LONGER VIEW

Transportation for the Anthropocene

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We are still designing, managing, and governing transportation systems that came out of a bygone era. Our principles, technologies, and governing institutions, as well as the decisions we make, reflect modes of thinking rooted in transportation goals from the industrial age, when many of our now aging highways, railways, and ports were first developed.

But we are living in a new epoch now, one where human activity has become the dominant influence on our planet's systems — not just the climate, but all of its biological, ecological, hydrological and geological phenomena. That's why scientists call this epoch the Anthropocene, or "Time of Man." When the Anthropocene first began is debated, but there's little question that it took off in the post-World War II period. This period is defined by rapidly accelerating technological change and human activity, which is transforming the planet faster than the natural environment ever could.

It is hard to imagine any part of daily life that isn't being affected, or soon will be affected, by the changes of the Anthropocene. The human transformation of our built environment, through the mass construction of physical infrastructure, including transportation systems, and demographic changes such as urbanization, has changed the course of rivers, altered natural patterns of soil deposition and erosion, impacted plant and animal species that humans rely on for food and other products, affected the spread of diseases (as we are seeing), and contributed to changing weather patterns. These changes have created hyperconnectivity by physical and virtual means, as well as new forms of intelligence, as software increasingly manages humans' relationships with the environment and themselves. These factors, in turn, will have a profound impact on transportation systems, from shifting from physical to virtual access, to the destructive effect of unpredictable extreme weather, to changes in travel patterns due to increasing software-based control, or changes in the production and distribution of food and other resources — to name just a few possible consequences. The frequency of all such occurrences, moreover, will likely increase.

These technological, organizational, and earth system changes necessitate changes to how we plan, construct, and manage our transportation systems. Specifically, our global transportation modalities — automobiles, trains, planes, even bicycles — which developed within the last hundred years or so, now face particular challenges from emerging developments in cybertechnology, information and communications systems, artificial intelligence, and the increasing integration of computer and physical systems.

Across the globe, transportation infrastructure are now vast in scale and composed of multiple layers of old and new technology. Meanwhile, the climate is becoming less predictable, and rapid advancements in cyberinfrastructure — from GPS to ride-hailing and cloud-based routing — are redefining our conventions of communication, travel and daily commuting. Taken together, these changes mean that our world is getting increasingly complex. As the idea of the planet

as a static foundation for humans to build upon loses relevance, we need to radically alter our thinking and planning around transportation, if we are going to serve future generations.

Up until now, transportation planners have approached questions of technology, governance, and educational norms with a tacit assumption that the world's conditions, and the conditions under which we consume transportation services, would be largely stable. This assumption might have been valid during periods when technological change was slow and incremental, but it is no longer valid today. We must instead embrace instability and be willing to navigate our systems amid the complex transformations that are occurring. We have already seen numerous "once-in-a-lifetime" climate events — devastating wildfires, snowstorms, hurricanes — wreck infrastructure that was never built to withstand them because such events seemed unimaginable or too rare to drive design decisions. Cyberattacks are on the rise, with infrastructure becoming battlefields in asymmetric warfare strategies. Companies like Amazon, Google, and Tesla are shifting the notion of what transportation systems are. How people perceive access is rapidly shifting. In just a short year, COVID-19 has disrupted living patterns, and thus commuting and traffic patterns at a global scale, and few can agree on what post-pandemic transportation demand will look like. It is no longer possible to design transportation systems under the assumption of predictable technologies, or predictable travel demand and weather conditions. Instead, new transportation systems must emphasize agility, flexibility, and the knowledge that today's impossibilities may be tomorrow's reality.

An Accelerating, Uncertain, and Volatile Environment

The past century has brought a remarkable evolution in transportation technologies. This evolution has been defined, in part, by a planning approach that emphasizes rigidity. The transportation system's core technologies, such as roads, have been designed to accommodate traffic flows, and withstand weather conditions, that planners believed would be predictable over the long term. This belief in predictability, moreover, allowed the bureaucracies that plan, construct and manage our infrastructure to splinter into knowledge silos. Transportation agencies became divisions of pavement materials, traffic, and so on, which experience significant barriers to coordinate with each other. This arrangement worked for a while, but as the societal, technological and environmental conditions surrounding transportation systems have become less predictable and more systemic, these existing transportation models have become increasingly unsustainable. The attributes of the system that arose from the relative stability in the past century prevent it from adapting to instability. Siloed knowledge and practice, an emphasis on rigid technologies, and educational norms that don't reflect the growing complexity of the world around us have locked us into a particular way of planning for transportation, even as that way becomes less appropriate.

