Development of Socially Sustainable Traffic-Control Principles for Self-Driving Vehicles: The Ethics of Anthropocentric Design

Miloš N. Mladenović
Montasir Abbas, PhD
Department of Civil and Environmental Engineering
Virginia Tech
Blacksburg, U.S.A.

Tristram McPherson, PhD
Department of Philosophy
Virginia Tech
Blacksburg, U.S.A.

***Abstract*—Converging effect of communication, sensing, and in-vehicle computing technology has ensured potential to develop large-scale deployment of self-driving vehicles. Considering the potential impact of this technology, the approach for development cannot overlook needs regarding sustainability and social considerations. This paper argues that control technology for self-driving vehicles has both direct and indirect effect on fundamental human rights, and that the anthropocentric design perspective is a necessary ethical approach. Furthermore, we present current perspectives on operational principles, and relevant theoretical and empirical social implications. We conclude that there is potential for development of traffic-control principles for self-driving vehicles on the basis of mutually-advantageous cooperative production. Finally, we present several important areas for further investigation.**

Keywords—sustainability, transportation, technology, human rights, cooperative production

I. Introduction

Development of communication, sensing, and in-vehicle computing technology in the last two decades has enabled the development of self-driving vehicle technology [1]. Considering the converging effect of all three technologies, self-driving vehicles will be able to “perform all safety-critical driving functions and monitor roadway conditions for an entire trip” [2]. In operating a self-driving vehicle, the user will only be expected to provide destination or navigation input, and not to take over the control of the vehicle at any point during the trip. Expected positive result of this emerging technology is to improve traffic safety, by exempting the human from the task of driving [3]. In addition to potential decrease in crashes, there should be improvements to mobility for people unable to drive, improvements in fuel economy, and decrease in environmental effects from vehicular traffic [4]. However, this technology will not only lead to benefits in transportation, but it will also provide benefits to the society in general. For example, there may be reduced need for new infrastructure, productivity improvements, potential for new business models [5], and return on investment [6].

Considering the aforementioned radical technological change coming with self-driving vehicles, traffic control technology will be subject to evolution. This will potentially result in a new generation of traffic control technology – traffic control 2.0 (C2). Our argument will focus primarily on traffic control technology (devices and principles) for self-driving vehicles. The perspective we have is that operating principles directly relate to the desired functionality that should be achieved with technology. On the other side, devices should follow the development of operational principles, as their materialization. Considering these points, the argument presented here will primarily focus on operational principles for intersection control, as an important traffic control case.

II. The Approach for Development of Technology

A general approach to control technology for self-driving vehicle should aim at improving quality of life, through contribution to the common good of man and through nonmaleficence [7]. Considering this goal of technology, the principles of sustainability should be foundation for development approach. Sustainable development would allow for satisfying our current needs, without constraints to fulfilling future generations’ needs [8]. However, it is important here to emphasize the complexity of envisioning a sustainable technology, since notion of sustainability does not solely include environmental considerations, as often thought of. Sustainability also includes economic and social considerations, and without this holistic approach (Figure 1), sustainable development is elusive [9].

In addition to the considerations of sustainable development, we need to take into account that, despite being a technical phenomenon, technology is also a social phenomenon. Technology connects humans and their reality [10], it enables relationships between humans and the surrounding world, and it is both a terminus and creator of context for human experience [11]. Consequently, technology

978-1-4799-4992-2/14/$31.00 ©2014 IEEE

is not a value-neutral tool but a force that is conditioning human agency [12]. Moreover, technology is restructuring the patterns of human relationships, relationships between means and ends, body and mind, individual and community, etc. Finally, technology mediates the relation between the technology user and the consequences of her action, influences her perceptions, possibilities and assessment of the good life, etc. [13].

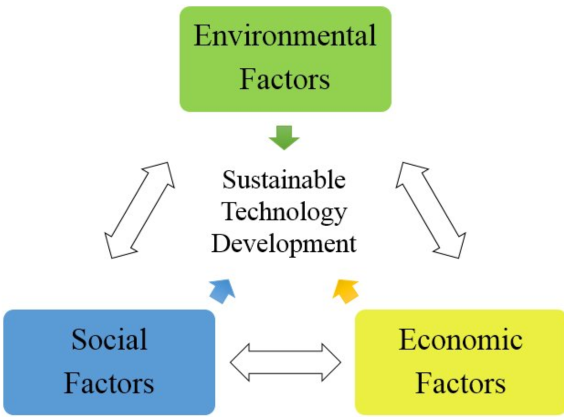

Figure 1: Sustainable technology development

Considering that technology evokes and fundamentally influences user's behavior, technology does not simply withholds some operational principles (e.g., safety, efficiency, ease of use), but it also promotes social, moral, and political values. Consequently, development of technology cannot include only developing some instrumental functionality, but needs to include the considerations of human actions and behavior [14, 15].

