THE CHARACTERIZATION OF AN ETHICAL SAFETY STANDARD FOR THE AUTONOMOUS VEHICLE (AV) FIELD: HOW WILL HUMAN SAFETY BE PRIORITIZED?

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By

Jaspreet Ranjit

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR
Catherine D. Baritaud, Department of Engineering and Society

HOW STANDARDS ARE FALLING BEHIND THE RAPIDLY GROWING AV FIELD

With the autonomous vehicle (AV) field growing rapidly at a compound annual growth rate of 18.06% (Mordor Intelligence, 2020), developers often overlook moral considerations regarding safety in favor of faster development and enhanced features. In the past five years, AVs have provided a lucrative market for investors with technology giants and start-ups investing more than 50 billion USD (Mordor Intelligence, 2020). Autonomous vehicles also potentially have incredible social benefits, namely offering a safer automobile for users. However, in order for consumers to develop trust in this new technology, developers and manufacturers need to develop reliable methods to demonstrate the safety the AV design provides.

Cho and Behl (2020) analyzed the development of safety standards amongst various AV manufacturers. They found that it is nearly impossible to compare the safety level provided by two AVs from different manufacturers. The plethora of safety standards makes it difficult for a consumer to make an informed decision about purchasing an AV. However, it also makes it difficult for developers to identify shortcomings in their designs. Although manufacturers will be most inclined to use metrics that portray their design more favorably in the competition landscape, competing standards can make it challenging to identify how AVs compare in terms of performance and safety. The introduction of a standard safety certification scheme will serve as a baseline for competing AV developers to identify where their designs fail compared to others and will instill more trust in consumers by providing a transparent evaluation of their vehicles (Winkle, 2016, p. 340).

With human life at risk, it is critical to outline the characteristics of a standardized safety certification scheme for AVs, and discuss how it will prioritize human safety while still maintaining optimal performance. The primary motivation of this research project is to propose a safety certification scheme that is grounded in moral principles and serves as an ethical guideline for developers in the AV field. The development of these ethical guidelines will be viewed through the lens of the Social Construction of Technology framework (Bijker & Pinch, 1987, p. 40) and the 11 guiding principles suggested by Busch (2013) in "Standards: Recipes for Reality" (p. 289) will serve as a guideline to construct the requirements of the safety certification scheme. The 11 guiding principles are a subset of the Social Construction of Technology framework where the relevant social groups for autonomous vehicles will be identified in order to develop guidelines that serve the interests of these groups. These principles prioritize moral considerations regarding safety rather than optimization and highlight fairness, equity, and effectiveness as keys to a balanced standard for AVs. The outline presented in this paper does not limit the specificity of the certification scheme; rather, it provides critical principles that the safety standard must consider.

This STS research paper will examine and evaluate the results of the technical project. The goal of the technical project was to develop a quantifiable certification scheme that evaluates and compares different AV designs and the level of safety they provide. The STS research paper will evaluate this certification scheme in accordance with moral and ethical principles regarding safety in the AV field, and suggest guidelines to ensure the safety standard prioritizes human life over optimization. In the following sections of this paper, I will apply the Social Construction of Technology (SCOT) framework (Bijker and Pinch, 1987, p. 40) to the development of guidelines for the standard that consolidate the goals of safety and optimization and serve the interests of the relevant social groups involved in the integration and development of AVs. Busch's 11 guiding principles are an example of SCOT and will serve as a subset of this framework, for developing an effective, moral standard and apply them to safety in AVs. The 11 guiding principles will be used to outline a framework for the development of the standard safety certification scheme. Furthermore, I will evaluate current safety standards used by AV manufacturers in addition to Busch's principles, and suggest alternative requirements for the safety metric beyond the framework presented in this paper.

