DOI:10.1145/3506574

Yu-Ju (Tony) Tu, Shari S. Shang, and Junyi Wu

Viewpoint
Is Your Autonomous Vehicle as Smart as You Expected?

Suggesting a better route to evaluate autonomous vehicles' smartness.

IMAGE BY OPEN STUDIO

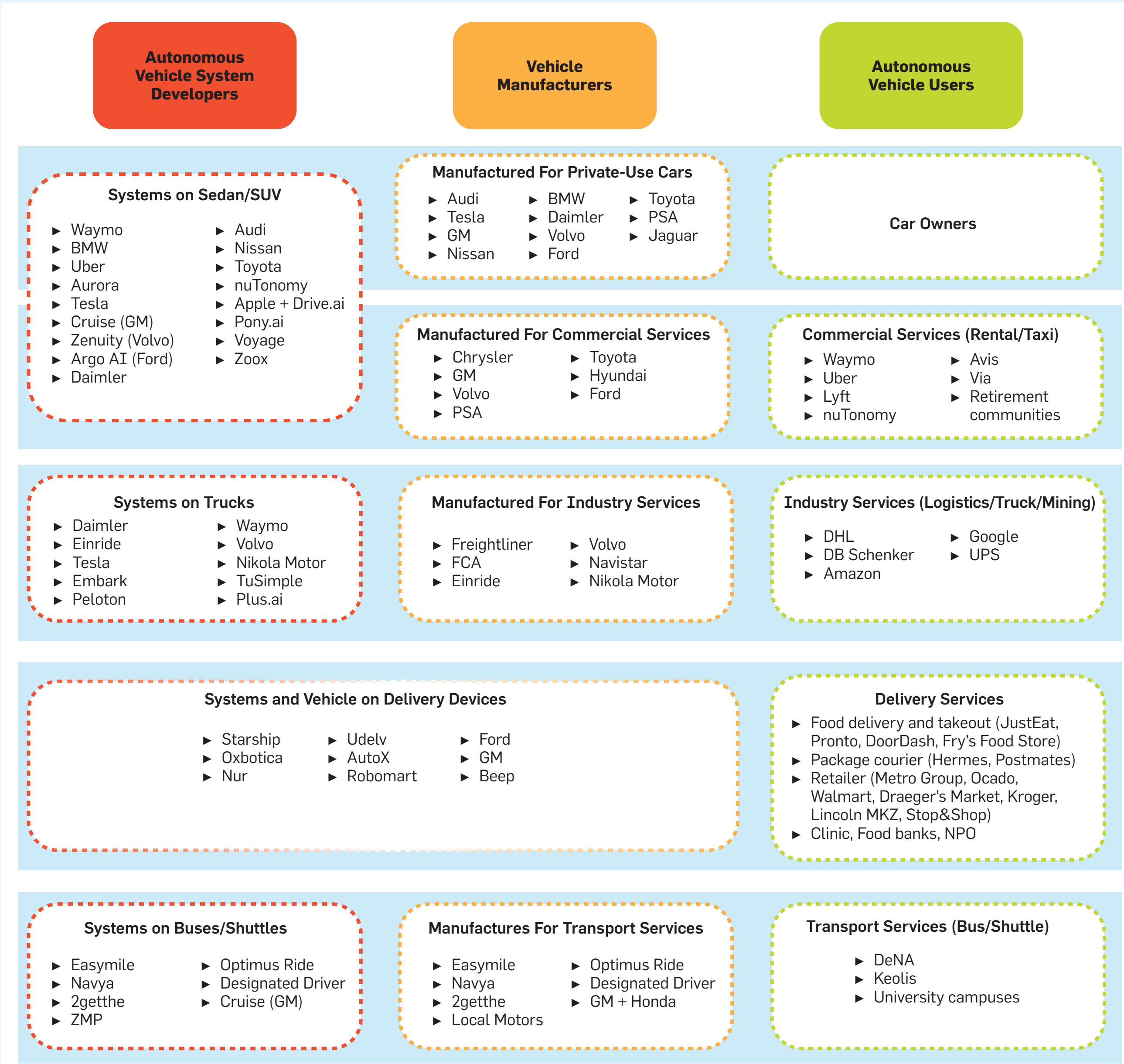
If your vehicle were self-driving on the road, will it crash into a truck towing a trailer as Tesla did in March 2019?[a] Despite the fatal accidents involving autonomous vehicles, such vehicles represent an unstoppable trend that will reshape the world. In this Viewpoint, we highlight why current autonomous vehicles would not be preferred by their users. Furthermore, we present a concise framework for profiling the characteristics of various autonomous vehicles based on intelligence quotient (IQ), ethical quotient (EQ), and adversity quotient (AQ).

