Toward Defining Driving Automation from a Human-Centered Perspective

Ji Hyun Yang
Kookmin University
Seoul, Republic of Korea
yangjh@kookmin.ac.kr

Jimin Han
Hyundai Motor Group
Seoul, Republic of Korea
jimin.han@hyundai.com

Jung-Mi Park
Hyundai Motor Group
Seoul, Republic of Korea
jungmi@hyundai.com

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the Owner/Author. Copyright is held by the owner/author(s).

CHI'17 Extended Abstracts, May 06-11, 2017, Denver, CO, USA

ACM 978-1-4503-4656-6/17/05.
http://dx.doi.org/10.1145/3027063.3053101.

Abstract
This paper aims to redefine the unfamiliar and ambiguous ideas related to autonomous driving such as “Is it permissible not to hold the steering wheel during autonomous driving?”, “Should the driver keep his/her eyes looking forward?”, “Can the driver sleep?”, “Is distraction always or sometimes possible?”, and “To what extent are non driving-related activities allowed in the autonomous vehicle?” These types of issues are examined from the viewpoint of drivers, not from automotive technical experts. In addition, after re-defining human-centered automation, this paper intends to analyze and compare it with the levels of tech-focused automation and utilize it as an indicator for needs of novel HMI(Human-Machine Interface)s of autonomous vehicles.

Author Keywords
Levels of automation; autonomous vehicles; human-centered; technology-centered; non driving-related activity.

ACM Classification Keywords
I.2.9. Artificial Intelligence- Robotics: Autonomous Vehicles; H.1.2 Information Systems-User/Machine Systems; Human factors.

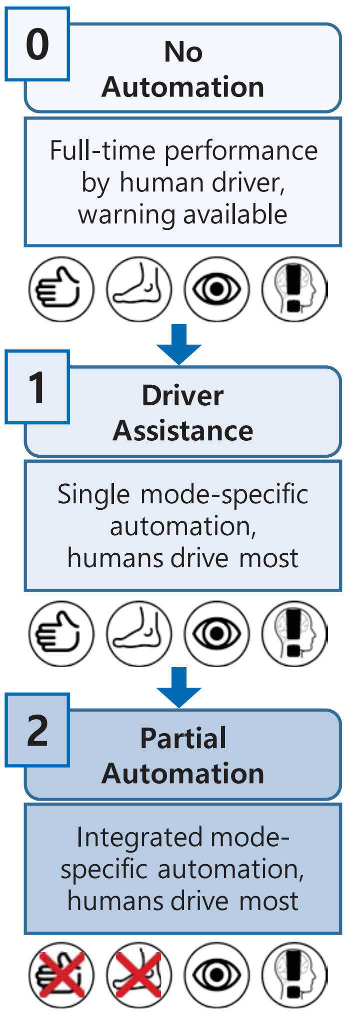

Figure 1: Tech-focused levels of automation Levels 0-2 (Modified from [2])

Introduction

Daimler-Benz AG acquired operational permission for a commercial autonomous vehicle in Nevada, U.S. for the first time in the world and an Audi A7 was driven safely for approximately 900 km from Silicon Valley in California to Las Vegas using autonomous driving technology. Hyundai Motors conducted a road driving exercise with a Genesis EQ900 vehicle equipped with an autonomous driving feature on Yeongdong Street in Seoul, Korea on November 2015. BMW published many papers describing technologies and lessons learned from their autonomous vehicles [4]. Several automotive manufacturers, suppliers as well as IT companies that used to seem uninterested in the automobile market are eagerly participating in the development of autonomous vehicles. Google's autonomous vehicle, which has been driven in autonomous mode almost 3 million kilometers as of July 2016, is also well known to the general public, and Tesla, which is famous for electric vehicles, also has developed and commercialized the partial autonomous driving function. In the meantime, various issues regarding autonomous vehicles continue to be raised and the fatality that occurred in Florida, U.S. on May 2016 while the autonomous function was being used has increased public awareness and concern about this matter [9].

The purpose of this paper is to review some of the research issues that have been overlooked as the focus on the trending technology called "autonomous driving" has grown and to examine points related to law and ethics. As previous literatures pointed out [5,11], automation is not a newly emerged technology, and it should be treated carefully by the human driver as a back-up system due to possibilities of weakened total performances. Moreover, unlike other fields including aviation or nuclear power, autonomous vehicles could be more dangerous with non-professional drivers. Test drives of automakers or policies developed by various governments have not elaborated these differences and expected behaviors of drivers. Even though the most recent reference [3] recommends automakers to publish a description of ODD (Operational Design Domain) on the owner's manual, it does not give drivers a clear understanding of potential behaviors inside vehicles. It only describes proper conditions of the system such as geographical location, roadway type, speed, or weather. By defining human-centered levels of autonomous vehicles and elaborating their feasible scenario, ambiguous questions such as "Should the driver keep his/her eyes looking forward?", "Can the driver sleep?", "Is distraction always or sometimes possible?" are answered in this paper. Expected HMIs which can support those non-driving related activities are also addressed.