Considering the holistic perspective of sustainable development, and the perspective of technology as socio-technical phenomenon, responsibility of technology designers is going beyond technical questions. Balancing all three aspects of sustainability highly depends on the social component. Not taking into consideration behavioral considerations during the development of this technology, we will be unable to accurately predict its impact on economic and environmental impacts. Sustainable design needs to include social considerations, as another design constraint, alongside technical, economic, or environmental constraints [16].

One additional consideration is that self-driving vehicle technology is currently undergoing its foundational development, there should be a high emphasis on developing a long-term vision. This is especially important since aiming at immediate efficiencies might introduce issues of long-term risks. Moreover, as technology matures and becomes widely present, it tends to have higher social impact [17].

As a result, social responsibility for technology designers is to include relevant social concerns into their design vision [18]. Overlooking the importance of social effects would not just conflict with an approach of sustainable technological development, but would be an unethical act in itself [14, 19, 20]. This is the reason why we believe that anthropocentric approach needs to be an origin of technological development.

III. Critical Relations to Fundamental Human Rights

Having in mind the need for social considerations while developing technology, emerging technology of self-driving vehicle can have many undesired consequences. For example, considering the capabilities of self-driving vehicles in collecting, storing, and transmitting user-sensitive information, there will surely be user privacy concerns. However, our line of argument will try to go in a different direction than any existing research. In order to establish a new relation between the principles of intersection operation and social concerns, we need to start by understanding traffic as a phenomenon.

1. *Traffic is a phenomenon with underlying social needs.* Traffic is a result of demand for transport of people and goods. Demand for travel from point A to point B occurs as a consequence of spatial and temporal dislocation of content. Behind all the vehicles and drivers, there are specific trip purposes that each individual needs to fulfill in specific time. People go to different places, planning to arrive at specific times, with a demand for fulfilling given purposes at the destination.
2. *Traffic involves large-scale and long-term human interactions.* The interactions in traffic include a large number of users that have dynamic character. In addition, the need for mobility and access is something that an individual has throughout a lifespan. That need changes in the nature, but rarely ceases to exist.
3. *Traffic includes strong interdependence among users.* This is especially evident at intersections. Intersections are critical points on the network, because they are trying to accommodate trips on the network in a limited space-time. The limitation originates from a physical constraint that objects, in this case users, cannot and should not occur at the same point in the intersection at the same time. Consequently, there is limited availability of dedicated time to cross through the intersection. Users are highly dependent on each other, since their positive or negative behavior affects the behavior of other users, affects the system, and as a feedback loop, each individual user too.

The underlying social needs, large-scale and long-term interactions, with interdependencies are all interrelated. It is an essential problem of differences in simultaneous users' needs. At a certain point in time, in usual traffic conditions, some people are going to a vacation destination, while some people are driving to the hospital in an emergency. Essentially, considering the sum of all these needs and their consequences, traffic becomes something that economists would recognize as system similar to a non-zero sum game [21].

We will consider these points from a standpoint of intersection's operational principle. The primary role of any intersection traffic-control principle is to prevent the occurrence of two vehicles at the same place and the same time. Prevention of simultaneous occurrence of users is performed by determining which user can enter the intersection space at every time point. This restriction can be justified by one central goal of traffic control: to protect the life and limb of roadway users. In fulfilling this goal, traffic control respects the human right to life, one of the fundamental human rights recognized by the United Nations [22].

However, as a consequence of any such operational principle, there is a delay for some of the intersection's users. This delay is a part of the extended travel time from point A to point B. This means that, in order to fully protect the fundamental right to life, there is an imposed control over another fundamental human right – the right to freedom of movement. In addition, considering that intersections are a public space and a public investment, the activity of intersection control technology is a public service. Consequently, intersections and their technology should be pure public goods [23], providing non-excludable and non-rival benefits to all people. This relates operation of traffic control technology to the human right to equal access to public service, as another fundamental human right recognized by United Nations [22].

However, the relations between traffic control principles and fundamental human rights are even more delicate than just explained. As a consequence of restricting the right to freedom of movement and the right to equal access to public service, there is an indirect effect on the fulfillment of other fundamental human rights: right to life, right to work, right to leisure, right to standard of living adequate for health, and right to education. For example, a person waiting excessively at an intersection on his way to the hospital might die. A person waiting excessively at an intersection might be late for an important job interview, leaving his family without income. On the contrary, the operation of traffic control system does not affect some other rights (e.g., the right to property and right to peaceful assembly).

As a result, the question of operating principle at the intersection, through its effect on distribution of delay among users, results in various effects on fulfillment of universal human rights, and places even higher emphasis upon the underlying social relations.

