of all organ donations come from motor vehicle accidents

- U.S. Department of Health & Human Services.

AV safety performance, so far

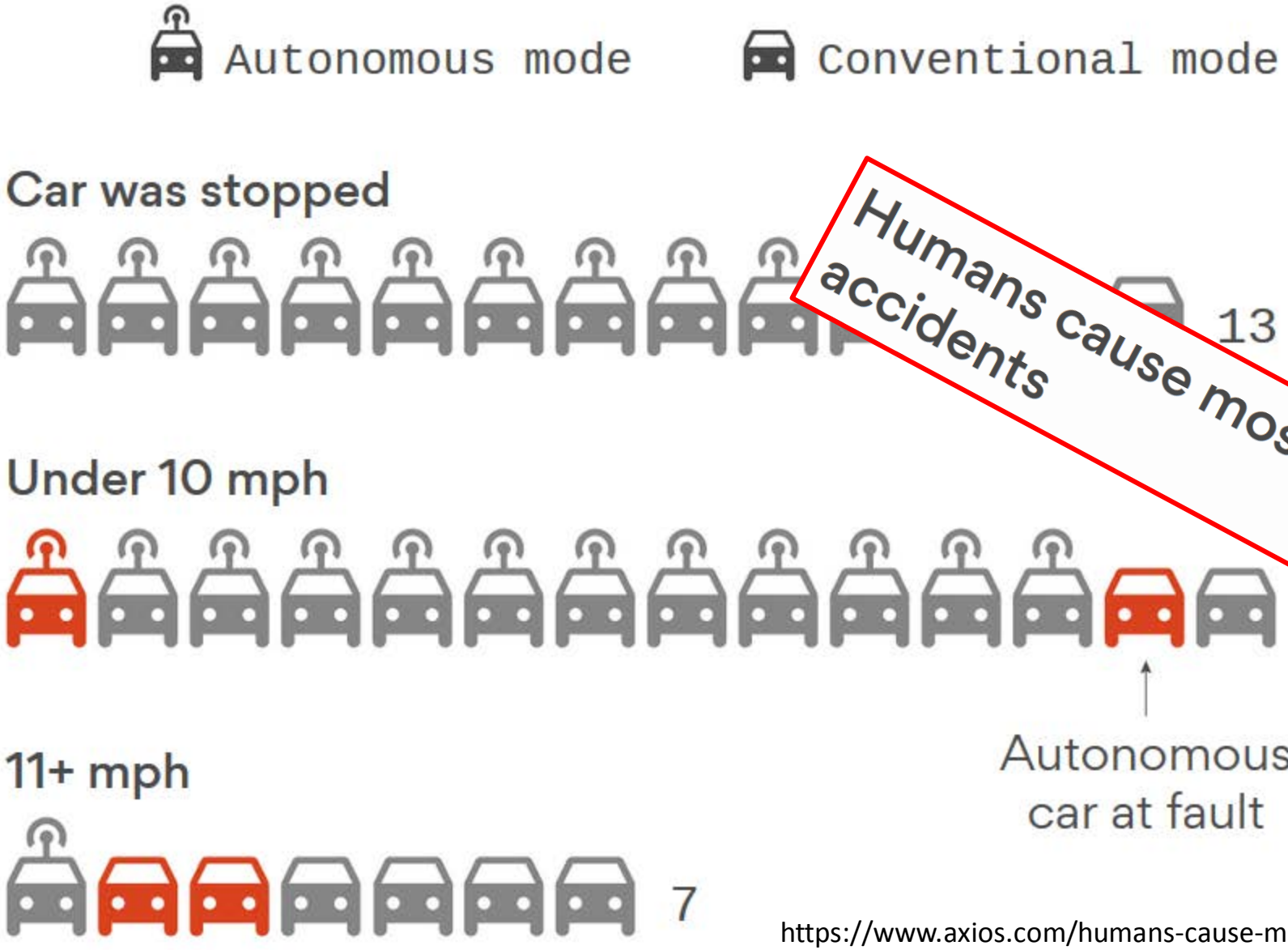
Interactions with non-CAVs

- 22 of 26 reported AV accidents, AV not at fault (CA crash study)
  - Of the remaining four, two were in manual mode
  - The other two were at speeds <10 mph

Type of Vehicle	Total Number of Vehicles	Percentage of Fleet	Percentage of Total Reported Accidents	Total Miles Travelled	Accident Frequency	Miles per Accident
Google Prototype	37	61.7%	46%	403,226	2.4e-5	40,322
Retrofitted Lexus	23	38.3%	54%	649,841	1.8e-5	54,153

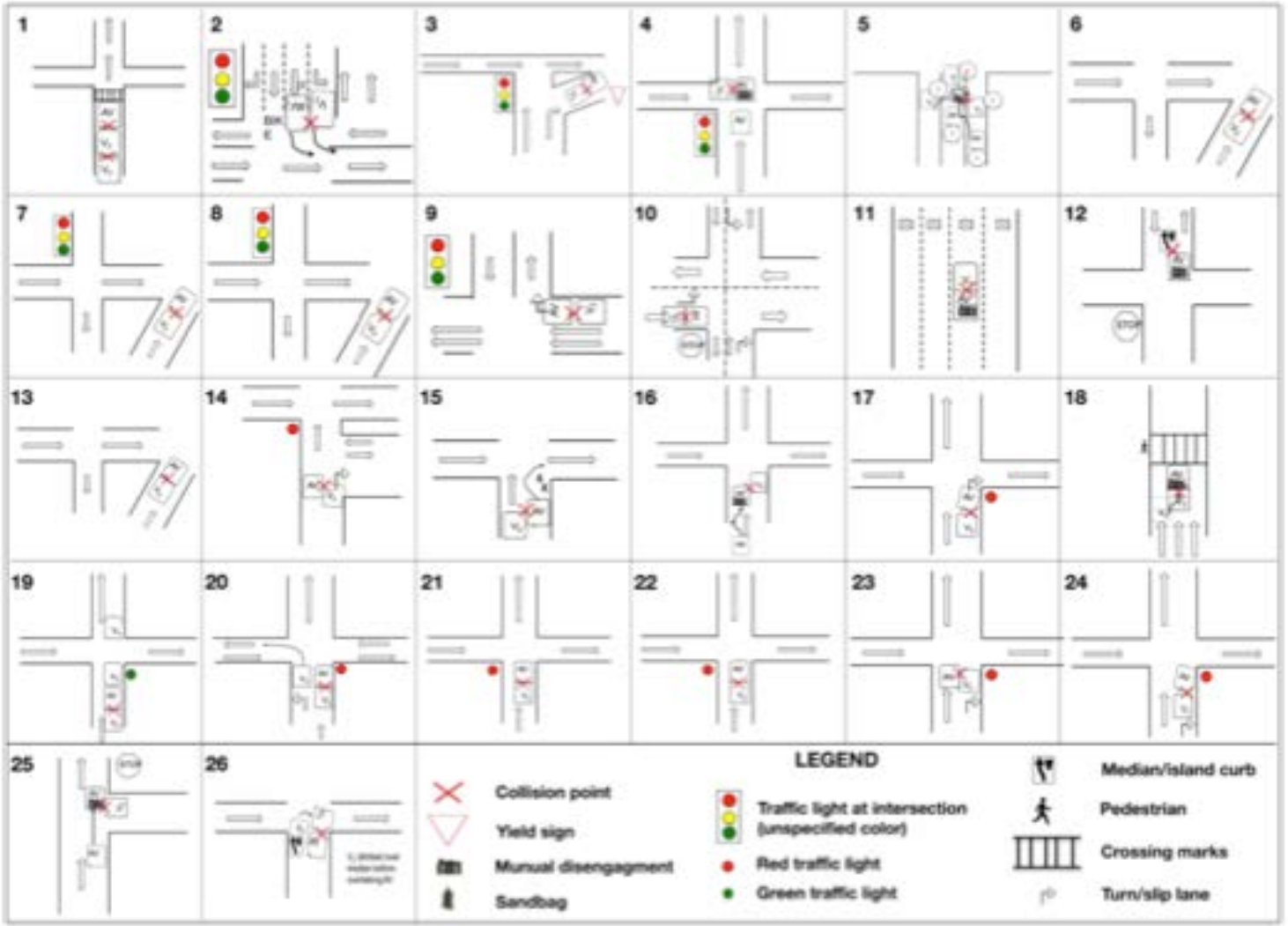
https://doi.org/10.1371/journal.pone.0184952.t002

Autonomous car traffic accidents in California by speed, 2014-2017



https://www.axios.com/humans-cause-most-self-driving-car-accidents-1513304490-02cdaf3d-551f-46e6-ad98-637e6ef2c0b9.html

