An Analysis of Testing Scenarios for Automated Driving Systems

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Levels of Driving Automation and some terms first:
Automated Driving System (ADS)
Dynamic Driving Tasks (DDT)
Object and Event Detection and Responses (OEDR)

- There are 6 standardized levels should be followed by the media, manufactures, suppliers and the public
- The first three levels are not being categorized as ADS due to the fact that the DDTs are not performed entirely by the system, i.e. there are occasional involvements from a driver.
- From level 3 onward, within each level, both OEDR and sustained lateral and longitudinal vehicle motion controls are handled solely by the system.

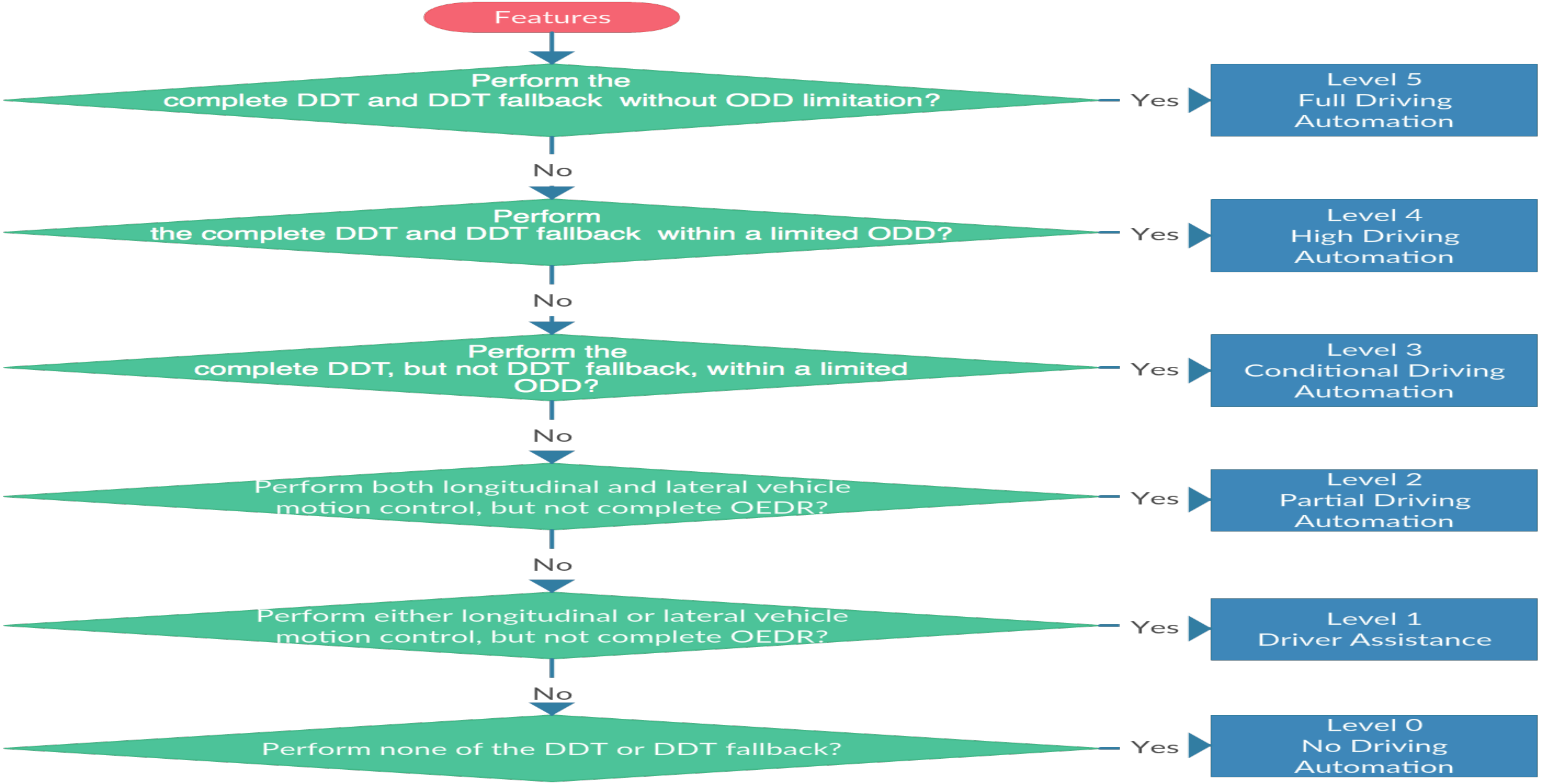
Six Levels of Driving Automation

Level	Name	Narrative Definition	ADS
0	No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems.	No
1	Driver Assistance	The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT.	No
2	Partial Driving Automation	The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system.	No
3	Conditional Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance relevant system failures in other vehicle systems, and will respond appropriately.	Yes
4	High Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	Yes
5	Full Driving Automation	The sustained and unconditional (i.e., not ODD specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	Yes

Determining the Levels of Driving Automation

- The following flowchart illustrates the automation level being determined.
- ODD denotes Operational Design Domain
- OEDR refers to Object and Event Detection and Response.