IV. Current Perspectives on C2 Operating Principles

Knowing the importance of the relation between fundamental human rights and operating mechanism for an intersection, we will briefly analyze the current operating principles developed for controlling self-driving vehicles at intersections. These principles are grouped as follows:

1. Conventional control principles (e.g., predefined right-of-way for certain movements over other movements through the intersection [24-26], minimizing the time a vehicle takes to cross the intersection [27], maximizing traffic throughput based on waiting delay or queue length [28], or minimizing total delay [29]);
2. Queuing principles (e.g., first-in, first-out [30], adversarial queuing [31], or priority queuing [32]);
3. Economic principles (e.g., auction for time-slot [33], purchasing the time-slot from intersection manager that tries to maximize "profit" [34]).

These principles might have technical drawbacks, especially for a large-scale network implementation, where issues of scalability and redundancy are important. However, we have focused on those issues elsewhere. The point that we want to make is that these principles focus solely on technical details, not taking into consideration actual social relations. First, the fixation of a control principle on a predefined "static" rule that uses the approaching link or predefines order of service bluntly neglects individuals' needs for crossing the intersection. Similarly, determination of optimality by minimizing aggregate negative effects neglects the individual user needs. A very good example is a person waiting on the "minor" intersection approach, on his way to the emergency room, while all the people on the "main" approaches are, for example, going shopping. This situation might happen if the operational principle aims at minimizing total delay. Such principle does not recognize the discrepancy in individual's needs, and cannot accommodate them. These current principles do not have a mechanism to obtain or include the information on specific trip purpose and desired arrival time of each individual, and include that information in the decisions. Control decisions are externalized, and, consequently, imprecise.

Another critical point is that operational principles are developed without consideration of relations between technology and human behavior. This is especially important in the operational principles that neglect human altruistic behavior or do not limit the pursuit of self-interest. In addition, "selling" the right to use the intersection space might be considered unfair, knowing that exploiting shifts in demand by raising prices is considered unfair [35]. In addition, aiming at profit maximization without fairness will lead to resistance by people [36], especially when there is singularity of supplier with service monopoly so the "customer" cannot avoid using the service.

V. Theoretical Implications from Social Science Research

Considering that the previous control approaches are primarily starting from a technical standpoint, perception of technological functionality and design might be restricted with these traditional views. Bearing in mind that technology need to be developed to take into consideration human behavior, this section turns towards the findings from social science research. These points will be grouped and discussed to direct towards a potential approach when developing intersection control principles for self-driving vehicle technology.

As the first point, development of C2 technology should take into account human tendency to cooperate and divide labor, especially at a group level. In general, in every social system, people belong to one of the three groups: reciprocal types, free-riders, or pure cooperators. Reciprocal types are people who contribute to the public good as a positive function of their beliefs about others' contributions, and they usually constitute the majority in the system (around 65%). On the opposite, there are only around 20% of free-riders that by default do not try to cooperate, and around 15% pure cooperators, that by default always try to cooperate [37-40]. Consequently, the structure of the system, can nudge people towards cooperation or non-cooperation.

It has been proven that people cooperate even with non-relatives, and often in situations of extremely high risk [41]. Cooperation has evolved primarily based on the principles of reciprocity [42], but people are willing to cooperate even in the case of indirect reciprocity [43]. In addition, development of C2 should rely upon the notion that people do not always follow strict self-interest hypothesis. People do care about the outcome other people in the system receive [44]. It is not true that people at all times pursue their material self-interest and do not care about the social goals, per se, because their utility diminishes from disadvantageous inequality [39]. It is important to emphasize that people do cooperate if they perceive that other people cooperate as well, especially in the long-term relations [40]. In addition, social consideration in interaction increases as the payoff from the cooperation and the degree of the common interest increase [45, 46]. Moreover, if individuals have the opportunity to affect the relative payoffs, they take into consideration equity outcomes, even in the presence of competition [39]. Finally, considering the size of cooperation groups, there is no explicit negative effect on the cooperation as the group size increases. The relation might be positive or negative, depending on the way in which individual and group payoffs are affected or how the communication is performed [47].

However, C2 cannot solely rely upon people's intrinsic willingness to cooperate and not being strictly self-interested. It is important to remember that cooperative acts are vulnerable to exploitation by selfish partners [41]. The problems may arise due to the time delay inherent in reciprocity, or when an individual does not (equally) contribute to the creation or maintenance of a shareable benefit or good. When public good is free for overusing, individuals or groups will usually overuse it. This problem is known as the "tragedy of the commons" [48]. Furthermore, operational principle of C2 should avoid the assurance problem [49]. This problem exists when individuals are better off if they follow the same minimal standard, but are second best off if, in the case when there are defectors, they join the defectors rather than continue to follow the standards. On the opposite, individuals are worst off if there are defectors but they do not join them. Without the external incentive (e.g. reputation, punishment, etc.) this cooperation might not be stable.

