LIVING WITH TRANSFORMATIONAL TECHNOLOGIES AND OTHER SURPRISES

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Above: In the near future, traditional land-based modes of local freight delivery—such as panel trucks—may be joined by growing fleets of unmanned aerial systems (or drones), technology that is transforming the speed of moving goods.

It's tough to make predictions, especially about the future. The observation—attributed variously to American baseball great Yogi Berra, Danish physicist Niels Bohr, and 19th-century author Mark Twain—is well supported by experience.

Thomas Watson, then president of IBM, famously averred in 1943, "I think there is a world market for maybe five computers." Of course, a computer at the time filled a large room, used vacuum tubes, and required trained operators with substantial programming skills. Today, the microchip-laden laptops, tablets, and cell phones that even young children carry pack more computing power than these early behemoths.

Physicist Albert Einstein, whose statue graces the front of the National Academies of Sciences, Engineering, and Medicine headquarters in Washington, D.C., wrote in 1932, "There is not the slightest indication that nuclear energy will ever be obtainable. It would mean that the atom would have to be shattered at will." He later observed that "I did not, in fact, foresee that [atomic energy] would be released in my time. I believed only that it was theoretically possible. It became practical through the accidental discovery of chain reaction, and this was not something I could have predicted."

When President Dwight D. Eisenhower signed the Federal-Aid Highway Act of 1956, he and his advisors looked forward to building a system that would "eliminate unsafe roads, inefficient routes, traffic jams, and all of the other things that got in the way of 'speedy, safe transcontinental travel (*1*).'" Although the Interstate highways spanned the nation and lifted motor vehicles out of the mud, congestion and crashes are still very much with us. But even automotive innovators Henry Ford (1863–1947) and Alfred Sloan (1875–1966) probably would have been hard-pressed to imagine that in 2019 there would be nearly 285 million registered motor vehicles in the United States for our estimated population of about 329 million people (*2*, *3*).

Photos: Eisenhower Archives

During the 1919 Transcontinental Motor Truck Convoy, then-Lt. Col. Dwight D. Eisenhower saw the poor condition of U.S. roads firsthand. Faced with one gully after another as they crossed Wyoming, engineers rolled up their sleeves and reinforced unstable wood bridges with planks (*left*). Then, they held their breath as the first truck lumbered across (*right*). That arduous journey—plagued by vehicles overturned in ditches and mired in mud—inspired later President Eisenhower to sign the Federal-Aid Highway Act of 1956 into law.

Photo: Virginia DOT

Highways have come a long way since the rutted roads, precarious curves, and eroded shoulders that were the nationwide norm 100 years ago. Today, technology such as toll booth E-Z Pass that reads prepaid, dashboard-mounted sensors in cars keep traffic moving along an intricate network of smoother thoroughfares that has transformed how we get around.

Prophecy, Prediction, and Transformation

Shakespeare's Macbeth encountered witches in the woods who foretold his rise and fall. Such foretelling is perhaps prophecy rather than prediction. Austrian British philosopher Karl Popper distinguished prophecy as an unqualified and essentially untestable assertion that something will or will not occur (*4*). In Popper's view, prediction is a result of logical deduction from a scientific theory. Failure of the future to unfold as prophesied is not taken by believers as convincing evidence against their faith, but outcomes contrary to prediction may call the theory into question.

Of course, the line between faith and theory is often fuzzy. For example, Moore's Law—cited frequently with regard to progress in microelectronics—is the product of an observation in the 1960s (by Gordon Moore, one of Intel Corporation's founders) of two concurrent trends: the number of transistors that could be fit on a microchip was doubling about every year, and production costs were declining. Anticipating that these trends would continue, Moore suggested that computing power—and the market for Intel's chips—would continue to grow dramatically. The trend line, adjusted a bit to account for the actual changes in chip design, looked very convincing in a graph and came to be viewed popularly as having predictive power akin to Newtonian physics. In today's chip fabrication plants, however, size shrinkage has slowed as production technology runs up against physical limitations.

