Expanding the Design Horizon for Self-Driving Vehicles

Distributing Benefits and Burdens

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With over one billion vehicles in the world today (1), the motorized road vehicle is the pillar of modern society. Since the beginning of the 20th century, the automobile has revolutionized our spaces, practices, cultures, and identities through a complex matrix of technical, financial, economic, political, and social linkages (2), (3). Visions of automobile use have always shaped its design, manufacture, and production. Now, motorized road transport is set to revolutionize our society once again on a huge scale. Recent technological developments in propulsion, telecommunication, sensing, and in-vehicle computing technology are expanding the range of vehicles’ capabilities. A technological convergence is underway, moving towards self-driving vehicle (SDV) technology. These vehicles will utilize computational algorithms, sensors, and communication devices to automatically navigate a variety of environments with limited or no intervention from human drivers.

While vehicular automation has existed in varying forms for quite some time (e.g., autopilot systems, automated trains), SDVs offer potential for revolutionary outcomes. SDV technology promises to shape society in broader and more pervasive ways, potentially resulting in a greater level of societal disruption than other automated vehicle systems. SDV technology might even bring about a level of societal disruption equal to that of personal computers. Current popular discourse is beginning to outline a vision of the benefits and limitations of this disruption.

In the spirit of responsible innovation, wherein the innovation process should be aligned with social needs (4)–(6), we will argue that SDVs introduce new challenges in terms of social justice, affecting the distribution of benefits and burdens across society as a whole (7). Our starting premise is that technology is a profoundly social phenomenon, with both intended and unintended consequences (positive and negative) for our everyday lives. By assuming a positive and unproblematic future for SDV technology, current design practices and institutions have systematically ignored a number of critical social and ethical challenges. Consequently, we will argue that a better understanding of the technology in a broader social context, along with open discussion of the distribution of burdens and benefits in a current and future society, enables the development of an improved design practice. We argue for an “expanded technological design horizon” that engages a more ethical design practice for SDV technology. In doing so, we aspire to steer current engineering practices beyond a narrow, technical perspective. Ultimately, we hope to broaden the conversation about design processes in general for technologies that are likely to shape societal development on a large scale.

How are SDVs Currently Defined?
It is essential to clarify the current technological definitions of SDV technology. The SDV is an arrangement of technologies whose aim is to remove some or all of a driver’s actions and interventions. Consequently, SDVs are expected to navigate their environment with little or no driver input. This development represents a vision of transport technology that has arisen from the technology market and is set to shape transport. According to this vision, five levels of automation or driver input are defined in engineering standards. These levels vary from driver assistance to full automation (8)–(13). The level of automation represents the level of driver responsibility for controlling the vehicle and monitoring the environment.

Before SDVs, conventional vehicles were already technologically sophisticated, making use of sensing, processing, and communications technologies to collect, process, and communicate data about the vehicle (such as engine performance) and its environment (such as parking sensors or reversing cameras). However, in order to navigate any environment with little or no human action, a multitude of powerful, sophisticated sensors must be included. These sensors gather many different kinds of data (e.g., geographical coordinates, speed, acceleration, and obstacles in close proximity) to build a comprehensive representation of the vehicle and its surrounding environment. To handle such complex data in real-time, SDVs require increased processing power and data storage capacity, accompanied by sophisticated algorithms to make and monitor driving decisions. According to some SDV visions, these two sets of technologies alone are enough to enable the SDV to navigate its environment. However, some visions argue that SDVs will also have to include communications technologies to enable direct, fast communication with other vehicles or surrounding infrastructure. This communication capability might enable advanced features such as “platooning,” where vehicles deliberately and intelligently coordinate their speed and share information about road conditions (such as seen in the film Minority Report).

What Are The Current Visions of SDV Benefits and Limitations?
An integral aspect of any technology is the underlying vision of the future and associated values. Such vision...
is commonly used to usher in new technologies. Technological visions have several themes. They typically seek to address a perceived social need rooted in the present, and tend to position contemporary technologies as being inadequate for modern society’s needs. They typically argue that the new technology will surpass prior technological transitions (14). Visions of SDV technology typically critique existing automotive technology, claim to address social needs, and solve many issues associated with the automobile.

