



Technology Revolutions

Bringing Tomorrow Here Today

Photo: John F. Williams for the U.S. Navy

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Above: Standing 5 feet 10 inches and weighing 143 pounds, SAFFiR—the Shipboard Autonomous Firefighting Robot—is armed with infrared stereovision sensors and a rotating laser that allows it to see through thick smoke. This futuristic technology for the U.S. Navy stands ready to keep sailors from the dangers of direct exposure to fire.

After a century of activity by the Transportation Research Board and others, transportation is experiencing several technological revolutions driven by research performed over multiple decades:

1. Alternative fuel vehicles, such as battery electric, hybrid, and hydrogen fuel cell vehicles, are available commercially and becoming more common in the vehicle fleet.
2. Automation is common in new vehicles, originally as warning systems but now including functions such as active forward-collision avoidance. Autonomous (driverless) vehicles are being tested and will eventually join the fleet.
3. Nearly ubiquitous communications are available for vehicles, individuals, and infrastructure (1).
4. Artificial intelligence (AI) and data analytics are improving transportation design and operations; virtually all aspects of transportation have been affected.



Photo: Pixabay

At the core of technology revolutions, AI will touch on virtually every industry in the future—even car rentals, in which vehicles may be equipped to rent themselves out, eliminating human involvement and resulting in reduced transaction costs.

5. New modes of transportation are appearing, resulting in greater choice and improved system performance for most users.

In this article, we describe likely changes from these technological revolutions for a wide variety of industry sectors that are experiencing near- and longer-term impacts: car rentals, supermarkets, wildfire fighting, and local government transportation.

Transforming the Passenger Car Rental Industry

Car rental companies were among the first fleet-based mobility providers in the early 20th century. Today, the industry is using vehicle connectivity, AI, data analytics, and automation to compete with newer players—such as Uber and Lyft—that use data analytics and mobile apps to meet consumers' personal transportation needs.

In late 2019, Avis Budget Group surpassed 200,000 connected vehicles globally, a significant marker on its journey to fully connect its 600,000-vehicle fleet to improve the customer experience while also streamlining operations and reducing costs (2–4). It is testing key-as-a-service applications that use the Avis mobile app to lock the car, unlock it, and start the engine, which allow a faster customer transaction.

Looking ahead, rental agencies will use autonomous driving features for rearranging vehicles and delivering vehicles to customers. Enterprise has entered into an agreement with self-driving vehicle startup Voyage to manage its fleet as a foray into its own autonomous operations (5).

Looking even farther ahead, decentralized peer-to-peer car rentals will be available for autonomous vehicles (AVs). Using AI, vehicles may be equipped to rent themselves out without human involvement, resulting in vast reductions in the transaction costs of renting a car. This has implications for not only further disrupting the car rental industry but also the future of vehicle ownership.



Photo: Melinda Young Stuart, Flickr

It may look like a cooler on wheels, but Kiwibot has become a regular on the University of California, Berkeley campus. The robot, part of a multimodal system, is one of three kinds in a fleet of 200 that has taken to the sidewalks—guided by camera sensors—and delivered more than 100,000 restaurant meals to hungry students and staff since it launched in 2017.

Transforming the Supermarket Industry

Data analytics, connectivity, automation, new modes, and battery electric vehicles are also transforming grocery inventories, delivery, and shopping. Walmart uses robots to manage stock and clean floors (6). Amazon has 200,000-plus robots working inside warehouses (7).

The e-grocery market is growing. In 2019, 37% of U.S. consumers bought groceries online, up from 23% in 2018 (8). Kroger has partnered with Nuro to pilot e-grocery delivery by autonomous pods from its Scottsdale, Arizona, and Houston, Texas, stores (9). The COVID-19 pandemic helped speed this change. New data indicate that 52% of consumers bought groceries online during COVID-19 (10).

AVs for delivery are appearing. Starship Technologies deployed its autonomous delivery ice chests on college campuses (11). Testing at the University of Pittsburgh was stopped (and later restarted) after one robot vehicle trapped a wheelchair-bound student in the street. The incident underscored the accessibility and safety challenges of delivery robots operating on crowded sidewalks and curbs.

Online ordering can also be improved. Dent Reality uses augmented reality

technology, which overlays information and virtual objects on real-world scenes in real time to enhance a shopper's in-store experience, providing up-to-date stock information, highlighting nutritional and allergen information, and enabling in-store navigation (12).

But, this assumes that there *are* supermarkets. Supermarket travel will diminish as food retail is decentralized through just-in-time supply chains and AVs—and as AI devices “learn” when (and when not) to order replacement items. Auto ordering, searching for best prices, and comparing brands might be done by chatbots and avatars that can optimize the mode and timing of delivery.