CAV Crash Modalities … useful to our work

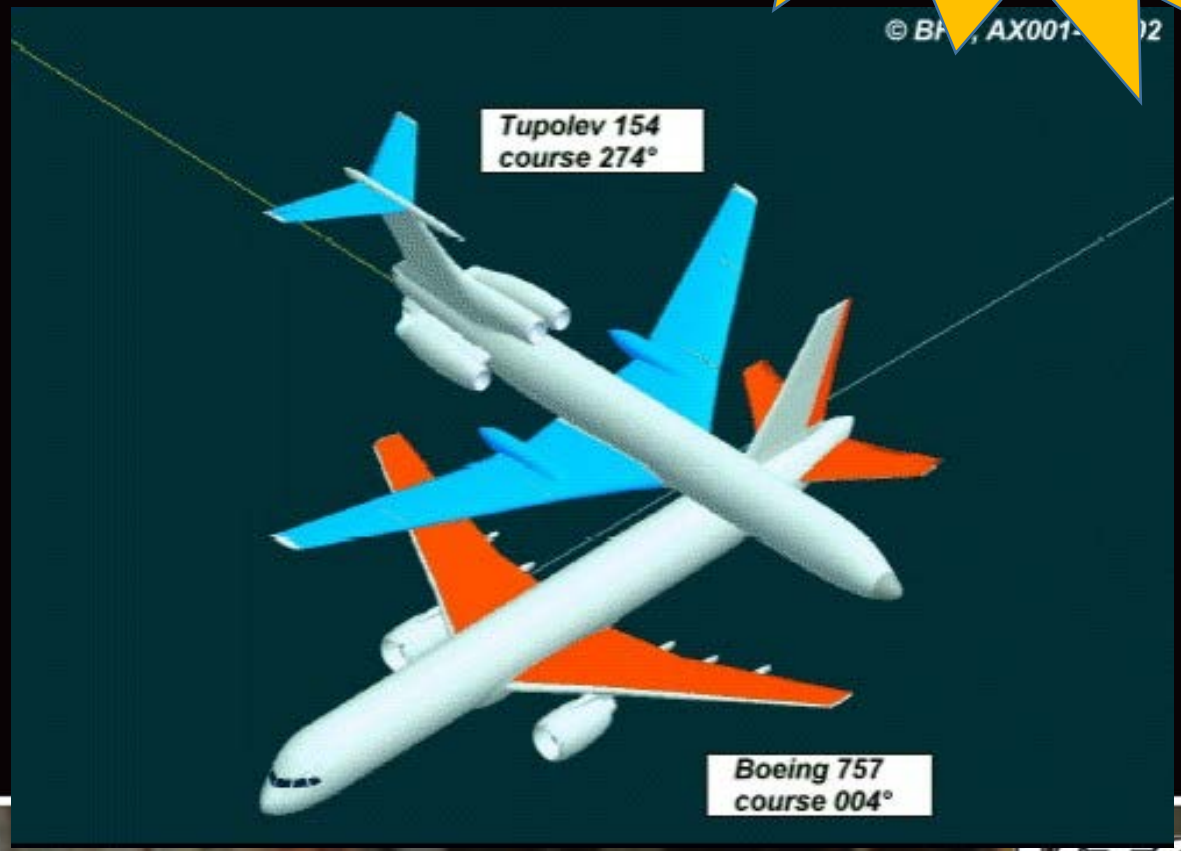


http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0184952

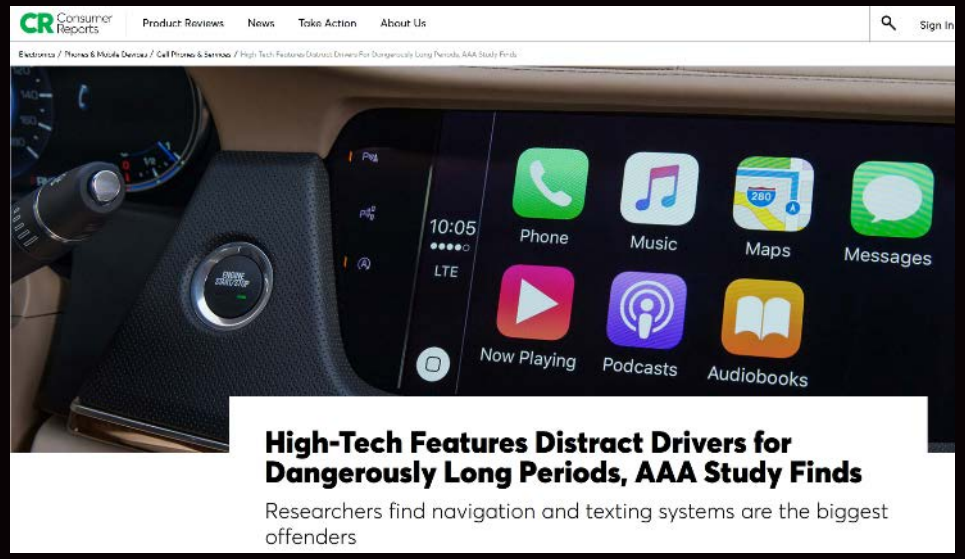
Underlying trends/components

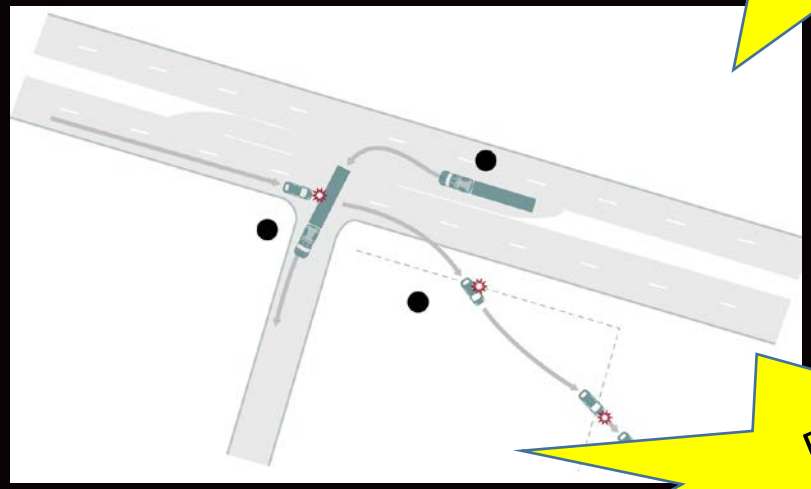
2002 Überlingen mid-air collision

Interactions with non-CAVs



Tesla fatality





Distractions

Proper Utilization

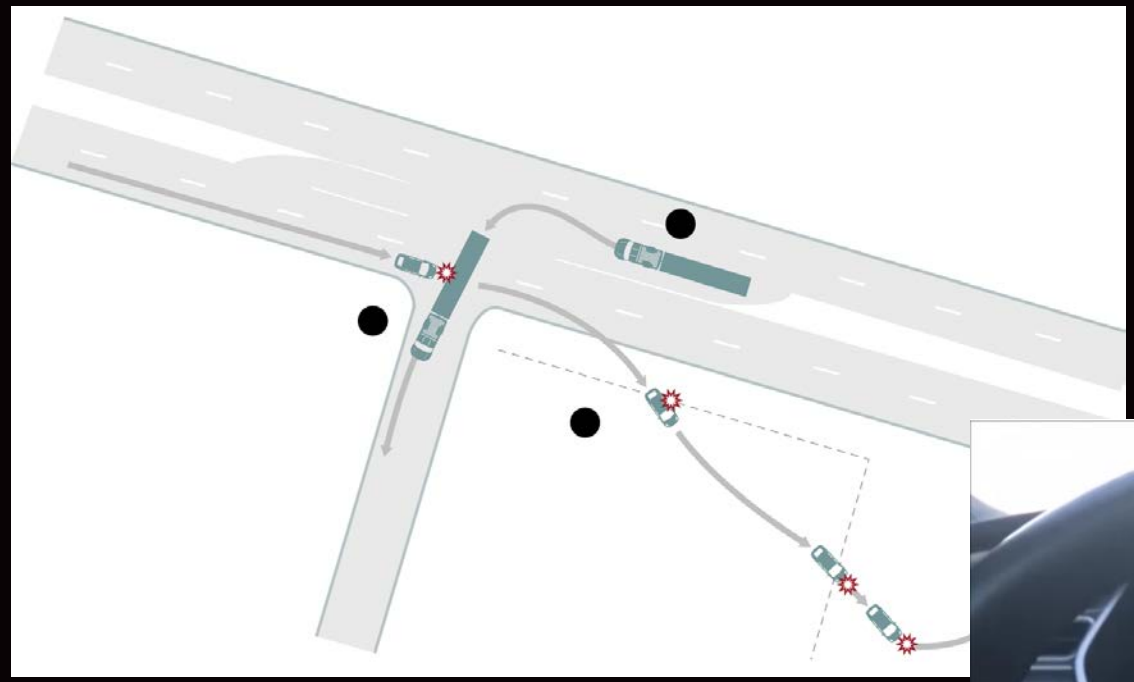
Why Car Safety Features Can Be Dangerous

Joann Muller, FORBES STAFF
I write about industrial innovation and the global auto indus

Car safety is on the minds of just about everyone th
proposing new vehicle-safety legislation that would
recorders and backup-brake technology.

