2018

RoboCar Progress Report

Preface

CityTram is primarily interested in effective public transportation – fast, cheap, reliable, safe, and environmentally sensitive. For several years now the development of autonomous vehicle technology has been anticipated by the public transit community as the coming answer to all those needs. While doubtful that is true, we are still interested. As veterans of Silicon Valley, we recognize that most of what is known by most people about this coming technology is the product of the hype machine, and is not to be trusted. So we have invested our time and energy to monitor what little hard factual data can be obtained by the public, as a way to objectively evaluate the status of the technology. Each year we publish these findings.

In 2018 AV testing was legal in 40 states, either by legislation or executive order. A number of companies are developing autonomous vehicles. On road testing of those vehicles was actually occurring in at least 6 states: Arizona, California, Florida, Nevada, Pennsylvania, and Texas. Some companies test only in California. Some test only in other states. Some test both in California and in other states. This document reports ONLY on the status of companies that tested in California, and it ONLY reports about the testing done in that state, because California is the ONLY state that has enacted responsible test reporting requirements. These requirements make objective test data available to the public at this link (https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing).

62 such companies held test permits in California as of January 2019. Not all of them are actually testing. Some are testing advanced ADAS (automation level 2) capabilities. Some are testing on private tracks, parking lots, or other such facilities. This document reports only on those actively testing, on public roads, at automation level 3 or higher. We only report on companies who reported 1000 miles or more of testing in the reported year.

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Basic Lingo Explained

If you are new to the technology, and its vocabulary, this should help.

Disengagement:

Imagine you are teaching your teen aged child to drive. Your child has passed the first tests, and has a learner's permit permitting him/her to drive, during the day, as long as accompanied and monitored by an adult fully licensed driver. So you climb into the passenger seat and the two of you head out to drive through your local community. Everything is going fine for awhile. Then, as you drive past a local mini-mall, a car with a mattress strapped to the roof pulls out of the parking a little too tight in front of you. Rather than lifting off of the gas pedal, or lightly applying the brakes, your child instead lets out a blood-curdling scream, pushes back in the seat, and takes both hands off the steering wheel and presses them against the roof for bracing. Something about the mattress confused your child too much. The vehicle is no longer being controlled.

THAT is a disengagement ! You reach across and grab the wheel, quickly slide over to get close, and swing your left leg over to reach the brake pedal with your foot.

An AV has various sensors that permit it to see the world around it: cameras, lidar, radar, ultrasound, etc. Its perception system allows it to take the input from all those sensors and create a model of the world around the car. Just like you, its perception system has certain sanity checks built in. If you walked into your living room and instead of seeing the lamp sitting vertically on the end table, you saw it sticking horizontally out of a wall, you would know something was wrong. Your perception doesn't make sense. First, the lamp is not where you expect it to be. And second, it is not behaving consistent with gravity as you understand it. So the AV is smart enough to know when it is hopelessly confused. It is also programmed to recognize certain threats, like a pedestrian walking into the roadway in front of you. But it may not be programmed with how to respond (slam on the brakes) for all threats. So, any time the AV is confused or does not know what to do, it throws up its hands and screams. It disengages. An alarm goes off inside the car, which alerts the "monitor" to take control of the car. That is why level 3 vehicles require a monitor (emergency response driver) to be behind the wheel at all times, and ready to take control.

Autonomous Mode vs Manual Mode vs Observer Mode

An AV equipped car can be operated just like a normal car, with a person driving it and the computerized "driver" turned off. This is called "manual mode", or sometimes "conventional mode". Alternatively the computerized driver can be given control of the vehicle. This is called "autonomous mode". Some vehicles are capable of a third mode, called "observer mode". In observer mode a person drives the car, but the computerized driver is on and observes the human driver's actions in order to learn.

Route Planning, Mapping, and Geo-Fencing

One of the functions an AV driver must perform is deciding where to go – which lane, which turn, etc. This is called "route planning". Route planning must occur within the context of a map of the area. This is typically a more detailed map than you might observe on-line at Google Maps or Open Street Maps. One of the main purposes of observer mode (and there is usually an observer function running in the background in autonomous mode) is to collect sensor and perception data to create these detailed maps. There are also separate companies whose whole business is the production of these maps.

In theory, availability of these detailed maps for an area permits the AV to do a better job of driving in that area. So the AV needs to know when it is in an area for which it has the map data. In fact some AVs can be programmed to only drive in these areas. This is called geo-fencing the AV.

Levels 3, 4, and 5

Level 3 automation is the first (lowest) level where the AV driver is capable of completely driving the vehicle. It may however fail or disengage at any time, and so a human emergency driver is required to "monitor" driving operations at all times, and be ready to assume control immediately upon notice (while the vehicle is in motion).

Level 4 automation is where the AV driver is capable of completely driving the vehicle, under specified circumstances and in a specified area. It is also capable of monitoring for the presence of those circumstances and location within that area, and of performing an orderly "hand-over" (disengagement). So for example, a vehicle capable of freeway driving in good weather in California could be switched into AV mode on the entrance ramp. It would drive completely independently along the freeway, while the human sleeps, reads, or whatever. At the destination the vehicle would drive down the exit ramp, pull off to the side of the road, stop, and alert the human that it was no longer capable of proceeding further. If at any time along the route it started to rain, the vehicle would likewise slow down to be safe, find a place to pull over, stop, and alert the human that it could no longer proceed.