Today, the transportation landscape is changing at a dramatic pace. Over the past two decades, we've seen the maturation of electric vehicle technologies, the rise of shared mobility, and remarkable advances in vehicle autonomy. We've also seen transportation systems become more integrated with other infrastructure systems, like the energy sector (e.g., electric vehicles that provide mobility and store energy) and public health (e.g., onboard thermometers in vehicles that relay temperature data, which is valuable to health professionals evaluating the risks of local heat exposure. But to reduce these developments to purely technological advancements is too simplistic.

Climate change, ideological polarization, financial uncertainty, geopolitical conflict carried out at cyberspace speed, and disruptive new technologies have created a more complex world than the one our transportation systems were designed for. Our ability to grasp how transportation needs are changing, and how our systems will behave when tested, is diminishing. Imagine, for instance, a hurricane hitting New York City. While we can anticipate that such

a storm would cause damage and disruption to the city's transportation systems, our ability to predict the impacts precisely in terms of time, location, and severity is limited given the remarkable complexity of the systems. Emerging third-party transportation services such as Google, Uber, and Lyft are creating new markets for transportation services and now steer demand in ways transportation practitioners never planned for, and still don't fully understand. How should a transportation agency plan for demand amid a rapidly changing landscape where cloud-based services informed by private data streams (e.g., mobile phones) route an increasing number of vehicles and increasingly negotiate mobility?

Cybertechnologies such as connected devices and pervasive sensor networks open up remarkable new possibilities to improve transportation services, through wayfinding, trip planning, and new ways to pay for travel. But they also create new vulnerabilities. Consider the growing number of cyberattacks directed at physical transportation systems that are integrated with digital technology.

Scientists who subscribe to the idea that the Anthropocene represents a decided change in global evolution point to data linking exponential growth (Great Acceleration Curves) across certain human activities with alarming changes to the planet. These studies capture accelerating conditions of uncertainty and volatility. When it comes to transportation, the fundamental question is whether our systems can be responsive — and if so, how quickly — to the changing conditions in which they must remain viable. If our transportation systems ignore the implications of this new epoch, we are only hastening their obsolescence.

To respond to this increasing complexity, current technologies, organizational structures, and educational practices will have to change. We need to move away from simple notions of physical mobility to recognize how transportation technologies and functions will be increasingly intertwined with other services, and increasingly managed by software.

As a result, our definitions of transportation, many of which are rooted in today's context, are likely to be upended. The artificial separations that we've historically used to manage infrastructure (e.g., transportation, water, information and communication technology, and power as independent from each other) are becoming increasingly obsolete. In the Anthropocene, is transportation really a separate system from, say, the fiber optic cables that run under streets facilitating information connectivity and enabling virtual workspaces to exist? As we integrate solar power into our roads and electric vehicles into our transportation system, and use such vehicles as power storage assets in a smart grid, should we treat the energy system as separate or should we co-design transportation and energy infrastructure with the climate in mind? As transportation systems become more tightly interwoven with other systems, we must adapt how we design and manage them.

From the Complicated to the Complex

Increasing uncertainty, rising volatility, and accelerating conditions suggest that complexity will dominate the Anthropocene. As unpredictable demand, more frequent extreme events, and disruptive technologies emerge, instability will come to define the landscapes that transportation systems function within. Furthermore, systems are poised to be managed by a greater diversity of stakeholders, including new companies and computer algorithms. Legacy technologies, governance processes, and educational norms will all require restructuring to address the rapidly shifting nature of transportation toward *cyberphysical* systems, where information can be used by many parties to affect services, and learning systems operate independently of human observation and analysis. For example, Android phones push transportation data to Google, which then uses that to power navigation apps like Google Maps and Waze.

In a more volatile future, our assumptions about long-term stability and predictability will be increasingly at odds with reality. That's why resilience efforts increasingly require new

approaches that are capable of adapting to ever-changing environments, by embracing instability and surprise. Our transportation systems are not likely to adapt quickly in response to changing environments, even if we want them to; the technologies are rigid, often decades old, and the bureaucracies that govern them show no signs of restructuring for future challenges. Given the long lead times for achieving results, we must create the conditions today for technologies, bureaucracies, and educational practices to evolve.