As an important point, C2 should incorporate the opportunity to build reputation in time [43]. The previous research shows that individuals respond differently in instances of anonymity versus instances where reputation building is possible [40, 50]. After a certain time, each individual begins to perceive herself as dependent on the others, and realizes that exploiting the others is hopeless. The notion of the future contact in the long term system results in the sense of dependence on the other's good will, which consequently leads to the goal of achieving mutual cooperation in the present [43, 51]. On the opposite, refusing to help the others in the system changes one's social status [40]. In addition to building reputation, C2 necessitates a structure that will prevent too many defectors from receiving the benefits of long-term cooperation. Individuals should/ought to realize the undesirable consequences of free riding through the established sanctioning system [52-54] and social pressure [55]. Moreover, development requires that people are willing to provide a sanctioning system, as a part of the public good [40]. Moreover, humans often care strongly about fairness and they are prepared to punish others who deviate from a fair principle, even at a personal cost [56] in order to maintain stable cooperation [39]. A good example is altruistic punishment, when individuals punish free riders that negatively deviate from the cooperation standard [40, 57].

VI. Empirical Implications

Besides considering theoretical implications, public opinions are important to investigate, since they can significantly influence the direction and pace of technology development. This is consequently important for the development of self-driving vehicle technology, which is already facing some negative preconceptions. For example, one previous survey [58] has shown that 75% of respondents think they can drive a car better than a computer could, and the same percentage answered they would not trust a driverless car to take their children to school.

To supplement traditional technology development approaches, we have investigated public concerns related to social aspects of traffic control technology for self-driving vehicles. Survey included 239 responses, the majority from United States. There were 56% male, and 44% female respondents, born in the range from 1933 to 1993. In one question, respondents were asked to describe their understanding of the term "better intersection control technology". The responses focused on "smarter" devices that adjust to the current traffic situation, technology that is efficient, economical, fuel-efficient, safer, causing less pollution and noise, or broad improvement suggestions (e.g., roundabouts). Respondents also mentioned the need for better education and understanding of human behavior, better rules and better enforcement, as well as technology that includes moral factors (e.g., providing fairness and general satisfaction).

These results show us that existing traffic control technology shapes respondents' perceptions about improved technology, since they most frequently refer to the examples from conventional technology. Conventional principles restrict the awareness of the needs for some of the users. However, people have expressed consideration for a "common good", and consideration for fairness, in a sense that no one should wait very long time at an intersection. In general, respondents have stated the opinion that whatever the "better technology" may be, it is not currently implemented.

In the next question, respondents were asked to estimate the impact of traffic control technology on their needs, grouped according to Maslow's hierarchy of needs [59]. Majority of respondents (58%) have identified the relation to the need for safety (e.g., security of body, security of employment, security of resources, security of health, security of property). However, 15% and 14% of respondents identified relation to esteem (e.g., self-esteem, confidence, respect for others, respect from others, etc.) and self-actualization (e.g., morality, creativity, problem solving, lack of prejudice, etc.), respectively. In the following questions, when presented with specific choices, respondents recognized the effect of traffic control technology on safety, travel time, environment, but also on human emotions and land use implications.

However, when respondents were presented with a question on relation between human rights and traffic control, they recognized the effect on human rights (especially right to life and right to work) and commented on relation between human rights and overall quality of life. Finally, when asked for what trip purpose they would accept waiting at the intersection, considering that the traffic was set up to benefit all the users, only 8% of respondents answered they would accept waiting while going to the hospital, and only 14% of respondents answered the delay would be acceptable while going to a job interview. Conclusively, respondents have shown that the relative importance of the delay depends on the trip purpose.

In final questions, when asked if they would support paying for the right-of-way at intersection, only 3% of respondents answered positively. However, majority of people (62%) would be willing to pay higher price for a self-driving vehicle technology that will protect human rights (e.g., by ensuring an individual receives the right-of-way in urgent situations). A point to underline is that majority of people (77%) thought that it would be beneficial to publicly decide on the mechanism for assigning the right-of-way at intersections. Finally, majority of people (66%) would provide support (political, financial, and social) for including social considerations into the development of control technology for self-driving vehicles.

VII. Paradigm Shift through Anthropocentric Design

Besides the sole broadening and diversification of social appraisal of technology by amplifying social impact, we need to consider designing technology in such a way that the responsibility of the end user is enhanced instead of limited. Considering theoretical and empirical implications, C2 can rely on human's tendency to cooperate, divide labor, and not be self-interested, in addition to a modifiable structure with communication, reputation-building, and sanctioning system. All these points can establish a structure that enables long-term and large-scale cooperation, while enhancing the end-user responsibility. Consequently, traffic, as a socio-physical phenomenon, will be to the mutual advantage of individual users.

In this structure, users will restrict their liberty in the ways necessary to yield advantages to users in need, while having the identical right to similar acquiescence on the part of those who benefited from their submission. Today, person A gives the right-of-way to person B since person B is having an emergency, while tomorrow person B gives the right-of-way to person A, in the opposite case. From this perspective, a regulative framework with a contractually defined structure will impose an ordering of conflicting claims. Moreover, parties are not to gain from the cooperative labors of others without doing their fair share.

