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Engineers' Roles and Responsibilities in Automated Vehicle Ethics: Exploring Engineering Codes of Ethics as a Guide to Addressing Issues in Socio-technical Systems

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Abstract

The ethical implications for the engineering profession of the development and deployment of automated vehicles (AVs) can be explored by analyzing the implications of AVs across three major socio-technical systems—technology, transportation systems, and policy. Mapping the ethical canons of professional engineering societies to these domains provides a lens to investigate existing ethical issues and uncover issues that still need attention. The codes of ethics for five engineering societies direct engineers to consider, identify, mitigate, and manage how their work affects the public. AV ethics literature in the technology domain has focused mainly on crashes, AV software capabilities, and hardware. This narrow focus signifies that engineers in the technology domain can do more to understand potential impacts beyond AV crash behavior. In the transportation systems domain, among the many ethical issues affected by AVs, how engineers design and deploy surface transportation infrastructure is an example of an ethical system-level problem yet to be addressed. Lastly, the policy domain has begun addressing primary effects like protecting the public from physical harm, but other ethical aspects remained unaddressed. All three domains could benefit from more holistic system-level assessments of the ethical implications of AVs. Engineers can use their professional engineering organization ethical canons to evaluate their contribution to managing ethical issues in these AV domains and improve how automated vehicles serve and safeguard the public.

Introduction

Automated vehicles (AVs) shift the tasks from human drivers to machines. When introduced to the passenger transportation sector, AVs could potentially result in many societal benefits–fewer crashes, less congestion, reduced vehicle emissions, increased mobility, increased access, and increased productivity (Anderson et al. 2016; Harper et al. 2016b, 2018; Levin and Boyles 2015; Mersky and Samaras 2016; Wadud et al. 2016). Yet they may also amplify negative externalities and inequities of transportation. There are increasing concerns about adverse impacts on land use and sprawl (Duarte and Ratti 2018; Freemark et al. 2019), mobility (Bagloee et al. 2016; Feigon et al. 2016; Zmud and Sener 2017), vehicle registration and licensing (Fagnant and Kockelman 2015), transportation infrastructure (Csiszár and Zarkeshev 2017; Litman 2018; Martinson 2017), wireless connectivity (Anderson et al. 2016; Hanna and Kimmel 2017), insurance and liability (Winkelman et al. 2019; Fagnant and Kockelman 2015; Hevelke and Nida-Rumelin 2015), and environmental impacts (Alarfaj et al. 2020; Chase et al. 2018; Greenblatt and Saxena 2015; Vasebi et al. 2018; Wadud et al. 2016).

The transition to automated vehicles on the road poses a challenge for those involved in developing, deploying, regulating, and using the technology. There are ethical issues that require input from policymakers, economists, automakers, the public, and many other stakeholders. Engineers from many disciplines contribute to or interact with AV technology, which offers a unique opportunity to contribute to the AV ethics conversation in a meaningful way.

A prominent AV-related ethical dilemma that was widely discussed revisited a thought experiment called the "trolley problem," which focused on the ethical choices between minimizing harm to drivers or bystanders when a crash is unavoidable (Thomson 1984). Ethical concerns about an AV's decision-making algorithm in the event of a crash have captured public and academic attention. The trolley problem is hypothetical, simplistic, and overused; however, the activity around this thought exercise has at least provided a benefit. AV ethical issues are now at the forefront, creating an opportunity to expand the discussion to more critical ethical issues that surround AV technology (Goodall 2016, 2017).

Here we focus on the responsibilities of one group of AV stakeholders: the engineers involved in the AV domains of technology, transportation systems, and policy. To elucidate the ethical responsibilities of engineers, we explore the codes of ethics established by the following engineering societies: American Society of Civil Engineers (ASCE), Association for Computing Machinery (ACM), Institute of Electrical and Electronic Engineers (IEEE), Institute of Transportation Engineers (ITE), and Engineering Council in the United Kingdom (EC). The ethical canons from these codes are then superimposed onto AV issues in the three AV domains. Each engineering organization was selected because AV development and deployment rely on the expertise of members found in these organizations.