Nevertheless, decades of explosive growth in capabilities and usage of cell phones, digital industrial control systems, and the like have conditioned us to the idea that new technologies will be "transformational" in the ways they affect our lives and society and not without some justification. When English urban planner Ebenezer Howard's influential diagrams illustrating urban growth through development of "slumless" "garden cities" at the periphery of primary urban centers was published in 1902, who would have predicted the sprawl that turned forests and pastures in many parts of the country into megaregions (*5*, *6*) (Figure 1)? And when American transport entrepreneur Malcolm McLean patented the idea of the shipping container in 1956, who would have predicted the growth of intermodal transport, huge container ships, and globalized supply chains delivering fresh South American asparagus to winter dinner tables in North America?

In surface transportation, a great deal of attention is being given to the transformational potential of connected and automated vehicles (CAV) and, more generally, connected and automated transportation (CAT) systems; CAT refers generally to all transportation modes. Proponents imagine a future of driverless cars, trucks, and transit vehicles providing safer, more reliable, and possibly less-expensive transportation services that afford travelers the freedom to read, cope with unruly passengers, and pursue other activities that today distract drivers. However, there are other technological developments under way, such as shared mobility (e.g., bicycles, e-scooters, and hourly auto rentals, as well as cellphone app–based services such as Lyft and Uber), use of unmanned aerial systems (UASs or drones) for package delivery and personal transportation, and smart cities and communities initiatives as forces for change in city living and economic activity.

An outgrowth of these discussions was National Cooperative Highway Research Program (NCHRP) Project 08-117, "Impact of Transformational Technologies on Land Use and Transportation." The project's objective was to provide guidance for state and other transportation agency decision makers on practical ways to assess the likely effect of transformational technologies on future activity centers, land use, and travel demand within their regions. The project's planners supposed that such technologies as 3-D printing, e-commerce, and UASs, as well as automated transit and other vehicles, may shift industrial supply chains and locations of warehousing, distribution, intermodal transfer facilities, and jobs in settings ranging from rural to intensely urban. Having insight into potential shifts can inform decisions and perhaps avoid—or at least defer—needless investment and regulatory obsolescence. A team led by Kittelson & Associates was engaged to conduct the research, but NCHRP's project panel also had opinions of its own. Offering guidance to transportation agency decision-makers would become a joint effort.

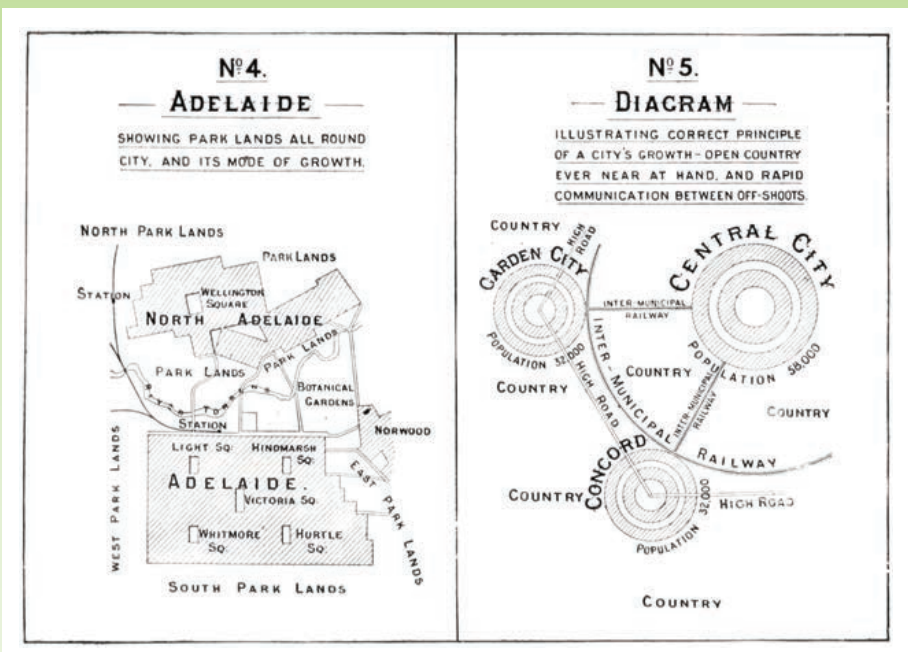

FIGURE 1 Ebenezer Howard's Garden City concepts.