Undertaking this paradigm shift would develop traffic control as a fair system of social cooperation, where parties gain in the long term. The premise here is that the gain to the person who needs help far outweighs the loss of those required for helping him/her. In addition, assuming that the chances of being the beneficiary are not much smaller than those of being the one who must give aid, especially during an individual's lifespan, the principle is clearly in the interest of all the parties. Furthermore, the premise is that the publicly known principles of fairness are enough to bind those who take advantage of it – not just to accept it, but also to maintain it. The mutually-acknowledged and publicly-known interests would be enforceable as self-imposed by all the parties. There is a prima facie duty of fair play if the parties accept to act in accordance with the principles while knowingly accepting their benefits. This duty, as a feedback loop, would support the structure by rewarding the members for contributing to the common good. In addition, through the increase in understanding, the people will appreciate the mutual benefits of establishing fair social cooperation. The assumption is that the parties would recognize there is no need to violate the rules to protect personal interests, and they are able to recognize one another's good faith and desire for justice. Finally, this would reduce the wish to advance personal interests unfairly to the disadvantage of others. The resulting paradigm shift will try to achieve technological development so that traffic becomes a *large-scale, long-term, social phenomenon with a high degree of cooperative automation, functioning as a system for mutually-advantageous cooperative production.*

VIII. Recommendations for Further Investigations

From the previous sections, we recognize a need for perspective shift in the approach to self-driving vehicle technology design. This sections will present some of the recommendations for further investigations for development of self-driving vehicle technology.

A. Expanded design horizon

As an important point to highlight is not narrowing down the design horizon for the self-driving vehicle technology. This primarily includes attempting to take into consideration a complete range of relevant impacts, by determining what are concomitant cultural or social losses of new technology [60]. As a result, there is a need for a proactive approach to technology development in relation to values. An example of one of the similar approaches is identified as Value Sensitive Design [61-63]. The focus of this design approach is on deliberately incorporating moral values into technological design, while meeting traditional design criteria. The augmented list of technical criteria would go beyond conventional considerations, to include values that people consider important to life. Morally better designs would come through iterative conceptual, empirical, and technical investigations [62]. Finally, some of the essential questions that this iterative design approach would need to answer are as follows:

1. What are the intentions of self-driving vehicle technology design?
2. What social values will this technology promote?
3. What vision of life will this technology support?
4. What will be the short-term and long-term effects on human behavior?

B. Expandend decision-making constituencies

Having in mind the potential impacts of this technology, although engineers have an important role in the design, decision power should not be concentrated solely in a small group of experts, especially if they are influenced exclusively by corporate interests. There is a need to engage all relevant societal constituencies in decision-making about technology development. Allowing for decision space where individuals can decide what is the good life for them, could result in redesign that supports democratic self-management for future development [61, 62]. Providing space for reflective vision and critical conversations would provide essential understanding of the relevant values and their function in lives of people and groups. On the contrary, in cases when the design vision of C2 technology does not include wide range of users, there is the danger of limiting possibilities for technological development, and consequently limiting a range of positive impacts.

C. Development of social justice framework

Knowing that the operation of the traffic control system relates to some of the fundamental human rights, this technology consequently relates to the distribution of advantages and disadvantages originating from those rights. Hence, this becomes an issue of social justice - a structure or framework for distribution of advantages and disadvantages in a society, which includes certain rules for distinguishing what is just and what is not [64]. Fairness is already considered as an important social value in designing technology [65]. However, the discussion on the social justice framework needs to become an integral part of the self-driving vehicle technology development. Conclusively, the design perspective requires ethical reflections, as some of the engineering fields have already recognized [66-70], along with similar consideration for transportation planning practices [71, 72].

D. Evaluation of development trajectories

It is inevitable that this revolutionary technology will result in countless novel opportunities, for which well though ethical policies might not be developed [17]. Consequently, there is a need to project and assess all the possible variations in development through constructive technology assessment [73]. In order to develop different development trajectories, there is a potential in using Ethical Delphi [74], crowdsourcing [75], and agent-based modelling techniques [76] to obtain large-scale and long-term interactions in different development trajectories.

IX. Conclusions

Since the introduction of internal combustion engine and microprocessor technology, transportation has not faced a potential technological impact of this scale. Self-driving vehicle technology is bound to revolutionize transportation, and probably our societies as well. In our research approach, we have tried to aim beyond resolving immediate negative effects, but to take into consideration the long-term impact on society that this technology might have. First, this is specifically related to the notion of common humanity, through our cross-generation responsibility for sustainable development of technology. Moreover, the standpoint for technological development considers that technology is a socio-technical phenomenon. Consequently, decisions related to design of technology seize to be solely technical decisions, but they tend to have direct social implications. We cannot lack the conscious reflections on the morals in technology, because it shapes the context of humans as moral agents and consequently it shapes humans themselves.