Transportation for the Anthropocene

When it comes to the future of transportation needs and challenges, is there anything we can know for certain? From climate change and COVID-19 to green energy sources to political leadership, geopolitical conflict targeting transportation systems, and digital communication, it's difficult to envision the changes a few decades could bring. And if we accept the premise of rapid evolution in the Anthropocene, the answer is a definite no. As we describe below, in the transportation sector, technology, governance, and education will need to progress, along with most conventions about moving people and goods from Point A to Point B. As the rigid thinking of our industrial past becomes less relevant, conceptualizing the future of transportation hinges on our ability to anticipate sustained and increasingly variable shifts while leaving room for continuous adaptation.

Agile and Flexible Technologies

The rigid frameworks that have traditionally informed transportation planning tend to result in systems that can withstand only a small range of disturbances. Going forward, the characteristics of *agility* and *flexibility* must be at the heart of what we design and build. We define agility to mean that assets can rapidly be redirected to maintain functionality in the face of uncertainty. Flexibility, on the other hand, describes a system's potential to meet demands unforeseen by its designers. Consider, for example, smart traffic lights that adjust timing based on traffic, reversible lane systems, intelligent lighting, and modular (and removal) paving systems.

Agility and flexibility are not tied to any particular mode of transportation. Instead, these terms describe a set of capabilities that are necessary for systems to adapt, including modularity, connectivity, compatibility, multifunctionality, and software-for-hardware substitution. An example of a project that incorporates both agility and flexibility is Kuala Lumpur's Stormwater Management and Road Tunnel (SMART), a hybrid structure designed to move both automobile traffic and floodwater to reduce congestion while simultaneously preventing flash floods from disrupting traffic.

Adaptive Governance

Changing how we design and build won't be enough to develop transportation for the Anthropocene. We must also question the systems of governance that surround transportation. To understand what a transportation system can and cannot do, it's necessary to better understand how its organizations function and why. Many transportation departments operate through separate divisions controlled by small leadership teams with few incentives to drive transformative change. While division directors are often imbued with considerable autonomy and authority, there are relatively few mechanisms for cross-division problem-solving when major issues arise and diverse expertise becomes critical. This is true both within transportation management structures and between transportation and other infrastructure modalities such as energy, information and communications.

This business model, which emerged with the railroads at the dawn of the 20th century and was later exported to other infrastructure, was remarkably effective for its time. It excelled in meeting fixed goals within fairly stable environments where outputs are standardized: miles of pavement maintained, vehicle miles of travel affected, or trips shifted to active transport. However, when the goals are more complex, like creating a resilient transportation

system that uses artificial intelligence and machine learning to reduce the systems' carbon footprint, while also improving social equity and providing space for AI software driven by pervasive mobile devices to manage traffic flows, our current practices are unprepared.

The sophistication of decision-making in transportation agencies must match the complexity of the environment. Most transportation agencies still operate in a top-down fashion: assessing shifting business conditions and making major decisions at the highest levels of leadership, far from the on-the-ground workers who are best equipped to sense change and fashion solutions. Industries that successfully respond to chaos do so by creating flexible leadership models. This leadership flexibility requires shifts in how we train transportation professionals, away from highly specialized technologists, toward graduates with the capabilities to work in complex social, economic and regulatory environments.

Education for Complexity

When it comes to education and job training for future transportation leaders, we must emphasize skill sets that address consensus-building, engaging with diverse stakeholders, and cybersecurity. Fundamentally, educators must recognize that the competencies needed to thrive in predictable environments are fundamentally different from those needed for complex environments. Traditional skills in transportation engineering and planning will continue to be needed (e.g., pavement design, traffic operations, integrated transportation, and land use planning, to name a few), but they may become secondary and increasingly the domain of software. The competent transportation planner or manager of the next century will also have to be able to manage complexity, where unpredictability and rapid change require a sustained focus on flexibility and adaptation.