The domains of technology, transportation, and policy, represent the ethical elements of key socio-technical systems and their interaction with AV technology (Borenstein et al. 2017b). Each domain was selected because they were reoccurring domains in existing engineering ethics literature on AVs, which most prominently explore the issues of this novel technology. In addition, technology, transportation systems, and policy systems are three encompassing domains that members of the professional societies we analyzed interact with. Technology is an important domain because it pertains to the development and application of software and hardware that enables the capabilities of AVs. The second domain, transportation systems, is comprised of the physical infrastructure, travel modes, and the resulting impacts from deployment. The transportation systems domain contains decisive ethical concerns because autonomous vehicles will be deployed onto existing transportation infrastructure and will influence future infrastructure decisions as AV technology diffuses through the automotive sector. Lastly, the policy domain is a critical component representing the regulatory actions at the state and federal levels as well as the bidirectional influence of AV technology and policy. Policy issues and decisions shape the transportation and technology domains and will therefore impact AV ethical issues that engineers may address. Examining ethical issues in each domain reveals focus areas for risk mitigation efforts. More specifically, issues in each domain offer an opportunity to better understand engineers' contribution to AV ethics in accordance with the canons from their given professional organizations.

In this paper, we aim to (1) analyze engineers' role and responsibilities in AV ethics (2) examine and map engineering codes of ethics in relation to the AV domains, and the explicit and implicit ethical duties and, as a result, (3) identify active topics in AV ethics literature in these three domains.

While engineers can contribute to the discovery and exploration of ethical issues in their work, they are not responsible for determining the legitimacy of topics presented as ethical issues. Borrowing a framework explored at the emergence of nanotechnology, any problem that lies at the intersection of fairness, equity, justice, or power can be considered a social and ethical issue for emerging technology (Lewenstein 2006). Here, the legitimacy of ethical issues is not argued; instead, we aim to assess engineers' responsibility using the codes of ethics established by these professional organizations.

Professional Engineering Society Codes of Ethics

A first step in understanding the value judgments embedded in the AV landscape is to examine the ethical canons of the professional organizations that engineers follow. The codes of ethics for the ASCE, ACM, IEEE, ITE, and EC are examined to discern the ethical responsibilities engineers have in the domains that represent critical socio-technical systems.

We start by classifying the ethical canons for each professional organization in Table 1 according to their relevance to the transportation systems, technology, and policy domains. Some canons were not included in the classification because they are not directly relevant to AV ethics. Some ethics canons provide directives about conduct in the profession such as not accepting gifts or money from clients. The remaining canons are placed in domains where they are most relevant. As shown in Figure 1, twelve ethical canons overlap all three AV domains, which can be summarized into five core actions that define engineers' role in AV ethics discourse. The core activities for engineers are considering, identifying, quantifying, mitigating, and communicating the risks to public welfare (American Society of Civil Engineers 2020; American Society of Mechanical Engineers 2012; Association for Computing Machinery 2018; Engineering Council 2017; Institute of Electrical and Electronic Engineers 2018; Institute of Transportation Engineers 2017).

Although five core activities apply to each domain, some canons provide more specific insight as they only apply to their respective domains. Considering the social implications of the system is the first canon that is solely relevant to the AV technology domain (Association for Computing Machinery 2018). The second canon from ACM calls its members to "understand the needs of users and to develop a system that adheres to those needs" (Association for Computing Machinery 2018). The majority of ethical issues related to transportation systems overlap with policy and technology except for ITE's fourth canon, which promotes a commitment to transportation system resiliency (Institute of Transportation Engineers 2017). Lastly, issues in the AV policy domain are also relevant in the technology and transportation domains, and consequently, the canons relevant to policy overlap both domains in Figure 1.

