Engineering social justice into self-driving vehicles?

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Abstract The convergence of computing, sensing, and communication technology will soon permit large-scale deployment of self-driving vehicles. This will in turn permit a radical transformation of traffic control technology. This paper makes a case for the importance of addressing questions of social justice in this transformation, and sketches a preliminary framework for doing so. We explain how new forms of traffic control technology have potential implications for several dimensions of social justice, including safety, sustainability, privacy, efficiency, and equal access. Our central focus is on efficiency and equal access as desiderata for traffic control design. We explain the limitations of conventional traffic control in meeting these desiderata, and sketch a preliminary vision for a next-generation traffic control tailored to better address the demands of social justice. One component of this vision is cooperative, hierarchically-distributed self-organization among vehicles. Another component of this vision is a priority system enabling selection of priority levels by the user for each vehicle trip in the network, based on the supporting structure of non-monetary credits.

Keywords *Traffic management · Self-driving vehicle · Engineering ethics · Transportation ethics · Priority level · Credit system*

Introduction

Transportation will be revolutionized in the near future by a series of important technological developments, including the coming ubiquity of self-driving vehicles. This revolution brings with it a host of new challenges and opportunities, both technical and ethical. One important locus for these challenges is the design of traffic control technology. This design problem includes several important ethical challenges, especially in light of increasing demand for transportation and changing travel patterns. Perhaps the most familiar of these challenges is *sustainability*: how to serve current needs and interests without compromising the ability of future generations to fulfil theirs (Maile et al. 2008; Mobility 2001: World mobility at the end of the 20th century - Overview 2001; Steg and Gifford 2005; Marsden et al. 2010). A less obvious challenge is to design traffic control systems in a way that enables them to realize *just social relations*. This paper focuses on that neglected challenge.

We have four aims in this paper. First, we aim to make vivid how issues of social justice are relevant to the design of traffic control technology, and why these issues are of special practical importance at the current moment in the development of such technology (§1). Second, we aim to clarify some of the dimensions of thinking about social justice that are relevant to traffic control design (§2). Then, focusing for the sake of brevity on efficiency and equal access as desiderata, we aim to evaluate conventional traffic control, and to explain how certain next-generation technologies can both contribute to social justice, and raise new concerns (§3). Finally, we aim to sketch a preliminary vision for next-generation traffic control tailored to better address the demands of social justice (§4).

This paper is a preliminary examination of these issues. As such, it is far from providing a complete account of how to engineer social justice into our traffic control system. For reasons of space, we neglect several important alternatives to the account of social justice that we work from. We also set aside important dimensions of the question of technical implementation: for example, we will focus only on the intersection as a locus of traffic control, ignoring important questions about roadway control more generally, and questions about broader transportation system planning.

The relevance of social justice for traffic control

Our project takes as its starting point the assumption that technology is not a value-neutral tool, but a potent force that can condition human experience, agency, and social relations (Borgmann 1987; Ihde 1990; Heidegger 1954). For example, technology can be implemented in ways that favour certain social classes over others (Bianchini and Avila 2014). In light of points like these, the IEEE Code of Ethics states that engineers should aim to improve their understanding of the technology, its appropriate application, and the likely consequences of its implementation (IEEE Code of Ethics 2006). In addition, several theorists have explored how technologies can shape our cultural or social spheres (Flanagan et al. 2008; Verbeek 2006; Heikkerö 2012; S. Cohen and Grace 1994). In our view, it is important not only to understand such consequences, but to use ethical reasoning to evaluate their significance.

It is easy for questions of social justice to appear invisible in the context of contemporary traffic control, however. Right-of-way is not determined by social class, and someone delayed by traffic is more likely to experience frustration, rather than the sort of indignation that we ordinarily associate with the experience of injustice. Further, certain broad claims about engineering ethics may make the ethics of traffic control appear straightforward or trivial. For example, the development of traffic control technology should aim at improving our quality of life, and serve the public interest with regard for safety, health, and welfare, while also preventing conditions that are threatening to life, limb, or property (Canons of Ethics for Members 2003; Code of Ethics for Engineers 2007; Code of Ethics 2010; Ramírez and Seco 2011; IEEE Code of Ethics 2006). From this perspective, the aims of intersection control technology may appear obvious: on the one hand, such technology should prevent collisions, and the harms collisions cause. On the other hand, such technology should promote the orderly and efficient movement of vehicles, which contributes to the common interest (Manual on Uniform Traffic Control Devices 2009).