A REVIEW OF THE INADEQUACY OF EXISTING STANDARDS IN THE AV FIELD

Standardization in the automotive industry is critical to building trust in a technology that puts human life at risk. With the surge of the autonomous vehicle (AV) industry, the standardized protocols that ensure the vehicle's safety will be paramount in ensuring the safety of the passengers and pedestrians and building trust in this new technology. Autonomous vehicles primarily rely on intelligent systems with machine learning components. These systems are non-deterministic, and thus, it can be challenging to evaluate how "safe" an AV is. Manufacturers want to ensure the vehicle operates optimally, while consumers are most concerned about safety and reliability. With human life at risk, it is critical to outline a standardized safety certification scheme for AVs and discuss how it will prioritize human safety while maintaining optimal performance.

In 2018, Takacs, Drexler, Galambos, Rudas, and Haidegger assessed the standardization of AVs and summarized trends and developments of a standard for the field (p. 185). Current regulations and guidelines for autonomous vehicles include the ISO 26262 standard, which define the functional safety of automobiles, and the Automotive Safety Integrity Levels (ASIL). However, ISO 26262 does not directly target the risks unique to AVs and does not provide a transparent evaluation of how these standards are developed. As a result, the IEEE is drafting guidelines to cover ethical standards related to social aspects of AVs with the most popular one being: Transparency of Autonomous Systems and Ontological Standard for Ethically Driven Robotics and Automation Systems (Takacs et al. 2018, p. 190). These projects are establishing ethically-driven methods for the design and testing of AVs. However, they do not develop specific metrics regarding safety that provide a transparent outline of how safe a vehicle is.

Given that the current ISO 26262 standard does not address safety concerns regarding AVs (Takacs et al. 2018, p. 187), the UL 4600, a standard detailing a list of requirements for what constitutes safe driving behavior, was developed a year later to directly provide guidelines for the safety evaluation of an autonomous vehicle (Koopman, 2019). The UL 4600 provides guidelines for a transparent assessment of a vehicle's safety and ensures that the vehicle's safety and validation depend upon keeping the passengers safe. It contains extensive lists of requirements for standards of an AV that emphasize human safety over optimization, along with definitions of what constitutes safe driving behavior, and safety cases that further define how an autonomous system should behave in situations where human life is at risk (Koopman, 2019). This standard, however, does not discuss a coherent way to balance human safety and optimization, and does not provide performance criteria for vehicles. It also fails to provide requirements for ethical aspects of AV behavior. Furthermore, it is challenging to translate extensive lists of requirements into quantifiable standards that assess AV safety. For autonomous vehicles to gain a competitive advantage in the automotive industry, they must perform optimally while also prioritizing safety.

Thus far, the most coherent progress in developing ethical guidelines for AVs was presented by Luetge in 2017 in the "The German Ethics Code for Automated and Connected Driving." This code provides a standardized approach to the ethical guidelines for the development of autonomous vehicles (Luetge, 2017, p. 547). The primary purpose of the code is to improve safety for all road users and ensure that the protection of individuals takes precedence over all other utilitarian considerations (Luetge, 2017, p. 549). The code also mentions how dilemmas such as deciding between one human life and another depend on the situation and cannot be standardized. Instead, the safety evaluation will rely on general ethical guidelines for how a vehicle should behave (Luetge, 2017, p. 552).

Due to the probabilistic nature of AI systems, it is difficult to evaluate the safety of an AV given a few standards and metrics. The assessment of the standardization of AVs (Takacs et al. 2018, p. 185), showed how existing automotive standards are not sufficient for autonomous systems. In contrast, the UL 4600 (Koopman, 2019) provides guidelines for AVs that prioritize human safety without providing a rational method to assess safety. "The German Ethics Code for Automated and Connected Driving" (Luetge, 2017), offers ethical guidelines for the design of autonomous systems that provides a baseline for the development of an ethical standard. However, the UL4600 and "The German Ethics Code for Automated and Connected Driving" fail to offer concrete guidelines for the development of a standard or metric. Instead, they provide general guidelines that should be followed for the development of AVs and indicate what specific tests a vehicle might need to pass to be considered safe. To move toward a numerical metric that quantifies the safety of autonomous systems, ethical guidelines that balance human safety with optimization need to be further investigated. The following sections will discuss a general framework that outlines the requirements of a metric that provides an adequate evaluation of the safety and performance of the vehicle.