Level 5 (the holy grail) automation is fully capable of driving independently anywhere under any conditions.

2018 Executive Summary

Despite states like Arizona recklessly luring many RoboCar development teams away from California in 2017, a surprising amount of testing continued in the state in 2018. This included new testing by Apple, Aurora Innovations, and others, and also by a couple of Chinese backed efforts in Jingchi WeRide and Baidu. Waymo, whose test mileage dropped substantially in 2017 as it set up shop in Arizona, once again recorded the largest chunk by far of test miles in California in 2018.

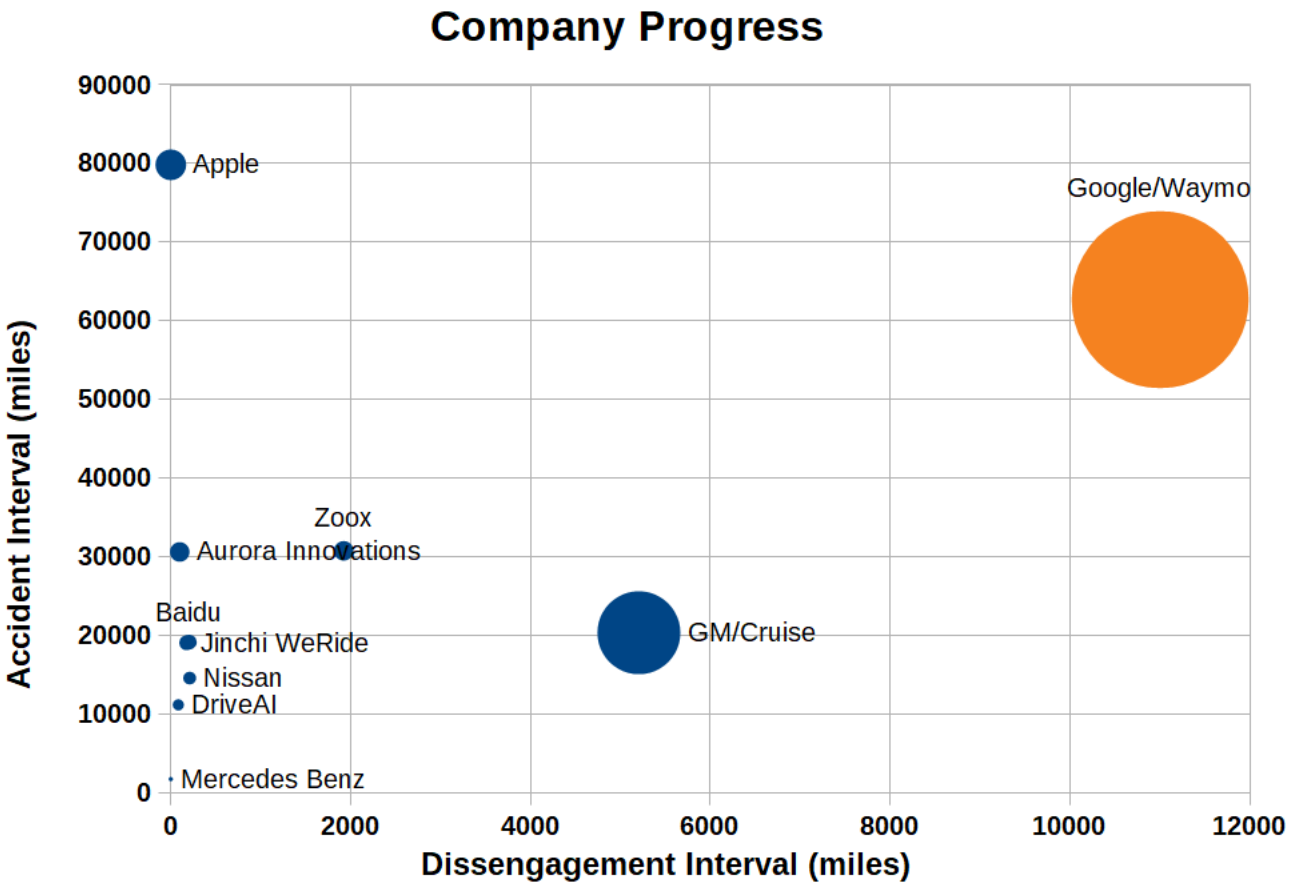
The Uber testing fatality in AZ clearly had a sobering impact. There is evidence in the CA accident data that a number of companies paused autonomous testing for a period, but continued manual operations – likely to collect mapping data while they re-evaluated their test programs.

Press coverage turned measurably more negative following the Uber fatality, as did conference sentiment. Gartner officially moved AV technology in its hype-cycle from the “peak of inflated expectations” stage to the “trough of disillusionment” stage. Conference presentations from industry insiders began openly calling for more stringent regulations and oversight from government. Meanwhile the US DOT updated its ADS 2.0 to ADS 3.0 late in the year, still without anything stronger than “guidelines”.

In terms of technology leadership mostly things stayed the same. Waymo likely stretched its leadership position slightly; GM/Cruise recovered from its floundering ways of 2017 and solidified its second place position; and 2017 newcomer Zoox overcame some internal chaos to continue in 3rd place.