It's All in the Timing

Technologies that may affect the spatial patterns of economic activity, travel, and land use potentially comprise a very large class, even if researchers imagine that only some of these technologies would qualify as transformational. Early in the NCHRP project, the research team had to address how and where to draw the line: What technologies are we talking about?

An early criterion for focusing the research was restricting consideration only to newer technologies. For example, technological advances continue to improve fuel efficiency for vehicles with gasoline- or diesel-powered engines, but the fundamental technology has been widely available for decades. Electric and other alternative-fuel vehicles, however, might qualify for attention.

NCHRP's audience inspired a second criterion. State transportation agencies—the sponsors and primary customers for NCHRP products—vary in the scopes of their responsibilities, but all of them have a substantial interest in highway-based transportation. Considering the limits of time and budget, the project panel and research team agreed that the project should focus on technologies that had a potential to significantly affect highway traffic in the not-too-distant future. Such technologies as passenger-carrying UASs, magnetic levitation trains, and hyperloop train systems were unlikely to have widespread impact within the coming two or three decades.

It makes a difference where the technology is applied in the complex system of transportation and land use, whether it be in vehicles, the infrastructure that carries and serves vehicular movement, or passenger or freight payloads. Again, the limits of time and budget motivated focusing the

Personal Communication Devices

- 5th-Generation (5G) Cellular
- Dedicated Short-Range Communications (DSRC)

"Active" Transportation Modes

- e-Bicycles
- e-Scooters

Motorized Auto, Mass Transit, and Freight Vehicles

- Alternative (combustion) Fuels
- Electric
- Autonomous (AV) Control
- Connected (CV)

Unmanned Aerial Vehicles (UAV) for Freight Delivery

Intelligent Transportation System (ITS) Applications

- Highway Operations
- Parking Systems

FIGURE 2 Potentially transformational technologies considered in NCHRP Project 08-117.

project on the road system and freight-delivery UASs as potential near-term competition for conventional delivery modes (e.g., panel trucks on neighborhood streets). Within the road system, several infrastructure-, vehicle-, and payload-embedded technologies were identified as sources of potentially significant impact in the relative near term (Figure 2).

How Impacts Become Transformational

Predicting that a technology will have any impact at all requires that we have some ideas or theories of how impact occurs and that we be able to deduce logically what the impact may be. If the theory is truly scientific (Newton's idea that gravity causes apples to fall down from the tree branch, for example), our confidence in the prediction will generally be greater than if it relies on anticipated continuation of a long-term trend (as was the case with Moore's Law). Because we are dealing with economic and social forces and systems (essentially the behavior of people as individuals and in groups or results of these behaviors), useful theories and the predictions they support may seem less certain than those of, for example, chemistry or structural mechanics.

The Kittelson research team started their prediction effort with a few fundamental but simple relationships from economic theory: when the price of transportation goes down, people use more of it. New technologies can reduce the travel times or monetary costs (or both) that users of a particular mode or service experience. New technology can offer attractive new options for travel (e.g., new modes or destinations). Anything that reduces the price of travel or offers attractive new travel options will not only shift travel patterns but also influence land use. Lower travel costs can make land more accessible and increase the land's value. The new technology that brings down travel times and monetary costs throughout a region make the region more attractive for people and businesses. Other regions without the new technology may lose out as their populations respond to these incentives by moving out.