Safety and efficiency are plainly important goals. However, it is a mistake to think that they exhaust the ethical significance of traffic control. Traffic control can constitute or enable social justice or injustice. This point can be illuminated in three ways.

First, while traffic is a physical phenomenon, it can be understood ethically as a manifestation of simultaneous human needs and interests. For example, some people approaching a certain intersection might be en route to their holiday destination, while others might be traveling to the hospital in an emergency. By controlling human movement, traffic control technology adjudicates these competing needs and interests, in a large-scale and long-term way. It is thus a central aspect of the concrete instantiation of relations of social justice or injustice.

Second, traffic control technology attempts to impose a strong control over human movement (McShane 1999), thus directly affecting our ability to exercise our right to free movement, which is arguably a fundamental human right. This is because all traffic control devices – together with the conventional and legal background that enables them to function – have the paradigmatic effect of restricting human movement. For example, consider conventional traffic signals, which allow or forbid the movement of users seeking to enter a specific intersection (Daganzo 1997). Embedded in an appropriate legal and cultural background, a red signal restricts one's freedom of movement as long as it is active.

Third, many of the needs and interests affected by traffic control are associated with further human rights, such as the right to life, the right to work, the right to leisure, the right to a standard of living adequate for health, and the right to education. For example, delaying the imagined emergency trip to the hospital could cause someone to die; delaying someone's trip to a job interview could deprive her of the chance to support her family, etc.

Questions about the relationship between social justice and traffic control technology are especially pressing at the current time, because we are in the midst of technological developments that have the potential to revolutionize traffic control. First, vehicles of the very near future will include powerful computers with capability of storing and processing large amounts of data (Leen and Heffernan 2002; Hsu and Chen 2005). Second, vehicles will be able to collect real-time data both about their state and the surrounding environment, including data about geographical coordinates, speeds, direction of movement, acceleration, and obstacles (Özgüner et al. 2011). Third, Wireless Local Area Networks will enable communication between vehicles (V2V) and between vehicles and infrastructure (V2I) (Misener et al. 2009; Hartenstein et al. 2010; Karagiannis et al. 2011). This technological convergence will progress towards the development of self-driving vehicles, in a continuum of automation levels (Standard J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems 2014). As a result, future vehicles will be able to monitor roadway and traffic conditions, and to perform all safety-critical driving functions (Preliminary Statement of Policy Concerning Automated Vehicles 2013).

This emerging technology promises several potential benefits. Immediate predicted benefits include reduction in the number of collisions and fatalities, fuel savings, ameliorating congestion, improving the mobility options of persons who are unable to drive, and mitigating environmental impacts (Fagnant and Kockelman 2013; Godsmark et al. 2015; Anderson et al. 2014; Delot et al. 2010; The Safety Promise and Challenge of Automotive Electronics: Insights from Unintended Acceleration 2012a; Self-driving cars: The next revolution 2013). Longer-term benefits include the potential to reduce individual car ownership, by enabling shared-vehicle mobility solutions or Mobility as a Service, with mobility service operators providing a comprehensive and integrated range of mobility services to customers (Godsmark et al. 2015; Schoettle and Sivak 2015; Spieser et al. 2014). Additional potential benefits include providing users with the opportunity to do other in-vehicle activities, such as reading or working (Barton 2015), enhancing the productivity of delivery vehicles (Kamin and Morton 2015), and changes in road design and maintenance (Lutin et al. 2013). Finally, self-driving vehicle technology is predicted to have a significant export potential (Shladover 2012) and potential for return on investment (Creative Disruption: Exploring Innovation in Transportation 2013).

