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An Analysis of Testing Scenarios for Automated Driving Systems

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***Abstract*—Automated Driving System refers to a vehicle system where hardware and software are collectively capable of on-road operational and tactical functions and such functions involve the detection, recognition, classification of objects and response to events. Many automotive companies are incorporating automated driving into their current R&D and are transforming their business models. To both conventional and disruptive manufacturers, safety is always one of the top priorities. Appropriate verification and validation procedures are needed and should be followed to mitigate unreliability and hazardousness. Sufficient testing scenario should be considered and planned to simulate and cover functional and non-functional requirements. Disengagement ratio serves as an indicator during performance evaluations because analysing root causes of both technical and non-technical disengagements is pivotal especially during testing strategy planning. Autonomous Vehicle Disengagement Reports and Autonomous Vehicle Collision Reports from the Department of Motor Vehicles (DMV), California, USA are collectively used for the purpose of this research. And the analytical result shows there is no clear relationship between mileage and disengagements. Influencing factors are generated and consolidated from the mentioned reports and are proposed in addition to a Society of Automotive Engineers International (SAE International) standard. Stakeholders will benefit from the presented rationales and consider the suggestive parameters throughout their developing and testing activities. This paper further recommends testing management for automated driving systems, especially test driver management and test routes planning. And the recommendations are in accordance with the analytical results and feedback from KPMG′s Global Automotive Executive Surveys.**

***Index Terms*—Automated Driving System, Milage, Disengagement, Collision, Developing and Testing**

I. Introduction

Autonomous vehicle refers to a vehicle that is capable of observing, identifying and distinguishing its surrounding environment, both static and dynamic, and handling, operating and maneuvering itself under unmanned conditions [1]. While the concept has attracted a great deal of attention and debate from both manufacturers and consumers, the technological development has shown an emerging transition from no automation to full automation along the way. Moreover, fingerprints of this technology can be seen almost everywhere, especially its conventional and state of the art capabilities in this radically changing consumer world. In addition, the application of this automated driving system has been deployed in many areas, such as autopiloted underwater vehicles, autopiloted drones and also the well-known autonomous ground vehicles, i.e. automated cars.

Automated cars are also known by other names, examples like automated driven cars, driver-less cars, autopilot cars or self-driving cars. Given the fact that automation in commercialized and mass-produced cars serves as an essential enabling factor to urban transportation, this paper will discuss the current development of automated driving systems and recommend testing strategies, which are in line with the analytical results, and also prompt the tremendous potential of achieving full automation in designing and building cars for commuters. Needless to say, such an evolutionary designing concept opens a novel yet promising research avenue, extending current research efforts from no automation to driver assistance and further to full automation [2].

Automated driving system and self-driving car are far more promising, as of now, compared to the time when this idea was initially brought up. With the advances in artificial intelligence, autonomous cars have a brighter future given their ability to prevent accidents and reduce road congestion. According to the Global Automotive Executive Survey for 2016 and 2017 prepared by KPMG International [3] [4], the surveyed companies, including premium Original Equipment Makers (OEM) like BMW and newcomers like Google or Waymo, have increased their investments significantly in automated driving systems and self-driving vehicles compared to 2014, when the survey started to take self-driving into account. Ranked as the 9th among all 11 trends with 37% rating of importance for both 2016 and 2017, automated driving is not just a disruptive concept that only researchers are interested in and have been working on, it has become fashionable for almost all major car makers who are putting effort into this area in order to maintain their status in the field as major players and also transforming their business models to service- and data-oriented models.

While the automated car industry is growing rapidly and convincingly, with massive media exposure in relation to the testing of automated driving system equipped prototypes on public roads, both governments and the public are becoming less skeptical of this disruptive technology. They may not have been completely confident in the conceptualization process , but they have undoubtedly shown their support in pushing the development of this approach. Despite all the labor costs and energy consumption that autopiloted systems can save, the convenience that automated driving systems bring to our daily lives is prodigious. In addition, fatal errors are still crucial and so achieving a close to zero error rate has a significant meaning in the context of self-driving. This requires all the players in the market to carefully validate their prototypes and more carefully verify their products before commercializing and bringing them onto public roads.