Tech-focused levels of autonomous vehicles: Limiting driver behaviors

The levels of autonomous driving have been defined by various organizations, and one of the most widely used standards is the definition presented by SAE International [2] that utilizes 6 levels from Level 0 to Level 5.

SAE Level 0 is no-automation and the driver takes full responsibility for lateral and longitudinal control of the vehicle in the manner that we drive currently. The driver carries out all vehicle controls from the time of entry into the vehicle until exiting the vehicle. The vehicle can only send an alarm signal to the driver and the driver carries out all vehicle controls. The lane

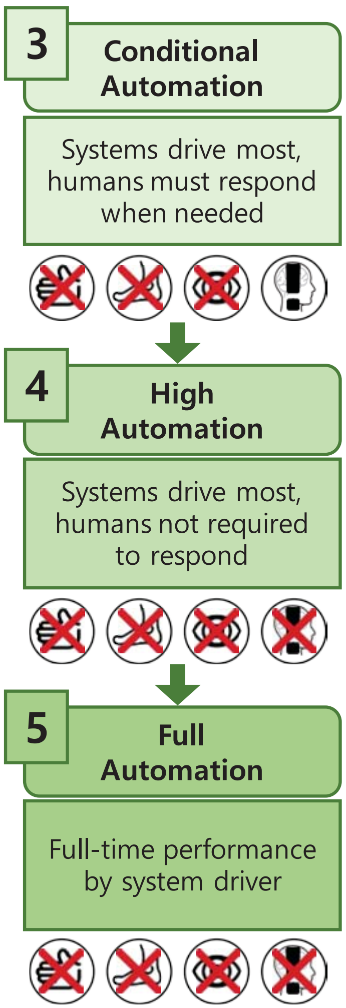

Figure 2: Tech-focused levels of automation Levels 3-5 (Modified from [2])

departure warning system (LDWS) and the front collision warning system (FCWS) fall under Automation Level 0. Level 1 is called “driver assistance” or “mode-specific automation” and Level 2 is called “partial automation.” In Level 1, the driver controls the vehicle most of the time, whereas the vehicle provides one or more specific control functions. In Level 2, the vehicle has the capability to integrate at least two primary control functions. For example, lane keeping assistance system combined with adaptive cruise control system can be thought of as a Level 2 autonomous vehicle.

Whereas human drivers are in charge of monitoring environments in Levels 0 to 2 (Figure 1), automated driving systems are expected to monitor environments in Level 3 to 5 (Figure 2).

Level 3 is called “conditional automation” and Level 4 is regarded as “high automation.” Automated driving systems perform all aspects of the dynamic driving tasks for both Level 3 and Level 4. However, the human driver is expected to respond appropriately when cued by the automated system and some occasional control is required and available to the driver under a specific traffic condition in Level 3. In contrast, the same appropriate human response is not required in Level 4. For example, the Google car can be considered an example of Level 3 automation [8]. Level 5 is full automation, where an automated system can handle all roadway and environmental conditions that can be managed by a human driver.

Similarly, levels of automation were classified by U.S. NHTSA [1] and BASt in Germany [6], and the automation levels and terms of each definition are compared in [14] as reference. Such levels of automation are presented from the viewpoint of vehicle technology development or policy development, so the initial point (i.e., Level 0) is the “current” vehicle technology. Such a viewpoint considers the advancement of active safety systems technology as the development of autonomous driving technology. This philosophy is further outlined in Figures 1 and 2. The main idea of the increase of the automation level corresponds to the addition of the technology or driving function from Levels 0 to Level 5.

Human-centered levels of automation: Incorporating drivers into the system

Various autonomous vehicles are being developed in diverse forms, and no social agreements or concrete definitions have been established yet. Any researcher or worker engaged in this field has likely experienced misunderstanding when discussing the same vehicle automation level due to confusion over automated vehicles or driving concepts. We think the main reason for the confusion originates from discrepancies regarding driving entities. At each level, the relationship and responsibilities between human and automation systems are not clearly defined. Sometimes we interchange the belief that either the human driver or the vehicle technology is the control authority. Transposing the idea of the control authority may be determined at a subconscious level by each individual, thus creating confusion. Therefore, limitations regarding existing tech-centered levels of automation when beginning this autonomous driving HMI study were recognized. In response, it was deemed necessary and urgent to define clearly human-centered levels of automation.