Cyberphysical Systems and Security

Cybertechnologies are already being deployed across transportation systems, often without a comprehension of their implications as agencies embrace the efficiencies of smart infrastructure. Vehicles are now efficiently routed by Google and Apple, considering network-wide conditions that are informed by smartphones. Third-party apps deliver remarkable insight about conditions and routes of public transportation. And with thousands of onboard microprocessors, vehicles can analyze driving behavior to calibrate engine performance with onboard software now deciding how to accelerate and when to shift from gasoline use to battery consumption. For example, hybrid Lincoln cars learn your travel patterns and seamlessly switch to electric mode when the vehicle determines that you're close to home. At the same time, few players in the transportation sector have demonstrated a comprehensive understanding of the implications these technologies pose for cybersecurity. This leaves our systems vulnerable to attack.

Asymmetric warfare and sophisticated forms of attack such as ransomware, logic bombs, and cyberespionage incidents are on the rise. Recent cyberattacks on the Southeastern Pennsylvania Transportation Authority (SEPTA), the San Francisco Municipal Transportation Agency (SFMTA), and the Colorado Department of Transportation have affected operations from scheduling to payment systems to email. Modern adversaries target the whole of our society, and, in particular, our national infrastructure. Thanks to the acceleration of artificial intelligence — a set of software capabilities that have the potential to make it easier to manage complex systems — the data and connectivity revolution may steer transportation services in ways that we never planned or imagined. Transportation managers need to become cybersecurity experts or at least be able to communicate with the experts. All transportation agencies should have cross-cutting cybertechnology teams capable of securing systems, designing systems for better human interaction, and responding to cyber threats. And when it comes to the future of education for the transit field, university-level and continuing education programs must make cyber proficiencies part of the curriculum.

Complexity Leadership

Transportation organizations that have traditionally viewed themselves as mere providers of physical mobility for people and goods must now recognize that the key to their survival will be making sense of and adapting to unforeseen changes in the environment, technology, and human behavior. Improving how agencies make sense of changing environments will require a realignment of the types of information they take in and the knowledge they generate. There are many facets to this reprioritization including leveraging emerging data streams like smartphones, building climate change expertise, and generating knowledge across diverse stakeholders.

If they don't respond to these challenges, agencies will likely find themselves losing customers to new players who are better able to recognize and meet changing conditions. Already, Google's ability to make sense of urban traffic using mobile data streams gives the company a cognition advantage over most public transit providers. Although it may not be apparent to travelers, Google's algorithms are increasingly responsible for the flow of traffic in cities around the globe. Meanwhile, Amazon's investments in drone delivery are building brand new transportation infrastructure, one free of the delays due to traffic congestion and the risks of relying on uncertain public investment in the existing road system.

Because professional and bureaucratic transportation planning continues to assume fairly stable conditions, the outcomes can be catastrophic when things go wrong. For example, demand assumptions and fixed resources worked just fine for airlines until COVID-19 hit, leaving multiple companies desperate for bailouts. One thing the pandemic has made clear is how ill-prepared the transportation sector is for the kinds of systemic shocks that will be bigger and more frequent in the Anthropocene. But given our entrenched practices and power structures, we shouldn't expect a meaningful response to this new reality anytime soon. Instead, we can only brace for the inevitable disasters.

That's where *complexity leadership* comes in, the ability to change how decision-making occurs across stable and unstable times. Complexity leadership makes use of ad hoc teams that are granted the flexibility to reallocate themselves when problems emerge and disruption occurs. During periods of stability, traditional leadership structures may be appropriate, but in unstable times, adaptive leadership is critical for creating, testing, and implementing the best solutions. More and more, transportation agencies will need to respond by quickly reallocating resources and personnel as conditions shift from stable to unstable. During a weather event like the extreme cold that caused widespread power outages in Texas earlier this year, complexity leadership would have allowed agencies to form cross-disciplinary expert teams quickly, and equip them with sufficient resources and decision-making authority as they make sense of the chaos. We also need to cultivate agile and adaptive leaders who accept unpredictable change as the new normal; this is a core competency of modern military leaders.

As we come to terms with the meaning of the Anthropocene and how it relates to transportation planning and infrastructure, it appears increasingly likely that a business-as-usual approach will leave agencies unable to manage the chaos in store. However, recognizing this is an essential first step to changing things. Next, we must ask ourselves some critical questions: What *is* transportation in the future? How should we design, govern, and operate systems for an accelerating world and very uncertain future? And if we want to keep up with the times, are we willing to make a radical break from the modes of thinking that have defined transportation thus far?

Further Reading

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