Most recently, two unsettling news items have been reported in the media about autonomous vehicles and concerns about automated driving and autopilot systems. On March 18, 2018, in Tempe, Arizona, United States, one of Uber Technologies Inc.'s automated vehicles caused a severe car accident that inflicted injuries on a victim whom was announced dead when being transferred from the scene to the nearby hospital [5]. This was the very first accident involving automated driving that caused a pedestrian fatality. About one week after the tragedy, on March 23, 2018, one of Tesla Inc.'s Sport Utility Vehicles (SUV), a Model X, caught fire after crashing into the barrier on Highway 101 in Mountain View, California, United States [6]. This accident caused another fatality, but this time it was the driver who was behind the wheel. After intensive investigation, Tesla released an update on March 30, 2018 and revealed the reason why the accident was this severe. It was due to the crash attenuator, which is part of a highway barrier to reduce the impact from concrete lane divider by absorbing the colliding car′s kinetic energy, crashed in a prior accident and was not being replaced [7] [8].

Under the shadow of these recent stories on this technology, the public has become less confident and the government has also added pressure to companies and regulating authorities. There are thoughts that this will undermine the optimism about this tech and cause delays in this nascent industry. Consequently, testing has definitely been given elevated importance. In terms of testing cars that are equipped with automated driving systems, the procedures are similar to those for testing conventional vehicles. In addition, there are explicit differences and these differences need to be given extra attention throughout the development life cycle.

This paper is about disengagement and accident analysis, and also developing and testing management. Additionally, recommendations are made based on the discussed topics and targeting not only OEMs but also suppliers and other stakeholders. The terms used in this paper are based on common understanding of this technology and common terms that are used by the public and media. Moreover, the terminology and taxonomy used in this paper are in accordance with J3016™ (R) Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles from the Society of Automotive Engineers International (SAE International) which was revised on September, 2016 [9]. Data about disengagements and collisions used in this paper are based those released by Department of Motor Vehicles, State of California, United States (DMV) [10] and collision reports from California Highway Patrol, State of California, United States (CHP) [11]. The recommendations presented in this paper are referring to J3018™ Guidelines for Safe On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving Systems (ADS) which was issued by SAE International on March, 2015 [12].

II. Background

A. Automated Driving System

Autonomous vehicles, autopilot systems, driverless cars, self-driving vehicles and automated cars are broadly used by the public and can be seen in many reports. However, Automated Driving System (ADS) is a more appropriate terminology and is deployed to cover a wider spectrum of functionalities and automation levels in modern vehicles. As per SAE International′s latest standard SAE-J3016™, ADS refers to a system of a vehicle where hardware and software are collectively capable of performing all aspects of Dynamic Driving Tasks (DDT). DDT refers to on-road operational and tactical functions which involve detection, recognition, classification and response to objects and events [9]. The National Highway Traffic Safety Administration (NHTSA) of United States is currently adopting this standard, and so as other major players in automobile industry.

B. Levels of Driving Automation

Based on SAE-J3016, total of 6 standardized levels should be followed by the media, manufactures, suppliers and the public. Since the standard is in consistent with industry, it could ease confusion and ensuring that all stakeholders are properly aligned. In Table I, major highlights of the classifications are shown.

The first three levels are not being categorized as ADS due to the fact that DDTs are not performed entirely by the system, there are occasional or frequent involvements of a driver. From level 3 onward, within each level, both Object and Event Detection and Responses (OEDR) and sustained lateral and longitudinal vehicle motion controls are handled solely by the system. A flow chart, refers to Figure 1, is presented and illustrates how does the automation level being determined. In the flow chart, ODD denotes Operational Design Domain and OEDR refers to Object and Event Detection and Response. The former specifies those appropriate conditions for a driving automation system to work properly while the latter is a subtask of DDT which focuses on detecting, recognizing, classifying objects and prepare to response.

C. Roles of Driver

In the context of ADS, drivers are classified into two subdivisions. One is signified as expert test driver and the other is human driver.

Expert test drivers are distinctively trained personnel with special skillsets and are able to safely monitor the ADS after successfully activate the system. Moreover, expert drivers need to know how to deactivate the ADS under certain circumstances especially in hazardous situations. All these actions are performed with the aid of experimental compound.