As presented in Figure 1, there are already major players focused on the automated driving market. In the next several years, millions of self-driving cars are going to hit the road, prompting tremendous business opportunities for what is referred to as "Mobility-as-a-Service" (MaaS).[b] However, public concerns regarding autonomous vehicles' "smartness" are escalating. For example, although some major players, such as BMW and Ford, have announced an upcoming rollout of their best models, does this mean that their autonomous vehicles have fixed all of their "smartness" problems? In other words, will autonomous vehicles be able to understand and deal with any object on the road and adapt to most environmental constraints when they are available for purchase? Will the vehicles be capable of "sacrificing themselves" for the greater good? As such, the level of autonomous vehicles' smartness remains a big question that has yet to be fully realized, especially considering the fact that almost each autonomous vehicle model has very different characteristics.

Simply speaking, autonomous vehicles are cars that employ sensor, computer, machine learning, or artificial intelligence (AI)-based systems to support automated driving decisions in regards to steering, changes in speeds, and monitoring the environment.[2] It is thus no surprise that almost all of the main players in automated driving are working hard to showcase their best equipment specifications (see the accompanying table). For example, Waymo's Level 4 autonomous vehicles are not equipped with radar, while Tesla's Level 4 autonomous vehicles are equipped with radar. Moreover, it is worth noting that both autonomous vehicles will also have different types of CPU, GPU, and SoCs (system-on-a-chip) as their different computing solutions. However, it remains challenging to gain a clear picture of autonomous vehicles' "smartness" by simply comparing their equipment specifications. After all, the quantity or specification of these items are not equivalent to any meaningful rankings. According to the Society of Automotive Engineers (SAE),[c] autonomous vehicles at Level 5—the highest—should be capable of handling all

a BBC (2019); https://bbc.in/3GN7Sh9
b Intel (2017); https://intel.ly/3pWDcDk
c See https://bit.ly/3oZFbaC

Figure 1. Major autonomous vehicle players (as of Jan. 11, 2021).*



* See https://bit.ly/31VfT4Z

roadway and environmental conditions managed by human drivers regardless of geographic location, roadway type, weather, speed, day and night conditions, and so forth. This means that autonomous vehicles' smartness relies upon their driving decisions as compared to human decisions.

We thus suggest that one smarter way to ascertain autonomous vehicles' smartness is to assess IQ, EQ, and AQ. In our definition, the smartness refers to the capability of an autonomous vehicle for satisfying its users' technical, social and environmental expectations in driving. First, an autonomous vehicle's IQ reflects the dimension for assessing how it could "see and understand" as much as possible in making driving decisions. An autonomous vehicle's IQ involves multiple subdimensions, such as detection, identification, risk analysis, and reaction and execution that together form a set of process-oriented indices for consideration. Inarguably, the IQ is directly associated with the type or quantity of sensor, processor, and so forth, however, the key point is the integration of such IT components for generating a useful perception of reality and enabling a safe driving experience. For example, the finding of Tesla's fatal crash in May 2016 indicates that, although the car detected a laterally crossing white truck in its path, it identified the truck as bright sky. Moreover, despite the fact that some autonomous vehicles can detect and identify road signs, pedestrians, and even bicycle riders' hand gestures,[d] they can barely "understand" the risk of bumping into a nearby kangaroo. This is because when a kangaroo hops in the air, it may be perceived as farther away

d ABC (2017); https://ab.co/328ZCsC

by some autonomous vehicles. In considering another Tesla's fatal accident in March 2018,[e] it was widely reported that no action was taken to stop the car before it crashed into a traffic barrier. More recently, in 2020,[f] the U.S. National Transportation Safety Board (NTSB) published its final report regarding Tesla's fatal crash in March 2019. According to NTSB, "Contributing to the crash was the operational design of Tesla's partial automation system, which permitted disengagement by the driver … " These examples signify the importance of assessing an autonomous vehicle's capability of detecting/identifying danger, analyzing risk, and mitigating it.