The development of self-driving vehicles has already raised some ethical questions (Hevelke and Nida-Rümelin 2014). However, this paper focuses on a distinct implication of the convergence of these computing, sensing, and communication technologies: they provide enormous opportunities for sophisticated and novel forms of traffic control that utilize rich real-time information. We thus have reason to expect that that contemporary conventional traffic control (C1) will be replaced by a next-generation of traffic control that utilizes these new technologies – traffic control 2.0 (C2).

As part of a continuously evolving perception of engineering ethics (Schmidt 2014; Smith et al. 2014), many engineering fields have already recognized the importance of ethics and social justice in designing new technologies (Grodzinsky 2000; Curiel-Esparza et al. 2004; Beamon 2005; Kleijnen 2011; Azath et al. 2011; Harvey 2010). From the perspective of social justice, the development of C2 presents enormous opportunities, but also two important dangers. The first is that the development of traffic control technology might suffer from design inertia: maintaining design assumptions that are tailored to earlier technology. The second is that the character of C2 might be shaped by private interests, to the detriment of social justice. This makes careful and public attention to the way C2 technology might realize or inhibit social justice especially important at this moment of technological transition.

Social justice as a source of desiderata for traffic control design

We have just seen why social justice is a significant issue for the design of traffic control, and why attention to this issue is especially needed at this time. In this section, we introduce a framework for thinking about applying social justice to traffic control. We briefly sketch the central desiderata we take to be at stake – safety, sustainability, privacy, efficiency, and equality of access – and explain our reasons for focusing on the latter pair of desiderata here. In arguing for these desiderata, we do not seek to adjudicate between competing comprehensive accounts of justice.[1] This is because we take our account of these desiderata to be compatible with most of these comprehensive accounts of justice.

Consider first safety. Currently, automotive travel risks death and other extremely serious harms. For example, over 30,000 people are killed and over 1,600,000 are injured in automotive accidents each year in United States alone (Traffic Safety Facts: 2012 Data 2014). It is arguable that the central ethical reason to promote development of self-driving vehicle technology is that such technology promises to significantly reduce the terrible human cost of automotive collisions (*The Safety Promise and Challenge of Automotive Electronics: Insights from Unintended Acceleration* 2012b). The core goal of self-driving vehicle technology is to allow the vehicle to take over responsibility for real-time driving decisions. This radical change in agency will potentially remove the major cause of traffic accidents – human error (Preliminary Statement of Policy Concerning Automated Vehicles 2013). Everyone will agree that the safety should be a top priority for design of traffic control technology: vulnerability to collision-producing malfunction or malevolent hacking must be minimized as much as possible. However, in order to keep our discussion manageable, we will largely set this issue aside in what follows, as the problem of securing safety in C2 is a largely independent engineering problem from those which we will focus on here.

Sustainability is also an important candidate element of social justice: institutions that secure just relations among existing people at the cost of harm to future generations are arguably ipso facto unjust (Meyer 2009). Here again the significance of sustainability as a desideratum is important for engineers and policy makers considering vehicle design, public vs. private transportation, infrastructure manufacturing, etc. As with safety, we will largely set this issue aside, in order to keep the scope of our discussion manageable.

Protection of personal *privacy* is a third candidate element of social justice. This is potentially of central importance to next-generation traffic control. This is because next generation technology will have the capability to collect, store, and transmit a great deal of sensitive user information. Sharing such information can potentially enhance the efficiency of next-generation traffic control. For example, sharing the planned route of each user's trip can enable calculations that aim to minimize overall system delays. However, collecting and sharing this information involves evident user privacy concerns

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[1] Philosophical debate about the nature of social justice is deep and complex. For a reasonable survey of contemporary views, see (Pojman 2006). (Rawls 1971) is the starting point for a wealth of contemporary theorizing. Important competitors to Rawls' theory include Neo-Lockeanism (e.g. (Nozick 1974)), welfarist consequentialism (e.g. (Goodin 1995)), egalitarianism (e.g., (G. A. Cohen 2011)), and the capabilities approach (e.g., (Nussbaum 2009)).