TABLE I: 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

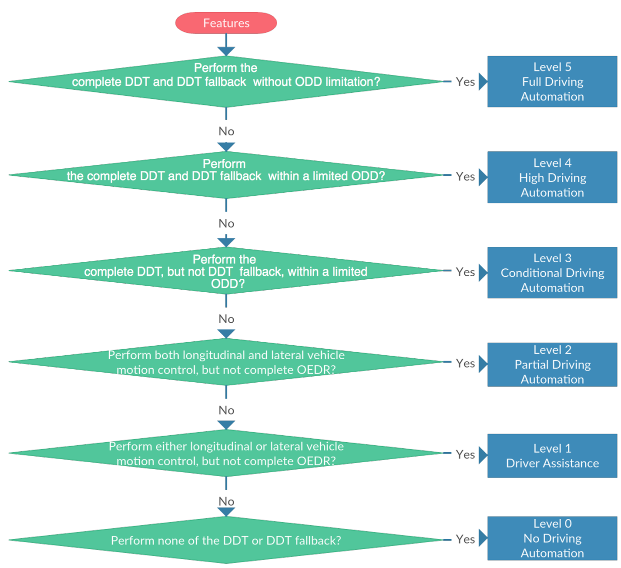

Fig. 1: Flowchart for determining driving automation level

Human drivers, on the other hand, are personnel operating a particular vehicle equipped with ADS and interact with the system to perform DDT.

III. Current Development

A. Impact Assessment

Nowadays, cars serve not only as a mode of commuting from point A to point B, besides the convenience and independence that cars bring to us, private owned cars save us time and energy and those mean a great deal to our daily life. Instead of waiting for public transportation, life is much easier with personal car, especially in countries like Canada and United States. However, people in country like Singapore would counter argue that private cars are not an essential part and do not affect their lifestyle significantly. As is well known, Singapore has an extraordinary public transportation system due to the nature of the country. The well-established infrastructures ensure that almost every corner of Singapore is covered by either bus or MRT (Mass Rapid Transit). Another factor that the public adore is the frequency and density of the system. The periodically scheduled buses and MRTs and the controlled traffic flow further ensure that the system operates as reliable as possible.

Despite all the good points that one can think of, drawbacks of public transportation system do exist. For instance, people with impairment would rather stay indoor than taking a bus simply because they want to avoid all the inconveniences. According to Canadian Survey on Disabilities (CSD) conducted by Statistics Canada in 2012. As estimated, 3.8 million adult Canadians are reported with disabilities and that are found restraining their daily activities significantly. This number appears to be 13.7% of total adult population as of 2012 [13]. Another factor that worth attention is that the worldwide demographic shift toward aging. In 2017, about 13% of the global population which is estimated as 962 million people, are aged 60 or over. This number is projected to reach 2.1 billion by year 2050 according to United Nations (UN) [14] [15] [16]. Despite the fact that the roads are also aging, the drastic increment itself is bring demands and pressures to the current transportation system. This leads to another needing factor of disrupting current automobile systems and work on something radical.

B. Industrial Status as of 2018

TableII is presented with collective highlights regarding automated driving related technologies and prototypes exhibited at Consumer Electronics Show (CES) International 2018. Some of the participating companies are also permit holders with DMV and they are authorized to perform automated driving system testing on public roads in California. The entire list of CES exhibitors can be found at [17] and the permit holders with DMV are listed in [18].

It is evident that the industry has progressed significantly over the past few years, many emerging players have shown their abilities by bringing prototypes or even commercialized cars to the show, such as Torc and University of Waterloo. Moreover, many major premium players like BMW, Tesla and Waymo, Google′s former self-driving project, have already reached a pivotal point by successfully demonstrating their capabilities in the industry.

IV. Disengagement and Accident

A. News Releases

The most recent influential news related to automated driving systems is the Model X, a SUV from Tesla Inc., crashed and caught fire on Highway 101 in Mountain View, California, United States on March 23, 2018. This accident took the life of the driver, who was a former Apple engineer. And according to the subsequent releases from Tesla, autopilot was engaged by the time of the accident. However, the hands of the driver were not sensed on the wheel for 6s prior to the collision even though there were several visual and audible warnings. Moreover, the severity of the accident was given escalated attention due to the fact that the car crashed directly into the concrete lane divider, while there supposed to have a crash attenuator to server as a buffer to reduce the impact. The crash attenuator was destroyed during a prior accident and had not been replaced since [6] [7] [8].

Another recent news piece is about a car accident in Tempe, Arizona, United States, and the company involved is Uber Technologies Inc.. On March 18, 2018, a woman was struck by an Uber car which was in self-driving mode and found dead while being transferred from the scene to nearby hospital. This accident is believed to be the first accident that caused a pedestrian′s death which was caused by an autonomous car. According to Uber′s spokesperson, there was a driver behind the wheel before the accident and the police had also confirmed that the car did not show signs of slowing down [5] [19] [20].