Second, an autonomous vehicle's EQ represents a dimension for accessing how an autonomous vehicle could "value what matters," as compared to a human driver with respect to making ethical decisions. These decisions may involve pedestrians' or other vehicle occupants' lives and deaths. The main difference between IQ and EQ is that, unlike EQ, IQ does not deal with ethical issues. For example, the trolley problem is a driving situation that any autonomous vehicle would face. There are two equally feasible solutions to this problem: sacrificing a passenger for saving pedestrians or sacrificing pedestrians for saving a passenger. Essentially, choosing either solution one or two requires an ethical decision and, therefore, falls within the domain of EQ. By contrast, although IQ may determine the optimality of road object detection, identification, risk analysis, and the related technical issues, its scope does not involve considering the importance of pedestrians' lives.

The EQ may be associated with several subdimensions, such as the utilitarianism principle, the legitimacy principle, and the social responsibility principle, which together form a series of descriptive indices for consideration. Fundamentally, when facing emergency situations, human drivers depend on individual value systems (for example, economic utility functions) to establish a priority in deciding what can be sacrificed. In other words, a smarter autonomous vehicle should have priorities for guidance in making emergency driving decisions, especially decisions involving the distribution of harm.[1] Mercedes-Benz once announced that the company's future Level 4 and above autonomous vehicles would always prioritize their own passengers regardless of any road situation. This means if there are options involving degrees of distributable harm, Mercedes-Benz autonomous vehicles will always choose to sacrifice pedestrians or any people outside the vehicle, while Audi and Volvo have both stated that their autonomous vehicles will not follow these same ethical algorithms in distributing harm.[g] Moreover, such examples also highlight the importance of considering the legitimacy principle in accessing an autonomous vehicle's EQ. Obviously, any autonomous vehicle decision making in an emergency situation may inevitably come at the cost of violating legal driving rules. On the other hand, if some autonomous vehicles are designed to always uphold legitimacy, it means such vehicles will never break any traffic rules for saving lives. Last but not the least, as autonomous vehicles' social responsibility is an emerging issue, smarter autonomous vehicles should be capable of dealing with such responsibility.

Generally, when any new mechanical and technological device is developed, ethical concerns always exist about its impact on social-ecological sustainability, and people have different concerns and interpretations about such an impact. For example, it is very common that, because of different concerns regarding fuel consumption or ecological protection, some human drivers in identical conditions would make different driving decisions even when it may not be necessary, such as maintaining a lower or higher driving speed or parking closer or further from a destination. According to an important study,[h] several critical issues for autonomous vehicles in the sustainable mobility ecosystem center around the trade-offs between driving efficiency and ecologi-

e Tesla (2018); https://nyti.ms/31WuCwz

f Zdnet (2020); https://zd.net/3GM2ydW

g Mercedes-Benz (2016); https://bit.ly/33u22Tn

h University of Michigan (2018); https://bit.ly/3dWvD9Y

Autonomous vehicles' systems specifications (announced by major companies as of Jan. 10, 2021).

System Developers	Vehicle Models	Automated Driving Levels	Sensor System Specifications				Target Time On the Road
			Camera	Ultrasonic Sensor	Radar	Lidar	
Audi	Audi A8 sedan	Level 3	4+1	12	4+1	1	TBA
Autonomous Intelligent Driving	TBA	Level 4	*				2021
Tesla	Tesla Model 3, S, X, Y	Level 2	8	12	1	n/a	Launched
Autopilot, Full Self-Driving		Level 4					TBA
GM Cruise	Cadillac CT6, CT5	Level 2	1+1	10	1+2+3	n/a	Launched
Nissan	Altima, Rogue	Level 3	7	12	5	n/a	Launched
ProPilot 2.0	Nissan Leaf	Level 5	7	n/a	1	8	TBA
Volvo Zenuity	XC90 SUV	Level 3	4+1	12	4+2	1	2022
Ford Co-Pilot 360 2.0	Mustang Mach-E	Level 4	*	n/a	5	1	2021
BMW	iNext	Level 3	4+1	*	*	1	2021
		Level 5		*			2024
Mercedes-Benz Drive Pilot	A-Class ~ S-Class	Level 4	*	*	4+1	1	2024
Waymo	FCA Pacifica minivans	Level 4	8	n/a	4+1	2	TBA
	Jaguar I-Pace SUV		29	n/a	*	1	TBA

* The exact quantity is not specifically designated

Figure 2. Smartness quotients of autonomous vehicles.

cal impact—for example, energy usage and greenhouse gas emissions. This suggests smarter autonomous vehicles cannot be exempt from social responsibility, which includes the principles regarding trading driving efficiency for ecological impact and vice versa.