If too many warning signals are triggered at once, drivers could become confused about how to respond, he says. Or they might ignore the warnings altogether, instead relying on the car to take evasive action.

"Technology is a two-edged sword," acknowledges Preuss. "It could be the thing that kills you, or the thing that absolutely saves you."



Risk compensation

Predicting Safety

Conventional Safety Data Analytics

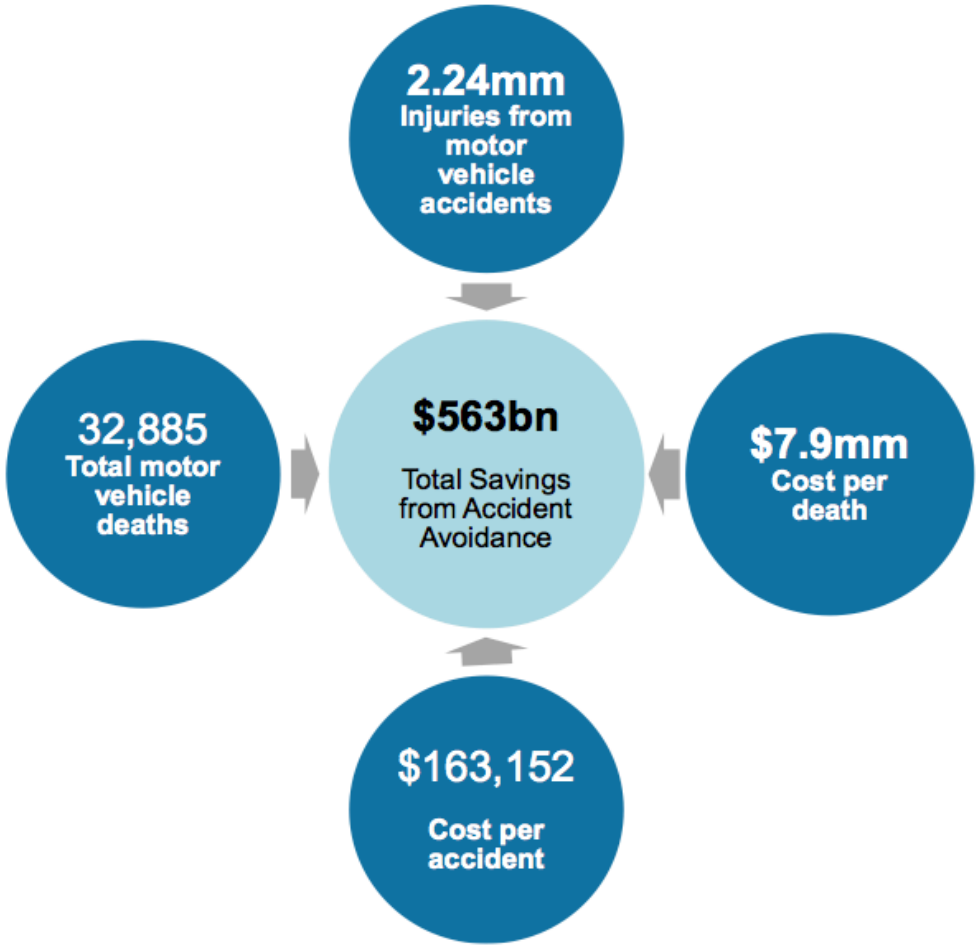
- State of the art is Highway Safety Manual
- Finally getting folks to accept Empirical Bayes (not everyone)
- Some researchers pointing out limitations (exposure, temporal effects)
- All assume static technology* – not even time series…

Sort of like estimating vehicle safety using past performance of the horse?

* Also a problem for design standards, e.g., Green Book

Cost of Motor Vehicles-related Fatal and Non-fatal Injuries

US data



How do we know?

Source: US Department of Transportation, National Highway Traffic Safety Administration,

Bull-Base-Bear Cases for Potential Savings in the US

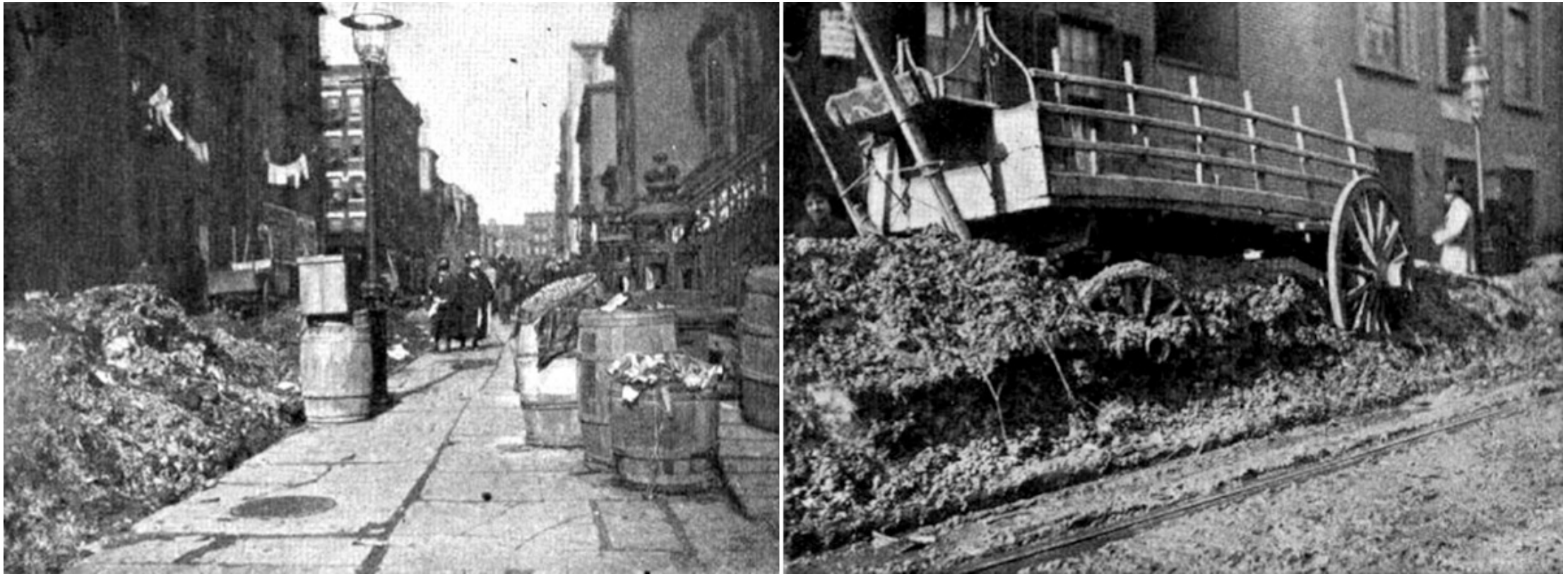
	Bull Case	Base Case	Bear Case
Autonomous Cars Total Savings	$2.2tn	$1.3tn	$0.7tn

Let’s look back … Issues in 1900:

AN UP-TO-DATE VEHICLE MADE BY FISCHER EQUIPMENT COMPANY.

You can tell that cars and electric trolleys are winning in 1911 by the near-absence of mounds of horse poop on the streets. 15 years before this film was shot, 2.5 million pounds of horse manure (and 60k gallons of horse urine) were left on the streets of NYC every day, and it was very evident:

It’s real hard to think beyond something like this ..



http://www.hhhistory.com/2017/08/the-great-manure-crisis-of-1894.html

FUTURE TENSE | THE CITIZEN'S GUIDE TO THE FUTURE. | JUNE 12 2012 6:30 AM

FROM SLATE, NEW AMERICA, AND ASU

I Think, Therefore I Yam

When farmland is scarce, will we all eat roots and tubers?

By Will Oremus

Sacrilege

Horses are most commonly infected with bovine **TB**, which may still carry a zoonotic risk; this means it may be passed to **humans**. ... Strains of this disease **can** affect mammals of all species, including **humans**, **horse**, cattle, cats, and dogs.