Ten (10) companies appear in the positioning graph below. Basically what we seek is an AV driver that is reliable, safe, and has enough experience to be trusted. Reliability is represented in the graph by the average interval between disengagements, on the X-axis. Safety is represented by the average interval between accidents, on the Y-axis. So progress is represented by moving up and to the right. The bubble size represents the total accumulated on-road test mileage, and so is an indication of experience. On October 31, 2018 Waymo became the first company to be authorized by the state of California for level 4 on road testing. This is indicated by the bubble color.

Waymo roughly doubled its disengagement interval this year. Level 3 testing is the most dangerous, basically because humans are terrible at monitoring functions. When the function being monitored triggers every 5 minutes or less, a human can stay relatively attentive. When the event happens once a week, they are likely not to be paying attention. Waymo’s rate is now in the once a year range, so a move to level 4 is likely a good thing for risk reduction. Accident rates for 2018 roughly returned to 2016 rates, doubling those of 2017. It is too soon to say if this is from the level 4 transition, or other factors. The Waymo driver is now about 7 times more accident prone than human drivers.



GM/Cruise was struggling with disengagement in 2017, and its accident rates blew up by 60%. They recovered both in 2018. The disengagement interval was increased by 10x, and is now just under half that of Waymo (about once every 5 months). Thus they are now in dangerous territory. Will they add a second monitor to each car as Waymo did? The accident interval was essentially tripled, and is now one third that of Waymo.

Zoox received major funding in 2018, but along with that came corporate power battles. The visionary founder and CEO Tim Kentley-Klay was ousted in August. It will be interesting to see if they continue to progress in 2019. Their safety record remains impressive, and actually 50% better than GM/Cruise. Their accident interval is already half that of Waymo. They also increased their disengagement interval by 10x. While they stepped up their test mileage, they are still 15x behind GM/Cruise. They may just be too small to catch up. Zoox might be an interesting acquisition play for another big player. Perhaps Apple?

Apple's on-again, off-again effort was back on in 2018, and Doug Field has returned from Tesla. They executed impressive test mileage in 2018, and have an excellent safety record. But their AV can barely drive 1 mile at a time. They do not report disengagements by month, and they have an extremely wide variation by vehicle in disengagement rates, so it is more difficult to discern their status. But they simply do not appear to be a credible player at present.

Aurora Innovations and DriveAI both use AI for drive control as well as for perception. They are using a different approach, that uses observer mode to learn from human drivers. They restrict the roads chosen for testing in a way that gradually increases the degree of challenge. This is expected to keep the disengagement interval low for a longer time. They are not serious contenders today, but it will be interesting to see if this approach bares fruit in 2019.

A video summary by AutoLine can be found here :
(https://www.youtube.com/watch?v=EvUxdi0iFVc&t=3797s)

GM/Cruise recently offered a new video of their testing – included in the video above, or directly at https://www.youtube.com/watch?v=6tiyZXKwdOA. It first should be noted that we have no way of verifying this is in fact from an autonomously driven vehicle. It could be manually driven. The vehicle does exhibit the cautious, jerky, and tight turning characteristics one would expect from autonomous control. But this could be a human mimicking AV control. The video does serve to exemplify very well the additional complexity posed by urban core testing (vs suburban testing). If real, it might indicate the gap between GM and Waymo is smaller than the numbers indicate. But it also raises the question of why Cruise remains dedicated to this test environment. Is the real market potential for robotaxis as a downtown taxi, or as a suburban solution ?

Editorial Comment

As described above, level 3 capability is the most dangerous. Specifically, timing the transition to level 4 is the highest risk period. As the disengagement interval grows in length the event frequency drops, making human monitoring less effective. On the other hand, removing the human monitor before AV control is robust offers its own risks. This transition also represents a significant milestone. Now that the leader Waymo has made that transition, there is additional pressure for GM/Cruise to transition also. And as these two leaders convert to commercial activities based upon level 4 (both have announced plans to do so this year), and begin capturing market share, the pressure on the remaining companies grows exponentially. This will naturally lead to greater risk taking. With no regulatory barrier or criteria in place to limit choices, this risk taking is very likely to result in public harm. The Uber fatality allowed engineers to push back against investor impatience for ROI, by highlighting the long term damage that recklessness could do to market potential. As the market stops being a future potential, and actually begins to materialize, competitive pressure will erode that ability to push back.

Lower cost lidar is not yet in production volume, and second generation (different wavelength, longer range) lidar is not yet available. ISO safety standard (26262) compliant control systems are not yet available, nor are industry standard test and validation methodologies. So root cause analysis on the failures that do occur may not be possible. Baidu has joined Tesla in using a lidar-less system (relies only on visual light cameras and radar), which have already proven through multiple Tesla crashes to be vulnerable to failures.

Although the cumulative test mileage is impressive, and continues to grow, we are aware of NO testing done in near proximity to other RoboCars. One can easily see how light pulses from the Lidar unit on one vehicle, could theoretically be miss-interpreted as reflected pulses from the Lidar unit on another nearby vehicle, thus corrupting its perception. We have yet to see anything published that discounts this possibility, nor any data published showing that mechanisms to defeat this effect actually work. It appears to be a test hole.