Flowchart for Levels of Driving Automation



Industrial Status

- The table presents collective highlights regarding automated driving related technologies.
- It is evident that the industry has progressed significantly over the past few years.
- Many major premium players like BMW, Tesla and Waymo, Google have successfully demonstrated their capabilities in the industry.

Industrial Status in 2018

Organization	Software	Year	Hardware	Year
ALMOTIVE INC	aiDrive, aiSim	2018	aiWare	2018
APTIV	Centralized Sensing Localization Planning (CSLP) platform, high-speed sensing and networking systems	2019	Work with Singapore Land Transport Authority (LTA)	2019
ARGO.AI	Work with Ford	2021		
AURORA INNOVATION			Work with VW	2021
BAIDU USA LLC	Level 4 automation		Commercializing Mass Producing	2018 2020
CISCO			Work with Hyundai	2019
CLARION	Smart Cockpit Solutions			
INTEL CORP A	Intel® GO™ Automotive Development Platforms			
NAVYA INC.			Work with Keolis on autonomous robotaxis	2018
NVIDIA			Work with Audi	2020
TORC	Asimov self-driving system	2007	Self-driving car	2018
TRANSDEV			Autonomous electric vehicles for public use	2018
U. OF WATERLOO			Work with Renesas	2018
ZENUITY			Work with TomTom	2018

Classifying Disengagement

- As per California Department of Motor Vehicles (DMV) regulation, disengagements are categorized into different types:
  - Automated driving with driver present
  - Automated driving without driver present
    - Technical disengagement due to failure of automated driving system and deactivation of the system is triggered
    - Non-technical disengagement due to driver discomfort and requires immediate manual control of the vehicle

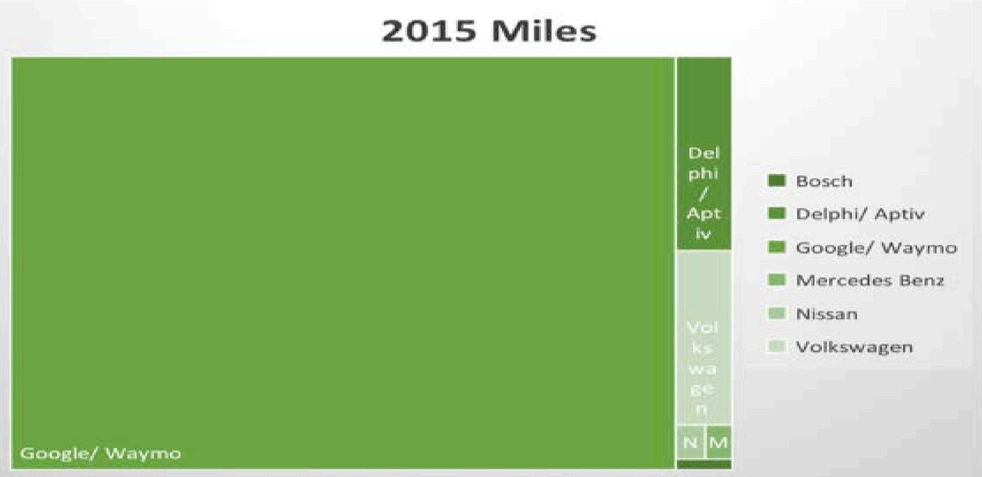
- We may think the disengagement ratio should be proportional to the miles travelled,
  - This turns out not to be the case.