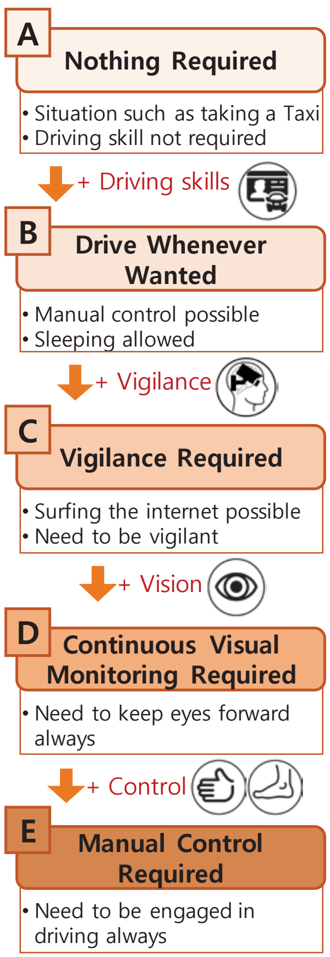

Figure 3: Human-centered levels of automation HuLOA Levels A-E

With this in mind, the paper defined the human-centered LOA (levels of automation). The acronym TeLOA and HuLOA are used to distinguish the term from the technology-centered LOA (TeLOA) and human/driver-centered LOA (HuLOA). The HuLOA suggested in this paper is classified into five levels: A, B, C, D, and E (Figure 3). Each level includes distinct user values and identifies typical driving-related and non driving-related activities to facilitate understanding. While most of activities are not primary or secondary driving tasks, we follow the concept from previous studies [7,12]. Accordingly, we can elaborate on novel interiors and HMIs of future vehicles supporting user behaviors as well as alternative activities of drivers.

From the perspective of the vehicle UX, Level A is a similar case of riding in a taxi or a vehicle operated by a chauffeur. That is, the role of the driver is replaced by an autonomous system. With this, passengers or users neither require driver's licenses nor credentials to drive a vehicle. In such a case, a vehicle can be operated by the autonomous driving mode only and human intervention is *not* allowed. A user does not need to be mindful about driving, filling up the gas, and vehicle maintenance. An example of a non driving-related activity is a teenager, who, without driver’s license, can ride in a vehicle waiting to take him to and from school in the morning and afternoon. Similar to current taxi and rideshare services, vehicles at this level need HMIs supporting schedules, remoted controls, and estimated times for departure and arrival.

Unlike Level A, Level B requires legitimate drivers. That is, only persons with a driver's license are allowed in the vehicle operator seat and manual driving is available only if desired by the driver. For example, drivers can use the Level B vehicle as if using a Level A vehicle, or drive at their discretion. If the driver feels tired and incapacitated, the autonomous driving mode can be used throughout the duration of the trip. Scenarios in which this level with non-driving activities can be appreciated include drivers who experience fatigue, sleepiness, or are in traffic jams. After drinking, drivers can rely on vehicles to return home safely. If TOR (take-over request) is activated in this particular situation, vehicles can drive sideways to stop, or send requests to V2X centers remoted driving. HMIs on this level have the capability to recognize and evaluate the driver’s condition and whether or not they can handle TOR.

Unlike Level B, Level C requires the human driver/passenger to be vigilant at *all times*. Continuity is one of the main differences between response capability in TeLOA and vigilance in HuLOA. Level C enables reading or web browsing while driving, but not sleeping or drinking. That is, the level C is limited autonomous driving and its sensor detects and alerts emergency and unexpected situations to the driver. This may result in a situation where the driver may have to take over the vehicle control even if he or she does not want to. Non driving-related activities of this level include various infotainment features to help drivers stay awake and focused. Reading, watching, and listening behaviors are allowable, whereas drinking and/or sleeping are not. Among cognitive or visual demands, better efficient activities pertaining to TOR have not yet been identified [7]. When TOR is active, HMIs must prompt drivers to take control of vehicle operation appropriately and in a timely manner. Multiple screens and physical seat adjustments can be utilized most in this situation.