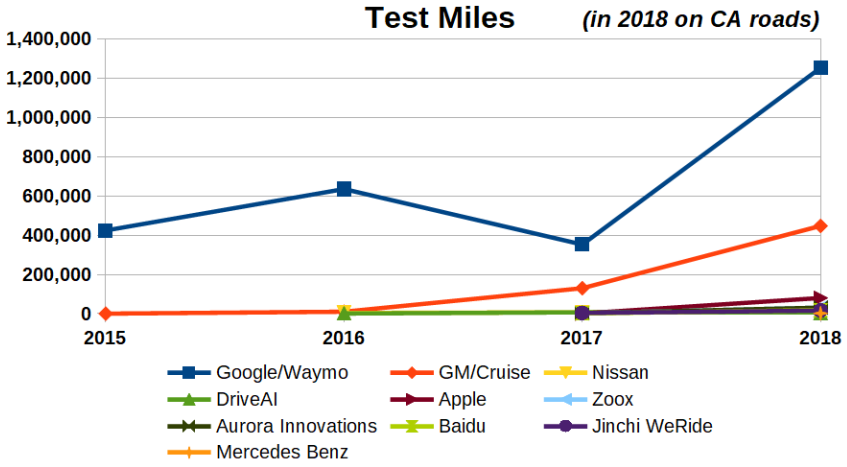
All this makes the coming year, 2019, the most critical and most dangerous year for this new technology. One or more additional fatalities are almost a certainty. And post-mortems on those fatality accidents will likely reveal easily avoidable flaws.

The nearly universal “completely hands off” policy by Federal and State governments, while allowing these risks onto public roads, is nothing short of negligence.

Test Results

Test Miles in 2018:

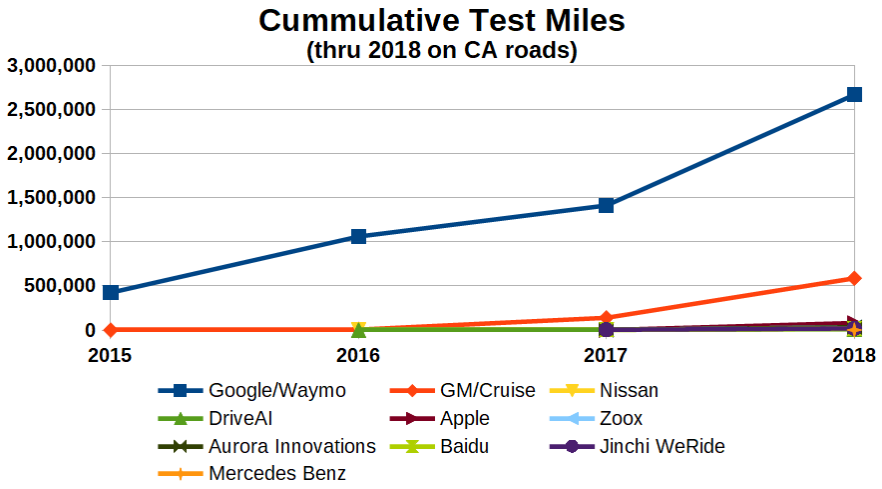
Test miles by Waymo and GM/Cruise far exceeded those by other companies.



Test Miles (on CA roads)	2015	2016	2017	2018
Google/Waymo	424,331	635,868	352,545	1,254,117
GM/Cruise	239	9,756	129,764	447,681
Nissan		4,099	5,007	5,473
DriveAI		557	6,015	4,617
Apple			838	79,845
Zoox			2,244	30,764
Aurora Innovations			2,397	30,618
Baidu			1,072	18,093
Jinchi WeRide			3,392	15,675
Mercedes Benz				1,749

Cummulative Test Miles:

Accumulated test experience (miles) by Waymo and GM/Cruise far exceed those by other companies.



Cumulative Test Miles	2015	2016	2017	2018
Google/Waymo	424,331	1,060,199	1,412,744	2,666,861
GM/Cruise	239	9,995	139,759	587,440
Nissan		4,099	9,106	14,579
DriveAI		557	6,572	11,189
Apple			838	80,683
Zoox			2,244	33,008
Aurora Innovations			2,397	33,015
Baidu			1,072	19,165
Jinchi WeRide			3,392	19,067
Mercedes Benz				1,749

Disengagements Reported 2018

These counts were reported for the year. When combined with the annual test mileage, interval data is produced.

Disengagements	2015	2016	2017	2018
Google/Waymo	321	124	63	114
GM/Cruise	103	181	105	86
Nissan		28	24	26
DriveAI		58	93	55
Apple			7074	69510
Zoox			14	16
Aurora Innovations			130	308
Baidu			48	88
Jinchi WeRide			162	89
Mercedes Benz				1194
AiPod				16