Disengagement Data

Company	2015 Mile	2015 Disengagement	2016 Mile	2016 Disengagement	2017 Mile	2017 Disengagement
Baidu	- [a]	-	-	-	1971.74	48
BMW	-	-	638	1	0	0
Bosch	935.10	625	983	1442	1454	588
Delphi/ Aptiv	16621	405	16662	405	1819.55	74
Drive.ai	-	-	-	-	6572	151
Faraday Future	-	-	-	-	0	0
Ford	-	-	590	3	0	0
GM Cruise	-	-	-	-	131675.94	105
Google/ Waymo	424331	341	635868	124	352544.60	63
Honda	-	-	0	0	0	0
Mercedes Benz	1379.08	1031	673.42	336	1087.70	842
NIO USA	-	-	-	-	0	0
Nissan	1485.40	106	4099	28	5007	24
NVIDIA	-	-	-	-	505	109
Telenav, Inc.	-	-	-	-	1697	58
Tesla Motors	0 [b]	0	550	182	0	0
Valeo	-	-	-	-	574.10	215
Volkswagen	14945	260	0	0	0	0
Wheego	-	-	-	-	0	0
Zoox	-	-	-	-	2244.60	14
Total	459696.6	2768	660063.42	2521	507153	2291

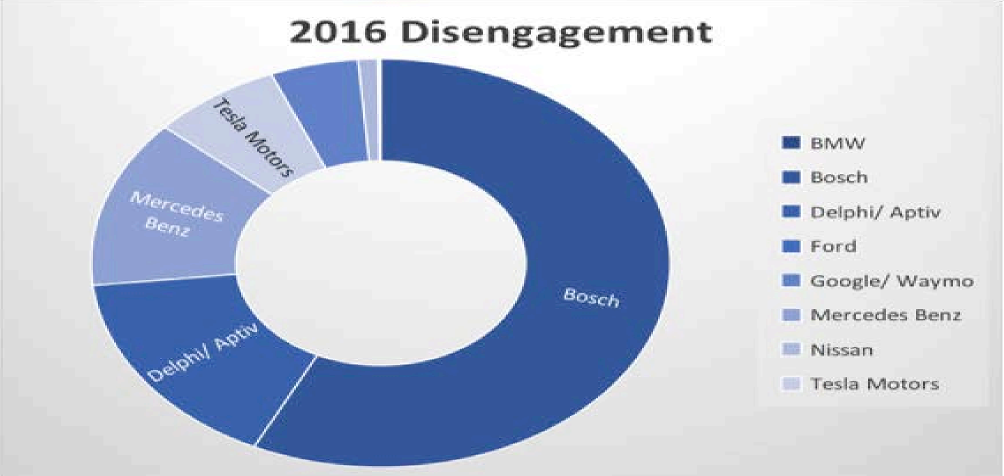
Miles versus Disengagement

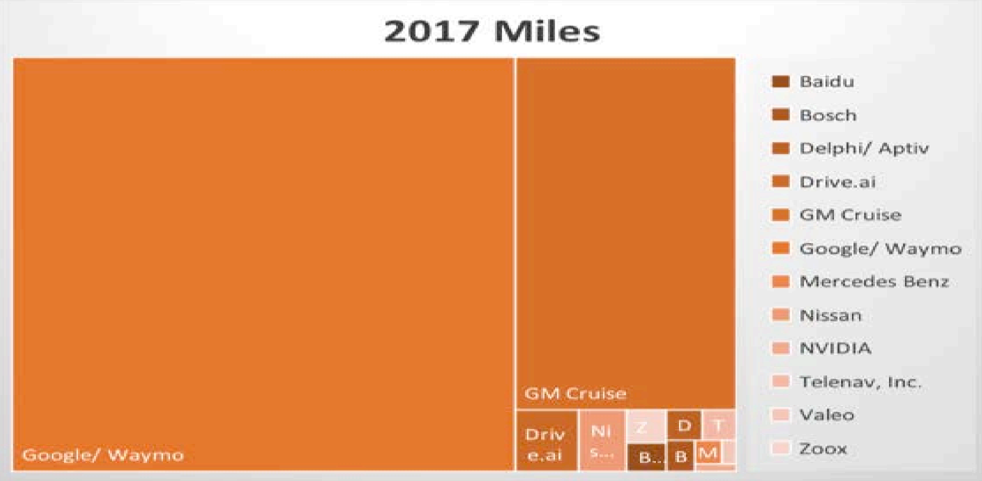
- Among all 20 companies, Waymo, formally known as Google Project, has accumulated the most distance travelled
- Delphi, also known as Aptive, has been the second most for 2015 and 2016
- GM Cruise started to participate and outperformed Delphi.