At first glance, SDVs are a panacea for issues such as traffic deaths and injuries, pollution, concerns over fossil fuel use, problems of congestion and parking shortages, expensive public transport provision, and the externalities of freight transport. Current visions of SDVs promise a future offering increased safety, speed, convenience, and productivity, while reducing energy consumption. For example, a common argument for SDV technology is its capability to engineer a future with fewer road accidents and, consequently, fewer injuries and casualties. SDVs will determine the route and how fast to travel to improve traffic flow, thereby optimizing energy use and reducing congestion. The visions of SDV technology promise substantial car sharing and even lower car ownership, thus reducing the amount of parking spaces required.

However, beyond the technologically-mediated visions of these futures, there are some real concerns about the impact of SDV technology, and many uncertainties about what SDVs may actually bring about. These uncertainties include whether occupants will be able to respond in time to hazardous situations, and whether SDVs can perform as well as human drivers. A common concern is liability in the case of traffic accidents. There are concerns about the level of infrastructure investment required to enable full automation across geographical areas, the potential economic and social impact of displacing driving jobs, and the potential energy demand based on the computing power and redundant systems potentially needed for SDVs. Little is known about who will own the vast quantities of data collected about the environment and about passengers, how private such data may or may not be, and vulnerabilities of the computer systems involved to hacking and criminal activity.

Current visions of expected benefits and limitations stem from technology development practices situated in the dominant economic culture. Our market-based culture is shaped by many interconnected institutions including the media, government, law enforcement, and the insurance industry. For example, the entertainment industry frequently glamorizes speed. The mass media receive substantial revenues from alcohol and automotive advertising, both of which air in programming typically targeting a young male audience. Many accidents involving young males result from beer consumption combined with speeding (15). The insurance and automotive industries, in combination with law enforcement and government, also shape the automobile and our experience with it (15).

The power originating from this complex context often shapes technological visions, as well as the decision-making related to those visions (16). While we do not know exactly which visions will be enacted, current visions risk blinding technology developers and regulators to potential beneficial transformative societal changes and challenges in transportation (17).

**What is Missing from Current SDV Visions?**

In addition to the challenges facing SDV technology that we have identified, the current vision of SDV technology has a narrow focus privileging the requirements of technological and commercial development, while at the same time neglecting potentially serious social consequences. One of the recurring themes is that SDVs are possessed of “algorithmic authority” superior to “human authority” that enable SDVs to navigate the environment more effectively. There are even visions of SDVs as ethical robots, programmable to solve moral dilemmas that they could face between killing an individual and killing a group. These visions of SDVs as ethical robots are part of an emerging trend in robotics (18). Yet we do not yet have the necessary rich set of scenarios and use cases about the difficult moral and ethical dilemmas that SDVs will have to resolve. These scenarios and use cases are necessary to assess the social consequences of this new technology.

We know from the history of the automobile how devastating the consequences can be. For example, a belief that passive devices were superior to active devices meant early airbags in U.S. cars were used instead of seat belts despite scientific evidence that their design increased the total number of deaths in accidents. Women were disproportionately affected, because of their smaller sizes (15). The societal costs of 1.24 million road deaths a year (nearly triple the UN’s annual global estimate of murders and twenty times the number of deaths attributable to wars each year), is a ghastly reminder of how lethal automotive transportation is (19), (20). This does not even take account the much greater number of those maimed as a result of traffic accidents.

One set of missing requirements in SDV development relates to the changing role of the driver’s ethical responsibility and legal liability for accidents. Most designs for SDVs do not completely do away with the driver, requiring them to take over in emergencies, thus raising the issue of who is responsible for negative outcomes. Future laws may not treat the occupants and the vehicle manufacturer equally, with the SDV driver potentially held accountable for failing to respond to danger.
warnings. In addition, by virtue of the human being present, the human may be made primarily or solely legally responsible, putting them at a significant disadvantage compared to the technology manufacturer (17). We do not yet have case law for assessing the division of human-machine responsibility, and the issues are very thorny indeed.

Another concern about the narrowness of the current technological visions revolves around daily mobility practices. The effect of SDVs on mobility practices is unknown. Despite assurances that they will save fuel, save time, and so on, their use might in fact increase the total distances traveled (as in a car-sharing model they travel instead of being parked), time traveled and so on, which would affect emissions. SDVs could bring about a “speed hierarchy” in which the extra speed gained from automation will command a premium price. Geographies of access to mobility could appear—such as those geographies of clean air shaped by electric car subsidies in California (21).