Applying these predictive relationships to the technology cases under consideration in the NCHRP project, the research team reasoned out some general predictions about each case. CAT applications that would support self-driving trucks or truck platooning for line-haul freight transportation, for example, could shift goods from rail to highways; increase truck traffic on major routes and, thereby, pose challenges for automobile drivers; slow traffic flow on mountainous routes; and increase demand for larger warehouses and distribution centers. Although some land for larger truck-transport shipping might be made available from railyard conversions, the rural fringes of large urban centers would likely face development pressures. With fewer vehicle drivers, however, the demand for truck stops and associated commercial development might not grow at the rates previously experienced.

Surprise!

Such general predictive relationships can be valuable by themselves, helping us envision the consequences of these new technology applications. However, the specific characteristics of a particular region are likely to make a big difference as to how substantial the effects will be and how quickly they may develop. Perhaps more importantly, the consequences are uncertain. Even chemistry, structural mechanics, and similar disciplines are subject to uncertainty, and the theories for predicting the behavior of individuals and groups and the results of these behaviors are even less certain than those of other subjects of scientific and engineering study.

Various statistical methods are useful for characterizing and trying to measure this uncertainty, but we sometimes still can be surprised. Harvey Brooks—the late Harvard University professor; presidential science advisor; and member of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine (now the National Academy of Medicine)—suggested three types of surprises that can make a shambles of our predictions:

1. Unexpected discrete events that shock the system being considered (e.g., the petroleum shortages and steep fuel price increases of the 1970s),
2. Discontinuities in long-term trends (e.g., the collision between Moore's Law and the limits of photolithography for printed circuit fabrication), and
3. Sudden emergence into political consciousness of new information that shifts the balance of values in peoples' decision making (e.g., societal response to our understanding of impending climate change) (*7*).

Former options trader Nassim Nicholas Taleb asserts that surprises may come simply from our ignorance—or lack of imagination—about possibilities. He refers to Black Swan events that are far out on the extreme tail of a probability distribution, possibly one of Brooks' "unexpected discrete events" but more momentous (*8*). Taleb takes the name Black Swan from the observation

Photo: Pixabay

Stripped of its sign, a storefront closed its door for good. The COVID-19 pandemic has had a devastating effect on many sectors of the global economy, including air travel, hospitality, entertainment, individual franchises, and mom-and-pop stores. Some economists see it as a Black Swan event—extremely rare with the possibility of serious consequences.

that Europeans could not imagine swans occurred in any color except white until the Dutch explorer Willem de Vlamingh in 1697 discovered black swans in Australia.

In Taleb's terms, Black Swan events are not only very rare but also very consequential. The investment and financial communities have adopted the concept in discussing the causes and impacts of such events as the 2001 Fukushima nuclear disaster and the 2007–2008 global financial crisis. The 2020 onset of the COVID-19 pandemic will almost certainly be seen as a Black Swan for many sectors of the global economy.

Planner's Mindset

Confronted with the possibilities of small surprises and black swans, Brooks and Taleb might agree that having a good imagination and a measure of skepticism are essential in making predictions—and in relying on predictions to make decisions. These two elements are apparent in the guidance for state and other transportation agency decision makers that NCHRP Project 08-117 research developed.

That guidance is presented in *NCHRP Research Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*, the primary research product. "It has become apparent," the report's authors suggest, "that 1) public agencies have less control than they used to over the transportation system and 2) agencies cannot let five years go by between updates of their plans and procedures (*9*)." Agencies, their planners, and managers must take on a new mindset: reset their perspectives on how they think about change.

To deal effectively with the challenges of technological change, agency planners must continually be attentive to maintaining their capabilities to understand new technologies and their implications. These planners must get accurate and current data to support their work and be smart about practical options for adapting and managing the systems they oversee. Above all, planners and policy makers must be nimble, adjusting their decision making as technology continues to change. *NCHRP Research Report 924* offers advice on how to develop and maintain these four capabilities and how to develop a practical procedure and template for assessing technology impacts within a region (Figure 3).

The linearity of Figure 3 is perhaps misleading. The process is circular; in fact, it is endlessly repetitive. Being nimble means remaining aware of a region's evolving situation. To be nimble, one must have current data and use them quickly to assess and explain the current situation. Being nimble means making smart decisions on the basis of what is being observed, adapting to new technology developments as they emerge. Being nimble means adjusting course quickly when the situation seems to be changing.