Tuberculosis in Horses - Symptoms, Causes, Diagnosis, Treatment ...
https://wagwalking.com/horse/condition/tuberculosis

A mean horse and a gentle car…


SCIENTIFIC AMERICAN

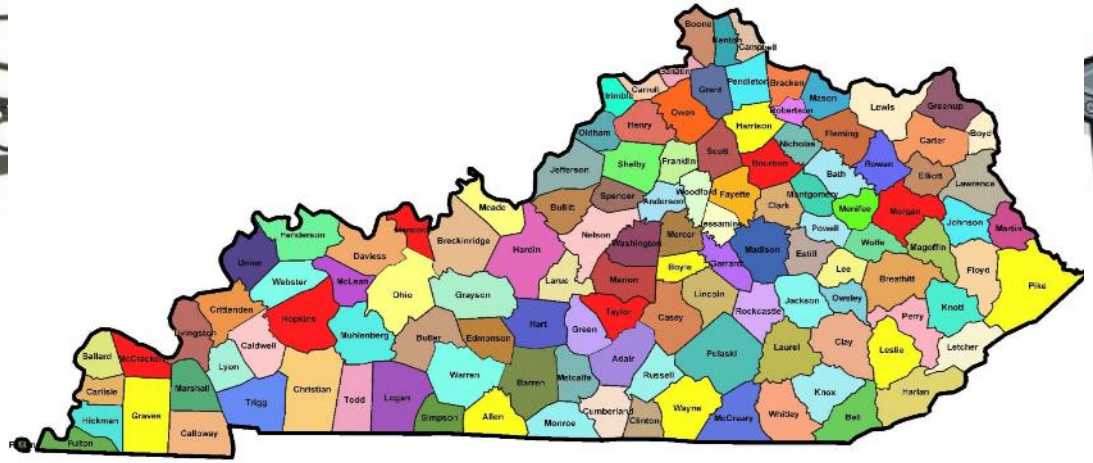
[Entered at the Post Office of New York, N. Y., as Second Class Matter. Copyright, 1899, by Munn & Co.]

A WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES.

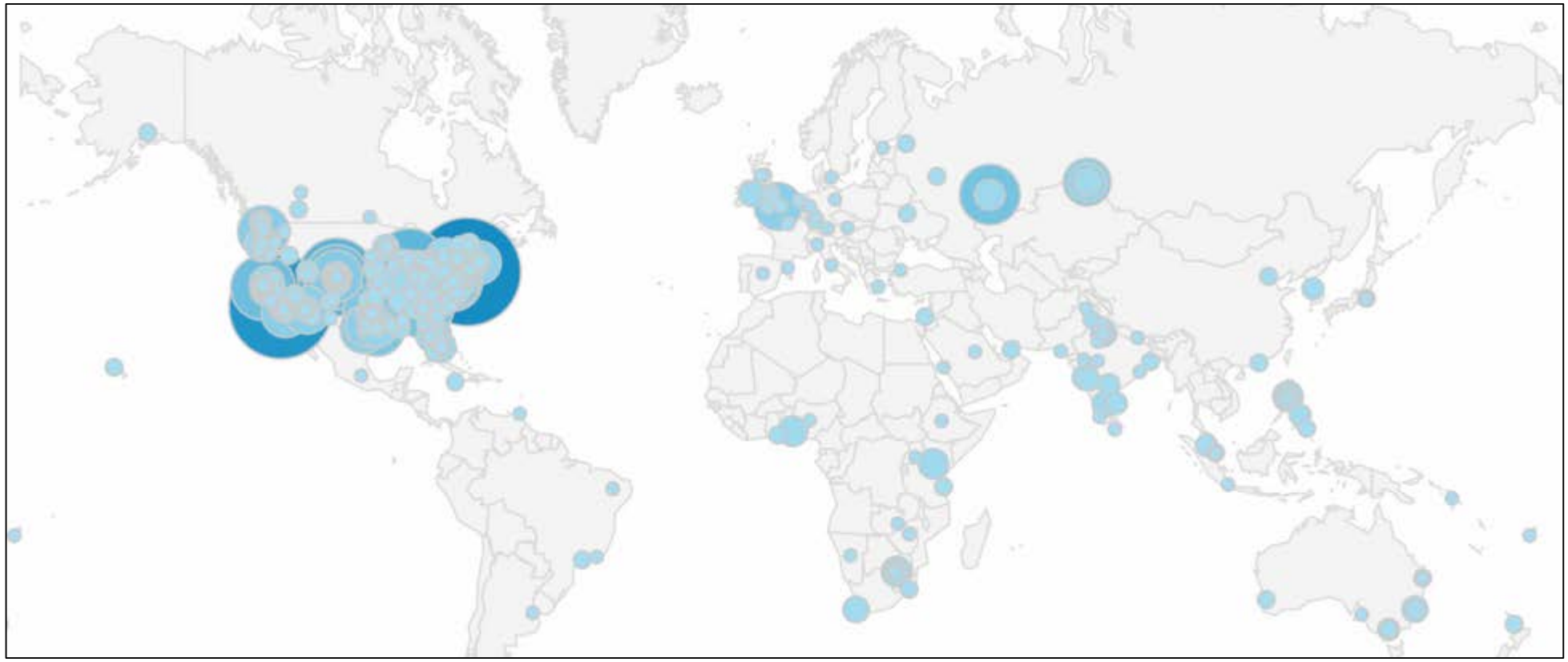
Vol. LXXX.—No. 19. [ESTABLISHED 184[illegible]] NEW YORK, MAY 13, 1899. [$3.00 A YEAR. WEEKLY.

"If there are faults with cars, only time is wanted to make them disappear … there is no mechanism more inoffensive, no means of transportation more sure and safe" -- Scientific American, 1900

What really happened?



What really happened?



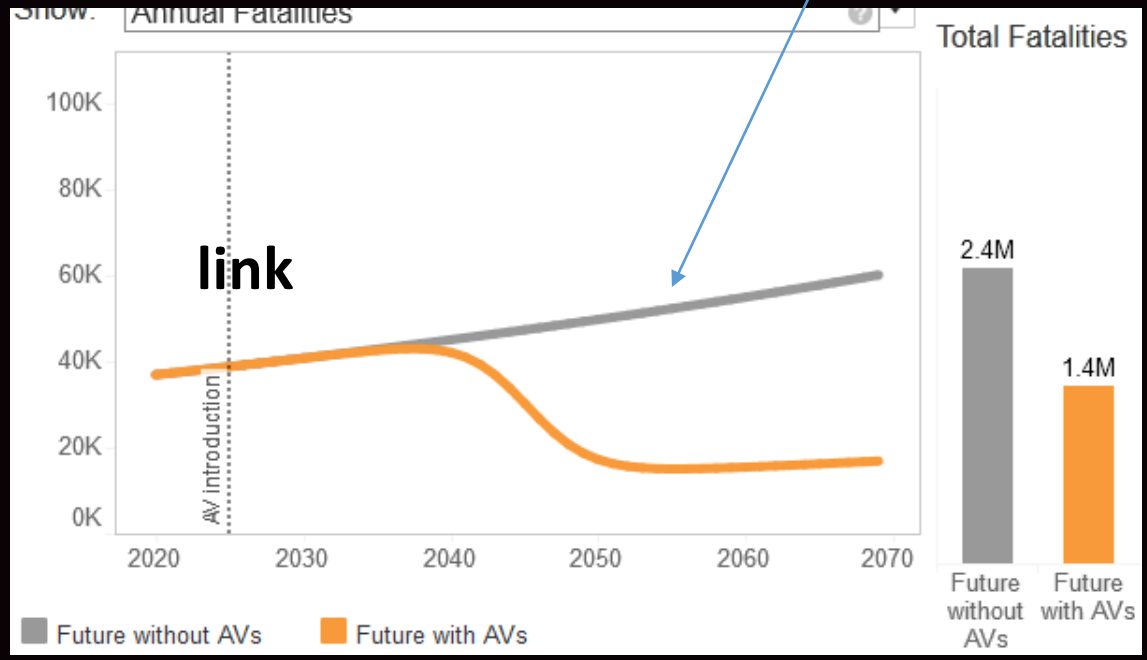
What really happened?

Predicting Safety for CAVs

Back to The Rand Study

Really?*

Autonomous Vehicle Safety Scenario Explorer



https://www.rand.org/pubs/tools/TL279/tool.html

*even with no full AV, the safety curve would probably bend down (blind spot warnings, stability control, automatic braking, etc.)

How bout some more dials?

What will cause crash reduction/increase, how, when and how much?

- Technology A reduces crash type 3 by x%
- Works best on facility type y (representing how many crashes?)
- Market penetration … How much of this technology do we have:
  - Now?
  - In 5 years?
  - Ultimately?