Third, an autonomous vehicle's AQ pertains to a dimension for assessing an autonomous vehicle's environmental adaptability or an autonomous vehicle's response to abnormal situations. The main difference between IQ and AQ is that AQ focuses on driving under environmental resources constraints or normal situations while IQ does not. For example, when external resources such as the Internet are all available or operating under normal constraints, the performance criteria, such as road object detection, identification, and risk analysis, falls within the domain of IQ. However, it is not rare that the Internet and others operate under extreme constraints or are even unavailable on occasion because they are generally uncertain resources, making it difficult for any autonomous vehicle to perform normally. AQ applies to these situations.

Similar to those sub-dimensions associated with the IQ and EQ, the sub-dimensions of an autonomous vehicle's AQ may include the adaptability to abnormal ICT (Information and Communication Technology) infrastructure conditions, road conditions, and information security conditions. These aspects together can form a set of distinctive and complementary indices. There is no doubt that smarter autonomous vehicles should have the ability to adjust to different environments where the quality of the ICT infrastructure may be inconsistent. For example, when GPS is not available for guiding autonomous vehicles in places such as tunnels or rural areas, given such situations, most human drivers can find directions and routes. Relatedly, most human drivers contingently adjust their regular driving patterns by changing lanes and speed limits to respond to unexpected situations on the roads such as bad surfaces conditions, animals, or pedestrians in their paths, or vehicles that disobey traffic rules. Thus, smarter autonomous vehicles should be adaptive to various road conditions to reduce the probability of causing any accident. Lastly, it is foreseeable that information security will be an important subdimension to consider in accessing an autonomous vehicle's AQ. For example, it has been proposed that malicious people can easily spoof autonomous vehicles' sensors by manipulating or transducing the input for GPS and Lidar.[3] Moreover, whenever an autonomous vehicle is connected to the Internet, it is the potential target of cyberattacks. In other words, smarter autonomous vehicles should also possess the ability to address security threats.

Conclusion

The IQ, EQ, and AQ as a whole (summarized in Figure 2) are a useful framework that covers the technical, social, and environmental perspectives for defining and clarifying the meaning of autonomous vehicle smartness. Using the terms of IQ, EQ, and AQ is mainly to facilitate communication. Without any detailed explanation, many people understand these terminologies conceptually denote multiple important capability dimensions and any of them should not be ignored. However, we do not intend to relate these terminologies to the issues such as anthropomorphizing artificial intelligence or machines learning.

Moreover, the three dimensions of IQ, EQ, and AQ in our proposed framework cannot replace each other. The smarter autonomous vehicles should not concentrate on one while ignoring the others. For example, it is very unlikely that any autonomous vehicle can possess greater EQ or AQ without any IQ improvement in a practical manner. Relatedly, the framework could be easily applied in any context for profiling autonomous vehicles, but we do not mean to label any specific brands or types of autonomous vehicles as inferior or superior to others.

Finally, what we have presented in this Viewpoint is also very valuable to considerable stakeholders in the automated driving market (for example, as shown in Figure 1) in terms of contrasting the characteristics of their autonomous vehicles and those of their competitors. In our opinion, there is no way to make the perfect and infallible autonomous vehicle. Autonomous driving is far more complicated and sophisticated than automatic chess playing, and ambiguous zones always exist. As such, not only technical issues (for example, IQ) but also social and environmental issues (for example, EQ and AQ) are very critical to advancing autonomous vehicles. **C**

References

1. Bonnefon, J.-F., Shariff, A., and Rahwan, I. The social dilemma of autonomous vehicles. *Science 352* (6293), 1573–1576; doi: 10.1126/science.aaf2654
2. Knight, W. Machine learning and data are fueling a new kind of car. *MIT Technology Review* (Mar. 14, 2017); https://bit.ly/3m7kbgw
3. Takefuji, Y. Connected vehicle security vulnerabilities. *IEEE Technology and Society Magazine 37*, 1 (Jan. 2018), 15–18.

Yu-Ju (Tony) Tu (tuyuju@nccu.edu.tw) is an associate professor of MIS, College of Commerce, National Chengchi University, Taipei, Taiwan.

Shari S. Shang (sshang@nccu.edu.tw) is a professor in the Department of Management Information Systems at National Chengchi University in Taipei, Taiwan.

Junyi Wu (99356506@nccu.edu.tw) holds a Ph.D. from the Department of Management Information Systems at National Chengchi University in Taipei, Taiwan.