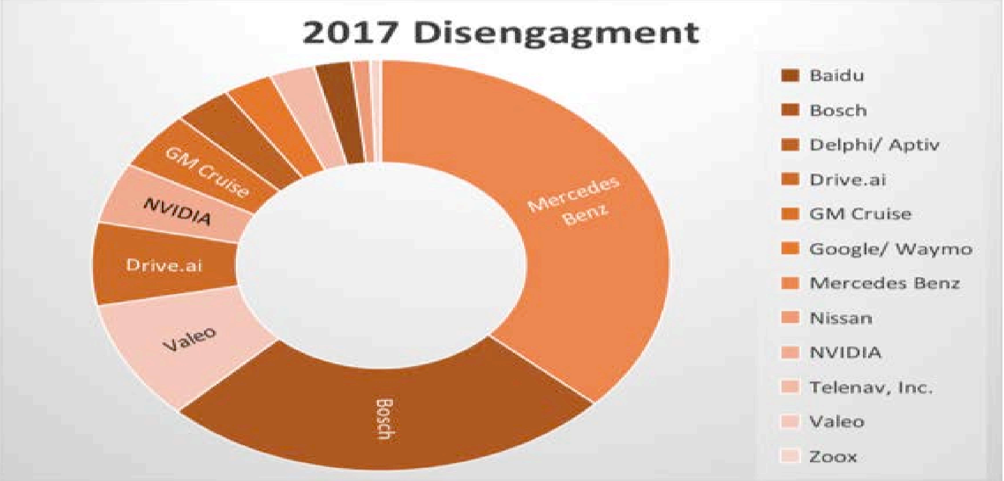

2015 Miles
Delphi/ Aptiv
Volkswagen
N
M
Google/ Waymo
Bosch
Delphi/ Aptiv
Google/ Waymo
Mercedes Benz
Nissan
Volkswagen


2015 Disengagement
Nissan
Volkswagen
Google/ Waymo
Mercedes Benz
Delphi/ Aptiv
Bosch
Bosch
Delphi/ Aptiv
Google/ Waymo
Mercedes Benz
Nissan
Volkswagen


2016 Miles
Delphi/Aptiv
Ni
Google/ Waymo
BMW
Bosch
Delphi/ Aptiv
Ford
Google/ Waymo
Mercedes Benz
Nissan
Tesla Motors


2016 Disengagement
Tesla Motors
Mercedes Benz
Bosch
Delphi/ Aptiv
BMW
Bosch
Delphi/ Aptiv
Ford
Google/ Waymo
Mercedes Benz
Nissan
Tesla Motors