Distractions

Risk compensation

Proper Utilization

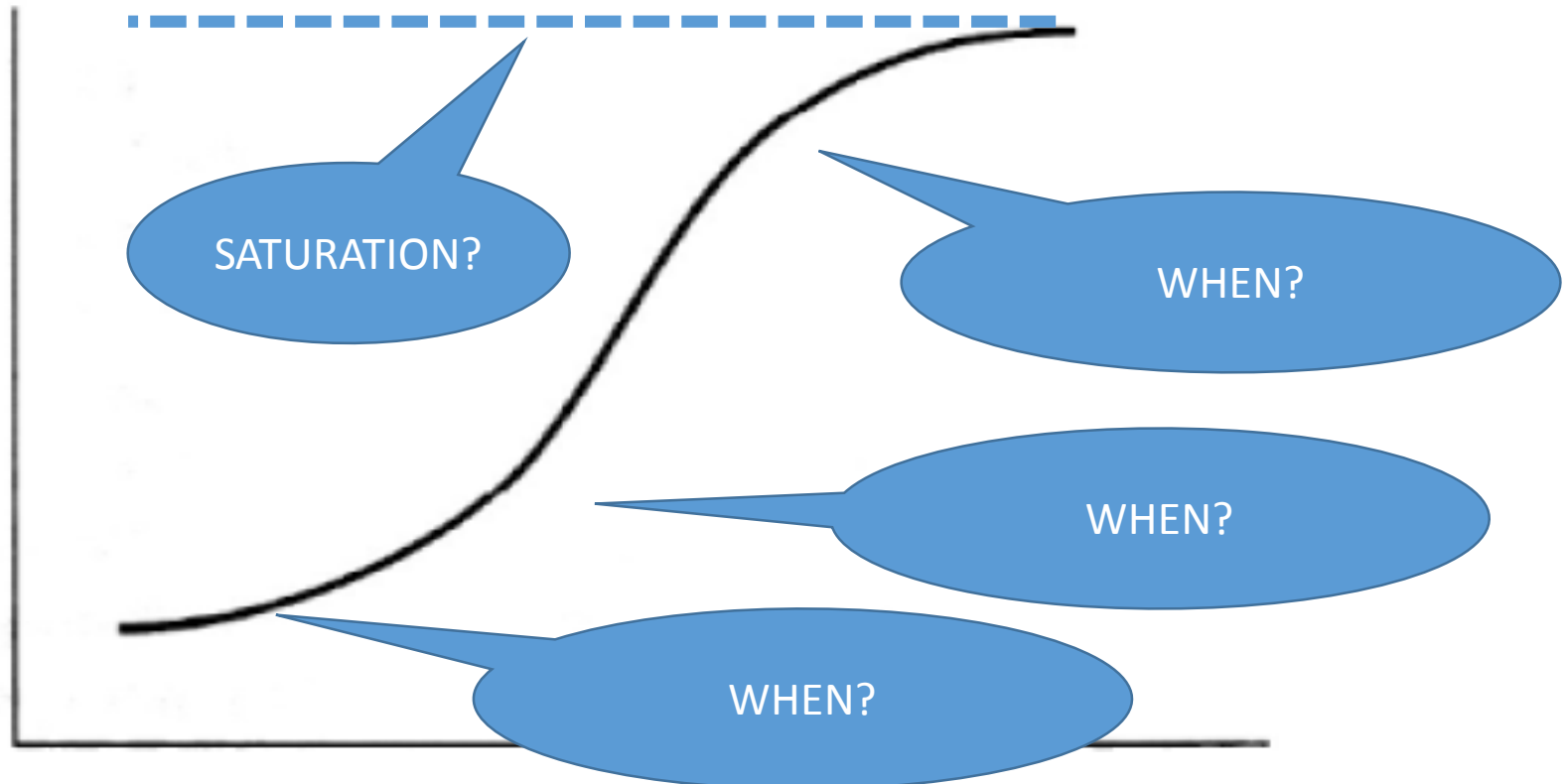
$$F=F_0 \times G_{VMT} \times (1-MP_{AV}) \times (1-CRF_{AV}) \times MP_{CAV\ tech} \times (1-CRF_{CAV1}) \times (1-CRF_{CAV2}) \times \ldots$$

Warning! Do not use this equation for anything

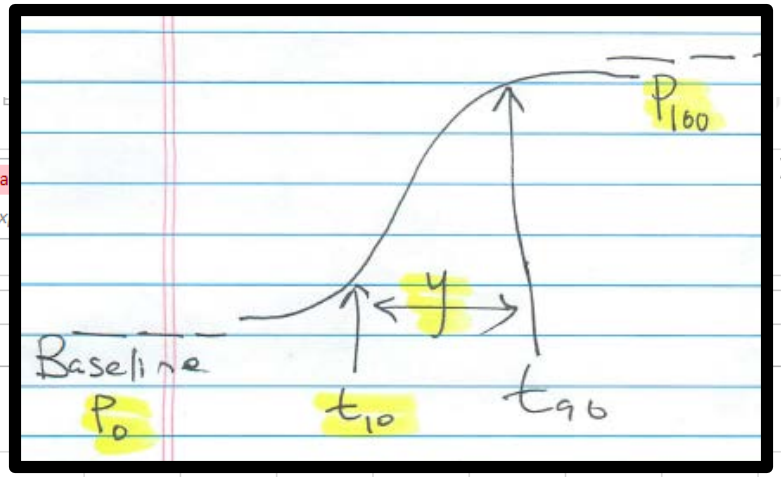
- Market Penetration = f (cost, regulation, …)
- Effectiveness = f(technology, road system, crash type, less fatigue, …)
- Proper Use = f(behavioral, quality, effectiveness, ease…)
- Risk Compensation = f(behavioral, other)
- Distraction = f(behavioral, familiarity, user interface quality/maturity, …)

- Subject to some limits, interactions, …

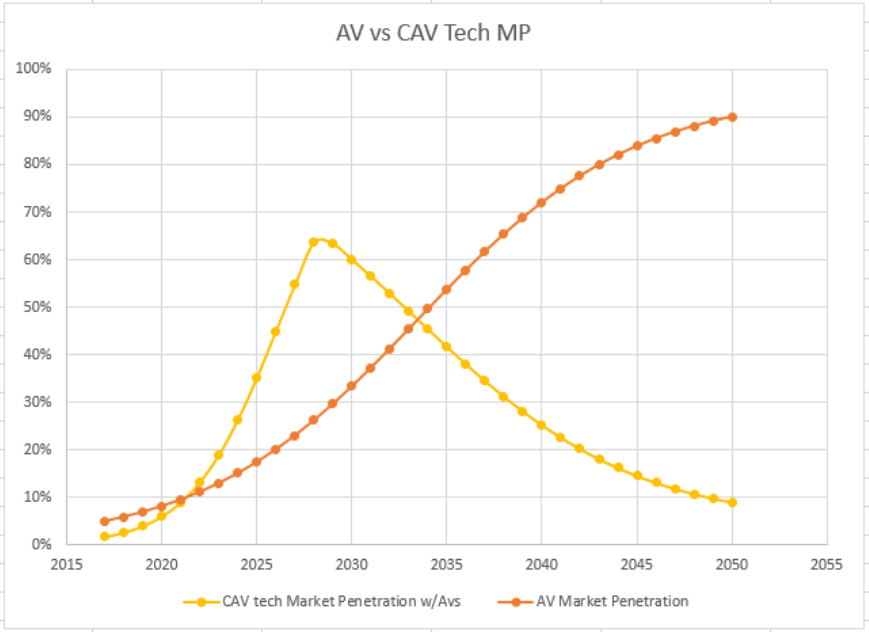
S curves can represent
- Market Penetration
- Effectiveness
- Various monotonic changes over time