Wide deployment of SDV technology might create inequality by pricing out certain segments of society, and constraining the available set of transport alternatives. We know from studies of the transition to the automobile in the U.S. that local residents objected to cars because they saw automobiles as transforming the street into a transport artery rather than a meeting place. In the end, the residents were right, and local trade and social life suffered (3). Traffic flow was prioritized over the safety of pedestrians, beginning the trend of a shockingly high rate of pedestrian deaths. In the case of SDVs, the high cost of infrastructure could deflect resources from alternatives such as public transport, walking and cycling, shaping urban land use even more heavily in favor of cars (22). SDVs could impose scarcity of choice, time, and cost, making the traveler merely a client of a service, not a citizen or a friend. This client is a person who can only ask for better service in the form of more complex technological solutions, but not for social justice (23). SDVs may then reshape transport practices broadly along the lines of those who can afford the use of SDVs and who cannot.

There is a danger that the scale of the infrastructure investment necessary for widespread SDV deployment would put further pressure on public funding, possibly resulting in funding cuts to other critical public services such as healthcare and education. In the U.S., the transition to the automobile demonstrates that a wealthy, educated middle class consisting of planners, judges, and entrepreneurs were able to define the use of the automobile, including deciding who could drive and where, and who would ride public transport (3). Three hundred million dollars was spent in the U.S. in 1906 to build roads, redefining social geographies in and outside of cities (3). More recently, the development of “smart cities” that purchase turnkey big data solutions has, in some cases, resulted in diverting public spending to finance the new “smart” technologies (24)–(26).

Other broader economic, institutional, and cultural factors come into play as well. For example, while SDV technology might be completely based on battery-electric propulsion, sustainability of such energy systems is neither considered nor proven. SDVs may change the political economy of employment in sectors such as delivery where higher speeds for delivery vehicles could enable an increase in the distance travelled by goods purely for profit. As a result, retailers could have increased choice in terms of potential suppliers. This could result in more competition thus driving down prices paid, for example, to local farmers.

Current development visions neglect a range of potential implications of the technology for civic values such as privacy, harmony, and mutual respect (7), (27). Reprising Langdon Winner, a technology that is socially-constructed to be totalitarian requires a police state to administer (28). Therefore, SDV technology, with the huge quantities of data involved, could open the possibility of a police state, or, some might argue, even more of a police state than we already have. Such changes could shift the range and nature of civic values toward totalitarian controls. The automation and sensor technologies that characterize SDVs have military applications, and are found in military autonomous vehicles and drones. Therefore the technological development of SDV technology may result in a growing market for military applications—an unfortunate outcome, in our view. The military-industrial complex is continually fed as corporations tap the military as a nearly bottomless pot of money (in the U.S. at least), encouraging the very socio-political complex we should be dismantling rather than sustaining and strengthening. Technology is being used to fight an increasing number of wars abroad (29), endangering harmony with foreign countries, and encouraging the use of war as an active component of foreign policy. Without explicitly declaring war, in their military applications the technologies involved could enable the erection of barriers to mobility across countries. Worldwide, 50-350 million people are expected to be displaced by 2050 by crop failures, drought, and wars caused by climate change (30). Meanwhile, the U.S. and the EU are investing heavily in robots, drones, and surveillance buoys (30) with the same sensor and automation technologies, meaning that an SDV society could be one with more wars and less social and geographical mobility.

Finally, it is important to emphasize that a society that uses forms of social control and discipline based on surveillance and monitoring will almost inevitably create new laws to support that social order. One
contemporary example is the creation of the crime of “theft of time,” “defined as the misuse of an employer’s time and property by an employee,” an offense punishable by dismissal from employment (16), (31), (32). A contemporary study of trucking finds a strong cost motive for the use of GPS technology for surveillance and monitoring, as well as a tool to control and discipline driver behavior (32). Consequently, SDV technology may give rise to new forms of social control and discipline by enabling knowledge of our practices.