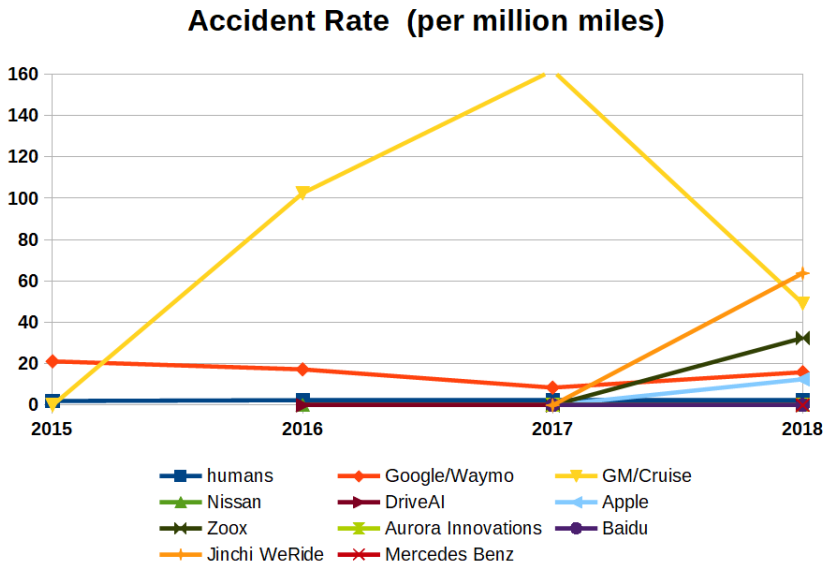
Avg Disengagement Interval	2015	2016	2017	2018
Google/Waymo	1,322	5,128	5,596	11,001
GM/Cruise	2	54	1,236	5,206
Nissan		146	209	211
DriveAI		10	65	84
Apple			0	1
Zoox			160	1,923
Aurora Innovations			18	99
Baidu			22	206
Jinchi WeRide			21	176
Mercedes Benz				1
AiPod				2

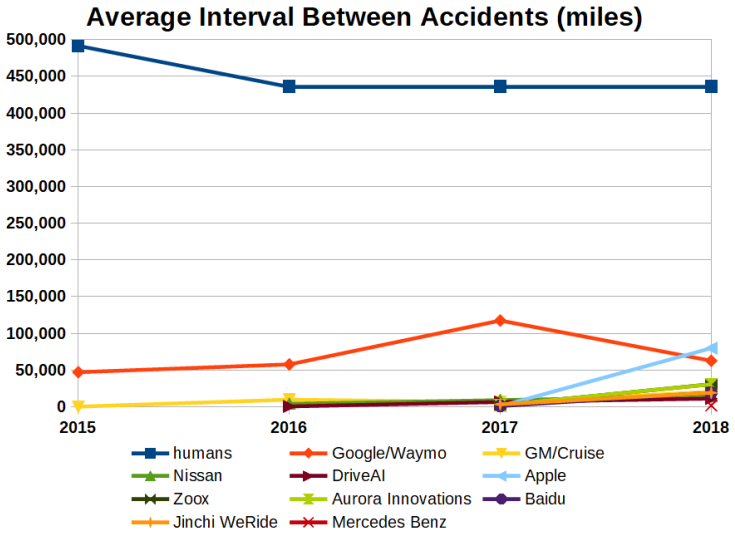
Accidents Rates/Intervals in 2018

Accident rates rose in 2018 for all testers except GM/Cruise. For Waymo this included a partial year of testing at level 4. For all other testers it was their first year of significantly greater test miles.

One should not miss the relative values compared to the "humans" curves. NHTSA provides annual reports on accident rates (of human drivers) 2 years in arrears (most recent report is for year 2016). Human accident rates have been increasing.

The least accident prone robocars (Apple, Waymo) are still 7x worse than humans. It is important to note that the Uber fatality is the ONLY accident for which the AV is acknowledged at fault. So "accident prone" is not equivalent to "legally liable". Insurers are likely to notice that "its never their fault" but they sure "get hit a lot".





Accident Rate (/M miles)	2015	2016	2017	2018
humans	2.03	2.29	2.29	2.29
Google/Waymo	21.21	17.30	8.51	15.95
GM/Cruise	0.00	102.50	161.83	49.14
Nissan		0	0	0
DriveAI		0	0	0
Apple			0.00	12.52
Zoox			0.00	32.51
Aurora Innovations			0	0
Baidu			0	0
Jinchi WeRide			0.00	63.80
Mercedes Benz				0
AiPod				0

Average Accident Interval (miles)	2015	2016	2017	2018
humans	491,582	436,169	436,169	436,169
Google/Waymo	47,148	57,806	117,515	62,706
GM/Cruise	239	9,756	6,179	20,349
Nissan		4,099	9,106	14,579
DriveAI		557	6,572	11,189
Apple			838	79,845
Zoox			2,244	30,764
Aurora Innovations			2,397	30,618
Baidu			1,072	19,165
Jinchi WeRide			3,392	19,067
Mercedes Benz				1,749
AiPod				31

Accident Reports Review

California requires companies to report any accident involving a vehicle registered as AV capable. The accident report form indicates if the vehicle was operating in autonomous mode or being driven in a traditional manual fashion. We do not include in our accident reporting, accidents involving AV cars in manual mode. Occasionally, an accident report begins in autonomous mode, then includes a disengagement, and ends in manual mode. We do include these cases in our accident reporting.

Waymo, GM/Cruise, Zoox, Apple, and Jingchi WeRide reported autonomous mode accidents in 2018. A total of 46 such accidents were reported. Overall, autonomous vehicles are extremely prone to low speed rear end collisions (57%). This no doubt is linked to them being overly cautious, detecting potential threats that humans don't see, leading to sudden stops not anticipated by the following drivers. GM/Cruise seems to be uniquely prone to corner collision accidents, from the same cause (36% of GM and 17% overall). In the tight confines of San Francisco neighborhoods the cautious behavior tests the patience of followers, causing them to attempt passing in tight quarters. When the AV moves again before the pass, a corner collision results. This makes the over-cautious nature responsible for a total of about 74% of accidents.

	percent	total	Waymo	GM	Zoox	Apple	Jingchi
accidents	**100%**	**46**	**20**	**22**	**2**	**1**	**1**
rear end	57%	26	15	7	2	1	1
corner	17%	8	0	8	0	0	0
bicycle	4%	2	1	1	0	0	0
other	22%	10	4	6	0	0	0

Some difficulty in detecting bicycles also seems to be present (4%), especially from the side.

