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Autonomous vehicles' disengagements: Trends, triggers, and regulatory limitations

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ABSTRACT

Autonomous Vehicle (AV) technology is quickly becoming a reality on US roads. Testing on public roads is currently undergoing, with many AV makers located and testing in Silicon Valley, California. The California Department of Motor Vehicles (CA DMV) currently mandates that any vehicle tested on California public roads be retrofitted to account for a back-up human driver, and that data related to disengagements of the AV technology be publicly available. Disengagements data is analyzed in this work, given the safety-critical role of AV disengagements, which require the control of the vehicle to be handed back to the human driver in a safe and timely manner. This study provides a comprehensive overview of the fragmented data obtained from AV manufacturers testing on California public roads from 2014 to 2017. Trends of disengagement reporting, associated frequencies, average mileage driven before failure, and an analysis of triggers and contributory factors are here presented. The analysis of the disengagements data also highlights several shortcomings of the current regulations. The results presented thus constitute an important starting point for improvements on the current drafts of the testing and deployment regulations for autonomous vehicles on public roads.

1. Introduction

Autonomous Vehicle (AV) technology is quickly becoming a reality on US roads. Testing on public roads is undergoing in several states, including among others California, Texas, Nevada, Pennsylvania, and Florida. AV manufacturers are targeting different levels of autonomy, with semi-autonomous vehicles currently in the lead (Favarò et al., 2016).

In semi-autonomous vehicles, a human driver is allowed to co-operate with the software that acts as the "brain" of the vehicle and serves as back-up whenever the software autonomous technology (AT) disengages after a failure. Regulators and manufacturers abide by the classification of levels of autonomy as defined by the Society of Automotive Engineers (SAE), and as reported in Fig. 1, (SAE, 2014).

SAE defined 6 levels of automation, ranging from Level 0 (no automation) to Level 5 (full unrestricted automation). The definition of the six levels (rows of Fig. 1) are based on four factors (the four columns to the right of Fig. 1) as follows:

A The agent responsible for executing steering and throttle control: either human driver or AT;
B The agent responsible for monitoring the external environment: either human driver or AT;
C The agent responsible for serving as "back-up" when a failure prompts a disengagement of the AT: either human driver or AT;
D The driving modes in which autonomous operations are allowed: either "all modes of operations" (meaning unrestricted conditions) or "some mode of operations" (meaning pre-specified conditions, e.g., good visibility).

Levels 1 through 3 are regarded as "semi-autonomous" due to the fallback performance (or back-up) of the driving tasks placed on the human driver. Currently, fully-autonomous vehicles (Level 4 and Level 5) are not permitted deployment on the market (i.e., selling). All Levels of autonomy are permitted to test on public roads as long as they are retrofitted in a way that allows for a back-up human driver (California Department of Motor Vehicles (CA DMV), 2016). Such regulation was imposed by the California Department of Motor Vehicles (CA DMV) to allow AV manufacturers to test the capabilities of the AT that controls Level 4 and 5 vehicles, but at the same time increasing safety of the public by mandating the presence of a control driver who has to undergo a specific training (California Department of Motor Vehicles (CA DMV), 2016). The CA DMV is also in the process of issuing a new regulation for market deployment. The current draft highlights the role

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SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Fig. 1. AV levels of automation. Reproduced AS-IS with permission from SAE-International J3016™, (SAE, 2014).

of the human driver, who is responsible *"for monitoring the safe operation of the vehicle at all times, and must be capable of taking over immediate control in the event of an autonomous technology failure or other emergency"* (California Department of Motor Vehicles (CA DMV), 2015). The wording of the deployment regulation (California Department of Motor Vehicles (CA DMV), 2015) again indicates that Level 4 and Level 5 cars are not permitted on the market.

In addition to restricting the autonomy levels permitted on public roads and including the provision for steering wheel and pedals retro-fit during testing, the CA DMV also mandates that reports for AT disengagements during *testing* on state roads be drafted and made available to the public (California Department of Motor Vehicles (CA DMV), 2016). During disengagement of the autonomous technology (AT), the car control authority shifts from autonomous to manual mode, thus handing the control back from the software to the human driver.

Given the safety-critical role of AV disengagements, the authors initiated a study to analyze the entirety of the data filed by AV manufacturers to the CA DMV. Previous work by the authors (Favarò et al., 2016; Favarò et al., 2017) examined in detail all the situations in which AV collisions were reported. On average, 1 event every 178 disengagements leads to an accident (here defined as an actual collision with other vehicles or pedestrian or property). This average is obtained by dividing the total number of reported disengagements (which can be either manually or autonomously triggered) by the total number of reported accidents up to July 2017. The scope of the present work is thus to get an in-depth look at the disengagements reported data, and understand which are the most frequent contributory factors leading to a disengagement. Trends and specific contributions per manufacturer are also analyzed.

Additionally, the work looks at potential limitations and concerns with the current regulations posted by the CA DMV. In fact, the data provided by the AV manufacturers is somewhat fragmented and inconsistent, partially due to imprecise and loose verbiage in the current regulations. The analysis brought forward in this work highlights specific shortcomings that the authors hope will be taken into consideration by the CA DMV for a careful revision of current regulations.

The remainder of this paper is structured in the following way. Section 2 provides an overview of the reporters and of the disengagements database we constructed. Section 3 presents the core of the analysis of the disengagements contributory factors and the taxonomy developed for the study. Section 4 derives results in terms of disengagement frequencies and mileage driven before disengagement. Section 5 concludes this paper.

2. Overview of disengagements reporting

2.1. The notion of disengagement and limitations in its definition

Whether forced by design choices or due to insufficient information regarding the context of a particular situation, an autonomous car can suffer from what it is called a "disengagement mode". During disengagement, the full control and authority of the car movement is handed from the autonomous technology that acts as "brain" of the vehicle to the human driver.

The CA DMV currently mandates that reports for such disengagements during testing and/or field operations be drafted and made available to the public (California Department of Motor Vehicles (CA DMV), 2016). Currently, 36 companies between OEMs, tier-1 suppliers, and tech startups are listed and authorized by the California Department of Motor Vehicle for testing on public roads (full list at https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing). As of July 2017, only 11 manufacturers have reported disengagements.

The data archive (available at (CA DMV, 2017a)) includes scanned copies organized by manufacturer of all disengagement reports occurred during testing on CA public roads between September 2014 and January 2017. The manufacturers' list includes: Bosch, Delphi