Table 1: Ethical codes from professional engineering organizations relevant to automated vehicle technology

Organization Canon Number	**Ethical Responsibility**
ASCE 1A	protect the health, safety, and welfare of the public
ASCE 1G	recognize the diverse historical, social, and cultural needs of the community, and incorporate these considerations in their work
ASCE 1H	consider the capabilities, limitations, and implications of current and emerging technologies when part of their work
ASCE 2B	consider and balance societal, environmental, and economic impacts, along with opportunities for improvement, in their work
ASCE 2C	mitigate adverse societal, environmental, and economic effects
ACM 2.5	Thoroughly evaluate computer systems and their impacts
ACM 3.1	Articulate and accept social responsibilities of one's work
ACM 3.4	Include the needs of affected users in a system and validate to ensure the system meets the requirements articulated
IEEE 5	Educate public on capabilities and social implications of emerging and conventional technologies

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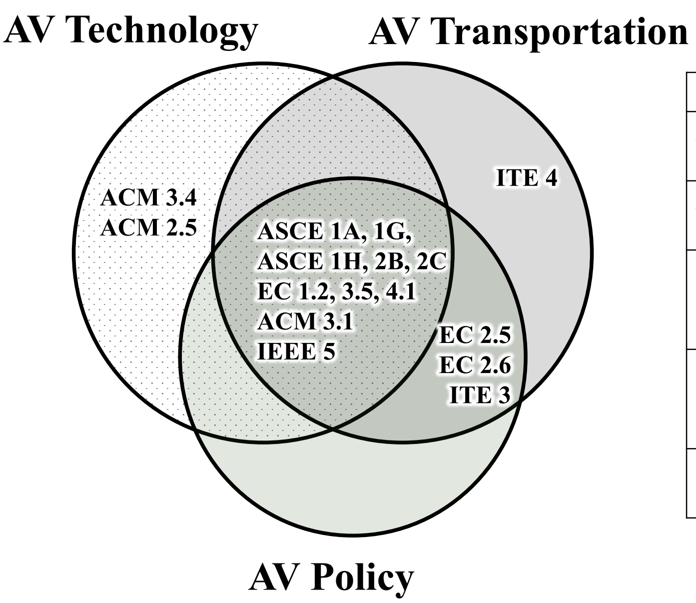
ITE Section 3	Improve the public's quality of life through a sound transportation system.
ITE Section 4	Enhance society's ability to respond to and recover from economic, technological, or physical interruption through transportation system resiliency
EC 1.2	Respect the privacy, rights and reputations of others
EC 2.5	Protect and improve the quality of built and natural environments
EC 2.6	Maximize the public good and minimize both actual and potential adverse effects
EC 3.5	Identify, evaluate, quantify, mitigate and manage risks
EC 4.1	Discern issues engineering and technology raise for society



Organization	Acronym
American Society of Civil Engineers	ASCE
Association for Computing Machinery	ACM
Institute of Transportation Engineers	ITE
Institute of Electrical and Electronic Engineers	IEEE
Engineering Council (United Kingdom)	EC

Figure 1: The ethical codes of five selected major professional engineering organizations are classified by the relevance to three socio-technical AV domains

Ethical Issues in AV Technology

Some ethical issues in the AV technology domain are very active topics in the ethics literature, while other issues are emerging as the technology continues to develop. To date, general safety, crash avoidance, and privacy are common topics found in AV ethics literature, with the most attention placed on crash avoidance. The level of research activity suggests that while engineers are exploring a range of ethical issues in the technology domain, there is an opportunity to further expand the issues being tackled. By broadening AV ethic issues beyond crash avoidance, engineers can continue to develop a more wholistic view of ethical issues in the technology domain.

The existing body of literature on AV ethics regarding crash avoidance is the most comprehensive in comparison to other topics. Technical stakeholders have considered, identified, and quantified many impacts of crashes and safety, with a consensus that AVs will reduce crashes overall (Bagloee et al. 2016; Goodall 2016; Harper et al. 2016b; Khan et al. 2019). Although crash probability is lower, the AV ethics literature includes different crash mitigation strategies through value-laden decisions about AV software and hardware (Applin 2017; Holstein et al. 2018; Leben 2017). Finally, the communication of these concerns is significant as the potential positive and negative implications of the technology can be found in academic literature and well as mainstream media publications (Fagnant and Kockelman 2015; Hevelke and Nida-Rumelin 2015; Khan et al. 2019). The responsibility for AV safety is codified in codes of ethics canons ASCE 1A, 1H, 2B, and 2C; and ACM 2.5, 3.1, and 3.4.