The ability to avoid accidents seems to be lacking. The programmed behavior under threat seems limited to braking. Human drivers are able to use judgment in applying acceleration and steering in addition to braking to avoid accidents.

Only Waymo and GM/Cruise experienced accidents other than low speed rear end collisions. We look in detail at a few of those accident reports in the following sections.

Waymo Accidents

	date	type	time	test miles	accident rate /M miles	normalized to humans	human rate /M miles
Google/Waymo							
2018				**1,254,117**	**15.95**	**6.96**	**2.29**
20	12/03/18	bicycle collision	10:34:00 AM				
19	11/29/18	side touch	06:25:00 AM				
18	11/28/18	rear end	03:25:00 PM				
17	11/14/18	rear end	04:30:00 PM				
16	11/14/18	driver error	09:20:00 AM				
15	11/07/18	rear end	11:30:00 AM				
	L4 testing approved						
14	10/24/18	rear end	02:31:00 PM				
13	10/19/18	side motorcycle	07:16:00 AM				
12	10/15/18	rear end	09:07:00 PM				
11	09/24/18	rear end	04:58:00 PM				
10	09/18/18	rear end	12:21:00 PM				
9	09/14/18	rear end	07:03:00 PM				
8	08/24/18	rear end	01:55:00 PM				
7	08/20/18	rear end	08:18:00 AM				
6	08/06/18	rear end	02:25:00 PM				
5	07/26/18	rear end	02:47:00 PM				
4	07/19/18	rear end	04:03:00 PM				
3	07/09/18	rear end	05:52:00 PM				
2	05/25/18	broadside	03:51:00 PM				
1	04/06/18	rear end	12:17:00 PM				

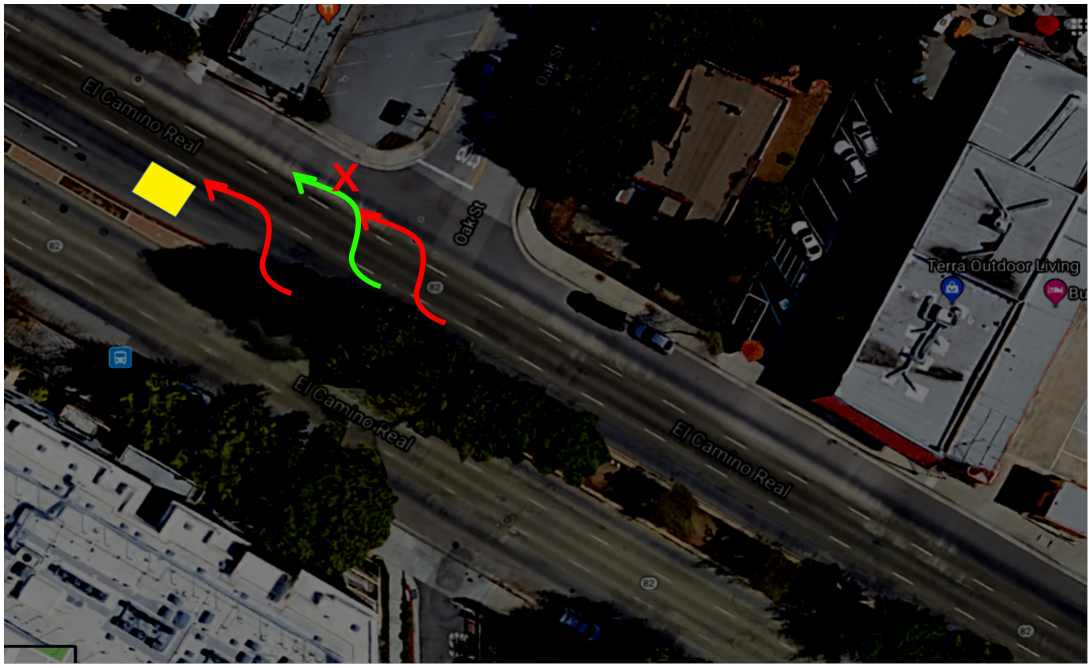
GM/Cruise Accidents

	date	type	time	test miles	accident rate /M miles	normalized to humans	human rate /M miles
GM/Cruise							
2018				**447,681**	**49.14**	**21.43**	**2.29**
22	12/01/18	rear end	09:58:00 AM				
21	11/15/18	rear end	11:16:00 AM				
20	11/06/18	bicycle collision	09:16:00 PM				
		appears to be testing in manual mode only					
19	08/16/18	corner collision	06:52:00 PM				
18	08/14/18	corner collision	08:23:00 AM				
17	08/07/18	side collision	09:36:00 AM				
16	07/31/18	side collision	03:15:00 PM				
15	07/20/18	rear end	02:56:00 PM				
14	07/05/18	corner collision	07:35:00 AM				
13	06/29/18	corner collision	02:52:00 PM				
12	06/11/18	rear end	09:41:00 AM				
11	06/03/18	rear end	08:29:00 PM				
10	05/22/18	rear end	07:27:00 AM				
9	05/13/18	corner collision	12:15:00 AM				
8	03/27/18	corner collision	12:53:00 PM				
7	03/24/18	rear end	01:54:00 AM				
6	03/19/18	corner collision	08:34:00 PM				
5	03/14/18	side collision	03:12:00 PM				
4	02/20/18	corner collision	04:58:00 PM				
3	01/28/18	taxi attack	10:55:00 PM				
2	01/08/18	side collision	11:12:00 AM				
1	01/02/18	ped attack	09:27:00 PM				