THE DANGERS OF THE PROBABILISTIC NATURE OF MACHINE LEARNING SYSTEMS AND CHOOSING OPTIMIZATION OVER SAFETY

With the surge of the autonomous vehicle (AV) industry, the standardized protocols that ensure the vehicle's safety will be paramount in ensuring the passengers' and pedestrians' safety and building trust in this new technology. Autonomous vehicles primarily rely on intelligent systems with machine learning components. These systems are non-deterministic and probabilistic; thus, it can be challenging to evaluate how "safe" an AV is. It is imperative to evaluate existing safety standards and investigate and compare their methodologies for prioritizing human safety over optimization. Cho and Behl (2020) found that it is nearly impossible to compare the safety level provided by two AVs from different manufacturers. Each manufacturer uses a separate test environment to evaluate the safety of its design. Cho and Behl (2020) stated, "Therefore, the lack of a unified safety testing method for AVs makes it ambiguous to compare safety across multiple autonomous vehicles" (p. 2). Furthermore, competing safety standards from different AV manufacturers make it difficult for consumers to make an informed decision about purchasing an AV and make it challenging to identify how AVs compare in terms of performance and safety.

Safety standards for AVs need to account for the vehicle's performance. However, they also need to have a hierarchy that accounts for the safety of human life over the technology's optimization. A high functioning vehicle does not translate into a safe vehicle for humans. In the past five years, several standards have attempted to incorporate ethical guidelines in defining the safety of an AV but have failed to directly target the risks unique to AVs, and balance both safety and optimization. To move toward a numerical metric that quantifies the safety of autonomous systems, it is essential to further investigate ethical guidelines that balance human safety with optimization. If an AV's safety cannot be guaranteed to prioritize human safety over optimization with quantifiable metrics that account for ethical concerns, it will be nearly impossible for consumers to instill trust in this new technology.

Manufacturers want to ensure the vehicle operates optimally, while consumers are most concerned about safety and reliability. The development of guidelines for the standard that consolidate both of these goals will be viewed through the lens of the Social Construction of Technology (SCOT) framework (Bijker & Pinch, 1987) in conjunction with the 11 guiding principles suggested by Busch (2013) in "Standards: Recipes for Reality" (p. 289). The Social Construction of Technology provides a framework that defines each actor and social group as having a different reference frame concerning the appropriate use of technology. The 11 guiding principles will serve as a guideline to consolidate the interests of the three primary actor groups in the development and integration of AVs: the users, non-users, and the manufacturers as depicted in Figure 1 on page 8. These principles prioritize moral considerations regarding safety rather than optimization, and highlight fairness, equity, and effectiveness as keys to a balanced standard for AVs. Like the automobile, AVs are a disruptive technology. As a result, they have the potential to impact both users and non-users of the AV. For example, a design decision that prioritizes the safety of humans in the car over the pedestrians' safety impacts both groups significantly. Furthermore, the users and non-users impact the decisions made by manufacturers. The integration of the AV into society is a social experiment. The design will be influenced based on the positive and negative outcomes as experienced by the users and non-users. The users and non-users not only influence and help define the usage of the AV, but they also influence the design decisions and safety measures implemented by manufacturers. The interaction between the social groups and their primary interests are illustrated in Figure 1 on page 8. Each group has its own norms and values that further influence the development of the AV.