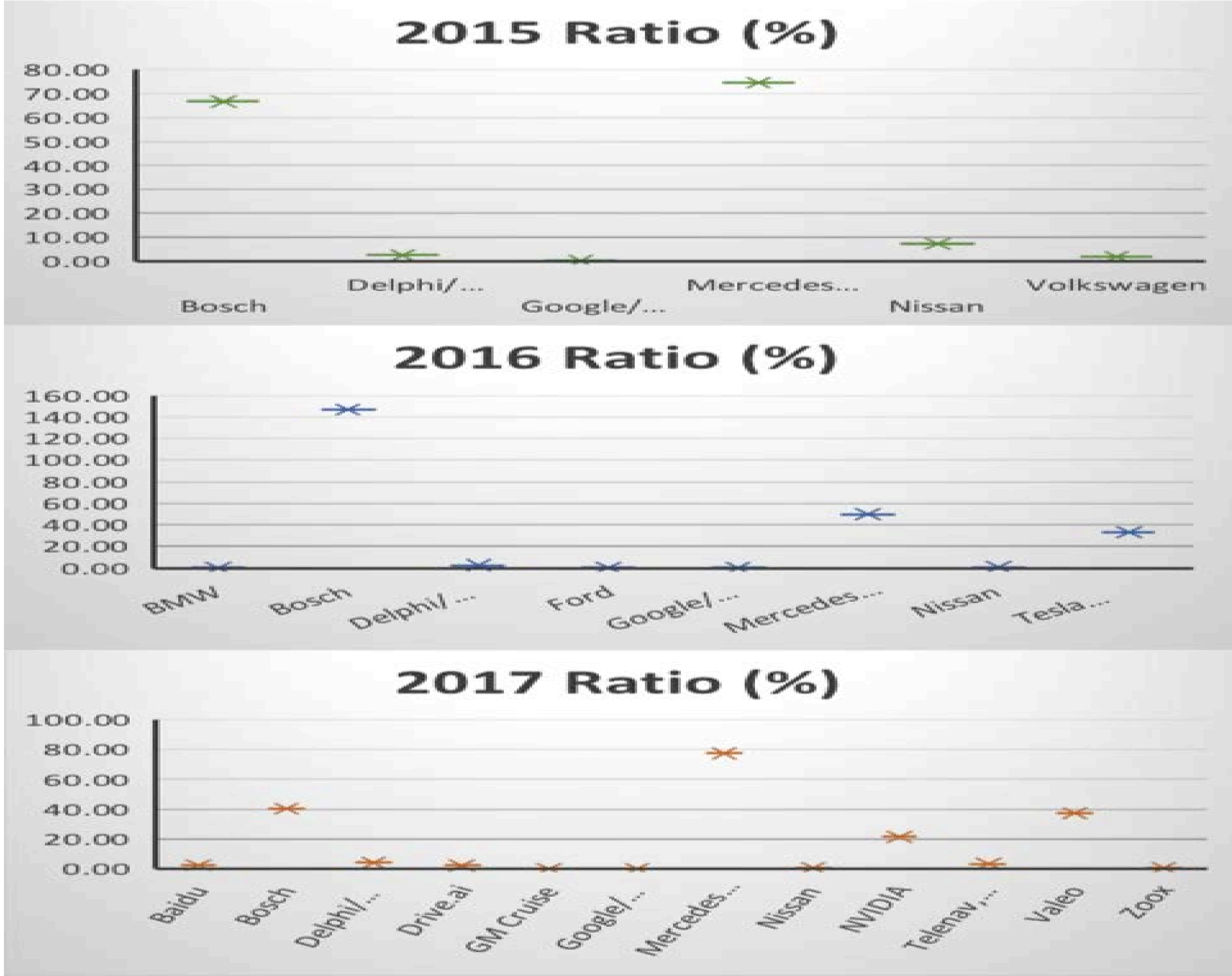

2017 Miles
GM Cruise
Drive.ai
Nis...
Z
D
T
B..
B
M
Google/ Waymo
Baidu
Bosch
Delphi/ Aptiv
Drive.ai
GM Cruise
Google/ Waymo
Mercedes Benz
Nissan
NVIDIA
Telenav, Inc.
Valeo
Zoox


2017 Disengagment
GM Cruise
NVIDIA
Drive.ai
Valeo
Mercedes Benz
Bosch
Baidu
Bosch
Delphi/ Aptiv
Drive.ai
GM Cruise
Google/ Waymo
Mercedes Benz
Nissan
NVIDIA
Telenav, Inc.
Valeo
Zoox

Miles versus Disengagement

- The following figure presents the ratio in percentage
  - It is the output of total number of disengagements over total number of miles travelled
- It is clear that Waymo, Delphi and GM Cruise are not top players in this respect.

Disengagement versus Companies



Collision Data

- A collision for autonomous car epitomizes situations when operating the vehicle on a public road causes damage to property or results in casualty.
- As of April/2018, a total of 63 reports were received by DMV.
- The collective data in accordance with companies are shown in table on annual basis.

Collision Data per Company

Company	2014	2015	2016	2017	2018
Delphi/ Aptiv	1	-	-	-	-
Drive.ai	-	-	-	-	1
GM Cruise	-	-	1	22	9
Google/ Waymo	-	9	13	3	-
Nissan	-	-	1	-	-
Zoox	-	-	-	1	1
Uber	-	-	-	1	-
Total	1	9	15	27	11

Possible Causes

- For both types of disengagements:
  - ➢for automated driving with driver present
  - ➢for automated driving without driver present
- The following root causes appear to be more frequently reported:
  1. Unwanted maneuver
  2. Perception discrepancy
  3. Software discrepancy
  4. Hardware discrepancy
  5. Behavior prediction failure
  6. Reckless behaviors from other road users

Recommendations

- Currently the test cars used for testing are prototypes built on existing commercial vehicles and equipped with embedded automated driving system.
- Commercialized vehicles refer to those cars that have already developed and are mass produced by OEMs.
- The electronic components in these cars are flashed with pre-defined software and such software has its own architecture.
- Upon completion of necessary modifications, companies are advised to carry out an impact analysis and making sure ADS does not cause any side effects to the existing system.

Recommendations (Cnt'd)

- Testing on a closed test track or controlled area before test on public road is an advisable practice.
- Tuning and calibration of ADS should be performed mostly by trained and skilled personnel, not ordinary drivers.
- Such action should be always bear the safety-first principle and reckless behaviors should not be encouraged and tolerated.
- Tests should not cause any danger to the vehicle, the occupant of the vehicle and the people on the road all the time.