Waymo Oct 19, 2018 accident

RoboCar
Human

Bad at Avoidance (multiple challenges & slow to react)



A Waymo Autonomous Vehicle ("Waymo AV") was traveling at approximately 21 MPH westbound in Lane 2 of El Camino Real in Mountain View in self-driving mode. A passenger vehicle in Lane 1,to the left of the Waymo AV, began to change lanes into Lane 2 to avoid a box truck blocking two lanes of traffic, Waymo's test driver took manual control of the AV out of an abundance of caution, disengaged from self-driving mode, and began changing lanes into Lane 3. A motorcycle, traveling at approximately 28 MPH behind the Waymo AV, had just entered Lane 3 to overtake the Waymo AV on its right. The Waymo AV and motorcycle collided at the Waymo AV's right rear corner. The motorcyclist reported injuries and was transported to the hospital for treatment. The Waymo AV sustained minor damage to the rear bumper.

Waymo Nov 29, 2018 accident

Waymo
Human

Bad at Avoidance

A Waymo Autonomous Vehicle ("Waymo AV".) was stopped in autonomous mode on Middlefield Road at Oregon Expressway in Palo Alto when a county bus came in contact with the passenger side mirror, pushing it towards the AV. The Waymo AV was stopped at a red light, and the bus was making a right-on-red in the adjacent right turn lane. The Waymo AV sustained minor damage to the mirror, and the bus did not stop to exchange information. There were no injuries reported at the scene.

Waymo Dec 03, 2018 accident

A Waymo Autonomous Vehicle ("Waymo AV") was traveling in autonomous mode on northbound View Street at California Street in Mountain View, approaching a four-way intersection with a traffic calming island. After coming to a complete stop at a two-way stop sign, the Waymo AV determined it was safe to proceed through the intersection and began to do so, when it detected a bicyclist approaching from the right. The Waymo AV then stopped for the bicyclist, whose front tire made contact with the passenger side of the stationary Waymo AV at approximately 3 MPH. The bicyclist remained upright and rode away without exchanging information. No injuries or damage were reported or observed.

GM/Cruise Aug 14, 2018 accident

RoboCar
Human

Bad Pass
(triggers impatience)

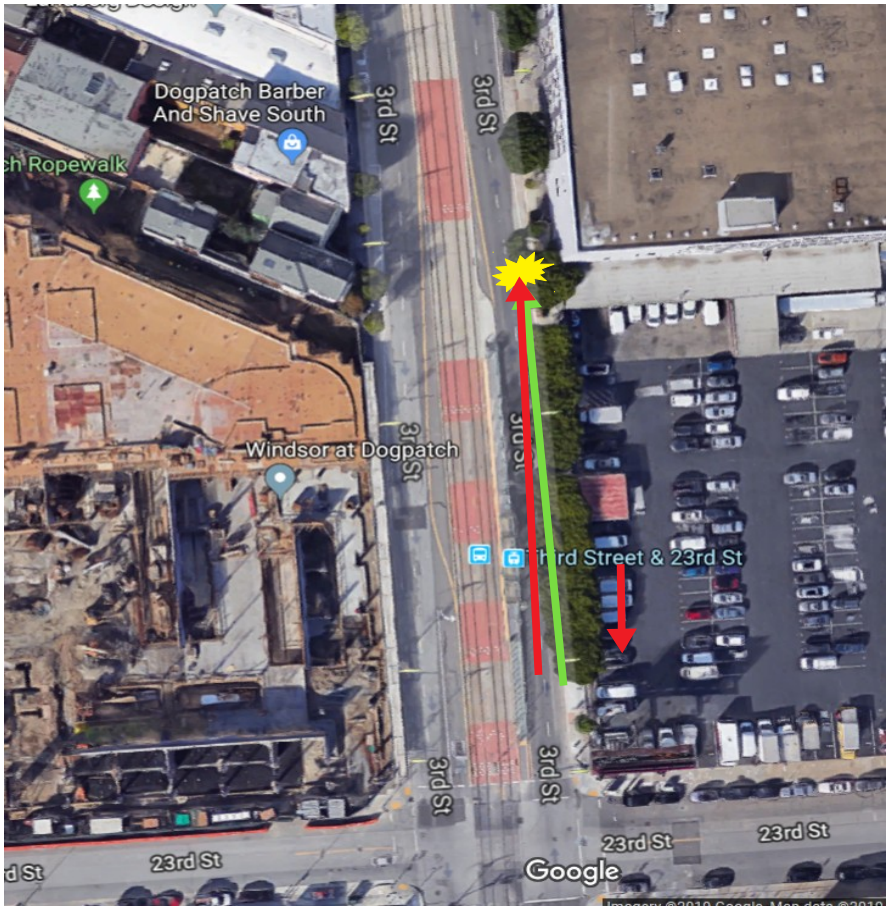
A Cruise autonomous vehicle (" Cruise AV"), operating in autonmous mode, was traveling southbound on Pierce Street between Ellis and Eddy Streets when a vehicle that had changed lanes to pass it on the left, turned back into the Cruise AV's lane too tightly and clipped the Cruise AV's front left radar damaging the sensor and it's casing. There were no injuries and police were not called. The driver of the other vehicle did not stop after the collision.