On the contrary, current development approaches do not place human into the center of attention. Focusing solely on technical details, there is a danger of “tunnel vision” in design of technology. These approaches neglect the features of traffic as a phenomenon, and they do not consider relations to human behavior and attitudes. Moreover, the very fact of missing references on relations between social impact and traffic control technology supports the notion that the mindset of the current generation of traffic engineers was never directed towards investigating social effects of technology under their purview.

In order to develop an expanded vision, we consider that the ethical approach requires anthropocentric perspective. We start from considerations of human needs, represented as fundamental human rights, in a relationship to operating principles for intersections. Human rights are selected as the most fundamental in hierarchy of values, and common to all humanity. In addition, theoretical and empirical investigations have determined the potential for technological development with social considerations included. This developmental approach also has potential for positive influence on public perception of the technology itself. Finally, our starting point for development is envisioning traffic as large-scale, long-term, social phenomenon with a high degree of cooperative automation, functioning as a system for mutually-advantageous cooperative production.

However, this vision leaves several points to highlight in the further development. First, there is a need for a framework of justice incorporated into technological design, which will guide the distribution of benefits and burdens from the new technology. Second, we highlight the Value Sensitive Design, as a formidable force which can help us in reflecting on ethical aspects in advance of technological development. Further investigations require the need for constructive technology assessment, which would involve discussions between different interest groups, interdisciplinary approach, and agent-based modelling. Hopefully, this research will be a useful addendum to a more comprehensive inquiry of relation between humans and self-driving vehicle technology.

REFERENCES

[1] Ü. Özgüner, T. Acarman, and K. Redmill, *Autonomous Ground Vehicle*. Norwood, MA: Artech House, 2011.

[2] "Preliminary Statement of Policy Concerning Automated Vehicles," National Highway Traffic Safety Administration2013.

[3] "The Safety Promise and Challenge of Automotive Electronics: Insights from Unintended Acceleration," Committee on Electronic Vehicle Controls and Unintended Acceleration, Transportation Research Board, Board on Energy and Environmental Systems, Computer Science and Telecommunications Board 2012.

[4] J. M. Anderson, N. Kalra, K. D. Stanley, P. Sorensen, C. Samaras, and O. Oluwatola, "Autonomous Vehicle Technology: A Guide for Policymakers," RAND Coorporation 0833083988, 2014.

[5] "Self-driving cars: The next revolution," Center for Automotive Research KPMG LLP2013.

[6] "Creative Disruption: Exploring Innovation in Transportation," Intelligent Transportation Society America - Leadership Circle2013.

[7] F. Ramírez and A. Seco, "Civil Engineering at the Crossroads in the Twenty-First Century," *Science and Engineering Ethics,* pp. 1-7, 2011.

[8] G. H. Brundtland, "Report of the World Commission on Environment and Development: Our Common Future," United Nations1987.

[9] J. Elkington, "Triple bottom line revolution: reporting for the third millennium," *Australian CPA,* vol. vol. 69, 1999.

[10] M. Heidegger, "Being and time, trans. J. Macquarrie and E. Robinson," ed: New York: Harper & Row, 1962.

[11] D. Ihde, *Technology and the lifeworld: From garden to earth*: Indiana University Press, 1990.

[12] A. Borgmann, *Technology and the character of contemporary life: A philosophical inquiry*: University of Chicago Press, 1987.

[13] T. Swierstra and K. Waelbers, "Designing a good life: A matrix for the technological mediation of morality," *Science and Engineering Ethics,* pp. 1-16, 2012.

[14] P.-P. Verbeek, "Materializing morality design ethics and technological mediation," *Science, Technology & Human Values,* vol. 31, pp. 361-380, 2006.

[15] T. Heikkerö, *Ethics in Technology: A Philosophical Study*: Lexington Books, 2012.

[16] D. Michelfelder and S. A. Jones, "Sustaining Engineering Codes of Ethics for the Twenty-First Century," *Science and Engineering Ethics,* pp. 1-22, 2011.

[17] J. H. Moor, "Why we need better ethics for emerging technologies," *Ethics and Information Technology,* vol. 7, pp. 111-119, 2005.

[18] S. Cohen and D. Grace, "Engineers and social responsibility: An obligation to do good," *Technology and Society Magazine, IEEE,* vol. 13, p. 12, 1994.

[19] A. C. v. Gorp, *Ethical Issues in Engineering Design; Safety and Sustainability* vol. 2: 3TU Ethics, 2005.

[20] S. Cohen and D. Grace, "Engineers and social responsibility: An obligation to do good," *IEEE Technology and Society Magazine,* vol. 13, p. 12, 1994.

[21] A. M. Colman, *A dictionary of psychology*: Oxford University Press, 2009.

[22] "Universal Declaration of Human Rights," United Nations General Assembly1948.