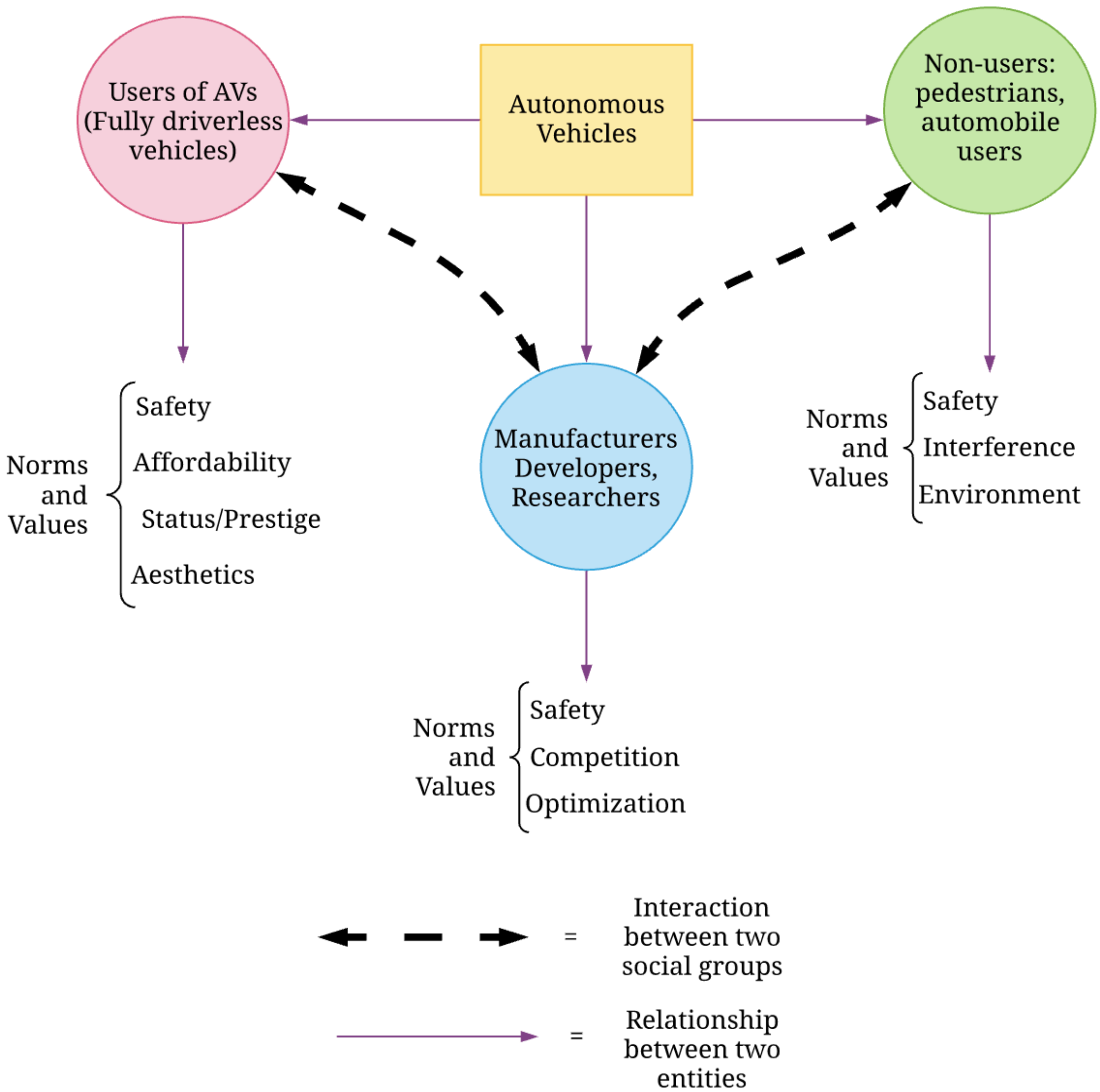

Figure 1: Values and Interactions of the Relevant Social Groups for AVs: Manufacturers' design decisions impact both users and non-users of AVs and the users and non-users' interaction with AVs influences design decisions over time (Created by Ranjit, 2020)