Radar fins stick out on front corners of vehicle – unusual configuration.

GM/Cruise Aug 16, 2018 accident

RoboCar
Human

Bad at Avoidance



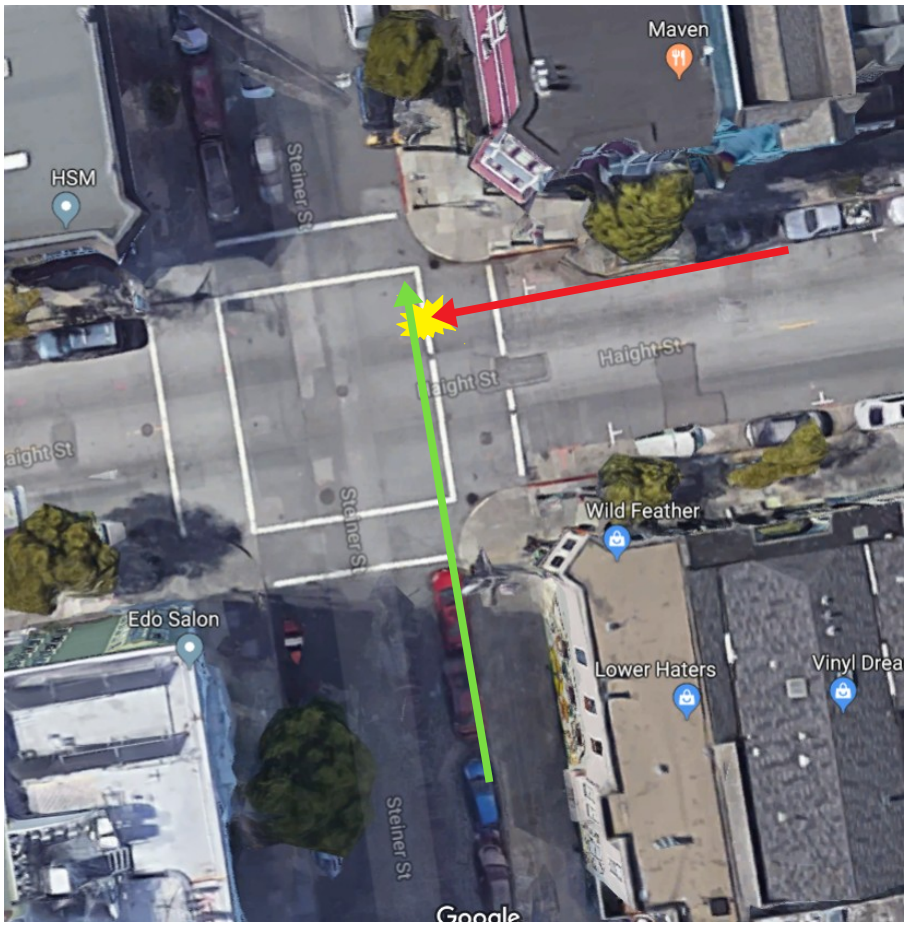
A Cruise autonomous vehicle(" Cruise AV"), operating in autonmous mode, was traveling northbound on 3rd Street between 22nd and 23rd Streets when a vehicle passing it on the left merged into the Cruise A V's lane too tightly and clipped the Cruise A V's front left radar bending the bracket that holds the sensor casing. There were no injuries and police were not called.

Radar fins stick out on front corners of vehicle – unusual configuration.

GM/Cruise Nov 06, 2018 accident

RoboCar
Bicycle

Bad at Avoidance
(brake vs accelerate)



A Cruise autonomous vehicle (" Cruise AV"), operating in autonomous mode, was proceeding northbound on Steiner Street at the intersection with Haight Street on a green light when a cyclist, traveling westbound through a red light, made contact with the right rear corner of the Cruise AV. The cyclist mentioned right shoulder pain, but denied needing an ambulance and left the scene on his own. The police were not called.

Bike attempted to cross behind vehicle. Vehicle detected threat and braked, making it harder.

GM/Cruise Nov 15, 2018 accident

RoboCar
Human

Weird Judgment
(why didn't you go ?)

A Cruise aut.onomous vehicle(" Cruise AV"), operating in autonomous mode, was waiting for oncoming traffic to clear the intersection before making a left turn onto Fulton Street from southbound Baker Street when another vehicle made contact with the right rear corner of the Cruise AV while attempting to pass it, causing damage to the Cruise AV' s rear bumper. There were no injuries and police were not called.

About the Author

Contact

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CityTram is about improving the way Americans commute in and around our cities. That is not, in and of itself, the end goal. It is simply the most practical and achievable means by which the end goal might be achieved. The end goal is to fight back against climate change. Since governments have proven to be wholly incapable of fighting climate change, it is left to we individuals to try. Using the powerful leverage of commercial interest to effect social change seems the smartest approach. This is the framework into which the CityTram project fits.

We make no effort to convince anyone that climate change is real, nor man-made, nor fixable, nor fixable at an affordable price. But we believe all of those, and it provides our motivation for this effort.