AUTONOMOUS VEHICLES

Self-driving cars: A city perspective

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The future of self-driving lies in the technologies embedded in the fabric of cities.

Hardly a week passes without publication of new research exploring self-driving cars. In the past 10 years, the Institute of Electrical and Electronics Engineers alone has published more than 2000 conference papers and 300 journal papers on the topic (*1*). Research has primarily focused on vehicle technology, driving models, and more recently, the legal liabilities and ethical aspects of autonomous vehicles (*2*, *3*).

When fully implemented, self-driving cars will seamlessly blend into our daily lives, but they will trigger changes in urban mobility and city design. However, academic and industrial research on self-driving cars often limits themselves by considering the city as a passive "context," an experimental backdrop. Cities are active sociotechnical artifacts, increasingly enmeshed with sensors and actuators carried by people, incorporated into infrastructures, and soon, integrated into building materials and human bodies. These infiltrated technologies range from self-tracking devices that measure health signals that could collectively create a real-time portrait of the relation between humans and their environment to fully transparent photovoltaic cells that absorb only infrared and ultraviolet light and can be used in glass façades, turning cities into energy generators. A major challenge in advancing robotics is to "mix elements from multiple input modalities [and] fully capture the rich, dynamic nature of social interactions" (*4*), in which self-driving cars are one element of a broader sociotechnical transformation.

The research and development community surrounding self-driving cars has been strongly focused on devising technological substitutes for human capabilities and embedding these within the vehicles themselves. However, a multiplicity of sensors, telecommunications, data processing, and artificial intelligence play increasingly critical and active roles in cities. For example, millions of smartphones carried by drivers can assess the infrastructure health of roads and bridges (*5*), citizen-science initiatives engage residents in collecting environmental data and influence policy decisions (*6*), and interconnected traffic lights and streetlights have been turned into urban sensors and actuators that help monitor public areas and dynamically organize traffic on micro- and macroscales. In the late 1930s, explorations of autonomous vehicles imagined automated highways with road sensors and rails that would help cars navigate cities. Indeed, instead of autonomy exclusively embedded within vehicles, the future of autonomy has to involve a distributed intelligence in which self-driving cars will continuously produce and exchange data with the technologies and sensors enmeshed in the urban fabric, which will alter cities in dramatic ways.

I would like to discuss three upcoming transformations in cities triggered by self-driving cars: urban transportation design, public health and road safety, and behavior norms.

Demand-responsive transportation schemes, such as shared mobility apps, draw upon the personal interconnectivity of social media, coverage of fast telecommunication technologies permitting seamless payment methods, and the availability of GPS services. The combination of self-driving cars and shared mobility could be a game changer in urban mobility. Cars roaming for parking account for up to 30% of the traffic in central areas, contributing to congestion. In fact, cars are idle 95% of the time, occupying parking spaces in homes and garages and on public streets; in the United States, parking covers 75 times the area of Manhattan—an area larger than Delaware and Rhode Island combined (*7*). In Singapore, shared mobility could meet all personal mobility needs with 30% of its fleet (*8*) and, combined with self-driving cars, could reduce parking needs by 70% (*9*). Cities could regain thousands of square kilometers currently used for parking. Filling this space with housing and leisure and productive activities would create denser and more active urban areas that shorten commutes, which in turn could be facilitated by shared scooters, bicycles, and small self-driving cars, as well as more pedestrian trips.

Combining self-driving cars and shared mobility (including electric bicycles and scooters) would also yield environmental and health benefits. Coordinating fleets to function as a network of interconnected vehicles could increase throughput by up to 20 times, saving 10% in fuel consumption, with self-driving cars forming bumper-to-bumper convoys (*10*).

Research also estimates that self-driving cars could also reduce road fatalities by up to 99% (*11*), saving more than 35,000 lives per year in the United States alone. Driver error is responsible for 93% of car accidents (*12*), with novice drivers (whose practice time before getting a license rarely reaches 30 hours) overrepresented in fatal crashes involving automobiles (*13*). At the same time, crashes also increase among older drivers, who demonstrate a decreased ability to scan the surrounding environment for unexpected threats (*11*). When self-driving cars hit roads, they will have been trained for the equivalent of hundreds of thousands of driving hours, using machine learning datasets composed of a vast range of driving conditions and driver behaviors. By collectively training cars and updating their systems, we could improve self-driving systems to be near faultless.

Underlying many of these transformations are behavioral changes. Younger generations are beginning to drive later than previous generations, and many opt not to get a driver's license—a tendency that can be boosted by demand-responsive transportation schemes and self-driving cars. However, changes in car ownership and car use might produce contradictory results, including major transformations in real estate. Self-driving cars may reduce overall driving in urban areas, freeing up road and parking spaces for more pedestrian-friendly uses; on the other hand, self-driving cars may attract segments of the population that currently either use public transportation or have limited mobility (such as the elderly and children). By reducing the burden of driving, with people using the travel time to do connected