(Wright 2011). Because of the distinctive complexities of designing privacy safeguards, we will again set this dimension of the problem aside.

In this paper we will focus on *efficiency* and *equality of access* as desiderata for traffic control. For almost everyone, use of public roadways is primarily an *instrumental* good: it is valuable as a means to pursue other goals. Holding fixed cost of implementation, we will call a traffic control system *efficient* to the extent that it enables users to pursue their (permissible) goals. One paradigm failure of efficiency in this context is a 'traffic jam' that could have been avoided by superior traffic control design. Conventional traffic control is replete with inefficiency. For example, inefficiency typically occurs when a vehicle waits at a red light in the absence of cross-traffic. Efficiency is a central goal of social justice because enabling persons to satisfy their needs and legitimate interests is a central function of public institutions.

It is important to emphasize that efficiency in this ethically relevant sense should *not* be identified with minimizing aggregate user delay. This is because a given period of delay can have radically different effects on different users: it could provide a pleasant chance to idly daydream, or it could have terrible implications if the delay occurs en route to a job interview or the emergency room, as noted above. When we evaluate how well a system of traffic control realizes social justice, these differences are highly relevant for the purposes of social justice.

The second desideratum for traffic control that we will focus on is *equality of access* to movement. A traffic control system provides equal access to movement to the extent that it provides all users with the same rights and privileges of movement. Transportation infrastructure regularly falls short of realizing this goal. For example, persons with a variety of disabilities often lack opportunities for movement that the able-bodied can routinely exercise as they may be prevented from driving. There are several reasons to think that equality of access to movement is a central criterion of social justice for traffic control. First, as we noted in the previous section, one might think that freedom of movement is a fundamental human right that each person is equally entitled to exercise (Universal Declaration of Human Rights 1948). Second, access to movement is a profoundly important means to the exercise of many of our other rights, such as the rights to a standard of living adequate for health or the rights to education or political participation. Third, insofar as roadways and traffic control are *public institutions*, just societies arguably have an obligation to protect equal access to the goods provided by these institutions. Fourth, inequality of access to public spaces like roadways would have substantial *symbolic significance*, potentially threatening crucial democratic assumptions of political equality. This point is made vivid by the historical example of the aristocratic convention that one give way to a person of higher rank.

It is worth emphasizing that both equality of access and efficiency should ultimately be assessed globally rather than locally. This is perhaps most obvious in the case of equality of access. If we focus on the intersection, we can see that locally speaking, traffic control can have a zero-sum character: only one vehicle can occupy a certain bit of space at a given time. In many cases, someone must be given priority, which may be incompatible with strict local equality of access. However, provided that priority access is provided in such cases based on rules that do not *globally* disadvantage certain users, there is no objection to the loss of equal local access.

Applying the criteria to traffic control technologies

This section applies our criteria to three schematically sketched traffic control systems. It begins by introducing and evaluating conventional traffic control (*C1*). It then considers two ways in which next-generation traffic control (*C2*) might be implemented, and evaluates them.

Arguably the most significant development in traffic control technology was the invention of the illuminated traffic signal (A History of Traffic Control Devices 1980; Mueller 1970). This initial engineering solution to the problem of intersection control introduced separation of conflicting flows using fixed periods of displayed green/red lights. This crucial operating principle – allowing alternating access to an intersection from different approaches for discrete intervals – was maintained by later developments in traffic signal control technology. These further developments – such as microprocessor technology – greatly enhanced the possibilities for automated traffic control operations. For example, this development allowed the introduction of cyclical repetition of the relevant time intervals, and coordination of operation between nearby intersections.

With these points in mind, consider how C1 fares with respect to efficiency and equality of access. If we set aside important background questions, such as who has access to vehicles, this system appears to provide equality of access. This is because no particular person has priority for right of way, this being determined by order of arrival, and the cyclical operation of the traffic signal. One important exception is provided by emergency vehicles, which have right of way. But if we make the (large) assumption that all have equal access to the health and safety benefits of such vehicles in case of emergency, this does not appear inconsistent with equal access.