[23] J. R. Minasian, "Public goods in theory and practice revisited," *Journal of Law and Economics,* pp. 205-207, 1967.

[24] R. Regele, "Using ontology-based traffic models for more efficient decision making of autonomous vehicles," in *Fourth International Conference on Autonomic and Autonomous Systems*, 2008, pp. 94-99.

[25] J. Alonso, V. Milanés, J. Pérez, E. Onieva, C. González, and T. De Pedro, "Autonomous vehicle control systems for safe crossroads," *Transportation research part C: emerging technologies,* vol. 19, pp. 1095-1110, 2011.

[26] V. Milanés, J. Pérez, E. Onieva, and C. González, "Controller for urban intersections based on wireless communications and fuzzy logic," *IEEE Transactions on Intelligent Transportation Systems,* vol. 11, pp. 243-248, 2010.

[27] F. Yan, M. Dridi, and A. El Moudni, "Autonomous vehicle sequencing algorithm at isolated intersections," in *12th International IEEE Conference on Intelligent Transportation Systems*, 2009, pp. 1-6.

[28] H. Ghaffarian, M. Fathy, and M. Soryani, "Vehicular ad hoc networks enabled traffic controller for removing traffic lights in isolated intersections based on integer linear programming," *Intelligent Transport Systems,* vol. 6, pp. 115-123, 2012.

[29] I. H. Zohdy, R. K. Kamalanathsharma, and H. Rakha, "Intersection management for autonomous vehicles using iCACC," in *15th International IEEE Conference on Intelligent Transportation Systems*, 2012, pp. 1109-1114.

[30] K. Dresner and P. Stone, "Multiagent traffic management: A reservation-based intersection control mechanism," 2004, pp. 530-537.

[31] M. Vasirani and S. Ossowski, "Evaluating policies for reservation-based intersection control," 2009.

[32] M. Mladenovic and M. Abbas, "Self-organizing Control Framework for Driverless Vehicles," presented at the 16th International IEEE Conference on Intelligent Transport Systems, Hague, Nederlands 2013.

[33] H. Schepperle and K. Böhm, "Agent-based traffic control using auctions," *Cooperative Information Agents XI,* pp. 119-133, 2007.

[34] M. Vasirani and S. Ossowski, "Towards reservation-based intersection coordination: an economic approach," in *11th International IEEE Conference on Intelligent Transportation Systems*, 2008, pp. 1-6.

[35] D. Kahneman, J. L. Knetsch, and R. Thaler, "Fairness as a constraint on profit seeking: Entitlements in the market," *The American Economic Review,* pp. 728-741, 1986.

[36] D. Kahneman, J. L. Knetsch, and R. H. Thaler, "Fairness and the Assumptions of Economics," *Journal of business,* pp. 285-300, 1986.

[37] R. Kurzban and D. Houser, "Experiments investigating cooperative types in humans: A complement to evolutionary theory and simulations," *Proceedings of the National Academy of Sciences of the United States of America,* vol. 102, p. 1803, 2005.

[38] R. M. Isaac, J. M. Walker, and S. H. Thomas, "Divergent evidence on free riding: An experimental examination of possible explanations," *Public choice,* vol. 43, pp. 113-149, 1984.

[39] E. Fehr and K. M. Schmidt, "A theory of fairness, competition, and cooperation," *The Quarterly Journal of Economics,* vol. 114, pp. 817-868, 1999.

[40] S. Gächter and B. Herrmann, "Human cooperation from an economic perspective," in *Cooperation in primates and humans: mechanisms and evolution*, P. M. Kappeler and C. van Schaik, Eds., ed: Springer Verlag, 2006.

[41] C. P. v. Schaik and P. M. Kappeler, "Cooperation in primates and humans: closing the gap," in *Cooperation in primates and humans: mechanisms and evolution*, P. M. Kappeler and C. van Schaik, Eds., ed: Springer Verlag, 2006.

[42] R. Axelrod and W. D. Hamilton, "The evolution of cooperation," *Science,* vol. 211, pp. 1390-1396, 1981.

[43] M. Milinski, "Reputation, personal identity and cooperation in a social dilemma," in *Cooperation in primates and humans: mechanisms and evolution*, P. M. Kappeler and C. van Schaik, Eds., ed: Springer Verlag, 2006.

[44] P. Kollock, "Social dilemmas: The anatomy of cooperation," *Annual review of sociology,* pp. 183-214, 1998.

[45] J. Henrich, R. Boyd, S. Bowles, C. Camerer, E. Fehr, H. Gintis*, et al.*, "“Economic man” in cross-cultural perspective: Behavioral experiments in 15 small-scale societies," *Behavioral and brain sciences,* vol. 28, pp. 795-815, 2005.

[46] H. H. Kelley and J. Grzelak, "Conflict between individual and common interest in an N-person relationship," *Journal of Personality and Social Psychology,* vol. 21, p. 190, 1972.