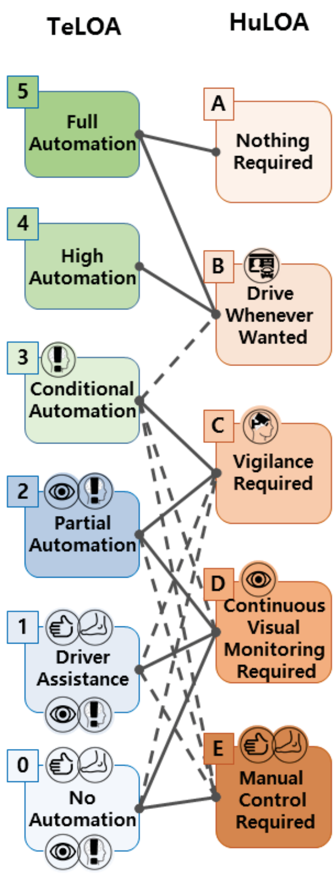

Figure 4: Connection between tech-focused levels of automation (TeLOA) and human-centered levels of automation (HuLOA). Solid lines: high-level correspondence; Dotted lines: low-level correspondence

Compared to Level C, Level D always requires human vigilance on road. That is, the autonomous driving function always requires the human driver to keep eyes on the road even when car lanes or speed are maintained or controlled autonomously. In the event of an oncoming danger the driver must be able to perform safe driving functions, such as detection and avoidance of dangerous situations. Currently, some vehicles follow "both hands on the wheel" rule. Along these lines, some HMI technology enact a role to make sure that drivers focus on driving, e.g., tracking head positions, gaze points, workload measurement, or augmented reality. In Level D, most of non-driving related activities are not allowed.

Level E has no autonomous driving function related to driving, which requires manual control, including monitoring of the driving situation, detecting dangerous situations, determining the appropriate response, and controlling the vehicle.

The starting point of TeLOA was the current status of the vehicle, i.e., Level 0. While mandatory behaviors are not expected at all, HuLOA sets the reference point from the viewpoint of free human status, rather than from the vehicle perspective (technical status). TeLOA is a classification based on technical criteria while HuLOA is based on minimum driving-related activities and responsibilities.

We examined the connection between Levels 0 to 5 of TeLOA and the Levels A to E of HuLOA. Consequently, TeLOA and HuLOA do not form a one-to-one correspondence. Rather, they show an *n*:*n* correspondence or partial correspondence.

As shown in Figure 4, the relevancy of each level of TeLOA and HuLoA is marked in solid lines or dotted lines. Although it is not clearly and quantitatively distinguished, the solid lines represent the case where the correspondence for each level is high, and the dotted lines represent the case where the characteristics for each level show partial correspondence.

For example, the Level 0 "Danger Warning" of TeLOA corresponds with Levels C, D, and E of HuLOA. That is, it requires manual control (Level E), continuous visual monitoring (Level D), and required Vigilance (Level C). While Level B (human operation allowed as desired) of HuLOA corresponds to Level 4 of TeLOA, the characteristics of Level 3 (conditional automation) also partially correspond with Level B.

The definition of autonomous driving vehicles should be refined further depending on technology and policy development. Hence, the current study aims to experiment with TeLOA and HuLOA to compare the connection with human understanding from the HMI perspective. We also expect that the working relationship between human and the automation system will be addressed; this relationship is mainly considered as a "collaboration" rather than as "supervision" as previous literatures [5,11] have inferred. If HuLOA proves to be an effective model in the future, many autonomous driving HMI will need to be re-designed. For example, the owner's manual should be re-written in terms of human perspective rather than sensor operation. When humans deal with automated systems, they should know the status of the automated system and be prepared for cooperative tasks. Each level of TeLOA, including several levels of

HuLOA, means human drivers need to actively transform their status inside the same vehicle. Moreover, while levels of HuLOA are distinguished based on physical, mental, and behavioral capabilities, it is natural that the transition to different HuLOA levels needs sufficient time and systematic help.

Conclusion

It is commonly believed that future smart vehicles, including autonomous vehicles or unmanned vehicles, will replace the previous role of drivers or operators to the extent that the role of human factors in the whole smart car system has not been fully recognized – in contrast to the development of sensor or autonomous driving technology. However, as shown in a study in the 1970's [13] that indicated that the traditional role of a driver would change (instead of disappear) as a result of automation, a new relationship between humans and systems is being established due to the introduction of smart/advanced automation/unmanned technologies. Accordingly, various challenges, such as consistent reliability between each element, communication and task re-allocation have arisen. For example, studies on vehicle collision countermeasure systems revealed that understanding of driver-vehicle interaction was essential for the development of smart vehicles. This was established upon finding that the driver's cognitive-behavior patterns with respect to the algorithm was a crucial factor that determined the performance of all collision prevention systems even when perfect sensor and radar performance was assumed [15].