THE RELATIONSHIP BETWEEN THE SOCIAL CONSTRUCTION OF TECHNOLOGY AND THE 11 GUIDING PRINCIPLES

The Social Construction of Technology (SCOT) defines a framework that derives the meaning of technology from its relevant social groups (Bijker & Pinch, 1987, p. 40). Because social groups have particular norms and values that can further define development, SCOT provides a framework for studying the relationship between technology and its broader context. The 11 guiding principles serve as a subset of SCOT. The guidelines for standards help technology reach stabilization by providing specific design regulations for manufacturers to follow over an extended period. Furthermore, the guidelines ensure the resulting standard serves the interests and values of the relevant social groups as defined in Figure 1 on page 8. By defining ethically sound principles, the resulting standards from Busch's 11 guiding principles will prioritize the safety of the users and non-users while maintaining optimal performance, allowing for easier integration of the technology into its broader context. An overview of how the 11 guiding principles serve the interests of the different social groups is illustrated in Figure 2 where the principles are listed in their appropriate social groups.

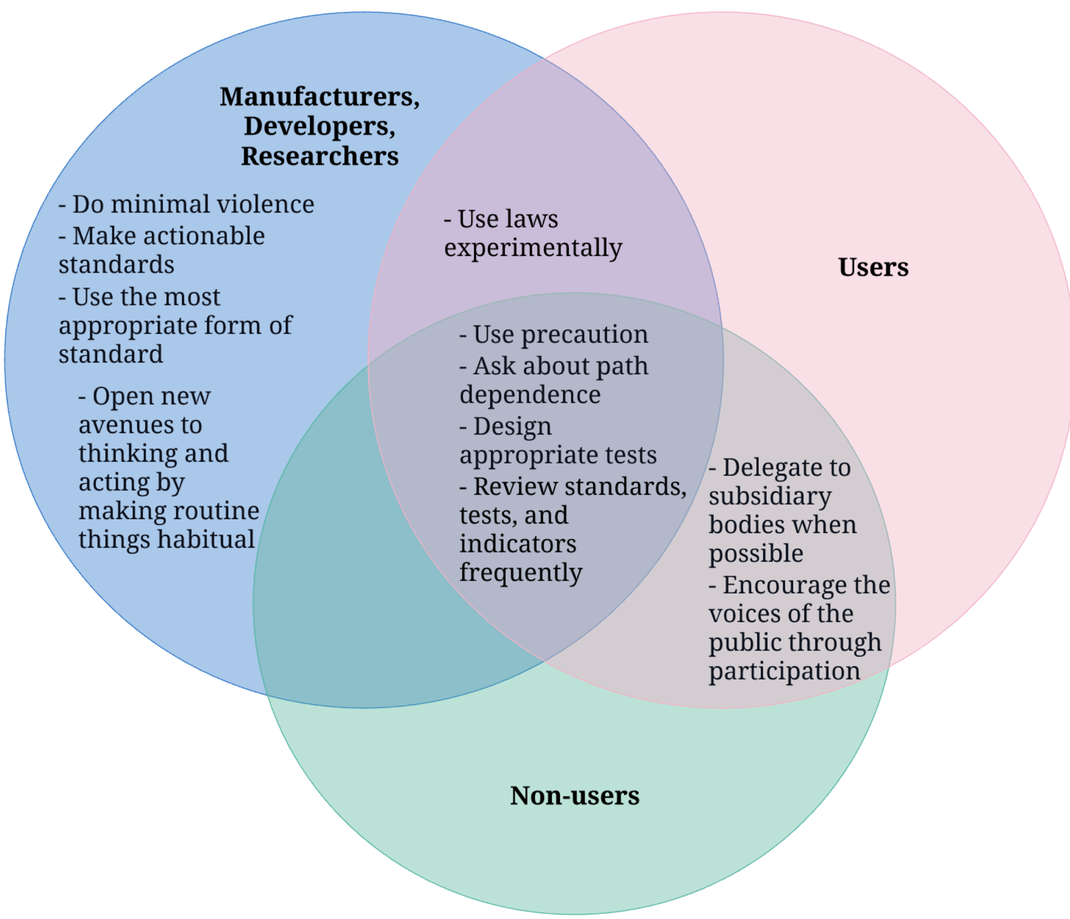

Figure 2: 11 Guiding Principles and the Relevant Social Groups: A depiction of how the 11 guiding principles serve the interests of each of the actors involved in the development and integration of AVs (Created by Ranjit, 2020).

AN ANALYSIS AND EVALUATION OF THE 11 GUIDING PRINCIPLES AND THEIR APPLICATION TO THE AV FIELD

Busch (2013) claims it is critical to ask: "Are standards the most appropriate form of governance in this particular instance?" (p. 301). If standards will not improve the technology, it is essential to consider alternative regulations such as laws or customs. Regulation of AVs will require a culmination of standards, laws, customs, and habits. Similar to the induction of the automobile, AVs are a type of disruptive technology and require new restrictions and regulations that govern their ethical and moral use. Busch (2013) provides a set of guidelines for standards to ensure they are ethical in nature. He emphasizes the importance of developing standards grounded in ethical principles and "realizable in some recognizable form" (p. 301). The following list further analyzes the 11 guiding principles and adapts their principles to AVs.

1. Delegate to subsidiary bodies when possible (Busch, 2013, p. 301)
    a. Subsidiarity is the principle that the group with the lowest, smallest, and most decentralized authority should make decisions. This principle applies to standards by giving higher precedence to local customs, traditions, and norms over an idea or technology implemented in a larger geographic area. The exception to this principle occurs when there is a compelling reason to override local knowledge in favor of an idea applied to a larger geographic area.