Food supply chains may become shorter as indoor farming offers not only a potential alternative use for the large retail spaces that will become vacant but also convenient access to locally grown food. Shorter supply chains, along with AVs, may make last-mile delivery economical, environmentally viable, and ubiquitous. At the same time, these shorter supply chains may add new curb management challenges.

In the United States, food waste is responsible for roughly the same amount of greenhouse gas emissions as 37 million



Photo: Bureau of Land Management

Drones are making an impact on fighting wildfires by using thermal cameras to guide firefighters to safe exits, a task traditionally left to piloted planes. But, before long, these aerial marvels will put out fires altogether using sound physics: pressure waves from loud noise disrupt the air that surrounds the fire and, ultimately, extinguish the flames.

cars (13). For perspective, in the 4th quarter of 2019, some 280 million vehicles were operating on U.S. roads (14). Many technologies are being applied to help food last longer. They include apps that connect unsold food from supermarkets with customers, farmers who use drones and sensors to maximize crop yields, and smart food labels that get more and more bumpy as food decays and are more accurate than printed dates (15).

Transforming the Wildfire Fighting Industry

From Siberia to the Amazon and from California to Australia, forest fires were unprecedented in 2019 (16). Wildfires cause widespread damage, destroying lives, buildings, transportation infrastructure, supply chains, and agriculture.

Drones provide aerial surveillance to make sure there are safe exits for firefighting teams and residents, a role currently filled by piloted aircraft (17). Drones equipped with thermal cameras do the job better and more safely.

Forest fires could soon be fought by drones that direct loud noises at the trees below (15). Sound is comprised of pressure waves; noise can disrupt the air surrounding a fire, cutting off the oxygen

supply. Drones could be especially useful for fighting fires at night when winds die down and fires theoretically become easier to control (18).

Not only flying robots but also surface-based ones battle wildfires in extreme conditions that are unsafe for humans (19). These robots can be remotely controlled or autonomous.

The fire truck of the future is electric with advanced functionality (20). Its chassis can be raised for driving and lowered for service at the scene. Electrical energy provides power for the extinguishing water pump, thus eliminating the need to carry a power generator. The fire truck is equipped with haptic feedback and rearview cameras, making it safer for firefighters while driving and on the scene.

Transforming Local Government

Local governments often provide public transportation service and manage transportation infrastructure. The ongoing technology revolutions will thus affect them in significant ways by prompting new modal considerations, rather than just buses and rail; riskier investments, such as private partnerships and, pos-

sibly, regulation of hydrogen stations for fuel cell vehicles; and transformative process changes.

Parking and traffic violation fees are significant sources of revenue for many counties and municipalities. The advent of new modes—such as private helicopters, ride-hailing, e-scooters, and driverless surface and aerial vehicles—not only increases mobility options but also reduces parking revenues substantially. Rather than parking a highly automated vehicle, it can be sent to a distant location and recalled as needed. Also, highly automated vehicles are typically programmed to obey all traffic restrictions, reducing fees for violations. Local governments will need new sources of revenue. Some localities are testing dynamic pricing of curb space, which could expand to airspace used by drones (27).

At the same time, there are possibilities for more efficient municipal services. Wi-Fi and 5G may be ubiquitous, enabling smart infrastructure and devices to work together seamlessly. Based on monitored real-time data, Internet-connected infrastructure may monitor public safety and adjust traffic flow, energy usage, street sweeping, and waste collection.

Regulations also require reconsiderations and changes. Building codes requiring a certain number of parking spaces should be reappraised. Land uses will also be rethought as the demand and space required for parking drops.



Photo: Carnegie Mellon University

Ready to go for a spin, Pennsylvania Governor Tom Wolf and other passengers test the features of a fully autonomous vehicle.

Research Needs and Policy Decisions

In addition to the likely changes and possible scenarios described in several industries, as well as the new technologies of transportation stakeholders introduced, a variety of research needs and policy changes are also apparent. Vehicle regulations, infrastructure standards, and vehicle operation policies should be reexamined. Resilience, sustainability, and nonvehicle transportation can be enhanced. Research to best integrate new modes and new technologies is now timely, especially to promote improved equity and performance for all travelers and for a variety of conditions.

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CENTENNIAL QUOTE

“In 2120, the Transportation Research Board’s activities will be, in many respects, unrecognizable from today’s mostly three-dimensional transportation structure—that is, two spatial dimensions plus a third temporal dimension. One hundred years from now, it will be primarily a four-dimensional structure—or three spatial dimensions plus a fourth temporal dimension. As a consequence, all transportation activities will be structured and carried out within a four-dimensional grid. More importantly, because of the speed required, humans will be assisted by artificially intelligent robots. Additionally, movements and communications will be nearly instantaneous, and accidents or conflicts over the four dimensions should be minimal.

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