These recent updates have caused a stir in the emerging of the technology, especially after some advocates have expressed their concerns about testing of autonomous cars on public roads. On March 16, 2018, Uber received a letter from the governor of the State of Arizona regarding the suspension of operating and testing its autonomous vehicles on public roadways across the state [21]. And Uber is not seeking to renew its permit with California DMV, and also seems like that the company is taking a recess on getting permission to continue test automated driving system on city roads across the country [22].

Due to the fact that this technology being increasingly downcast, companies who are currently developing it are undergoing an incredibly tensed period. From all perspectives, safety is always supreme to all other factors and testing is needed to be carried out more cautiously and throughout.

B. Data from DMV California, US

The Department of Motor Vehicles, California (DMV) monitors and regulates the activities in relation to perform testing of automated driving system on public roads. In order to legally test their prototyped motor vehicles equipped with automated driving systems, companies need to apply for permits. As of those companies have already been granted one, they need to file reports on collision and disengagement during testing to DMV on annual basis.

On March 2, 2018, DMV issued a notice on applications filed by manufacturers concerning testing of automated cars without a driver will be accepted. As prior to that, permits were only issued to on-road testing with a driver′s presence for automated cars. However, permits are not to be issued until April 2, 2018 and the driverless testing regulations were approved by the Office of Administrative Law, California, United States on February 26, 2018 [23].

As of April 1, 2018, a total of 52 companies are listed as Autonomous Vehicle Testing Permit (with drivers) holders. Companies need to file disengagement since the year that the permit was granted. Since 2014, 20 companies, on the record, have been granted a permit. The reports have become available since 2015. As of April 4, 2018, DMV has received 6 traffic collision reports which involve an autonomous vehicle.

C. Disengagement

As per DMV′s regulation, disengagements are categorized into two different types. One for automated driving with driver present, one for automated driving without driver present. For the former, from technological perspective it can be further classified as following,

- Technical disengagement
  Due to failure of automated driving system and deactivation of the system is triggered
- Non-technical disengagement
  Due to driver′s discomfort and requires immediate manual control of the vehicle

For driverless car equipped with automated driving system, disengagements are accounted for following purposes,

- For the safety of the vehicle
- For the occupant of the vehicle
- For the public needs

The collective data, from DMV Autonomous Vehicle Disengagement Reports 2015 to 2017, listed in Table III are companies with testing permit and they are listed in alphabet order. The table includes the miles travelled and number of disengagement reported by each company.

D. Special Case of Tesla

Tesla Inc., as one of the leading companies in automated driving and electric car industry, is a permit holder with DMV. However, Tesla did not include much information in the reports as other companies did.

Unlike what other companies did in terms of testing automated driving system, Tesla does not conduct its solely on public roads worldwide, the company also perform testing on test tracks. Besides, the company has established a special technology for collecting data. The shadow mode of Tesla′s production car is not considered as autonomous mode as per California law. In ‘shadow mode’, the system does not

TABLE II: Industrial Status as of 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

TABLE III: Company′s Automated Driving Testing Mileage and Disengagements from 2015 to 2017

Company	2015		2016		2017	
	Mile	Disengagement	Mile	Disengagement	Mile	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

a) - denotes companies without permit in that year.
b) 0 denotes companies did not perform autonomous car testing on public roads in the State of California in that year.

take control and operate the vehicle, it registers the actual behavior and what the system could have done under the same circumstance [24]. The gathered statistics are used to simulate and improve accuracy of the system. Comparatively analyzing the system and detect underlying risks that autopilot could cause any accident and collision. The company believes that with the deployment of the collected data, the improvement in disengagement ratio over non-automated driven cars is material.

With the fleet of hundreds of thousands of customer-owned vehicles that support the shadow mode, Tesla is able to utilize billions of miles of real-time data during development and testing of its technology. And this is all driver oriented, as they are able to compare the system with how the drivers actually drive in various of road conditions and weather conditions under various circumstances.

E. Data Analysis

As per data listed in Table III, it is not evident that the more mileage that companies have tested, the higher chance that they have more disengagements. There is no clear relationship between these two elements.

In terms of miles travelled autonomously, it has large variances between companies. Among all 20 companies, Waymo, formally known as Google Project, has accumulated the most distance travelled with 424331 miles which accounts for 92.31% of total miles in 2015, 635868 miles which accounts for 96.33% in 2016 and 352544.6 miles which accounts for 69.51% in 2017. The increment of total miles in 2017 was because of a newly joint force, the GM Cruise. In the same year, GM Cruise started to test their autonomous driving system equipped prototypes. The company drove the car with 131675.94 miles which is about 25.96%. Figure 2 clearly shows that Google has the most contributions for all three years. Delphi, also known as Aptive, has been the second most for 2015 and 2016. However, in 2017 GM Cruise started to participate and outperformed Delphi.