With respect to efficiency, sophisticated C1 systems clearly does better overall than simpler systems like the conventions and laws that govern the unsigned intersection or the four-way stop. This efficiency improvement is especially true given increasing traffic volume. However, there are two significant and relevant limitations to C1 systems. First, even assuming an easily measurable operationalization of efficiency – such as aggregate delay – the foundational constraints introduced by C1 traffic control technology make it difficult to optimize across a traffic network in real time (Papageorgiou et al. 2003). Even the advanced traffic control technology, such as adaptive traffic control systems, require human supervision during operation and do not guarantee benefits (Mladenovic 2012; Mladenovic and Abbas 2012). Call this the *optimization problem*. Second, the examples of trips to the emergency room or job interviews discussed in the previous section show that some user delays are much worse relative to efficiency than others. Call the task of designing sensitivity to these contrasts of importance into a traffic control system the *operationalization problem*. Because C1 utilizes very limited information about users, it cannot distinguish the relative importance of different user trips. For example, any control principle based on a predefined “static” rule, such as a function of the approaching link or order of service, completely neglects individuals’ needs for crossing the intersection. In addition, C1 widely utilizes the concepts of the major and minor road, where larger amount of green time is dedicated to a “major” approach, and approach priority is determined, for example, by total traffic volume (Daganzo 1997; Gartner and Stamatiadis 2009). By using such rules or principles, C1 can address the optimization problem to a limited extent, but it cannot solve the operationalization problem.

The technological developments mentioned at the beginning of the paper permit significant improvements in efficiency. In the remainder of this section, we will consider two operating principles that represent broad ways of exploiting the potential of self-driving vehicle technology in developing next-generation traffic control (C2).

The first operating principle that we will consider (OP1) exploits three important possibilities made available by the new relevant technologies. First, sensing technologies entail that vehicles can collect rich real-time information about their location and trajectory, and any obstacles in their environment. Second, self-driving vehicle and vehicle-infrastructure communication technology entail that intersection control can directly communicate with a self-driving vehicle, rather than a (slow and error-prone) human operator. Third, the availability of computing power both for next generation vehicles and intersection controllers makes possible real-time dynamic assignment of intersection access to individual vehicles or platoons of vehicles.

Like C1, OP1 gives highest priority access to dedicated emergency vehicles, and traffic is otherwise controlled by giving access to the intersection to all vehicles on a given approach for a certain period of time. In OP1, however, intersection control collects location and trajectory information from all vehicles from within range. The cycle of periods of time allotted to various approaches are then determined by applying hypotheses concerning what will minimize aggregate delay at the intersection. Access to the intersection is then communicated directly to the self-driving vehicle, rather than with a human operator via visual signals.

OP1 promises significant gains over C1 with respect to the optimization problem. For example, given the fast responsiveness and reliability of self-driving vehicles compared to human drivers, access to the intersection can be given to the waiting vehicles as soon as their trajectories would not conflict with the vehicles already in the intersection, rather than building in extra waiting time to safely manage human unreliability, as C1 does. And, at least within the scope of a single intersection OP1 has the ability to successfully minimize aggregate delay.

Notice, however, that OP1 makes no progress on the *operationalization problem.* One important way to make progress on this problem uses communication technology to permit *user input* to contribute to the assigning of priority access to the intersection. This possibility immediately faces several difficult challenges in its implementation:

1. The ethical priority of various needs and interests is a paradigmatic locus of reasonable disagreement. While reasonable people will likely agree that a trip to the emergency room is higher in priority than a trip to the park, we can predict reasonable disagreement about a wide range of more interesting cases.
2. On an influential liberal conception of political legitimacy, governments should, where possible, avoid imposing on their citizens answers to ethical questions that are the objects of reasonable disagreement (Rawls 2005).
3. Even were these problems soluble, there is a problem of *honest reporting*: people will have an incentive to exaggerate the importance of their trip, and mechanisms intended to dissuade such exaggerations are likely to be costly.