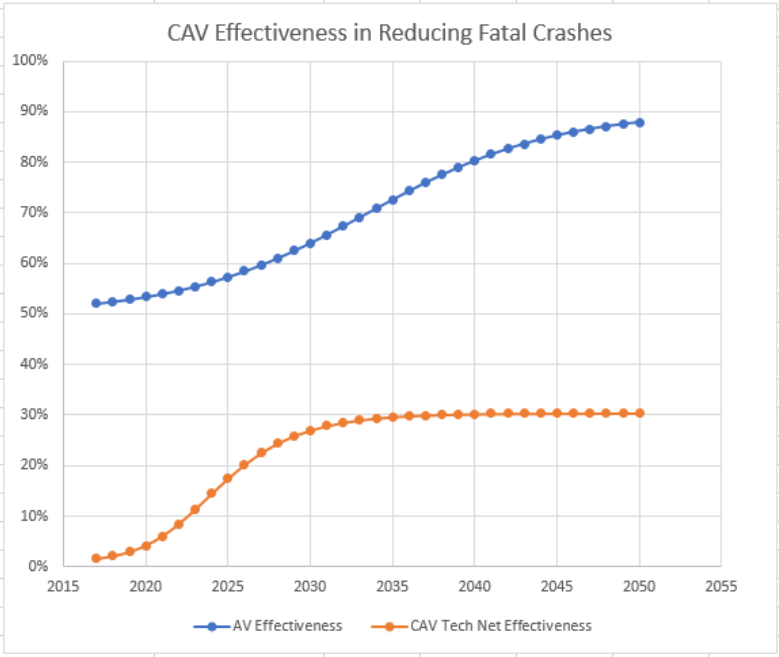


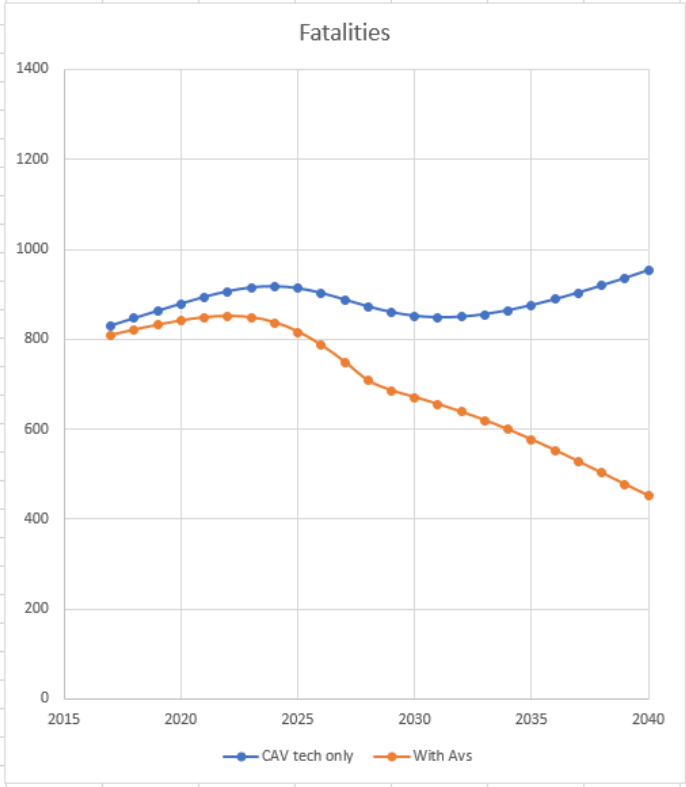
More Dials



	A	B	C	D	E	F	G	H
1		AV Market Penetration	AV Effectiveness	CAV tech Market Penetration w/o Avs	CAV tech Effectiveness	CAV tech Use%	Distraction Factor	Risk Compensation Factor
2	min	0%	50%	0%	10%	45%	50%	30%
3	max	95%	90%	90%	40%	95%	100%	80%
4	years until t_{10}	5	5	5	0	0	0	0
5	$y = t_{90}-t_{10}$	25	25	10	10	10	10	15
6								
7	base fatalities	814	21,749	KY Lives Saved by AVs				
8	VMT growth	2%						







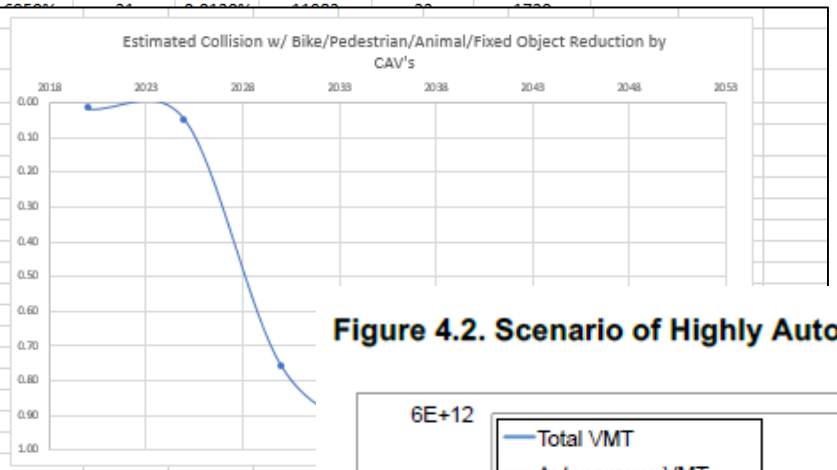
What’s next?

Learn more from others

Crash Data (2017)												
Directional analysis	Today	CAV efficacy	Total Collisions	%	w/ Injury	%	w/ Fatality	%	w/ Property Damage	Total fatalities	Total Injuries
Collision with Pedestrian/Bike/Animal/Fixed Object	15%	100%	20269	12.5880%	3720	2.3103%	204	0.1267%	16345	210	4596
Left Turn Collision		100%	4739	2.9431%	1325	0.8229%	19	0.0118%	3395	21	2274
Right Turn Collision		100%	1096	0.6807%	115	0.0714%	0	0.0000%	981	0	165
Both Vehicles Moving Straight		100%	17054	10.5914%	2861	1.7768%	26	0.0161%	14167	32	4564
Rear End Collision		100%	21845	13.5668%	3174	1.9712%	25	0.0155%	18646	32	4889
Sideswipe											
Head-on Collision											
Vehicle Backing											
Ran Off Roadway											
Vehicle Moving in Wrong Direction											
Crossover Collision w/ Median											
Overturning											
Avoidance											
Steering											
Braking											
Steering and Braking											
No avoidance											
Environmental											
Glare											
Construction Zones											
Slick Surfaces											
Shoulder Drop-offs/Slides											
Air bags											
Deployment											
Not installed											
Switch on											
Switch off											
No switch											
Driver age											
16-24											
25-40											
41-64											
65+											
Human factors											

S-curve Graphing

2020	2025	2030	2035	2040	2050	Penetration Factor
0.02	0.05	0.76	0.94	0.97	0.98	6
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	
0.11	0.18	0.18	0.74	0.89	0.93	5
0.00	0.00	0.00	0.00	0.00	0.00	
0.05	0.11	0.40	0.96	0.97	0.98	6
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	



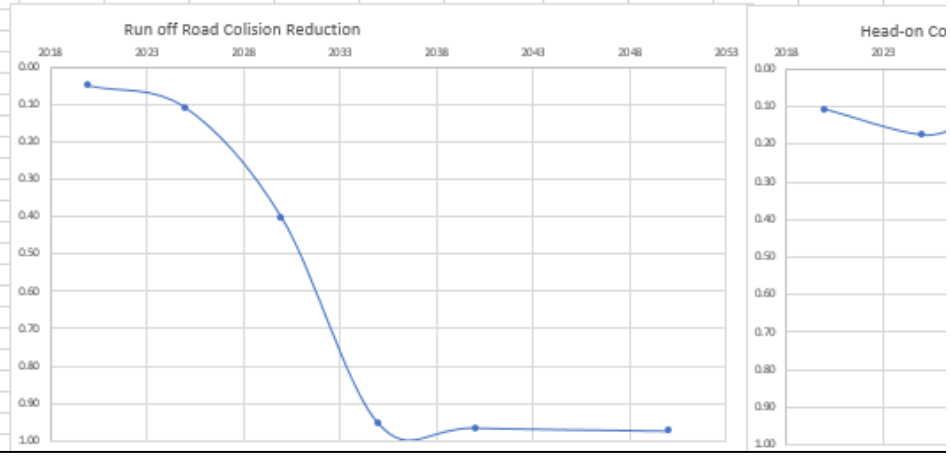
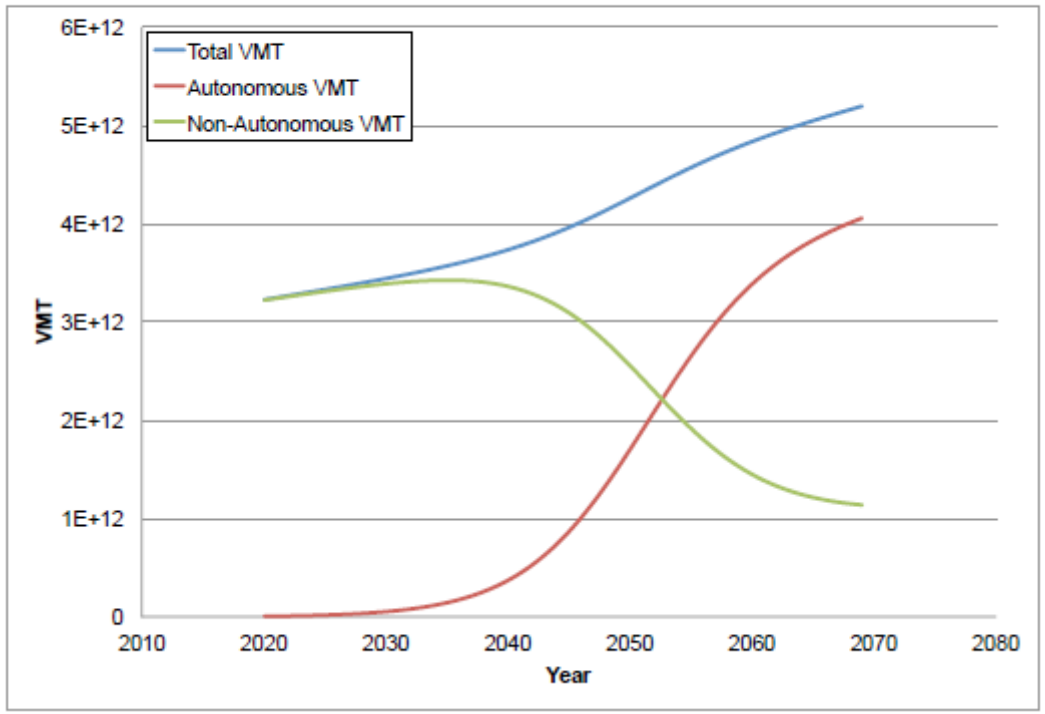