Data privacy is another ethical issue that engineers are addressing as technology develops. While big data issues are not unique to AVs, the intersection with the policy domain regarding liability as well as personal and national security add new layers of complexity. The advent of automated vehicles will also bring about complementary technologies, such as vehicle connectivity. "V2X" is a broad category of vehicle connectivity technology that allows cars to be connected to other cars, traffic or road infrastructure (e.g., traffic signs and signals), pedestrians' and bicyclists' mobile phones, public transit fleets, etc. (M. Gerla et al. 2014). Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) are two heavily researched subsets of V2X technologies with a focus on data transmission between vehicles and road infrastructure. Protecting all forms of data from AVs and complementary technologies is a high research priority and undergoing evaluation in terms of the magnitude of threat and mitigation options (Stark and Hoffmann 2019; Tse et al. 2015). Potential social and economic implications are already readily available to the public (Data Center Frontier 2019; Hoffmann 2018). Data privacy could also be viewed as a more indirect ethical issue that engineers will operationalize within the technology domain once policy decisions are made. The responsibility for data privacy and security in AV systems is codified in ethical canons ASCE 1A, 1G, 1H, 2B and 2C; and ACM 2.5, 3.1, and 3.4; IEEE 5; and EC 1.2.

Ethical issues in vehicle design are still emerging, because AV technology may result in substantial changes to vehicle design. Recent literature has identified potential changes to future vehicle design, driver-vehicle interface (Cellario 2001), lighting (Stone et al. 2019), and more. Implications of a new human-machine interface in AV and chassis designs have been identified as an ethical issue as well (Duarte and Ratti 2018; Fink et al. 2021; Flipse and

Puylaert 2018). Inclusive decisions for vehicle design and human-computer interface are priority research agendas that are underway and important to ensuring everyone has access to the technology. Stakeholders that represent certain populations (e.g., elderly, differently-abled communities) have brought attention to the potential ethical dilemmas around AV design (Borenstein et al. 2017a; Hayeri et al. 2015). The ethical considerations of AV design fall under ASCE 1G and ACM 3.4; engineers are accounting for AV users of different abilities as vehicle design changes with automated technology.

Collectively, the evidence presented in this section suggests that engineers and programmers are discussing multiple ethical issues in the technology domain. Crash avoidance and data security are highly active topics as information can be found in ethics research literature and news media. Apart from crash avoidance and chassis weight, there was not a lot of information found where impacts were quantified. This may be because AV technology is still developing, and therefore, quantifiable information may not be available until deployment. Each issue in the technology domain had a solution for managing the potential risks; but given the iterative nature of development, it would make sense that solutions are updated as more information is made available. Given the novelty of the technology, each issue has circulated to the public at varying levels and will likely iterate with more information in the future (Applin 2017; Birnbacher and Birnbacher 2017; Borenstein et al. 2017a; Gogoll and Müller 2017; Hayeri et al. 2015; Howard and Borenstein 2018; Stark and Hoffmann 2019; Tse et al. 2015). Two additional ethical canons were specific to the technology domain. ACM canon 3.5 directs members to account for all users in a system and the autonomous vehicle design issue is a fitting example of addressing this directive. Lastly, ACM canon 2.5 guides engineers to consider the social implications of a technology. The social implications of crash avoidance technology for AVs have undergone extensive study (Awad et al. 2018; Davnall 2019; Harper et al. 2016b; Hevelke and Nida-Rumelin 2015; Keeling 2019; Khan et al. 2019; Liu 2016; Marchant and Lindor 2012). AV crash avoidance research is so pervasive that other studies call for the expansion of AV ethical issues (Borenstein et al. 2017b; Goodall 2016). Studies considering the ethical issues germane to AV designs also address social impacts on certain communities, as mentioned. Studies that consider and quantify the risk to AV data privacy also address ACM canon 2.5 by explicating the potential types of threats that can come from an AV data breach. As the technology matures, engineers can use the canons related to the technology domain to further crystallize the ethical dimensions of these issues while discovering and addressing others in this domain.

Ethical Challenges for integrating AVs into Transportation Systems

Like engineers in the technology domain, professional engineering ethical canons direct transportation engineers and planners to consider, identify, quantify, mitigate, and manage potential threats to the public. These directives are applicable in the transportation systems domain regarding land use, environmental impacts, mobility and access, and resilience.