Why the SDV Vision Should Not Remain Narrow
We argue that the current vision of SDV technological development cannot retain its narrow perspective. It neglects to take account of the fact that technology embodies social relations and political meanings (28), and has the potential to shape society, infrastructure, practice, and ideology. Technology may be useful for certain purposes and, at the same time, carry serious consequences such as loss of privacy, alterations in social relations, degradation of skills, and environmental devastation (33). Ultimately, technology is a profoundly social phenomenon, with both intended and unintended consequences for our everyday lives (23), (34)–(37), and the potential to shape society, infrastructure, practice, and ideology.

By aiming primarily to solve the problems of the previous technology, i.e., the automobile, the current vision of SDV technology falls short in two important aspects. First, it neglects a range of societal dimensions of technology. It fails to recognize interdependencies between societal dimensions. It does not account for the broader picture of why and how society uses technology in the first place, and how technology continues to influence and shape societal structures and relations. Second, the current approach to SDV development is deterministic, assuming that the specific future it imagines is “inevitable.” The current design approach thus does not allow for the development and evaluation of alternative futures that might be based on broad, democratic public discussions with multiple stakeholders. Consequently, a single potential future becomes the one that is decided and inevitable, and we must move toward it.

Ultimately, the development of SDV technology is a question of social justice, and should be assessed in nuanced, pluralistic ways according to the manner in which it carries out distribution of benefits and burdens across current and future societies. It is exactly this pre-eminence given to a single positive and unproblematic future that has led to systematic sidestepping of important ethical and social challenges. As technology designers and implementers, we have a responsibility to design for the future for all people in an equitable way. SDV development is, then, an activity of moral choice, laden with an imperative to imagine a range of desired alternative futures. We need to make normative choices about which future we will aspire to, and the future cannot be based on profit alone.

How Can We Expand the SDV Design Vision?
If design practice is to account for this wider and future-oriented perspective, there is a need for a significant paradigm shift and evolution of design practices. If we consider only narrowly-conceived notions of the usability and usefulness of technology, there is a danger of neglecting the complexity of broader sociotechnical systems and the interdependencies between technical and social justice considerations. A starting point for such a paradigm shift is to study what people are doing with technical systems and why. Such an approach would require expanding the focus on SDVs as primarily technical objects, and taking account of the broader sociotechnical systems in which they are embedded, including multiple stakeholders, impacts on infrastructure and environment, and distribution of benefits and burdens. Design should be seen as “inventing the future,” by imagining a range of possible and desired futures, while considering a range of values (38). It is important to take seriously the cultural-historical imperative and to understand design influences as flowing from global technocapitalism and socio-technical change (38).

An immediate challenge arises when designers are faced with accommodating conflicting values such as a traffic control mechanism for SDVs that balances questions of safety, privacy, mobility, and environmental sustainability. A framework for the ethical design of SDVs must consider a range of implications of technology automation and the future. These include greater degrees of embeddedness and interconnectedness that generate social and political complexities, issues of privacy and responsibility, and changes in cultural values. The first step in dealing with this complexity in technology design would be accepting that complexity exists. By looking away or shrugging at this complexity, engineers and designers are losing a critical opportunity to better understand the distribution of benefits and burdens that SDV technology will have on current and future generations.

Shaping the Future
A complexity- and foresight-based approach enables a perspective in which the future is something that can be shaped; it is neither “already decided” nor “inevitable.” A sociotechnical design framework should account for the changing role of the human inside and outside the vehicle as well as consequent impacts on sociotechnical structures and practices. For example, how would the SDV reconfigure practices of driving and mobility planning for different users, different trip purposes, and different daily
activities? The framework should focus on the development of a range of possible and desired futures, and assessment of their system-level impacts. These assessments should include environmental and social justice perspectives on the distribution of burdens and benefits across society, both now and in the future. The sociotechnical framework should account for the roles, objectives, and design approaches of those interested in technological development, including corporations, government, and researchers. Finally, a paradigm shift would require involving the general public throughout the entire design process. This element would include cooperation with institutional mechanisms to evaluate a wide range of general and localized values in the design of SDV technology. SDVs are potentially highly disruptive technologies with profound implications on social justice in the transport system and beyond. As the technology is at its foundational stage of development, the critical concerns related to the improvement of design practices must be addressed right now.

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