Figure 4.2. Scenario of Highly Automated and Non–Highly Automated VMT



Analyze *these* technologies:

- L0
  - Blind Spot Monitoring
  - Lane Departure Warning
  - Traffic Sign Recognition
  - Left-Turn Assist
  - Adaptive Headlights
- L1
  - Adaptive Cruise Control
  - Cooperative Adaptive Cruise Control
  - Automatic Emergency Braking
  - Lane Keeping (Page 10, good for striping)
  - Electronic Stability Control
  - Parental Control
- L2
  - Traffic Jam Assist
  - High Speed Automation
  - Automated Assistance in Roadwork and Congestion
- L3
  - On-Highway Platooning
  - Automated Operation for Military Applications
- L4
  - Google's Driverless Car (Not tested in bad weather)
  - Kill Switch
- L5
  - Fully Autonomous

And *these* crash types:

- Directional Analysis
  - Collision w/ peds/bikes/fixed objects
  - LT Collision
  - RT collision
  - Rear End
  - Sideswipe
  - Head-on
  - Crossover Collision w/ median
  - Ran-off roadway
  - Overturning
  - Wrong Direction
- Driver Distraction
  - Cell-phone
  - Other – inside Vehicle
  - Outside Vehicle
- Environmental
  - Glare
  - Construction Zones
  - Slick Surfaces
  - Drop-offs & Slides

- Directional Analysis
  - Collision w/ peds/bikes/fixed objects
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  - Slick Surfaces
  - Drop-offs & Slides

2006 – 2010 Collision History

2006 – 2010 Collision History		Fatal and Serious Crashes – Thurston County Percentage	Fata Cr P
Overall Numbers	Total number of collisions	3	
By Collision Type	Hit fixed object	48	
By Collision Type	Overturn	10	
By Collision Type	Angle (left turn)	9	
By Collision Type	Head on	7	
By Light Condition	Daylight	52	
By Light Condition	Dark – no street lights	33	
By Junction Relationship	Intersection-related	19	
By Junction Relationship	Driveway-related	5	
By Junction Relationship	Non-Intersection	77	
Hit Fixed Object Crashes Only – By Fixed Object Hit	Tree/stump (stationary)	14	
Hit Fixed Object Crashes Only – By Fixed Object Hit	Roadway ditch	7	
Hit Fixed Object Crashes Only – By Fixed Object Hit	Utility pole	7	
By Roadway Curvature	Straight and level	42	
By Roadway Curvature	Horizontal curve (all)	45	
By Speed Limit (Number of Drivers)	35 mph	28	
By Speed Limit (Number of Drivers)	50 mph	69	
By Contributing Circumstance Number of Drivers)	Exceeding safe/stated speed	48	
By Contributing Circumstance Number of Drivers)	Under influence of alcohol/drugs	42	
By Contributing Circumstance Number of Drivers)	Over centerline	16	
By Contributing Circumstance Number of Drivers)	Inattention/distraction	11	
By Driver Age Group	Ages 16-20	26	
By Driver Age Group	Ages 41-50	28	
By Seat Belt/Car Seat Use (Number of Occupants)	No restraint	33	

Crash type mitigation levels (effectiveness)

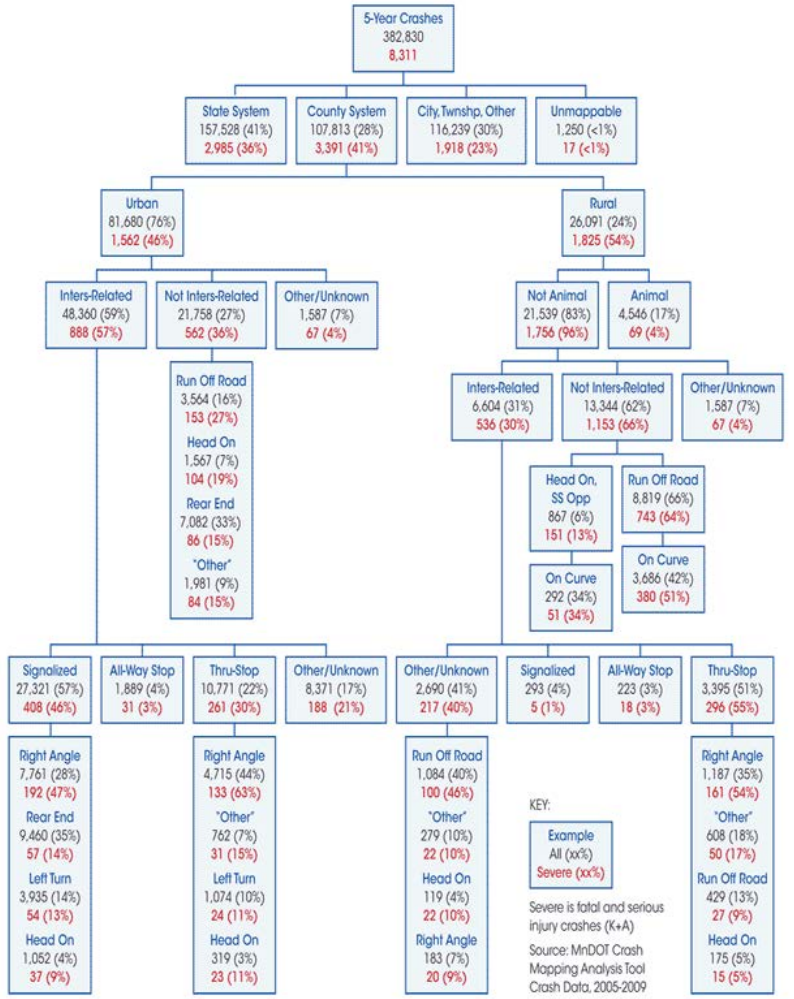
- Many crash types (e.g., ROR, speeding with parental control;) can be effectively mitigated by level 2 or 3 CAV technology
- Some crash types (e.g., Speeding) might be mitigated somewhat by level 2 or 3 (e.g., with speed limit sign recognition and reminders, IF the driver does not wish to intentionally speed)
- Others (e.g., drunk driving) can only be effectively mitigated by truly self driving cars?



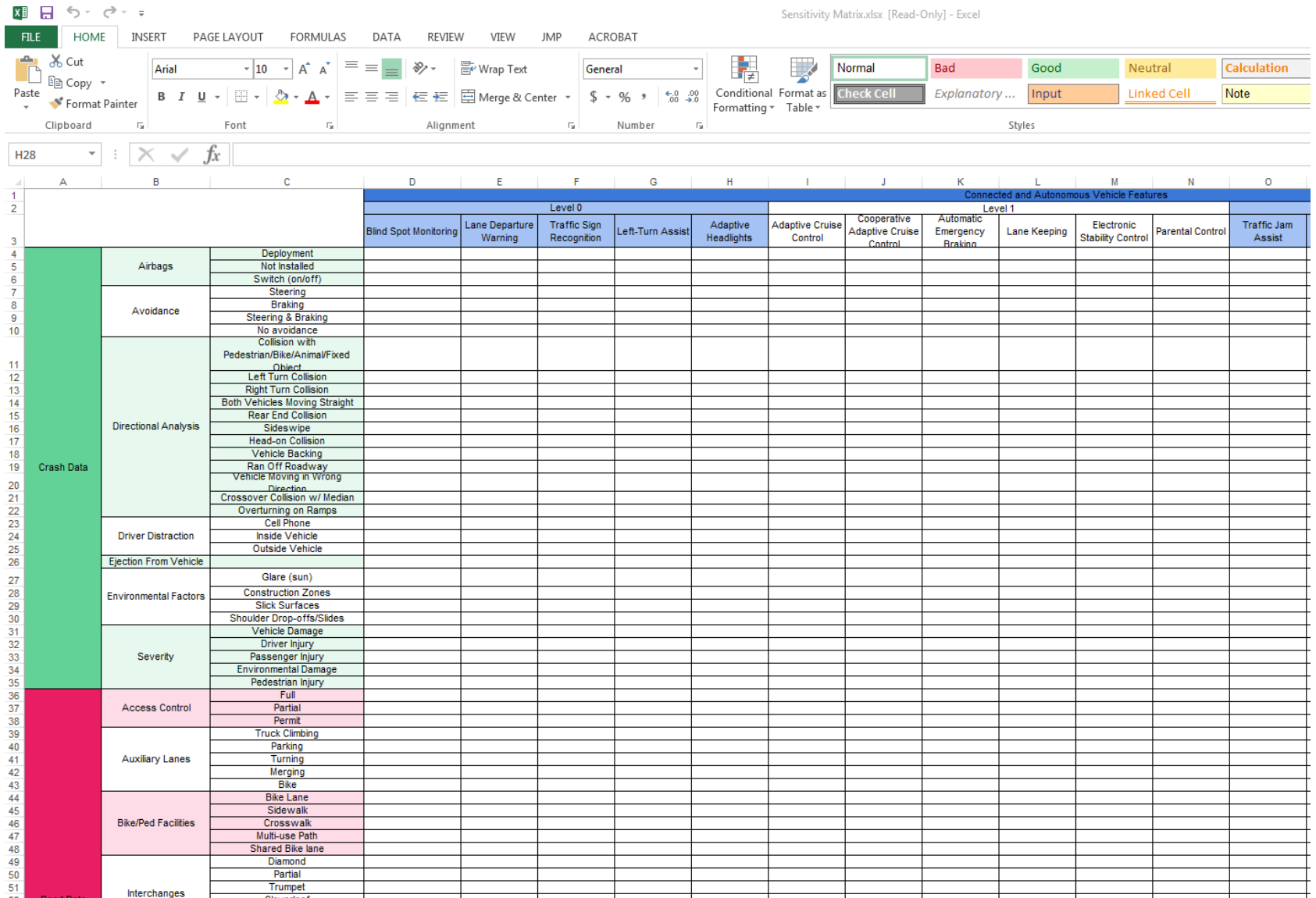
In the context of *these* facility characteristics:

- Access Control
  - Full Access
  - Partial Access
  - Permitted Access
- Auxiliary Lanes
  - Truck Climbing
  - Parking
  - Turning
  - Merging
  - Cycling
- Bike/Peds
  - Cycling lane
  - Sidewalk
  - Crosswalk
  - Multi-use path
  - Shared lanes

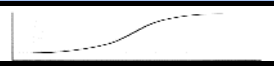
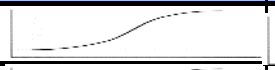
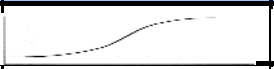
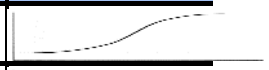
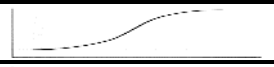
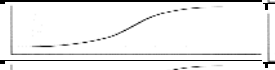
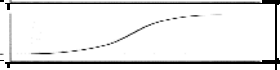
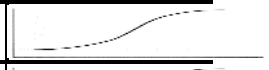
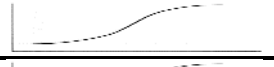
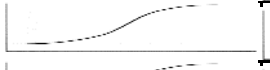
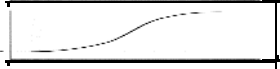
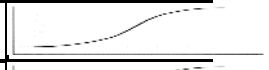
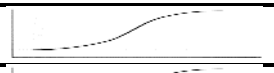
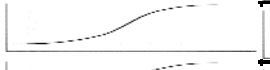
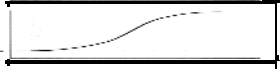
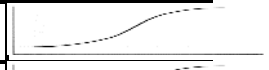
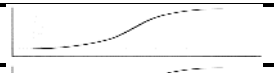
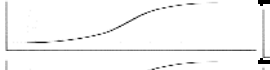
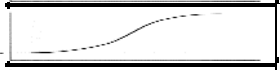
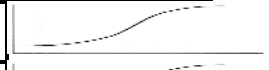
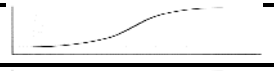
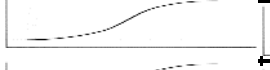
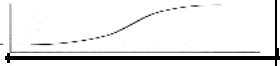
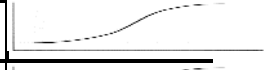
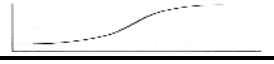
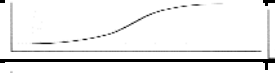
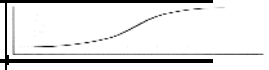
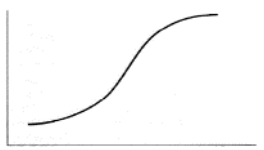
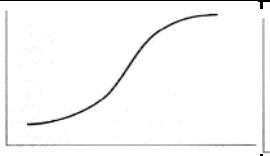
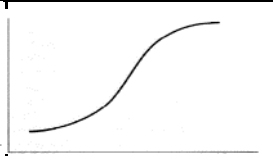
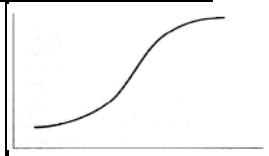
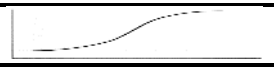
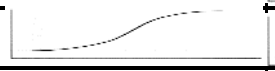
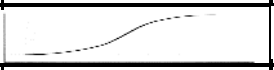
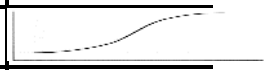
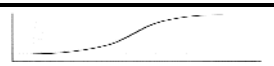
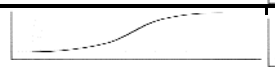
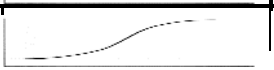
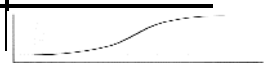
- Interchanges
  - Diamond
  - Double diamond crossover
  - Partial
  - Trumpet
  - Cloverleaf
  - Displaced LT
- Pavement
  - Unimproved/primitive
  - Graded & Drained
  - Soil/Gravel/Stone
  - Highly Flexible
  - Concrete
  - Composite
- Operation Type
  - One-way
  - Two-way



Research typology

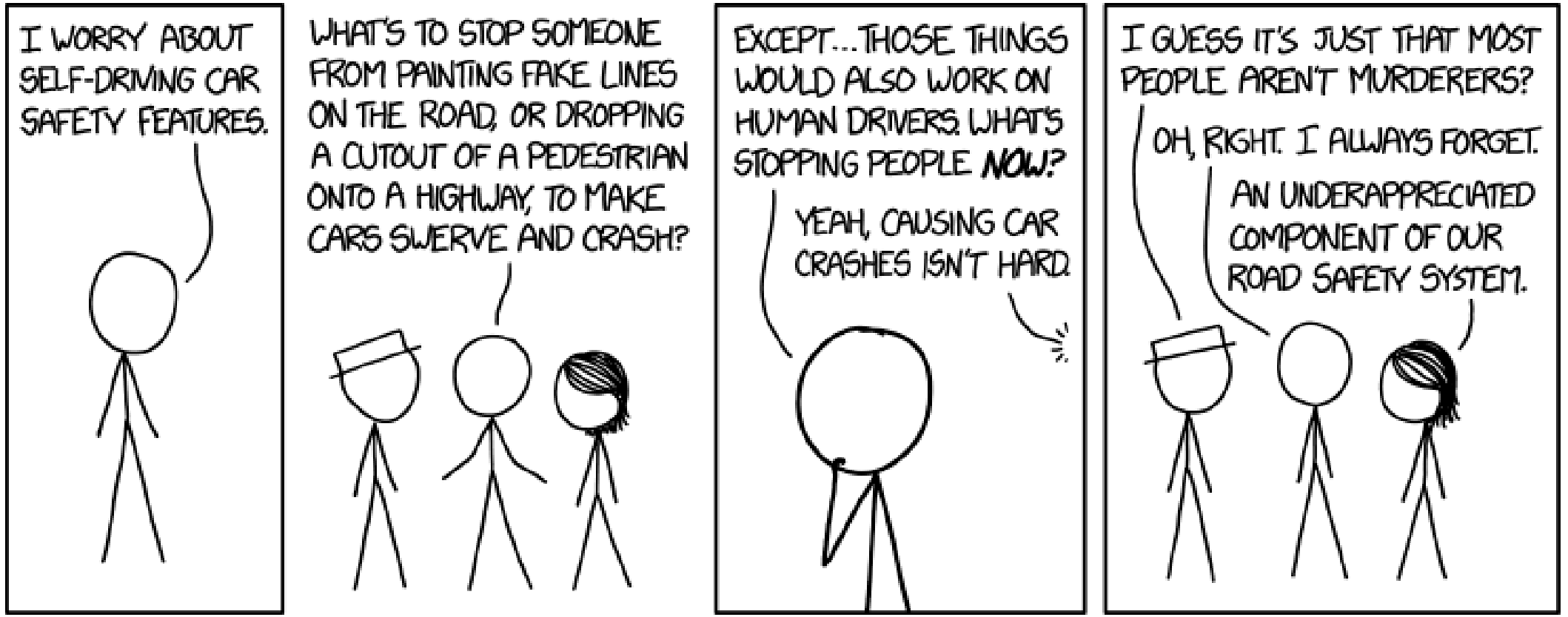


Specific component s-curves

			Level 0			
			Blind Spot Monitoring	Lane Departure Warning	Traffic Sign Recognition	Left-Turn As
	Airbags	Deployment				
		Not Installed				
		Switch (on/off)				
	Avoidance	Steering				
		Braking				
		Steering & Braking				
		No avoidance				
		Collision with Pedestrian/Bike/Animal/Fixed Object				
		Left Turn Collision				
		Right Turn Collision				

Questions/suggestions?

- Thank you, and Go Cats! ☺



https://xkcd.com/1958/