[47] P. Bonacich, G. H. Shure, J. P. Kahan, and R. J. Meeker, "Cooperation and group size in the n-person prisoners' dilemma," *Journal of Conflict Resolution,* vol. 20, pp. 687-706, 1976.

[48] G. Hardin, "The tragedy of the commons," *New York,* 1968.

[49] R. M. Isaac, D. Schmidtz, and J. M. Walker, "The assurance problem in a laboratory market," *Public choice,* vol. 62, pp. 217-236, 1989.

[50] E. H. Hagen and P. Hammerstein, "Game theory and human evolution: A critique of some recent interpretations of experimental games," *Theoretical Population Biology,* vol. 69, pp. 339-348, 2006.

[51] D. G. Pruitt and M. J. Kimmel, "Twenty years of experimental gaming: Critique, synthesis, and suggestions for the future," *Annual review of psychology,* vol. 28, pp. 363-392, 1977.

[52] T. Yamagishi, "The provision of a sanctioning system as a public good," *Journal of Personality and Social Psychology,* vol. 51, p. 110, 1986.

[53] M. D. Caldwell, "Communication and sex effects in a five-person Prisoner's Dilemma Game," *Journal of Personality and Social Psychology,* vol. 33, p. 273, 1976.

[54] E. Fehr and S. Gächter, "Cooperation and punishment in public goods experiments," *The American Economic Review,* vol. 90, pp. 980-994, 2000.

[55] M. Olson, *The logic of collective action: Public goods and the theory of groups* vol. 124: Harvard Univ Pr, 1965.

[56] R. Trivers, "Mutual benefits at all levels of life," *Science,* vol. 304, p. 964, 2004.

[57] E. Fehr and S. Gachter, "Altruistic punishment in humans," *Nature,* vol. 415, pp. 137-140, 2002.

[58] M. Vallet. (11/11/2013). *Survey: Drivers ready to trust robot cars?* Available: http://www.carinsurance.com/Articles/autonomous-cars-ready.aspx

[59] A. H. Maslow and K. J. Lewis, *Maslow's hierarchy of needs*: Salenger Incorporated, 1987.

[60] M. Flanagan, D. Howe, and H. Nissenbaum, "Embodying values in technology: Theory and practice," *Information technology and moral philosophy,* pp. 322-353, 2008.

[61] B. Friedman, P. H. Kahn Jr, and A. Borning, "Value sensitive design and information systems," *Human-computer interaction in management information systems: Foundations,* vol. 5, pp. 348-372, 2006.

[62] J. Van den Hoven, "Design for values and values for design," *Information Age,* vol. 4, pp. 4-7, 2005.

[63] J. Van den Hoven, "ICT and value sensitive design," *The Information Society: Innovation, Legitimacy, Ethics and Democracy In honor of Professor Jacques Berleur sj,* pp. 67-72, 2007.

[64] D. Miller, *Principles of social justice*: Harvard University Press, 1999.

[65] C. Shelley, "Fairness in Technological Design," *Science and Engineering Ethics,* pp. 1-18, 2012.

[66] F. S. Grodzinsky, "Equity of access: Adaptive technology," *Science and Engineering Ethics,* vol. 6, pp. 221-234, 2000.

[67] J. Curiel-Esparza, J. Canto-Perello, and M. A. Calvo, "Establishing sustainable strategies in urban underground engineering," *Science and Engineering Ethics,* vol. 10, pp. 523-530, 2004.

[68] B. M. Beamon, "Environmental and sustainability ethics in supply chain management," *Science and Engineering Ethics,* vol. 11, pp. 221-234, 2005.

[69] J. Kleijnen, "Ethical issues in engineering models: an operations researcher’s reflections," *Science and Engineering Ethics,* vol. 17, pp. 539-552, 2011.

[70] M. Azath, R. Wahida Banu, and A. Neela Madheswari, "Improving Fairness in Network Traffic by Controlling Congestion and Unresponsive Flows," *Advances in Network Security and Applications,* pp. 356-363, 2011.

[71] K. Martens, "Basing Transport Planning on Principles of Social Justice," *Berkeley Planning Journal,* vol. 19, 2006.

[72] K. Martens, A. Golub, and G. Robinson, "A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States," *Transportation research part A: policy and practice,* vol. 46, pp. 684-695, 2012.

[73] A. Genus, "Rethinking constructive technology assessment as democratic, reflective, discourse," *Technological Forecasting and Social Change,* vol. 73, pp. 13-26, 2006.

[74] K. Millar, S. Tomkins, E. Thorstensen, B. Mepham, and M. Kaiser, *Ethical Delphi: Manual*: LEI, 2006.

[75] D. C. Brabham, "Crowdsourcing as a model for problem solving an introduction and cases," *Convergence: the international journal of research into new media technologies,* vol. 14, pp. 75-90, 2008.

[76] F. Squazzoni, *Agent-based computational sociology*: Wiley. com, 2012.