Land redevelopment and transportation equity are commonly found in AV literature related to the transportation domain. Land redevelopment caused by changes in parking demand has been identified as a potential effect of AV deployment. Several papers forecast a drastic decline in parking as more AVs enter the vehicle fleet (Fagnant and Kockelman 2015; Harper et al. 2018; Kockelman et al. 2016) due to an AV's ability to drop off and pick up passengers as needed and decouple parking locations from passenger destinations.

This could create congestion in some areas from an increase in passenger-loading demand which may hinder productive use of street space (Roe and Toocheck 2017). Many authors mentioned land redevelopment for commercial, recreation, and residential space (Bezai et al. 2020; González-González et al. 2019; Wang and Kockelman 2018), as well as impacts on parking revenue (Harper et al. 2018). Shifts in parking demand open new possibilities for street design and land development; engineers may directly or indirectly influence urban and transportation planning decisions to optimize these new opportunities. Studies by researchers and reports from a variety of stakeholder organizations elucidate the impacts of AVs on land use (Milakis et al. 2017; Organisation for Economic Co-operation and Development 2015; Rouse et al. 2018). AVs will add to the changing landscape of infrastructure, mobility, energy use, and sustainability, but the implications are uncertain. Overall, these studies demonstrate that engineers have begun identifying and quantifying the potential impacts of AV deployment on transportation infrastructure. These responsibilities are codified in ethical canons ASCE 1A, 1B, 1G, 2A, 2B, and 2C; ACM 3.1; IEEE 5; ITE Section 3; and EC 2.5 and 2.6.

AVs will also impact equitable mobility access, but the timing, magnitude, and often the direction of the implications are uncertain and largely depend on policy choices. There is a possibility that AV mobility will compete with public transport by commandeering passengers from public transit systems, causing an increase in vehicle miles traveled (VMT) and congestion (Borenstein et al. 2017b; Zmud and Sener 2017). However, AVs could improve mobility and access for individuals unable to drive because of medical conditions, lack of a driver's license, or lack of a vehicle (Harper et al. 2016a). Shared automated mobility is another feasible deployment scenario that also provides a strategy for improving equitable access to AVs. Studies have quantified the impacts of shared autonomous mobility, reporting that shared AVs may lead to more efficient use of public transportation and equitable access (Csiszár and Zarkeshev 2017; Murray et al. 2012). Mixed fleet scenarios where AVs will share roads with public transit, pedestrians, bicyclists, and non-AVs (Nyholm and Smids 2018) allow transportation decision-makers to develop solutions to safely integrate the technology into the system. Equity concerns as they relate to autonomous vehicles have surfaced in mainstream media and research articles for public consumption (Epting 2016; Howard and Borenstein 2018). Together, these studies reveal how engineers are identifying equity and access issues, have quantified the impacts under various future scenarios, and are working towards mitigating negative impacts. These responsibilities are codified in ethical canons ASCE 1B, 1G 2B, and 2C; ACM 2.5; IEEE 5; ITE Section 3; and EC 2.6 and 4.1.

Additionally, engineers are responsible for ensuring transportation system resilience (Institute of Transportation Engineers 2017). Transportation system resilience can be enhanced by increasing or expanding access to the system as well as using information to reroute and manage traffic during emergencies. A system must be robust in operational and physical design to maintain services under stress like natural disasters and human-made events (Heaslip et al. 2009). Ethical considerations as they pertain to the system resiliency are understudied when compared to the other issues in the transportation system domain. Vehicle connectivity does pose some potential threat in terms of a data breach as described in the technology domain section. The risks of vehicle connectivity are important but cannot fully inform the threats to physical system resiliency. Therefore, engineers have an opportunity to further their contribution to AV ethics literature by developing more information on system resiliency.

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Ethical Concerns about AVs in Policy

While engineering codes of ethics may not explicitly include a directive that applies to the policy domain, the bidirectional relationship between AVs and policy necessitates investigation. Engineers' work in the technology and transportation domains is influenced by policies set in place at the local, state, and federal levels. Concurrently, policies are developed based on the technology that engineers and others develop and deploy. Policy is also influenced by engineers conducting technical policy assessments and providing expert testimony. Engineers can contribute their expertise in the AV policy domain along with ethicists, public policy professionals, political theorists, philosophers, legal and governance experts, transportation planners, and other stakeholders.