    b. Concerning safety for AVs, this guideline requires the safety certification scheme to allow for flexibility and more stringent restrictions on the threshold for what constitutes a safe vehicle. Dependent on the region, some areas will be more populated have more foot traffic than others. Furthermore, other regions will be quicker to adopt AVs than others. These differences can change the details and specifications of a standard. For example, a more populated area will require more

extensive testing of the AV before its acceptance into society. As a result, it is crucial to allow for flexibility in the definition of the safety certification scheme while not compromising its obligation to provide safety for all.

2. Use precaution (Busch, 2013, p. 301)
    a. Given that standards influence human and nonhuman behavior, it is imperative to proceed with caution. If a human life or lifeless entity may be at potential risk, it is prudent to experiment with smaller populations before integrating and promoting its use over a larger area.
    b. This guideline is critical in developing a standard for AVs. Autonomous vehicles, if not designed or tested correctly, pose many risks to humans. Many risks, specifically with Tesla and Uber, have been documented and criticized in previous testing of the vehicles (Wakabayashi, 2018). Although this is a broad guideline, it is vital to consider its implications concerning AV standards. Any changes to the standard, significant or minute, must go through extensive testing and experimentation on a smaller scale, which does not put human life at risk, before being marketed to consumers. The standard described in the technical paper will be tested on a simulator using test data that does not put any humans at risk of the AV. The testing procedure ensures the standard applies to a significant number of scenarios before being considered for use in an industrial setting.
3. Do minimal violence (Busch, 2013, p. 301)
    a. Standards have the potential to cause violence toward human beings. As a result, during the design of the standard, it is essential to consider whether individuals' rights are at risk, if the standard discourages unethical behavior, and if the benefits of the

standard outweigh social and economic costs. Violence, as a result of a standard, can also be reduced by ensuring professionals in the field have met the qualifications to develop such standards. Imposing standards on decision making that is to be done by professionals in the field runs the risk of undercutting professional judgement. However, standards that evaluate the outcomes of professionals' work can help identify pitfalls and oversights of decisions.