People may think the disengagement ratio should be proportional to the miles travelled. However, this turns out not to be the case. Figure 3 presents the ratio in percentage, which 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.

People may think the disengagement ratio should increase proportional to the miles travelled. However, this turns out not to be the case. Figure 3 shows the ratio as the output of number of disengagements over number of miles. None of the top mileage contributors still outrank the other companies under this context.

F. Collision

A collision for autonomous car epitomizes situations when operating the vehicle on a public road causes damage to property or results in casualty. When a collision which involve a driverless car occurs, regardless of the responsibilities, the traffic authority should be informed. In California, DMV requires companies to file Report of Traffic Collision Involving an Autonomous Vehicle, within 10 days after the accident.

As of April 4, 2018, a total of 63 reports were received by DMV. The collective data in accordance with companies are shown in Table IV on annual basis.

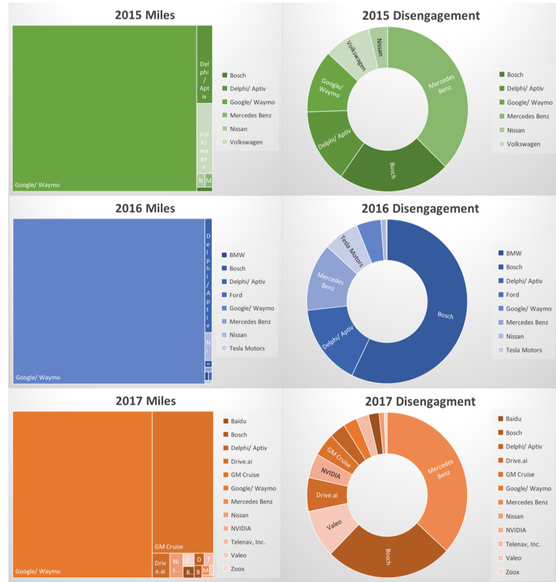

Fig. 2: Mileage and Disengagement by company

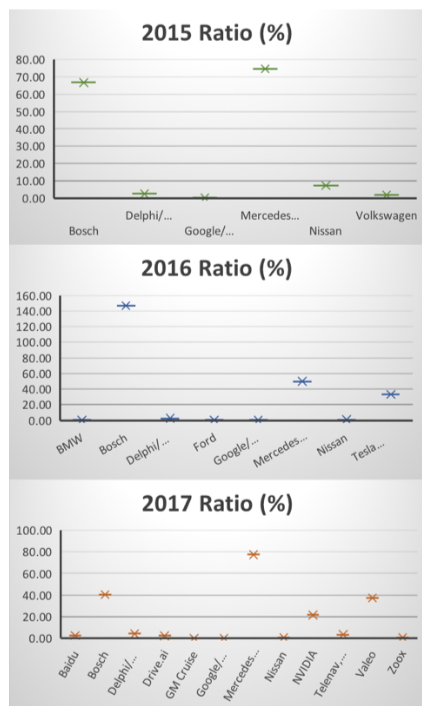

Fig. 3: Disengagement Ratio by company

G. Possible Causes

As DMV requires companies to include reasons of each disengagement and time taken for driver to react to this disengagement. Majority of the companies managed to collect the required data and there are two types of disengagement reported, one is auto disengagement which refers to technical failure of the system and the other one is manual disengagement which means that driver has to take control of the car over the system.

TABLE IV: Company′s Automated Driving Testing Collision from 2014-2018

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

Regarding the rationales, DMV has provided some indicative examples including weather conditions, road surface conditions, constructions, emergencies, accidents or collisions. Moreover, for both types of disengagements, the following root causes appear to be more frequently reported by company than those indicative causes.

- Unwanted manoeuvre
- Perception discrepancy
- Software discrepancy
- Hardware discrepancy
- Behaviour prediction failure
- Reckless behaviours from other road users

V. Developing and Testing Recommendations

A. System Development and Modification

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. For instance, Aptiv has been using an Audi SQ5 (Model year: 2016) and Drive.ai has different cars from three car makers, i.e. Lincoln MKZ (Model year: 2016), Audi A4 (Model year: 2017) and Nissan NV200 (Model year: 2016). The companies are using these cars as test bed to test their automated driving systems. In Canada, a Lincoln MKZ Hybrid has been modified and equipped with full suite of radar, sonar, lidar, inertial and vision sensors by University of Waterloo and is used to test their customized autonomy software [25].