In 2013, states began developing regulations outlining the requirements for AV testing. These regulations focused heavily on mitigating risks of physical harm from the presence of AVs on streets with conventional vehicles. The first AV-specific policies were established when California and Nevada released licensing and safety provisions for testing AVs (Lyons 2015). In California, this list of requirements for driving included: insurance bonding, ability to quickly engage in manual drive (Level 3 automation), fail-safe systems in the case of technology failure, and sensor data storage to capture information before a collision. Special AV regulations in Nevada focused on proving the ability of automated driving through complex situations such as various traffic control devices or in the presence of dynamic objects, like pedestrians and bicyclists.

Since then, AV policy continues to progress; federal entities are delineating the roles of federal, state, and local government and taking steps to identify and mitigate the potential threats. Physical safety is at the root of the discussions as stakeholders try to determine how much testing must occur to prove that AVs are as safe or safer than human drivers. The National Highway Traffic Safety Administration (NHTSA) warned against releasing a vehicle technology to the public without making sure it is safe as manufacturers claims (U.S. Department of Transportation 2017). Engineers have quantified testing time according to different safety thresholds. If regulations establish a very high testing threshold for pre-market on-road testing such as requiring hundreds of millions of miles to be driven, it could take tens to hundreds of years to complete the task with the existing autonomous fleet, resulting in more human-driver induced fatalities in the meantime (Kalra 2017).

NHTSA has released a series of reports that outline AV safety concerns. The 2018 report *Vision for Safety 2.0* outlined 12 areas of safety that could be generally grouped into the following: establishing well-defined limitations of the technology, crash avoidance protocols, data retrieval, cybersecurity, and finally, and training and education of the technology to the public (U.S. Department of Transportation 2018). The question of how an AV should act in the event of a crash is of importance in the policy domain and heavily researched in the technology domain. The U.S. Department of Transportation (USDOT) suggests that information is shared among manufacturers in addition to sharing the sensor data from a crash with NHTSA for evaluation (U.S. Department of Transportation 2017). The processes for AV data collection and retrieval are unique to the policy domain because it shifts focus from what to do in a crash to information about the crash. As stated before, engineers can operationalize policies that are set. Engineers' role, according to their engineering canons, is to offer insight into the potential benefits and risks of policies that interact with the technology and transportation domains.

Another report, *Preparing for the Future of Transportation: Automated Vehicles 3.0* builds on earlier USDOT guidance. The report considers safety concerns as they relate to all modes of transit and further expounds on the safety and cybersecurity concerns of 5G wireless technology (U.S. Department of Transportation 2018). The focus on safety and proposed policies will impact the technology and transportation domains. The dimensions of safety being considered and identified will inform the mitigation measures that come in the form of regulatory decisions.

Secondary and tertiary impacts, such as the impact on equity and other modes of transit have also been raised (Milakis et al. 2017; Mladenovic and McPherson 2016; Ryan 2020) but policy actions are not yet in place. Many policy issues still possess a great deal of uncertainty like AVs mixed with non-AVs on the road (Chase et al. 2018; Nyholm and Smids 2018), wireless connectivity standards, licensing, insurance, and previously discussed land use impacts (Anderson et al. 2016; Rouse et al. 2018; Wang and Kockelman 2018). The transition to AVs may also bring about change to the transportation labor market. Studies have shown that AVs could result in U.S. unemployment rates raising 0.06-0.13 points at the peak of AV deployment between 2040 and 2050 (Montgomery et al. 2018; W.E. Upjohn Institute and Groshen 2019). Bus, freight, delivery, and taxi driving jobs are expected to be most immediately displaced. The loss of driving occupations may disproportionately impact Black, Hispanic, and Indigenous workers whose median wages in driving occupations are greater than the median wages for non-driving jobs (Center for Global Policy Solutions 2017). Studies also highlight the opportunity to retain and retrain the workforce by training them for the new jobs that will result in AV deployment. Engineers can contribute to the conversation by articulating skills needed for the new technology. AV policy responsibilities are codified in canons ASCE 1A, 1B, 1G, 1H, 2A, 2B, and 2C; ACM 2.5; IEEE 5; ITE Section 3 and Section 4; and EC 1.2, 2.5, 2.6, 3.5, and 4.1.