b. Developers and manufacturers in the AV field have a responsibility and duty to prioritize the safety of humans over the vehicle's optimization. Developers of a safety standard for an AV should not compromise this general rule to make their product look more favorable in the competition landscape. Prioritizing safety requires the developers and manufacturers to be qualified to develop such safety standards to minimize harm to consumers. Concerning the AV field, the people designing the standards should be evaluated based on their qualifications, the outcomes of the standards, and how much safety the standard provides. The safety certification scheme described in the technical paper was directed by Madhur Behl, a Ph.D., and M.S in Electrical and Systems Engineering from the University of Pennsylvania. He specializes in research on the foundation of cyber-physical systems. He co-founded the F1/10 International Autonomous Racing Competitions and is an assistant professor at the University of Virginia. Given his extensive experience and qualifications in autonomous systems, he served as a qualified professional in directing research for a safety standard for AVs.

4. Make actionable standards (Busch, 2013, p. 302)

   a. It is crucial to implement standards that imply an action to be taken by either the manufacturer of a specific technology or users of that same technology. Otherwise, standards can be ignored or create more anxiety, deeming them useless for advancing the field.
   b. Previous standards in the AV field have made it challenging to translate broad guidelines into actionable standards that can be implemented by developers and manufacturers. As a result, the safety certification scheme must provide a quantifiable metric that serves as a measure of how safe an AV is, and reveal the pitfalls of one design compared to others. Furthermore, this quantifiable metric should consider the importance of humans' safety over the optimization of the vehicle. The proposed safety certification scheme in the technical paper provides a numerical method to evaluate a vehicle's safety compared with alternative designs. Although the project is still in its early stages, future research will define a simulator that tests the standard by providing scenarios that endanger human lives to evaluate how well the certification scheme prioritizes human life over optimization.
5. Encourage the voices of the public through participation (Busch, 2013, p. 302)
   a. Standards should be designed by considering input from all affected parties, which increases the legitimacy of the standard and helps develop detailed processes and practices instead of broad guidelines.
   b. In order for the safety certification scheme to be widely accepted by multiple social groups, it will serve all affected parties' interests. The users, non-users, the government, manufacturers, and researchers in the field are the primary groups

involved with AVs. The certification scheme must consider all these social groups to develop a widely accepted standard.

6. Use the most appropriate form of standard (Busch, 2013, p. 302)
    a. The four forms of standards presented by Busch are olympian, ranks, filters, and divisions. Olympic standards identify a single person or thing as the "best." Filters allow multiple people or things to pass through a threshold to be considered as having met the standard. Ranks are standards that put things into a hierarchical order based on favorable characteristics. Divisions are standards that further subdivide groups into smaller, more specific categories that may or may not have an internal hierarchy.
    b. The standard safety certification scheme presented in the technical paper is a filter standard. The certification scheme defines a threshold and requirement that AVs would be required to meet to be considered safe. The result of this filtration process can also have the potential to develop a hierarchy among vehicles that outperform one another on the standard.
7. Ask about path dependence (Busch, 2013, p. 303)
    a. It is imperative to consider the economic and social costs of introducing a new standard and consider the burdens placed on future generations.
    b. A safety certification scheme will introduce competition in the AV landscape. The standard will allow for easy comparison between two AV designs and identify where one fails compared to another. The ease of comparison will start an upward innovation trajectory that imposes costs on companies to continually improve their design and gain a competitive advantage. Consequently, a standard can also define

what the field progresses towards, making it imperative that it prioritizes human safety.