ADS can either be flashed into existing Electronic Control Units (ECU) through CAN reprogramming or serve with an additional external hardware as add-on. Either way, interfaces between software and hardware should not collide and should not cause any conflict. The software needs to be validated and verified as per standard software testing conventions. The modules should be able to perform self-diagnostics and should be monitored all the time along with all other pre-equipped electronic modules. And prior to perform dynamic on-road testing, static stationary testing should be performed on compound and safety critical measurements should be performed.

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. Testing on a closed test track or controlled area before test on public road is an advisable practice. Tuning and calibration of ADS should only be performed by trained and skilled personnel, the driver should not take up this role. And such action should be always bear the safety-first principle and reckless behaviors should not be encouraged and tolerated. Moreover, testings should not cause any danger to the vehicle, the occupant of the vehicle and the people on the road all the time.

B. Test Driver Management

In order to maintain the on-road safety, test car drivers should take certain training before operating vehicles with automated driving system. The aim of this training program is to provide sufficient information on vehicle handling and advice appropriate actions in different situations. This should be included as a part of risk management. Drivers normally know how to handle routine activities and going through the training is to make sure they are familiar with ADS and its possible malfunctions. Such program can be in any form, information session, certified program or even through hands-on workshops. The main objective is to prepare drivers to operate the system and vehicles, and the training should be arranged progressively. Upon completion of the training, drivers should know how to react to emergencies and be able to spot technical failure.

Another imperative element in safety management involves management of test drivers from business perspective. Such management should include retain safety standard during testing activities and writing incident reports when needed. Clear instructions should be given to drivers beforehand to avoid confusion. Prior to driving, drivers should be briefed with information that will be beneficial to them. They should be constantly or regularly updated about the modifications to the car they are driving as well. Such updates could be software updates or hardware updates and could also be testing techniques.

Driving and testing activities should always complying local law, such as speed limit, traffic light and using of mobile devices. Restrictions on hours that drivers can work consecutively should be followed, this is to proactive the safety-first policy.

C. Test Driver Workload

The scope of ADS test car drivers and non-ADS test car drivers are highly similar but with some additional requirements. For expert drivers, they need to be able to activate, monitor and de-activate ADS with and without hardware interfaces. Such activities are needed to be performed only when necessary. Emergency handling is another requirement, not only reacting to road emergency but also system emergency, such as technical failure. When the system is disengaged, drivers need to override the system and carry out non-automated operations.

Safety compliance requires that drivers must not percolate into vehicle testing when car is on the move and should not be assigned to handle other engineering activities simultaneously. Static testing, on the other hand, can involve test drivers and they could collaborate with other testing engineers.

For driver′s safety, the vehicle and the system should be able to alert the driver of malfunctions. The alerts are not limited to visual or audible warnings, could be both or even in other forms, and such warnings should be installed on the prototype car. These alerts together with malfunctions should be reported and recorded for further analysis.

D. Test Routes Planning

Since most of the testing activities are performed either on test tracks or public roads, many interrelated variables are needed to be taken into consideration. For instance, speed handling on wet or dry road during daytime and nighttime. If each condition is treated as one parameter, then a matrix could be formed by linking one parameter to another. Based on such matrix, almost all scenarios could be covered. However, some of the scenarios could be hypothesis and are not feasible, such scenarios could be eliminated during test routes planning.

In the context of testing, limitations exist as per automation levels, and such limitations need to be acknowledged during implementation and preparation phase. There are cases that need to deliberately interrupt the system, and such action should only be performed under safe and quiet circumstances.

Below are some suggestions of parameters that can be considered during test routes planning to build a matrix,

- *Type of road:* Freeway, expressway, driveway, intersections, roundabout
- *Timing:* Peak hour, non-peak hour, nighttime, daytime
- *Weather condition:* Dry, raining, snowing, windy
- *Season:* Spring, summer, fall, winter
- *Traffic:* Heavy vehicle, pedestrian, cyclist
- *Sign:* Speed limit, place of interest, directions, signals
- *Road condition:* Curb, slope, uphill, highway barrier
- *Location:* Car park, residential neighborhood, military base

Additionally, special testing in irregular environment should also be considered and only need to be carried out when condition permits. Testing on construction sites or testing during extreme weather conditions, these can also be added to the standard testing procedures providing that safety can be ensured.

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