One way to finesse these problems is to assign access to the intersection via a real-time monetary auction. This has two significant virtues relative to the challenges just identified. First, people are allowed to value their own trips in any way they like. This respects reasonable evaluative disagreement, and avoids the government legislating certain goals as more important than others. Second, because achieving priority is costly given the monetary auction, users have a financial incentive not to exaggerate the importance of their trips.

These ideas are implemented by OP2. Like C1 and OP1, OP2 gives highest priority access to dedicated emergency vehicles. And like OP1, access to the intersection is communicated directly to the self-driving vehicle. However, the order of priority access to the intersection is otherwise determined by real-time monetary auctions that users of all vehicles approaching an intersection can participate in.

If we assume that the size of bids in the auction are positively correlated with the importance of timely progress through the intersection, OP2 will fare better with respect to the operationalization problem than OP1. This assumption is at least initially plausible: in our examples, it is likely that users heading to the emergency room or a job interview would be willing to make bids high enough to ensure their timely progress.

The very mechanism that allows OP2 to achieve this goal, however, also leads OP2 into conflict with the second desideratum of social justice: securing equality of access. To see this, notice that in any social context marked by significant economic inequality, the wealthy could afford to ensure that they always have priority access to intersections, given OP2. No matter how important a poorer person's trip, she may not be able to afford to outbid a much wealthier person for priority access. This threatens to amount to a plutocratic variant of the old aristocratic rule that required one to make way for a vehicle containing a member of a higher social class.

Intersection traffic control thus seems to face a dilemma: either sacrifice equality of access, or leave the operationalization problem unsolved, thus compromising efficiency. If the dilemma were insoluble, we would opt to preserve equality. However, in the remainder of this paper we will sketch an alternative approach that promises to achieve both efficiency and equality of access.

A vision for next-generation traffic control

What we seek is a system of traffic control that preserves the virtues of OP2, while avoiding its inegalitarian implications. It may help to restate the virtues we identified in OP2:

- Highest priority access is guaranteed for emergency vehicles (this was also a feature of C1 and OP1)
- The efficiency gains permitted by self-driving vehicles and real-time intersection-vehicle communication (this was also a feature of OP1)
- Priority can be based on information that is correlated with the objective importance of priority access
- User control over providing this information avoids difficult and objectionable central adjudication of the importance of various trips

- Linking priority information to user expenditure of scarce resources provides incentive for accurate user reporting of perceived importance of timely passage through the intersection.

These virtues can be preserved by a model of intersection control that replaces monetary auctions with a system of *priority credits* (₵). The core idea is to develop an alternative to monetary auctions which preserves the scarcity incentive and information-value of the auction model, while avoiding the inegalitarian implications of that model. The core amendment is that, unlike money, ₵ are to be made available to all on a transparently fair basis. Further, ₵ are to be made monetarily non-fungible, preventing economic inequality from directly entailing inequality in the access to movement that ₵ provide.

In what follows, we sketch some provisional details of this approach to traffic control. As we have emphasized throughout, we focus on the intersection. However, the approach that we develop has the potential to be expanded to any vehicle-to-vehicle interaction on the network scale (e.g., lane change, platoon formation, etc.).

We develop our approach under several important technological assumptions, including seamlessly operational inter-vehicle and inter-infrastructure communications, in-vehicle processing and sensing capabilities. Besides the existence of distributive computing power via wireless communications, the proposal has the capability to accommodate both current and future vehicle technology, which will potentially include driverless vehicles.

The framework includes two main components:

1. Cooperative, hierarchically-distributed self-organization among vehicles.
2. A priority system enabling selection of priority levels by the user for each vehicle trip in the network, based on the supporting structure of non-monetary credits.