Coincidentally, while the NCHRP project research team and panel were preparing their guidance to help planners deal with potentially transformational technologies' impacts on geographic regions and their transportation systems, another team working under the auspices of NCHRP's U.S. Domestic Scan Program (NCHRP Project 20-68) was preparing their Scan 18-02 report, *Leading Practices in Modifying Agency Organization and Management*

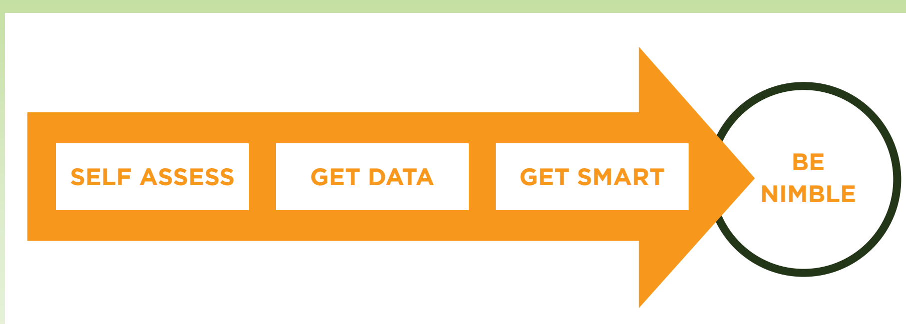

FIGURE 3 A new mindset for planning. (Source: *NCHRP Research Report 924*.)

to Accommodate Changing Transportation System Technologies (*10*). The objective of that team's work was to identify how leading government transportation agencies are changing their organizations, institutional arrangements, and management practices to improve transportation system performance through adoption of new technologies. The scan team interviewed staff at several state transportation agencies and studied these agencies' leadership, organizations, staffing, business processes, performance management, and collaboration practices to discover useful lessons that might inform their peers throughout the nation.

The team concluded that sometimes agency culture is a concern. The functional silos typically found in many agencies—insularity among business-area and geographic units within the agency—impede acquisition and retention of workforce talent; obstruct self-assessment of agency capabilities; and add to costs of data collection, maintenance, and effective use. Smart and creative management thinking and nimble response to change can flourish in more open organizations.

Inventing the Future

Like many large structures, silos are not easily dismantled. On the one hand, fear of change and our human inclination to protect our own turf feed resistance to change and paralysis in the face of change. American author Alvin Toffler came to prominence when his 1970 book, *Future Shock*, became an international bestseller (*11*). The shock associated with the perception of "too much change in too short a period of time" in one's life causes stress, disorientation, upset, and erosion of peoples' conviction that they can cope with the forces of new patterns of economic and political activity, social expectations, and interpersonal interactions. At a societal level, the result is apparent confusion and conflict of values, loss of direction, and a breakdown of decision making. After half a century, the idea of future shock continues to resonate, not least in the thought that technologies have become transformational.

On the other hand, there is the complacency that comes from overconfidence that everything is under control, that familiar trends will continue forever, and the idea that a frog placed in tepid water that is gradually brought to a boil will stay put and be cooked. Anecdotal reports suggest that experimental evidence disproves that folklore. Taleb gives a better example: a commercially raised turkey—fed reliably and well for 1,000 days—may come to look forward to old age. But as Thanksgiving draws near, the turkey learns how drastically wrong its expectations were (*12*).

We cannot afford to let shock or complacency lead to paralysis. Predictions about the future may be difficult and uncertain, but people who take on responsibility for making long-term investments to ensure the continued survival and prosperity of future generations must cope.

British–Hungarian Nobel Prize physicist Dennis Gabor wrote: "The future cannot be predicted, but futures can be invented" (*13*). Considering in a reasonable and logical way what the implications of new technologies may be and acting on our conclusions is how the future is invented. The guidance presented in *NCHRP Research Report 924* and the *Scan 18-02* report help with the tasks of invention.

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