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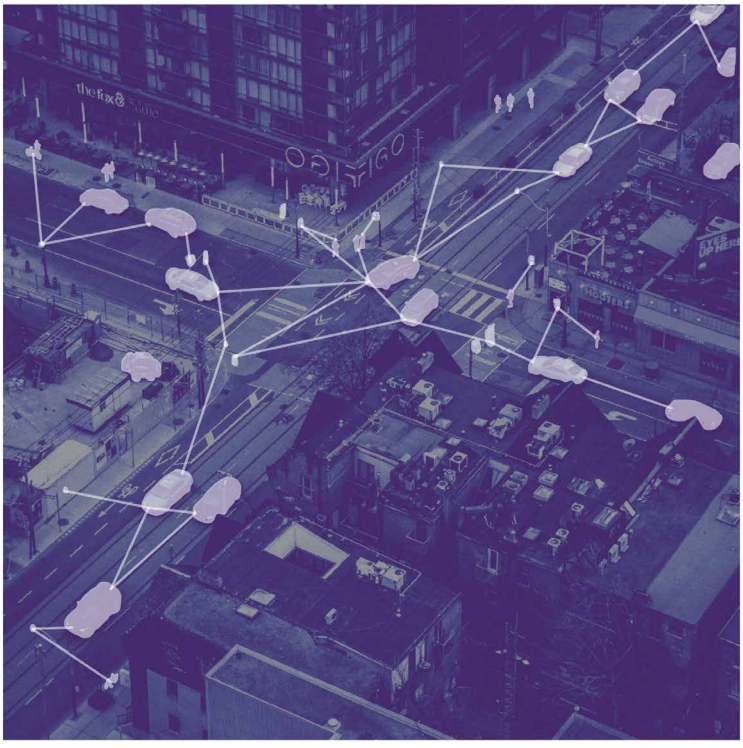

work while on autonomous cars and buses, self-driving mobility may push people to suburbs even farther from the central business districts, increasing regional traffic, therefore offsetting the possible benefits that self-driving cars could bring to central areas. Yet, even at the regional level, impacts of autonomy may be beneficial, with sleeper buses used for short-haul flights—similar to the impacts that high-speed trains have had in Europe and Japan for trips shorter than 5 hours.

The road to autonomy will be reached by considering humans, regulations, urban infrastructures, self-driving cars, and other transportation modes as interdependent units. When these components are organically integrated, cities will become more responsive and adaptive.

REFERENCES

1. Search criteria included "self-driving cars," "driverless cars," and "autonomous vehicles" at IEEEXplore Digital Library (http://ieeexplore.ieee.org/xpl/opaccnf.jsp).
2. E. Awad, S. Dsouza, R. Kim, J. Schulz, J. Henrich, A. Shariff, J.-F. Bonnefon, I. Rahwan, The moral machine experiment. *Nature* **563**, 59–64 (2018).
3. J.-F. Bonnefon, A. Shariff, I. Rahwan, The social dilemma of autonomous vehicles. *Science* **352**, 1573–1576 (2016).
4. G.-Z. Yang, J. Bellingham, P. E. Dupont, P. Fischer, L. Floridi, R. Full, N. Jacobstein, V. Kumar, M. McNutt, R. Merrifield, B. J. Nelson, B. Scassellati, M. Taddeo, R. Taylor, M. Veloso, Z. L. Wang, R. Wood, The grand challenges of *Science Robotics*. *Sci. Robot.* **3**, eaar7650 (2018).
5. T. J. Matarazzo, P. Santi, S. N. Pakzad, K. Carter, C. Ratti, B. Moaveni, C. Osgood, N. Jacob, Crowdsensing framework for monitoring bridge vibrations using moving smartphones. *Proc. IEEE* **106**, 577–593 (2018).
6. A. Irwing, No PhDs needed: How citizen science is transforming research. *Nature* **562**, 480–482 (2018).
7. E. Ben-Joseph, *Rethinking a Lot* (MIT Press, 2012).
8. K. Spieser, K. Ballantyne, R. Z. Treleaven, E. Frazzoli, D. Morton, P. Pavone, Toward a systematic approach to the design and evaluation of automated mobility on-demand systems: A case study in Singapore, in *Road Vehicle Automation*, G. Meyer, S. Beiker, Eds. (Lecture Notes in Mobility, Springer, 2014), pp. 229–245.
9. D. Kondor, H. Zhang, R. Tachet, P. Santi, C. Ratti, Estimating savings in parking demand using shared vehicles for home-work commuting. *IEEE Trans. Intell. Transp. Syst.* (2018); doi: 10.1109/TITS.2018.2869085.
10. M. M. Waldrop, Autonomous vehicles: No drivers required. *Nature* **518**, 20–23 (2015).
11. Y. A. Momtaz, R. Kargar, R. Hosseiny, R. Sahaf, Rate and pattern of road traffic accidents among older and younger drivers. *Healthy Aging Res.* **7**, (2018); doi: 10.12715/har.2018.7.8.
12. U.S. Department of Transportation, National Highway Traffic Safety Administration, *National Motor Vehicle Crash Causation Survey: Report to Congress* (2008); https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811059.
13. R. Ivers, T. Senserrick, S. Boufous, M. Stevenson, H.-Y. Chen, M. Woodward, R. Norton, Novice drivers' risky driving behavior, risk perception, and crash risk: Findings from the DRIVE study. *Am. J. Public Health* **99**, 1638–1644 (2009).

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