Hierarchically-distributed self-organization

To develop the technical principle, we need to be aware that traffic as a system has a large number of agents and dynamic character. This results in unpredictable and hard-to-measure disturbances, which are consequently hard to control. If we are to develop C2 by maintaining centralized control principle as in C1, we would need to have unattainable levels of information and processing power (Pfeifer and Verschure 1992; Unsal and Bay 1994; Seeley 2002). This is because it is technically difficult for automated decision-making systems to efficiently aggregate and use large quantities of decentralized information. In light of this, C2 should – unlike C1 – operate on the principle of decentralization, having a form of hierarchical and cooperative self-organization. A system is *self-organizing* when control and responsibility are transferred to the individual end-users. This enables a dynamic, adaptive, and decentralized control principle based upon the relationships between the behavior of the individual agents (the microscopic level) and the resulting sophisticated structure and functionality of the overall system (the macroscopic level), where elements acquire and maintain structure without external control (Prigogine and Nicolis 1977; Kaufmann 1993; Heylighen 2001; Prehofer and

Bettstetter 2005; De Wolf and Holvoet 2004). Self-organization is applicable to traffic control, since new technology can provide capability to develop it as an open system that continuously exchanges information with the environment, and as a complex system that has numerous and changing elements (Portugali 2000). The adaptive nature of self-organized systems also has the virtues of robustness against failure and scalability for future expansion. However, the system will also need to include network-level structure, in light of the complexity of traffic phenomena at the network level. For example, it will be important for vehicles to be able to cooperate on both the intersection and network levels. And this will require a background system of rules for managing such cooperation, in order to maximize the benefits from self-organization and prevent system failure.

The first level of cooperation occurs at the intersection. First and foremost, intersection-level rules will focus on ensuring the safety of all persons and vehicles in the vicinity of the intersection. Second, the rules will assign right-of-way to specific vehicles and platoons, according to their time of arrival at the intersection and their *Individual Priority Index* (IPI). IPI is the numerical representation of individual trip priority for each vehicle.

The second level of cooperation is the link level, where vehicles can create platoons, based on their IPI value and overlapping routes. This cooperation would be arranged by communication between the vehicles themselves. Each vehicle, while entering the network will invite other vehicles with overlapping routes to join their platoon. Vehicles will have incentives to join platoons, as platoons will receive some priority preference for movement through intersections, in light of the efficiency gains of platoon movement.

The third level of cooperation would be across the transportation network. At this level, central control, vehicles, and other agents will disseminate information about relevant features of the network (traffic volume and delay on various routes, etc.). This information can be used by individual vehicles or platoons to choose efficient routes beyond the intersection.

The priority system

Given that priority access to intersection space will be determined by IPI, it is evidently crucial to spell out how IPI is determined. IPI is a function of two elements: Base Priority Index (BPI) and External Factors Index (EFI). In-vehicle calculation of IPI on the basis of these factors are performed according to universally known and uniform rules.

The External Factor Index (EFI) will be based upon features like vehicle dynamic characteristics, intersection geometry, queue formation, etc. It will be used to adjust BPI to promote efficiency. For example, consider a case in which two vehicles – a car and a truck – are approaching the same intersection at the same time, and have the same BPI. If the truck is approaching the intersection downhill, while the car has a level approach, then it would be more efficient to provide the truck with right-of-way. In this and similar cases, EFI helps to limit wear on the vehicles, as well as minimize pollution or enhance fuel-efficiency. As we are largely ignoring issues of sustainability here, we do not explore in detail how EFI would be determined.

The Base Priority Index for any given vehicle is set by the user, who will spend Priority Credits (₡) to acquire a given base priority level (PL).

The PLs will be defined on the ordinal scale from where each user will select their respective PL. Our initial suggestion is that this ordinal scale should have 10 levels (Figure 1). The approach is similar to the 9-point Saaty's scale based on linguistic variables for evaluating criteria used in Analytic Hierarchy Process ranking (Bhushan and Rai 2004). However, the actual number of PLs that would be optimal needs to be determined by extensive consideration of user input and social science evidence.

1. Extremely unimportant	**2. Very unimportant**	**3. Unimportant**	**4. Slightly unimportant**	**5. Neutral**	**6. Slightly important**	**7. Important**	**8. Very important**	**9. Extremely important**	**10. Emergency**

Fig. 1 Priority Levels

Using this scale, each user will spend ₵ in order to assign their trip one of these priority levels according to her own judgment about the important of timely completion of their trip.