The same hypothesis applies to the study and development of autonomous vehicles. Based on the driver-centered levels of automation introduced in this paper, we are designing an experimental comparison study. The simulated experimental result is expected to be analyzed in a follow-up article. To conduct a qualitative evaluation, we are planning a driver survey (n=30) or expert focus group interview. In this survey participants will brainstorm the many kinds of activities that drivers can be engaged in while a vehicle is moving according to each level of TeLOA and HuLOA. After that, they will discuss the reasons why activities are different between TeLOA and HuLOA. Simulating driving environments of each TeLOA and HuLOA level is concurrently being examined to validate HuLOA quantitatively, assess systematic TOR, and study communication between the driver and the vehicle. In order to prevent human error in autonomous vehicles, the method and purpose of driver-vehicle communication is important in order to know each other's status. Research topics such as HMI's ability to perceive driver status for TOR, designing prior environments for TOR, and confirming HMI for notified states of automation are being pursued based on the HuLOA system.

Acknowledgements

This work was supported by the Hyundai Motor Group Academy Industry Research Collaboration. The first author was partly supported by Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Science, ICT, and Future Planning (2014R1A1A1002037). We are grateful to Mr. Boo Yong Ahn and Mr. Sung Lae Kim for supporting literature survey and illustration work.

References

1. NHTSA. U.S. Department of Transportation Releases Policy on Automated Vehicle Development.

2013. Retrieved September 19, 2016 from http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development

2. SAE International. Taxonomy and definitions for terms related to On-Road motor vehicle automated driving systems. 2014. Retrieved September 19, 2016 from http://www.sae.org/misc/pdfs/automated_driving.pdf
3. The U.S. Department of Transportation. Federal Automated Vehicles Policy. 2016. Retrieved from https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016
4. Aeberhard, Michael, Sebastian Rauch, Mohammad Bahram, Georg Tanzmeister, Julian Thomas, Yves Pilat, Florian Homm, Werner Huber, and Nico Kaempchen. 2015. Experience, Results and Lessons Learned from Automated Driving on Germany's Highways. *IEEE Intelligent Transportation Systems Magazine* 7, 1: 42-57.
5. Robert N. Charette. 2009. Automated to Death. Retrieved March 27, 2009 from http://spectrum.ieee.org/computing/software/automated-to-death
6. Tom M. Gasser and Daniel Westhoff. 2012. BASt-study: Definitions of Automation and Legal Issues in Germany. In *Proceedings of Road Vehicle Automation Workshop.* Retrieved from http://onlinepubs.trb.org/onlinepubs/conferences/2012/Automation/presentations/Gasser.pdf
7. Christian Gold, Lutz Lorenz, Mehdi Farid, and Klaus Bengler. 2014. How Traffic Situations and Non-Driving Related Tasks Affect the Take-Over Quality in Highly Automated Driving. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 58, 1: 2063-2067.
8. Yeong I. Gong. 2013. Trends and Direction of Google Car, vol. 25. KISDI, Korea.
9. Jim Kerstetter. 2016. Daily Report: Tesla Driver Dies in 'Autopilot' Accident. Retrieved September 19, 2016 from http://www.nytimes.com/2016/07/02/technology/daily-report-tesla-driver-dies-in-autopilot-accident.html?_r=0
10. Jae G. Lee. 2015. Trends and Implications of Autonomous vehicle. KATECH, Korea.
11. Don Norman. 2015. The Human Side of Automation. *Road Vehicle Automation 2*: 73-79. Retrieved from http://www.jnd.org/dn.mss/the_human_side_of_au.html
12. B. Pfleging, A. Schmidt. 2015. Driving-Related Activities in the Car: Defining Driver Activities for Manual and Automated Driving. *Proceedings of CHI'15. Workshop on Experiencing Autonomous Vehicles.*
13. Thomas B. Sheridan and William R. Ferrell. 1974. Man-Machine systems; information, control, and decision models of human performance. The MIT Press.
14. Bryant W. Smith. 2013. SAE Levels of Driving Automation. Retrieved September 19, 2016 from http://cyberlaw.stanford.edu/lod
15. Lee Yang, Ji Hyun Yang, Eric Feron, and Vishwesh Kulkarni. 2003. Development of a Performance-Based approach for a Rear-End collision warning and avoidance system for automobiles. In *Proceedings of Intelligent Vehicles Symposium*, 316-32