8. Design appropriate tests (Busch, 2013, p. 304)
    a. In order for a standard to be widely accepted and implemented in a field, it needs to be designed in such a way that tests can be developed to measure compliance with the standard. Busch (2013) claims the tests must be able to "measure what they claim to measure in a sufficiently robust manner, provide sufficient hurdles to prevent exaggerated claims, and have neither too great nor too little precision and accuracy" (p. 305).
    b. Before a standard is used in a field, it must undergo extensive testing. In the AV field, it is challenging to test standards in real-life scenarios. In the past, this has put human life at risk, reduced the validity of the standard, and increased hostility towards the technology (Wakabayashi, 2018). As a result, the certification scheme presented in the technical paper will undergo extensive testing with a simulator. The simulator enumerates different traffic scenarios and accounts for edge cases not captured in datasets but ones that can still occur. The simulator also ensures the standard is tested by the most vigorous means possible. Furthermore, the technical project provided a scenario description language that defines the elements of a traffic scenario in order to test whether the vehicle is abiding by safety laws. It will be important to evaluate whether the defined language is robust enough to capture different situations in which human life is at risk.
9. Open new avenues to thinking and acting by making routine things habitual (Busch, 2013, p. 305)

a. An upgraded standard should "open up new opportunities for thought and action" (Busch, 2013, p. 305), alleviate professionals of menial tasks, and not serve as a replacement in times when critical decision-making and judgment are needed.
b. The safety certification scheme presented in the technical paper accounts for apparent scenarios in which the AV should prioritize human life above all else. Future steps in evaluating the scheme with a simulator will help render edge cases otherwise unaccounted for in datasets used to develop AV decision making technology. This will open up new avenues for design and thinking for AV developers and manufacturers to consider.

10. Review standards, tests, and indicators frequently (Busch, 2013, p. 305)
    a. Tests that measure the validity of a standard should continuously be improved and changed as the technology changes.
    b. With the AV field changing rapidly year after year, this guideline is critical for the development of a standard. The changing field and new technology deem older standards inadequate, and thus, new standards are required to provide a proper assessment of the technology. For example, existing standards for automobiles do not apply to AVs. As a result, the old standards have undergone revision in response to the new technology. Similarly, in the AV field, rapid technology innovation requires the standard to be flexible.
11. Use laws experimentally (Busch, 2013, p. 305)
    a. Just as laws can be considered "social experiments in need of frequent revision in light of their consequences" (Busch, 2013, p. 305), standards are based on

experiments and their outcomes. They should be flexible to adapt to changing circumstances and results.

b. This guideline will be crucial once fully driverless cars are ready for market introduction. Standards and the design of the AVs can develop in different directions with changing socio-cultural conditions. As referenced in the Social Construction of Technology framework (Pinch & Bijker, 1987), the socio-cultural environment can influence the use and design of technology.

TRANSLATING ETHICAL GUIDELINES INTO A QUANTITATIVE MEASURE OF SAFETY FOR AVS

Busch's 11 guiding principles serve as a broad, yet actionable list of guidelines for the development of standards. He focuses on the ethical principles the standard must follow to be accepted by relevant social groups. The 11 guiding principles were adapted to safety standards for the AV field and served as a guideline for developing an actionable standard. The resulting standard for AVs measured both the optimization of the AV compared to others and prioritized human safety over an optimal vehicle. The standard accomplishes this task by being flexible and open to changes following the rapidly developing field, being designed with input from the relevant social groups, and being adaptable to the changing socio-cultural environment. As illustrated in Figure 2 on page 9, each guideline serves the interests of at least one of the social groups involved in the development and integration of AVs, and the certification scheme provides an avenue for the AV to be influenced and defined by its relevant social groups.

Future research will involve extensive testing and evaluation of the certification scheme's technical nature and the use of a simulator to generate scenarios to test the ethical nature of the certification scheme. More specifically, the testing phase will test the certification scheme's ability to compare two AV designs based on the level of safety they provide. However, it will also test whether the safety standard abides by the 11 guiding principles outlined by Busch as they were adapted to AVs. With AVs becoming more of a reality than a distant, futuristic vision, it is essential to remain grounded in moral and ethical principles of safety.

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