Although moral values are considered as a constraint on technological development (Van den Hoven et al. 2012), in this case ethics is used a source of technological development by enhancing the end-user's responsibility. The system for distribution and management of ₵ will require careful design, in order to produce and preserve fairness and efficiency. There are several considerations here, including:

- Avoiding unproductive activities, or activities with negative externalities, that have the effect of 'farming' ₵
- Avoiding inflationary or deflationary characteristics, which would lead users to have significant incentives to select PL 1 or 9, whatever the perceived importance of their trip.

Here is a basic framework for the ₵ system, intended to address these concerns in a very partial and preliminary way:

- All users would receive the same initial amount of regular (i.e. non-emergency) ₵
- The mechanism for spending or gaining ₵ will have uniform rules for all. A mechanism for spending and gaining ₵ will depend on the PL selection and interaction with other agents on the network
- In order to avoid induced demand, there will be a minimum ₵ spending for every day/trip the vehicle interacted with other users on the network
- Limits to the number of ₵ a user could accumulate in a day, or at all, would help to prevent hoarding and farming activities
- Reputation effects: users who demonstrate a pattern of responsible use of ₵ would have the ability to thereby either earn ₵ or a higher 'ceiling' on the maximum number of ₵ they could hold.

This framework would evidently need to go through extensive testing to determine its optimal parameters.

Emergency Priority Credits (E₵) are distinct from ₵. They are intended to be used only in emergency situations. The initial assignment of E₵ would be different among individuals. People with disabilities or special medical conditions, for example, might be assigned higher initial number of E₵, considering that these credits are used for emergency situations, which are more likely to happen to these people (Alexander 2008). A system of pre- and /or post-use verification would be needed in order to protect against misuse of these credits.

Evidently, we have provided only an initial sketch of our vision for next-generation traffic control. This sketch would need to be filled out with detailed technical specifications, underwritten by careful social-scientific research to vindicate the aspirations we have suggested for it. However, we think that if this work can be accomplished, the vision we offer has a strong claim to being the most promising way of engineering social justice into next-generation traffic control.

Conclusions

Radical changes in transportation technology are arriving as we speak. Because these changes create both substantial challenges and opportunities, transportation engineers and their allies have an obligation to begin serious public policy discussion about these topics that is both technically informed and ethically responsible. In this paper, we have sought to contribute to this important discussion by both making vivid the relevance of social justice, and exploring significant alternative ways that next-generation traffic control can address social justice.

While we have sketched a positive vision in this paper, its provisional nature needs to be emphasized. Considerable further attention to both the technical and ethical dimensions of this issue are needed before such a vision could be made policy-ready. On the technical side, social-scientific investigation is needed in order to determine whether our vision can be implemented in a way that avoids the distinctive challenges it faces. On the ethical side, our discussion has set aside several ethically important issues – including safety, sustainability, and privacy – that need to be cogently examined and addressed before any proposal can be considered ethically acceptable overall. The overall question – how should we engineer social justice into traffic control – is of great importance, and is something that cannot be answered in this paper alone. The intention of this paper is to initiate a much-needed discussion of this question by providing one ethical perspective on technological development in this area. We hope that other researchers will join with us to further explore the important technical and ethical dimensions of the rapidly evolving possibilities that new technology presents for transportation.

Finally, it is worth noting that the ethical principles at stake in C2 design are subject to deep and reasonable controversy. This fact, together with the scope of the potential impact of this technology, leads us to emphasize the importance of including broad public participation in the development of C2. While engineers clearly have an important role in the design, decision-making power should not be concentrated solely in a small group of experts, especially if they are influenced exclusively by financial interests. Consequently, we cannot reduce practical questions about the good life to technical problems for experts, and we cannot eliminate the need for public and democratic discussion of the relevant societal values that technology shapes. As a result, there is a need to transparently engage all relevant societal constituencies in critical conversations and decision-making about C2 technology development.

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