Conclusion

The codes of ethics from major engineering professional societies were superimposed on three AV domains–technology, transportation, and policy, and used to identify and assess ethical issues that have garnered attention to date. The mapping of the ethical canons onto these AV domains revealed engineering responsibilities in AV ethics and the ethics literature review clarified which topics are currently being discussed. The 16 most relevant ethical canons identified five core activities that must occur in each AV domain. Engineers are responsible for considering, identifying, quantifying, mitigating, and spreading awareness of ethical issues across the AV domains. Notably, ASCE released an updated code of ethics in late 2020, explicitly guiding engineers to consider and balance the implications of current and emerging technology. This update could signal a shift in professional engineering organizations expanding their thinking about engineers' ethical responsibilities beyond the technical aspects and into the broader impacts of technology.

Our investigation into each core activity around ethical issues showed that while some ethical issues across the domains have received attention, other issues remain unresolved and are currently being explored at various stages. First, many ethical issues have already been considered and identified such as crash implications and avoidance, as evidenced by the large popular press discussion of the AV trolley problem. It is also well established that software and hardware ethics are crucial to AVs operating safely. A review of the literature with solutions to crash avoidance shows that engineers are addressing these issues in accordance with the ethical canons from their professional societies. However, issues like hardware selection, hardware validation, and safety have been considered but are still understudied in comparison. Quantification, mitigation, and education of stakeholders and the public for hardware related ethical issues are ongoing. In the transportation system domain, most studies focused on transportation infrastructure and land-use redevelopment, revealing the focus of ethical issues in this domain. The impacts for these two issues have been quantified and literature explores potential traffic management solutions. There is a gap in research that explores transportation system resiliency, which is a responsibility explicitly outlined by the ITE code of ethics. The research activity in the policy domain demonstrates that decision-makers are still focused on safety as it is a baseline structure for regulating the technology. As stated, secondary and tertiary impacts have surfaced but are not yet addressed in terms of quantitative impact or concise mitigation strategies. Issues such as data privacy, liability, transportation surface resiliency, lane allocation, and equity still need substantial quantitative research and regulatory action. Action to advance these issues proves difficult because many areas still possess a great deal of uncertainty.

While deep uncertainty pervades the AV space due to technology novelty, the ethical canons provide directives for engineers to follow but do not comprehensively address ethical issues in any domain. Engineers must work with fellow stakeholders and decision-makers with relevant expertise, which may cause some instances of responsibility gaps. Gaps can occur from a gap in ethical, technical, or other responsibilities amongst the working group (Matthias 2004). Implementing a robust multi-disciplinary process can help overcome responsibility gaps across the domains.

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Engineering codes of ethics also place a responsibility on engineers to be a part of the public conversation on the benefits and negative impacts throughout the development and ultimate deployment of AVs. Public-facing conversations about AVs mainly focus on the trolley problem, VMT, and privacy. Other issues like equity and access have been considered and identified, and these issues must also be addressed in any public conversation about AVs. Engineers, again, are one of many groups in the larger AV ethics conversation, and one way they can continue to contribute is through analysis or simulation. Engineers can develop new or use established scenarios to create new information on the magnitude of impacts or issues for decision-makers and stakeholders to consider. Approaching the uncertainty in this manner is a more constructive action than the current widespread speculation. Sharing data and results publicly provides an opportunity for feedback from the public which can, in turn, be used to help prioritize issues. Low-impact or low priority issues can be kept from overpowering critical ethical issues to be addressed while including the public in the process.

The assessment approach used in this study could prove useful beyond automated vehicle technology for those that develop and use codes of ethics. By identifying the relevant domains of automated technology, the codes of ethics are evaluated through each domain. For automated vehicles, each domain highlights different concerns, which creates a more robust conversation and will improve how engineers are looking at automated vehicles to serve the needs of the public. For those that develop codes of ethics, considering the affected socio-technical systems separately can help significant value judgments emerge. In the case of engineers or other decision-makers applying codes of ethics, making sure to satisfy the directives while considering each domain will result in a more comprehensive perspective.

As such, ethics can evolve with advancing technology and continue to act as a safeguard for the public.

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Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

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